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Hydrochemical and Hydrogeostatistical Groundwater Quality Assessment for the Nile Valley and its Fringes at Qena, Egypt

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***Abstract*— Hydrochemical and Hydrogeostatistical analysis for groundwater quality are vital tools for characterizing groundwater quality, defining the suitability of water for irrigation, description and analysis of hydrogeological variables based on the physical-chemical properties. The overall objective of this research is to assess groundwater quality hydrochemical and hydrogeostatistical including water type assessment, groundwater suitability for irrigation, basic statistical analysis, multivariate statistical analysis, and spatial distribution of groundwater quality parameters, to determine the relationship between groundwater quality parameters and to evaluate and upgrade groundwater well network in the study area Qena governorate. Groundwater samples have been analyzed from groundwater wells in Qena governorate Egypt. The analysis was done for nine parameters including pH, electric conductivity (EC), Calcium (Ca2+), Magnesium (Mg2+), Sodium (Na+), Potassium (K+), Chloride (Cl-) Sulphate (SO42-) and bicarbonate (HCO3-). The hydrochemical evaluation was done using Piper diagram, Gibbs diagram, and irrigation water quality indices. Basic descriptive and multivariate statistical analysis was done through correlation coefficient determination among the nine parameters also regression analysis to predict groundwater salinity in terms of electrical conductivity for groundwater. Kriging concept was used to determine the spatial distribution of groundwater quality based on the variogram model and to upgrade the groundwater monitoring network in the study area. Hydrochemically, the results indicated that according to Piper diagram water type is NaCl and according to Gibbs diagram, most samples are in the rock dominance zone and evaporation dominance zone. Irrigation quality indices reveal that majority of groundwater samples fall under a suitable category for irrigation. Based on hydrogeostatistical analysis, the results show correlations between parameters and show the regression equation, which predicts groundwater quality parameters. According to the spatial distribution analysis, the results show the contouring maps for the nine parameters all over the area were drawn, and upgrading the groundwater monitoring network was done. This method was applied to upgrade a regional groundwater quality monitoring network and to locate groundwater monitoring wells.**

Keywords*—Groundwater; hydrochemistry; hydrogeostatistics; quality; statistics, kriging, groundwater monitoring network.

I. INTRODUCTION

In Upper Egypt, River Nile is the main water source. Groundwater from the Nile aquifer is the second water source in the Upper Egypt region. Assessment of groundwater quality in the Nile valley and its fringes is essentiales.

Quantitative aspects of groundwater have been investigated with extensive attention in Egypt for many years. Qualitative issues started to gain attention during recent years. Groundwater quality hydrochemical and statistical assessment are major tools for the development and support of environmental management of water resources. In this research, groundwater quality assessment will be applied for groundwater aquifers in Qena governorate, which is one of the Upper Egypt governorates.

Numerous studies assessed groundwater qualitatively and quantitatively. Groundwater quantitative assessment describes the water quantity according to the changes in water levels, water extraction, water recharge, and annual rainfall. [1] evaluated groundwater quantitatively and qualitatively in Isfahan, Iran. For quantitative analysis, they determined the decline in groundwater levels and discharge from the aquifer by time. For qualitative assessment, several physicochemical parameters were analyzed to evaluate groundwater quality. [2] evaluated groundwater qualitatively and quantitatively in Romania. [3] evaluated groundwater quality according to 40 wells for 20 water quality parameters using descriptive analysis and correlation analysis in India. [4] used statistical analysis for groundwater quality assessment in Dindigul City. Correlation analysis, factor analysis, and regression analysis were performed to determine the relationship between groundwater quality parameters.

[5], [6], [7] and [8] evaluated groundwater quality hydrochemically by using the hydrochemical characteristics evaluation using Piper, Stiff, Gibbs and Wilcox diagrams and studied the suitability of groundwater for irrigation in India, Iraq, Sohag, and Cameron, respectively.

For hydrogeostatistics analysis, multivariate statistical analysis was used. Multivariate statistical analysis is used to analyze, predict, and study the relationship between several variables. It includes basic statistics, correlation, regression analysis, analysis of variance, and principal component analysis. Multivariate analysis is used in water quality field, waste management, business, and sales data. [9] and [10] used multivariate statistical analysis and principal component analysis for groundwater quality assessment. [11] used linear regression equations for predicting the concentration of different parameters based on electrical conductivity.

Spatial distributions of hydrogeological variables and groundwater quality parameters are essential for groundwater resources development and protection. Therefore, the

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estimation method is necessary to interpolate the unknown values between measurements. kriging is a method for interpolation minimum error. Kriging was developed by [12] based on the theory of regionalized variables. The regionalized variables are variables varying spatially such as groundwater heads and chemical components. Kriging can provide the estimation of groundwater heads or chemical components at any location in space from a set of measurements and their estimation variances. [13] approved kriging depends on the number and spatial distribution of observation points. They optimized the groundwater quality monitoring program in the Maheshwaram catchment area in India. [14] evaluated groundwater quality in Beijing and upgraded the groundwater quality monitoring network by studying the state of the groundwater monitoring network. Kriging method was used to upgrade of groundwater level monitoring network for 825 wells. The results indicated the newly designed monitoring network in Beijing. [15] assesses the current condition of groundwater quality and analyze the spatial distribution of groundwater quality in the Sylhet city by using the semivariogram and kriging method. Also, [16] assessed the groundwater quality using the geostatistical algorithm, semivariogram models, and kriging interpolation in Poland, Somalia. [17] determined the spatial distribution of groundwater quality parameters in Turkey by geostatistical analysis and the semivariogram model and kriging interpolation method.

This research addresses hydrochemical analysis, hydrogeostatistical analysis, Multivariate statistical analysis, the spatial distribution of groundwater quality parameters in Qena governorate, Egypt. The overall objective of the study is to assess groundwater quality hydrochemical and hydrogeostatistical, to determine the relationship between groundwater quality parameters and to evaluate and upgrade groundwater well network in the study area. Qena governorate is selected for the assessment.

II. MATERIALS AND METHODS

A. Study Area

The study area is Qena governorate. It is a governorate in Upper Egypt. Upper Egypt is the area located in the south of Egypt and borders the Nile River from the eastern and western sides. The domain extends between latitudes 32º 00' 00" to 33º 00' 00" and longitudes 25º 45' 00" to 26º 20' 00". This governorate has been selected as being representative of the Nile valley region. It is bounded from the north by the administrative border of Sohag governorate and from the south by Luxor governorate. The study area includes six districts Abu Tisht, Nag Hamadi, Dishna, Qena, Qift, and Qus as shown in figure 1. The study area covers about 1825 km2; a distance of nearly 150 km measured along the Nile course and the average width of the valley within the governorate ranges from 15 to 25 kilometers. It includes both the Nile flood plain system and the desert fringes system and it is bounded from the east and the west by Limestone plateau. The land surface ranges from about 62 m to 140 m according to mean sea level (AMSL). In the fringes, the topography is very high in comparison with the topography of the flood plain.

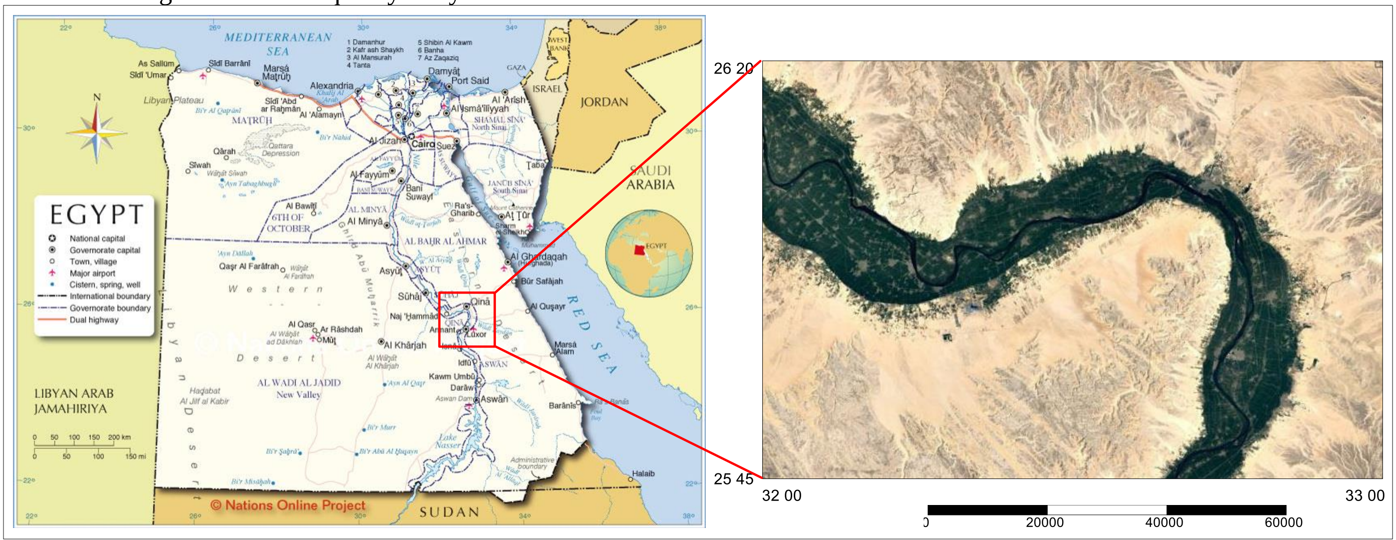

Fig. 1. Location of the study area

B. The Methodology

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The research was applied to Qena governorate as a study area to represent the Nile valley aquifer. To evaluate the groundwater quality in the study area, groundwater samples from 139 operated wells and distributed all over the area in at 2012 were used. A Field survey was conducted and water samples were collected from 139 wells. The samples are analyzed in the lab according to the American Public Health

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Association (APHA) 2005.The data obtained from the RIGW data bank.

In this research the water samples analysis and evaluation are divided into two main parts; 1) hydrochemical analysis, and 2) hydrogeostatistical analysis. The assessment included nine parameters: pH, , electrical conductivity (EC), Calcium (Ca++), Magnesium (Mg2+), Sodium (Na+), Potassium (K+), Chloride (Cl-) Sulphate (SO4--) and bicarbonate (HCO3-).

The main objective of the first part, hydrochemical analysis, is to evaluate and to classify the quality of groundwater in the study area. The assessment was conducted through the classification of the groundwater quality using hydrochemical plots and by studying the groundwater suitability for irrigation. Hydrochemical plots include [18] and [19]. The groundwater suitability for irrigation was done according to Wilcox diagram, [20] and [21] classification by calculation of the irrigation water quality indices.

The main objective of the second part, hydrogeostatistical analysis, is to assess groundwater quality parameters statistically. The assessment was conducted through four steps; 1) Descriptive statistics analysis and normality check to determine the range and the distribution of data and to check the accuracy of data, 2) Multivariate statistical analysis including correlation and regression analysis to define the relationship between the quality parameters; 3) Spatial distribution analysis for the nine groundwater quality parameters to produce and draw contouring maps Surfer ® (Golden Software, LLC) for the distribution of each parameter, and 4) groundwater monitoring network upgrading using variogram model and kriging interpolation method [12]. Kriging calculations depend on the variogram. The variogram models were used to build the groundwater quality contour maps and to calculate the standard deviation of interpolation errors of the existing wells.

In this work, Microsoft Excel and Surfer ® (Golden Software, LLC) were used for calculations, data classification, statistical analysis, and generating the contour maps.

C. Description of the geological and the hydrogeological settings

Geology and hydrogeology of the study area were studied by [22], [23], [24], [25] and [26] according to the geologic map of Qena [27] ,which shows that the study area located on the flood plains, and is surrounded by eastern and western Limestone plateau as shown in figures (2 & 3).

The aquifer system in the study area was classified hydrogeological from younger to older to:

Holocene clay cap: It is the silty clay cap layer overlay the Pleistocene layer. It is 20 m thickness. It has low horizontal and vertical permeability.

Quaternary aquifer: It composed of old and young alluvial deposits. It consists of sand and gravel. Its thickness is about 300 m. The aquifer thickness is big in the central part and decreases towards the fringes on both sides of the Nile Valley. According to the pumping tests analysis and the previous studies [23], hydraulic conductivity of the aquifer ranges from 50 m/d to 100 m/d and the transmissivity range from 2000 m2/d to 6000 m2/d. The aquifer is highly productive and has good groundwater quality. The main source of groundwater for this aquifer is the infiltration from irrigation canals and excess irrigation water. The groundwater flow map indicates that the groundwater movement is towards the river Nile [28]. The groundwater levels range from 75 m and 90 m and the depth to groundwater increases toward the plateau.

The Plio-Pleistocene aquifer: It consists of clay, sand. Its thickness is about 50 m near the flood plain and decreases towards the Limestone plateau. This aquifer is low productive. It is recharged from excess irrigation water from new desert lands. The groundwater quality is worse than the Quaternary aquifer.

Paleocene-Eocene sediments: It consists of Limestone interbedded siltstone, sandstone, and shale. The formation includes Tarawan formation, Esna shale, and Thebes formation.

Upper Cretaceous: It is sandstone with shale intercalations. It overlies the basement. It includes Quseir shale, Daklha shale, siltstone, and sandstone.

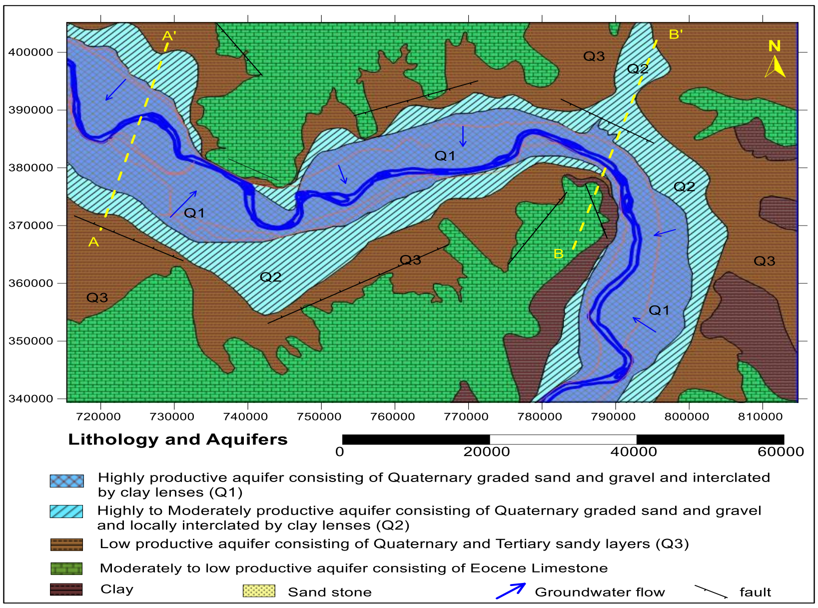

Fig. 2. Aquifer system of Qena (RIGW 1994)

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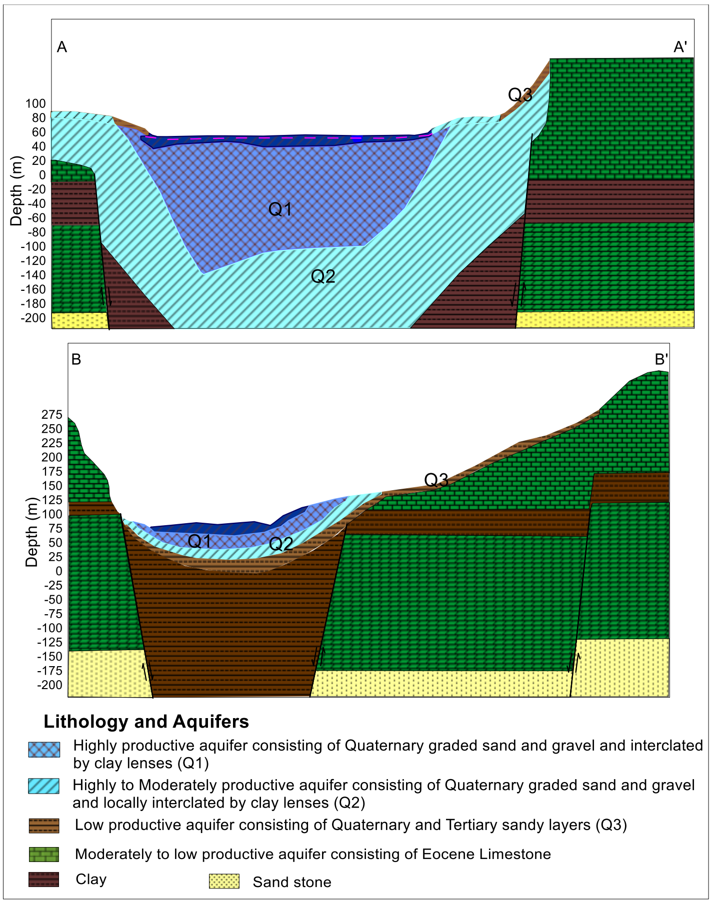

Fig. 3. a) Hydrogeological cross section A-A' for Nag Hammadi, b) Hydrogeological cross section B-B' for Qena (RIGW 1994)

III. RESULTS AND DISCUSSION

The analysis was applied to the results of the chemical analysis of 139 groundwater samples. Samples of groundwater are distributed all over the study area as shown in figure (4). The analysis included basic statistics, multivariate statistics, and spatial distribution analysis. (pH, electrical conductivity (EC), Calcium (Ca++), Magnesium (Mg2+), Sodium (Na+), Potassium (K+), Chloride (Cl-) Sulphate (SO4--) and bicarbonate (HCO3-)were selected for the analysis.

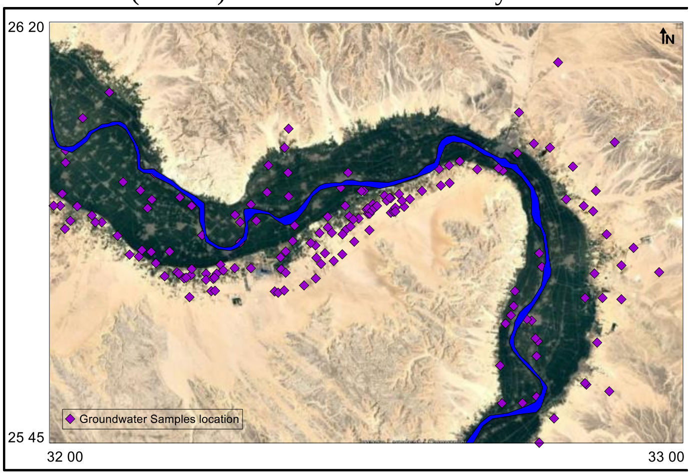

Fig. 4. Locations of the groundwater samples

A. *Hydrochemical Assessment*

The hydrochemical processes help to understand the interaction between groundwater and surface water and between groundwater and soil water interaction on groundwater quality.

To check the accuracy of data, the accuracy of the concentrations of anions and cations, to identify the geochemical mechanism and the chemical budget of groundwater samples ionic balance error IBE was calculated for the concentrations of total cations (Na+, K+, Ca2+, Mg2+) and the total anions (CO32-, HCO32-, Cl-, SO42-) in milliequivalent per liter (meq/l). According to IBE calculations, the computed ionic balance error IBE was within the acceptable limit of less than 5% Domenico and Schwartz, 1990).

$$IBE = \frac{\sum Cations - \sum Anions}{\sum Cations + \sum Anions} x\,100$$

B. *Hydrochemical plots for the hydrochemical classification*

Hydrochemical plots were used to evaluate the hydrochemical characteristics of groundwater and to determine the relationship between the hydrochemical components.

The concentrations of major cations and anions of groundwater samples in meq/l were plotted in the Piper diagram as shown in figure 5. The Piper diagram indicates 74.1% of the hydrochemical faces reflect a NaCl water type, while 16.5% of the samples are represented by mixed CaNaHCO3, while 9.35% of the samples are represented by mixed CaMgCl type and 4.32% of the samples are represented by CaCl type.

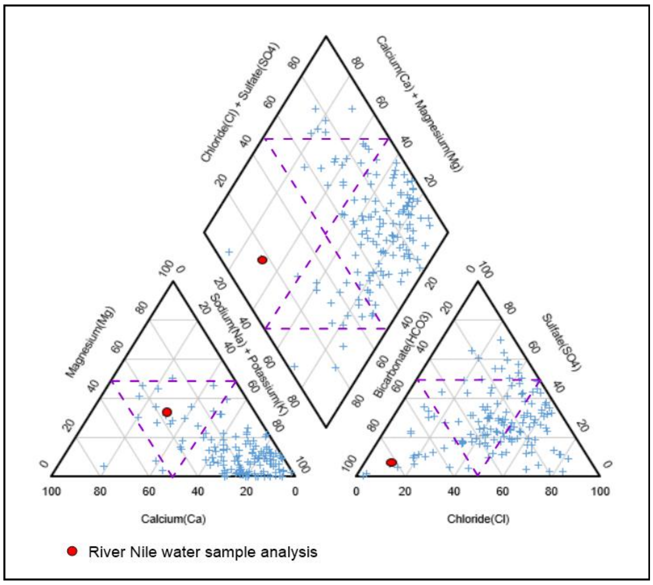

Fig. 5. Piper Diagram for groundwater samples

Gibbs diagram is divided into three fields (precipitation dominance, evaporation dominance, and rock dominance area). All groundwater samples were plotted as shown in figure 6 to show the ratio of anions (Na + K) / (Na + K + Ca) and cations (Cl) / (Cl + HCO3) plotted versus TDS. Most samples are in the rock dominance zone and evaporation dominance zone.

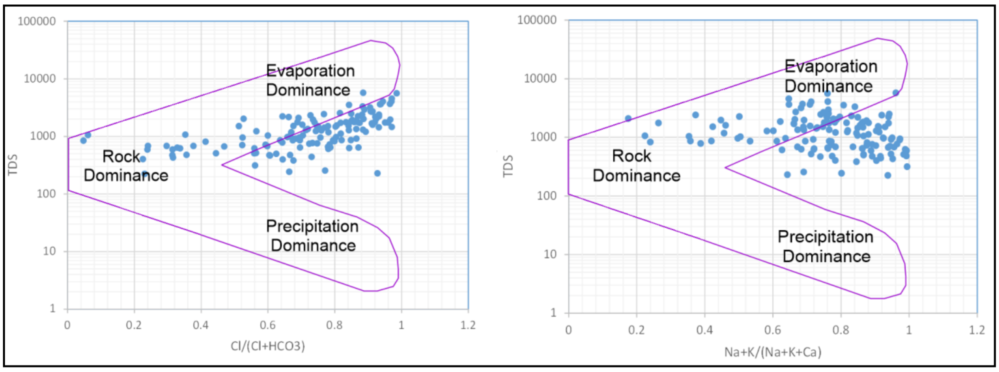

Fig. 6. Gibbs Diagram for groundwater samples

C. *The suitability for irrigation*

Groundwater suitability for irrigation was assessed by [29],[20], [21] and by determining of irrigation quality indices like Sodium adsorption ratio (SAR), Percent Sodium (%Na) [30], Permeability Index (PI) [31], Residual Sodium Carbonate (RSC) [32] and Magnesium Hazard (MH) [33]. Groundwater classification based on irrigation water quality parameters is shown in table 1.

TABLE 1. GROUNDWATER CLASSIFICATION BASED ON IRRIGATIONAL WATER QUALITY PARAMETERS USSL 1954.

parameter	categories	ranges	No of samples	%
SAR	Excellent	0 – 10	84	60.4
	Good	10 – 18	38	27.3
	Fair	18 – 26	8	5.8
	Poor	>26	9	6.5
Na%	Excellent	0 – 20	7	5.0
	Good	20 – 40	15	10.8
	Permissible	40 – 60	28	20.1
	Doubtful	60 – 80	66	47.5
	Unsuitable	>80	23	16.5
PI	Suitable	>75	79	56.8
	Good	25 – 75	55	39.6
	Unsuitable	<25	5	3.6
RSC	Safe	<1.25	121	87.1
	Doubtful	1.25 – 2.5	10	7.2
	Unsuitable	>2.5	8	5.8
MH	Harmful and unsuitable	>50	79	56.8
	Suitable	<50	60	43.2

According to the calculation, the results indicated that; SAR: it is an important parameter because of the greater value of SAR, the greater is the hazard to the crops due to excess sodium. In the case study, 60% of the samples belong to an excellent class, 27.3% is good, 5.8% is fair and 6.5% is poor. Besides, the suitability of irrigation is tested by Wilcox diagram as shown in figure 7.

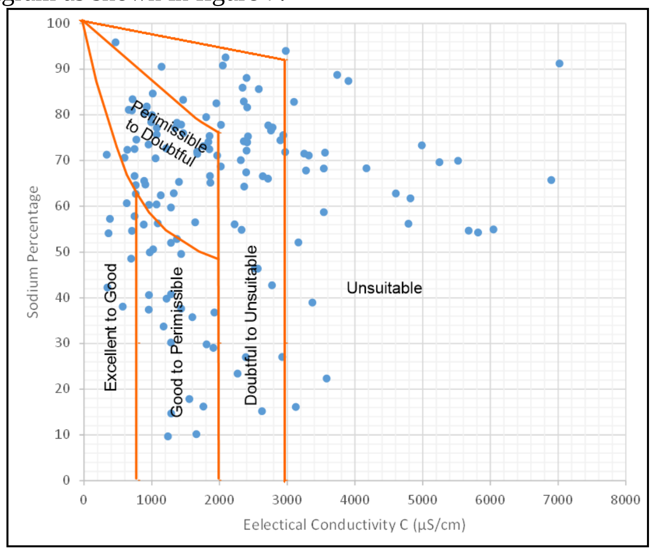

Fig. 7. Wilcox diagram for groundwater samples

%Na: it is also an important parameter for evaluation of the suitability of groundwater for irrigation because the increase of sodium percentage causes decreasing in soil permeability. According to %Na calculation and Wilcox diagram, 5% of the groundwater samples belongs to an excellent class, 10.8% is good class, 20.1% is permissible, 47.5% is doubtful and 16.5% is unsuitable for irrigation.

PI: The decrease of permeability index PI has harmful effects on plant growth. The results indicated that the majority of the samples were permissible for irrigation purposes. The results indicated 56.8% of groundwater samples are suitable, 39.6% are good and 3.6% are unsuitable.

RSC: it exists when carbonate and bicarbonate concentration is greater than calcium and magnesium concentration. In the study area, 87.1% is safe.

MH: when this value is less than 50, it is suitable for irrigation but if the value is greater than 50, so the groundwater is not suitable for irrigation. In our case study, 56.8% of groundwater is not suitable for irrigation and 43.2% is suitable.

In addition to irrigation water quality indices, US salinity laboratory method was used as a graphical method. It depends on the relation between two parameters electric conductivity and sodium adsorption ratio as shown in figure 8. The results indicated that:

- 18% of the samples are classified as low alkalinity and high salinity.
- 14.4% of the samples are classified as medium alkalinity and high salinity.
- 14.4% of the samples are classified as high alkalinity and very high salinity.
- 13% of the samples are classified as high alkalinity and high salinity.

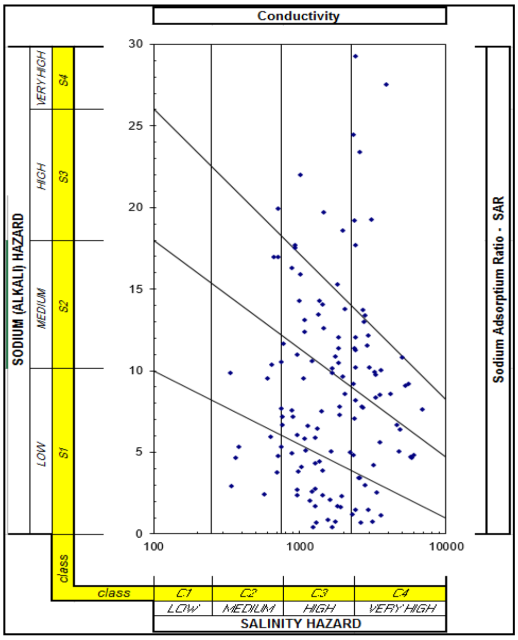

Fig. 8. USSL diagram for groundwater samples

According to [21] classification, the groundwater classification according to the guidelines for interpretations of water quality for irrigation. For the groundwater samples in the study area based on Ec and SAR values 72% of the samples are classified as (none degree of restriction on use), 49% are classified as (slight to moderate degree of restriction on use) and 18% are classified as (severe degree of restriction on use).

[21] established constraints and limitations to test the suitability of groundwater for irrigation and its use in agriculture on some chemical elements. The results show that 78.5%, 83.5%, 74%, 78.5%, 99.28%, 99.28%, 97.13% and 100% of the water samples for TDS, Ca, Mg, Na, HCO3, Cl, SO4 and K respectively are suitable for irrigation.

D. Hydrogeostatistical Assessment

Basic descriptive statistics are calculated including graphical displays of data such as histogram and probability plots which are very important in recognizing how data are distributed and to know the spreading of data, frequency of values, and normality of the data and the homogeneity of the samples [34]. Table (2) summarizes descriptive statistics for the groundwater quality parameters. To check the distribution of data histogram graphs and the normality check plots were plotted for each parameter as shown in figure (9).

TABLE 2. DESCRIPTIVE STATISTICAL ANALYSIS

Soil media	Mean	Median	Standard deviation	Variance	Skewness	min	max
pH	7.97	8	0.05168	0.267	-0.987	6	9
EC	2076	1803	1374.7	1889783	1.4	334	7020
Ca	94.3	56	82.38	6787.16	1.482	1	432
Mg	42.77	25.2	44	1936	1.493	0.02	191
Na	294.65	242	228.42	52175.1	1.384	29	1114
K	5.1	2.4	5.122	26.23	0.946	0.1	21.8
Cl	419.2	325	348.5	121485	1.82	21	2130
SO4	279.14	180	290.63	84468.3	1.799	1.44	1634
HCO3	193.22	175	108.47	11765.8	1.48	24	744

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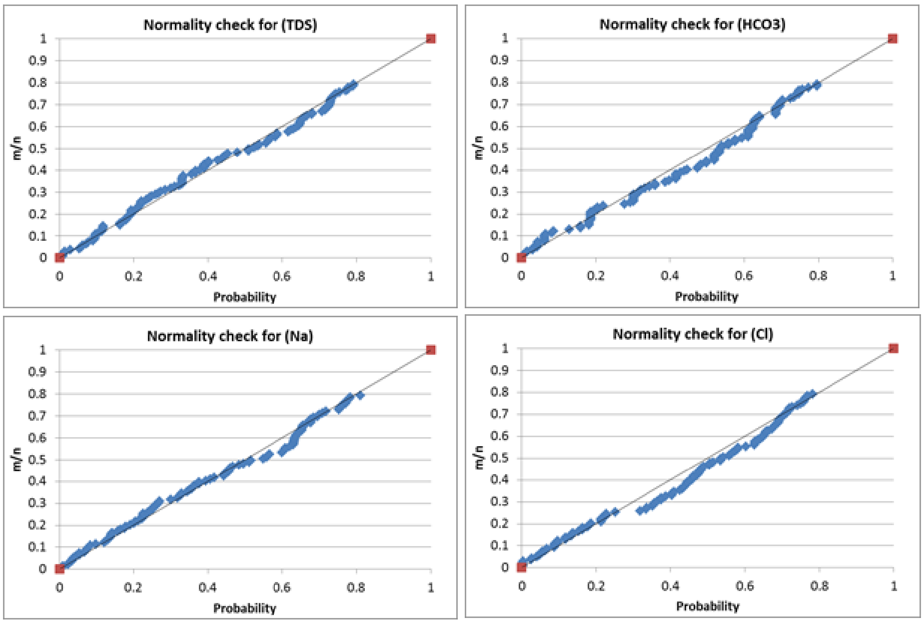

Fig. 9. Normality check plots for the quality parameters

E. Multivariate statistical analysis

Multiple regression analysis provides equations for estimating the effect of independent variables such as (pH, Ca, Mg, Na, K, HCO3, Cl, SO4 and HCO3) on EC as a dependent variable.

The equation of the general form of regression procedure is:

$$y = b_0 + b_1 x_1 + b_2 x_2 + \cdots + b_n x_n$$

Where b0 to bn are partial regression coefficients, and x1 to xn are measured variables. This equation is used to predict the values of the dependent variable y from several independent variables x.

To get the relationship between two parameters, correlation coefficients between the quality parameters were calculated as shown in table (3). The correlation coefficient matrix for the case study indicated that there is a high correlation between EC and (Na, Cl & SO4). Also, there is a high correlation between Na and (Cl & SO4).

TABLE 3. CORRELATION COEFFICIENT MATRIX OF QUALITY PARAMETERS

	EC	pH	Ca	Mg	Na	K	Cl	SO4	HCO3
EC	1								
pH	-0.113	1							
Ca	0.713	-0.231	1						
Mg	0.407	-0.386	0.534	1					
Na	0.801	0.064	0.478	0.154	1				
K	0.562	0.170	0.391	0.069	0.686	1			
Cl	0.782	-0.180	0.664	0.491	0.744	0.437	1		
SO4	0.734	-0.008	0.638	0.213	0.773	0.562	0.578	1	
HCO3	-0.075	-0.057	0.034	0.156	-0.119	-0.032	-0.148	-0.192	1

To assess the relationship between one dependent variable and the independent variables, regression analysis was done. Electrical conductivity was considered as an independent variable and other parameters were considered as dependent variables. The correlation and regression analysis were used to determine a relationship between electrical conductivity and the other parameters.

From the regression analysis, it is known that the electric conductivity (EC) is directly related to concentrations of (pH, Ca, Mg, Na, K, Cl, SO4 and HCO3), multiple linear regression equation of EC on (pH, Ca, Mg, Na, K, Cl, SO4 and HCO3) is found as:

$$Ec = 98.71 - 11.2\,PH + 0.737\,Ca + 2.58\,Mg + 0.856\,Na + 2.56\,k - 0.152\,Cl - 0.33\,SO4 + 0.225\,HCO3$$

Figure (10) shows the multiple linear regression analysis for EC, the adjusted R2 for this model reaches 0.99139. The result of ANOVA for the multiple linear regression equation of EC on (pH, Ca, Mg, Na, K, Cl, SO4, and HCO3) is listed in table (4). It can be calculated the degrees of freedom in the source (Df), the sum of squares due to the source (SS), the mean sum of squares due to the source (MS), and F-statistics. The relationship between the measured EC and calculated EC is plotted in figure 10.

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TABLE 4. ANOVA TABLE

	Df	SS	MS	F	Significance F
Regression	9	258544126.3	28727125	1650.0	1.32E-128
Residual	129	2245885.3	17409.96		
Total	138	260790011.7			

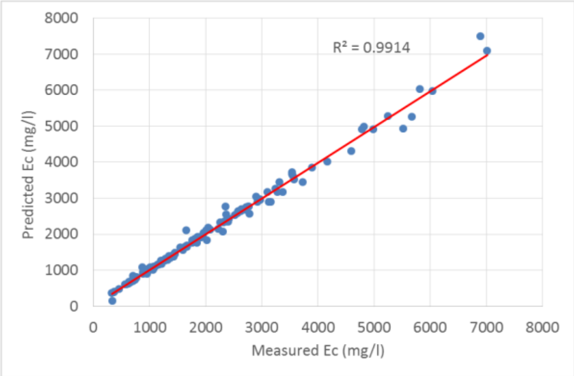

Fig. 10. The relation between measured EC and calculated Ec

F. Spatial distribution analysis

Spatial analysis of the nine quality parameters was developed to interpolate these parameters to determine an optimal groundwater monitoring network for the study area based on the initial conditions of existing groundwater wells. The spatial distribution of groundwater quality parameters includes data postings, contour maps, variograms, and kriging interpolation method.

This process was done by the variogram model and a kriging interpolation method. The variogram is a function describing the degree of spatial dependence. It depends on the distance between samples. [35] defined variogram as the variance of the difference between field values at two locations. It is used to assess the spatial continuing of data. Kriging is a very flexible gridding method. It can be custom-fit to a data set by specifying the appropriate variogram model (Cressie 1993).

Kriging was developed by [12]. It can provide the estimation of groundwater quality parameters at any location and the estimated variances in the study area. The contouring maps and kriging standard deviation (KSD) maps are useful to upgrade the observation point's distribution in the study area. To measure the existing observation point's effectiveness, the kriging variance of the interpolation error can be used. The main objective of this part is to design a groundwater monitoring network in Qena governorate as a case study to help decision-makers for sustainable development of groundwater resources and to monitor the changes in groundwater quantity and quality to benefit from the existing observation wells. Kriging is used to interpolate groundwater quality parameter measurements (pH, electrical conductivity (EC), Calcium (Ca++), Magnesium (Mg2+), Sodium (Na+), Potassium (K+), Chloride (Cl-) Sulphate (SO4--) and bicarbonate (HCO3-) to determine the contour maps. It depends on the spatial correlation structure of groundwater quality, location, and distribution of groundwater samples in the study area.

For the study area, 139 groundwater samples were used for computing the variograms for groundwater quality parameters. Variogram values are examined to determine the best fitting for the nine groundwater quality parameters. Then the variograms used for interpolating the data to determine the contouring maps by kriging. The spatial distribution of different groundwater quality parameters was carried out through Surfer 13 using ordinary Kriging. Figures (11a to 11i) show the contour maps of the spatial distribution of (pH, electrical conductivity (EC), Calcium (Ca++), Magnesium (Mg2+), Sodium (Na+), Potassium (K+), Chloride (Cl-) Sulphate (SO4--) and bicarbonate (HCO3-) respectively. The maps show the concentration variation of water quality parameters within the region. The water salinity is very high on both sides of the Nile, east and west and it increases also in the places of increasing numbers of extraction wells from groundwater, especially on the eastern side of the study area and west of the Nile River.

The maps indicated that pH concentration in the study area varies between 6 and 9 with an average value of 7.9, EC value varies between 334 and 7020 with average value of 2076 µS/cm, Ca concentration varies between 1 and 432 with an average value of 84 mg/L, Mg concentration varies between 1 and 191 with an average value of 42 mg/L, Na concentration varies between 29 and 1114 with an average value of 295 mg/L, K concentration varies between 0.1 and 21.8 with an average value 5 mg/L, Cl concentration varies between 21 and 2130 with average value of 420 mg/L, SO4 concentration varies between 1.44 and 1634 with an average value of 279 mg/L, and HCO3 concentration varies between 24 and 744 with an average value of 193 mg/L.

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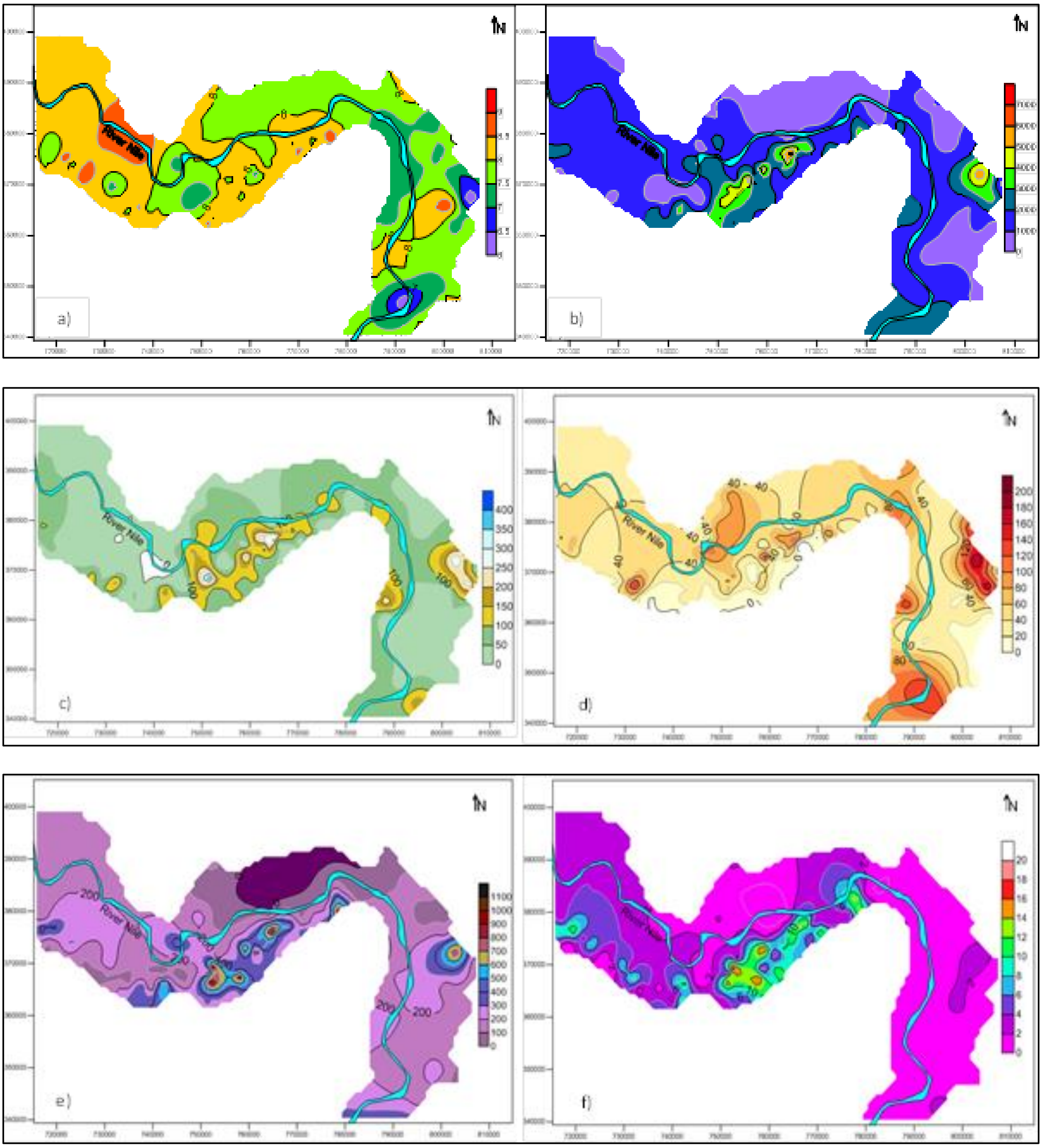

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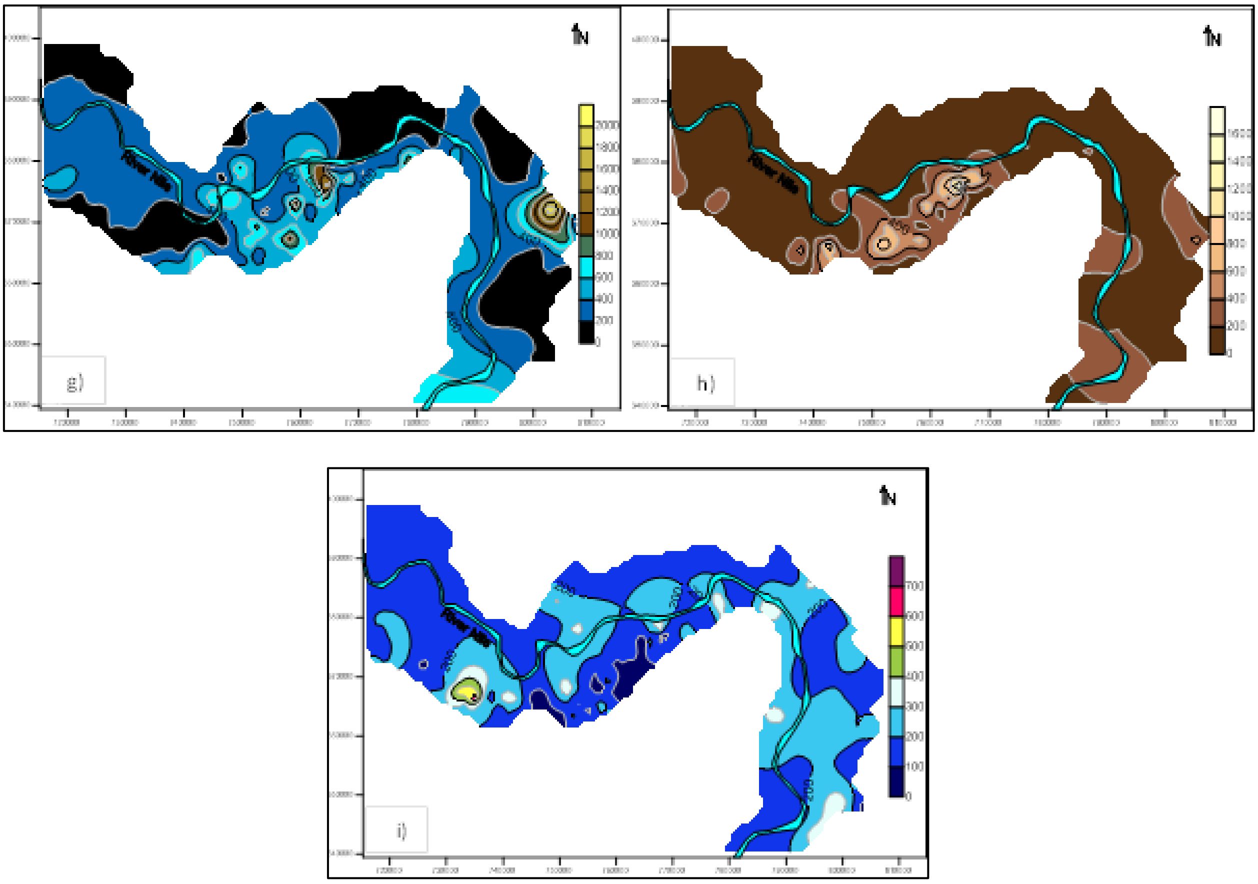

Fig. 11. Groundwater quality parameters contouring map a) pH, , b) Electric conductivity, c) Calcium, d) Magnesium, e) Sodium, f) Potassium, g) Chloride h) SO4 and i) HCO3 contouring maps

The maps in figures (11a to 11i) show that there is a high density in the contour lines of the groundwater quality parameters in the areas of the presence of water samples and the presence of wells, which indicates the poor distribution of wells and samples over the study area, which led to the need to develop the places of water samples from the wells and upgrading a monitoring network in the region as shown in figures (12a & 12b).

For the design of network density, the monitoring network is inversely proportional to the standard deviation of the estimation error. To design a groundwater monitoring network, the existing observation points should be evaluated by calculating the standard deviation of the interpolation error by the kriging method. Kriging is an interpolation method to optimize network density. Figures (12a & 12b) show the contour map of kriging interpolation of standard deviation with the existing observation points and with the proposed observation points respectively. The results show that 61 wells from the existing groundwater quality monitoring wells were cancelled, 30 new wells were added and the upgraded groundwater quality monitoring wells now consist of 108 wells with accurate distribution.

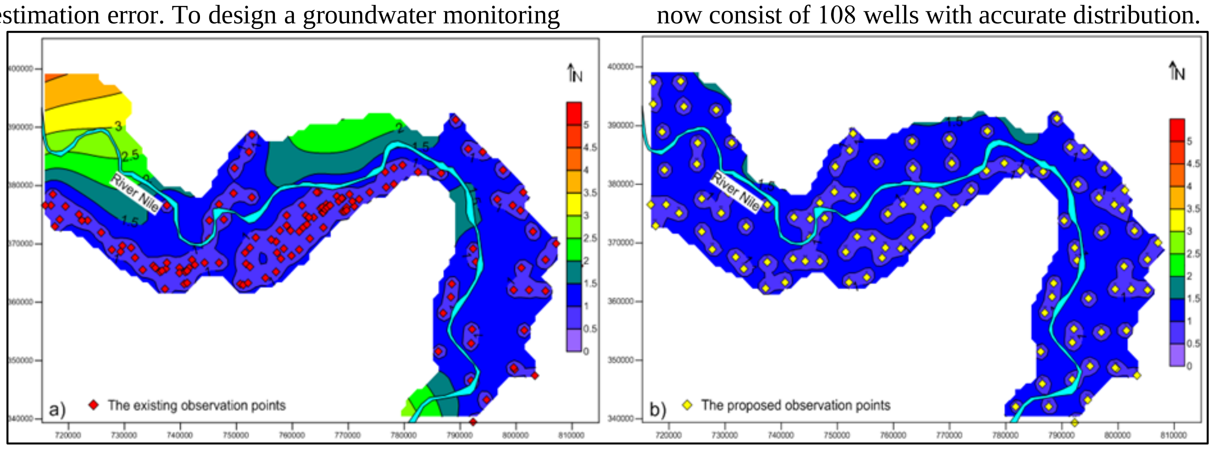

Fig 12. Contouring map of standard deviation of kriging interpolation with a) existing observation points and b) proposed observation points

IV. CONCLUSION

This research represented hydrochemical and hydrogeostatistical analysis for groundwater quality parameters of 139 wells in Qena governorate for nine parameters including pH, electric conductivity (EC), Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), bicarbonate (HCO3), Chloride (Cl) and Sulphate (SO4). The research included hydrochemical analysis and hydrogeostatistical analysis.

Hydrochemical analysis was conducted to classify groundwater quality and to explore the suitability of groundwater for irrigation by using the Piper diagram, Gibbs diagram, and irrigation water quality indices. The results indicated that the projection of data in the Piper diagram shows that most of the groundwater samples fall in NaCl faces. According to Gibbs diagram, the most of the samples were in the zone of rock dominance and evaporation dominance. In addition, the hydrochemical analysis provide additional information about the suitability of groundwater for irrigation. Based on the USSL and Wilcox diagram 36% of samples can be used for irrigation. The suitability for irrigation use was examined Sodium adsorption ratio (SAR), Percent Sodium (%Na), Permeability Index (PI), Residual Sodium Carbonate (RSC), and Magnesium Hazard (MH). Irrigation water quality indices reveal that majority of groundwater samples fall under a suitable category.

The second part of the research is the hydrogeostatistical analysis which was conducted through basic statistical analysis, multivariate statistical analysis, and spatial distribution analysis. The results of correlation analysis indicated that there was a high correlation between EC and (Na, Cl & SO4). Also, there is a high correlation between Na and (Cl & SO4). In addition the results show the regression equation between the nine parameters which predicts groundwater quality parameters. The hydrogeostatistical analysis also included spatial distribution analysis which was included data postings, contour maps for the nine parameters, variograms and kriging interpolation. Spatial distribution analysis was conducted to upgrade the groundwater quality observation points. The results of the spatial distribution show contouring map for the nine parameters all over the area and the upgraded groundwater monitoring network to give the best overview of the groundwater quality status for effective management and groundwater monitoring.

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