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INVESTIGATION OF SOME POTENTIAL PARAMETERS AND ITS IMPACTS ON SALTWATER INTRUSION IN NILE DELTA AQUIFER

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ABSTRACT

Coastal aquifers represent an important source of freshwater in arid and semi-arid regions. The increased extraction from coastal aquifers decreases the freshwater spilled out to the sea. Consequently, seawater intrusion increases inland and wells become contaminated. Nile delta aquifer in Egypt is one of these aquifers which subject to sever seawater intrusion from Mediterranean Sea. Saltwater intrusion is considered one of the main processes that degrade water-quality by raising salinity. It may occur due to human activities and/or by natural events. Over-pumping is considered the main cause of saltwater intrusion. Moreover, sea level rise accelerates saltwater intrusion. Due to climate change, it is expected a rise in temperature which would lead to an increase in the rates of evaporation and this will be accompanied by decrease in water level of the Nile, also this change would lead to sea level rise (SLR) .A result to rise in population intensity and expected shortage in surface water would lead to an increase of extraction rate from groundwater. In this paper 3-D model (SEAWAT) is used to study seawater intrusion in Nile delta aquifer considering different scenarios, the **first** scenario is the increase of sea level by 25, 50 and 100 cm, the **second** is to decrease the surface water system by 25, 50 and 100 cm, the **third** is to increase the extraction rate by 25, 50 and 100 % and **fourth** scenario is a combination of while the three scenarios. **The results** show that saltwater intrusion in **East** Nile delta reach 76.25 km from shore line for base case, but reaches to 79.25 km, 79 km, 82 km and 83 km for Equiconcentration line 35 and reaches to 92.25 km, 92 km, 91.75 km and 92.75 km for scenarios1, 2, 3 and 4 respectively after 100 year for Equiconcentration line 1.00. **It is also observed** that salt water intrusion in the **Middle** reaches to 63.75 km from shore line for base case, but reaches to 67.75 km, 67.25 km, 65.75 km and 67.50 km for Equiconcentration line 35 and reaches to 97 km, 97.50 km, 107.75 km and 110 km for scenarios1, 2, 3 and 4 respectively after 100 year for Equiconcentration line 1.00. **It is clear that** saltwater intrusion in the **West** reaches to 48.00 km from shore line for base case, but reaches to 49.00 km, 48.75 km, 45.50 km and 47.75 km for Equiconcentration line 35 and reaches to 73.75 km, 74 km, 79.50 km and 79.50 km for scenarios1, 2, 3 and 4 respectively after 100 year for Equiconcentration line 1.00. **Finally** increasing SLR or decreasing recharge from

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surface water or increasing extraction rate from wells increases saltwater intrusion in land direction but applying combination of these scenarios will damage large quantity of fresh water in the aquifer.

Keywords: Saltwater Intrusion, Climate Change, Sea Level Rise, Over-Pumping, SEAWAT, Nile Delta aquifer.

1. Introduction

Saltwater intrusion is a natural process that occurs in virtually all coastal aquifers connected to the sea as a consequence of the greater density of the seawater relative to the water in the aquifer, saltwater intrusion is a phenomenon with a long history of study as shown in Fig.1 [8].Saltwater intrusion has a direct impact on groundwater resources, soil salinity, agricultural productivity and quality in the coastal zone [11].

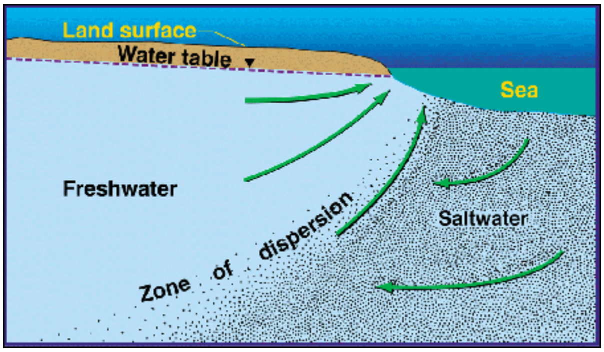


Fig. 1. Groundwater Flow Patterns and the Zone of Dispersion in Homogeneous Coastal Aquifer. Source:Water.Usgs.Gov/Ogw/Gwrp/Saltwater/Salt.htm

Saltwater intrusion or encroachment is shoreward movement of saltwater from ocean into coastal aquifers due to the over pumping of groundwater, and it is a dynamic equilibrium of groundwater movement, consequently leading to the possibility of polluting the groundwater and corroding subsurface structures [13]. When the groundwater is pumped from aquifers which are in hydraulic connection with the sea, the gradients that are set up may induce a flow of seawater from the sea toward the well [14]. The main causes of saltwater intrusion include over-abstraction of the aquifers, Seasonal changes in natural groundwater flow, Tidal effects, Barometric pressure, Seismic waves, Dispersion and Climate change – global warming and associated sea level rise . Different measures have been presented to control saltwater intrusion in coastal aquifers [6].The intrusion controlled by Physical model includes fresh water injection, saltwater extraction, and subsurface barrier. The fresh water injection rate of about 10% of the usage rate can effectively push the interface toward the shoreline, and keeping the pumping well free of salinity [38]. Presented various methods of preventing saltwater from contaminating groundwater sources including reduction of pumping rates, relocation of pumping wells use of subsurface barriers natural recharge artificial recharge abstraction of saline water combination techniques [37]. Coastal aquifers are affected by the rise in the sea level due to climate change and global warming. The rise in sea level will shift the saltwater interface further inland. As a result, the extraction wells that were originally in fresh groundwater may then be located in brackish water or saline water and upconing may occur [1]. Nile Delta aquifer is among the largest groundwater reservoirs in the world, due to the excessive pumping over the last few decades, the groundwater quality in the northern parts of the Delta has been deteriorated considerably, any additional pumping should be practiced in the middle Delta and pumping from the eastern and western parts should be reduced [33]. Abd-Elhamid and Javadi [2] developed a numerical model for simulating solute transport through saturated and unsaturated soils with the application to predict saltwater intrusion in coastal aquifers, the model includes coupling of transient water flow, air flow, heat transfer and solute transport, the model results showed that the developed of numerical model is capable of simulating saltwater intrusion into coastal aquifers with a good accuracy. Javadi et. al. [19] carried out a new methodology to control seawater intrusion in coastal aquifers using artificial surface recharge, this proposed method is based on a combination of abstraction of saline water near shoreline and recharge of aquifer using surface ponds, numerical model SUTRA is used to simulate this aquifer system in both 2D and 3D under steady state conditions, the model results show that the proposed system performs significantly better than using abstraction alone as it gives the least cost and least salinity in the aquifer**.** There are two type of interface first is sharp interface can solve by Analytical or numerical models and the second is diffuse interface can solve by numerical models.

Future sea-level rise is expected to occur at a rate greatly exceeding that of the recent past; the predicted increase in the sea level rise is in the range of 20-88 cm within the next 100 years**.** Numbers of studies have been carried out to estimate the future sea level changes based on past sea level changes due to thermal expansion, glaciers and ice caps and Greenland and Antarctic ice sheets melting. **Fig .2** shows the estimated global average sea level rise from 1990 to 2100 [17].

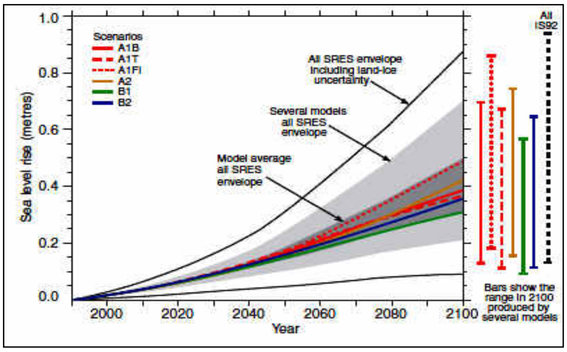


Fig. 2. SLR According to Global Climate of the 21stCentury **(IPPC, 2001) [17].**

The main transport processes of concern in groundwater include physical Transport Processes as advection, diffusion and dispersion, geochemical transport process as adsorption, biodegradation and chemical reactions. **Advection** describes the movement of groundwater under hydraulic or pressure gradient. The rate of advective transport is described by a modified version of Darcy's Law [9]**. Molecular diffusion** is the process describes the spread of particles through random motion from regions of higher concentration to regions of lower [4]. **Dispersion** is Spreading of pollutants due to heterogeneity of flow field (small scale dispersion, macro dispersion). There are two Kinds of Dispersion micro dispersion and macro dispersion (Small scale or large scale [26]. **Mechanical dispersion** is mixing caused by velocity variations around a mean flow velocity; it is expected to increase with increasing flow velocity. The groundwater models used to the simulation of groundwater flow and transport of pollutants in groundwater and can be classified as physical (e.g. a sand tank) or mathematical [5]. **Mathematical** models including analytical models and numerical models, like finite difference, finite element models [25]**. Analytical** equations that deal solely with the effects of changes in hydraulic head or gradient are gross simplifications of the real situation, and also cannot be expected to accurately predict the position of the saltwater interference. According to the **Ghyben-Herzberg's** Equation, the depth to the fresh water/sea water interface equals 40 times the freshwater hydraulic head or water level above sea level [24].

The available numerical models to estimate the variable density and concentration effects of the sea-water/fresh water groundwater interface (e.g. SHARP, SUTRA, HST3D and the SEAWAT program of MODFLOW) [24].Several numerical methods are available to solve the advection-dispersion equation for solute transport [23] such as Eulerian method, Lagrangian method Mixed Eulerian-Lagrangian method. SEAWAT is selected in this study to simulate saltwater intrusion in Nile delta one of the strong programs in simulate saltwater intrusion. A number of pervious researchers studied the effect of SLR and increasing extraction rate from groundwater in two-dimensional but the study of decreasing surface water changes due to climatic change in River Nile and combination of these scenarios did not study yet in three-dimensional in Nile delta aquifer so this research aimed to study these scenarios.

2. Study area

Study area is Nile delta which located on Northern Egypt, The area is bounded by River Nile in South, Ismailia canal in East, Mediterranean Sea in North and Nubaria canal in West. It located between Latitudes 30˚ 00` and 31˚ 45`N, and longitudes 29˚ 30`and 32˚ 30`E. Its area of about 25,000 km^2 with about 200 km from South to North, and the coastline is about 300 km long. [21].

2.1. Geological properties

Nile Delta is mostly occupied by the Tertiary and Quaternary deposits, Tertiary aquifers are including the Eocene, Oligocene, Miocene rocks and Pliocene Rocks. Quaternary aquifers cover the greater part of the Nile Delta and are particularly developed in the northern portion and are dominant in the Nile Delta. The sediments constitute variable proportions of sands, clays and gravels with lateral variation and variable thicknesses [30]. Quaternary aquifers are including Holocene deposits with maximum thickness of about 77 m and Pleistocene deposits composed of coarse-grained Quartizitic sands and gravels with discontinuous occasional clay lenses with an average thickness of 700 m [15].

2.2. Hydraulic parameters of the Aquifer

The Nile is completely controlled by the High Aswan Dam and a series of barrages along its course to the Mediterranean Sea. Water released from the dam is distributed among the whole country through a network of major and branch canals, lateral and distribution canals and field channels [21]. The Nile Delta Quaternary aquifer is considered as a semi-confined aquifer. It covers the whole Nile Delta. Its thickness varies from 200 m in the Southern parts to 1000 m in the Northern parts, [28]. **Figure.3** shows the depth to the groundwater table in this aquifer ranges between 1–2 m in the North, 3 – 4 m in the Middle and 5 m in the South. Different estimated depths to groundwater table that have been reported by RIGW (2002) [29] and (Morsy, 2009) [22]. According to RIGW database the distribution of groundwater salinity as iso-salinity 1000 PPM comparison from period 1960, 1980, 1992 and 2008 as shown in **Fig.4.**

Fig. 3. Average Depth to Groundwater in the Quaternary Aquifer Recorded in 2002 (**RIGW, 2002**) **[29]**.

Fig. 4. Salinity (TDS) in GW during Period 1960, 1980, 1992 and 2008 (**Morsy, 2009**) **[22]**

The most important parameter for controlling flow characteristic is the hydraulic prosperities such vertical and horizontal hydraulic conductivity, Specific yield, storage coefficient, transmissivity and porosity as show in **Table.1.** Recharge by the downward leakage due to irrigation excess water and canals infiltration towards the aquifer ranges between 0.25 and 0.80 mm/day also recharge by rainfall to the study area aquifer takes place only during the winter months with average rainfall of 25mm/year **(RIGW, 1980) [27]**. Abstraction well inventory for Nile delta region has been carried out by RIGW in 1992, 1995, 1997 and 2002 and new functionality is added to it in 2008. Values of extraction rate in Nile delta region for different governorate and for tow period 1992 reach 3.30 Mm^3/year and 4.90 Mm^3/year 2008.

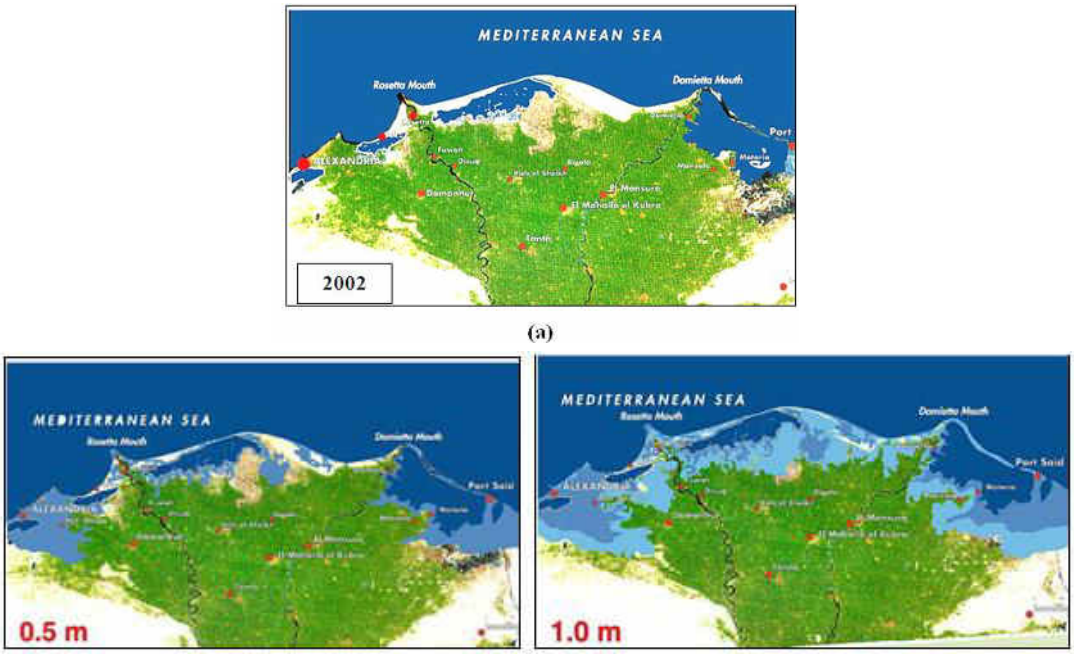
Table. 1.
Hydraulic Properties of Quaternary Aquifer in Nile Delta

Main hydraulic units	Hyrollic Conductivity	Transmissivity	Storage Cofficient	Specific yield	Prosity	Effective Prosity
	K	T	S	Ss	n	n_{eff}
	m/day	(m^2/day)	(m/day)	(1/m)	%	%
RIGW(1992)[28]	**75**	**15000-75000**	**10^{-4}- 10^{-3}**	**……..**	**25 - 40**	**……..**
Farid(1980)[12]	**112**	**……..**	**$2.35*10^{-3}$**	**……..**	**40**	**37.35**
Zaghloul(1958)[39]	**119**	**………**	**10^{-4}- 10^{-3}**	**0.15**	**30**	
Shahin(1981)[31]	**50**	**2500-25900**	**10^{-5}- 10^{-4}**	**0.2**	**25**	**23.25**
Leaven(1991)[20]	**150**	**10350-59800**	**……..**	**……..**	**25 - 30**	**……..**
Bahr(1995)[7]	**75**	**……..**	**$1.1*10^{-3}$**	**……..**	**25**	**18**

2.3. Meteorological aspects and climatic changes

Egypt's climate is hot, dry, deserted and is getting warmer. During the winter season (December– February), Lower Egypt's climate is mild with some rain, primarily over the coastal areas, while Upper Egypt's climate is practically rainless with warm sunny days and cool nights. During the summer season (June- August), the climate is hot and dry all over Egypt. Summer temperatures are extremely high, reaching 38°C to 43°C with extremes of 49°C in the southern and western deserts. The northern areas on the Mediterranean coast are much cooler, with a maximum of about 32°C [21]. The climate system is a complex, interactive system consisting of the atmosphere, land surface, snow and ice, oceans and other bodies of water, and living things. There are three fundamental ways to change the radiation balance of the Earth as changing the incoming solar radiation, changing the fraction of solar and by altering the long wave radiation from Earth back towards space [16].The global warming due to increasing concentrations of greenhouse gases in the atmosphere is estimated at 0.13 degree per decade [18] and is expected to have a full range of temperature projection of 1.1 degree to 6.4 degree by the end of this century. This range of temperature rise is expected to lead to melting of polar caps and expansion of water in deep oceans with a corresponding increase of sea level.

The Nile Delta shoreline extends from Alexandria to the west to Port-Said to the east with total length of about 240 km and is typically a smooth wide coast. The Nile Delta region is presently subject to changes, including shoreline changes, due to erosion and accretion, subsidence and sea level rise due to climate changes [3]. the Nile Delta coastal zone is highly vulnerable to the impacts of sea level rise through direct inundation and salt water intrusion.



(a)

(b) (c)

Fig. 5. (a, b, c) Satellite Maps of Nile Delta, Showing the Potential Impact of SLR with a- the Occurring Status in 2002 and the Coastal Inundation with a 0.5 and 1m SLR**[35].**

3. Numerical model

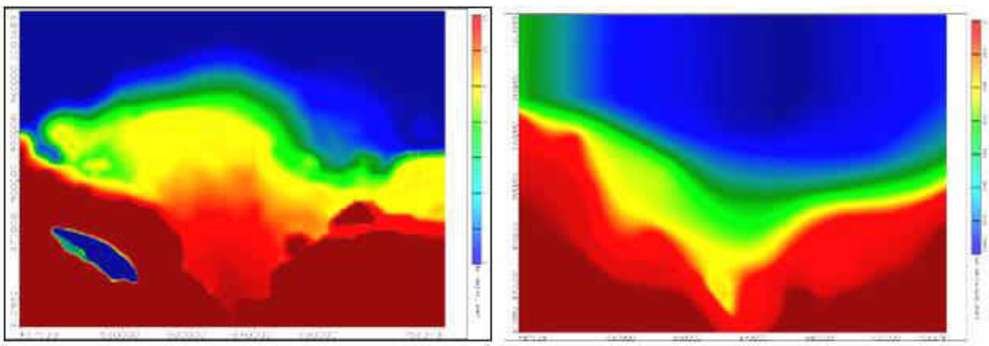
SEAWAT-2000 is the latest release of SEAWAT computer program for simulation of three-dimensional, variable-density, transient ground-water flow in porous media. SEAWAT-2000 was designed by combining a modified version of MODFLOW-2000 and MT3DMS into a single computer program. SEAWAT-2000 contains all of the processes distributed with MODFLOW-2000 and also includes the Variable-Density Flow Process (as an alternative to the constant-density Ground-Water Flow Process) and the Integrated MT3DMS Transport Process [36]. The partial-differential equation of solute transport of contaminant in ground-water flow used in SEAWAT is [40]:

$$\frac{\partial C}{\partial t}=\frac{\partial}{\partial Xi}\left(D_{ij}\frac{\partial C}{\partial X_i}\right)+\frac{\partial}{\partial X_i}\left(V_i * C\right)+\frac{q_s}{\theta} * C_S+\sum_{k=1}^{k=n} R_k \quad \text{.....................................(1)}$$

Where C is concentration of contaminant dissolved in ground water, ML^{-3}, t is time (T), X is the distance along the respective Cartesian coordinate axis (L), D_{ij} is the hydrodynamic dispersion coefficient (L^2T^{-1}) , V is the seepage of linear pore water velocity $L\,T^{-1}$,q_s is the volumetric flux of water per unit volume of aquifer representing sources (positive) and sink (negative) , Cs is concentration of sources or sink, ML^{-3} , Θ is the porosity of porous media ,dimension less and R_k is a chemical reaction term ($ML^{-3}T^{-1}$).

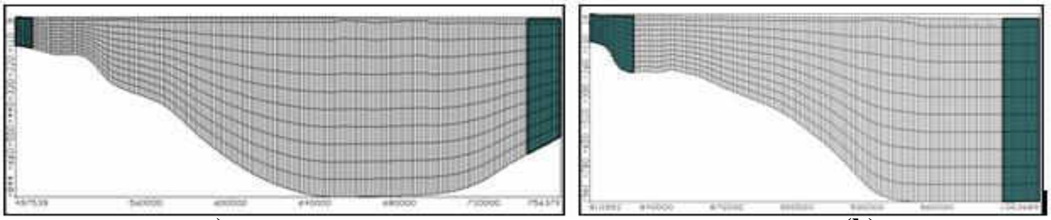
3.1. Model geometry and boundary conditions

Numerical model applied using SEAWAT-2000 software by using 194 rows and 260 columns for active and inactive cell with cell dimension 1.00 km*1.00 km with variation depth for 200 m in South to 1000 m at shore line of sea. The model divided to eleven layers, the first represent clay layer as semi confined layer with average thickness 50 m, other layer represent a quaternary aquifer with average depth 100 m as shown in **Fig.6-a**. Elevation of ground surface varies from 18.00 at South to zero level at North above MSL as shown in **Fig.6-b**; the thickness of aquifer varies between 200 m in South to 1000 m in North. **Figure.7-a** shows the vertical cross section in x direction from East to West and **Fig.7-b** shows the vertical cross section in y direction from North to South in Nile delta aquifer.



(a) (b)

Fig. 6. Contour Maps for **(a)** Topographic and **(b)** Aquifer base surface



a) (b)

Fig. 7. Vertical Section in (a) X direction from East to West and (b) Y direction from North to South

The model bounded by constant head as 16.96 m above mean sea level at South and by constant head as zero value along shore line at North. South East bounded by Ismailia canal as water level in field start by 16.17 m from South to 7.01 m at East. South West bounded by El Rayah El Behery and Nubaria canal as water level in field start by 16.00 m from South to 0.50 m North above mean sea level and East boundary leave as free as shown in **Fig.8-a**. A concentration of 35000 mg/l (seawater TDS) is applied along the coastal zone where an inland flow from the sea occurs, the initial concentration of the groundwater was set to 0 mg/l as shown in **Fig.8-b** [34].

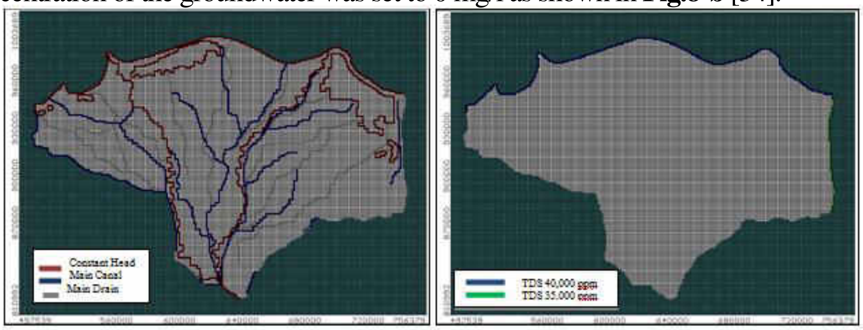


Fig. 8. Model Boundary Condition for (a) Head (b) Concentration

3.2. Model hydraulic parameters

Hydraulic parameters for each layer in model as hydraulic conductivity (K), specific storage (S_s), specific yield (S_y) and total porosity are shown in **Table.2.** Recharge depend on the excess water from irrigation process and water seepage from canal plus and rainfall value this values was conducted **by (RIGW, 1980) [27]** as shown in **Fig.9** location map of wells distribution as shown in **Fig.10** based on the data collected by (RIGW) with total abstraction equal $2.78*10^9$ m^3/year in 2008. The values of scale dependent as Longitudinal dispersivity (α_L) equal 100 m, Lateral dispersivity (α_T) equal 10 m, vertical (α_V) dispersivity equal 1.00 and the value of diffusion coefficient equal 10^{-4} m^2/day [32].

Table 2.
Values of Hydraulic Properties in Nile Delta **(El Arabi, 2007) [10].**

Main Hydraulic Units	Layer No	Hydraulic Conductivity	Hyrollic Conductivity	Storage Cofficient	Specific Yield	Effective Prosity
		K_h	K_v	S	Ss	n
		m/day	(m^2/day)	(m/day)	(1/m)	%
Clay	1	0.10 --- 0.25	0.01 --- 0.025	10^{-3}	0.10	50 - 60
Fins Sand with LenSesof Clay	2,3,4 and 5	5 --- 20	0.5 --- 2	$5*10^{-3}$	0.15	30
Course Sand Quaternary	6,7,8 and 9	20 --- 75	2 --- 7.50	$2.50*10^{-3}$	0.18	25
Graded Sand and Gravel	10 and 11	75 --- 100	7.50 --- 10	$5*10^{-4}$	0.20	20

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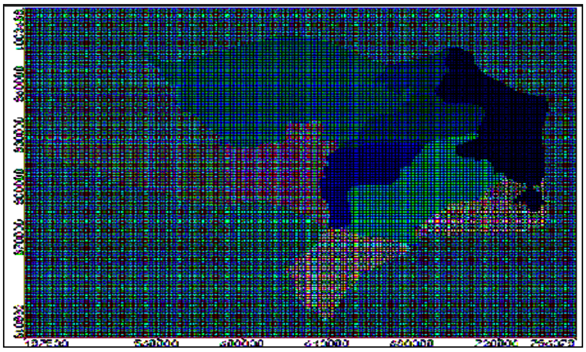


Fig.9. Distribution Map of Recharge

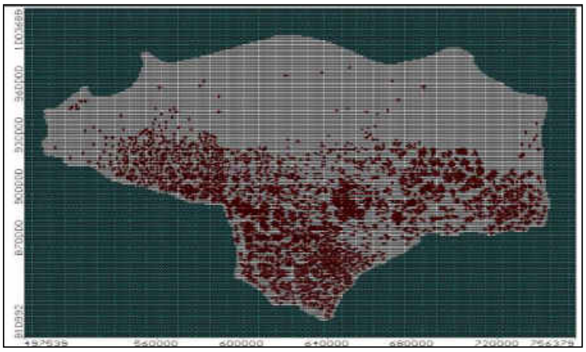
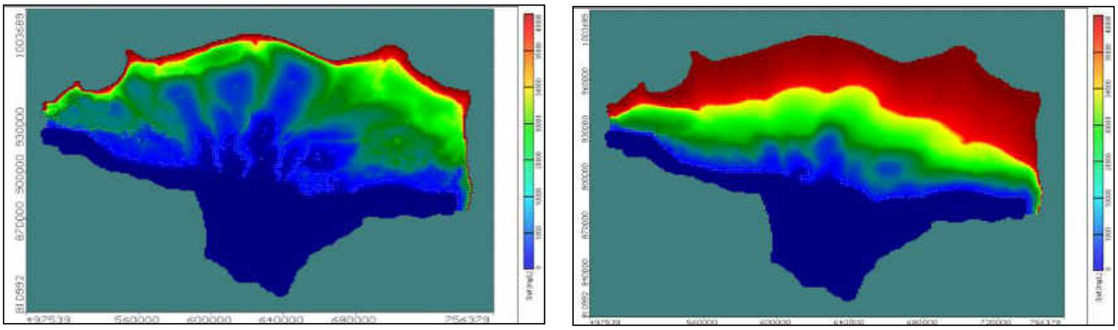


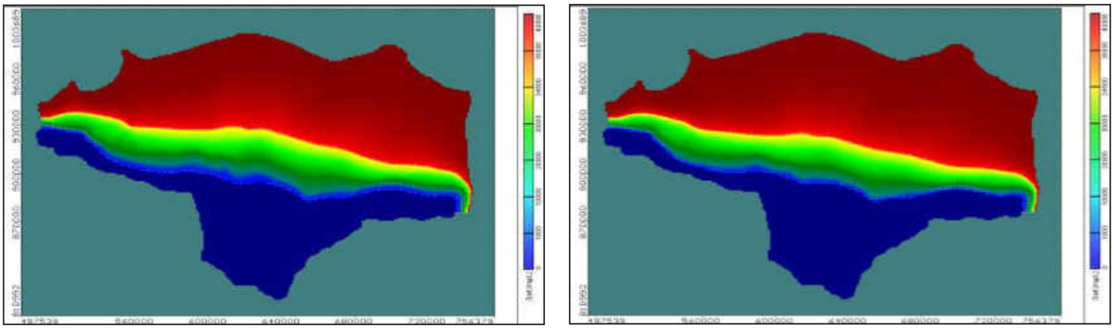
Fig. 10. Location Map of Extraction Wells

4. Model output and calibration

Distributions of Saltwater intrusion in Nile delta aquifer are the main output of transport model based on available data in 2008 compared with the values as shown in **Fig.4**. **Figure 11-a** shows distribution of TDS at layer 3 with average thickness 225 m in North and 50 m at south, at layer 6 with average thickness 450 m in North and 100 m at south as shown in **Fig.11-b**, at layer 9 with average thickness 675 m at North and 150 m at south as shown in **Fig.11-c** and bottom of Aquifer with average depth 900 m in North (at sea) and 200 m at south as shown in **Fig.11-d**.



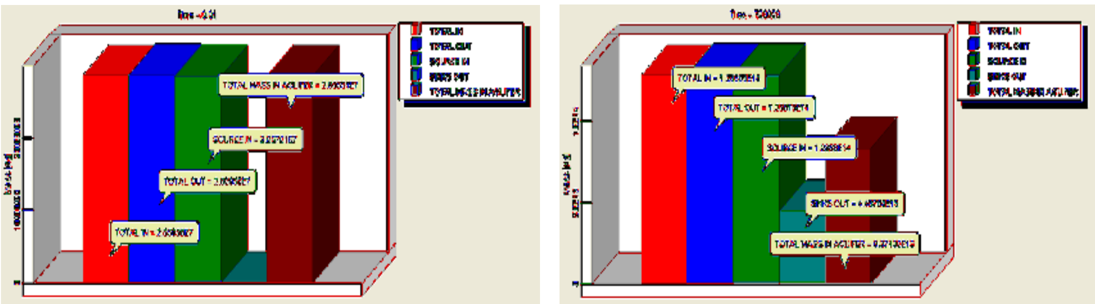
(a) (b)



(c) (d)

Fig. 11. Areal Distribution of TDS in Nile Delta Aquifer at (a) Layer 3, (b) Layer 6, (c) Layer 9 and (d) Layer 11

Calibration is a process that show the difference between calculated salt concentration from model and salt concentration in observation well at field based on available data from (RIGW) at 2008 as shown in **Fig.4**. Number of transport model such as SEAWAT need period of time to reach steady state, this period depend on software type as 2D or 3D and aquifer geometry such as area or depth, when the concentration keep to constant with time at this time the model reach to steady state. This model took about 730000 day to reach steady state condition. After this time the different scenarios applied to the model. On the other hand, **Fig.12- a** shows the mass balance of salts entering and leaving the system through all sources and all sinks at start of simulation, it is also the total mass of salts remain in the system at the end of each stress period and salt balance take place when the input salt equal output salt as shown in **Fig.12-b**.



(a) (b)

Fig. 12. Salt Balance Components at (a) Initial time and (b) End time

5. Results and Discussions

The model run and calibrated under available data in 2008 this case consider base case, the values of head and concentration as mentioned before which considered the base case. Three typical cross section applied in Nile delta, the first (Sec I) in West delta, Second in (Sec II) Middle delta, third (Sec III) in East Nile delta as shown in **Fig.13**.

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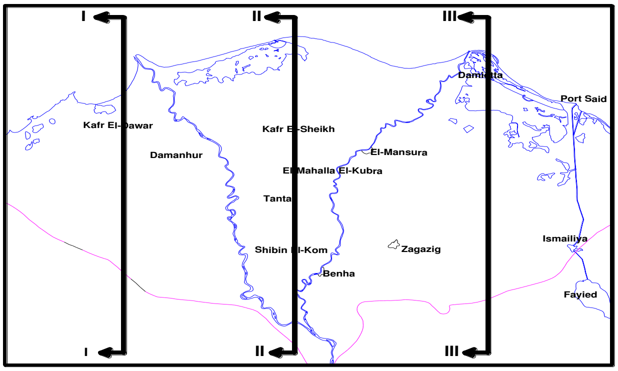
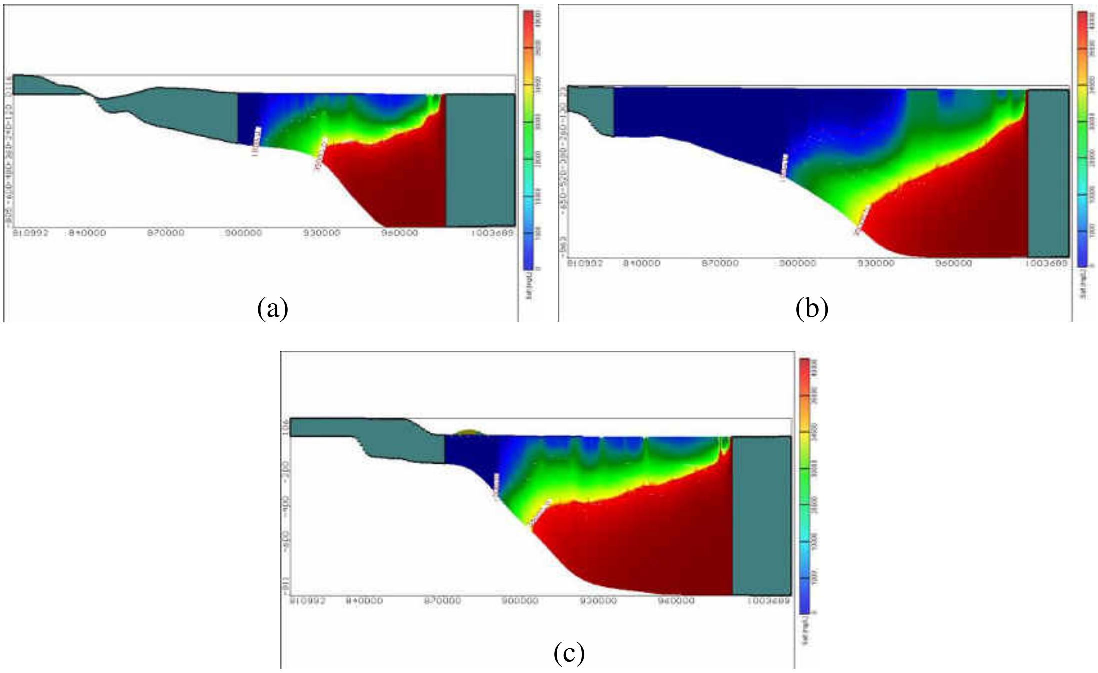


Fig. 13. Typical Cross Section in Nile Delta Aquifer

5.1. Base Case

Distribution of saltwater intrusion as TDS in Nile delta aquifer Equiconcentration line 35 and 1 is shown in **Fig.11**. According to **Sec I** in the West the line 35.0 moved inland by a distance of 48.00 km from shore line and Equi-line 1 moved inland by a distance of 72.50 km from shore line so the transition zone equal 24.50 km as shown in **Fig.14-a**. It is also clear that at **Sec II** in the Middle the Equi-line 35 moved inland by a distance of 63.75 km from shore line and Equi-line 1 moved inland by a distance of 93.75 km from shore line so the transition zone equal 30.00 km as shown in **Fig.14-b**. It is also observed that at **Sec III** in the East the Equi-line 35 moved inland by a distance of 76.25 km from shore line and Equi-line 1 moved inland by a distance of 90.75 km from shore line so the transition zone equals to 14.50 km as shown in **Fig.14-c**.

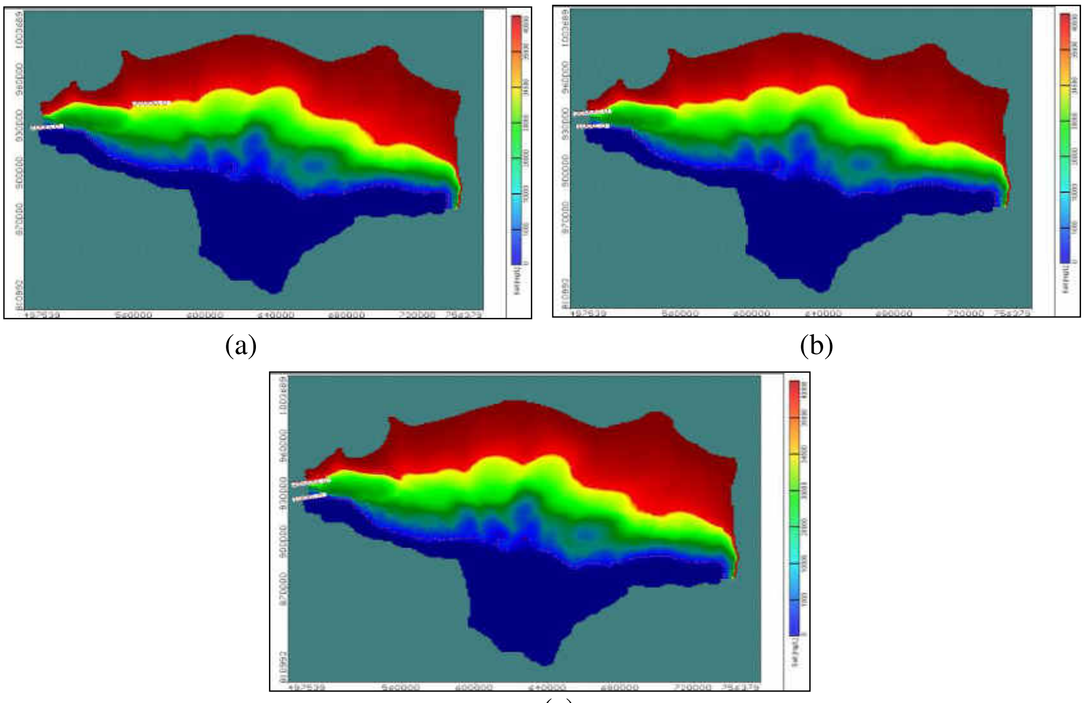


(a) (b) (c)

Fig. 14. Areal Distribution of TDS in Nile delta Aquifer for Base Case at (a) **Sec** I (b) **Sec** II and (c) **Sec** III

5.2 Impact of sea Level rise (SLR) on saltwater intrusion (SWI) (scenario-1)

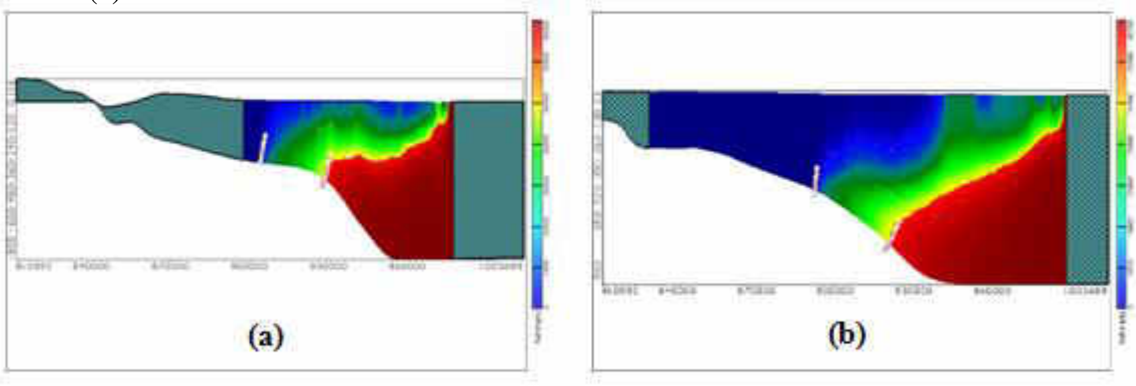
The results of increasing SLR by 25 cm, 50 cm and by 100 cm are shown as in **Fig (15-a**, **b** and **c)** respectively. The Figure prevailed that, increasing SLR increases saltwater intrusion in the aquifer from North to South. Increasing SLR by 25 cm, 50 cm and 100 cm at **Sec I** is shown in **Fig.16**. The results show that SWI reaches to 78.75 km, 79.00 km and 79.25 km from shore line for Equiconcentration line 35.00 and reach 91.50 km, 91.75 km and 92.25 km for Equiconcentration line 1.00 respectively. The results also show at **Sec II** as shown in **Fig.17,** SWI reaches to 66.75 km, 67.00 km and 67.75 km from shore line for Equi-line 35.00 and reaches to 95.75 km, 96.25 km and 97.00 km for Equi-line 1.00 respectively. **Figure.18** indicates the results at **Sec III;** the SWI reaches to 48.50 km, 48.75 km and 49.00 km from shore line for Equi-line 35.00 and reaches to 73.00 km, 73.25 km and 73.75km for line 1.00 respectively.



(a) (b)

(c)

Fig. 15. Areal Distribution of TDS at Increasing SLR by (a) 25 cm, (b) 50 cm and (c) 100 cm



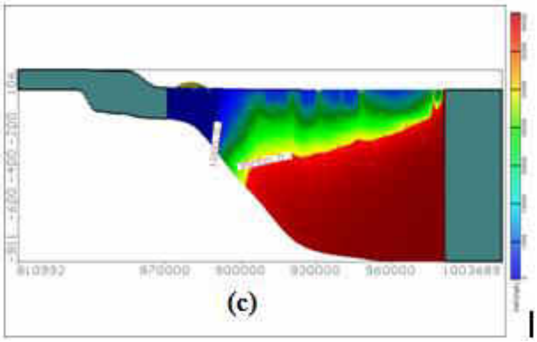
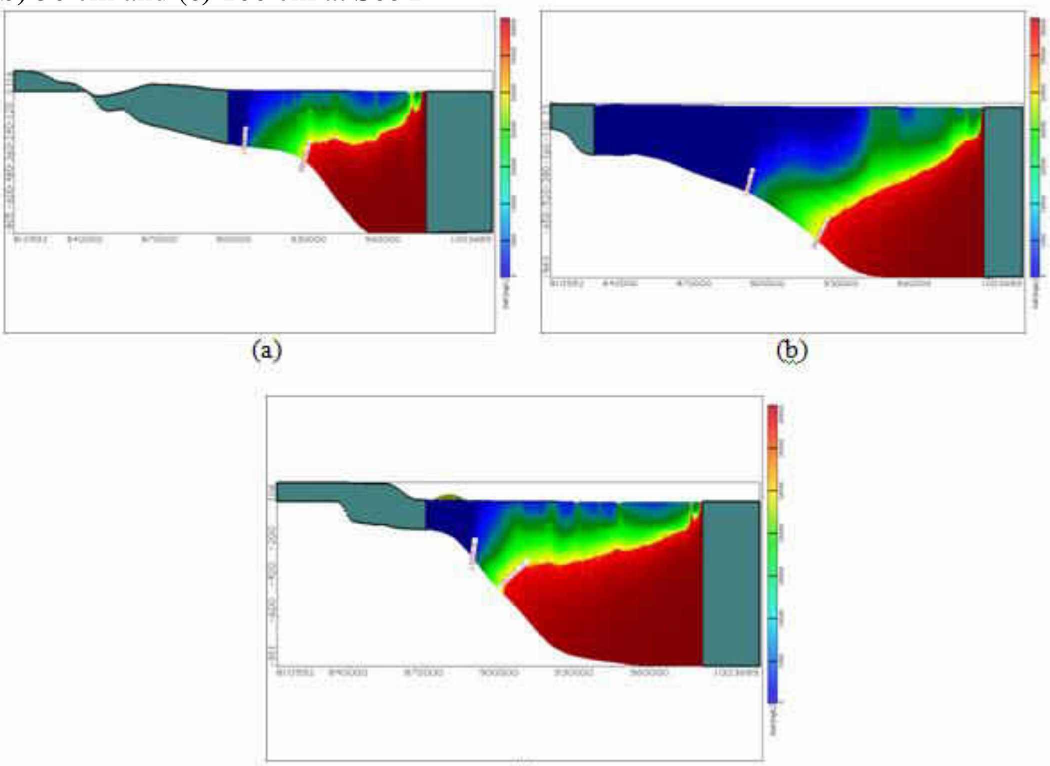
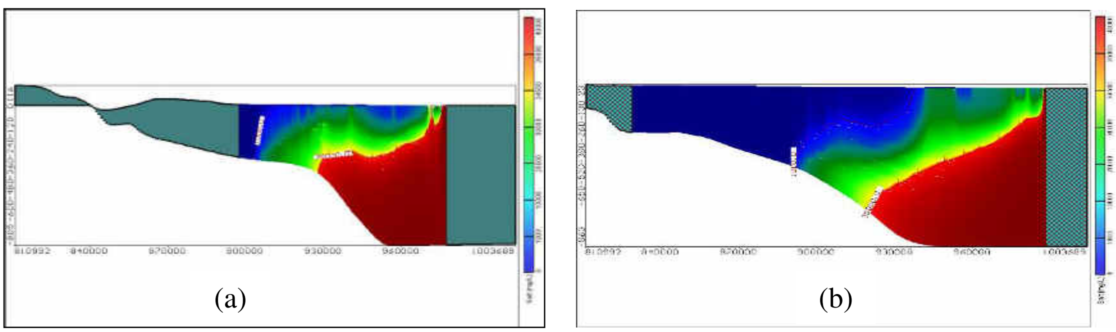


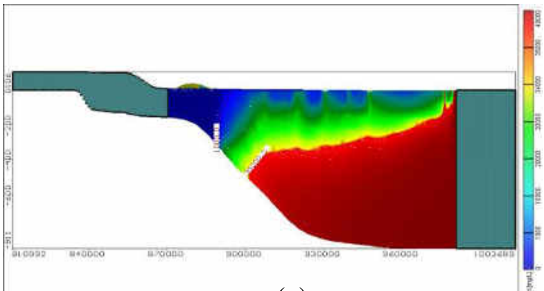
Fig. 16. Vertical Distribution of TDS in Nile delta Aquifer at SLR by **(a)** 25 cm, **(b)** 50 cm and (**c**) 100 cm at **Sec I**



(c)

Fig. 17. Vertical Distribution of TDS in Nile delta Aquifer at SLR by **(a)** 25 cm, **(b)** 50 cm and (**c**) 100 cm at **Sec II**



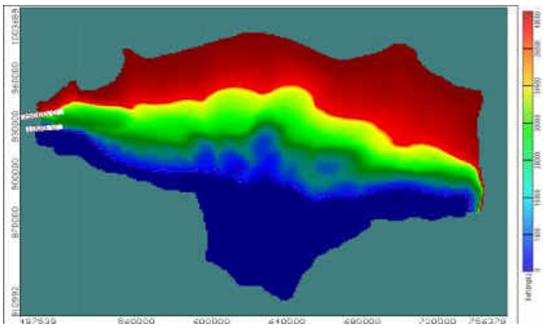


(c)

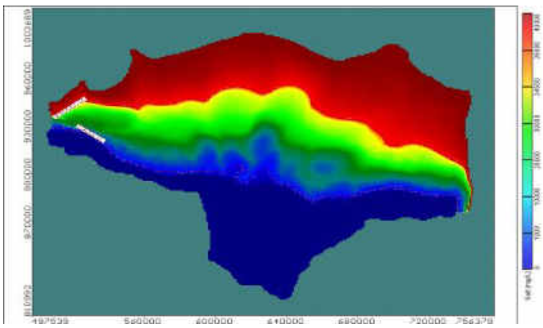
Fig. 18. Vertical Distribution of TDS in Nile delta Aquifer at SLR by **(a)** 25 cm, **(b)** 50 cm and (**c**) 100 cm at **Sec III**

5.3. Impact of surface water level change on swi (scenario-2)

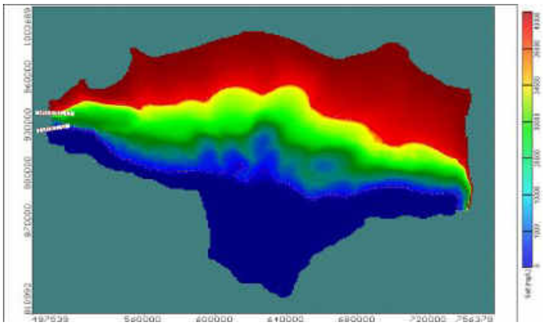
The results of decreasing surface water level by 25 cm , 50 cm and 100 cm are shown as in **Fig.19-a**,**b** and **c** respectively. The Figures show that decreasing of surface water level will increase saltwater intrusion in aquifer from shore line to South. The results at **Sec I** as shown in **Fig.20**, SWI reaches 78.50 km, 78.75 km and 79.00 km from shore line for line 35.00 and reaches 91.25 km, 91.75 km and 92.00 km for Equi-line 1.00 respectively. The results show also at **Sec II** as shown in **Fig.21**, SWI reaches 78.50 km, 78.75 km and 79.00 km from shore line for Equi-line 35.00 and reaches 91.25 km, 91.75 km and 92.00 km for Equi-line 1.00 respectively. The results at **Sec III**, as shown in **Fig.22** show that SWI reaches 78.50 km, 78.75 km and 79.00 km from shore line for Equi-line 35.00 and reaches 91.25 km, 91.75 km and 92.00 km for Equi-line



(a)



(b)



(c)

Fig. 19. Areal Distribution of TDS at Decrease Surface Water by **(a)** 25 cm, **(b)** 50 cm and **(c)** 100 cm

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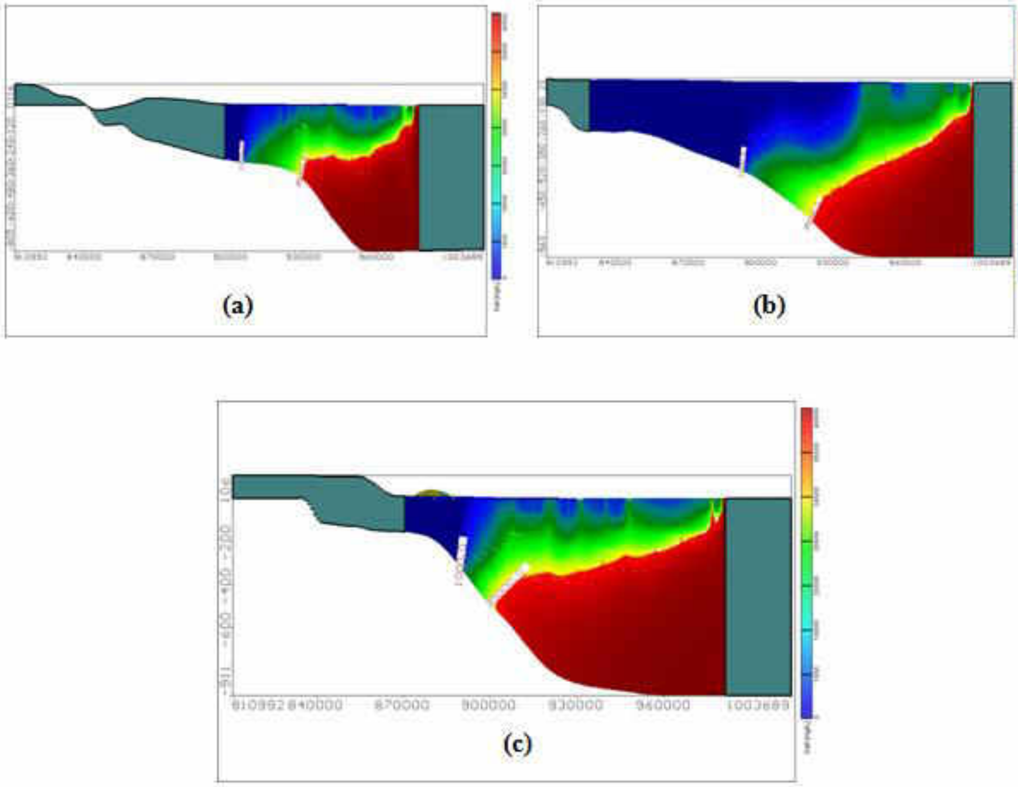


Fig. 20. Vertical Distribution of TDS in Nile delta Aquifer at Decrease Surface Water by **(a)** 25 cm, **(b)** 50 cm and (**c**) 100 cm at **Sec I**

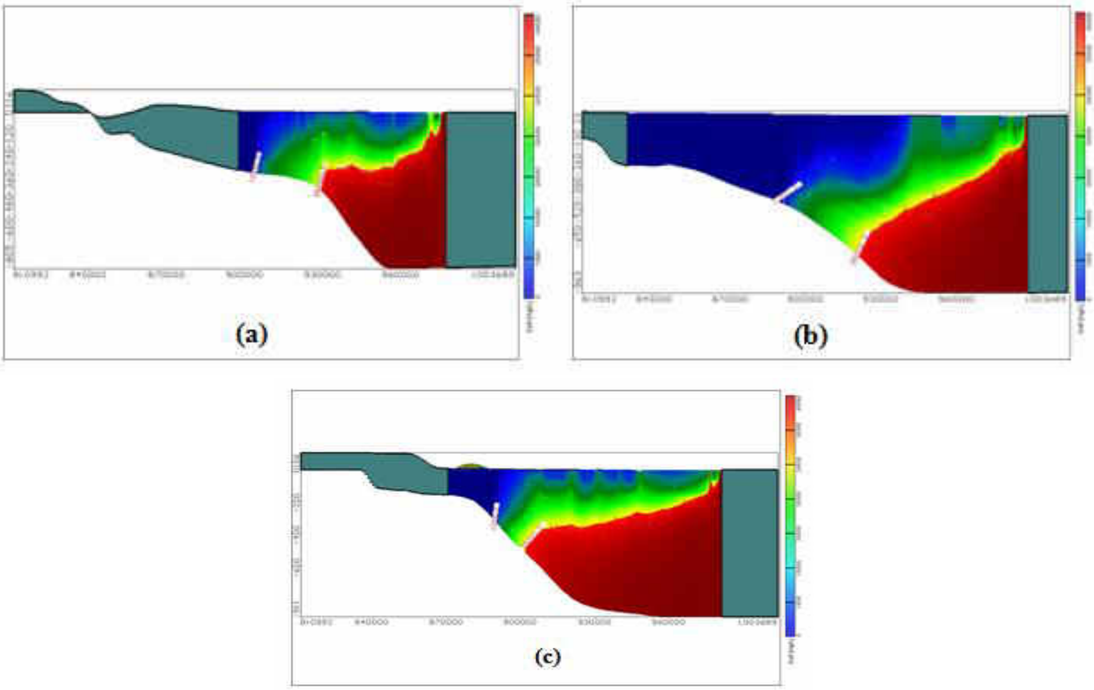


Fig. 21. Vertical Distribution of TDS in Nile delta Aquifer at Decrease Surface Water by **(a)** 25 cm, **(b)** 50 cm and (**c**) 100 cm at **Sec II**

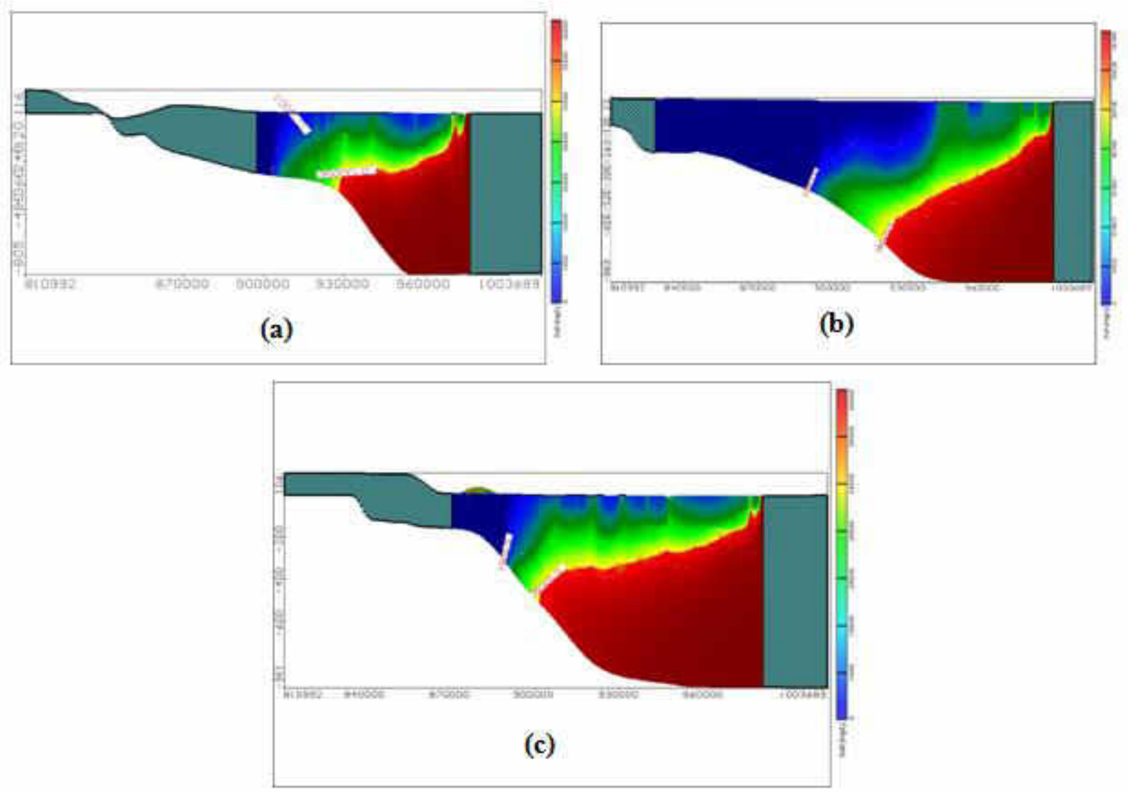
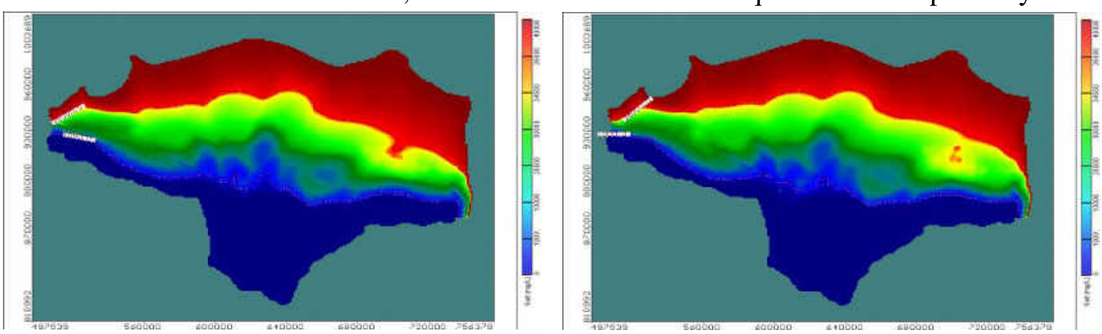


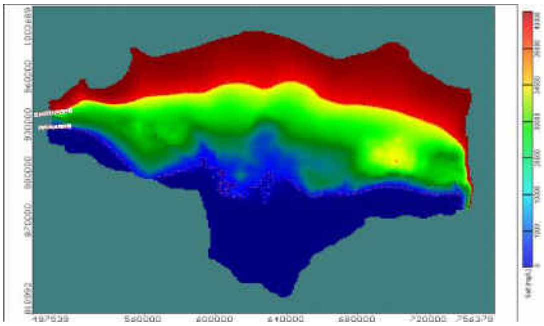
Fig. 22. Vertical Distribution of TDS in Nile delta Aquifer at Decrease Surface Water by **(a)** 25 cm, **(b)** 50 cm and (**c**) 100 cm at **Sec III**

5.4 Impact of increasing extraction wells change on swi (scenario-3)

The results of increasing extraction rate by 25 %, 50 % and 100 % are shown as in **Fig.23-a**, **b** and **c**. The Figures indicate that the increase of extraction rate increases SWI in aquifer from shore line to South. Increasing extraction rates by 25 %, 50 % and 100 % on SWI at **Sec I**, as shown in **Fig.24** causes the SWI reaches 48.25 km, 47.50 km and 45.50 km from shore line for Equi-line 35.00 and to 73.00 km, 74.00 km and 79.50 km for Equi-line 1.00 respectively .The results show also at **Sec II** as shown in **Fig.25**, the SWI reaches 63.75 km, 66.50 km and 65.75 km from shore line for Equi-line 35.00 and reaches 98.25 km, 101.25 km and 107.75 km for Equi-line 1.00 respectively. Again the results at **Sec III** as shown in **Fig.26** show that the SWI length reaches 80.50 km, 81.50 km and 82.00 km from shore line for Equi-line 35.00 and reaches to 91.00 km, 91.50 km and 91.75 km for Equi-line 1.00 respectively.



(a) (b)



(c)

Fig. 23. Areal Distribution of TDS Increasing Extraction Wells by (a) 25 %, (b) 50 % and (c)100 %.

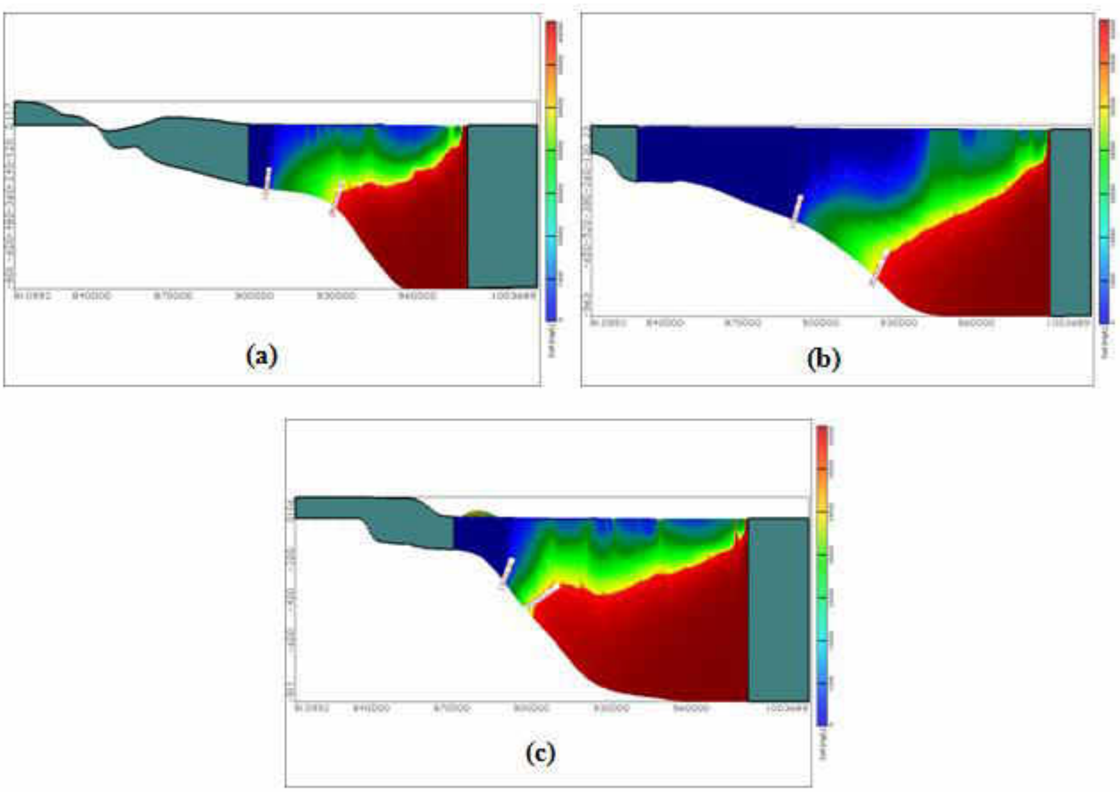


Fig. 24. Vertical Distribution of TDS in Nile delta Aquifer for Increasing Extraction Wells by (a) 25 %, (b) 50 % and (c) 100 % at **Sec I**

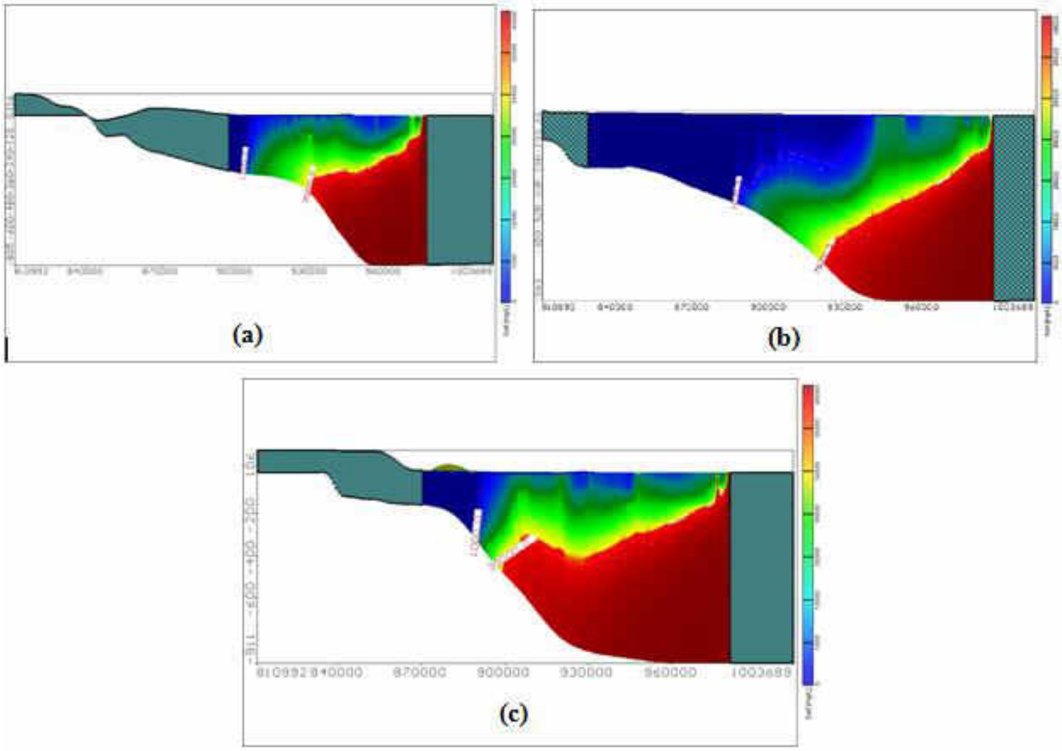


Fig. 25. Vertical Distribution of TDS in Nile delta Aquifer for Increasing Extraction Wells by (a) 25 %, (b) 50 % and (c) 100 % at **Sec II**

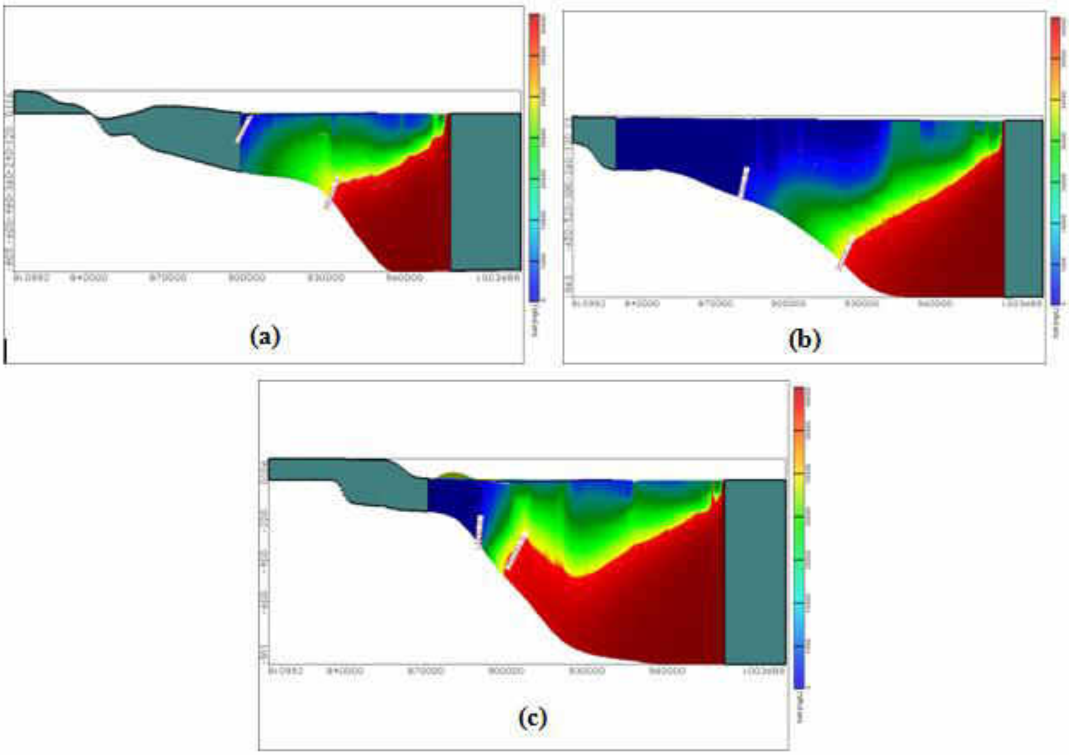
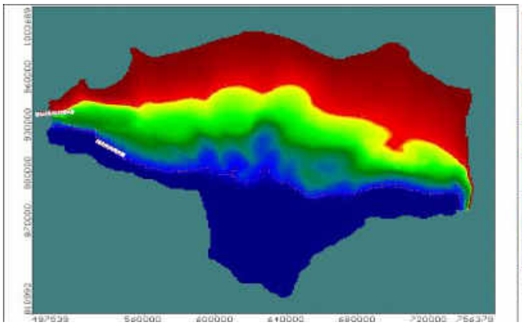


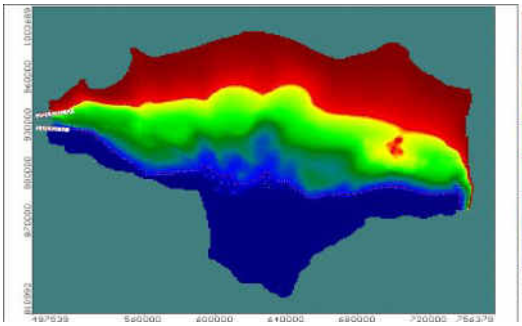
Fig. 26. Vertical Distribution of TDS in Nile delta Aquifer for Increasing Extraction Wells by (a) 25 %, (b) 50 % and (c) 100 % at Sec III

5.5 Impact of three combination scenario change on SWI (scenario-4)

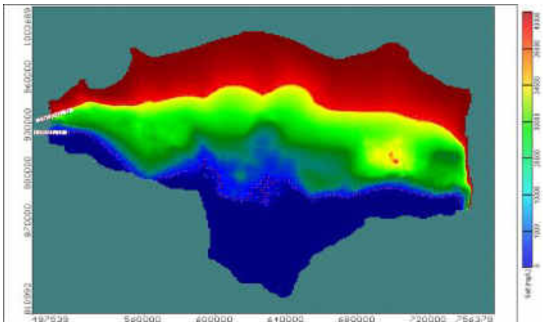
The results of increasing SLR by 25 cm,50 cm and 100 cm, decreasing surface water system by 25 cm,50 cm and 100 cm and increasing extraction rates by 25 % 50% and 100% are shown as in **Fig.27-a**,**b** and **c** show the increase of SWI in aquifer from shore line to South. The results at **Sec I** as shown in **Fig.28** the SWI reaches 48.75 km, 48.50 km and 47.75 km from shore line for Equi-line 35.00 and reaches 73.50 km, 76.25 km and 79.50 km for Equi-line 1.00 respectively. Also The results at **Sec II** as shown in **Fig.29** concluded that SWI reaches 66.75 km, 67.25 km and 67.50 km from shore line for Equi-line 35.00 and reaches 99.25 km, 103.25 km and 110.00 km for Equi-line 1.00 respectively. The Combination of three Scenarios results that , at **Sec III** as shown in **Fig.30** the SWI reaches 80.50 km, 82.00 km and 83.00 km from shore line for line 35.00 and reaches 91.50 km, 91.75 km and 92.75 km for Equi-line 1.00 respectively.



(a)

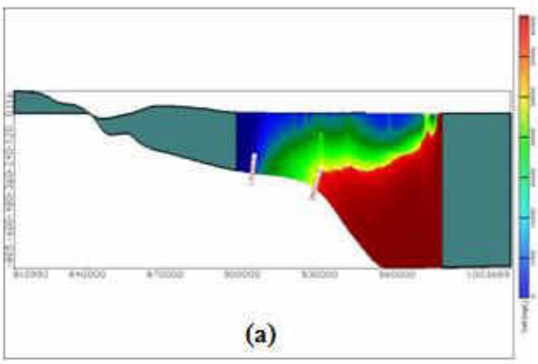


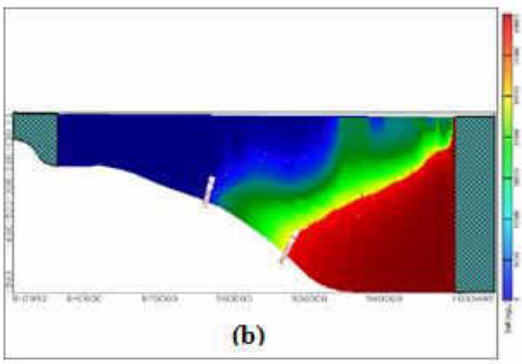
(b



(c)

Fig. 27. Areal Distribution of TDS for Combination of Three Scenarios Change by (a) 25 %, (b) 50 % and (c) 100 %.





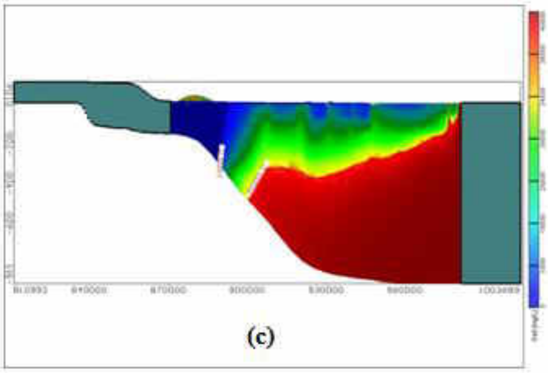


Fig. 28. Vertical Distribution of TDS in Nile delta Aquifer for Combination of Three Scenarios Change by (a) 25 %, (b) 50 % and (c) 100 % at **Sec I**

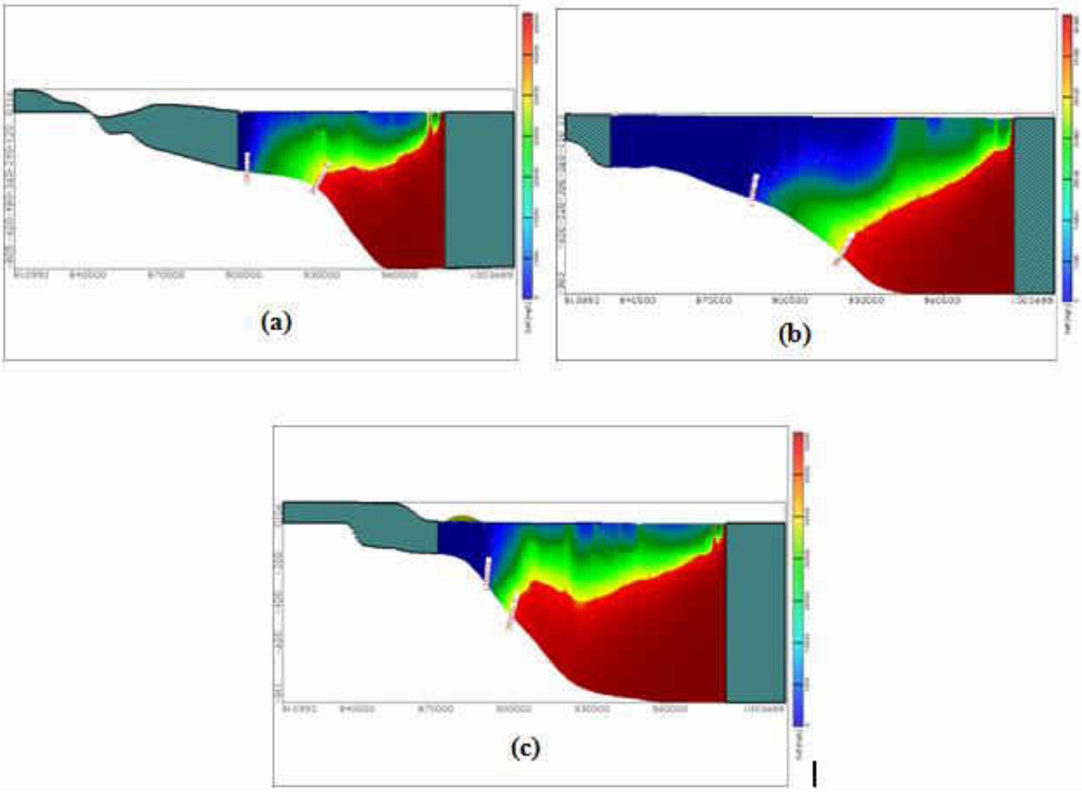


Fig. 29. Vertical Distribution of TDS in Nile delta Aquifer for Combination of Three Scenarios Change by (a) 25 %, (b) 50 % and (c) 100 % at **Sec II**

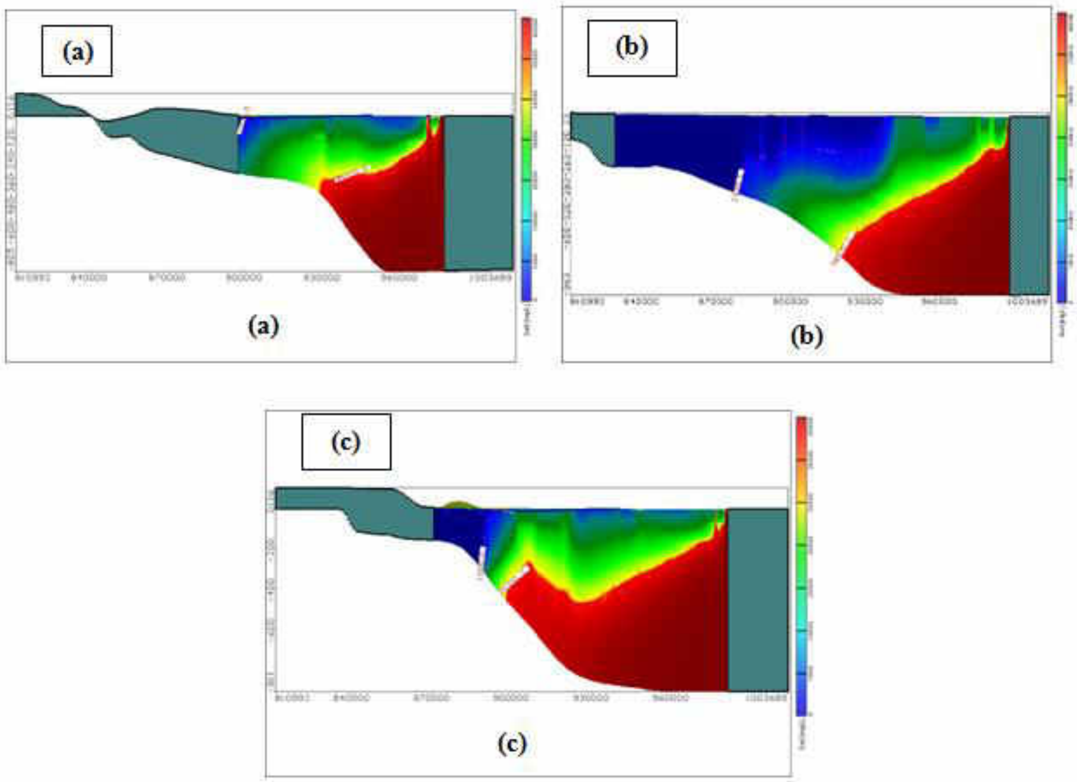


Fig. 30. Vertical Distribution of TDS in Nile delta Aquifer for Combination of Three Scenarios Change by (a) 25 %, (b) 50 % and (c) 100 % at **Sec III**

6. Conclusions

The main objective of this research was to study the effect of SLR, decreasing surface water level, increasing extraction and combination of this scenarios on saltwater intrusion in Nile delta aquifer. The results of show that:

1. **Increasing** SLR by 25 cm, 50 cm and 100 cm (Scenario-1) leads to an increase in SWI to reach 73, 73.25 and 73.75 km in the West, at the Middle the SWI reach 95.75 km, 96.25 km and 97 km, also at the East the SWI reach 91.50, 91.75 and 92.25 km respectively for Equi-line 1.00.
2. **Decreasing** surface water level by 25 cm, 50 cm and 100 cm (Scenario-2) increases SWI to reach 73.25 km, 73.75 km and 74 km at the West, at the Middle the SWI reach 96 km, 96.50 km and 97.50 km, also at the East the SWI reach 91.25 km, 91.75 km and 92 km for Equi-line 1.00.
3. **Increasing** extraction rates by 25%, 50% and 100% (Scenario-3) leads to an increase in SWI to reach 73 km, 74 km and 79.50 km at the West, at the Middle the SWI reach 98.25 km, 101.25 km and 107.75 km, also at the East the SWI reaches 91 km, 91.50 km and 91.75 km for Equi-line1.00.
4. The most **effective** scenarios is the combination of increasing extraction rates, increasing SLR and decreasing surface water system (Scenario-4) causes the SWI

intrusion reach to 73.50, 76.25 and 79.50 km at the West, at the Middle the SWI reach 99.25 km, 103.25 km and 110 km, also at the East the SWI reach 91.50 km, 91.75 km and 92.75 km for Equi-line 1.00. Combinations of three Scenarios have strong effect on SWI.

6. Recommendations

It could be recommended to study different scenarios to control of saltwater intrusion considering climatic change in Nile delta aquifer to protect groundwater.

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"دراسة تأثير التغيرات المناخية لتداخل المياه المالحة علي خزان الدلتا بمصر"

الملخص العربى

تعتبر ظاهرة تداخل المياه المالحة داخل الخزانات الجوفية الساحلية من أخطر الظواهر الطبيعية التي تهدد نوعية المياه العذبة بالخزانات الجوفية الساحلية . حيث قام جايبن هيرتزبج بدراسة تلك الظاهرة عام 1860 ولكن لاتزال هذة الظاهره تشغل أذهان العلماء في كيفية التحكم في تلك الظاهرة ويهدف هذا البحث الي دراسة تأثير التغيرات المناخية علي الخزان الجوفي بدلتا النيل وذلك بدراسة تأثير إرتفاع منسوب مياه البحر وكذلك إنخفاض مناسيب المياه السطحية وأيضا تأثير زياده معدلات السحب من االمياه الجوفية .بعد تطبيق الدراسة علي الخزان الجوفي بالدلتا توصلت الدراسة الي :

1- **من خلال تطبيق** النموذج علي خزان الدلتا إتضح أن التداخل يصل الي 90.75 كم في شرق الدلتا وأيضا الي 93.75 كم في وسط الدلتا وتقريبا 72.50 كم في غرب الدلتا بالنسبة لخط تركيز الملوحة يصل الي 1000 جزء في المليون.

2- **إرتفاع** منسوب مياه البحر(**سيناريو 1**) بمقدار 25 سم و50 سم و100 سم سوف يؤدي الي زيادة تداخل المياه المالحة داخل الخزان لتصل الي 91.50 كم و91.75 كم و92.25 كم في شرق الدلتا ويصل التداخل تقريبا الي 95.75 كم و96.25 كم و97.00 كم في وسط الدلتا وفي غرب الدلتا يصل التداخل تقريبا الي 73.00 كم و73.25 كم و73.50 كم في شرق الدلتا علي الترتيب.

3- **إنخفاض** منسوب مياه السطحية (**سيناريو 2**) بمقدار 25 سم و50 سم و100 سم سوف يؤدي الي زيادة تداخل المياه المالحة داخل الخزان لتصل الي 91.25 كم و91.75 كم و92.00 كم في شرق الدلتا ويصل التداخل تقريبا الي 96.00 كم و96.50 كم و97.50 كم في وسط الدلتا وفي غرب الدلتا يصل التداخل تقريبا الي 73.25 كم و73.75 كم و74.00 كم في شرق الدلتا علي الترتيب.

4- **زيادة** معدل السحب من المياه الجوفية (**سيناريو 3**) بمقدار 25 %و50 % و100 % سوف يؤدي الي زيادة تداخل المياه المالحة داخل الخزان لتصل الي 91.00 كم و91.50 كم و91.75 كم في شرق الدلتا ويصل التداخل تقريبا الي 98.25 كم و101.25 كم و107.75 كم في وسط الدلتا وفي غرب الدلتا يصل التداخل تقريبا الي 73.00 كم و74.00 كم و79.50 كم في شرق الدلتا علي الترتيب.

5- **يعتبر** أكثر السناريوهات السابقة تأثيرا علي تداخل المياه المالحة هو زيادة معدل السحب من الخزان(**سيناريو 3**) ثم إرتفاع منسوب مياه البحر (**سيناريو 1**) وبعد ذلك تقليل منسوب المياه السطحية داخل حدود الخزان (**سيناريو 2**) ولكن **بالجمع** بين السيناريوهات المختلفة السابقة من إرتفاع منسوب مياه البحر وخفض مناسيب المياه السطحية وزيادة معدل السحب من الجوفية (**سيناريو 4**) بمقدار 25 %و50 % و100 % سوف يؤدي الي زيادة تداخل المياه المالحة داخل الخزان لتصل الي 91.50 كم و91.75 كم و92.75 كم في شرق الدلتا ويصل التداخل تقريبا الي 99.25 كم و103.25 كم و110.00 كم في وسط الدلتا وفي غرب الدلتا يصل التداخل تقريبا الي 73.50 كم و77.25 كم و79.50 كم في شرق الدلتا علي الترتيب ويعتبر هذا السيناريو من أخطر السناريوهات التي ستهدد نوعية المياه العذبة بالخزان الجوفي بالدلتا.