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Degradation of groundwater quality of quaternary aquifer at Qena, Egypt

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Summary
Qena area, Upper Egypt has a limited water resources represented by the River Nile, irrigation canals and groundwater resources. The Quaternary groundwater aquifer is the main water source in the study area. Urbanization and agricultural activities in the study area constitute the main pollution sources of groundwater. Pollution sources in the study area include mixing from wastewater and agrochemicals from agricultural activities. Results of hydrochemical analysis of thirty groundwater samples collected from the study area revealed that groundwater sources are polluted by nitrates, phosphates, ammonia and E.Coli bacteria. Groundwater quality in the study area varied from locality to another concerning its suitability for drinking purposes according to the World Health Organization and Egyptian standards. Most of the collected groundwater samples are not suitable for drinking purposes. On the other hand, groundwater is suitable for irrigation purposes with limited restriction. The present study recommended management of pollution sources including application of agrochemicals and controlling the seepage of wastewater from rural areas as well as management of wastewater treatment plants.

Keywords: Groundwater contamination, Quaternary aquifer, Qena, Egypt.

Introduction

Study area
The study area is a part of Qena Governorate and includes five villages (Dandara, Tramssa, Gablaw, Salhya, and Karm Imran), besides the main campus of South Valley University. The area is located between latitudes 26° 01´ 29´´ and 26° 13´ 54´´ N and longitudes 32° 36´ 49´´ and 32 ° 51´ 17´´ E (Fig. 1). The major source of fresh water in the study area is the River Nile which diverted through Asfun and El-Kalabia irrigation canals and the Quaternary groundwater aquifer.

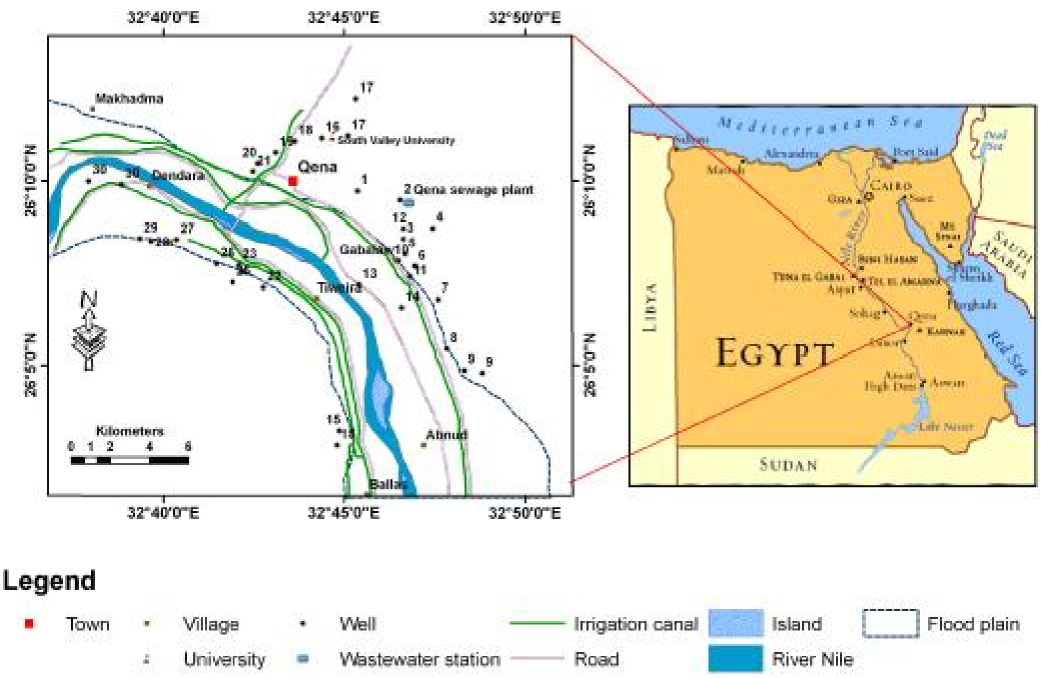

Fig. 1: Location map of the study area and sampling points.

Background
The demand for clean drinking water supply is one of the most important priorities of the Egyptian government in recent years. Increasing population and improved quality of life lead to greater personal water use. This will reduce the quantity of water available per person unless additional sources of water become available.

Extensive activities of agriculture and absence of sewage network in rural areas caused pollution of groundwater sources with agrochemicals and pathogens.

The majority of the study area is considered as cultivated lands. Qena is known as an agricultural Governorate which is famous for cultivating sugar cane with four major sugar factories located at Qus, Dishna, Nag Hammadi and Armant. So, the widespread use of the different agrochemicals (fertilizers and pesticides) is considered a main source of pollution.

Increased use of nitrogen and phosphorus fertilizes after the construction of the Aswan High dam has led to increased potential of groundwater contamination with nutrients. As a result, excess of nitrogen is leached downward into shallow groundwater by the infiltrated irrigation water. Nitrate in drinking water has been linked to blue-baby syndrome and many types of cancer (Comly 1987; Drury et al. 1993; Levallois and Phaneuf 1994). Nitrate is a mobile and stable solute in many shallow aerobic groundwater systems. These characteristics make nitrate a contaminant of concern with respect to drinking water quality and surface water eutrophication (Robertson et al. 1991; Wilhelm et al. 1994; Valiela et al. 1997).

In the residential areas the major source of contaminants is from domestic wastewater disposal practice including the use of cesspoles. In addition, the improper sewage wastewater disposal in the area of the Qena wastewater plant, built in 1981, is considered as another source of environmental pollution. Here, raw wastewater is discharged directly on the ground without any treatment forming some ponds (Fig. 2). The raw wastewater is used in irrigating a woody tree farm and some crops in the area.

Disposal of domestic wastewater from sewage into the shallow subsurface is a common practice that introduces contaminants such as nitrate, phosphate and bacteria into the environment.

The use of indicator bacteria such as Colliform and E. Coli is of great importance in water quality assessment and health risk evaluation (Giannoulis et al. 2005). Pathogens are seriously concerned because excessive amounts of faecal bacteria in sewage and urban run-off have been known to indicate risk of pathogen-induced illnesses in humans (Fleisher et al. 1998).

The aim of this study is to address the groundwater quality degradation due to the different pollution sources recorded in the study area as a baseline for management of pollution sources and monitoring groundwater degradation in the study area.

A **B** **C**

Fig. 2 A: Deterioration of properties at the Qena sewage water treatment plant. B, C: Seepage of wastewater and formation of ponds.

Hydrogeological setting

Climate

The study area is located in the arid zone characterized by very dry and hot weather condition. The annual rainfall is very rare and precipitation scarcely occurs as flash floods during winter. The average temperature ranges from 23 ^{o}C in winter to 44 ^{o}C in summer. The relative humidity ranges between 53% in winter and 29% in summer.

Geology

Geology of Qena area was studied by many authors such as Said (1962, 1981, 1983, 1990), Ahmed (1983), Askalany (1988), Issawi and McCauley (1992), El-Balasy (1994), Abadi (1995), Mansour et al (2001). The sedimentary succession in Qena area (Fig. 3) can be classified from top to bottom as follows:

Holocene

The Holocene unit in the study area is represented by the silty clay layer of the Nile floodplain as well as the wadi deposits. The silty clay layer has a thickness ranging from 1 to 14 m and forms the fertile soil of the cultivated lands.

Late Pleistocene

This unit is represented by the Pre-Nile deposits composed of sand and gravel with a thickness of 30 m and extends below the silty clay layer and forms the main Quaternary aquifer in the study area.

Plio-Pleistocene

This unit is represented by the Proto-Nile and Pre-Nile deposits composed of clay, sands and gravels locally capped by travertine beds. The exposed thickness of this unit is about 60 m.

Pliocene

This unit is represented by the Paleo-Nile deposists dominated by clay facies represented by clay with sand interbeds. This unit overlies the eroded surface of the Eocene carbonate and acts as an aquiclude for the overlying Quaternary aquifer.

Eocene

The Eocene unit in the study area is composed of the karstified chalky and dolomitic limestone and marl with flint bands and nodules. The exposed thickness of this unit is more than 200 m and acts as a fissured carbonate aquifer.

Paleocene-Late Cretaceous

This unit is dominated by shale facies with thin interbeds of chalk and phosphate which acts as an aquiclude separating the Eocene fissured carbonate aquifer from the Nubian aquifer underneath.

Upper Cretaceous-paleozoic

This unit is represented by sandstone with shale intercalations. This unit unconformably overlies the basement complex and forms the most common and extended water bearing formation of the Nubian aquifer.

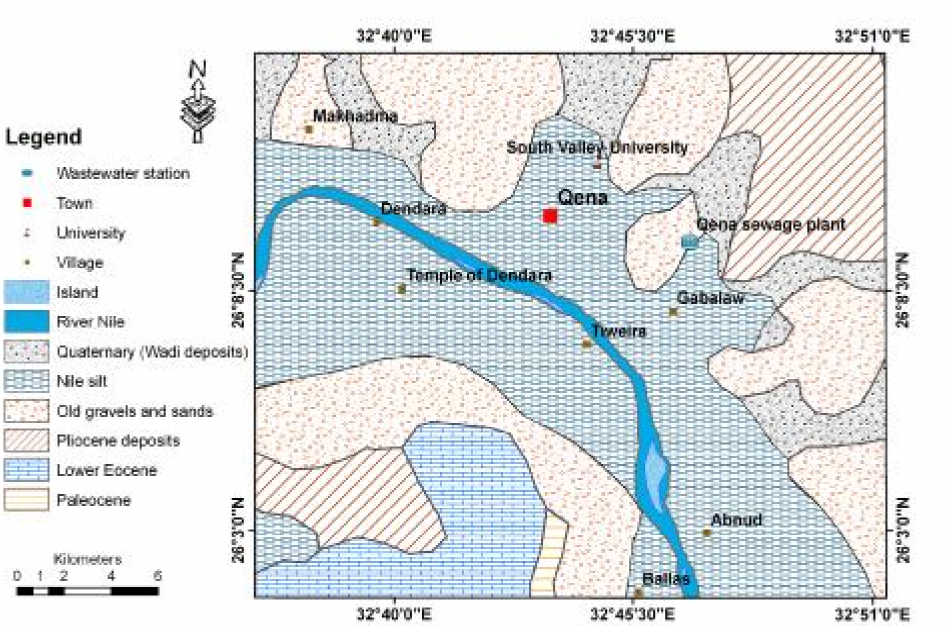

Fig. 3 Geologic map of the study area showing the exposed stratigraphic units (TEGPC and CONOCO 1987)

Hydrogeology

The groundwater system in the study area belongs to the regional Quaternary aquifer that extends along the Nile Valley. This aquifer can be categorized into two hydrogeologic units with distinct hydraulic properties. The two units are the Holocene aquitard which composed of clay, silty-clay and clayey-silt deposits and graded sand and gravel intercalated with clayey lenses (Fig. 4). The Holocene aquitard including the phereatic groundwater that constitutes the base of the cultivated lands with thickness varies from 12.5 m to 26 m in the western bank of the River Nile (Kamel 2004). This unit receives the surface water seepage from irrigation activities. The horizontal and vertical permeability ranges from 0.40 to 1.00 m/day while the vertical hydraulic conductivity is low and increases with depth (Abd El-Moneim 1988). The Quaternary aquifer in the Nile Valley is extensive and highly productive and distinguished into semi-confined conditions under the cultivated areas and unconfined conditions under the new reclaimed areas at the desert fringes on both sides of the Nile Valley.

The aquifer thickness decreases from 300 m at the northern boundary to a few meters in the south western boundary of the study area (Sayed 2004). The hydraulic conductivity of this aquifer ranges from 60 to 100 m/day and transmissivity ranges from 2000 to 6000 m^2/day (Attia 1985; Abd El-Bassier 1997).

The main component of recharge of the aquifer is the seepage from irrigation canals, subsurface drainage from the irrigated lands and upward leakage from the deep aquifers through fault planes.

The depth to groundwater in the Quaternary aquifer as measured from some available wells varies from few meters to about 30 m below ground level. The groundwater in the study area is extracted through public and private wells as well as hand pumps to be used for irrigation and domestic purposes. Some wells have been drilled within the campus of the South Valley University to be used for gardening purposes. The groundwater flow in the aquifer decreases gradually towards the Nile. The River Nile is acting as a discharging line for the Quaternary aquifer as the

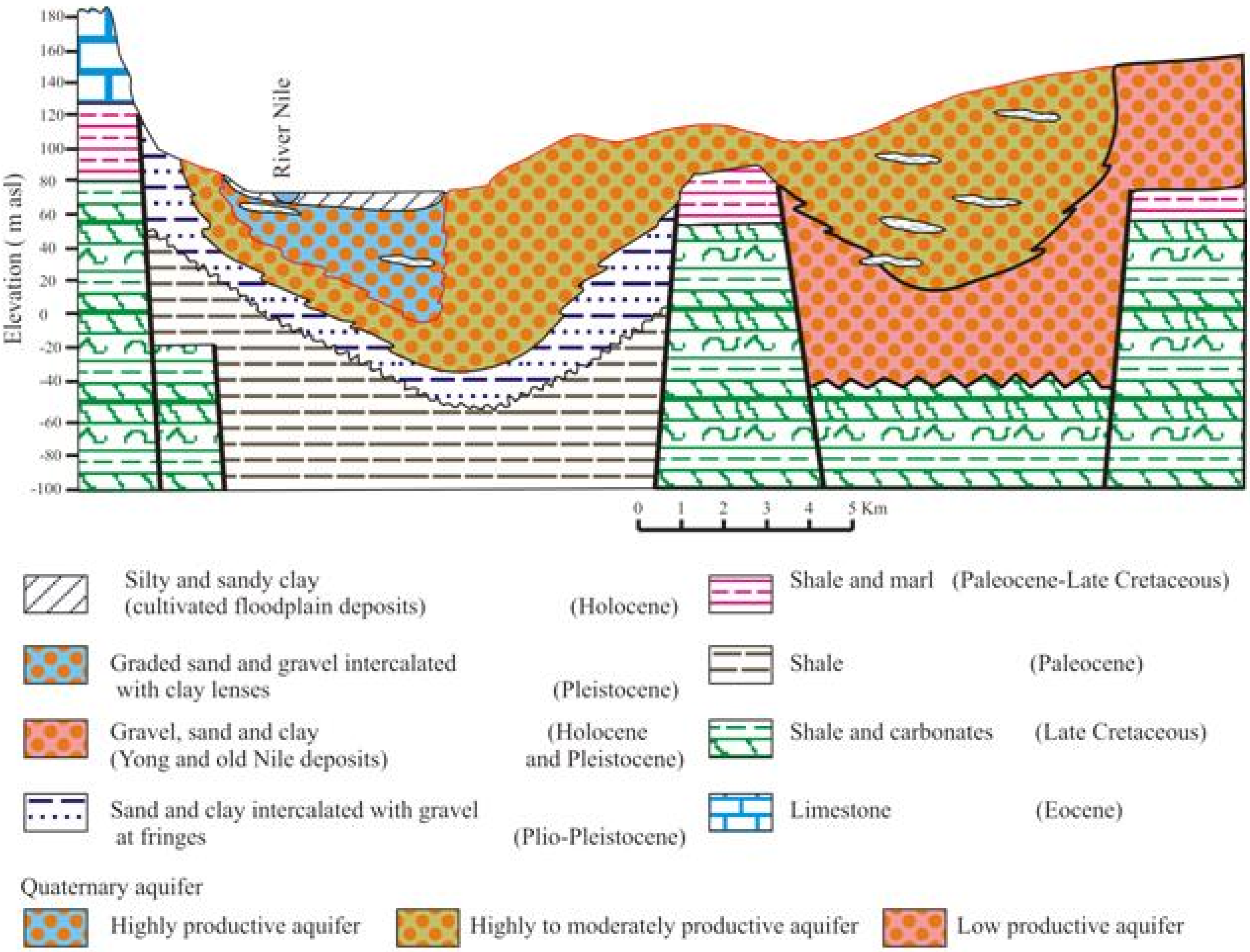

Fig. 4 Hydrogeologic section of the study area (RIGW 1994)

groundwater levels are higher than those of the River Nile except at the upstream of the barrages (Barber and Carr 1981, Abdel Moneim 1988, Ahmed 2007).

Methodology.

Thirty groundwater samples representing the groundwater of the Quaternary aquifer were collected from the study area. pH and electrical conductivity (EC) of the water samples were measured immediately at the sampling sites. The samples were analyzed for major ions, nitrates, ammonia, phosphates, and E.Coli bacteria according to standard methods of analysis of APHA et al (1985).

pH values are determined using the digital pH meter (Model Cole Parmer). EC was determined using the EC meter (Model WPA cm 35). The Atomic Absorption Spectrophotometer (Perken-Elmer 2380) was used for measuring of Mg, Fe, and Mn. The Flame Photometer (Jenway PFP7) was used for measuring of K, Ca, and Na. The spectrophotometer (S110) was used for estimating SO_4, PO_4, NO_3 and NH_4. Chloride and HCO_3 were determined volumetrically. Results of chemical analysis for the concerned groundwater samples are given in table (1).

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Table 1: Results of chemical analysis for groundwater samples in the study area (mg/l).

Well No.	pH	EC [(1)]	TDS	K	Na	Ca	Mg	Cl	SO_4	HCO_3	TH	SAR [(2)]	NO_3	NH_4	PO_4	E.Coli
1	8.00	1178.00	800.5	8.64	208.6	22.38	17.22	151.2	144.0	220.8	126.8	8.06	27.64	0.00	0.00	Positive
2	7.67	2140.00	1540.3	7.14	328.0	49.21	55.47	388.0	182.6	434.9	351.1	7.62	95.02	0.00	0.04	Positive
3	7.74	1021.00	754.1	9.68	124.0	35.00	36.29	54.2	66.1	391.6	236.7	3.51	37.18	0.00	0.00	Positive
4	7.69	2190.00	1315.2	8.72	284.0	51.40	72.00	391.0	174.7	297.7	424.6	6.00	35.70	0.00	0.00	Positive
5	8.15	301.00	220.7	4.79	14.9	28.29	12.79	21.9	7.4	128.7	123.3	0.58	1.92	0.00	0.00	Negative
6	7.60	2160.00	1320.0	8.54	274.0	83.74	61.60	412.0	176.0	269.0	462.6	5.54	32.86	2.18	0.00	Negative
7	7.40	3510.00	2249.2	22.50	471.2	174.08	80.57	604.8	576.8	226.9	766.2	7.41	92.36	0.00	0.00	Negative
8	7.39	812.00	635.9	7.18	125.0	30.49	18.04	51.2	59.4	320.3	150.4	4.44	22.53	1.81	0.00	Positive
9	7.75	1295.00	1037.7	10.62	179.4	56.41	40.63	121.7	142.2	407.5	308.1	4.45	79.03	0.12	0.09	Positive
10	7.66	1730.00	1119.1	27.54	174.0	59.42	70.70	253.0	131.6	325.7	439.3	3.61	77.08	0.00	0.00	Positive
11	7.47	4340.00	2986.5	18.85	767.5	161.27	82.66	872.3	548.8	449.6	742.8	12.25	85.47	0.00	0.04	Positive
12	7.32	1013.00	761.0	8.64	83.0	52.00	42.11	92.2	64.4	405.7	303.1	2.07	11.85	0.92	0.26	Positive
13	7.97	1801.00	1302.8	4.05	334.0	5.87	33.29	40.4	201.6	651.5	151.7	11.80	30.07	0.49	1.58	Positive
14	8.15	2710.00	1930.8	0.80	458.0	14.38	82.57	73.5	586.9	627.1	375.7	10.28	86.71	0.41	0.52	Positive
15	7.73	3500.00	2292.3	6.76	579.0	85.54	71.87	725.3	620.0	133.0	509.4	11.16	70.80	0.00	0.00	Negative
16	7.77	4720.00	3035.2	9.44	663.0	162.27	130.98	960.0	880.3	183.0	944.2	9.39	46.15	0.00	0.00	Negative
17	7.75	5000.00	3284.8	8.99	724.0	154.46	148.39	1380.0	684.0	184.2	996.3	9.98	0.73	0.00	0.00	Negative
18	7.79	650.00	518.5	6.19	70.5	38.90	23.29	75.3	74.5	222.0	193.0	2.21	7.81	0.00	0.00	Negative
19	7.48	2020.00	1445.1	7.70	337.0	54.81	43.17	373.5	171.9	436.2	314.5	8.27	19.95	0.90	0.00	Positive
20	7.66	1213.00	863.8	6.68	162.0	48.51	33.46	260.0	98.0	237.9	258.8	4.38	17.21	0.00	0.00	Positive
21	7.67	1294.00	984.0	6.14	162.0	48.91	47.23	260.2	112.0	308.1	316.5	3.96	38.98	0.50	0.00	Positive
22	7.98	2400.00	1602.7	1.98	385.0	27.69	74.13	418.1	230.7	393.5	374.2	8.66	70.49	0.51	0.71	Negative
23	7.76	1348.00	1114.8	28.31	188.0	18.58	52.81	26.5	156.8	595.4	263.7	5.04	47.80	0.13	0.53	Positive
24	7.79	729.00	539.7	2.06	93.0	3.57	39.77	46.5	60.0	253.2	172.6	3.08	41.63	0.00	0.06	Negative
25	7.79	1603.00	1101.4	13.49	195.0	67.22	59.66	249.6	137.8	341.6	413.3	4.17	37.03	0.00	0.00	Positive
26	7.85	293.00	226.6	4.40	12.0	27.79	13.98	38.6	16.1	111.6	126.9	0.46	1.37	0.00	0.73	Positive
27	7.85	1429.00	1178.7	19.07	126.0	65.62	77.57	90.4	175.8	586.8	483.1	2.49	37.30	0.10	0.00	Positive
28	7.97	1754.00	1238.9	7.22	236.0	23.08	83.68	248.0	219.0	341.6	402.0	5.12	79.83	0.46	0.00	Positive
29	7.67	747.00	577.1	38.90	43.3	58.82	25.42	58.0	46.2	270.8	251.5	1.19	32.53	0.37	2.74	Positive
30	8.00	387.00	270.9	4.93	21.3	15.58	20.75	17.1	18.9	170.2	124.3	0.83	1.21	0.31	0.70	Negative
Min	7.32	293.00	220.7	0.80	12.0	3.57	12.79	17.1	7.4	111.6	123.3	0.46	0.73	0.00	0.00	
Max	8.15	5000.00	3284.8	38.90	767.5	174.08	148.39	1380.0	880.3	651.5	996.3	12.25	95.02	2.18	2.74	
Average	7.75	1842.93	1274.9	10.67	260.8	57.51	55.07	291.8	225.5	330.9	370.2	5.60	42.21	0.31	0.27	

(1) µS/cm
(2) meq/l

Total hardness (TH)

Total hardness (Table 1) was calculated from the following equation (Todd 1959):

$$TH = 2.497Ca^{2+} + 4.115Mg^{2+}$$

Where values of Ca^{2+} and Mg^{2+} are in mg/l.

Natural waters are classified into several categories according to the total hardness (TH) as follows (Table 2):

Table 2 Classification of natural waters in terms of total hardness (ASTM 1976).

Hardness	Water type
00 - 55	Soft
56 – 100	Slightly hard
101 - 200	Moderately hard
201 - 500	Very hard
> 500	Excessively hard

Water quality assessment

Several parameters were calculated to determine the suitability of the groundwater in the study area for domestic and irrigation purposes. The fitness of this water was determined by comparing its chemical and bacteriological characteristics with the standards given by the Egyptian Higher Committee for Water (EHCW 2007) and World Health Organization (WHO 1996, 1998) as listed in Table 3.

Table 3 Maximum permissible limits according to WHO and Egyptian standards

Parameter	EHCW (2007)	WHO (1996 and 1998)
pH	-	6.5-8.5
Ammonia, NH_4	0.5	No guideline
Nitrate, NO_3	45	50
Phosphate, PO_4	-	-
Ca	-	200
Mg	-	125
Na	200	200
K	-	12
Cl	250	250
SO4	250	400
HCO3	-	350
TDS	1000	1000
TH	500	-

In addition, salinity and sodium hazards were estimated to assess the suitability of groundwater for irrigation purposes. The percent of sodium was used to evaluate the sodium hazards and it was determined using the following relation (Wilcox 1954):

$$\%Na = \frac{Na^{+}}{(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})}100$$

Where Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} are in meq/l.

According to the percent of sodium, groundwater can be classified into five categories (Table 4):

Table 4 Water classes for irrigation according to sodium percent.

Sodium (%)	Water class
< 20	Excellent
20 – 40	Good
40 – 60	Permissible
60 – 80	Doubtful
> 80	Unsuitable

The sodium adsorption ratio (SAR) was calculated as follows (Richards 1954):

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

Where Na^{+}, Mg^{2+} and Ca^{2+} are in meq/l.

The water quality for irrigation can be classified according to SAR into the following classes (Table 5).

Table 5 Classification of water quality for irrigation according to SAR (Richards 1954)

Quality of water	SAR (meq/l)	Usage
Excellent (low sodium)	< 10	In all soils
Good (medium sodium)	10-18	In coarse texture soils with good permeability
Fair (high sodium)	18-26	Can produce harmful effect
Poor (very high sodium)	>26	Unsuitable for irrigation

The SAR of the groundwater samples is plotted against their electric conductivity (μS/cm) into the Wilcox diagram (Wilcox 1954, Fig. 15). The salinity hazard is described by four intervals of electrical conductivity (C1, C2, C3 and C4). The higher the grade of SAR, the more salinity of water. The sodium hazard (S1, S2, S3 and S4) indicates how far harmful levels of exchangeable sodium are produced in the soil water.

GIS analysis

A geo-spatial database was built using ArcGIS 9.2 (ESRI 2006) for analysis of the hydrochemical data and visualization of results. A GPS system is used for locating sampling sites. All hydrogeologic data are created as layers within the ArcGIS environment for spatial analysis.

Results

Hydrochemical properties of groundwater

pH variation

The pH values of groundwater in the study area ranged between 7.3 to 8.15 which reflect slightly alkaline conditions. This alkaline condition might be due to the high concentration of base compounds such as bicarbonates.

Total dissolved solids (TDS)

Total dissolved solids (TDS) almost ranged between 220.7 and 1294.9 mg/l (Fig. 5).

According to Chebotarev 1955, salinity of groundwater in the study area can be classified as fresh to slightly brackish water. TDS values are well correlated with sodium, chloride and sulphate which indicate that these ions are the major controlling factors of salinity in the study area (Fig. 6).

Total hardness (TH)

Total hardness in the study area ranges between 123.3 and 370.2 mg/l. High values of total hardness may be due to dissolution of carbonates and sulphates.

Major ions

Major ions vary greatly within the study area (Fig. 7).

Potassium ranged between 0.8 and 38.9 mg/l. Generally, low concentration of potassium may be related to depletion by plants through agricultural activities accelerated by the minimum use of potassium fertilizers used in the past years and after construction of the High Dam where natural fertilization from silty sediments of the flood plain has been stopped.

Sodium concentration ranged between 12.0 and 767.5 mg/l. High concentration of sodium may be due to dissolution and leaching of sodium salts such as halite during movement of groundwater through sediments.

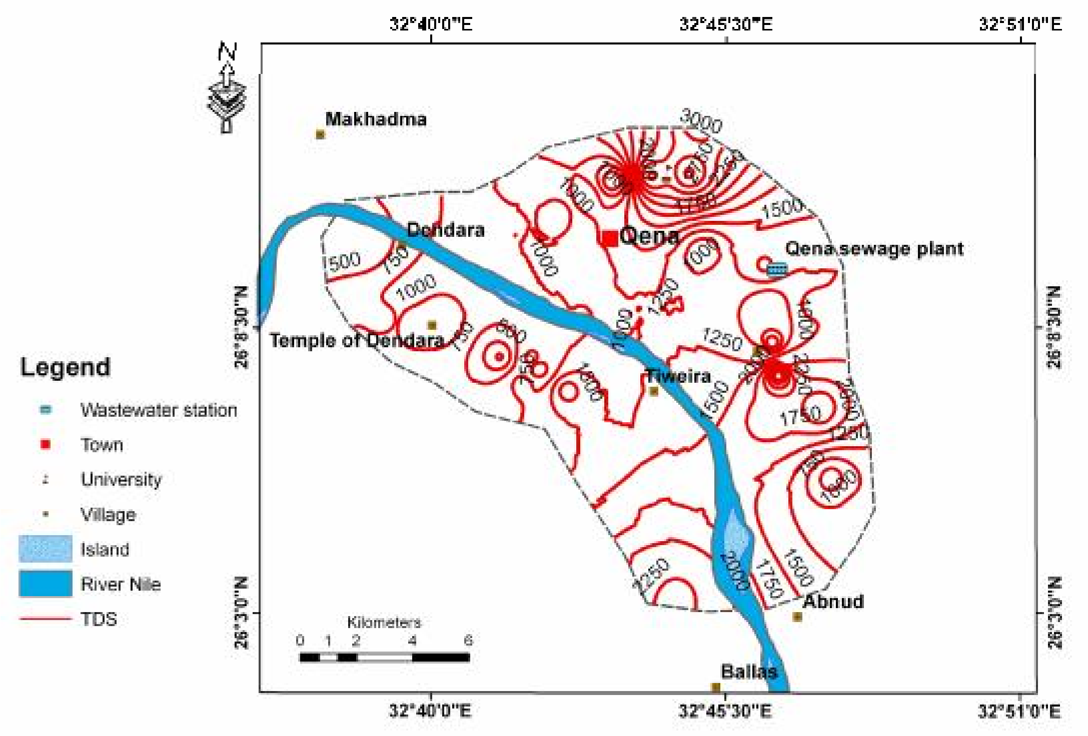

Fig. 5 TDS distribution in the study area.

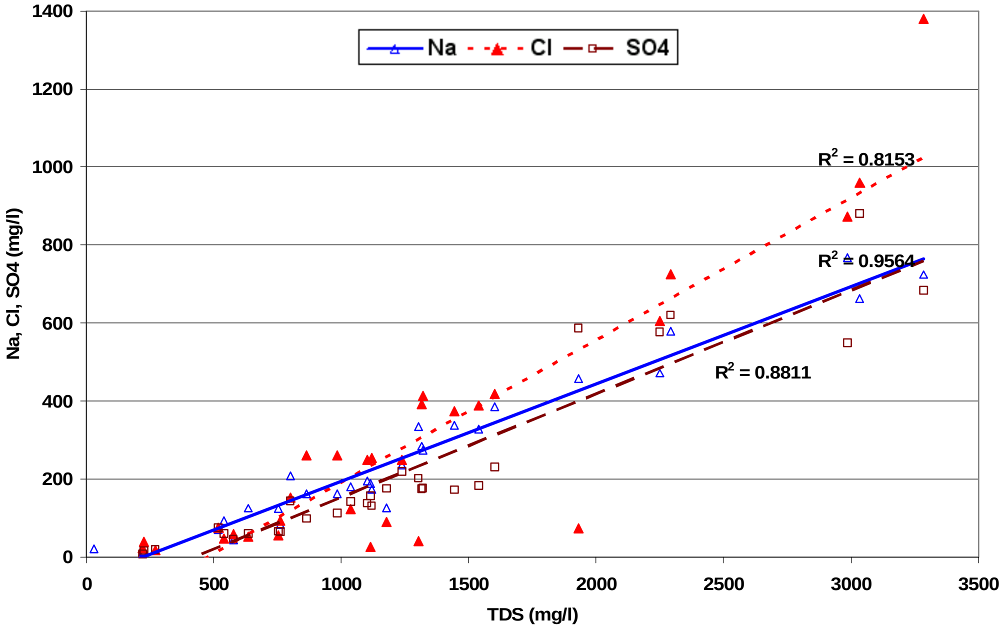

Fig. 6 Correlation of Na, Cl and SO_4 with total dissolved solids.

Magnesium content ranged between 12.8 and 148.4 mg/l. Higher magnesium content at the desert areas may be due to dissolution of dolomite or leaching from the clay-rich sediments.

Chloride ranged between 17.1 and 1380.0 mg/l. Higher concentrations of chloride are associated with Pliocene sediments which contain marine salts such as halite.

Sulphate content ranged between 7.4 and 880.3 mg/l. Higher concentrations of sulphate in groundwater may be due to dissolution of sulphates from gypsum-bearing sediments and additional input from sulphate fertilizers such as potassium sulphates.

Bicarbonate content ranged between 111.6 and 651.5 mg/l and increases towards the River Nile due to increasing solubility of carbonates with the aid of CO_2.

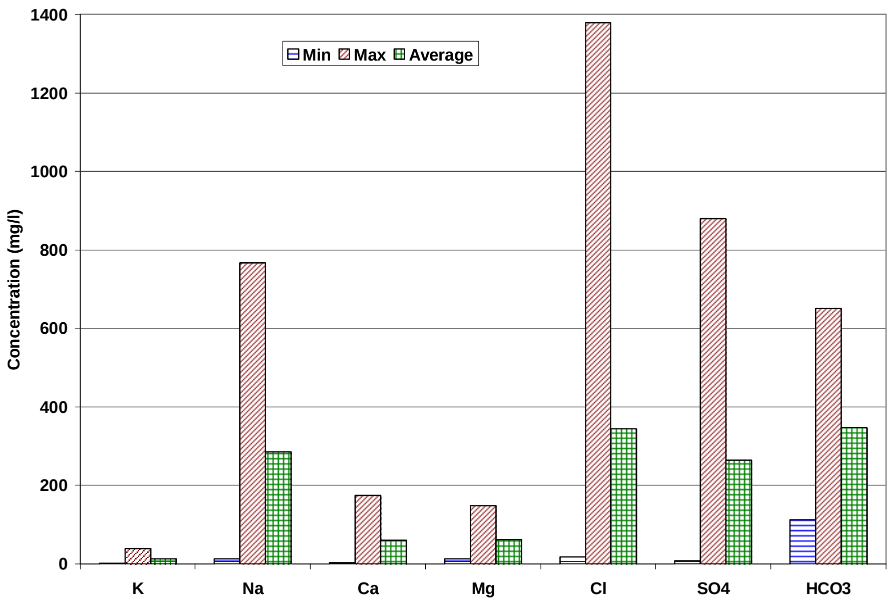

Fig. 7 Variation of major ions in groundwater of study area.

Groundwater types

The groundwater types in the study area were determined based on their chemical composition using the piper trilinear diagram (Piper 1944).

The predominant groundwater types in the study area include chloride and bicarbonate as the dominated anions and sodium as the dominated cation (Fig. 8).

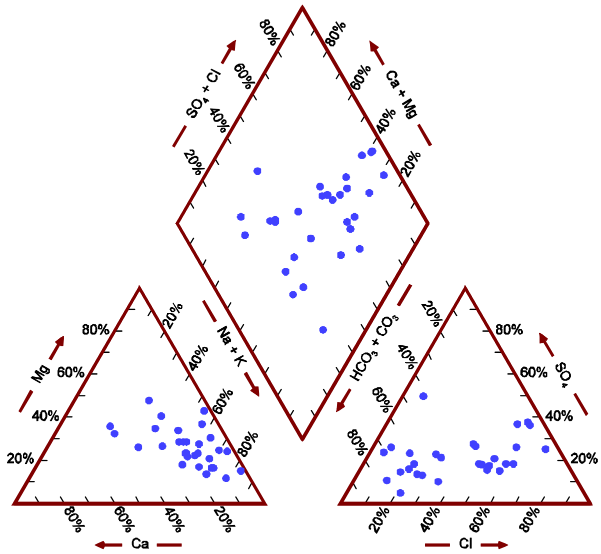

Fig. 8 Piper diagram illustrating the results of the analyzed samples.

Hydrochemical parameters

The hydrochemical parameters rNa/rCl, rK/rCl, rMg/rCl, rCa/rCl and rSO4/rCl have been calculated and compared with the standard values of the normal sea water. These hydrochemical parameters can be used as a tool for detecting the chemical contribution of water and water mixing from different sources. The average of the calculated hydrochemical parameters in the study area are higher than those of sea water (Ovitchinikov 1955) indicating addition of Na^+, K^+, Mg^{2+}, Ca^{2+} and SO_4^{2-} into the aquifer (Fig.9).

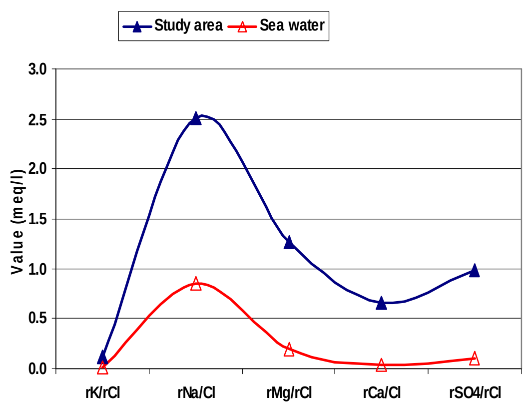

Fig. 9 The hydrochemical parameters in the study area compared with sea water

Groundwater quality

The results indicated that there is a great variation in groundwater quality at Qena area for domestic and irrigation purposes according to the World Health Organization (WHO, 1996, 1998) and Egyptian Drinking Water Standards (EHCW 2007).

For drinking purposes, the results showed that the groundwater in the study area for most of the investigated samples is unsuitable for drinking purposes. pH of groundwater meets the permissible limits of WHO and EHCW. Total hardness of groundwater is within the permissible limits of EHCW for about 83.3% of the collected samples. The total dissolved solids (TDS) of the groundwater in the study area ranged between 162 mg/l (for 60% of the samples collected) which is fit with the standards of WHO and EHCW and more than 1000 mg/l (for 40% of the samples collected) which is higher than the recommended value of 1000 mg/l. Groundwater hardness for 87 % of the samples is below the maximum permissible level for drinking water.

Most of cation concentrations are within the maximum permissible levels of WHO and EHCW. Potasium concentration is within the limits of WHO drinking water standards except wells no. 7, 10, 11, 21, 25, 27, and 29. Sodium is almost above the permissible limits of WHO and EHCW. Calcium concentration is entirely within the permissible limits of WHO and EHCW. Magnesium is almost within the permissible limits of WHO except samples no. 16 and 17.

Concentration of anions is varied compared with WHO and EHCW drinking water standards. Chloride concentration in about 50 % of the collected groundwater samples exceeded the WHO and EHCW drinking water standards.

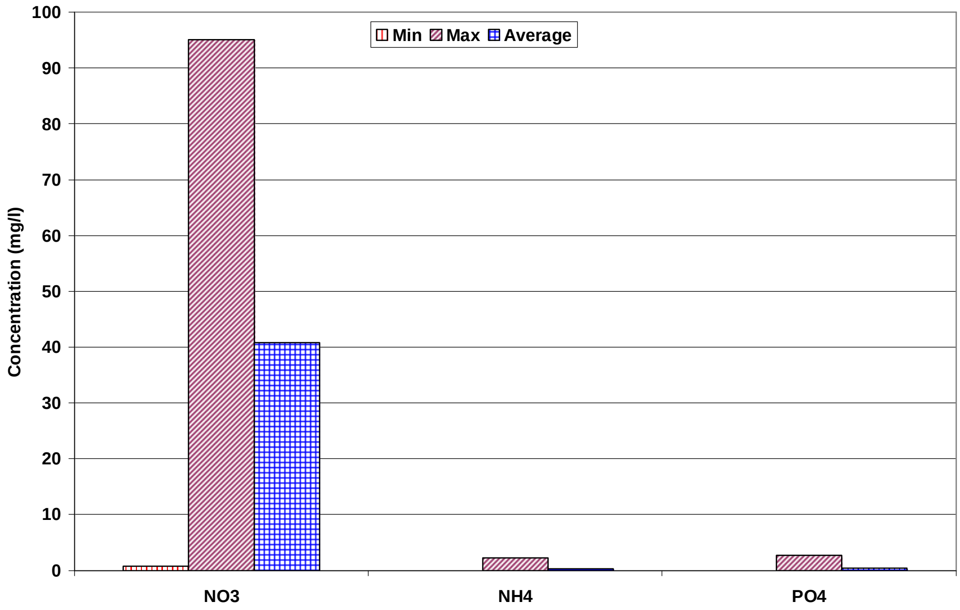

Fig. 10 Variation of NO_3, NH_4 and PO_4 in the study area.

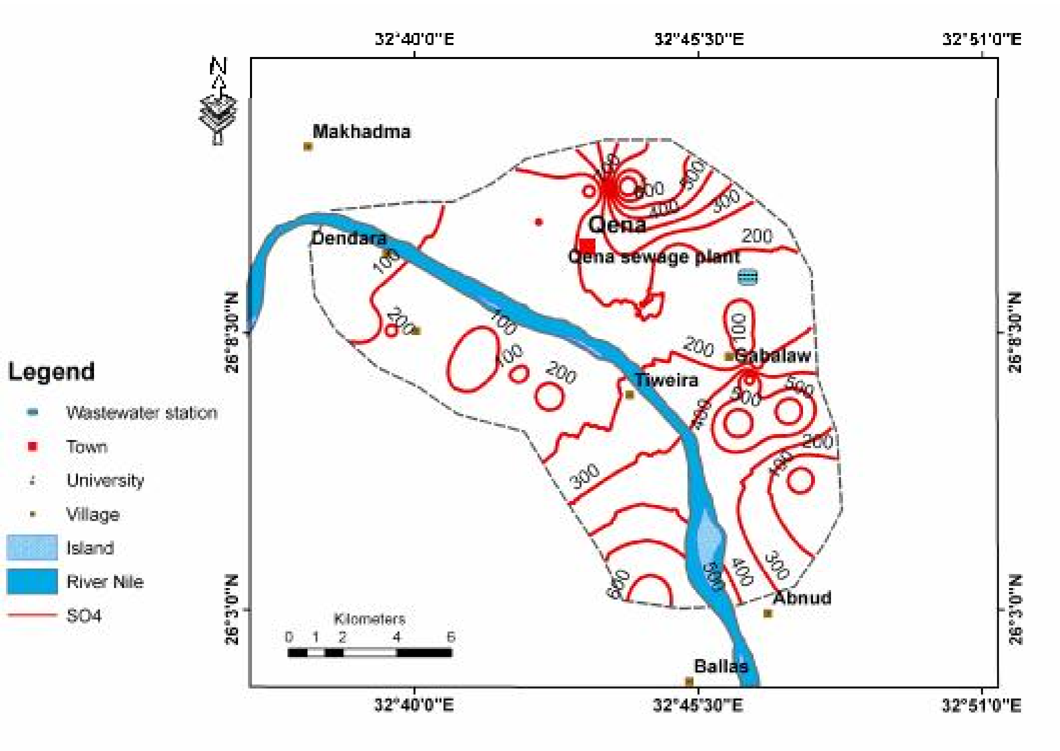

Fig. 11 SO_4 distribution in the study area (Contour interval = 100).

Elevated chloride level indicated impacts from anthropogenic sources such as sewage discharge which contain detergents and water softener. Sulphates have been found in higher concentration than the permissible limits in about 20% of the samples (Fig. 11), which is unsuitable for domestic use without treatment or dilution by mixing with freshwater sources. Bicarbonates are above the permissible limits of WHO guidelines in 36.7% of the samples. Nitrate is higher than the permissible limits of WHO and EHCW.

Nitrate shows high concentration levels beneath the new cultivated area around the swage treatment station and where the wells are enclosed by near standing houses and latrines. Its concentration varies between 2 and 97 mg/l (Fig. 12). The frequent high level of nitrate could be attributed to the mixing of groundwater with sewage water and the extensive use of nitrogen fertilizers in cultivated lands (Fig. 10).

Concentrations of ammonia in groundwater are almost within the permissible limits of EHCW except samples no. 6, 8 and 12. The presence of ammonia and phosphates indicated the contamination from sewage water as well as the chemical fertilizers.

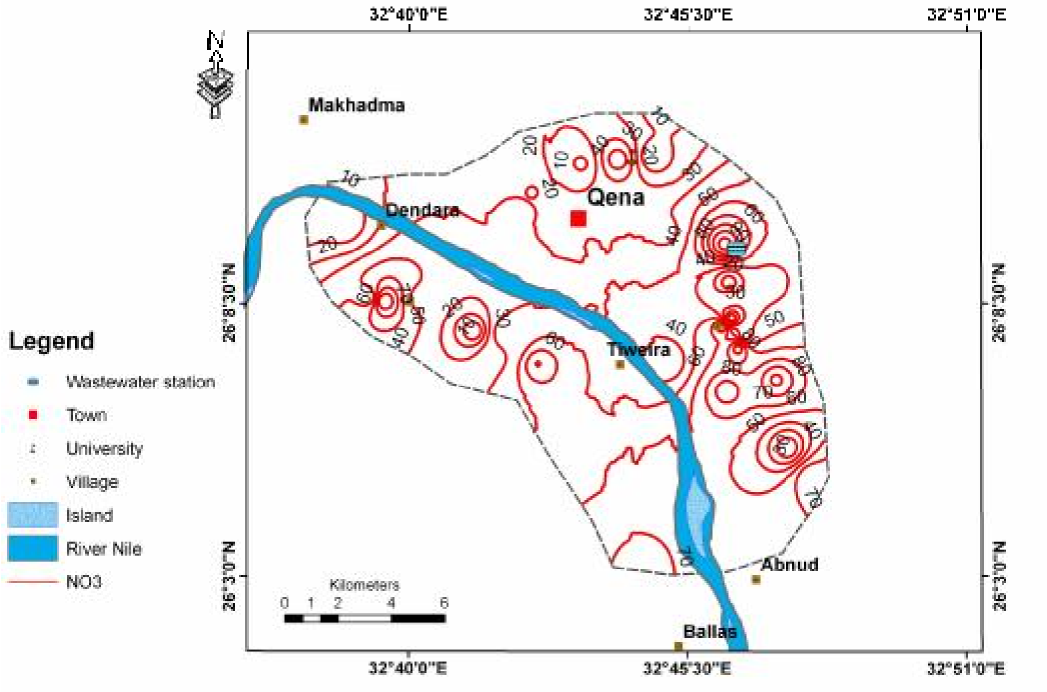

Fig. 12 NO_3 distribution in the study area (Contour interval = 10).

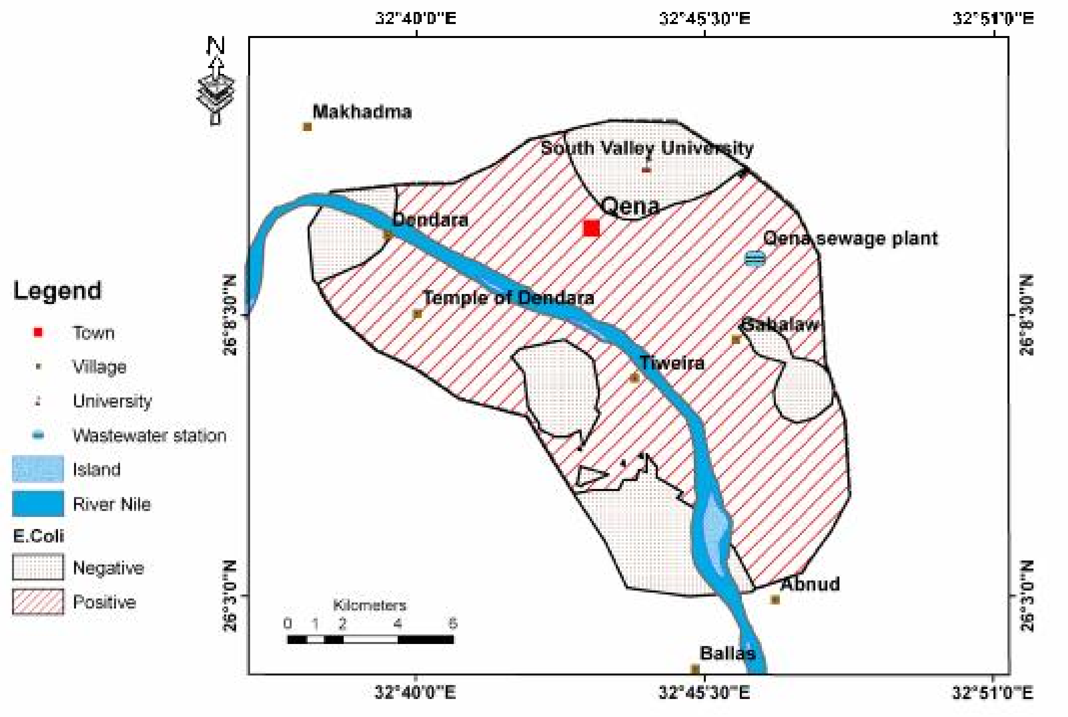

Fig. 13 E.Coli bacteria in the study area.

The majority of the collected groundwater samples are found to be positive with respect to E.Coli bacteria. The presence of E.Coli bacteria (Fig. 13) is an indicator that a potential health risk exists for individual using this water.

For irrigation purposes, the results indicated that the groundwater in the study area is suitable for irrigation with few restrictions concerning salinity and sodium hazards. According to percent of sodium in groundwater, most of groundwater samples fall in the good to permissible water classes (Fig. 14).

Based on the calculated values of SAR, all the examined groundwater samples lie in the excellent water class except for wells no 11, 13, 14 and 15 which appear in the good water class. Therefore groundwater within the study area can generally be safely used for irrigation with a low risk of sodium hazard.

Using Wilcox graph (Fig. 15), the majority of samples fall in the C3-S1 (high salinity with low sodium), C3-S2 (high salinity with medium sodium) and C4-S3 (very high salinity with high sodium) categories.

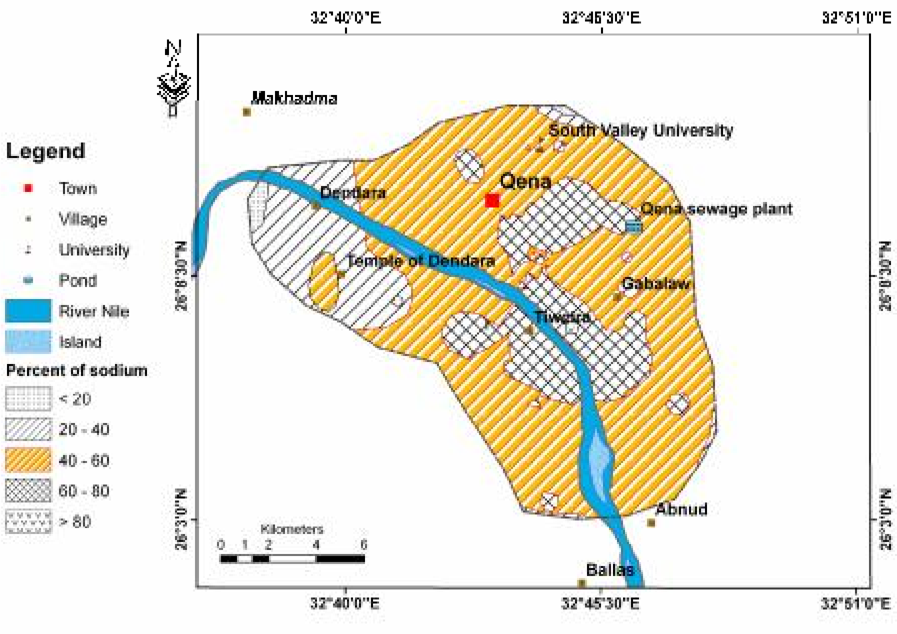

Fig. 14 Percent of sodium in groundwater of the study area.

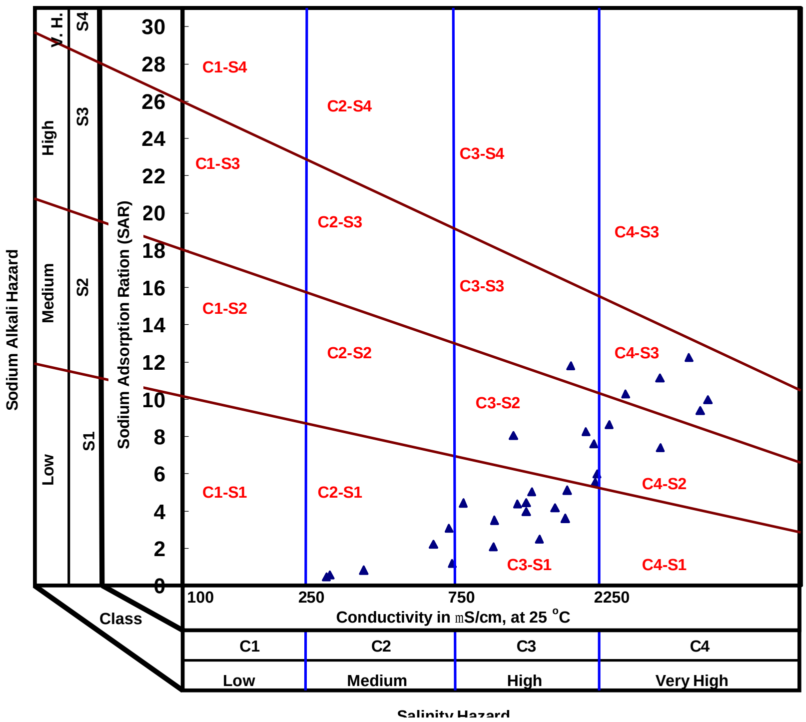

Fig. 15 Plot of collected groundwater samples on Wilcox graph.

Discussion and recommendations

Groundwater of Quaternary aquifer in Qena area is currently threatened by pollution from agricultural and anthropogenic activities.

The area has lithologic characteristics that facilitate the movement of contaminants and mixing with wastewater released from rural areas and Qena waste water treatment plant.

Water quality in the study area varied greatly with respect to suitability for drinking and irrigation purposes.

Many locations in the study area are highly polluted and need urgent measures to protect the Quaternary aquifer and mitigate further pollution.

Lack of sewage water systems at rural areas, improper application of wastewater treatment plants as well as uncontrolled use of agrochemicals in the study area are the main factors responsible for groundwater pollution.

The present conditions indicate that groundwater of Quaternary aquifer in the study area will become more worsened unless urgent measures are taken.

To protect the Quaternary groundwater aquifer and mitigate the risk of pollution, the following recommendations should be followed:

1- Controlling the application of agrochemicals at the agricultural lands and managing the application and use of the hazardous fertilizers and pesticides.
2- Controlling the use of groundwater for irrigation at the desert lands to avoid salinity hazards.
3- Using surface water for irrigation and leaching soils at the desert lands to mitigate salinity and hardness of groundwater.
4- Management of waste water treatment plants by selecting the best safe locations and managing the processes of waste water treatment.
5- Determining the vulnerability of Quaternary aquifer to pollution to determine the priority areas to be managed.
6- Continuous monitoring of pollution and degree of water quality degradation to help in decision making.

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الملخص العربى

تدهور نوعية المياه الجوفية للخزان الرباعى بمنطقة قنا، مصر

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تعتبر مصادر المياه بمنطقة قنا محدودة والتى تتمثل بنهر النيل وقنوات الرى والمياه الجوفية. يعتبر الخزان الجوفى لعصر الرباعى المصدر الرئيسى للمياه الجوفية بمنطقة الدراسة والذى يتعرض للتلوث فى الاونة الاخيرة. تمثل التوسعات الحضرية والانشطة الزراعية المصادر الاساسية لتلوث المياه الجوفية. تشمل مصادر التلوث بمنطقة الدراسة اختلاط المياه الجوفية بمياه الصرف الصحى والمواد الكيميائية المستخدمة نتيجة الانشطة الزراعية.

اعتمدت الدراسة الحالية على نتائج تحاليل عينات المياه الجوفية من القرى والمناطق المحيطة بمنطقة قنا وتحديد خصائصها وتقييم نوعية المياه باستخدام نظم المعلومات الجغرافية. كما تم اجراء تحليل بكتريولوجى للمياه لتحديد مدى تلوث المياه ببكتريا E.Coli.

لقد بينت نتائج تحليل عدد واحد وثلاثين عينة مياه جوفية تم تجميعها من منطقة الدراسة ان مصادر المياه ملوثة بالنترات والفوسفات والامونيا وبكتريا E.Coli. لقد تباينت جودة المياه فى منطقة الدراسة ومدى صلاحيتها لاغراض الشرب طبقاً لمعايير منظمة الصحة العالمية والمعايير المصرية. ومن ناحية اخرى فان المياه الجوفية بمنطقة الدراسة تعتبر صالحة للاغراض الزراعية وغير صالحة للشرب فى كثير من المناطق وتحتاج الى معالجة.

لقد اوصت الدراسة الحالية بضرورة ادارة مصادر التلوث بالتحكم فى استخدام الكيماويات الزراعية والتحكم فى تسرب مياه الصرف الصحى من المناطق القروية وايضاً ادارة محطات معالجة مياه الصرف الصحى.