Investigation and control of seawater intrusion in the Eastern Nile Delta aquifer considering climate change

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ABSTRACT

Seawater intrusion is considered one of the main processes that degrade water quality by raising salinity. Over-pumping and decreasing recharge are considered the main causes of saltwater intrusion. Moreover, climate change and sea-level rise accelerate saltwater intrusion. In this paper, SEAWAT code was used to study groundwater flow and seawater intrusion in the Eastern Nile Delta aquifer considering four scenarios of climate change including sea-level rise, increasing abstraction, decreasing recharge and the combination of these scenarios. The results showed that decreasing recharge has a significant effect on seawater intrusion. However, the combinations of these scenarios resulted in harmful intrusion and loss of groundwater. The soil salinity increased, which decreased agricultural production. The control of seawater intrusion and protection of groundwater resources and soil is very important. Different scenarios were implemented to protect the aquifer from seawater intrusion including decreasing abstraction, increasing recharge, abstracting brackish water and the combination of these three scenarios. The abstraction of brackish water gave a higher reduction of seawater intrusion and decreased groundwater table in the aquifer near the shore line, which protected the soil from salinity and increased agricultural production. However, the combination of these three scenarios gave the highest reduction of seawater intrusion.

Key words | climate change, over-pumping, sea-level rise, SEAWAT, seawater intrusion

INTRODUCTION

One-third of the world’s drinking water is provided by groundwater. Groundwater is considered the main water source in many coastal regions. Population growth increases water requirements, which increases pumping from aquifers. Saltwater is common in coastal aquifers where the aquifers are in direct contact with the sea (Bear et al. 1999). Saltwater intrusion affects groundwater resources, soil salinity, agricultural productivity and quality in the coastal zone. This may lead to mass migration of farmers looking for jobs somewhere else (El Raey 2009).

Climate change has already increased the mean sea level during the last century by 10–20 mm/yr (IPCC 1996). Future sea-level rise due to climate change is expected to be between 20 and 88 mm/yr (IPCC 2001). The long-term effect of climate change and sea-level rise on saltwater intrusion should be considered. Population growth and continuous development require larger quantities of water, which increases the net abstraction from aquifers to secure the water demand. It is necessary to protect limited resources from saltwater intrusion and other pollutants. The concentration of people in coastal regions and increased related activities has increased the abstraction of groundwater, and this has led to the movement of saltwater toward aquifers and increased the salinity of groundwater. Higher salinity of groundwater limits its usage for irrigation and drinking purposes unless desalinated or mixed with lower salinity water (Abd-Elhamid 2010).

Analytical and numerical models have been used to predict the location and movement of the saltwater/freshwater interface. The numerical models can be
categorized as sharp interface models or diffusive (dispersive) interface models. The first attempt at simulating seawater intrusion was introduced by Ghyben (1889) and Herzberg (1901). This model is known as the Ghyben–Herzberg model, which assumes that saltwater and freshwater are immiscible and separated by a sharp interface. Henry (1959) presented a numerical solution of steady saltwater intrusion into a coastal aquifer based on a sharp interface assumption. Henry (1964) developed the first analytical solution including the effect of dispersion in a confined aquifer under steady-state conditions. Henry’s problem was later solved by Lee & Cheng (1974) in terms of stream functions. Segol et al. (1975) developed the first transient solution based on a velocity-dependent dispersion coefficient. Numerous other researchers, such as Pinder & Cooper (1970), Frind (1982) and Huyakorn et al. (1987), employed numerical models in the simulation of saltwater intrusion using the diffusive interface approach.

A number of mathematical models have been developed to simulate saltwater intrusion based on a diffusive interface. Tasi & Kou (1998) developed a finite element model, considering density-dependent flow and transport. The model was used to simulate saltwater intrusion and to evaluate the major effects of hydrological and geological parameters, including hydraulic conductivity and hydraulic gradient on saltwater intrusion. Benson et al. (1998) studied the effect of velocity gradient on solute transport. Their study showed that in the case of saltwater intrusion, the velocity is so high that it affects solute transport. Cheng et al. (1998) developed a 2-D finite element model for density-dependent flow and solute transport through saturated and unsaturated soils. Sakr (1999) presented a finite element model to simulate density-dependent solute transport. He used the model to investigate the limitation of the sharp interface approach in coastal aquifers for steady and unsteady states.

The Nile Delta aquifer provides about 85% of total groundwater abstractions in Egypt. About 6.1 BCM/yr are annually extracted from the aquifer. A number of studies have been carried out to simulate saltwater intrusion in the Nile Delta aquifer using different models. Sherif & Al-Rashed (2003) used two models to simulate the problem of saltwater intrusion in the Nile Delta aquifer in the vertical and horizontal directions. The two models were 2D-FED and SUTRA. The 2D-FED model was employed to simulate the current conditions and predict the effect of the seawater level rise in the Mediterranean Sea under the conditions of global warming. SUTRA was used to define the best location of additional groundwater pumping wells from the Nile Delta aquifer and to assess the effect of various pumping scenarios on the intrusion process.

El-Arabi (2007) used Visual MODFLOW to study the environmental impacts of new settlements on the groundwater. The model was used to simulate groundwater behavior and the migration of the pollution plume under the initiated industrial and agriculture activities. Morsy (2009) used Visual MODFLOW and solute transport model MT3D to evaluate the future potential quantitative and qualitative impacts of the proposed national water policy on the aquifer system of the Nile Delta. Monem (2009) used MODFLOW to study environmental impacts on the groundwater system in the Nile Delta. Hendy (2012) used Visual MODFLOW to study groundwater management in the north of Sharkia. The study indicated that increasing the abstraction rate will lead to more saltwater intrusion. Sherif et al. (2012) discussed the concept of equivalent freshwater head in successive horizontal simulations of seawater intrusion in the Nile Delta using FEFLOW (a 3-D finite element variable density model). Their results demonstrated increasing saltwater intrusion with time and the location of the transition zone moving towards land side as it moves down with depth.

Abd-Elaty (2014) carried out a numerical and experimental study of the impacts of climate change and sea-level rise on the Nile Delta aquifer using MODFLOW and SEAWAT. The study proved that increasing seawater level increased the intrusion of saline water in the aquifer. A few studies have addressed the possible impacts of climatic change and seawater level rise on seawater intrusion in the Nile Delta aquifer (e.g., Sefelnasr & Sherif 2014). Few studies have been conducted on controlling saltwater intrusion in the Nile Delta aquifer and protecting the soil from high salinity to safeguard agricultural production. Todd (1974) for example presented various methods of preventing saltwater from
contaminating groundwater sources, including reduction of pumping rates, relocation of pumping wells, usage of subsurface barriers, natural recharge, artificial recharge, abstraction of saline water and combinations of these.

This study uses the SEAWAT code to investigate groundwater flow and seawater intrusion in the Eastern Nile Delta aquifer considering different scenarios of climate change including sea-level rise, increased groundwater abstraction, decreased groundwater recharge and a combination of the three. A number of scenarios were employed to control saltwater intrusion into the aquifer including decreasing groundwater abstraction, increasing aquifer recharge, abstracting brackish water from the saline zone and a combination of the three. Protecting soil from salinity to increase agricultural production is discussed.

**STUDY AREA**

The current study involved the Eastern Nile Delta (END) aquifer. The aquifer is bounded by the Mediterranean Sea in the north, the river Nile in the south, the Ismailia canal in the south-east and the Demitta branch in the south-west as shown in Figure 1. The study area is located between latitudes 31° 00’ and 32° 30’N, and longitudes 29° 30’ and 32° 30’E.

The Nile Delta consists of flat, low-lying areas, mainly used for agriculture. The ground elevation is about 18 m above mean sea level in the south, sloping gently in the northward direction by an average value of 1 m/10 km (Saleh 1980). The average daily temperature ranges from 17 °C to 20 °C along the Mediterranean Sea to more than 25 °C in Upper Egypt (SNC 2010). Evaporation rates range between 7 mm/day in Upper Egypt to about 4 mm/day on the northern Mediterranean coast (WMRI-NWRC 2002). Average rainfall is very low and varies from 25 mm/year in the south and middle parts to 200 mm/year in the north (RIGW 1992).

The most important parameters to model groundwater flow are hydraulic properties such as vertical hydraulic conductivity (kv) and horizontal hydraulic conductivity (kh), specific yield, storage coefficient, transmissivity, and total and effective porosity. The clay cap average vertical hydraulic conductivity (Kcv) was estimated as 2.50 mm/day and the average horizontal hydraulic conductivity (Kch) as 25–55 mm/day. The quaternary aquifer sediments average a horizontal hydraulic conductivity (Kh) of 75 m/day (RIGW/IWACO 1999). The transmissivity (T) is estimated to be 5,000 m/day. The storativity (S) is estimated to be $2.5 \times 10^{-3}$ (RIGW 1980). The values of $K = 100 \text{ m/day}$ and $S = 10^{-4}$ to $10^{-3}$ may be used to represent the regional values of hydraulic conductivity and storativity of the Delta aquifer (Farid 1980). Longitudinal and lateral
dispersivity values were estimated to be 100 m and 10 m, respectively, in accordance with Sherif et al. (1988).

**NUMERICAL MODEL**

SEAWAT code is employed in the current study. The code combines MODFLOW and MT3DMS into a single program that solves coupled groundwater flow and solute transport equations. Moreover, it allows for the calculation of variable density groundwater flow. SEAWAT has been tested and verified against benchmark problems involving variable density groundwater flow such as the Henry problem, Elder problem and HYDROCOIN problem. The variable-density flow (VDF) process of SEAWAT uses the familiar and well-established MODFLOW methodology to solve the variable density groundwater flow equation (Langevin et al. 2008). The MT3DMS part of SEAWAT refers to the integrated MT3DMS transport (IMT) process which solves the solute transport equation.

The VDF Process solves the following variable density groundwater flow equation (Langevin et al. 2008):

\[
\nabla \left[ \rho \frac{\mu_o}{\mu_o + \mu} + K_0 \left( \nabla h_0 + \frac{\rho_f - \rho_t}{\rho_f} \nabla Z \right) \right] = \rho s S_{s,0} \left( \frac{\partial h_0}{\partial t} \right) + \theta \left( \frac{\partial C}{\partial t} \right) - \rho_s q'_s
\]

(1)

The IMT process solves the following solute transport equation (Langevin et al. 2008):

\[
\left( 1 + \frac{\rho_b K^k_2}{\theta} \right) \frac{\partial (\theta + C)}{\partial t} = \nabla \left( \theta D \nabla C^k \right) - \nabla \left( q^s C^k \right) - \left( q'_s + C^k_s \right)
\]

(2)

where,

- \( \rho \): is the fluid density [ML\(^{-3}\)],
- \( \rho_f \): is the density of the saline groundwater [ML\(^{-3}\)],
- \( \rho_t \): is the density of freshwater [ML\(^{-3}\)],
- \( Z \): is the depth of saline water below the mean sea level [M],
- \( \mu_o \): is dynamic viscosity of the fresh groundwater [ML\(^{-1}\)T\(^{-1}\)],
- \( \mu \): is dynamic viscosity of the saline groundwater [ML\(^{-1}\)T\(^{-1}\)],
- \( K_0 \): is the hydraulic conductivity [LT\(^{-1}\)],
- \( h_0 \): is the hydraulic head [L],
- \( S_{s,0} \): is the specific storage [L\(^{-1}\)],
- \( t \): is time [T],
- \( \theta \): is porosity [-],
- \( C \): is salt concentration [ML\(^{-3}\)], and
- \( q^s \): is a source or sink [T\(^{-1}\)] of fluid with density \( \rho_s \).
- \( \rho_b \): is the bulk density (mass of the solids divided by the total volume) [ML\(^{-3}\)],
- \( K^k_2 \): is the distribution coefficient of species k [L\(^3\) M\(^{-1}\)],
- \( C^k \): is the concentration of species k [ML\(^{-3}\)],
- \( D \): is the hydrodynamic dispersion coefficient [L\(^2\)T\(^{-1}\)],
- \( q \): is specific discharge [LT\(^{-1}\)], and
- \( C^k_s \): is the source or sink concentration [ML\(^{-3}\)] of species k.

**Model geometry**

The numerical model SEAWAT code is used in this study for simulation of groundwater flow and saltwater intrusion in the END aquifer. The domain is divided into 175 rows and 135 columns with cell dimension 1.00 km \( \times \) 1.00 km as shown in Figure 2. The domain is divided into 11 layers; the
first layer represents the clay cap, the others represent the Quaternary aquifer divided into ten layers of equal thickness. The first layer thickness varies from 20 m in the south to 50 m in the north. The thickness of the Nile Delta aquifer varies between 200 m south to 1,000 m north. Two cross-sections are taken in the X-direction and in the Y-direction (Figure 3).

**Boundary conditions**

Two types of boundaries are used in this study representing head and concentration. The head boundary conditions were set in the model as zero in the north along the shore line. The south was bounded by constant head of 16.96 m above mean sea level and the east boundary was set free. The south-east was bounded by the Ismailia Canal where the water level started from 16.17 m in the south to 7.01 m in the east above mean sea level. The west was bounded by Damietta branch where the water level started from 16.00 m in the south to 0.50 m in the north. Figure 4(a) shows the head boundary conditions. A concentration of 40,000 mg/L is applied along the Mediterranean Sea coastal zone, and a concentration of 35,000 mg/L is applied along the Suez Canal coast line. The initial concentration of the groundwater was set to 0 mg/L (Figure 4(b)).

**Hydraulic parameters**

The initial values of the hydraulic parameters of the Eastern Nile Delta aquifer are presented in Table 1. These data were collected from previous studies (El-Arabi 2007). The scale-dependent values were set as longitudinal dispersivity ($\alpha_L$) equal to 100 m, lateral dispersivity ($\alpha_T$) equal to 10 m, vertical ($\alpha_V$) dispersivity equal to 1.00 and the value of the diffusion coefficient ($D^*$) equal to $10^{-4}$ m$^2$/day (Sherif et al. 1988).

**Recharge and abstraction**

The recharge to the Eastern Nile Delta aquifer ranges between 0.25 and 0.80 mm/day (RIGW 1980) as shown in Figure 5(a). The abstraction rate equalled $3.48 \times 10^6$ m$^3$/year in 2008 and the distribution of abstraction wells was assigned to the study area as estimated by RIGW (1980) (Figure 5(b)).

**Model calibration**

Calibration is a process that shows the difference between the calculated values and the observed ones. A number of observation wells have been used to compare the model
calculated heads with the measured data from (RIGW 1980). Figure 6(a) shows a comparison between calculated and observed heads in the Eastern Nile Delta aquifer; it also shows that the root mean square (RMS) is 0.499 m and normalization RMS is 7.314%. The model results for calculated head values match with the field data for piezometric heads. One of the important results from the model calibration is water balance for the aquifer to determine the situation of the groundwater system, and the main components of the groundwater system are constant head, general head, well extraction, river, drain, recharge, lake seepage, stream leakage and change in aquifer storage. The inflow and outflow of the model is 5,151,600 m$^3$/day. The validation target achieved 0.0005% which is lower than 1.00% of the total inflow. The difference between inflow and outflow equals 46.00 m$^3$/day, with the percentage discrepancy equal to zero (Figure 6(b)).

<table>
<thead>
<tr>
<th>Main hydraulic units</th>
<th>Layer no.</th>
<th>Hydraulic conductivity</th>
<th>Storage coefficient</th>
<th>Specific yield $S_n$</th>
<th>Effective porosity n</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$K_h$ (m/day)</td>
<td>$K_v$ (m/day)</td>
<td>$S$ (m/day)</td>
<td>$S_n$ (1/m)</td>
</tr>
<tr>
<td>Clay</td>
<td>1</td>
<td>0.10–0.25</td>
<td>0.01–0.025</td>
<td>$10^{-3}$</td>
<td>0.10</td>
</tr>
<tr>
<td>Fine Sand with Lenses of Clay</td>
<td>2, 3, 4 and 5</td>
<td>5–20</td>
<td>0.5–2</td>
<td>$5 \times 10^{-3}$</td>
<td>0.15</td>
</tr>
<tr>
<td>Course Sand Quaternary</td>
<td>6, 7, 8 and 9</td>
<td>20–75</td>
<td>2–7.50</td>
<td>$2.50 \times 10^{-3}$</td>
<td>0.18</td>
</tr>
<tr>
<td>Graded Sand and Gravel</td>
<td>10 and 11</td>
<td>75–100</td>
<td>7.50–10</td>
<td>$5 \times 10^{-4}$</td>
<td>0.20</td>
</tr>
</tbody>
</table>

**SIMULATION OF GROUNDWATER FLOW AND SEAWATER INTRUSION IN THE END AQUIFER**

The numerical model SEAWAT was employed to simulate groundwater flow and seawater intrusion in the Eastern Nile Delta aquifer.
Nile Delta aquifer. Figure 7(a) shows the areal view of groundwater levels in the Eastern Nile Delta aquifer. The groundwater levels vary from 16.00 m in the south to 0.0 m in north. The velocity direction in Eastern Nile Delta aquifer is shown in Figure 7(b) with prevailing groundwater flows from south to the north. The velocity in the clay cap layer equals 0.0007 m/day and the average velocity in the aquifer equals 0.12 m/day.
The distribution of saltwater intrusion in the Eastern Nile Delta aquifer is shown in Figure 8(a), which is considered the base case. A vertical cross-section (Y-Y) is taken in the middle of the aquifer from top to bottom as shown in Figure 2. The vertical cross-section (Figure 8(b)) showed that the intrusion length of isoline 35 (35,000 ppm) reached 75.75 km from the shore line. However, isoline 1 (1,000 ppm) intruded to a distance of 90.25 km from the shore line.

**IMPACT OF CLIMATE CHANGE ON SEAWATER INTRUSION IN THE END AQUIFER**

SEAWAT code was used to study the impact of climate change by 2100 on seawater intrusion in the Eastern Nile Delta aquifer. Different scenarios were considered, including sea-level rise, increasing abstraction, reducing recharge and the combination of all these. The results of the different scenarios are presented in Table 2.
In Scenario 1, the seawater level was raised to 100 cm to simulate expected climate change by the end of this century. Figure 9(a) shows the vertical distribution of total dissolved solids (TDS) in the aquifer. A new position of the transition zone was detected as the intrusion lengths of isolines 35 and 1 reached 77.00 and 90.75 km landward, respectively. Seawater level rise increased seawater intrusion. Scenario 2 represents the case where the groundwater levels at the land side decreased due to increasing abstraction of the aquifer. In this scenario, the seawater head was maintained constant and abstraction was increased by 100%. The intrusion lengths of isolines 35 and 1 reached 79.60 and 91.50 km from the shore line respectively as shown in Figure 9(b).

Scenario 3 represents the case where the groundwater levels at the land side decreased due to decreasing recharge to the aquifer. In this scenario, the seawater head was maintained constant and the recharge was decreased by 100%. The intrusion lengths of isolines 35 and 1 reached 85.25 and 95.40 km from the shore line respectively as shown in Figure 9(c). In Scenario 4 the combination of raising seawater level by 100 cm, decreasing groundwater levels by increasing abstraction by (100%) and decreasing recharge by (−100%) is analyzed. This scenario represents the worst cases, where the increase of seawater level is associated with decreasing groundwater levels due to over-abstraction and decreased recharge. Isoline 35 reached 99.40 km and isoline 1 reached 110.25 km from the shore line as shown in Figure 9(d). Isoline 35 moved inland 25.00 km and isoline 1 moved inland 23.65 km. The results of these scenarios reveal that increasing the seawater level and decreasing groundwater levels would increase seawater intrusion. A combination of these scenarios causes more seawater intrusion, which further deteriorates groundwater storage in the Eastern Nile Delta aquifer.

### CONTROL OF SEAWATER INTRUSION IN THE END AQUIFER

The intrusion of saline water in the Eastern Nile Delta aquifer is expected to increase due to climate change. The groundwater levels near the shore line are expected to increase, which will negatively affect the soil and the agriculture in these areas. The control of seawater intrusion in the Eastern Nile Delta aquifer and decreasing groundwater level in the north is very important. Different scenarios were employed to control seawater intrusion in the Eastern Nile Delta aquifer. The results of the different scenarios of seawater intrusion control are presented in Table 2.

In Scenario 1, the abstraction rate from the aquifer was decreased to 50%. Figure 10(a) shows that the intrusion lengths of isolines 35 and 1 decreased to 69.95 and 88.40 km from the shore line, respectively. Scenario 2 represents the case where the recharge to the aquifer is increased. In this scenario, the seawater head was maintained constant and recharge was increased by 50%. The intrusion lengths of isolines 35 and 1 decreased to 77.75 and 88.00 km, respectively (Figure 10(b)).

Scenario 3 represents the abstraction of brackish water from the aquifer. In this scenario, the seawater head was maintained constant and the abstraction rate from the brackish water zone increased by 50%. The intrusion lengths of isolines 35 and 1 decreased to 61.00 and 87.80 km, respectively (Figure 10(c)). Abstraction of brackish water from the aquifer is one of the effective methods to control saltwater intrusion, with isoline 1 moving back toward the sea 2.95 km and isoline 35 moving back toward the sea 16 km.

In Scenario 4, a combination of the three scenarios was employed to control seawater intrusion into the aquifer. The abstraction rate was decreased by 50%, the recharge was increased by 50% and the abstraction rate from the brackish water zone was increased by 50%. This scenario represents the best case, with isoline 35 decreasing to 59.80 and isoline 1 decreasing to 85.90 km (Figure 10(d)). This scenario moved isolines 1 and 35 back toward the sea 4.85 and 17.2 km, respectively.

The first three scenarios applied to control saltwater intrusion are capable of decreasing the intrusion. Abstraction of brackish water gave good results but the combination of these three scenarios is cost-effective and can stop the intrusion of saline water and protect the Eastern Nile Delta aquifer from deterioration. Abstraction of saline water helps to decrease groundwater levels in the aquifer. Figure 11(a) shows the groundwater levels in the END aquifer due to a 100 cm rise in seawater level but Figure 11(b) shows the
groundwater levels in Scenario 4 of controlling SWI (combination of the three Scenarios 1, 2 and 3). Comparing the groundwater levels in Figure 11(a) and 11(b) show that the groundwater levels have been decreased. The reduction in groundwater level in this area will reduce the soil salinity and increase agricultural production.

Table 2 | Results of different scenarios for investigating and controlling SWI in the END aquifer

<table>
<thead>
<tr>
<th>Case</th>
<th>Scenario</th>
<th>Scenario description</th>
<th>Isoline 35</th>
<th>Isoline 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>Current situation</td>
<td>75.75</td>
<td>90.25</td>
<td></td>
</tr>
<tr>
<td>Different scenarios for investigating SWI due to climate change</td>
<td>SLR 100 cm</td>
<td>77.00</td>
<td>90.75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increasing abstraction rate 100%</td>
<td>79.60</td>
<td>91.50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Decreasing recharge 100%</td>
<td>85.25</td>
<td>95.40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Combination of 1, 2 and 3</td>
<td>99.40</td>
<td>110.25</td>
<td></td>
</tr>
<tr>
<td>Different scenarios for controlling SWI</td>
<td>Decreasing abstraction 50%</td>
<td>69.95</td>
<td>88.40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increasing recharge 50%</td>
<td>70.75</td>
<td>88.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Abstracting brackish water 50%</td>
<td>61.00</td>
<td>87.80</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Combination of 1, 2 and 3</td>
<td>59.80</td>
<td>85.90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Decreasing abstraction 50%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increasing recharge 50%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Abstracting brackish water 50%</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

SWI: saltwater intrusion; SLR: sea-level rise.

Figure 9 | Vertical distribution of TDS in the END aquifer due to different scenarios of climate change: (a) Scenario 1, (b) Scenario 2, (c) Scenario 3 and (d) Scenario 4.
Climate change has a clear impact on water resources in the coastal regions. SEAWAT code was used to simulate groundwater flow and seawater intrusion in the Eastern Nile Delta (END) aquifer in Egypt, considering different scenarios of climate change. The results indicated that the rise in seawater level, increase in abstraction from the coastal aquifer, and rise in seawater level, increase in abstraction from the coastal aquifer, and increase in abstraction from the coastal aquifer, all contribute to the severity of seawater intrusion.

**CONCLUSION**

Climate change has a clear impact on water resources in the coastal regions. SEAWAT code was used to simulate groundwater flow and seawater intrusion in the Eastern Nile Delta (END) aquifer in Egypt, considering different scenarios of climate change. The results indicated that the rise in seawater level, increase in abstraction from the coastal aquifer, and increase in abstraction from the coastal aquifer, all contribute to the severity of seawater intrusion.
aquifer and the decrease of recharge to the aquifer increased the rate of seawater intrusion (Scenarios 1, 2 and 3). A combination of all these resulted in more intrusion (Scenario 4) and resulted in large losses of freshwater. The salinity of soil has increased due to increasing groundwater levels near the shore and agriculture in these areas has been affected. Scenarios to control saltwater intrusion were presented. The results indicated that increasing aquifer recharge, decreasing total groundwater abstraction and increasing brackish water abstraction (Scenarios 1, 2 and 3) are expected to be able to reduce seawater intrusion. A combination of all (Scenario 4) led to further reduction in seawater intrusion. Increasing abstraction of saline water from the saline zone helps to decrease seawater intrusion and decrease groundwater levels in the aquifer, which reduces the soil salinity and increases agricultural production. This study presented an example of measures which can be applied to mitigate the impact of climate change on groundwater resources, soil and agricultural production in coastal areas.

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First received 27 January 2016; accepted in revised form 25 July 2016. Available online 3 August 2016