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Groundwater Quality Assessment to Estimate its Suitability for Different Uses in Assiut Governorate, Egypt

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Abstract ***Groundwater in Assiut governorate has a particular importance where it is the second source for fresh water used for drinking, agricultural, domestic, and industrial purposes. Three hundred and thirty five wells were available during the period 2006 to 2009, and were subjected to analysis for chemical characteristics. These data has been used to conclude two main results; the first one is preliminary evaluation of suitability of groundwater for drinking and irrigation purposes by comparing those parameters with world health organization (WHO) standards and Egyptian standards. the second one is building the correlation matrix between the groundwater quality parameters which are major ions, EC, TDS, SAR, Na%, RSC, TH, KI, PI, MH, CAI, and C.R. with comparing chemical parameters with WHO (1996) and Egyptian standards for drinking, it shows that concentrations of Na+, K+, Ca2+, Mg2+, Hco3-, SO42−, and Fe are lower than the permissible limits in 80% of wells. Groundwater wells were classified according TDS as about 93 % of wells have TDS less than 3000 mg/l, thus groundwater is suitable for irrigation.***

Keywords: Groundwater pollution, Groundwater quality, Assiut governorate, world health organization (WHO), standards and Egyptian standards.

I. INTRODUCTION

Groundwater in Assiut area has a particular importance where it is the second source for fresh water used for agricultural, domestic, and industrial purposes. Groundwater resources of Assiut, Egypt face a very serious problem which is contamination from agricultural and urbanization activities. The parameters of water quality i.e. pH, EC, TDS, TH, chloride, sulfate etc. should be in permissible limits according to drinking water standards of WHO (1996) [1] and Egyptian Standards (1995) [2]. If these parameters cross the permissible limit of concentration, it may causes serious health hazards and such water is known as contaminated water. The first objective of this contribution is to evaluate groundwater quality whereupon can determine its suitability for different uses through comparing certain parameters which are TDS, SAR, Na%, RSC, TH, PI, MR, CAI, K.R, and C.R. with WHO standards and Egyptian standards.

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The second objective is to establish correlation matrix among the groundwater quality parameters with each others. Many attempts have been applies in Assiut area to study groundwater characteristics.

In 1988, Sobih et al. [3] talked about the chemical and bacterial pollution of groundwater by assessing 25 water wells established at Assiut city. In 1993, Bakheit et al. [4] measured Electrical resistivity and applied Schlumberger layout in the entrance of Wadi El-Assiuti - east of Assiut city to deduce the corresponding geological layers, its true resistivities and thicknesses using the available computer program.

Geo-electrical and hydro-geological studies on the Quaternary aquifer in the Nile valley in Assiut and Sohag governorate was carried out by Aboul-Fetoh in 1994 [5]. Ebrahim (1997) [6] used Schlumberger geoelectrical depth soundings and horizontal geoelectrical profiling using the Wenner configuration to determine the distribution of the contaminated and uncontaminated zones of groundwater in (El-Madabegh) area, northwest of Assiut city. Electrical geophysics was used by Shaker (1999) [7] in the area between Manfalut & Bany Ady to determine the thickness of the water-bearing layers.

The impact of septic system on groundwater quality in the Nile valley village was investigated in 2001 by Abdel-Lah and Shamrukh [8]. Many water samples from handpumps and deep wells in an Nile Valley village were analyzed biologically and chemically. All the samples were reported pathogenic contaminated.

Sebaq et al. (2003) [9] used surface geoelectrical methods for delineation of groundwater pollution in Beni Ghalib area, northwest of Assiut city. They stated that the area northwest of Assiut is suffering from pollution, which is generated from different sources, e.g. sewage station and agriculture activities. Relationships between groundwater pollution and surface waters were studied on Nile aquifer by Wahaab and Badawy (2004) [10]. They concluded that due to the interaction of groundwater with surface waters, pollution of Nile aquifer is closely related to adjacent (polluted) surface waters. Mohamaden et al. (2009) [11], carried out Forty-two vertical electrical soundings (VES.'s), using Schlumberger array in Assiut area in order to elucidate hydrogeological information and delineate subsurface structural elements. Abdalla et al. (2009) [12], studied the groundwater quality with compared its parameters with the World Health Organization (WHO) and Egyptian standards.

II. Study Area

Assiut area covers part of the Nile Valley, Egypt on the reach extending from the northern edge of Sohag Governorate at latitude 27˚37´ N to the southern edge of El-Minia Governorate at latitude 26˚47´ N. It is bounded between longitudes 30˚37´ - 31˚34´ E, as shown in figure 1. The total area of Assiut governorate is 25,926 km². [13].

River Nile divides the study area into a western and an eastern part. The Eastern part expands between El-Badary in the South and Manfalut in the North, while the Western part of the study area expands between El-Ghanayim in the South, and Dairut in the North. [14].

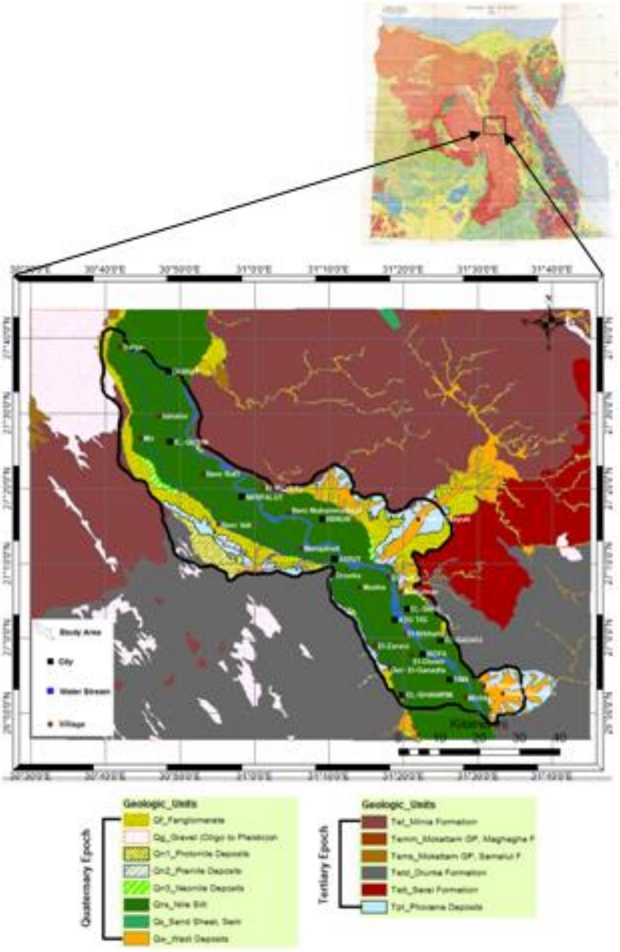

Figure 1: Scope of Assiut region as a part of Egypt [15].

III. Methodology

1. *Determining groundwater quality parameters*

Some physicochemical parameters related to groundwater quality were investigated in this attempt to assess suitability of groundwater for the purpose of drinking and irrigation as follows.

1.1 Electrical Conductivity (EC)

Conductivity is ability of water to carry an electrical current. This ability mainly depends on presence of anion and cations in water and also depends on mobility, valence of ions and temperature. It is an indicator of the degree of mineralization of water [16].

1.2 Total Dissolved Solids (TDS)

Total dissolved solids (TDS), is defined as the concentration of all dissolved minerals in the water. The concentration of TDS in natural water is usually less than 500 mg per litre, while more than 500 mg per litre is undesirable for drinking and many industrial uses. TDS value of 500 mg per litre as the desirable limit and 2000 mg per litre as the maximum permissible limits [17].

1.3 Sodium Adsorption Ratio (SAR)

Sodium concentration is an important factor in classifying water for irrigation because it is a measure of alkali/sodium hazard to crops. Because sodium reacts with soils and reduce its permeability which makes cultivation difficult. Sodium Adsorption Ratio (SAR) is defined as the following equation [18].

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} \qquad (1)$$

Where, the concentrations of the constituents are expressed in meq /L.

The salinity laboratory of the United States Department of Agriculture recommended the SAR as an index (Table 1) for sodium hazard.

Table 1: Sodium adsorption ration classification [19]

Water class	Alkali Hazard (SAR)
Excellent	up to 10
Good	10-18
Fair	18-26
Poor	>26

1.4 Percent Sodium (Na %):

Excess sodium in water produces the undesirable effects of changing soil properties and reducing soil permeability [20]. Hence, the assessment of sodium percentage is necessary while considering the suitability for irrigation, which is computed by Eq. (4-2).

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

Where the quantities of Ca2+, Mg2+ Na+ and K+ are expressed in milliequivalents per litre (epm)

Wilcox [21] classified groundwater for irrigation purposes based on percent sodium and Electrical conductivity.

Table 2: Classification of Percent sodium [22]

Percent Sodium, %	Categories
0-20	Excellent
20-40	Good
40-60	Permissible
60-80	Doubtful
>80	Unsuitable

1.5 Residual Sodium Carbonate (RSC)

In addition to the SAR and % Na, the excess sum of carbonate and bicarbonate in groundwater over the sum of calcium and magnesium also influences the unsuitability of groundwater for irrigation. This is denoted as residual sodium carbonate (RSC), which is calculated as following equation [23]:

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$$RSC = (Hco_3^- + Co_3^{2-}) - (Ca^{2+} + Mg^{2+}) \quad (3)$$

Where the concentrations are reported in meq/l
RSC has been calculated to determine the hazardous effect of Co32− and Hco3− on the quality of water for agricultural purpose.

Table 3: Classification of Residual sodium carbonate [23]

Ranges of (RSC)	Categories
<1.25	good
1.25-2.5	doubtful
> 2.5	unsuitable

The classification above means that wells have RSC <1.25 are safe for irrigation, it is considered unsuitable if it is greater than 2.5 [24].

1.6 Permeability Index (PI)

The permeability index (PI) values also indicate that the groundwater is suitable for irrigation. The soil permeability is affected by the long term use of irrigation water as it is influenced by Na+, Ca2+, Mg2+ and Hco3− content of the soil. Permeability index formula has been evolved by (Doneen, 1964) [25], to measure the soil permeability for assessing the suitability of water for irrigation purposes as follows.

$$PI = \frac{(Na^+ + \sqrt{HCo_3^-})}{(Ca^{2+} + Mg^{2+} + Na^+)} \times 100 \quad (4)$$

Accordingly, the PI is classified under class I (>75%), class II (25 – 75%) and class III (<25%) orders. Class I and class II waters are categorized as good for irrigation with 75% or more of maximum permeability. Class III waters are unsuitable with 25% of maximum permeability.

1.7 Magnesium Hazard (MH)

Generally, alkaline earths are in equilibrium state in groundwater. In other words, Ca+ and Mg+ maintain a state of equilibrium in groundwater. More Mg+ present in waters affects the soil quality converting it to alkaline and decreases crop yield [24, 26].
Szabolcs and Darab (1964) [27] proposed MH value for irrigation water as given by the following formula (where the concentrations are expressed in meq/l):

$$MH = \frac{Mg^{2+}}{(Ca^{2+} + Mg^{2+})} \times 100 \quad (5)$$

MH values >50 are considered harmful and unsuitable for irrigation purposes.

1.8 Kelley Ratio

Kelley (1940) [28] and Paliwal (1967) [29] introduced an important parameter to evaluate irrigation water quality based on the level of Na measured against Ca and Mg. It can be calculated by Equation (6).

$$KI = \frac{Na^+}{(Ca^{2+} + Mg^{2+})} \quad (6)$$

where all the ion concentrations are expressed in meq/L. A Kelly's ratio (KR) or Kelly's index (KI) of more than one indicates an excess level of sodium in waters. Therefore, water with a KI (<1) is suitable for irrigation, while those with greater ratio are unsuitable [26].

1.9 Total Hardness (TH)

Hardness is defined as water that is rich in calcium (Ca+2) and/or magnesium (Mg+2). Probably the most common problem identified with groundwater quality is that of hardness [19].
TH of the groundwater was calculated using the formula given below [22, 30].

$$TH\ (as\ CaCo_3)\ mg/l = (Ca^{2+} + Mg^{2+})\ meq/l \times 50. \quad (7)$$

According to Todd 1980 [19], total hardness is customarily expressed as the equivalent of calcium carbonate. Thus,

$$TH = Ca \times \frac{Caco_3}{Ca} + Mg \times \frac{Caco_3}{Ca} \quad (8)$$

Where TH, Ca, and Mg are measured in milligrams per liter and the ratios in equivalent weights
Equation (4-8) reduce to

$$TH = 2.5\ Ca + 4.1\ Mg \quad (9)$$

The degree of hardness in water is commonly based on the classification listed in table 4.

Table 4: Hardness classification of water [31]

Hardness, mg/l, as $CaCo_3$	Water Class
0-75	Soft
75-150	Moderately Hard
150-300	Hard
Over 300	Very Hard

1.10 Chloro Alkaline Indices (CAI)

Schoeller (1967) [32] has evolved a formula, Chloro alkaline indices (CAI) to know the ion exchange between the groundwater and its surroundings during residence or travelling in the aquifer. The CAI can be measured as

$$CAI = \frac{(Cl^- - (Na^+ + K^+))}{Cl^-} \quad (10)$$

Where, all ionic concentrations are expressed in terms of meq L-1. The negative value of CAI indicates that there is exchange between sodium and potassium (Na++K+) in water with calcium and magnesium (Ca+2 +Mg+2) in the rocks by a type of base-exchange reactions. The positive value of CAI represents the absence of base-exchange reactions and existence of cation-anion exchange type of reactions.

1.11 Corrosively Ratio (C.R)

The corrosivity ratio is important to know whether the water can be transported in metallic pipes or not. The groundwater with corrosively ratio < 1 is considered to be safe for transport of water in any type of pipes, whereas >1 indicate corrosive nature and hence not to be transported through metal pipes [33]. The corrosively ratio is calculated using a formula as follows.

$$C.R = \frac{\frac{Cl^-}{35.5} + 2\left(\frac{SO_4^{2-}}{96}\right)}{2\left(\frac{HCO_3^- + CO_3^{2-}}{100}\right)} \quad (11)$$

The intensity of corrosion depends upon certain physical factors like temperature, pressure and velocity of flow of water. In addition to higher concentration of CL and So4 also increase the corrosion rate [34].

2. Estimating groundwater suitability

Groundwater suitability for drinking purpose can be estimated by comparing chemical parameters with WHO (1996) and Egyptian standards for drinking. Table 5 displays the Classification of groundwater on the basis of various parameters to evaluate its quality and suitability for drinking.

Table 5: WHO guidelines and Egypt standards for drinking water quality [1, 2]

Parameter	Unit	WHO Guidelines	Egypt Standards	Unit	WHO Guidelines	Egypt Standards
Sodium (Na)	Mg/l	200	200	Meq/l	8.7	8.7
Potasium (K)	Mg/l	12	*	Meq/l	0.3	*
Calcium (Ca)	Mg/l	200	200	Meq/l	10	10
Magnesium (Mg)	Mg/l	125	150	Meq/l	10.25	12.3
Chloride (Cl)	Mg/l	250	500	Meq/l	7	14
Sulphate (So4)	Mg/l	250	250	Meq/l	5.2	5.2
Bicarbonate (HCO3)	Mg/l	350	*		5.55	*
Iron (Fe)	Mg/l	0.3	0.3			
TDS	Mg/l	1000	1200			
TH	Mg/l		500			10.15
Manganese (Mn)	Mg/l	0.4	0.4			
pH		6.5-8.5	6.5-8.5			
Turbidity	NUT	5	1			

Groundwater suitability for irrigation purpose can be estimated as categorized form according to each class as mentioned before in the item of estimating of groundwater parameters. Groundwater in the study area has an intensive use in irrigation. Eleven criteria were used to evaluate groundwater quality and its suitability for irrigational purposes as summarized in table 7. These criteria are TDS, Na%, SAR, RSC, Cl-, KI, PI, TH, MH, CAI and C.R.

3. Estimation of correlation coefficient between different parameters

Correlation coefficient is a commonly used measure to establish the relationship between two variables. It is simply a measure to exhibit how well one variable predicts the other [35].

For this purposes, Spearman's rank correlation coefficient has been calculated between groundwater quality parameters in Assiut governorate as shown in Table 8. Spearman's rank correlation coefficient is denoted by "r" and its value will always be between -1.0 and +1.0. A positive "r" corresponds to an increasing while a negative "r" corresponds to a decreasing monotonic trend between two water quality parameters. A high correlation coefficient (near 1 or -1) means a good relationship between two variables and its value around zero means no relationship between them [36]. The correlation co-efficient 'r' was calculated using the equation

$$r = \frac{N\sum(X_iY_i) - (\sum X_i).(\sum Y_i)}{\sqrt{[N\sum X_i^2 - (\sum X_i)^2][N\sum Y_i^2 - (\sum Y_i)^2]}} \quad (12)$$

Where,

Xi and Yi represents two different parameters.

N = Number of total observations.

IV. RESULTS AND DISCUSSION

1. Determining groundwater suitability for different purposes through wells classification

The three hundred and thirty five groundwater data wells during the period from 2006 to 2009 have been used to determine preliminary suitability of groundwater for drinking and irrigation purposes. Various physical and chemical parameters have been applied to classify these wells in order to evaluate the quality of groundwater and its suitability for different uses. Groundwater quality determines its suitability for different purposes depending on the specific standards.

1.1 Evaluation of groundwater quality for drinking

The water used for drinking should be soft, low in dissolved salts and free from toxic constituents. The drinking water standards of WHO (1996) and Egyptian Standards (1995) were the basis for the groundwater quality evaluation (see table 5).

Table 6: Classification of groundwater to evaluate its suitability for drinking

Classification pattern		Range	Permissible limits	No. of Wells	% of Wells
Sodium	Min	0.54		67 up	20
(Na+)	Max	77.22	8.7 meq/l	268 down	80
	Mean	6.19			
Potassium	Min	0.03		17 up	5
(K+)	Max	1.53	0.3 meq/l	318 down	95

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Classification pattern		Range	Permissible limits	No. of Wells	% of Wells
	Mean	0.13			
Calcium	Min	0.64		26 up	7.8
(Ca++)	Max	46	10 meq/l	309 down	92.2
	Mean	4.56			
Magnisium	Min	0.39		20 up	6
(Mg++)	Max	31.87	10.25 meq/l	315 down	94
	Mean	4.22			
Bicarbonates	Min	0.12		58 up	17.5
(Hco3-)	Max	9.45	5.55 meq/l	277 down	82.5
	Mean	3.92			
Sulphate	Min	0.27		48 up	14.3
(So4--)	Max	2.84	5.2 meq/l	287 down	85.7
	Mean	13.96			
Chloride	Min	0.27		114 up	34
(Cl-)	Max	83.1	7 meq/l	221 down	66
	Mean	7.78			
Total Dissolved Solids	Min	245.76		143 up	42.7
(TDS)	Max	10200	1000 mg/l	192 down	57.3
	Mean	1335.76			
Total Hardness	Min	59.67		335 up	100
(TH)	Max	3893.44	10.15 meq/l	0 down	0
	Mean	440.16			
Iron	Min	0.005		52 up	15.5
(Fe)	Max	31	0.3 mg/l	283 down	84.5
	Mean	0.277			
Manganese	Min	0.001		105 up	31
(Mn)	Max	2.6	0.05 mg/l	230 down	69
	Mean	0.168			
PH	Min	4.5		15 up	4.5
	Max	8.8	6.5-8.5	320 within range	95.5
	Mean	7.85			

By noticing the chemical parameters; it shows that Na+ concentration in groundwater ranges from 0.54 to 77.22 meq/l with an average of 6.19 meq/l. According to WHO (1996) guidelines, the maximum admissible limit is 8.7 meq/l. Sixty seven wells (20%) are above this limit. K+ concentration in groundwater ranges from 0.03 to 1.53 meq/l with an average value of 0.13 meq/l. The concentration of Ca2+ ranges from 0.64 to 46 meq/l with an average of 4.56 meq/l. The desirable limit for Ca2+ for drinking water is specified as 10 meq/ l (WHO 1996 and Egyptian Standards 1995). About 7.8% of groundwater wells in study area exceed the permissible limit as per WHO standards. The concentration of Mg2+ found in the groundwater wells ranges from 0.39 to 31.87 meq/l with an average value of 4.22 meq/l. Most of the Mg2+ concentrations (94%) are within the desirable limit of 10.25 meq/l. The concentration of Hco3- in groundwater wells varys from 0.12 to 9.45 meq/l with an average value of 3.92 meq/l. two hundred and seventy seven wells (About 82.5%) of total wells have the permissible limit of Hco3- which are 5.55 meq/l. It was found that amount of SO42− ions range from 0.27 to 13.96 meq/l with an average of 2.84 meq/l, and 287 wells (about 85.7%) are within the desirable limit of 5.2 meq/l. The concentration of Cl- ions varies from 0.27 to 83.1 meq/l with an average of 7.78 mg/l. The desirable limit of Cl− for drinking water is specified as 7 meq/l as per WHO and 114 wells (34%) are above this limit.

For some trace elements, the concentration of Fe ranges from 0.005 to 31 mg/l with an average of 0.28 mg/l. The desirable limit for Fe for drinking water is specified as 0.3 mg/ l (WHO 1996 and Egyptian Standards 1995). There are 283 wells (about 84.5%) are within permissible limit. The concentration of Mn ranges from 0.001 to 2.6 mg/l with an average of 0.17 mg/l.

The desirable limit for Mn for drinking water is specified as 0.05 mg/ l (WHO 1996 and Egyptian Standards 1995). There are 230 wells (about 69%) are within permissible limit. large amount of Mn in groundwater is attributed to agriculture practices, fertilizers usage, sewage and animal waste disposal. A higher concentration of Mn is toxic and is usually bad in terms of taste, odor and discoloration of food.

By noticing the physical parameters; it appears that the pH values of groundwater range from 4.5 to 8.8 with an average value of 7.85. The desirable limit of PH for drinking water is identified as from 6.5 to 8.5 (WHO 1996 and Egyptian Standards 1995). Fifteen wells in the study area don't achieve the permissible limit as per WHO standards. TDS of groundwater in the study area vary in the range of 246–10200 mg/l with an average value of 1336 mg/l. As per TDS classification, 42.4% of the wells are brackish (TDS from 1000 to 10000) water type and 57.3% wells are fresh (TDS <1,000) water. With the increase in concentration of Ca2+, Mg2+, HCO3−, Cl− and SO42− ions in water, it results in TH and makes the water unsuitable for drinking. TH as CaCO3 in the study area ranges from 59.67 to 3893.44 meq/l with an average value of 440.16 meq/l, which is beyond the safe limit as suggested by WHO 1996 and Egyptian Standards 1995. The classification of groundwater (Table 5) based on TH shows that almost all the groundwater wells fall in the very hard (60.30%) to hard (36.72%) category.

1.2 Evaluation of groundwater quality for irrigational purposes

In Assiut area, the agriculture activities depend strongly on groundwater as a main source in irrigation. TDS, Na%, SAR, RSC, Cl-, KI, PI, TH, MH, CAI and C.R. were used to evaluate groundwater quality and its suitability for irrigational purposes.

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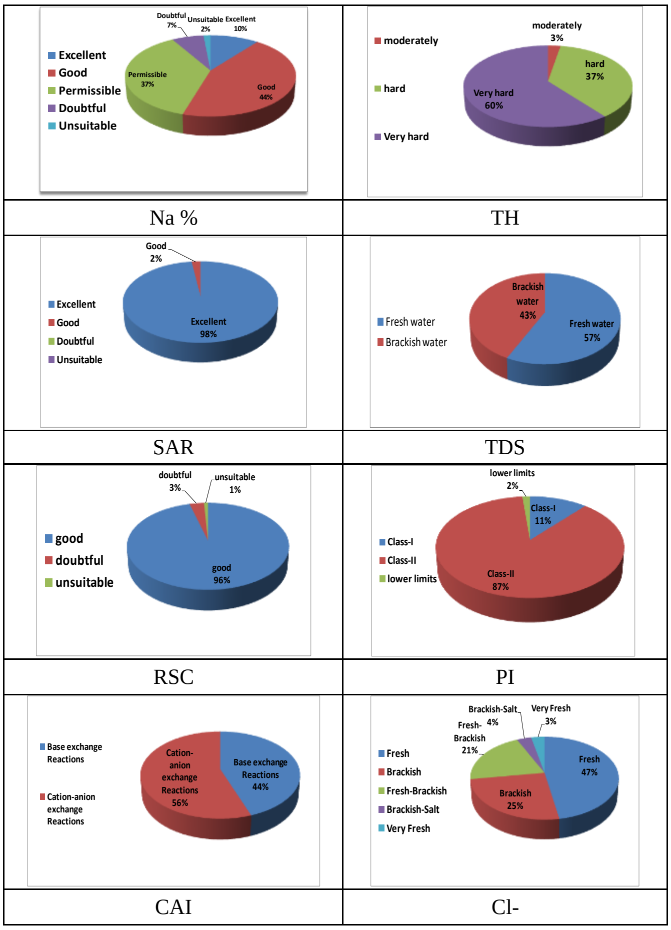
As TDS has been illustrated before, it varies from 245.76 to 10200 mg/l and 312 wells (about 93 %) have TDS less than 3000 mg/l, thus groundwater is suitable for irrigation; whereas 23 wells (about 7 %) have TDS more than 3000 mg/l and its water is unfit to irrigation or drinking as shown in table 7. The classification of groundwater wells with respect to the Na% reveal that Na% in the study area ranged between 9% and 87.85%, with an average of 38.4% in the groundwater. It is observed that the most of groundwater samples fall within the category of good (44.18%) to permissible (37%) and a few samples fall under excellent (10.45%) and doubtful (6.87%) category.

The calculated value of SAR in this area ranges from 0.33 to 17.27 and has been classified as Excellent (328 wells) and good (7 wells) suitable for irrigation. The rest parameters are introduced in table 7 by the same method as the following.

Table 7: Classification of groundwater to evaluate its suitability for irrigation

Classification pattern	Categories	Ranges	No. of wells	% of wells
Total Dissolved Solids	Desirable for drinking	<500	45	13.5
(TDS)	Permissible for Drinking	500-1000	147	44
	Useful for irrigation	1000-3000	120	35.5
	Unfit for drinking and irrigation	>3000	23	7
Percent Sodium	Excellent	0-20	35	10.45
(% Na)	Good	20-40	148	44.18
	Permissible	40-60	124	37.01
	Doubtful	60-80	23	6.87
	Unsuitable	>80	5	1.49
Sodium Absorption Ratio	Excellent	0-10	328	97.91
(SAR)	Good	10-18	7	2.09
	Doubtful	18-26	0	0.00
	Unsuitable	>26	0	0.00
Residual Sodium Carbonate	good	<1.25	321	95.82
(RSC)	doubtful	1.25-2.5	11	3.28
	unsuitable	> 2.5	3	0.90
Permeability Index (PI)	Class-I	>75	38	11.34
	Class-II	25-75	292	87.16
Chloro-Alkaline Indices (CAI)	Base exchange Reactions	Negative value	149	44.48
	Cation-anion exchange Reactions	Positive value	186	55.52
Chloride (Cl-)	Extremely-Fresh	<0.14	0	0.00
	Very Fresh	0.14-0.85	11	3.28
	Fresh	0.85-4.23	158	47.16
	Fresh-Brackish	4.23-8.46	69	20.60
	Brackish	8.46-28.21	85	25.37
	Brackish-Salt	28.21-282.06	12	3.58
	Salt	282.06-564.13	0	0.00
	Hyper Saline	>564.13	0	0.00
Total Hardness	Soft	0-75	0	0.00
(TH)	Moderately	75-150	9	2.69
	Hard	150-300	123	36.72
	Very hard	>300	202	60.30
Magnesium Hazard (MH)	Unsuitable	> 50 %	126	37.61
	Suitable	< 50 %	209	62.39
Kelley's Index (KI)	Unsuitable	>=1	60	17.91
	Suitable	<1	275	82.09
Corrosive Ratio (C.R)	noncorrosive	<1	140	41.79
	Corrosive	>1	195	58.21

Figure 2 illustrates Pie charts of various parameters to classify 335 groundwater wells during period from 2006 to 2009.



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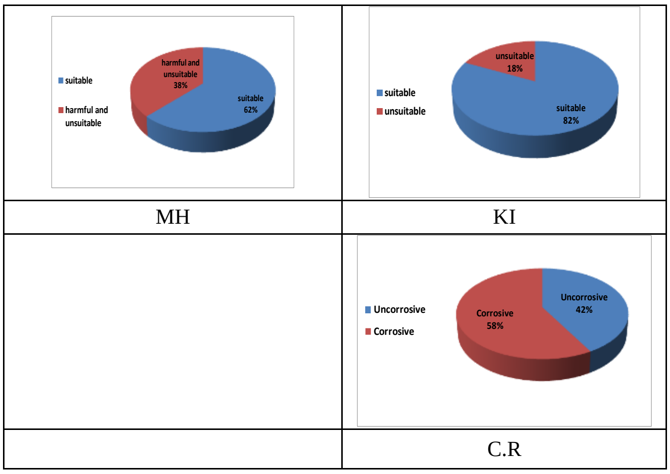

Figure 2: Pie charts of various parameters to classify 335 groundwater samples during period from 2006 to 2009

2. Correlation of physicochemical parameters of groundwater

Data of 335 wells during the period from 2006 to 2009 has been used to build the correlation matrix between the groundwater quality parameters which are major ions, EC, TDS, SAR, Na%, RSC, TH, KI, PI, MH, CAI, and C.R. The results of correlation matrix revealed that the very strong positively correlated values were found between TDS and EC (0.99), TDS and Cl- (0.91), EC and Cl- (0.92), TH and Ca2+ (0.97), TH and Mg2+ (0.95). The strong positively correlated values - which range between (0.7 to 0.9), were observed between Cl- and Na+ (0.71), Cl- and Ca2+ (0.87), Cl- and Mg2+ (0.83), SAR and Na+ (0.84), TDS and Na+ (0.70), TDS and Ca2+ (0.81), TDS and Mg2+ (0.78), TDS and Na+ (0.73), TDS and Ca2+ (0.81), TDS and Mg2+ (0.79), TH and Cl- (0.89), TH and TDS (0.83), TH and EC (0.84), Na% and SAR (0.83), PI and Na% (0.82), KI and SAR (0.85), KI and Na% (0.85), C.R and Ca2+ (0.72), C.R and Mg2+ (0.75), C.R and Cl- (0.84), C.R and TDS (0.75), C.R and EC (0.76), C.R and TH (0.76). The very strong Negative correlated values were appeared between RSC and Ca2+ (-0.94), RSC and Mg2+ (-0.93), RSC and Cl- (-0.91), RSC and TH (-0.98). In addition to some strong negatively correlation were observed between RSC and TDS (-0.83), RSC and EC (-0.84), RSC and C.R (-0.84).

Table 8: Correlation matrix for different water quality parameters

Parameter	Na+	K+	Ca++	Mg++	CO3- -	HCO3-	SO4- -	CL-	SAR	TDS	EC	RSC	TH	Na%	(PI)	(CAI)	MH	KI	(C.R)
Na+	1.00																		
K+	0.36	1.00																	
Ca++	0.51	0.46	1.00																
Mg++	0.55	0.34	0.84	1.00															
CO3- -	0.02	0.00	-0.07	-0.10	1.00														
HCO3-	-0.02	0.21	0.06	0.04	-0.09	1.00													
SO4- -	0.40	0.32	0.42	0.53	-0.07	0.04	1.00												
CL-	0.71	0.39	0.87	0.83	-0.02	-0.16	0.38	1.00											
SAR	0.84	0.19	0.17	0.20	0.16	-0.09	0.29	0.47	1.00										
TDS	0.70	0.38	0.81	0.78	-0.04	-0.05	0.46	0.91	0.47	1.00									
EC	0.73	0.39	0.81	0.79	-0.04	-0.05	0.49	0.92	0.50	0.99	1.00								
RSC	-0.55	-0.37	-0.94	-0.93	0.12	0.16	-0.47	-0.91	-0.20	-0.83	-0.84	1.00							
TH	0.55	0.42	0.97	0.95	-0.09	0.05	0.48	0.89	0.19	0.83	0.84	-0.98	1.00						
Na%	0.52	0.01	-0.16	-0.14	0.15	-0.17	0.11	0.16	0.83	0.16	0.19	0.13	-0.16	1.00					
(PI)	0.17	-0.14	-0.50	-0.50	0.14	0.00	-0.24	-0.26	0.52	-0.21	-0.22	0.52	-0.52	0.82	1.00				
(CAI)	-0.01	0.05	0.26	0.25	0.02	-0.34	-0.07	0.34	-0.18	0.23	0.24	-0.33	0.27	-0.29	-0.48	1.00			
MH	-0.03	-0.11	-0.30	0.13	-0.08	0.03	0.09	-0.13	-0.01	-0.11	-0.10	0.12	-0.12	0.05	0.11	-0.12	1.00		
KI	0.46	0.01	-0.14	-0.14	0.33	-0.15	0.07	0.13	0.85	0.14	0.16	0.13	-0.15	0.85	0.69	-0.27	0.00	1.00	
(C.R)	0.51	0.16	0.72	0.75	-0.08	-0.43	0.48	0.84	0.35	0.75	0.76	-0.84	0.76	0.13	-0.29	0.27	-0.06	0.09	1.00

Strong and Very strong positive Correlation

Strong and Very strong negative Correlation

Radar charts were plotted to clarify the positive and negative correlation as shown in Figure 3. It is observable that there are very strong positive correlation between (Ca-TH), (Mg-TH), (Cl-TDS), (Cl-EC), and (EC-TDS), on the other hand, there are very strong negative correlation between (Ca-RSC), (Mg-RSC), and (RSC-TH).

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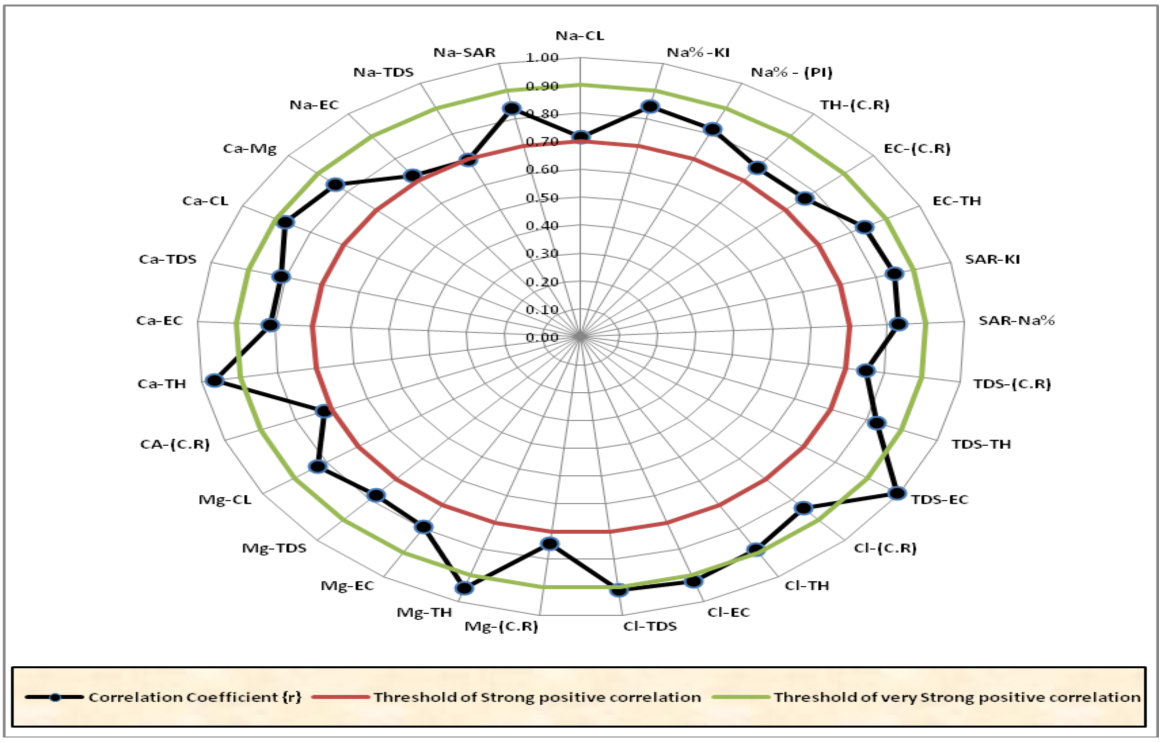

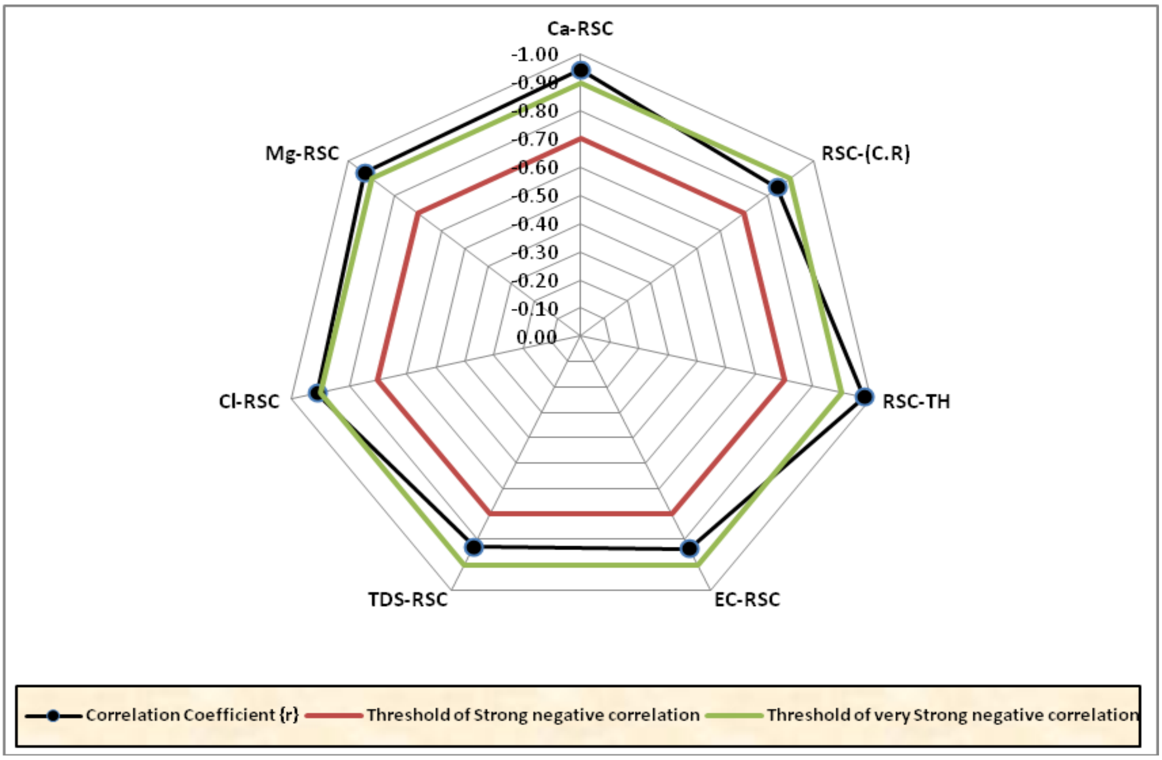

Figure 3: Radar charts of correlation coefficient between groundwater quality parameters

V. CONCLUSION

Data of 335 wells during the period from 2006 to 2009 has been classified according to groundwater categories whether for drinking or irrigation. The drinking water standards of WHO (1996) and Egyptian Standards (1995) were the basis for the groundwater quality evaluation.

with comparing chemical parameters with WHO (1996) and Egyptian standards for drinking, it shows that concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, SO_4^{2-}, and Fe are lower than the permissible limits in 80% of wells.

Then, eleven criteria were used to evaluate groundwater quality and its suitability for irrigational purposes.

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These criteria are TDS, Na%, SAR, RSC, Cl-, KI, PI, TH, MH, CAI and C.R. Groundwater wells were classified according TDS as about 93 % of wells have TDS less than 3000 mg/l, thus groundwater is suitable for irrigation. The classification of groundwater wells with respect to the Na% reveal that most of the groundwater wells fall within the category of good (44.18%) to permissible (37%). The calculated value of SAR ranges from 0.33 to 17.27 and has been classified as about 98% of groundwater wells are suitable for irrigation.

Radar charts were plotted to clarify the positive and negative correlation and results were concluded as follows: It is observable that there are very strong positive correlation between (Ca-TH), (Mg-TH), (Cl-TDS), (Cl-EC), and (EC-TDS), on the other hand, there are very strong negative correlation between (Ca-RSC), (Mg-RSC), and (RSC-TH).

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