

Hydrochemical Modeling and Assessment of Quaternary Aquifer in the Nile Valley, Qena, Egypt

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Abstract: *The study was conducted on the Quaternary Aquifer in the Nile Valley of Qena area in Egypt. Sixty-six groundwater samples were collected from the study area along with two surface water samples. The hydrochemical analyses were carried out for the collected samples comprising the major ions and heavy metals. The application of the software package (PHREEQC for windows version 2.8.00) is the main target in this study. PHREEQC was used to perform a variety of aqueous geochemical calculations including the saturation indices (SI) of the major mineral phases, testing of water corrosivity and to apply water mixing models. The Saturation Indices show a supersaturated with respect to the main carbonate minerals (calcite, aragonite and dolomite) nearly in all the samples. Calcite, aragonite, and dolomite represent the major sediments that built up the geology of the study area (the Limestone Plateau). The investigated groundwater samples varies from moderately corrosive (1.5%), mild corrosion (7.57%), faint coating (22.72%), and mild scale forming (68.18%). The mixing models were conducted between water from different sources as a proposed solution for lowering the chemical content especially nitrate levels in the highly contaminated wells to acceptable limits. As indicated from the results of mixing, mixing can be used as an effective water treatment method.*

Keywords: *Quaternary Aquifer, hydrochemical, corrosivity, mixing models, contaminated wells.*

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I. Introduction

The steady increase of the population and the rapid expansion of the national economy in Egypt in the last few years has become a progressive vital problem which represents the greater challenge to Egypt's future and compelled the Egyptian authorities for establishment of new settlements and land reclamation projects.

As water is vital for all of us and we depend on its good quality and quantity for drinking, reclamation, use in industry and growing crops, it is necessary for the development of water supplies to satisfy the demand of agricultural municipal and industrial requirements. Even in Egypt there is a continuous demand for more water for reclamation of new land to be added to the existing cultivated acreage.

As Egypt is essentially a desert land (about 97%), and in the desert areas of Egypt the surface water resources are generally very limited, therefore, groundwater resources constitute a cornerstone for any development project. The study of groundwater in the Eastern Desert is of a great important since the water resources are rare and thus constitute a major obstacle for both living and projects. Groundwater serves only 7% of water demand in Egypt [1].

In fact, groundwater is more desirable than surface water for many reasons including the absence of pathogenic organisms, color and turbidity, its constant chemical composition with no radiochemical nor biological contaminations and its great storage. The contamination of groundwater cannot be polluted easily as compared with surface water because it is protected naturally, so it is more reliable [2]

. Unfortunately, the continues development of the human societies as well as the land reclamation and agricultural projects lead to the water and soil pollution by the septic systems, waste water disposals, fertilizers and pesticides by both point and non point source of pollution.

The selected area for the present investigation comprises a part of the Eastern Desert which have the two parts (the cultivated area and the reclaimed area) (Figure 1). Both the quantity and the quality had been considered before evaluating the groundwater resources. The study are at Qena represents an area of most extensive groundwater resources in the Upper Egypt, where considerable amounts of groundwater have been exploited and used in the reclamation. Groundwater is very important source for drinking, irrigation and domestic uses in the study area for both rural and urban and varies from the first to second source of water along with the River Nile. Tube wells have also been the only source of irrigation water in small-scale reclamation schemes. In most cases wells are constructed on farmer's initiatives. Individual farmers or groups of farmers

share their wells. Also the large-scale reclamation projects in the Desert, which depend upon the groundwater, were expanded and developed.

In this study the software package (PHREEQC for windows version 2.8.00) [3] was used to evaluate the subsurface geochemical processes and provides an indication of the reaction potential of the system. PHREEQC was used for performs a variety of aqueous geochemical calculations as the Saturation Indices (SI) of the major mineral phases, testing for water corrosivity, and to apply water mixing models. Inverse modeling is currently used to assess the geochemical reactions prevailing within the aquifer and approach enables the deduction of the geochemical processes that account for the changes in the chemical composition of the groundwater and to construct its evolution history.

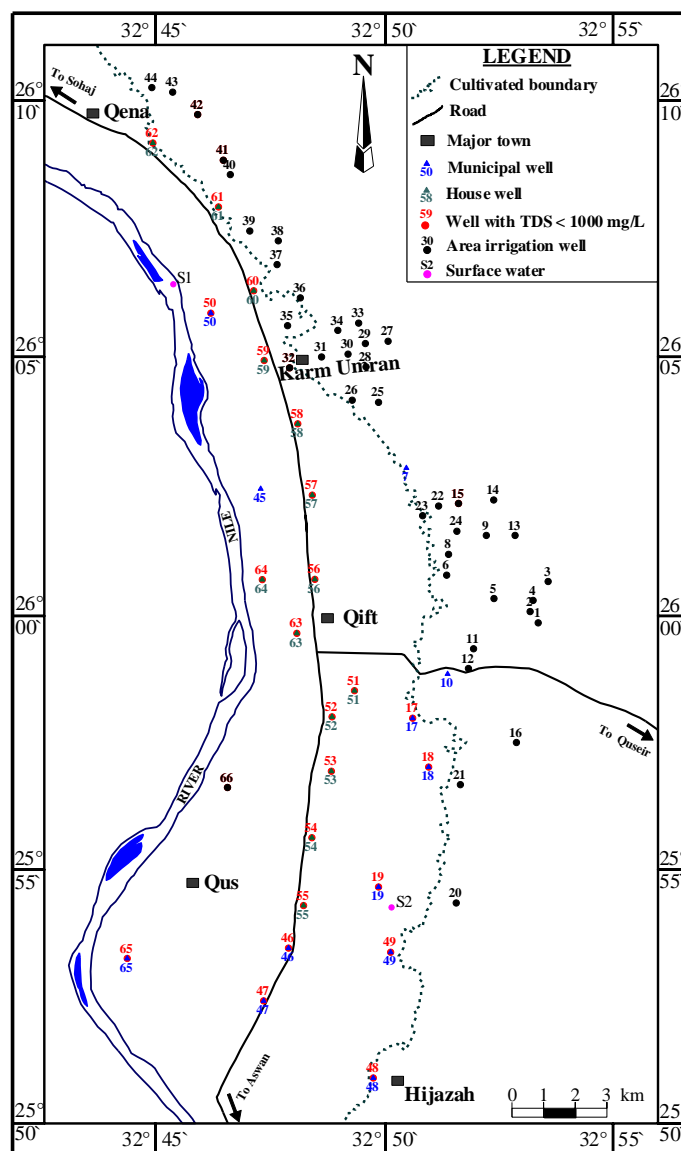


Figure 1: Location map of the collected water samples in the study area.

II. Study Area

Topography and Geology:

The study area lies to the east of the River Nile within the transition part between the Eastern Desert and the Nile valley. The area is characterized by simple topography follows the regional northwest slopes towards River Nile. The study area is located between latitudes 25° 50' and 26° 11' N and longitudes 32° 42' and 32° 56' E, and bounded from the west by low lands which is a strip of cultivated land of the River Nile flood plain representing the lowermost part in the area, ranging in elevation between 72 and 78 m above sea level, while the ground elevation is about 126 m above sea level in the Eastern part with a gentle slope to the northwest.

The sedimentary sequence exposed in the investigated area is composed of different sedimentary rocks belonging to a wide range of geologic time from Upper Cretaceous to Quaternary [4]-[9]. The alluvial deposits covering most of the study area, consists mainly of Conglomerates interbedded with clays, Sand and Gravel, and clay. Near the River Nile bank, the area is covered by the Nile mud and silt which is composed of very finely derived mineral matter with comparatively little admixture of sand.

The study area represents a part of the arid belt of the North Africa which characterized by hot, dry and rainless climate in summer and being mild with rare rainfall in winter. The mean annual rainfall in the study area is less than 5 mm and the intensity of evaporation is about 11.28 mm/day [10]

Surface Water:

The surface water systems in the study area are principally represented by the River Nile, the irrigation canals and the agricultural drains. The River Nile extends to about 950 km from Aswan Dam to Cairo. Within the study area, the River Nile extends to about 60 km from south to North with an average width ranges from 600.00 to 900.00 m.

The River Nile water is used either directly for irrigation or indirectly by several irrigation canals. Water delivered from the Nile Rivers to the farms through an extensive system of canals. Canals are classified according to size and functions to principal, main, branch, and distributary canals [11]. El-Kalabia canal is the principal irrigation canal in the study area. It receives water directly from the River Nile for conveyance water to the main canals; it is extend to about 53 km with width between 12 to 25 m.

The drains in Egypt comprise a system of large open drains. The main drains in the study area are Hebail main drain, Higgaza main drain, Qift main drain. A part of the drainage is used for irrigation directly or discharges into the River Nile and main irrigation canals.

The area is traversed by relatively wide wadies, which comprise some flash flood plains. These floods were mainly due to rainfall in the high lands of the basement rocks to the east of the River Nile. The study area was subjected to destructive flash floods many times during the years 1954 and 1994.

Hydrogeology:

Based on the present study and previous work, there are three main groundwater aquifers in the study area, namely, the Upper Cretaceous Nubian Sandstone Aquifer, Eocene Fissured Limestone Aquifer and the Quaternary Alluvial Aquifer. The most important one and the main for the present work is the Quaternary aquifer.

The Quaternary aquifer represents the most important groundwater aquifer in the area. It is essentially restricted to the Nile valley and also to the bottom of the adjacent Desert wadies. It is mainly consists of graded sands and gravels overlain in the majority of the region, by semi-permeable (semi-confining) silty clay layer (Holocene age), and underlain in some locations by impermeable compact Pliocene plastic clays (very low hydraulic conductivity). Generally the water in this aquifer is found under semi-confined conditions (under the cultivated area) and unconfined conditions (under the reclaimed area) where the overlay Nile silts layer is absent. The thickness of the groundwater bearing layer (sediments) is different from one location to another within the aquifer. The hydraulic conductivity of the aquifer which is determined from the pumping test is range from 30 to 100 m/day, with regional average of 50 m/day [12].

The major source of recharge to the aquifer is mainly from applied irrigation water, seepage from the surface water conveyance system, inflow from the River Nile, rainfall, and sub-surface inflow across boundaries [12]. On the other hand, the discharge from the Quaternary aquifer takes place through lateral outflow to the River Nile, outflow through the drainage system, the wells drilled for drinking and irrigation purposes, and evaporation from the water table [13].

The regional groundwater flow direction in the study area is from Southeast to Northwest and also from East to West towards the River Nile.

III. Methodology

Sampling

Sixty six wells were sampled from the study. The geographic location (Longitude and Latitude) of these wells were detected by the of Global Positioning System (GPS) instrument, their topographic elevations were measured and the wells were classified according to their uses. Figure 1 represents the locations of the collected samples.

Two bottles were prepared for each sampling site. Two water bottles (one liter and 100 ml) were collected for each sample for chemical and heavy metal analysis. The bottles were filled by direct flow of the groundwater with the help of the installed pumps. However, in cases of pumps malfunctioning or missing pumps a bailer was lowered 1 to 2 meters below the surface of the water in the well for sampling. Before sampling the water was allowed to flow for few minutes before the samples were taken. As a general rule all the

bottles were first rinsed with the water intended for sampling and then filled to the top. The 100 ml bottles were filtered using 0.45 µm pore-sized filters and acidified nitric acid to be analyzed for the heavy metals. All the collected and filtered samples were placed in a cold box and kept in the refrigerator until the analysis.

Analysis

Direct measurements were made at each site in the field giving readings for temperature, electrical conductivity (EC) and pH. In the laboratory the samples were analyzed according to the methods adopted by the United States geological survey [14] for the major ions (Ca²⁺, Mg²⁺, Na⁺, K⁺, CO₃²⁻, HCO₃⁻, Cl⁻, and SO₄²⁻), for the minor ions (SiO₂, PO₄³⁻, B³⁺ and NO₃²⁻), and for heavy metals (Fe, Cu, Mn, Pb, Cd, Cr, Ni, Co and Zn).

The Ca²⁺ and Mg²⁺ are analyzed by using titration with Na2EDTA, CO₃²⁻ and HCO₃⁻ are analyzed by using titration with H₂SO₄, Na⁺ and K⁺ are analyzed by using Flame Photometer, SO₄²⁻ are analyzed by using Turbidimetric method, Cl⁻ are analyzed by using titration with AgNO₃, SiO₂, PO₄³⁻, B³⁺ and NO₃²⁻ are analyzed by using Colorimetric methods, and heavy metals are analyzed by using Inductively Coupled Plasma (ICP).

The obtained chemical data are expressed in mg/L and the charge balance errors were calculated for each sample, all the samples are within the accepted balance. The descriptive statistics (minimum, maximum, average, median and standard deviation) of the results of the chemical analysis of the collected samples are summarized in Table 1.

Table 1: Descriptive statistics of the groundwater sample collected from the Study area.

	Groundwater samples (n = 66)						
	Min.	Max.	Stand. dev.	Median	Average	No. of samples	No. samples exceeds WHO limits 2003
pH	7.10	8.50	0.246	8.1	8.059	66	--
Temp.	22.0	30.7	2.57	26.95	26.6	66	
EC	319.00	7810.00	1857.01	2145.0	2335.14	66	
TDS	173.67	5745.60	1228.22	1335.53	1483.29	66	38
TH	10.00	1904.00	443.12	309.00	481.30	66	25
Alkal.	75.00	330.00	61.34	141.00	157.70	66	
Ca ²⁺	2.03	400.80	100.32	64.96	101.904	66	
Mg ²⁺	1.23	243.19	51.414	37.0	55.219	66	
Na ⁺	22.99	1500.00	284.63	279.47	338.84	66	41
K ⁺	4.00	72.00	11.377	10.95	14.273	66	27
CO ₃ ²⁻	3.60	162.00	24.253	14.40	21.338	64	
HCO ₃ ⁻	29.28	340.38	58.847	135.42	150.332	66	
SO ₄ ²⁻	1.00	1920.00	415.831	338.62	419.235	66	24
Cl ⁻	15.74	1771.28	437.167	381.91	457.993	66	36
B ³⁺	0.03	2.05	0.531	0.48	0.715	28	13
PO ₄ ³⁻	0.058	3.71	1.819	0.08	0.982	4	
SiO ₂	4.26	39.25	6.375	21.50	21.87	66	
NO ₃ ⁻	0.17	66.80	22.012	38.58	36.832	52	20
Cr	0.0002	0.134	0.03	0.016	0.024	51	7
Mn	0.0006	1.16	0.249	0.0345	0.163	34	5
Ni	0.0011	0.024	0.013	0.0016	0.009	3	1
pb	0.0002	0.094	0.026	0.0413	0.04	55	44
Zn	0.0003	2.537	0.503	0.0457	0.203	32	--
Fe	0.0204	0.649	0.132	0.0612	0.113	66	6

IV. Resultand Discussion (Geochemical Modeling)

Chemical equilibrium and Saturation Indices (SI)

The quality of the recharge water and its interactions with soil and rocks during its percolation and its storage in the aquifers are key factors in the chemistry of ground water. These interactions involve mainly dissolution and precipitation processes, which are controlled by the solubility products of the different involved mineral phases.

Generally, the Saturation Indices are used to express the water tendency towards precipitation or dissolution. The degree of water saturation with respect to a mineral is given by:

$$SI = \log \frac{K_{IAP}}{K_{SP}}$$

where K_{IAP} is the ionic activity product, K_{SP} is the solubility product, and SI is the Saturation Index of the concerned mineral. When SI is equal to zero then the water is at equilibrium or saturated with the mineral phase, where as SI values less than zero (negative values) indicate undersaturation and that the mineral phase tends to dissolve, while SI values over zero (positive values) indicate supersaturation and that the mineral phases tends to precipitate.

The Saturation Indices (SI) of the major mineral phases in the investigated groundwater samples were calculated using the software package (PHREEQC for windows version 2.8.00). The results of the Saturation Indices of the groundwater samples collected from the study area are summarized in Figure 2. The obtained results show that the groundwater is; 1) supersaturated with respect to the main Carbonate mineral (Calcite, Aragonite and Dolomite) nearly in all samples. Calcite, Aragonite, and Dolomite represent the major sediments that built up the geology of the study area, the Limestone Plateau to the East of the study area.

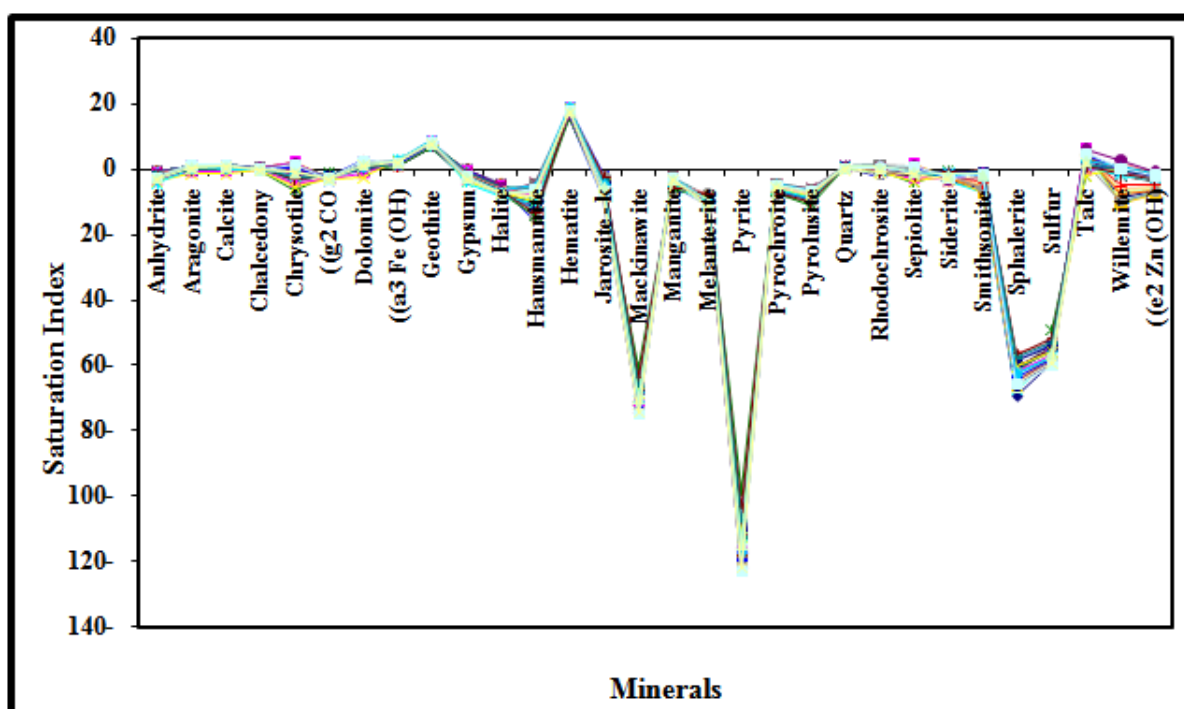


Figure 2: Saturation Indices with respect to minerals in the investigated groundwater samples of the study area. The figure demonstrates that the groundwater has a qualitative resemblance in their saturation levels that confirm its genetic similarity.

That is also evidenced by the elevated concentrations of alkalinity and the values of the pH in the wells located close to the Limestone Plateau; 2) supersaturated with respect to Quartz and Chalcedony. Quartz and Chalcedony is another indicator for the effect of the geology on the water types, where they increased in the groundwater due to the erosion of chert bands in the limestone and dolomite of the Limestone Plateau in the study area; 3) supersaturated with respect to the iron mineral phases (hematite, goethite and $Fe(OH)_3$), which reflects the sensitivity of the iron to oxidation even if in low concentrations; 4) supersaturated with respect to chrysotile, sepiolite, talc and rhodochrosite, which indicate the effect of leaching of the soil materials that come from weathering of the surrounding rocks and also the agricultural activities.

Corrosivity and scale formation

Corrosion is a complex series of reactions between water and metal surfaces and materials in which the water is stored or transported. The corrosion process is an oxidation/reduction reaction that returns refined or processed metals to their more stable ore state. The primary concerns of the corrosion potential of water include the potential presence of toxic metals as lead and copper, deterioration and damage to the household plumbing, and aesthetic problems such as: stained laundry, bitter taste, and greenish-blue stains around basins and drains. In soft water, corrosion occurs because of the lack of dissolved cations such as calcium and magnesium while in hard water a precipitate or coating of calcium or magnesium carbonate forms inside of the piping. This coating can inhibit the corrosion of the pipe, because it acts as a barrier, but it can also clog the pipe. Water with high levels of sodium, chloride, or other ions will increase the conductivity of the water and promoting corrosion [15].

The saturation indices were used as an indicator of water corrosivity or scale forming. Table 2 presents a typical range of SI of calcite that may be encountered in a drinking water and a description of the nature of the water and general recommendations regarding treatment [15]. Based on the above classification, where using of the saturation indices as indicator of water corrosivity or scale forming, the groundwater samples of the study area are;1) moderately corrosive only in well (58); 2) mild corrosion in about of 7.57% of the investigated samples; 3) faint coating in about 22.72% of the investigated samples. Faint coating occurs in the municipal wells (17, 18, 47, and 48) that may (by the time) lead to clog the pipes which transport the water to the inhabitants, so, treatment is recommended; and 4) mild scale forming, represented by most of the investigated groundwater samples (about 68.18%). Table 3 summarizes the saturation index and the corrosivity potentials of the investigated samples in the study area.

Table 2. Classification of the water corrosion potential based on the calcite (SI) values and recommended treatment.

Saturation Indices (SI)	Description	General recommendations
- 5.0	Severe corrosion	Treatment recommended
- 4.0	Moderate corrosion	Treatment recommended
- 3.0	Moderate corrosion	Treatment recommended
- 2.0	Moderate corrosion	Treatment should be considered
- 1.0	Mild corrosion	Treatment should be considered
- 0.5	Mild corrosion	Treatment probably not needed
0.0	Balanced	Treatment typically not needed
0.5	Some faint coating	Treatment typically not needed
1.0	Mild scale forming	Some aesthetic problems
2.0	Mild scale forming	Some aesthetic - considered
3.0	Moderate scale forming	Treatment should be considered
4.0	Severe scale forming	Treatment probably required
5.0	Severe scale forming	Treatment required

Mixing models

The mix samples generate solution concentrations resulting from the step-wise mixing of specified proportions of two selected samples from the investigated samples. You can select the parameters that will be included in the mixing calculations; typically you should select parameters that you know are common to each sample. These mixing can indicate that the evolution of the brackish water is possibly due to hydraulic mixing of fresh and saline waters within the aquifer matrix and/or in well mixing. In this section, mixing models were conducted between water from different sources as a proposed solution for lowering the chemical content especially nitrate levels in the highly contaminated wells to the acceptable limits. For mixing each of the input solutions is multiplied by its mixing fraction and a new output solution is calculated stoichiometrically[16].

In this model, the water of well (11) (well own to Qena cement factory) and well (62) (housing well) are mixed with Nile water (S1), irrigation cannel water (S2), and housing well (well 60). The mixing models for lowering the chemical content especially nitrate levels in the highly contaminated wells to the acceptable limits. For mixing each of the input solutions is multiplied by its mixing fraction and a new output solution is calculated stoichiometrically[16]

Table 3. The classification of the water samples in the study area based on its tendency to be corrosive.

Well No.	(SI) Calcite	Corrosivity	Well No.	(SI) Calcite	Corrosivity
1	1.05	Mild scale forming	35	0.95	Mild scale forming
2	0.84	Mild scale forming	36	1.20	Mild scale forming
3	1.16	Mild scale forming	37	1.01	Mild scale forming
4	0.49	Faint coating	38	1.14	Mild scale forming
5	0.98	Mild scale forming	39	0.67	Mild scale forming
6	1.07	Mild scale forming	40	0.75	Mild scale forming
7	0.82	Mild scale forming	41	- 0.09	Mild corrosion
8	0.62	Mild scale forming	42	0.75	Mild scale forming
9	0.58	Mild scale forming	43	0.77	Mild scale forming
10	0.76	Mild scale forming	44	0.81	Mild scale forming
11	0.88	Mild scale forming	45	1.06	Mild scale forming
12	0.73	Mild scale forming	46	0.60	Mild scale forming
13	- 0.16	Mild corrosion	47	0.22	Faint coating
14	0.88	Mild scale forming	48	0.33	Faint coating
15	0.66	Mild scale forming	49	0.57	Mild scale forming
16	1.05	Mild scale forming	50	0.70	Mild scale forming
17	0.35	Faint coating	51	0.35	Faint coating
18	0.26	Faint coating	52	0.11	Faint coating
19	0.85	Mild scale forming	53	0.35	Faint coating
20	1.01	Mild scale forming	54	- 0.05	Mild corrosion
21	0.82	Mild scale forming	55	0.40	Faint coating
22	0.75	Mild scale forming	56	- 0.37	Mild corrosion
23	0.97	Mild scale forming	57	- 0.67	Mild corrosion
24	0.39	Faint coating	58	- 1.36	Moderate corrosion
25	0.74	Mild scale forming	59	0.28	Faint coating
26	0.90	Mild scale forming	60	0.75	Mild scale forming
27	0.40	Faint coating	61	- 0.04	Mild corrosion
28	0.54	Mild scale forming	62	0.18	Faint coating
29	0.85	Mild scale forming	63	0.57	Mild scale forming
30	0.94	Mild scale forming	64	0.22	Faint coating
31	0.49	Faint coating	65	1.32	Mild scale forming
32	0.53	Mild scale forming	66	0.68	Mild scale forming
33	0.79	Mild scale forming	S1	0.57	Mild scale forming
34	0.80	Mild scale forming	S2	0.76	Mild scale forming

In this model, the water of well (11) (well own to Qena cement factory) and well (62) (housing well) are mixed with Nile water (S1), irrigation cannel water (S2), and housing well (well 60). The mixing models in this section mainly aims to lower the chemical content of well (11) for using it in irrigation and industrial uses by mixing with Nile, irrigation cannel or fresh water well (well 60). Another aim also to lower the high nitrate concentration of well (62) to levels that are below the acceptable levels of nitrates according to WHO [17] guidelines for drinking water (50 mg/L) with the same mixing wells. The mixing could be done in the house cisterns, the roof tanks and in the pools. The averaged chemical composition of the water of wells (11 and 62) was mixed with different percentages (0.9:0.1, 0.8:0.2,..., 0.1:0.9) with water wells (S1, S2 and 60). The changes in the nitrate concentration in the water of the wells (11 and 62) as a result of the mixing processes are summarized in Table 4, while the changes in the concentrations of the major cations and anions are summarized in Tables 5 and 6.

Table 4.The concentration of nitrate in water wells (11 and 62) due to mixing with water wells (S1, S2, and 60).

Well		Well (11) (56.16 mg NO ₃ /L)			Well (62) (61.32 mg NO ₃ /L)		
Mixing water		W. (S1)	W. (S2)	W. (60)	W. (S1)	W. (S2)	W. (60)
		0.0 mg/L	1.5 mg/L	7.93 mg/L	0.0 mg/L	1.5 mg/L	7.93 mg/L
Mixing Percentage	1.0 : 0.0	56.16	56.16	56.16	61.32	61.32	61.32
	0.9 : 0.1	50.54	50.69	51.34	55.19	55.34	55.98
	0.8 : 0.2	44.93	45.23	46.51	49.06	49.36	50.64
	0.7 : 0.3	39.31	39.76	41.69	42.92	43.37	45.30
	0.6 : 0.4	33.70	34.30	36.87	36.79	37.39	39.96
	0.5 : 0.5	28.08	28.83	32.05	30.66	31.41	34.63
	0.4 : 0.6	22.46	23.36	27.22	24.53	25.43	29.29
	0.3 : 0.7	16.85	17.90	22.40	18.40	19.45	23.95
	0.2 : 0.8	11.23	12.43	17.58	12.26	13.46	18.61
	0.1 : 0.9	5.62	6.97	12.75	6.13	7.48	13.27
0.0 : 1.0	0.00	1.50	7.93	0.00	1.50	7.93	

Table 4 shows, that 80% or less mixing percentage of water wells (11 and 62) with 20% or more of mixing water from wells (S1, S2, and 60) is necessary to lower the nitrate concentration in water wells (11 and 62) to and even to less than the WHO acceptable level of nitrate in drinking water. Nitrate content is only an example of the water characteristics that could be improved and controlled by mixing, thus mixing could be considered as an effective water treatment method. Mixing is used also for lower the Total Dissolved Solids (TDS) of the saline water wells in the desert or in the coastal areas by mixing with fresh water wells to use it for constructions, and industrial and agricultural projects.

Table 5: Chemistry changes of water well (11) as a result of mixing with water wells (S1, S2, and 60).

Parameter	Mixing water		Well (11)	Mixing percentages (well 11 : mixing water)									
	Well (S1)	Well (S2)		0.9 : 0.1	0.8 : 0.2	0.7 : 0.3	0.6 : 0.4	0.5 : 0.5	0.4 : 0.6	0.3 : 0.7	0.2 : 0.8	0.1 : 0.9	
pH	Well (S1)	8.5	8.2	8.23	8.26	8.29	8.23	8.35	8.38	8.41	8.44	8.47	
	Well (S2)	8.7		8.25	8.3	8.35	8.4	8.45	8.5	8.55	8.6	8.65	
	Well (60)	8.4		8.22	8.24	8.26	8.28	8.3	8.32	8.34	8.36	8.38	
TDS	Well (S1)	181.67	1669.68	1520.88	1372.08	1223.28	1074.48	925.68	776.87	628.07	479.27	330.47	
	Well (S2)	152.35		1517.95	1366.21	1214.48	1062.75	911.02	759.28	607.55	455.82	304.08	
	Well (60)	317.89		1534.50	1399.32	1264.14	1128.96	993.78	858.61	723.43	588.25	453.07	
Ca ²⁺	Well (S1)	18.27	97.44	89.52	81.61	73.69	65.78	57.86	49.94	42.02	34.10	26.19	
	Well (S2)	20.30		89.73	82.02	74.30	66.58	58.87	51.16	43.44	35.73	28.01	
	Well (60)	20.30		89.73	82.02	74.30	66.58	58.87	51.16	43.44	35.73	28.01	
Mg ²⁺	Well (S1)	8.63	66.59	60.79	54.99	49.20	43.41	37.61	31.81	26.02	20.22	14.43	
	Well (S2)	8.63		60.79	54.99	49.20	43.41	37.61	31.81	26.02	20.22	14.43	
	Well (60)	15.81		61.51	56.43	51.36	46.28	41.2	36.12	31.04	25.97	20.89	
Na ⁺	Well (S1)	36.78	413.79	376.09	338.39	300.69	262.99	225.29	187.58	149.88	112.18	74.48	
	Well (S2)	20.69		374.48	335.17	295.86	256.55	217.24	177.93	138.62	99.31	60.00	
	Well (60)	75.86		379.99	346.20	312.41	278.62	244.83	211.03	177.24	143.45	109.66	
K ⁺	Well (S1)	5.00	9.00	8.6	8.2	7.8	7.4	7.0	6.6	6.2	5.8	5.4	
	Well (S2)	7.00		8.8	8.6	8.4	8.2	8.0	7.8	7.6	7.4	7.2	
	Well (60)	10.56		9.16	9.31	9.47	9.62	9.78	9.94	10.09	10.25	10.40	
CO ₃ ²⁻	Well (S1)	7.20	7.20	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	
	Well (S2)	18.00		8.28	9.36	10.44	11.52	12.6	13.68	14.76	15.84	16.92	
	Well (60)	36.00		10.08	12.96	15.84	18.72	21.6	24.48	27.36	30.24	33.12	
HCO ₃ ⁻	Well (S1)	112.87	109.21	109.58	109.94	110.31	110.67	111.04	111.41	111.77	112.14	112.50	
	Well (S2)	95.16		107.81	106.4	104.99	103.59	102.19	100.78	99.38	97.97	96.57	
	Well (60)	170.84		115.37	121.54	127.69	133.86	140.03	146.19	152.35	158.51	164.68	
SO ₄ ²⁻	Well (S1)	10.00	365.03	329.53	294.02	258.52	223.02	187.52	152.02	116.51	81.01	45.50	
	Well (S2)	14.41		329.97	294.91	259.84	224.78	189.72	154.66	119.60	84.53	49.47	
	Well (60)	34.58		331.99	298.94	265.89	232.85	199.81	166.76	133.72	100.67	67.63	
Cl ⁻	Well (S1)	39.36	656.03	594.36	532.69	471.03	409.36	347.70	286.03	224.36	162.69	101.03	
	Well (S2)	15.74		592.0	527.97	463.94	399.91	335.89	271.86	207.83	143.80	79.77	
	Well (60)	39.36		594.36	532.70	471.03	409.36	347.70	286.03	224.36	162.69	101.03	
NO ₃ ⁻	Well (S1)	0.00	56.16	50.54	44.93	39.31	33.70	28.08	22.46	16.85	11.23	5.62	
	Well (S2)	1.50		50.69	45.23	39.76	34.30	28.83	23.36	17.90	12.43	6.97	
	Well (60)	7.93		51.34	46.51	41.69	36.87	32.05	27.22	22.39	17.58	12.75	

Table 6: Chemistry changes of water well (62) as a result of mixing with water wells (S1, S2, and 60).

Parameter	Mixing water	Well (62)	Mixing percentages (well 11 : mixing water)									
			0.9 : 0.1	0.8 : 0.2	0.7 : 0.3	0.6 : 0.4	0.5 : 0.5	0.4 : 0.6	0.3 : 0.7	0.2 : 0.8	0.1 : 0.9	
pH	Well (S1)	8.5	7.7	7.78	7.86	7.94	8.02	8.1	8.18	8.26	8.34	8.42
	Well (S2)	8.7		7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6
	Well (60)	8.4		7.77	7.84	7.91	7.98	8.05	8.12	8.19	8.26	8.33
TDS	Well (S1)	181.67	739.64	683.84	628.05	572.25	516.45	460.66	404.86	349.06	293.26	237.47
	Well (S2)	152.35		680.91	622.18	563.45	504.72	445.99	387.27	328.54	269.81	211.08
	Well (60)	317.89		697.46	655.29	613.11	570.94	528.76	486.59	444.42	402.24	360.07
Ca ²⁺	Well (S1)	18.27	32.48	31.06	29.64	28.22	26.80	25.37	23.95	22.53	21.11	19.69
	Well (S2)	20.30		31.26	30.04	23.83	27.61	26.39	25.17	23.95	22.74	21.52
	Well (60)	20.30		31.26	30.04	28.83	27.61	26.39	25.17	23.95	22.74	21.52
Mg ²⁺	Well (S1)	8.63	24.66	23.06	21.45	19.85	18.25	16.65	15.04	13.44	11.84	10.23
	Well (S2)	8.63		23.06	21.45	19.85	18.25	16.65	15.04	13.44	11.84	10.23
	Well (60)	15.81		23.78	22.89	22.01	21.12	20.24	19.35	18.46	17.58	16.69
Na ⁺	Well (S1)	36.78	165.00	152.18	139.36	126.53	113.71	100.89	88.07	75.25	62.42	49.60
	Well (S2)	20.69		150.57	136.14	121.71	107.28	92.85	78.41	63.98	49.55	35.12
	Well (60)	75.86		156.09	147.17	138.26	129.34	120.43	111.52	102.60	93.69	84.77
K ⁺	Well (S1)	5.00	63.00	57.2	51.4	45.6	39.8	34.0	28.2	22.4	16.6	10.8
	Well (S2)	7.00		57.4	51.8	46.2	40.6	35.0	29.4	23.8	18.2	12.6
	Well (60)	10.56		57.76	52.51	47.27	42.02	36.78	31.54	26.29	21.05	15.80
CO ₃ ²⁻	Well (S1)	7.20	28.80	26.64	24.48	22.32	20.16	18.0	15.84	13.68	11.52	9.36
	Well (S2)	18.00		27.72	26.64	25.56	24.48	23.4	22.32	21.24	20.16	19.08
	Well (60)	36.00		29.52	30.24	30.96	31.68	32.4	33.12	33.84	34.56	35.28
HCO ₃ ⁻	Well (S1)	112.87	183.00	175.99	168.97	161.96	154.95	147.94	140.92	133.91	126.90	119.88
	Well (S2)	95.16		147.22	165.43	156.65	147.86	139.08	130.30	121.51	112.73	103.94
	Well (60)	170.84		181.78	180.57	179.35	178.14	176.92	175.70	174.49	173.27	172.06
SO ₄ ²⁻	Well (S1)	10.00	176.75	160.08	143.4	126.73	110.05	93.38	76.7	60.03	43.35	26.68
	Well (S2)	14.41		160.52	144.28	128.05	111.81	95.58	79.35	63.11	46.88	30.64
	Well (60)	34.58		162.53	148.32	134.10	119.88	105.67	91.45	77.23	63.01	48.80
Cl ⁻	Well (S1)	39.36	157.45	145.64	133.83	122.02	110.21	98.41	86.60	74.79	62.98	51.17
	Well (S2)	15.74		143.28	129.12	114.94	100.77	86.60	72.42	58.25	44.08	29.91
	Well (60)	39.36		145.64	133.83	122.02	110.21	98.41	86.60	74.79	62.98	51.17
NO ₃ ⁻	Well (S1)	0.00	61.32	55.19	49.06	42.92	36.79	30.66	24.53	18.40	12.26	6.13
	Well (S2)	1.50		55.34	49.36	43.37	37.39	31.41	25.43	19.45	13.46	7.48
	Well (60)	7.93		55.98	50.64	45.30	39.96	34.63	29.28	23.95	18.61	13.27

V. Conclusion

The Quaternary aquifer represents the most important groundwater aquifer in the area. It is essentially restricted to the Nile Valley and also to the bottom of the adjacent Desert Wadies. The aquifer is mainly recharged by downward leakage from the overlying semi-confining layer where the aquifer is semi-confined or by direct recharge from the irrigation water where the aquifer is unconfined. The groundwater of the study area have normal physical properties where the temperature ranged from 22.0 °C to 30.7 °C, their pH ranged 7.1 to 8.5 and their TDS ranged from 173.63 mg/L to 5745.6 mg/L.

The Saturation Indices (SI) of the samples collected in this study was calculated for the major mineral phases using the software package (PHREEQC for windows version 2.8.00). The Saturation Indices show a supersaturated with respect to the main carbonate mineral (calcite, aragonite and dolomite) nearly in all samples. Calcite, aragonite, and dolomite represent the major sediments that built up the geology of the study area (the Limestone Plateau). The saturation indices were used as an indicator of water corrosivity or scale forming. The groundwater samples in this study are ranges between moderately corrosive, mild corrosion, faint coating to mild scale forming.

The mixing program was used to evaluate the theoretical composition of the mixed water and the proportion of such mixing. In this section, mixing models were conducted between water from different sources as a proposed solution for lowering the chemical content especially nitrate levels in the highly contaminated wells to acceptable limits. An example was carried out as mixing water wells (11 and 62) with Nile water (S1), irrigation canal water (S2) and water well (60), the result was tabulated in the accompanied tables. As indicated from the results of mixing, mixing can be used as an effective water treatment method.

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