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Impact of Groundwater Quality Status on its Sustainable Use Case study: Northwest of Giza, Egypt

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Abstract: The research area is located in the northwest of Giza city. The main objective of the study is to evaluate the groundwater quality status and the hazardous impacts for sustainable uses. Chemical results showed that the total dissolved solids (TDS) in drains are ranging between 633 mg/l and 1746 mg/l and nitrate (NO_3) concentrations range from 48 mg/l to 88 mg/l. High TDS in the groundwater reaching 4768 mg/l and high concentrations of nitrate more than 45 mg/l are found only in the western and southwestern parts of the study area referring to agricultural and domestic wastes. Simulation of groundwater flow using MODFLOW indicated that the aquifer in the modeled area is recharged dominantly from excess irrigation water and leakage from irrigation network. Both MODPATH and MT3DMS results confirmed that contaminants migrate downward and extending into the unconfined highly vulnerable aquifer part, which affected the groundwater sustainable use.
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Keywords: Groundwater; quality; wastewater; MODFLOW; sustainable use; Giza, Egypt

1. Introduction

Greater Cairo is the most populous area in Egypt with estimates of around 18 million citizens. The domestic wastewater quantity raised due to high intensity of the population. There are approximately 164 wastewater treatment plants in Egypt mainly execute the secondary treatment. Only three plants execute primary treatment: two in Alexandria and one in Cairo (Abu Rawash wastewater treatment plant WWTP). The capability of the current primary Abu Rawash WWTP in Cairo is 1.2 million m^3/day, which does not meet the legal requirements. Excess sewage amounts are discharged without treatment causing water pollution in drains and subsequently contributing pollution loads to the Rosetta branch. Only primary treatment will remain insufficient to satisfy environmental and legal limitations. the provision of at least secondary treatment facilities is essential to meet the conditions and to improve the water quality and environment of the receiving water bodies. The wastewater utilities were created in 1981 and 1979 by Presidential Decrees (MHUUD, 2010).

In Egypt, groundwater is performing a vital role in development. Therefore, it is necessary to take in mind the hydrogeology of the groundwater aquifer and its vulnerability to pollution to protect it from pollution. Nowadays, groundwater model has become an essential tool for hydrogeologists to perform various tasks including helps in formulating the management strategy, the assessment and forecast of groundwater, the discovery of groundwater pollution and human activities on groundwater and related environment (Namitha et al. 2019, Zhou and Li, 2011, Loucks et al., 1985). Moreover, groundwater modeling gained wide application due to the availability of modern software packages and powerful computers. Many studies have been followed out on numerical groundwater modeling for assessment and management (Namitha et al. 2019, Khalaf and Gad, 2015, Chao et al. 2010, Senthilkumar and Elango, 2004, Balazova et al. 2002), as well as studies deal with the pollution and the contamination of groundwater (Zeidan et al., 2013, El-Araby,2008, Shamrukh,2001). Therefore, the present study aims at evaluating the groundwater quality status in the northwest of Giza city and the hazardous impacts for sustainable use.

The research area is present in the northwest of Giza city among longitudes from 31° to 31° 10' E and latitudes from 30° to 30° 10' N (Figure 1). There is a main wastewater treatment plant at Abu Rawash area with maximum effluents 1,450,000 m^3/day (Mohamed, 2015). The whole drainage system discharges treated with untreated wastewater into Barakat drain that reaches the extension of El Mouhit drain and then El Rahawy drain that discharges finally huge amounts of wastewater at the Rosetta branch, therefore it has harmful impacts on its water quality due to its high organic loads (Mohamed, 2015).

2. Description of the Study Area

The present study area is marked by a gentle slope in topographic features, where ground elevation varies between less than 20 m +msl at the east and greater than 50 m + msl at the southwestern portions (EGSA, 1997). The geomorphologic features in the study area include i) The young alluvial plain; ii) The old alluvial plain, and iii) El Hassana dome and bounding slopes.

- Young alluvial plains cover the eastern part that contains the old cultivated lands, irrigation canals, drains and towns with the extensive population.
- Old alluvial plain covers the western part forming gravel terraces (Said, 1990). It contains new reclaimed lands irrigated using groundwater and partly reused drainage water to cover water the shortage in some locations.
- El Hassana dome is a geologic structure covering an area of one square kilometer, which is located about 23 km northwest from Cairo (Said, 1990).

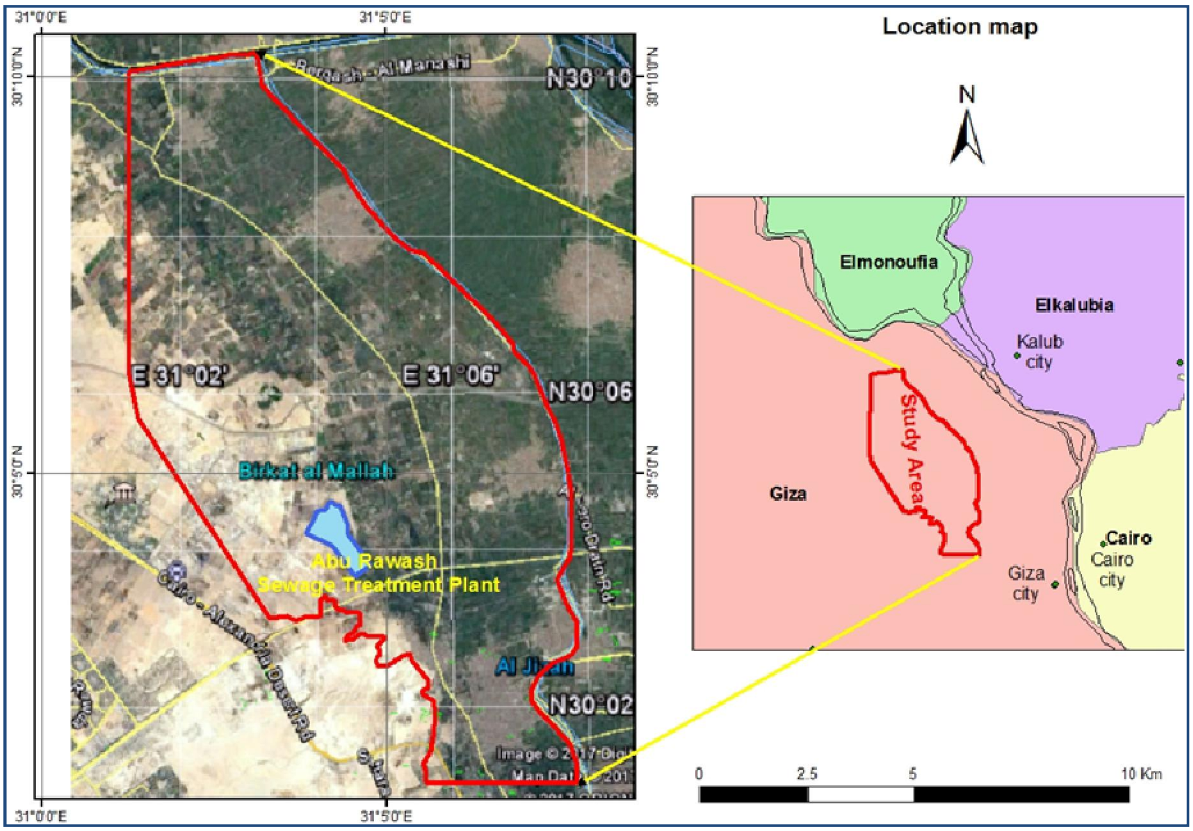

Figure 1: Location of the present study area on Google earth image.

The air temperature (T) rises in summer with maximum average values exceeding 40 ºC during July, while minimum average values below 14are measured during January. The relative humidity (R.H.) reaches its maximum average values of 55% in July and August and its minimum values of 37% in April (Sharaky et al. 2017). Evaporation intensity (Ev) is a significant factor affecting water quality, particularly where groundwater is close to the ground surface. The rainfall effect on the surface and groundwater is insignificant, especially during summer due to limited quantity (UNDP, 2013).

3. Hydrogeological Setting

The surface water system includes the El Mansuriya canal that is passing through pervious and semi-pervious layers (Figure 2). There is a direct contact between surface water and subsurface. There are many open drains in the study area that are giving a chance for the wastewater and excess irrigation water to move down to the subsurface causing recharge to the groundwater aquifer.

The geological map, as shown in figure 2, shows the surface outcrops of different geological formations and structures in the study area (EGPCO, CONOCO, 1987, RIGW, 1989). The Quaternary aquifer consists of consecutive layers of sand and gravels intercalated by clay lenses. Its maximum thickness is about 200 m in the northern part and decreases to the south reaching 100 m in the south. Also, the aquifer thickness vanishes westward until the Quaternary sediments overlap with the tertiary sediments of

Miocene, Oligocene or older rocks (Figure 3). The thickness of Miocene sediments is about 50 m of sand and clay. Oligocene basalts are occasionally underlying the Miocene and overlying the Oligocene sediments. The layer forming the Quaternary aquifer is saturated with groundwater especially northeastern portion. The groundwater exists dominantly under free water table conditions (unconfined) to semi-confined where semi-pervious clay cap covers the aquifer, especially in the eastern parts.

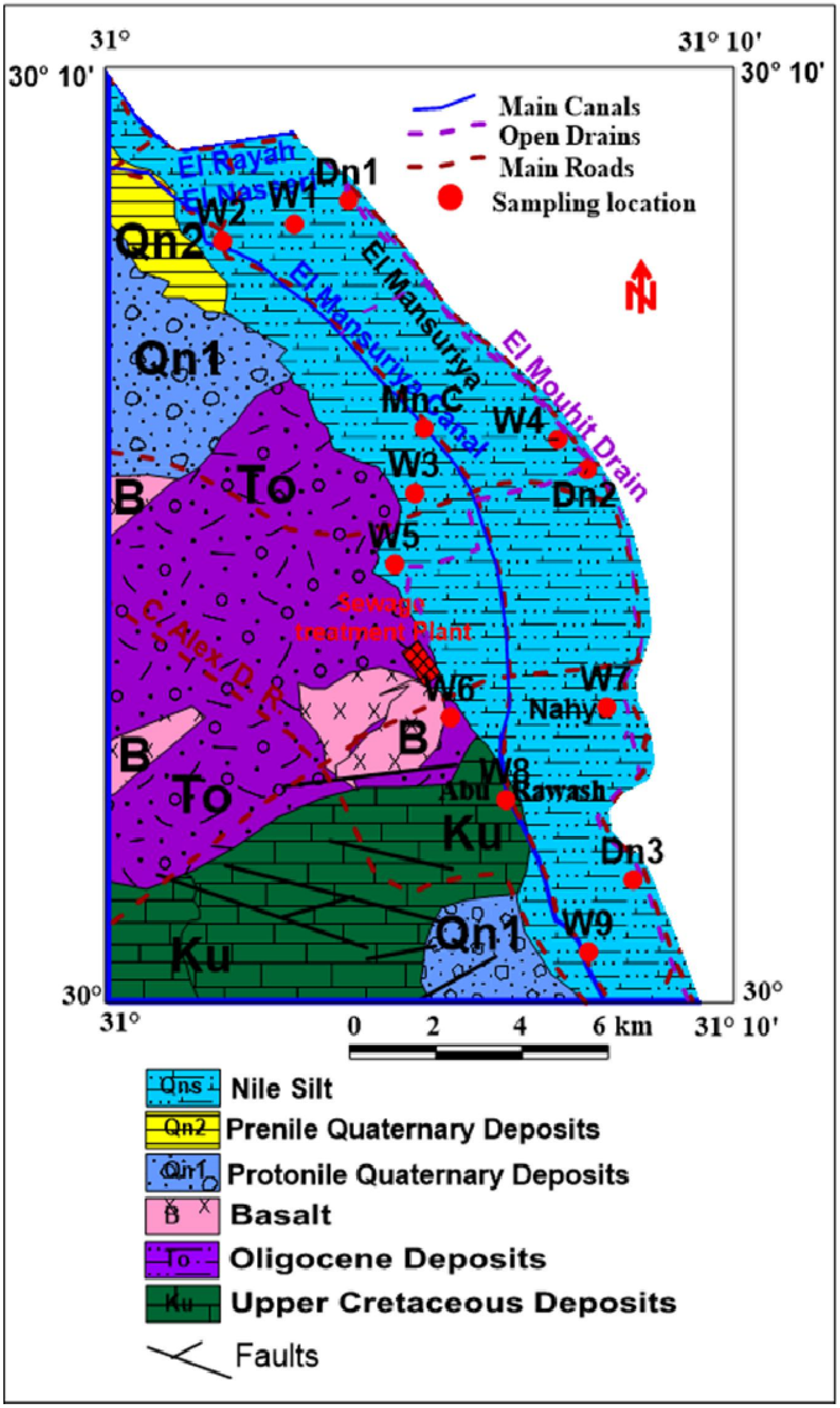

Figure 2: Geological map of the study area (after EGPCO, CONOCO, 1987).

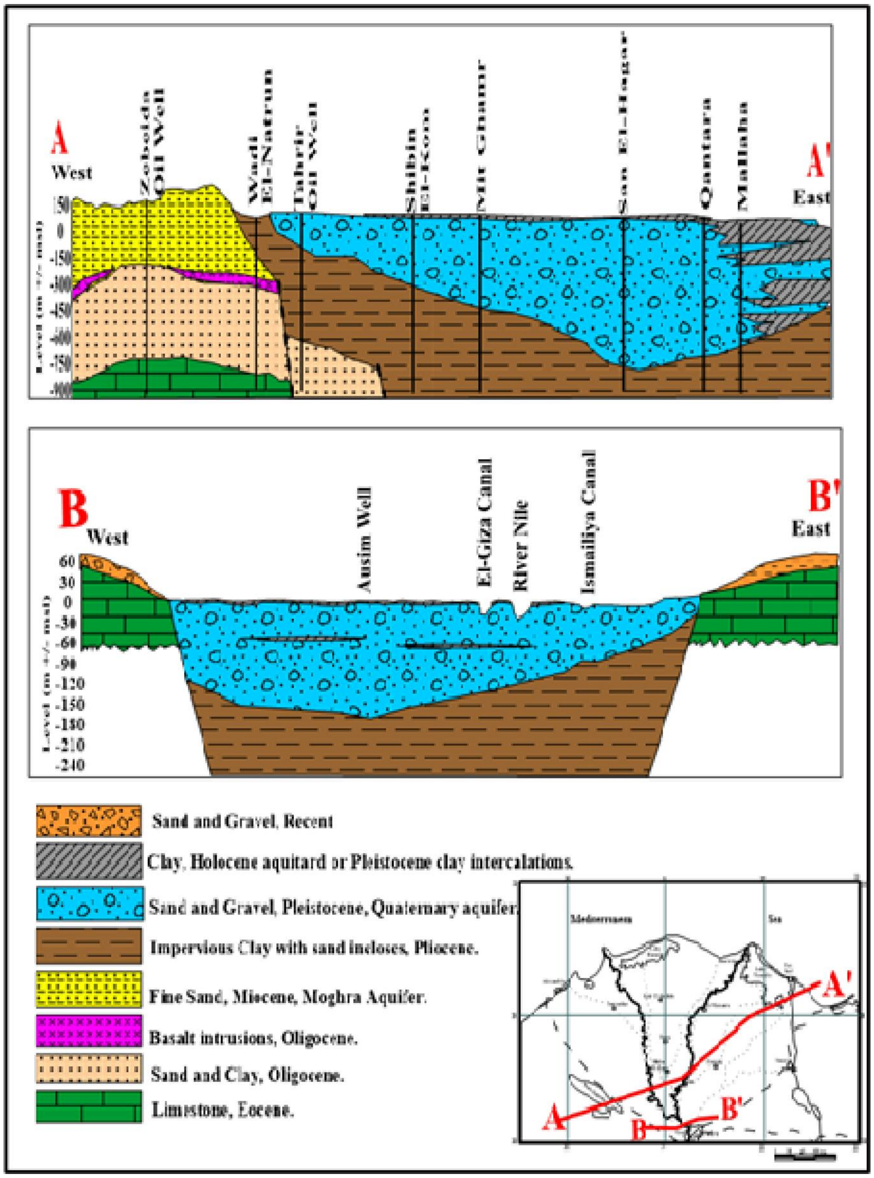

Figure 3: Hydrogeological cross sections (after RIGW, 1989).

Table 1: locations and sources of water samples.

Sample Code	Well Depth (m. -GL)	Depth to Water Table (m. -GL)	Groundwater Levels (m. +msl)
W1	65	6,5	12
W2	48	7.3	11.5
W3	62	11.5	12.6
W4	70	1.5	14
W5	35	8.5	12
W6	65	10	11
W7	56	5	12.5
W8	54	10.5	12
W9	35	8	12.5
Mn. C	El Mansouriya Canal		
Dn1	El Mouhit Drain		
Dn2	El Mansouriya Drain		
Dn3	El Mouhit Drain		

4. Material and Methods

Geological, hydrogeological and hydrochemical data have been collected and inventoried in the fieldwork and used for the present study (Table 1). Data about groundwater levels were collected and measured in wells to update the groundwater levels map. Then, groundwater vulnerability map used for quantifying the availability of pollutants from hazardous sources to reach groundwater.

Standard methods of water sampling and chemical investigations was applied for major cations and anions, nutrients and trace elements contents in groundwater and surface water samples. All these chemical analyses have been carried out in the Central Laboratory, NWRC according to the standard methods (APHA, 2017). Methods of chemical titration by standard indicators; flame photometer; spectrophotometer and the highly sensitive analytical methods have been used. Thirteen water samples have been examined for dissolved chemical constituents (EC, pH, K, Ca, Na, Mg, HCO3, SO4, Cl, NO3 and some trace elements.

The sodium adsorption ratio (SAR) is a simple method used to evaluate the danger of high sodium concentrations in irrigation water (Freeze and Cherry, 1979). Wilcox classification diagram has used to distinguish the groundwater samples for irrigation uses (Wilcox 1955). Electrical conductivity (EC) shows the salinity hazard and SAR ratio shows the alkalinity hazard. Water types divided into four categories (S1, S2, S3, S4) based on salinity hazard and another four categories (C1, C2, C3, C4) based on sodium hazard as shown in table 2 (Wilcox, 1955).

Table 2: Classification of Water Suitability for Irrigation (After Wilcox, 1955).

Class	EC (uS/cm) at 25° C	Salinity content	Class	SAR	Na content	Usage
C1	<250	Low	S1	< 10	Low	Can be used for all soils
C2	250-750	Medium	S2	10 - 18	Medium	used for coarse texture, soils of good permeability
C3	750-2250	High	S3	18 - 26	High	Can produce harmful effects and good soil management is essential
C4	>2250	Very high	S4	>26	Very high	Not satisfactory for irrigation purposes

The groundwater flow model software (Visual MODFLOW), based on the finite-difference technique (McDonald and Harbaugh, 1988), has been used to simulate the hydrogeological conditions of the groundwater aquifer system in the study. The modeled area extends with a width of 10.5 km and a length of 18 km, with an area of about 189 km^2. The grid, of rectangular shape, covered the modeled area and consisted of 361 rows and 211 columns (Figure 4). Three layers have been modeled; 1) clay cap layer covering the aquifer with a thickness 15 m to the east and vanishing westward (Al-Agha et al. 2015), 2) Quaternary aquifer layer with a maximum depth of 200 m, and 3) Miocene/Oligocene aquifer layer located in the southwestern part of the modeled area.

The boundary condition was selected depending on the hydrogeological situation of the modeled area (Figure 4).

- The northern boundary is a constant head boundary coinciding with El Rayah El Nasseri channel.
- The eastern boundary is a constant head boundary coinciding with El Mouhit drain.
- The western boundary is a specified head boundary coinciding with the piezometric head line 12 m +msl.
- The southwestern boundary is no flow boundary coinciding with the limestone plateau.
- The southern boundary is a specified head boundary coinciding with the piezometric headlines ranging from 12 m +msl to 13.5 m +msl.

The sources of the data include the RIGW database and field measurements. Hydrogeological studies showed a semi-confined groundwater aquifer under the old lands to the east, while in the western fringes the aquifer is phreatic due to the loss of the superficial clay cap layer (RIGW, 1992). The horizontal hydraulic conductivity of the groundwater aquifer ranges from 50 to 75 m/day and decreases to 40 m/day in the phreatic aquifer to the west of the study area. The horizontal permeability of the semi pervious clay cap layer ranges from 1.0 to 2.0 m/day, while the vertical permeability ranges from 0.01 to 0.2 m/day (RIGW, 2002).

The particle tracking module (MODPATH) used to show pollutant transport and to calculate three-dimensional particle tracking with pathlines using steady-state flow simulation achieved by MODFLOW (Pollock, 2017). The pathlines outline the transport pathlines and travel time of particles due to groundwater flow.

MT3DMS is a groundwater three-dimensional solute transport model used to simulate contaminant transport in groundwater aquifer (Zheng and Wang, 1999). That model has been designed to be used after the construction and calibration of the flow model

(MODFLOW) at the beginning. Therefore, the solute transport model (MT3DMS) was used to simulate and forecast the effect of TDS and NO_3 transportation processes as wastewater contaminants on the aquifer system.

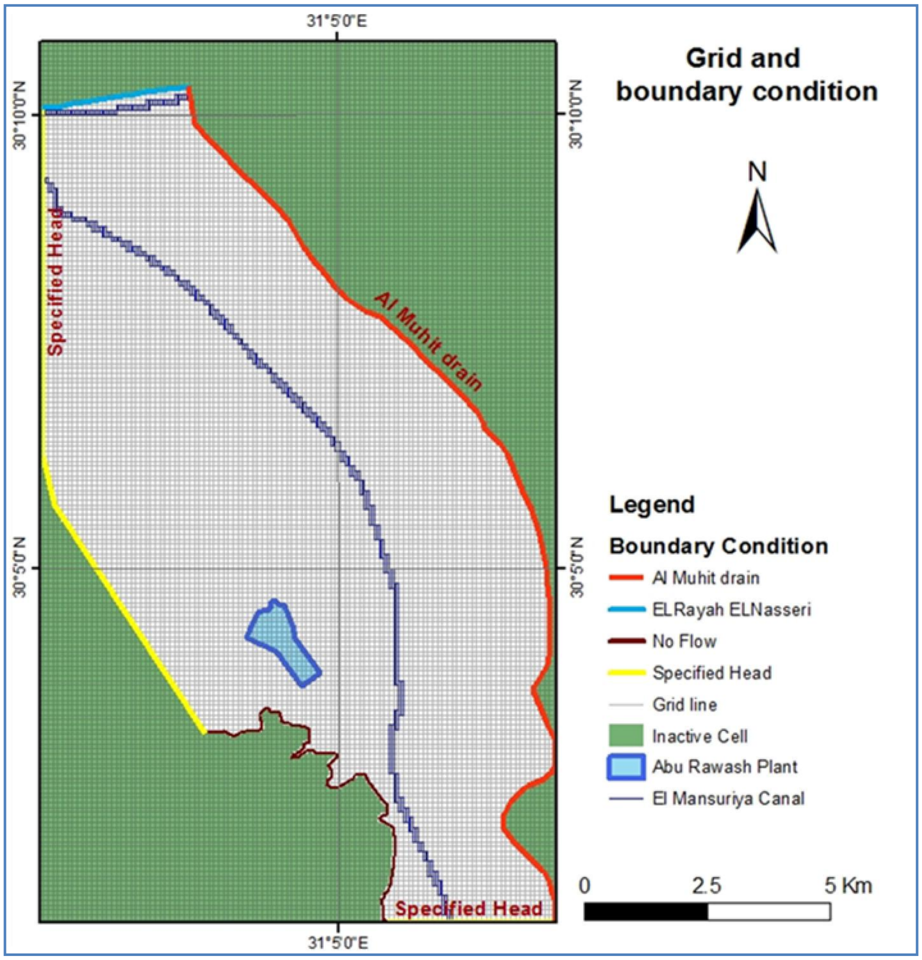

Figure 4: Grid and boundary conditions.

5. Results and Discussion

The present study revealed groundwater status in the research area and its sustainability use in the following:

5.1. Groundwater Level

Measured and collected data about groundwater levels (Table 1) used to update the groundwater levels map (Figure 5). The depth to water table is about 1 m in the northeastern part and increases southward to more than 7 m and westward to more than 12 m along the western fringes. The groundwater level in the west is about 12 m +msl, to about 16 m +msl in the east (Figure 5). The groundwater flows mainly towards the west indicating aquifer recharge mainly from surface water and excess irrigation water.

5.2. Groundwater vulnerability

Groundwater vulnerability map used for quantifying the availability of pollutants from hazardous sources to reach groundwater. Vulnerability maps serve as guidelines for land use and the development of policies for groundwater protection (UNESCO-ACSAD, 1995). The concept of vulnerability has evolved in the past for the assessment of contamination risk placed upon aquifers by human activities. In the newly planned areas for projects as industrial, agricultural, urban…etc, Actions for groundwater protection must be taken according to its vulnerability. The most important hydrogeological characteristics that influence groundwater vulnerability are the thickness of the covering clay cap; recharge rate to groundwater; and depth to the groundwater table (RIGW and IWACO, 1990, Al-Adamat and Al-Shabeeb, 2017). Therefore, Groundwater vulnerability map was drawn to quantify the availability of pollutants to reach groundwater (Figure 6). The resultant vulnerability zones in the research area are as follow:

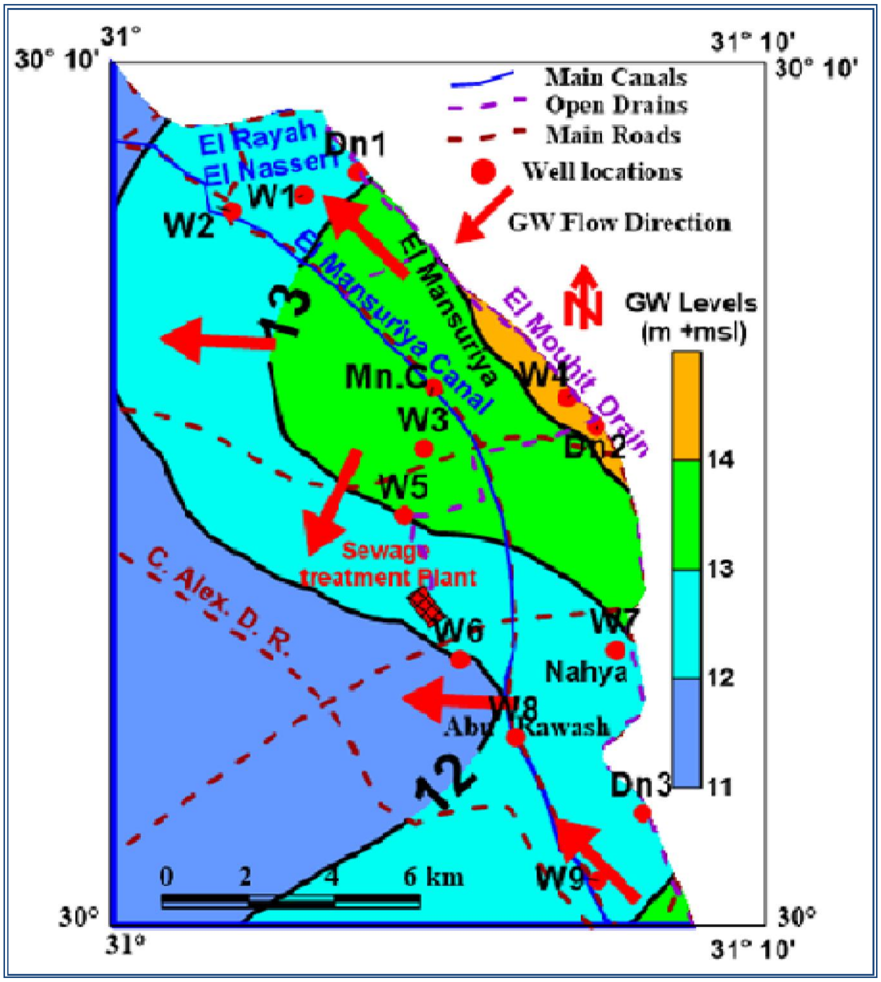

Figure 5: Updated groundwater levels map based on collected data (m +msl).

- Moderate vulnerability zones: These include parts characterized by a thin clay cap and deep groundwater table. Groundwater in such areas could be polluted and some cautions must be considered while planning for new projects in such areas.

- High vulnerability zones: These areas are present in the west where the clay cap is absent. Groundwater in these areas could be easily polluted and severe cautions must be recognized when planning for developing such areas.

5.3. Water quality assessment

The results of chemical analyses for groundwater samples, (Table 3), and those for surface water samples, (Table 4), have been used for drawing distribution maps of different dissolved chemical parameters in groundwater. These maps represent the trends of increase or decrease of elements in groundwater. Evaluation of water uses for drinking are based on guidelines of World Health Organization (WHO, 2011) and the Egyptian Ministry of Health (EMH, 2007) and the guidelines of FAO, 1985 for irrigation water.

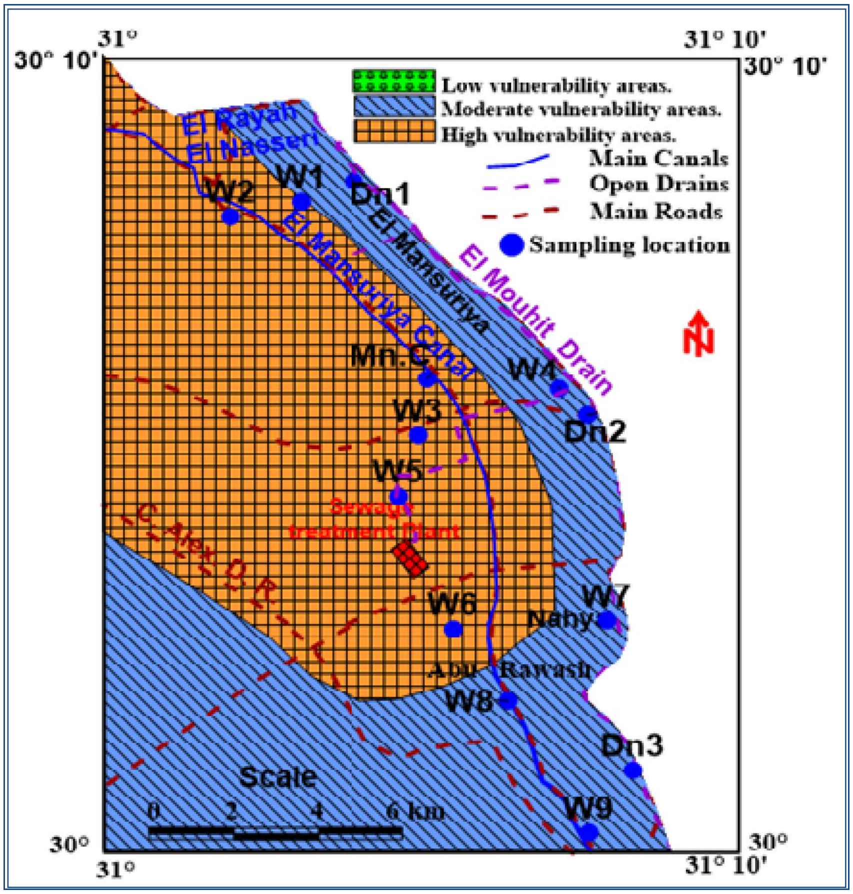

Figure 6: Distribution map of groundwater vulnerability zones.

Table 3: Chemical analysis for groundwater samples.

Sample Code	W1	W2	W3	W4	W5	W6	W7	W8	W9	Drinking Guidelines	Irrigation Guidelines
pH (Value)	8.18	7.83	7.93	8.9	7.75	7.64	8.05	7.59	7.91	6.5-8.5	6.5-8.5
EC (mmhos/cm)	1.755	1.51	1.234	1.418	0.96	7.45	1.1	2.41	1.13	1.6	3.1
TDS (mg/l)	1124	966	789	907	612	4768	705	1507	794	1000	2000
K^+ (mg/l)	14	8	12	8	8	15	5	17	5		
Na^+ (mg/l)	160	190	120	155	62	1251	85	248	97	200	
Mg^{2+} (mg/l)	51	27	37	34	38	60	33	69	63	150	
Ca^{2+} (mg/l)	156	86	99	86	77	328	104	124	44	200	
Cl^- (mg/l)	170	275	122	157	85	1962	107	380	124	250	355
SO_4^{2-} (mg/l)	287	150	157	114	140	1084	147	320	132	250	
HCO_3^- (mg/l)	351	200	331	395	278	390	326	350	329		520
CO_3^{2-} (mg/l)	0	0	0	0	0	0	0	0	0		
NO_3^- (mg/l)	50	40	2	6	8	138	2	50	40	50	135
NO_2^- (mg/l)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1	
Al (mg/l)	0.006	0.005	0.006	0.006	0.005	0.006	0.006	1.564	0.28	0.2	20
Ba (mg/l)	0.034	0.287	0.066	0.099	0.612	0.023	0.073		0.101	0.7	--
Cr (mg/l)	0.001	0.042	0.001	0.001	0.027	0.001	0.001			0.05	1
Cu (mg/l)	0.011	0.081	0.013	0.01	0.075	0.015	0.012			2	5
Fe (mg/l)	0.008	0.298	0.008	0.008	3.279	0.008	0.02		0.624	0.3	20
Pb (mg/l)	0.003	0.001	0.003	0.003	0.001	0.003	0.003	1.773		0.01	10
Mn (mg/l)	0.005	0.368	0.005	0.005	1.509	0.005	0.092		0.427	0.4	10
Ni (mg/l)	0.091	0.01	0.004	0.005	0.001	0.004	0.004	1.077		0.07	2
Zn (mg/l)	0.001	0.323	0.001	0.001	0.667	0.001	0.001			5	10
T.Hard. (mg/l)	599	328	399	355	349	1065	393			500	
SAR (Value)	2.84	4.56	2.61	3.58	1.44	16.66	1.86		2.20	-	10

Table 4: Chemical analysis for surface samples.

	Mn. C	Dn1	Dn2	Dn3		Mn. C	Dn1	Dn2	Dn3
pH (Value)	7.7	7	8.1	7.4	NO_3^- (mg/l)	4.3	88	80	48
EC (mmhos/cm)	0.55	2.75	1.96	0.99	Al (mg/l)	0.056	0.006	0.006	0.006
TDS (mg/l)	342	1746	1203	633	Ba (mg/l)	0.038	0.033	0.034	0.026
K^+ (mg/l)	5	16	17	15	Cr (mg/l)	0.001	0.001	0.001	0.001
Na^+ (mg/l)	39	513	312	122	Cu (mg/l)	0.037	0.068	0.04	0.026
Mg^{2+} (mg/l)	14	41	24	27	Fe (mg/l)	0.011	0.008	0.008	0.043
Ca^{2+} (mg/l)	37	92	81	54	Pb (mg/l)	0.003	0.003	0.003	0.003
Cl^- (mg/l)	44	542	394	97	Mn (mg/l)	0.005	0.018	0.005	0.069
SO_4^{2-} (mg/l)	35	204	147	62	Ni (mg/l)	0.004	0.006	0.001	0.006
HCO_3^- (mg/l)	168	338	228	256	Zn (mg/l)	0.001	0.001	0.001	0.001
CO_3^{2-} (mg/l)	0	0	0	0	SAR (Value)	1.82	9.76	8.84	3.05

5.3.1. Surface water assessment for domestic uses

The total dissolved salts (TDS) in El Mansuryia canal is quite low reaching 342 mg/l, while the TDS values in El Mouhit and El Mansuriya drains ranges between 633 mg/l and 1746 mg/l. High nitrate (NO_3) concentrations are detected in drains ranging from 48 mg/l to 88 mg/l. These high concentrations could be referred to receiving considerable amounts of agricultural and domestic wastes. The wastewater treatment plant at Abu Rawash is not enough to treat all wastewater due to huge quantities of drainage water in the area.

5.3.2. Groundwater assessment for domestic uses

The total dissolved salts (TDS) in the groundwater samples ranged between 612 mg/l and 4768 mg/l. Figure 7 showed that fresh to brackish groundwater (TDS < 1500 mg/l) dominated the area. The high TDS (>1500 mg/l) in the south and southwestern parts could be referred to infiltrated and mixed domestic and industrial wastewater with dissolution and leaching of salts from the aquifer sediments.

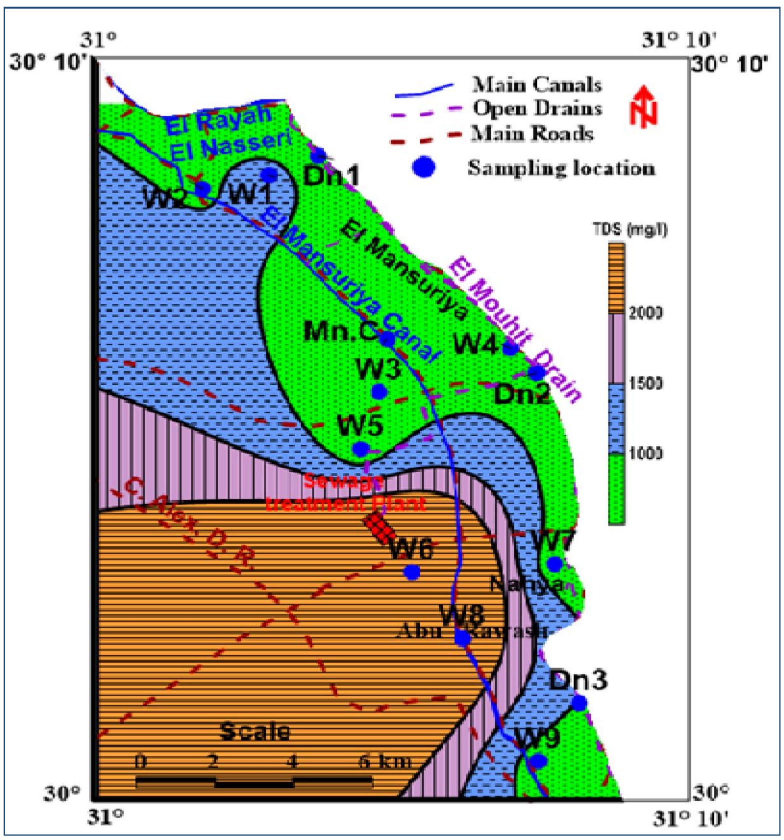

Figure 7: Distribution map of groundwater salinity (TDS).

The nitrate concentration in groundwater samples varied from 2 mg/l to 138 mg/l (Table 3). The groundwater is mostly dominated by low nitrate concentrations less than 45 mg/l as shown in figure 8. High concentrations of nitrate (> 45 mg/l) are observed in the west and southwestern portions indicating pollution from domestic and agricultural wastewater especially in high vulnerability areas to pollution.

Beside the major elements, some heavy metals (trace elements) are of special and considerable importance for the study of groundwater quality (Farrag et al, 2016). In the present study, trace elements that analyzed in water samples are Al^{3+}, Ba^{2+}, Cr^{2+}, Cu^{2+}, Fe^{2+}, Mn^{2+}, Ni^{2+}, Pb^{2+}, and Zn^{2+}. Based on the limits presented by WHO (2011) and EMH, (2007), the concentrations of all analyzed trace elements in both surface and groundwater samples are within suitable limits for the different water uses. The low contents of groundwater trace elements could be referred to cation exchange and adsorption processes in the aquifer especially in locations where a thin clay cap is present and where carbonate material is present through the aquifer sediments.

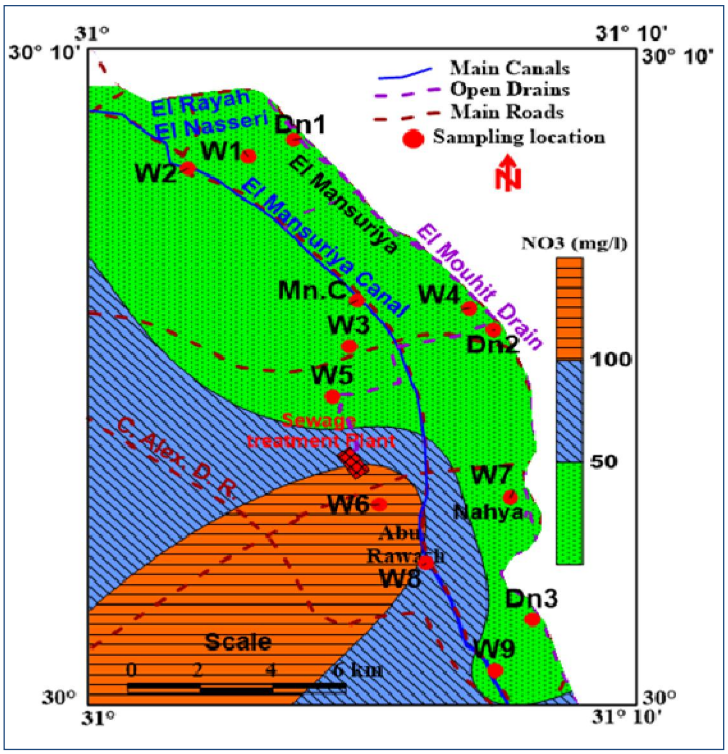

Figure 8: Nitrate distribution in Groundwater.

5.3.3. Groundwater assessment for irrigation

The TDS values of the groundwater (Table 3 and Figure 7) indicate suitable water for irrigation without any problem except in the southwestern location where TDS values of groundwater exceed 2000 ppm (Figure 7). While the TDS of the other locations increased due to the impact of irrigation water and leaching of salts. The tendency of increasing the TDS of the groundwater will be predicted by using a mathematical model.

The values of SAR in groundwater samples range between 1.44 and 16.66 with an average of 4.58 (Table 3). As shown in figure 8, most of groundwater samples have low SAR content (<10) indicating suitable water for irrigation in coarse textured good permeability soils. Some samples in the southwestern part have medium (10-18) SAR content (Wilcox classification), which indicating harmful water for irrigation, which means a need for certain management techniques to prevent or decrease that risk by adding Gypsum to the soil to increase the calcium to improve sodium/calcium ratio as shown in the following equation.

$$2Na\ clay + CaSO_4 \longrightarrow Ca\ clay + Na_2SO_4$$

AQUACHEM hydrochemical software has been used to construct the Wilcox diagram for samples of the present study as shown in figure 10. According to Wilcox Diagram, most groundwater samples are found in C2-S1, C3-S1 and C3-S2 classes indicating suitable water for irrigation with most crops in most soils.

Some samples are plotted in C4-S3 class indicating unsuitable water for irrigation under common circumstances due to very high salinity risk.

5.4. Numerical Model Results

Prior to prediction runs, the model has been calibrated in the steady state conditions by comparing the available historical data and the measured groundwater levels (observed heads) (Table 1 and Figure 5), against the calculated heads. The calibration has been achieved through trial and error by adjusting the recharge rate and hydraulic conductivity until a good match between the calculated and observed head values has been obtained. Figure 11 represents calculated calibrated piezometric head in the modeled area.

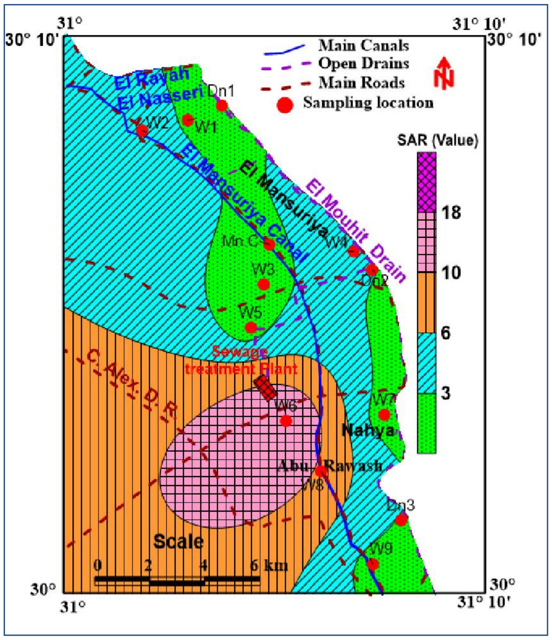

Figure 9: Distribution map of sodium adsorption ratio (SAR) in groundwater.

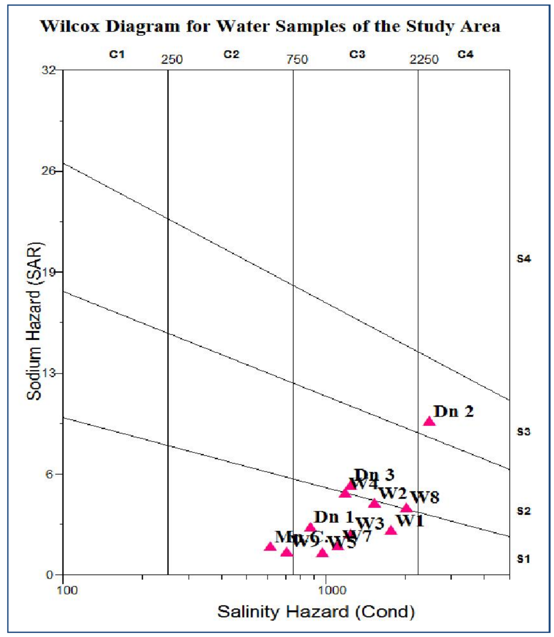

Figure 10: Wilcox diagram for groundwater and surface water samples.

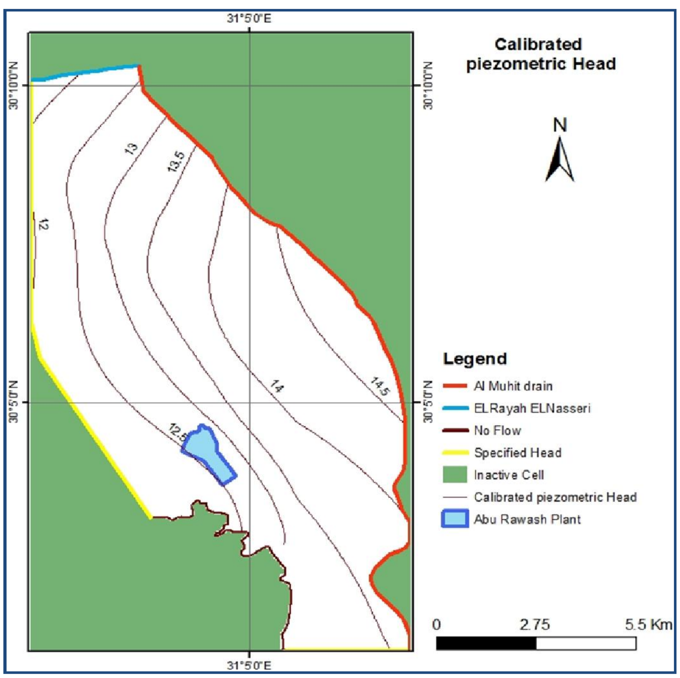

Figure 11: Calculated calibrated piezometric heads in the modeled area.

Figure 12 illustrates chart for steady state water balance (budget) given by MODFLOW simulation of the hydrogeological system in the modeled area. The MODFLOW water budget showed the following facts:

- The flow to the aquifer through boundary is about 51745 m3/day and the flow out from the aquifer through boundary is about 56542 m3/day.
- The extraction through pumping wells from the study area is about 51250 m^3/day and discharge by drainage through El Mouhit drain is about 613 m^3/day.
- Canals was added to the model as a river boundary, therefore the leakage to the aquifer from El Rayah El Nasseri and El Mansuriya canal is about 12604 m^3/day and discharge out from the aquifer is about 561 m^3/day.
- Recharge from surface activities to the aquifer is about 7985 m^3/day.

Thus, the analysis of the water budget indicated recharging the aquifer through leakage from irrigation network and surface activates. Therefore, the aquifer in the modeled area is renewable and affected by surface activates.

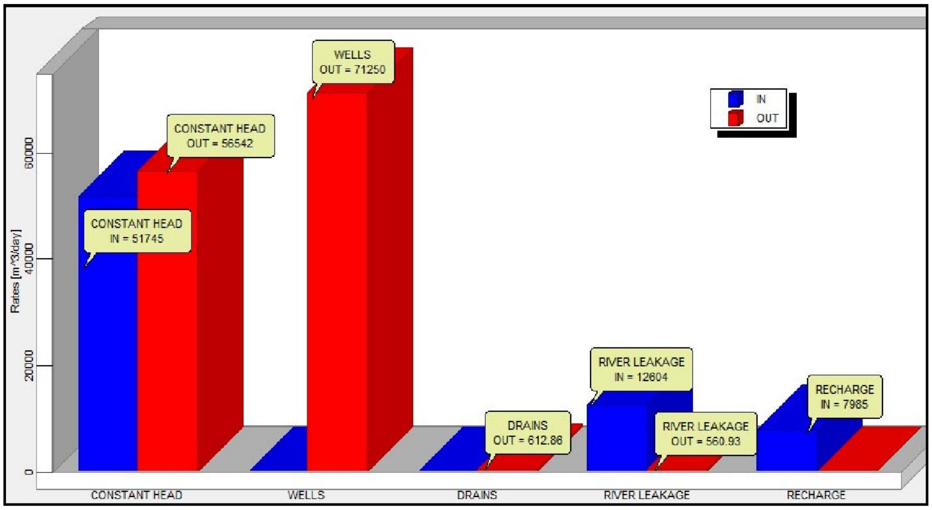

Figure 12: Calculated water balance (budget) in the modeled area.

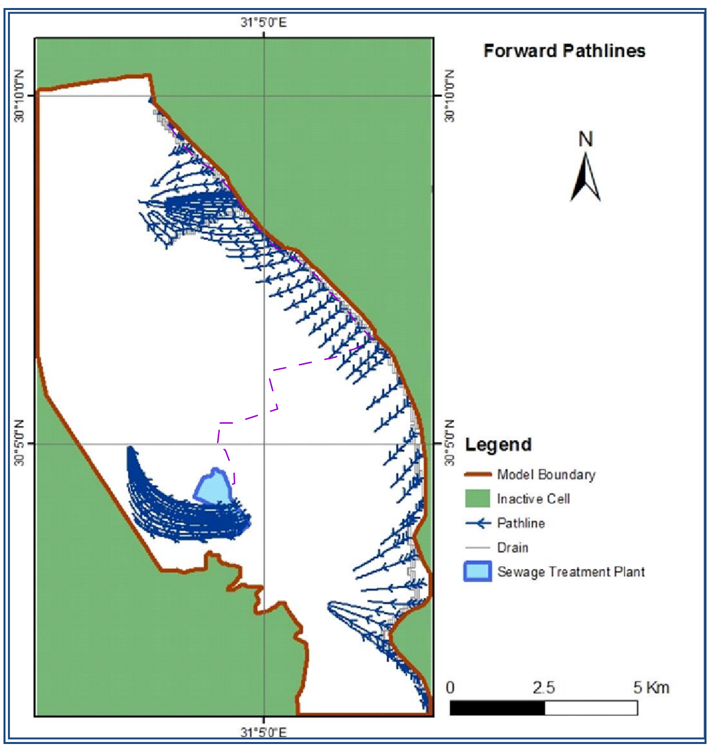

Figure 13: Calculated MODPATH results in the modeled area.

The travel time of particles with groundwater flow was set to 50 years (life time for sustainable development). Results of MODPATH indicated that the water flows and also drain pollutants transport mainly from northeast to southwest and from east to north at wastewater treatment plant (Figure 13). This indicates recharging the aquifer in the modeled area from the surface water. Therefore, the aquifer is renewable and surface activities affected on it. The model indicated that the velocity of groundwater flow and the maximum transport of pollutants were about 0.31 m/day.

The MT3DMS quality model has been used for prediction of the effect of nitrate and total dissolved solids on the groundwater quality status. Results of MT3DMS model regarding TDS concentration (Figures 14a, b) indicated that the groundwater salinity (TDS) reaches to more than 1200 mg/l along the drain route, then decreases to reach 400 mg/l outside at a distance of 1 km far from the drain route. Predictions showed that the TDS concentration could be increased with time to greater than 1800 mg/l after 50 years. This means that the groundwater sustainable use at the study area could be affected due to future increase of groundwater salinity.

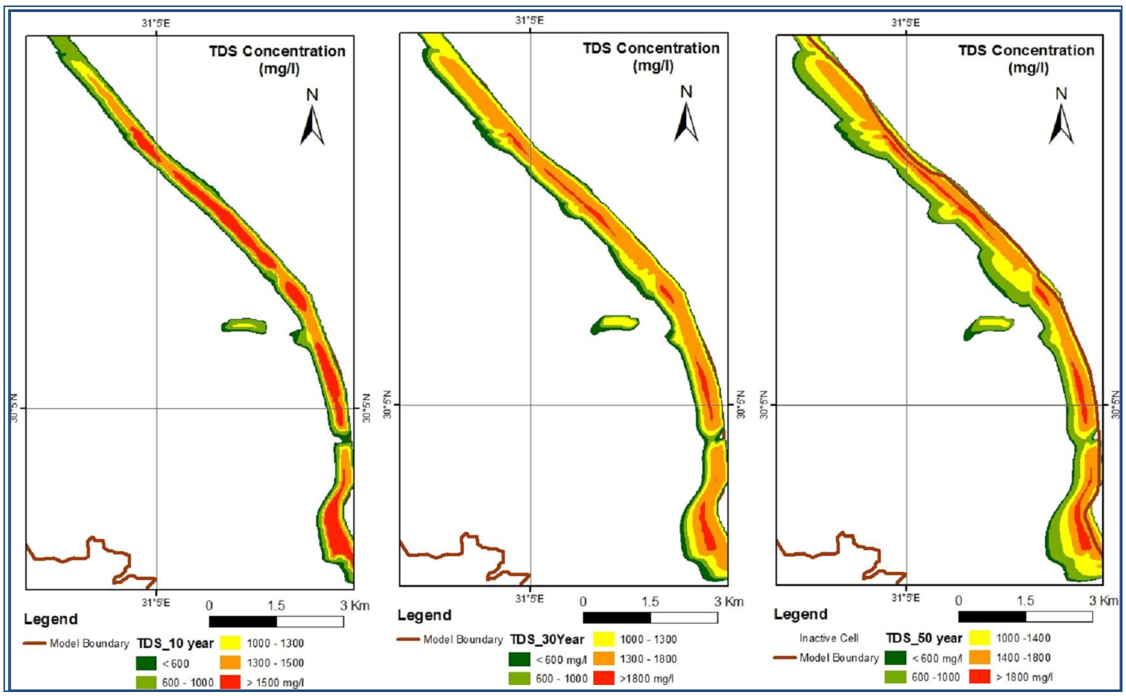

Figure 14a: Calculated TDS concentration from MT3DMS model results with time.

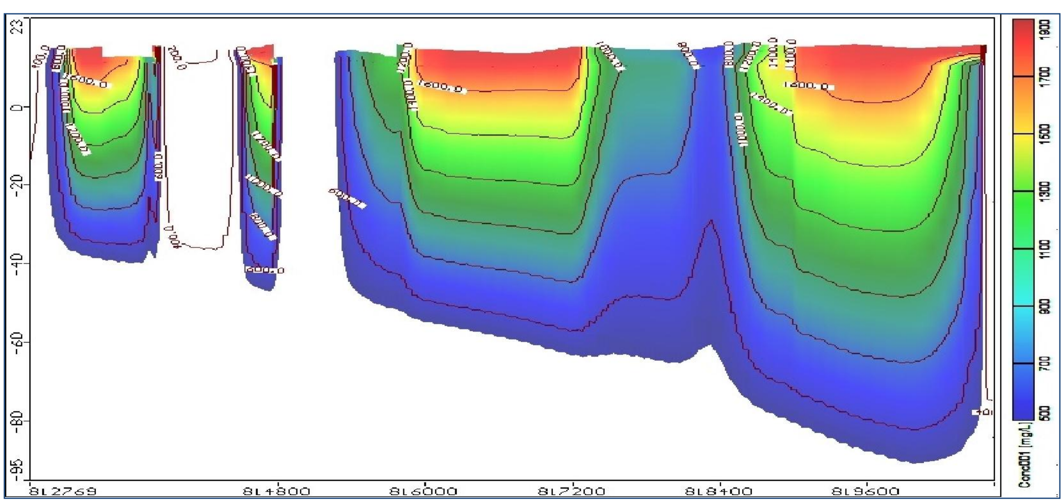

Figure 14b: Calculated TDS concentration along El Mouhit drain route after 50 year.

Results of MT3DMS model regarding nitrate groundwater (Figures 15a, b) indicated that the NO_3 concentration is about 80 mg/l in small reaches along and near the drain route, then decreases to 10 mg/l outside at a distance of 1 km far from the drain route. Predictions showed that the nitrate concentration could be increased with time to greater than 80 mg/l after 50 years. This means that NO_3 concentration may violate the permissible limit of irrigation. This may affect negatively sustainable use of groundwater in the study area.

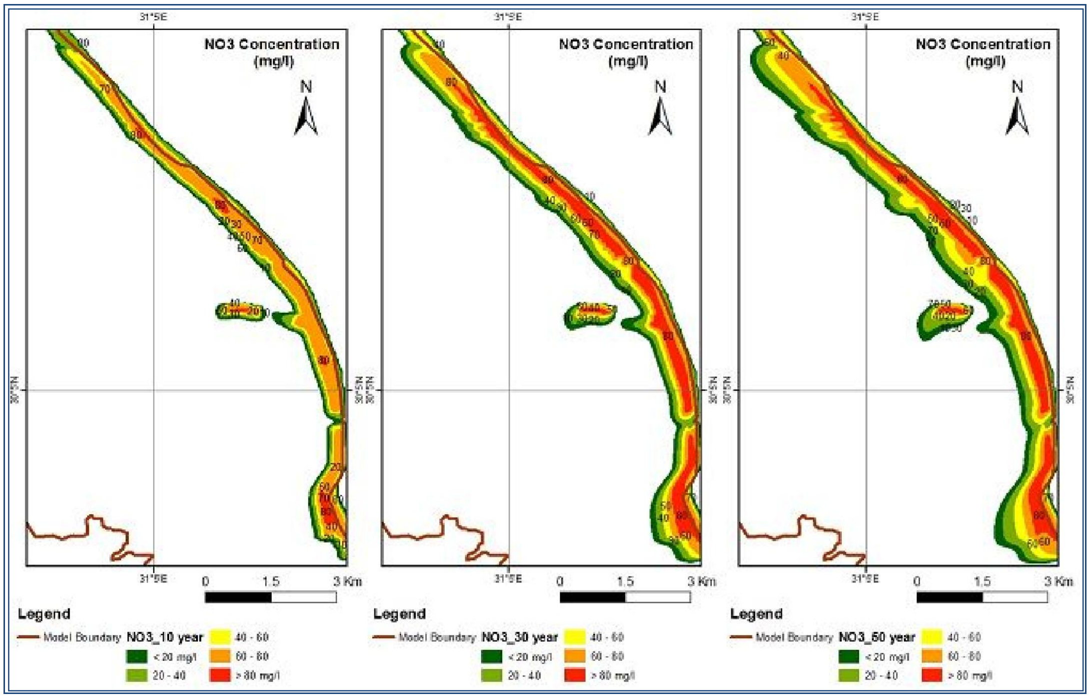

Figure 15a: Calculated NO_3 concentration from MT3DMS model results with time.

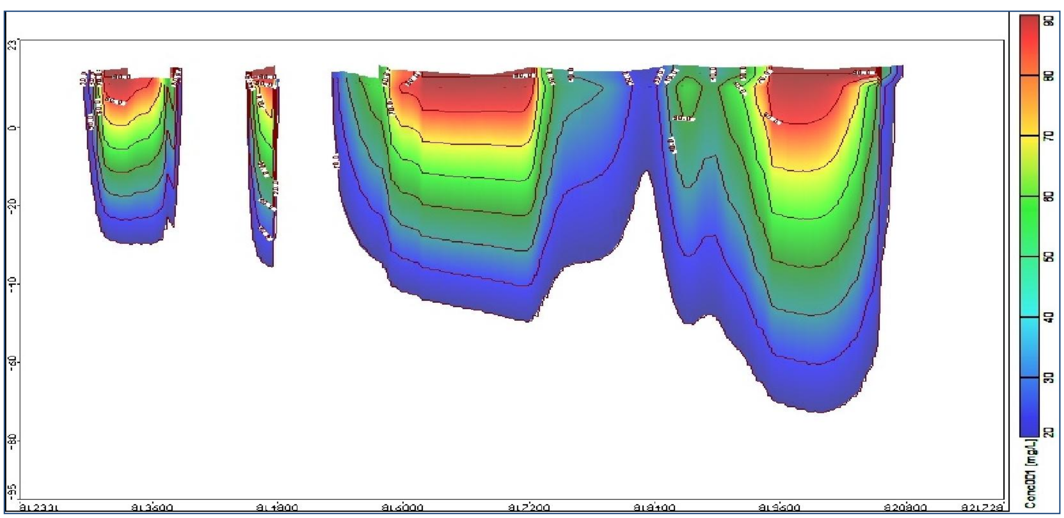
Figure 15b: Calculated NO_3 concentration along El Mouhit drain route after 50 year.

7. Conclusions and recommendations

The study area is located in the northwest of Giza city. The main objective is to evaluate the groundwater quality status and the hazardous impacts for sustainable uses in the study area.

The results indicated that TDS in drains ranges between 633 mg/l and 1746 mg/l. Somewhat high concentrations of nitrate observed in drains ranging from 48 mg/l to 88 mg/l referring to contamination from agricultural and domestic wastewater discharged into these drains. TDS in the groundwater samples ranges from 612 mg/l to 4768 mg/l. The study area is dominated by fresh to brackish groundwater, while saline groundwater observed only in the southern and southwestern parts. The groundwater is dominated by nitrate low concentrations (< 45 mg/l). High nitrate concentrations greater than 45 mg/l are found only in the western and southwestern parts indicating contamination from domestic and agricultural wastewater in areas near of high vulnerability to pollution.

Visual MODFLOW simulation for groundwater flow showed that the aquifer is recharged from excess irrigation water and leakage from irrigation network. MODPATH model indicated that the main groundwater flow and also drain pollutants transport from northeast to southwest and from east to north at wastewater treatment plant with a maximum velocity of about 0.31 m/day. These indicate that the aquifer is renewable and affected by surface activities.

MT3DMS model results regarding to TDS and NO_3 concentrations indicated increase of these elements in groundwater with time. TDS concentration is expected to increase to greater than 1800 mg/l after 50 years where the TDS of the groundwater was 612 ppm. Also, NO_3 concentration is expected to increase to greater than 80 mg/l after 50 years. High concentration occurred through the zone beneath the drain pass and decreased outside confirming that contaminants from agricultural and domestic wastes that migrate downward and may be extended into the unconfined portion of the aquifer system, which is high vulnerable to pollution. This means that the groundwater sustainable use could be affected by future quality changes.

The following recommendations must be taken in mind to avoid hazardous impacts of drainage water on groundwater in the study area:

✓ It is utmost requirement for better management of wastewater and increasing the treatment degree to secondary or even tertiary degree.

✓ Better management of using fertilizers in agriculture is very important.

✓ Continuous monitoring for water quality should be achieved.

✓ Legislations should be acutely applied for conservation of water quality.

✓ Spreading public awareness through different organization is important to minimize pollution.

References

1. Al-Adamat, R., Al-Shabeeb, A., 2017. A simplified method for the assessment of groundwater vulnerability to contamination. J. Water Res. and Prot., 9, 305-321. https://doi.org/10.4236/jwarp.2017.93020.
2. Al-Agha, D. E., Closas, A., Molle, F., 2015. Survey of groundwater use in the central part of the Nile Delta. Water and salt management in the Nile Delta: Report, (6). http://horizon.documentation.ird.fr/exl-doc/pleins_textes/divers16-02/010066349.pdf.
3. APHA, 2017. Standard methods for the examination of water and wastewater, 23rd edition. Amer. Publ. Health Assoc., Amer. Water Works Assoc., Water Envir. Fed., AWWA catalog no: 10086, ISBN: 9780875532875. https://www.awwa.org/Store/Product-Details/productId/65266295.
4. Balazov, A., Barokova, D., Mikulaz, K., Pfenderx, D. and Soltesz, A. 2002. Numerical modelling of the groundwater flow in the left floodplain area of the Danube River. *Proceedings of Algoritmy,* 237-244.
5. Chao, D., Changlai, X., Xiujuan, L., Ji, L., Tonglin, X. and Guangjun, G. 2010. Numerical Simulation of Groundwater Flow for Sustainable Utilization in Jixi City, China. *IEEE*, 978-1-4244-4713-8/10/
6. EGPCO (The Egyptian General Petroleum Corporation), CONOCO (Conoco Coral), 1987. Geological map of Egypt 1:500 000: NH 36 NW Cairo. Printed in Germany. http://geospatial.com/products/series/geological-scientific-maps/egypt-scale-1-500000-geological-maps-3000141/.
7. EGSA (Egyptian General Survey Authority), 1997. Topographic map of Egypt, Scale 1:50000", Cairo west, NH 36-13a.
8. El-Araby, M., El Arabi, N., 2008. Modeling potential environmental impact of new settlements on groundwater, Nile Delta, Egypt".
9. EMH (Egyptian Ministry of Health), 2007. Ministerial decree on drinking water quality and the water quality for household use. Decree 458, May 2007. http://documents.worldbank.org/curated/en/702261468233071240/pdf/E26430V30REVIS1IC10ES1ESIAF1English.pdf.
10. FAO, 1985.Water quality for agriculture. FAO irrigation and drainage paper No. 29, Rev. 1, Rome, FAO. http://www.fao.org/docrep/003/t0234e/T0234E01.htm#tab1.
11. Farrag, K., Elbastamy, E., Ramadan, A., (2016) Health risk assessment of heavy metals in irrigated agricultural crops, El-Saff Wastewater Canal, Egypt. Clean Soil Air Water 44(9):1085–1260.
12. Freeze, R.A., Cherry, J.A., 1979. Groundwater. Prentice-Hall, Inc., Englewood Cliffs, U.S.A.
13. Khalaf, S., Gad, M.I., 2015. Modeling of contaminant transport in 10th of Ramadan city area, East Delta, Egypt. Int. J. of Water Res. and Env. Eng., 7(10), 139-152. http://www.academicjournals.org/IJWREE.
14. Loucks, D.P.; Stedinger, J.R., Shamir, U., 1985. Modelling water resources systems: issues and experiences. *Civil Engineering Systems*, 2, 223–31.
15. McDonald, M.G., Harbaugh, A.W., 1988. A modular three-dimensional finite-difference

groundwater flow model – MODFLOW. U.S. Geol. Surv., Technique of water resources investigations, Book 6. https://doi.org/10.3133/twri06A1.
16. MHUUD (Ministry of Housing Utilities and Urban Development), 2010. Availability and operation of Abu-Rawash wastewater treatment plant: Amended information memorandum. http://www.investment.gov.eg/en/Documents/AbuRawashIMFINALclean.pdf.
17. Mohamed, K. M., 2015. Improve effluent water quality at abu-rawash wwtp using aluminum chloride and carbon dioxide. J. Water Res. and Prot., 7, 1049-1057. http://dx.doi.org/10.4236/jwarp.2015.713086 and http://www.scirp.org/journal/paperinformation.aspx?paperid=59571.
18. Namitha, M.R., Devi K.J., Sreelekshmi H., and Muhammed Ashik P., 2019. Ground water flow modelling using visual modflow. J. of Pharmacognosy and Phytochemistry; 8(1): 2710-2714.
19. Pollock, D.W., 2017. MODPATH: A particle-tracking model for MODFLOW: U.S. Geological Survey Software Release. http://dx.doi.org/10.5066/F70P0X5X.
20. RIGW, 1989. Hydrogeological map of Egypt, Scale 1:100000, Cairo Map Sheet, 1st Edition. Res. instit. for groundwater (RIGW), Egypt.
21. RIGW and IWACO, 1990. Vulnerability of groundwater to pollution in the Nile Valley and Delta, El Kanater El Khairia, Egypt TN 70.130-89-02.
22. RIGW, 1992. Hydrogeological map of Egypt, Nile Delta, scale 1:500000, 1st edition. Res. instit. for groundwater (RIGW), Egypt.
23. RIGW, 2002. Nile Delta groundwater modeling report. Res. instit. for groundwater (RIGW), Egypt.
24. Said, R.,1990. The geology of Egypt. pp. x + 734, Rotterdam, Brookfield: A. A. Balkema. ISBN 90 6191 856 1. doi:10.1017/S0016756800019828.
25. Senthilkumar, M. and Elango, L. 2004. Three-dimensional mathematical model to simulate groundwater flow in the lower Palar River basin, southern India. *Hydrogeology Journal,* 12, 197–208.
26. Shamrukh, M., 2001,"Modeling the Effect of Chemical Fertilizers on Groundwater Quality in the Nile Valley Aquifer, Egypt", Groundwater, Vol.39, No.1, pp.59-67.
27. Sharaky, A.M., El Hasanein, A.S., Atta, S.A., Khallaf, K.M., 2017. Nile and Groundwater Interaction in the Western Nile Delta, Egypt. The Handbook of Environmental Chemistry Springer 33-62.
28. UNDP (United Nations Development Programme). Cairo, Egypt, 2013. Potential Impacts of Climate Change on the Egyptian economy. http://www.eg.undp.org/content/egypt/en/home/library/environment_energy/publication_1.html.
29. UNESCO-ACSAD, 1995. Groundwater protection in the Arab region. IHP, Paris-Cairo. https://www.ircwash.org/sites/default/files/212.0-95GR-13942.pdf.
30. WHO (World Health Organization), 2011. Guidelines for drinking-water quality. 4th ed., ISBN 978 92 4 154815 1, NLM classification: WA 675. https://apublica.org/wp-content/uploads/2014/03/Guidelines-OMS-2011.pdf.
31. Wilcox, l. V., 1955. Classification and use of irrigation water. USDA Circ. 696, Washington D.C. https://www.ars.usda.gov/arsuserfiles/20360500/pdf_pubs/P0192.pdf.
32. Zeidan B.A., Aly, A.I., Rashwan, I.M., Ahmed, M.A., Ghoraba, S.M., 2013. Ground water quality management in middle Nile Delta utilizing environmental isotopes and solute transport modeling. NGWA summit, the national and international conference on groundwater, 29 Apr–2 May, Texas, USA.
33. Zhou, Y., Li W., 2011. A review of regional groundwater flow modeling. Geoscience Frontiers.; 2(2):205-214.
34. Zheng, C., Wang, P.P., 1999. MT3DMS, A Modular three-dimensional multispecies transport model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater systems. Vicksburg, Mississippi: Waterways Experiment Station, U.S. Army Corps of Engineers. https://www.researchgate.net/publication/242586434_MT3DMS.

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