Evaluation of Groundwater Quality of the Saq Aquifer, Saudi Arabia

إعـــداد

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ABSTRACT

The Saq aquifer represents one of the major groundwater sources in Saudi Arabia. The study area constitutes the northwestern part of Saudi Arabia that includes major cities from Qassim and Hail in the east to Al-Jouf in the north, Tabuk in the northwest and Al-Madinah Al-Monawarah in the southwestern part.

The analysis of hydraulic parameters of ground water shows that the regional flow system is directed towards the northwest. Statistical analysis of groundwater was carried out using scatter plots, correlation, cluster, principle components, and factor analysis. The results of analyzing data by these techniques indicated the presence of strong relation between sodium, calcium, chloride, Electrical Conductivity and Total Dissolved Solids. Two main clusters were identified and these clusters were divided into six subgroups. Further classification by principal component and factor analysis, shows three factors responsible for the variations in groundwater quality of the Saq aquifer.

INTRODUCTION

Keywords

Saq aquifer, Groundwater, Evaluation, Hydraulic parameters,
Statistical analysis, scatter plots, Correlation, Cluster analysis, Principle Components, Factor analysis, Electrical, Conductivity, Total Dissolved, Solids, Spatial distribution .

Objectives of the study

The main purpose of this study is to evaluate the groundwater quality of the Saq aquifer using both conventional and statistical methods through the following;

- Major ions composition.
- Groundwater types and facies.
- Clustering, factor and principal component analyses.
- Spatial variation in groundwater quality.

Research Methodology

The above mentioned objectives are realized through a number of applied procedures and methods. These include:

1- Preparation of well location map using Garmin 12 Global Positioning System (GPS).

2- Complete well inventory in the area. The inventory includes, well location, groundwater depths, levels, well diameter, well depth and the major ions concentrations of groundwater.
3- Construction of water level contour map to predict groundwater movement.

HYDROGEOLOGICAL ASSESSMENT FOR SAQ AQUIFER

Groundwater level

In this study, the groundwater-head-contour or piezometric map of the Saq aquifer has been drawn based on water levels recorded in 340 wells. These wells are not equally distributed over the aquifer, as information is concentrated near towns and irrigated areas. Moreover, despite its presence below almost the entire area, the water levels are not known where its depth is below 2,000 m. For this reason, the piezometric map was drawn using plain contour lines wherever the water-table elevation is known with a certain degree of reliability (sufficient data both in quantity and quality), but using dashed lines where this elevation is estimated or extrapolated.

Water level through the area of study ranges from 1050.5 m in the southern part to 217 m in the northeastern part Fig(1). This great variation may be due to either topographic changes for Saq aquifer or the intensive pumping or both. Accordingly, study area differentiated into three main regions can be distinguished based on the groundwater flow directions: a) the Qassim-Ha'il region with a natural flow direction towards the northeast; b) the Tabuk-Al-Madinah region where the main flow direction is northward; and Al-Jouf and northern area.

In the Qassim - Ha'il region, the groundwater level for the Qassim and Hail area increases from east to west. This level varies between 454.5 m at the northeastern part and 936 m at the northwestern part Fig(2). A particular situation is encountered along Wadi ar Rimah, where the alluvial aquifer appears to be in contact with the Saq aquifer. The groundwater in the alluvial aquifer is highly mineralized also shows high conductivity, indicating downward percolation of water from the alluvial aquifer.

In Tabuk and Al-Madinah area the ground water level ranges from 669m at the northwestern part to 1050.5 m at the southeastern part of the area Fig(3). The area of Al-Madinah represents the largest unconfined part of the Saq aquifer. The natural flow direction is generally northward, except in unconfined areas near the contact with the basement where it follows the dip towards the centre of the basin. Along the basement border some 100 km south of Tabuk, drainage is also directed outward from the Saq basin. This "leakage" is confirmed by the existence of springs in the valley draining towards the Red Sea. East of Tabuk the natural flow bends northwards. It seems that the general water flow in the Saq aquifer in the northwestern part of the study area. Tabuk has the largest depleted area of the western region, with a drawdown estimated at 100 m in the north of the irrigated area.

Al-Jouf and northern area, water level recorded at 217 m at the eastern part and at 635.5 m at the northwestern part Fig(4). The general slope of the water level is towards the eastern part.

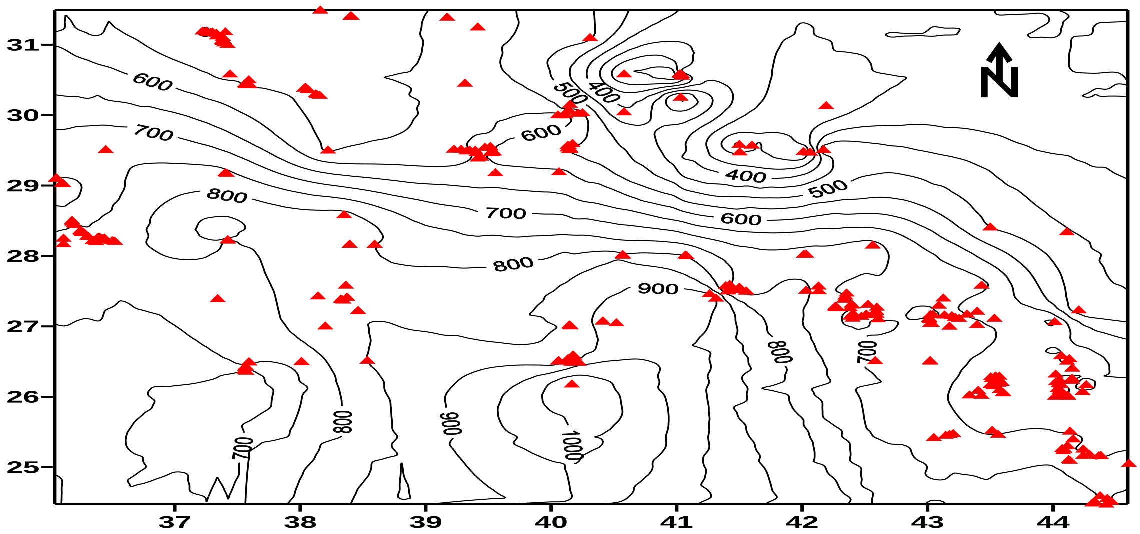


Fig. (1) Water level (m.a.m.s.l.) of Saq Aquifer in the study area.

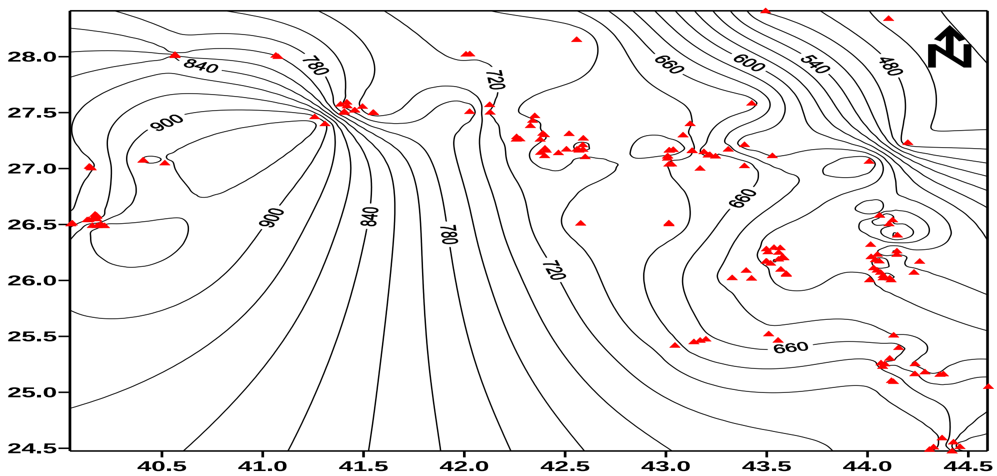


Fig**. (2) Water level (m. a. m. s. L.) at Qassim - Hail region area.**

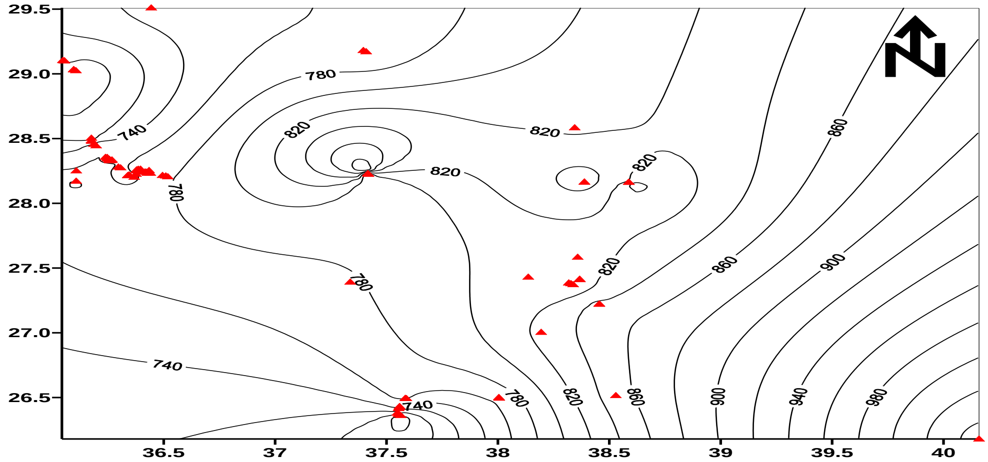


Fig. (3) Water level (m. a. m. s. L.) at Tabuk and Al-Madinah area.

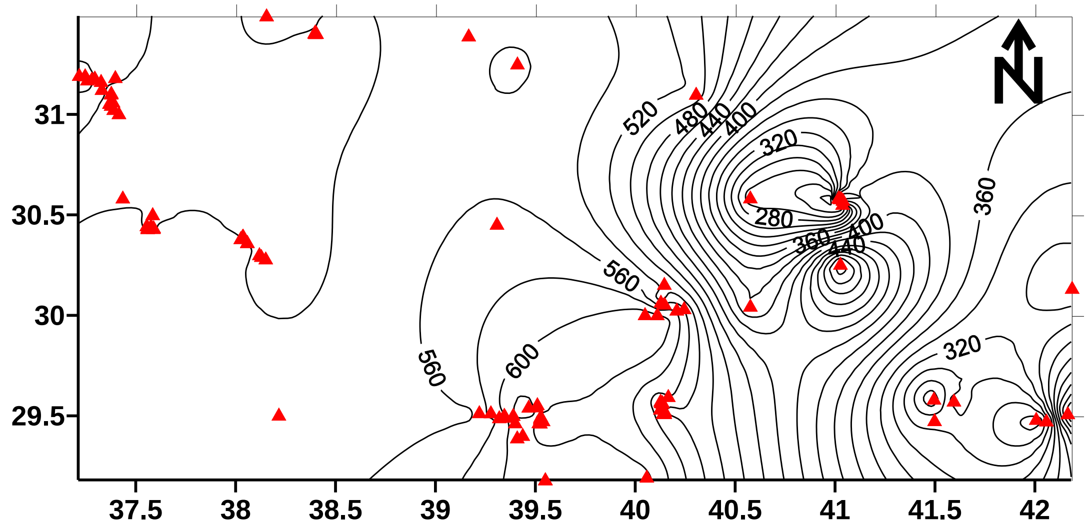


Fig. (4) Water level (m. a.m. s. L.) at Al-Jouf and Northern area.

HYDROCHEMISTRY

Hydrochemical Parameters

The collected data for the hydrochemical elements are characterized by positive values with a lower bound of zero; the higher and lower values lead the data to be skewed and non normality (Helsel and Hirsch, 1992). The samples were collected at random from the saq aquifer. The statistical evaluation of the measured hydrochemical parameters is presented on Table(1). The total dissolved solids varies from 190.3 to 5073.5 mg/L, and the electrical conductivity has a mean of 1599.3 micromohos/cm and maximum value of 7270 micromohos/cm. The dominant cation is sodium, which has mean concentration of 171.04

mg/L, followed by calcium, which has mean of 106.93 mg/L, then followed by magnesium, with mean of 37.87 mg/l. Sulfate is the dominant anion, having a mean value of 242.41 mg/L. It has a wide range of concentrations, where the minimum value is 19.8 mg/L and the maximum is 2120 mg/L. Chloride and bicarbonate have mean concentrations of 278.42 and 153.56 mg/L, respectively.

Statistic	EC	TDS	PH	Ca^{2+}	K^{+}	Mg^{2+}	Na^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	NO_3^{2-}
Mean	1599.3	1007.9	7.5	106.93	12.21	37.87	171.04	278.42	242.41	153.56	28.47
Median	1075	674.55	7.6	68.5	8	20.3	103.4	167.8	118.5	138	13.2
Standard Deviation	1492.39	953.15	0.4	105.07	12.22	46.78	203.02	343.1	332.7	68.9	80.8
Skewness	2.21	2.38	0.25	3.21	2.21	3.22	2.72	2.87	3.08	2.34	10.81
Std. Error of Skewness	0.16	0.17	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.17	0.17
Kurtosis	4.63	5.67	2.92	13.7	5.9	13.21	8.05	9.28	11.16	7.98	136.88
Std. Error of Kurtosis	0.39	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Range	6986	4883.2	3.2	756	76.3	332.6	1138.1	2047.1	2100.2	484	1070
Minimum	284	190.3	6.4	17	0.9	2.9	15.6	12.9	19.8	59	0
Maximum	7270	5073.5	9.6	773	77.2	335.5	1153.7	2060	2120	543	1070
Sum	327853	205600	1533.3	21922	2504.2	7763.8	35063.7	57076.8	49694.4	31481	5837.44
Count	205	204	203	205	205	205	205	205	205	205	205

(Ionic concentrations are in mg/L, EC in micromohos/cm)

Table (1) Summary statistics of measured hydrochemical parameters.

Interpretation of the Pearson's Correlation Matrix

The Pearson's correlation coefficient ranges between -1 and +1. The closer correlation is to ±1, the closer to a perfect linear relationship. If the relationship between the two variables is positive, (*r*) will be positive while, if it is negative, (r) will be negative. Major ions concentrations were converted into mg/L before calculation of the correlation matrix. Table(2) shows a Pearson's correlation matrix between the different pairs of major ions, TDS, EC and PH.

Scatter Plots

Scatter plots are similar to line graphs where they use horizontal and vertical axes to plot data points although they reveal the specific purpose. Scatter plots present how much one variable is affected by another parameter. The relationship between these two variables is called correlation coefficient. Scatter plots usually consist of a large amount of the measured data. The closer data points can be achieved after plotting and tend to present a straight line. The higher correlation coefficient between the two variables reflect the strongest relationship.

The variables have a positive correlation, if the data points make a straight line going from the origin to high x- and y- values. Whereas, in case of the line goes from a high-value on the y-axis down to a high value on the x-axis, the variables have a negative correlation. A perfect positive correlation is given the value of 1. A perfect negative correlation is given the value of -1. If there is no correlation, absolutely, present the value of correlation coefficient is 0. The closer number is to 1 or -1, the stronger correlation, or the stronger relationship between the variables. The closer number is to 0, the weaker etalic correlation. Scatter diagrams were constructed using arithmetic scale Figs(5-8). All plotted ionic concentrations are in mg/L values.

Interpretation of the Pearson's Correlation Matrix

Correlation coefficients give an idea about the relationships between the hydrochemical parameters of the study area, and that may help to identify the main processes contributing to the groundwater salinization. The correlation coefficient measures the strength of a linear relationship between two variables. The correlation coefficient is always between -1 and +1. The closer the correlation is to ±1, the closer to perfect linear relationship.

Variable	EC	TDS	PH	Ca^{2+}	K^{+}	Mg^{2+}	Na^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	NO_3^{2-}
EC	1.00										
TDS	0.95	1.00									
PH	-0.14	-0.14	1.00								
Ca^{2+}	0.83	0.78	-0.12	1.00							
K^{+}	0.48	0.49	-0.05	0.18	1.00						
Mg^{2+}	0.81	0.88	-0.12	0.72	0.38	1.00					
Na^{+}	0.95	0.93	-0.11	0.68	0.54	0.71	1.00				
Cl^{-}	0.92	0.90	-0.08	0.74	0.47	0.74	0.92	1.00			
SO_4^{2-}	0.81	0.86	-0.13	0.82	0.27	0.86	0.72	0.65	1.00		
HCO_3^{-}	0.33	0.38	-0.16	0.11	0.52	0.31	0.39	0.27	0.26	1.00	
NO_3^{2-}	0.41	0.20	-0.12	0.52	-0.06	0.09	0.36	0.30	0.32	-0.02	1.00

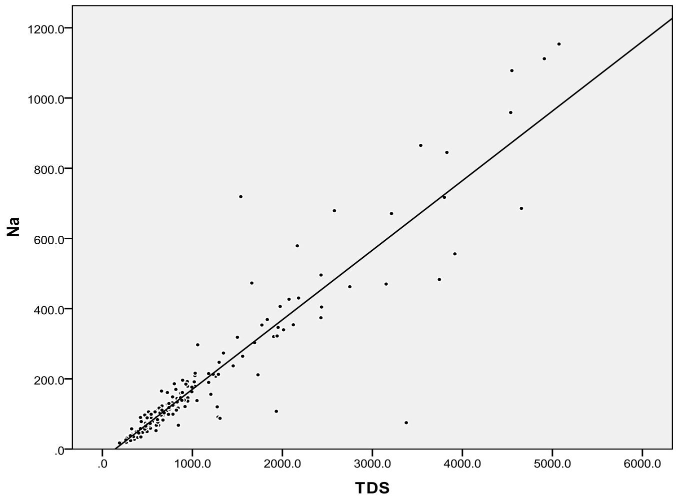
Table (2) Pearson's correlation matrix.

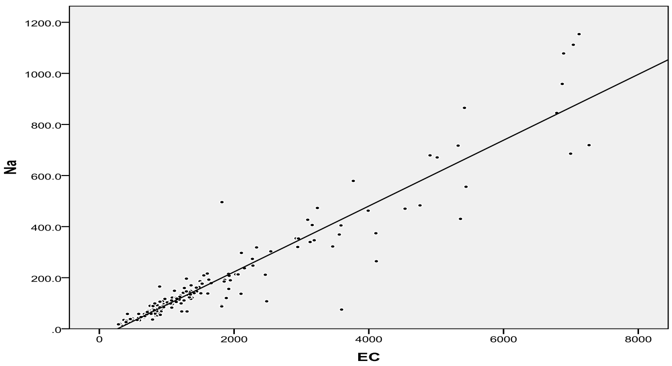
The Pearson's correlation matrix Table(2) shows positive relationship between the ions Na^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, $SO_4^{\,2-}$, except for the ions $SO_4^{\,2-}$- Cl^{-} shows weak positive correlation coefficients.

Description of Scatter Plots

Scatter plots Figs(5- 4) gave a view of the relationships between the hydrochemical parameters. Plots of Na^{+} against TDS and EC and Mg^{2+} Fig(5) show similar patterns, strong positive relationship. This means that these ions have much contribution to the groundwater mineralization. Plots of Mg^{2+} against TDS, EC and Ca^{2+} Fig(6) show strong positive relationship.

Plots of Ca^{2+} against TDS and EC present strong positive relationship Fig(7). Furthermore, the plot of EC-TDS shows typical positive relationship**.** Fig(8) reveals strong positive relationships among $SO_4^{\,2-}$, Mg^{2+} and Ca^{2+}. Figures (9) and (10) shows the same pattern for HCO_3^{-} and Na^{+}.





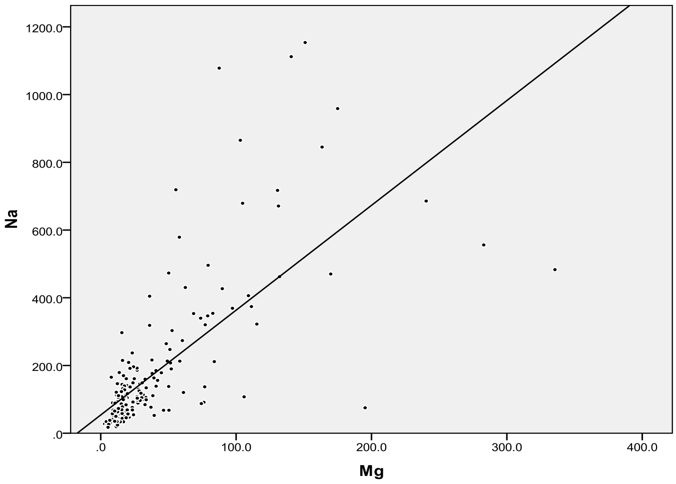
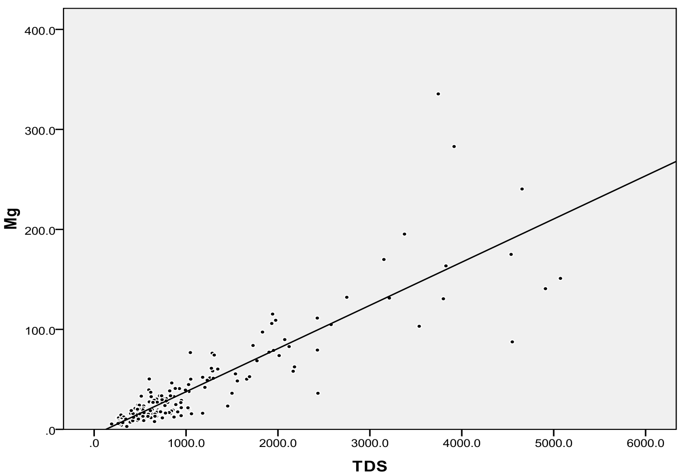


Figure (1) Scatter plot diagrams of Na^{+}, TDS, EC and Mg^{2+}.



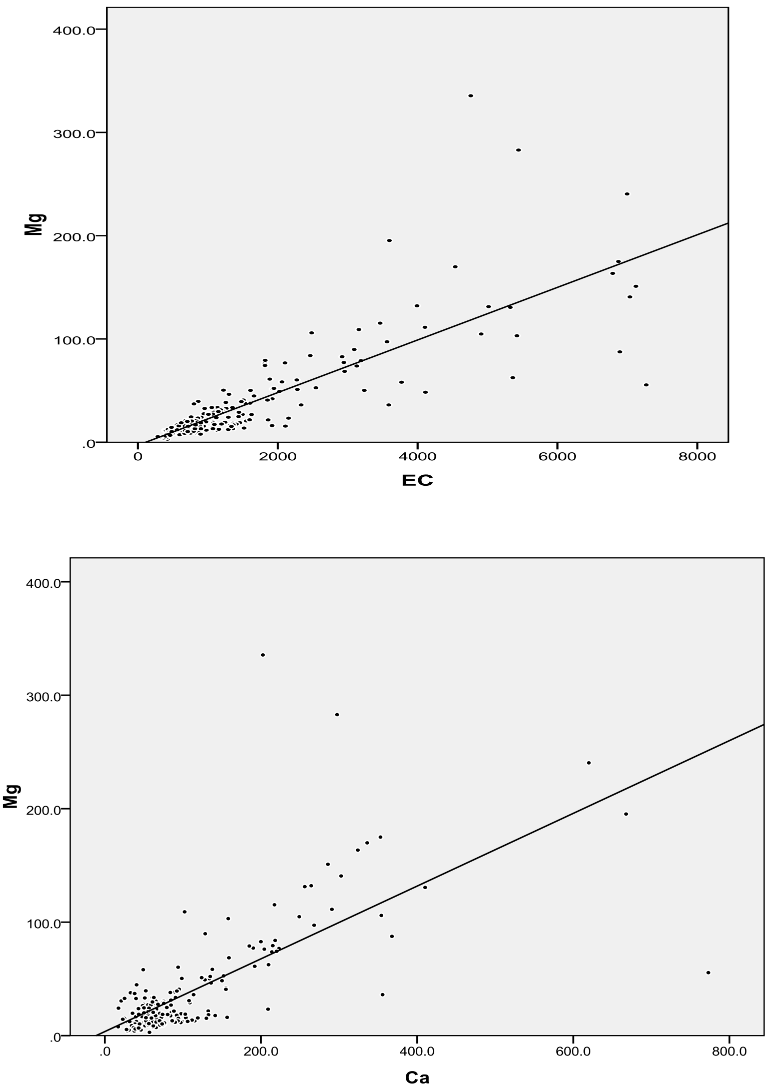
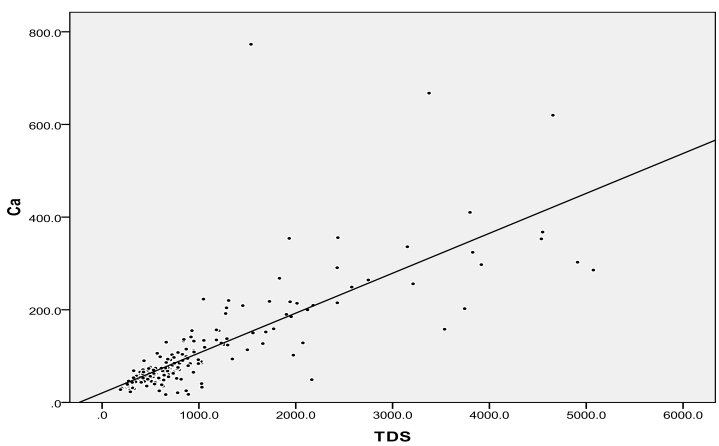
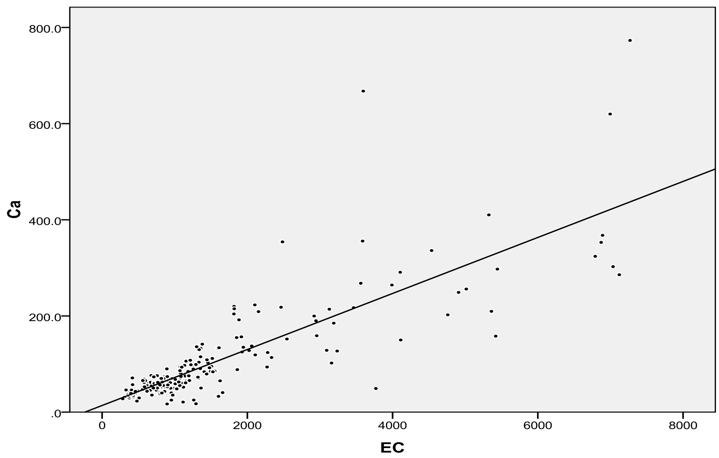


Figure (6) Scatter plot diagrams of Mg^{2+}, TDS, EC and Ca^{2+}.





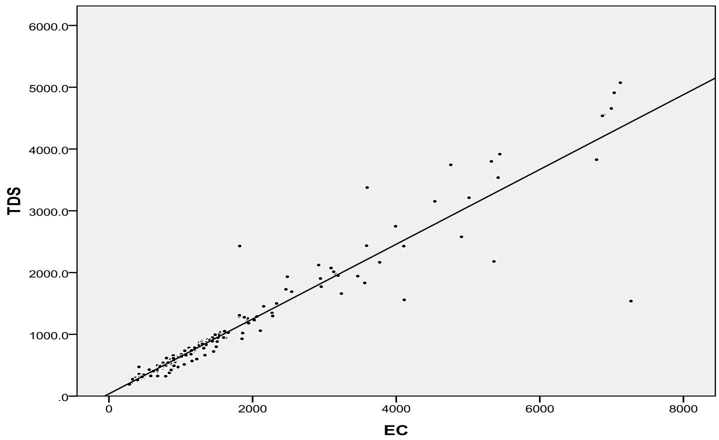
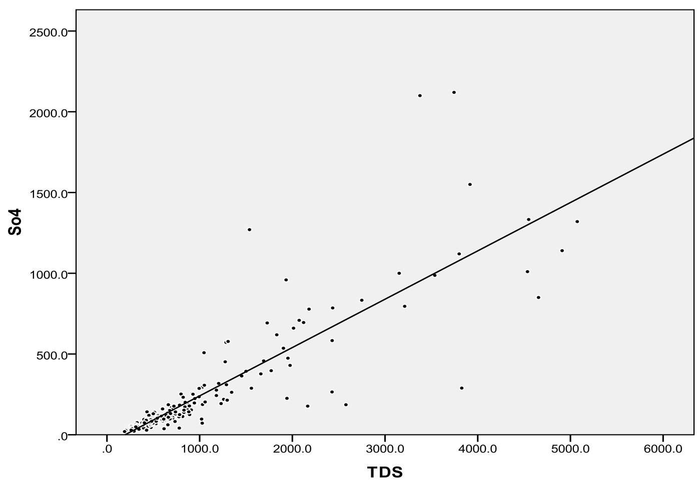
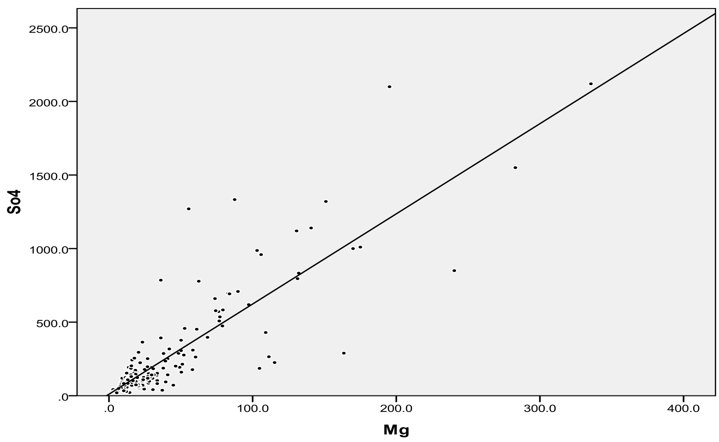


Figure (7) Scatter Plot diagrams of Ca^{2+}, TDS and EC.





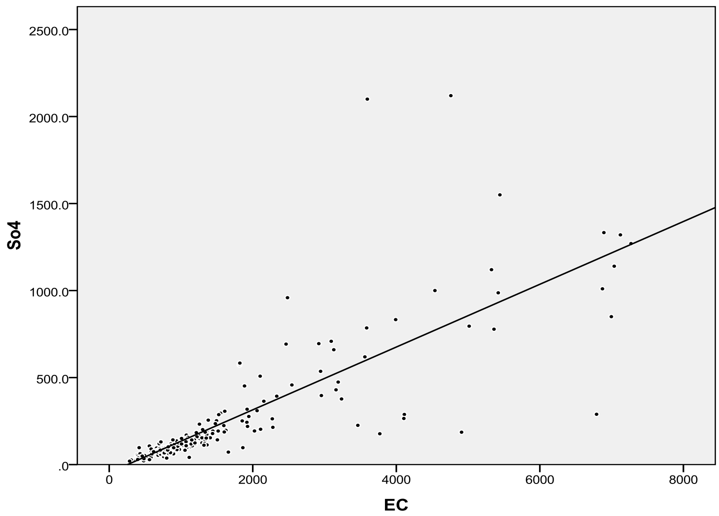
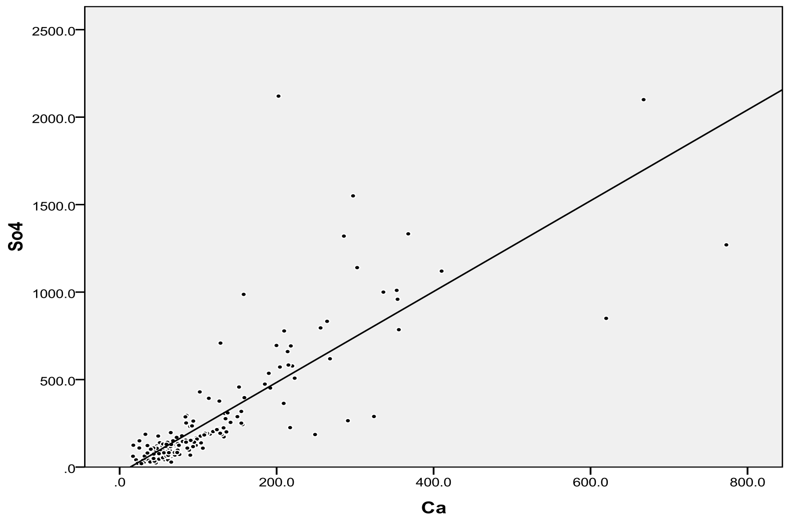
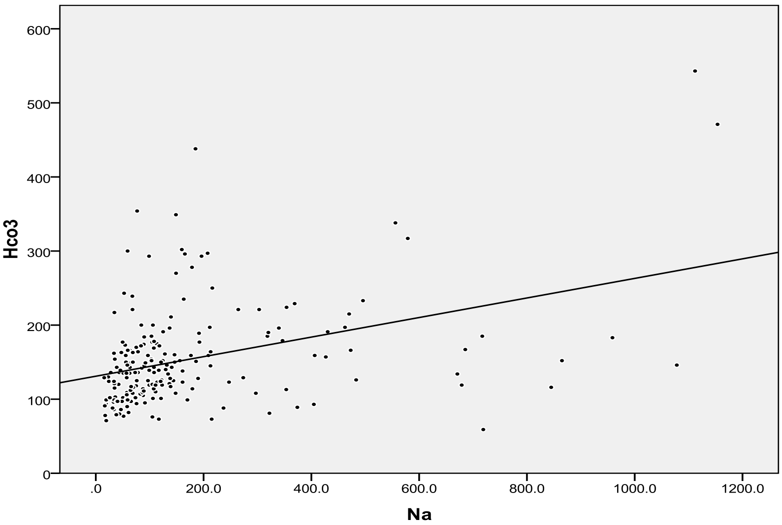


Figure (8) Scatter Plot diagrams of $SO_4{}^{2-}$, TDS, Mg^{2+} and EC.





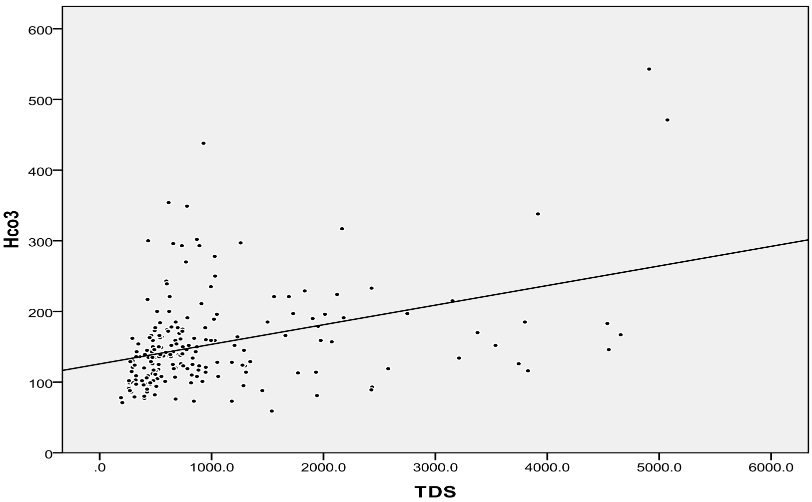


Figure (9) Scatter Plot diagrams of SO_4^{2-} and Ca^{2+}; HCO_3^-, Na^+ and TDS.

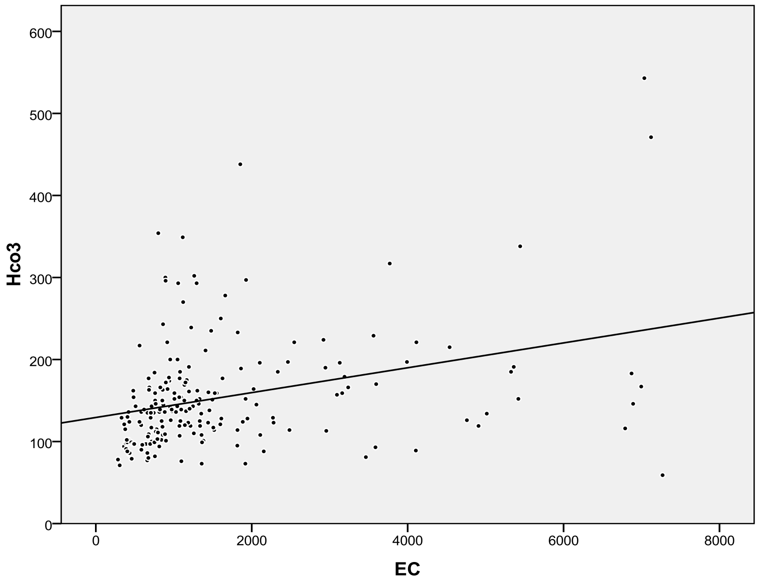


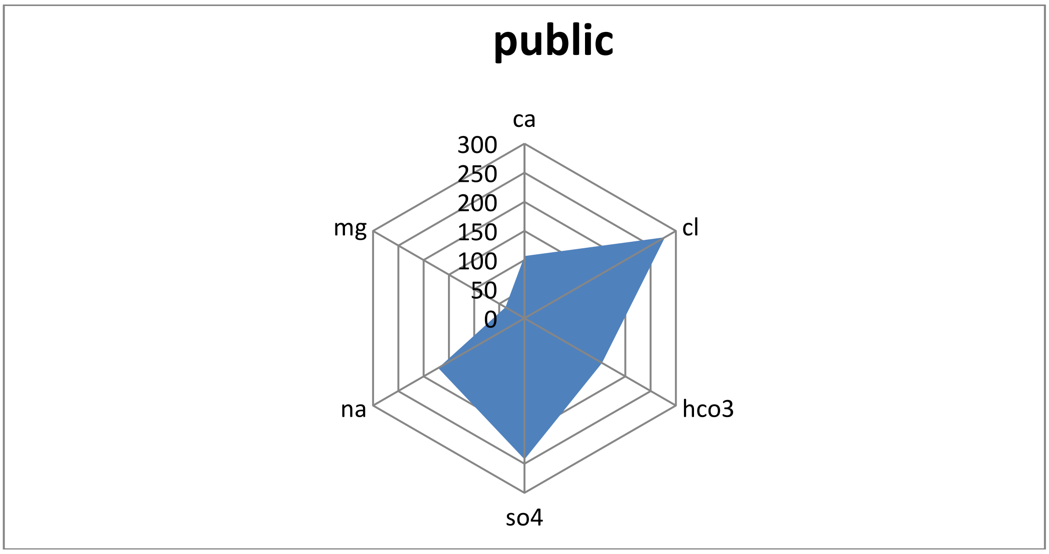
Figure (10) Scatter Plot diagrams of HCO_3^- and EC.

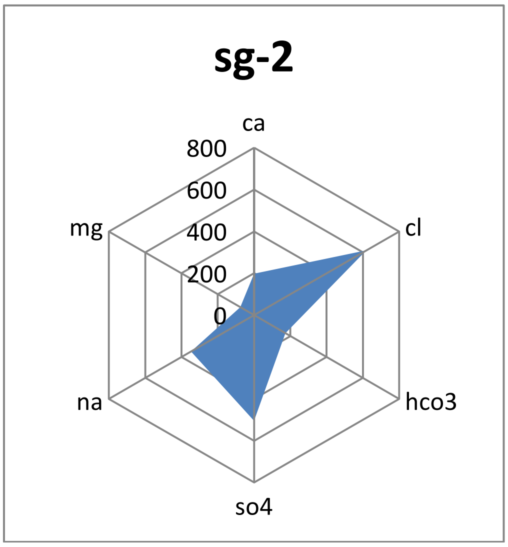
Cluster Analysis

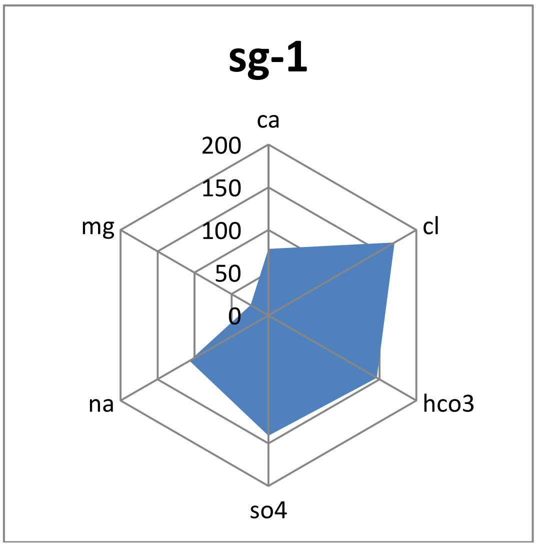
Groundwater of Saq Aquifer in study the area has been clustered using SPSS software package. The resulting dendogram was interpreted and classified the groundwater into two major groups and six subgroups using eleven variables. Table(3) shows the means of each parameters produced by the hierarchical cluster analysis.

These values reveal some trends between the major groups. The samples of Group two have higher TDS than group one. Subgroups three and six have only 2 and 1 members respectively. Subgroup five distanced by higher Na^+ and Cl^-. Subgroup three can be distinguished from all subgroups by lower values for most of ions.

Fig(11) shows radial diagrams for six subgroups while, the final cluster centers are shown in Table(3).







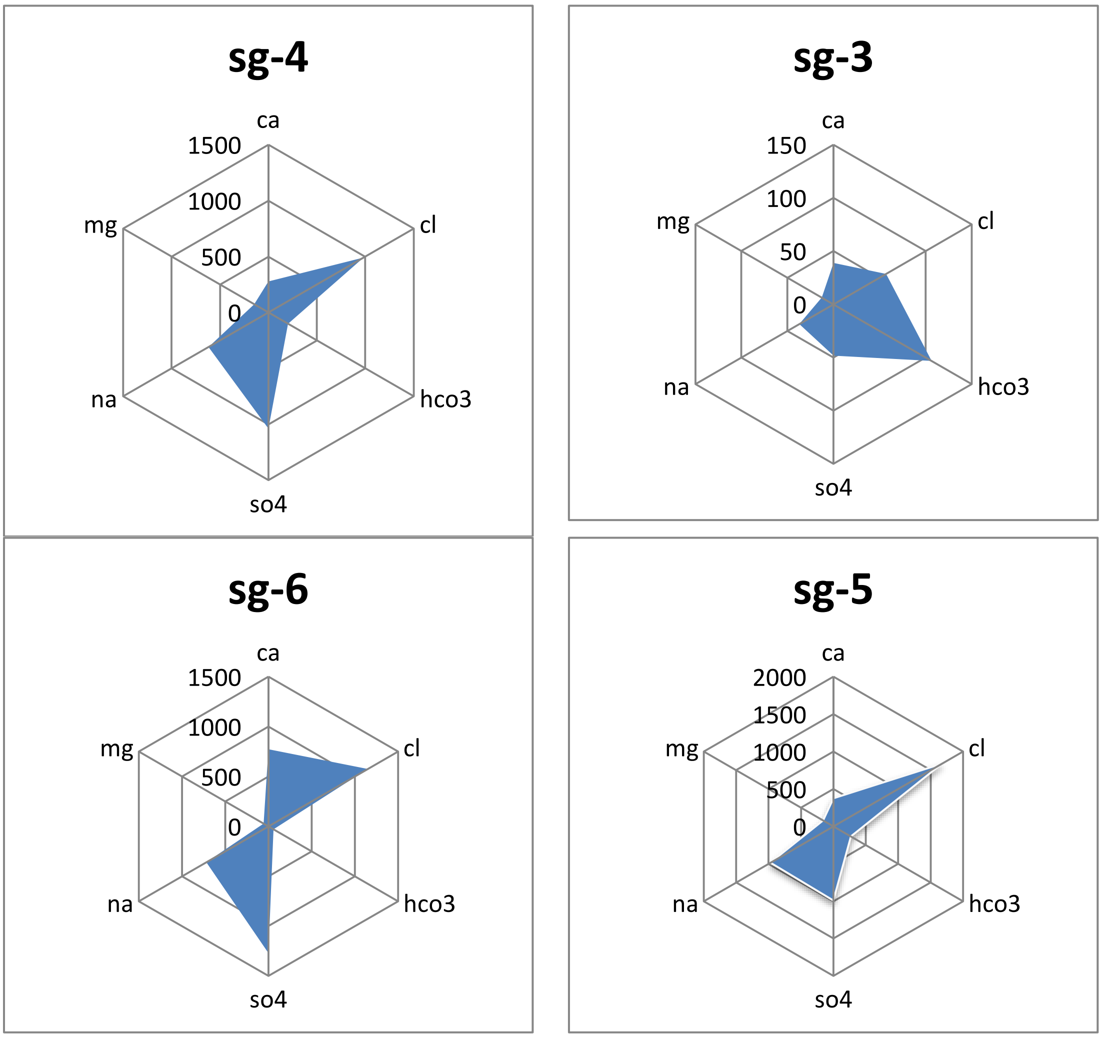


Figure (11) Subgroups of Radial Diagram.

Group	Subgroup	No.	EC	TDS	PH	Ca^{2+}	K^{+}	Mg^{2+}	Na^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}
1	1	175	1090.34	692.2	7.58	77.78	10.45	24.09	106.76	170.52	141.10	146.57
	2	15	3187.73	1927.84	7.42	198.05	19.24	75.9	347.42	619.04	504.77	172.86
2	3	2	495	330.9	7.8	38.9	5.9	12.75	37.15	57.1	48.3	106.5
	4	6	5183.83	3299.6	7.4	277.86	24.9	146.71	618.23	982.84	1038.4	202.5
	5	6	6951.33	4592.26	7.43	375.48	34.31	159.68	972.18	1675	990.35	271
	6	1	7270	1537.7	7.1	773	2.8	55.5	719	1150	1270	59

Table (3) The means of the parameters produced by the hierarchical cluster analysis.
(Ionic concentrations in mg/L)

Final Cluster Centers		
Variable	Cluster	
	1	2
EC	5228.55	1149.42
TDS	3232.69	731.07
PH	7.39	7.57
Ca^{2+}	325.37	80.13
K^{+}	25.18	10.46
Mg^{2+}	137.42	25.62
Na^{+}	617.96	115.10
Cl^{-}	1063.37	185.28
SO_4^{2-}	947.98	158.32
HCO_3^{-}	201.05	148.53
NO_3^{2-}	99.30	19.97

Table (4) Final Cluster Centers.

Factor Analysis

The correlation matrix of hydrochemical parameters shown in Table(5) was used in FA. To determine the number of principle component to extract, a scree plot Fig(12) of all components variable against their eigenvalues was constructed, and then only components having eignvalues greater than one were chosen to be extracted. Extraction was performed by principle component analysis, using variance maximizing (varimax) method. The loading of each variable in the component and rotated matrix are shown on tables(6, and 7), and the total variance explained by each component of factor is shown in table (8). The component score coefficients are shown graphically in fig(13).

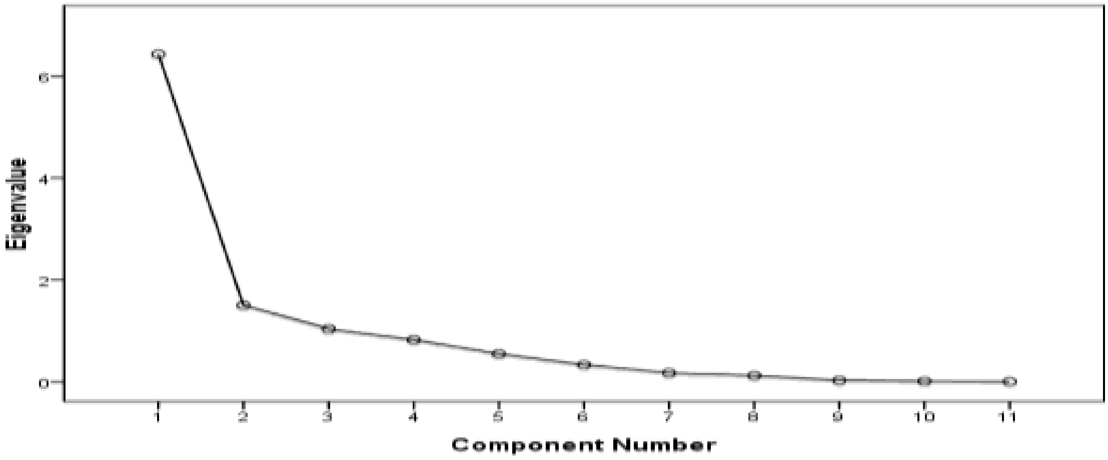


Figure (12) Scree Plot of Components to Extract.

Factor Analysis yields three factors that are responsible of variation water chemistry as follows:

- High loading on Ca^{2+}, EC, Cl^-, TDS, $SO_4^{\ 2-}$, Mg^{2+} and Na^+. This factor presents the contribution of these ions to the total mineralization of groundwater.
- Medium loading of K^+ and HCO_3^-.
- Lower values of pH indicating its low contribution for the water.

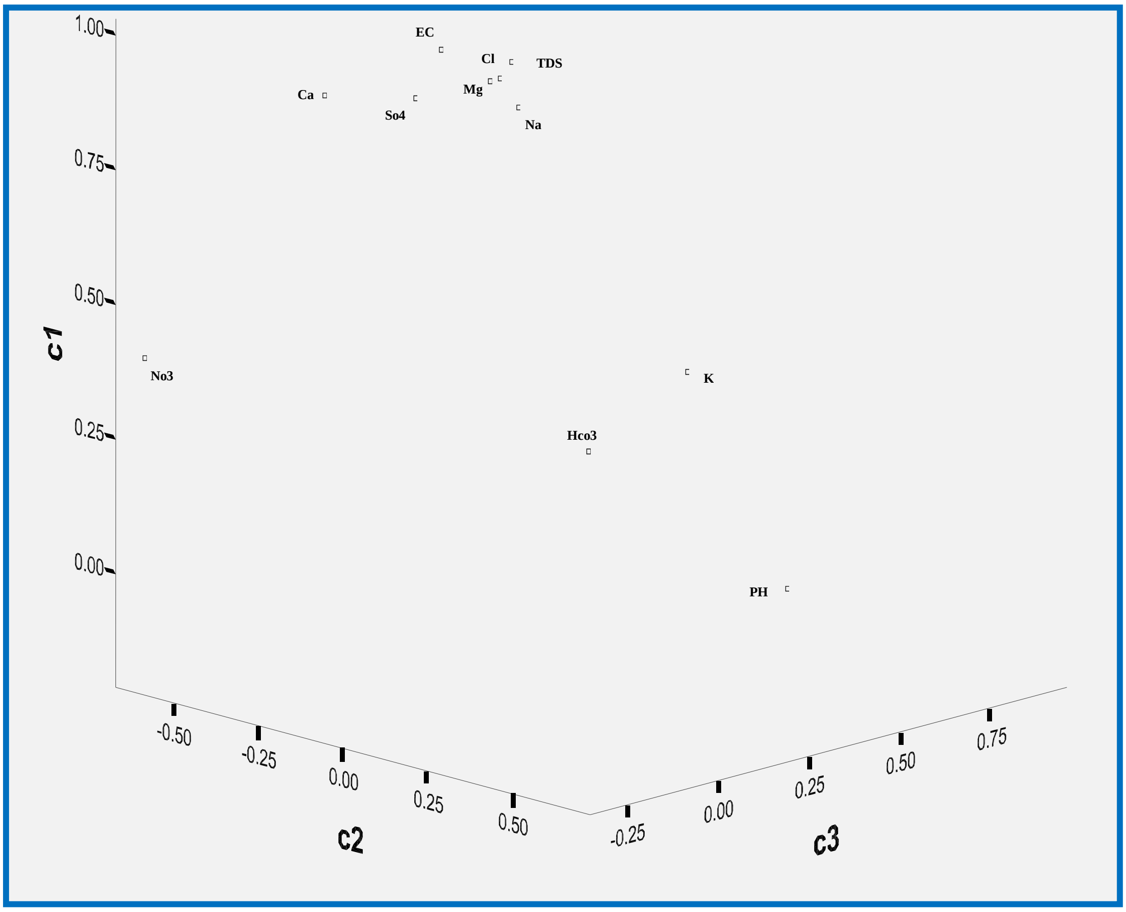


Figure (13) Components Scree coefficients.

Correlation	EC	TDS	Ca^{2+}	K^{+}	Mg^{2+}	Na^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	NO_3^{2-}
EC	1.000	0.949	0.826	0.458	0.810	0.946	0.935	0.821	0.335	0.408
TDS	0.949	1.000	0.778	0.479	0.877	0.929	0.906	0.863	0.388	0.2035
PH	-0.138	-0.137	-0.119	-0.051	-0.121	-0.107	-0.081	-0.133	-0.158	-0.128
Ca^{2+}	0.826	0.778	1.000	0.166	0.716	0.676	0.740	0.824	0.114	0.524
K^{+}	0.458	0.479	0.166	1.000	0.363	0.525	0.485	0.276	0.539	-0.061
Mg^{2+}	0.810	0.877	0.716	0.363	1.000	0.709	0.741	0.867	0.317	0.084
Na^{+}	0.946	0.929	0.676	0.525	0.709	1.000	0.933	0.729	0.399	0.365
Cl^{-}	0.935	0.906	0.740	0.485	0.741	0.933	1.000	0.644	0.266	0.300
SO_4^{2-}	0.821	0.863	0.824	0.276	0.867	0.729	0.644	1.000	0.260	0.315
HCO_3^{-}	0.335	0.388	0.114	0.539	0.317	0.399	0.266	0.260	1.000	-0.024
NO_3^{2-}	0.408	0.203	0.524	-.061	0.084	0.365	0.300	0.315	-0.042	1.000

Table (5) Correlation matrix used for factor analysis.

Component Matrixa			
	Component		
	1	2	3
electrical conductivity	0.98	-0.07	0.02
total dissolved solids	0.97	0.07	0.08
Calcium ions	0.84	-0.41	0.01
Potassium ions	0.51	0.68	0.00
Magnesium ions	0.87	0.04	0.13
Sodium ions	0.94	0.06	0.03
Chloride ions	0.92	0.00	0.11
Sulfate ions	0.87	-0.17	0.04
Bicarbonate ions	0.41	0.67	-0.27
Nitrate ions	0.36	-0.62	-0.03
Extraction Method: Principal Component Analysis.			
a. 3 components extracted.			

Table(6) Component Marixa

	Rotated Component		
	1	2	3
electrical conductivity	0.96	0.19	0.11
total dissolved solids	0.93	0.31	0.04
Calcium ions	0.90	-0.17	0.15
Potassium ions	0.32	0.78	-0.03
Magnesium ions	0.84	0.25	-0.02
Sodium ions	0.89	0.30	0.08
Chloride ions	0.89	0.23	0.01
Sulfate ions	0.88	0.06	0.09
Bicarbonate ions	0.19	0.78	0.22
Nitrate ions	0.45	-0.47	0.43

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 5 iterations.

Table(7) Rotated Component

Total Variance Explained								
Component	Initial Eigen values			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings	
	Total	Variance%	Cumulative %	Total	Variance%	Cumulative %	Total	Variance%
1	6.431848405	58.47134914	58.47134914	6.4318484	58.471349	58.471349	6.0111036	54.646396
2	1.498037777			1.4980378	13.618525	72.089874	1.824036	16.582145
3	1.035696628	9.415423891	81.50529828	1.0356966	9.4154239	81.505298	1.1304433	10.276757

Extraction Method: Principal Component Analysis.

Table (8) Priciple components loading and variance explained

CONCLUSIONS

The Saq Aquifer is one of the main aquifers that is characterized by great areal extent through central and western parts of Saudi Arabia. The age of the Saq Sandstone and its equivalent units ranges from Cambrian to Ordovician, based on the identification of several forms of trilobite tracts algal bodies and nondescript spore-like forms in the samples. The Saq Formation composed of poorly to well sorted medium to coarse grain sandstone, but locally contain quartz sandstone. It is commonly cross - bedded and is devoid of shale.

The Saq Sandstone is water-bearing only at great depth. The hydraulic properties of the aquifer were obtained mainly from areas near the cities of Tabuk, Hail and Qassim where the aquifer had been extensively developed. The amount of the recharge to the aquifer was estimated to be very small. Infiltration in Tabuk area was estimated to be 150 million cubic meters per year and in the Qassim area to be 80 million cubic meters per year. The recharge from runoff was insignificant; an estimated 20 million cubic meters per year in an area of Hail.

In this study, the groundwater contour maps of the Saq Aquifer were drawn based on water levels recorded in 170 wells that concentrated near the main towns and irrigated regions through the study area. The depth to water level through the whole study area ranges from 1050.5 m in the southern part to 217 m in the northeastern part. This great variation may be due to topographic changes and/or the intensive pumping. Accordingly, the study area has been divided into three main subareas as; a) Qassim-Hail subarea with a natural flow direction towards the northwest; b) Tabuk-Al-Madinah subarea where the main flow direction is northward; and c) Al-Jouf and northern area having a north to south flow direction.

In Qassim - Ha’il subarea, the depth of groundwater level increases from east to west. This depth varies between 454.5 m in the northeastern part and 936 m in the northwestern part. In Tabuk and Al-Madinah subarea the ground water level ranges from 669 m in the northwestern part to 1050.5 m in the southeastern part of the area. The area of Al-Madinah represents the largest unconfined part of the Saq Aquifer where, the natural flow direction is generally northward, except in unconfined areas near the contact with the basement where it follows the dip towards the centre of the basin. Along the basement border some 100 km south of Tabuk, drainage is also directed outward from the Saq Basin. Furthermore, the water level has been recorded in 217 m depth in the eastern part and at 635.5 m depth at the northwestern part at Al-Jouf and northern area.

The hydraulic conductivity of Saq Aquifer in the study area ranges between 1.26 x 10^{-2} m/minute to 1.9 x 10^{-2} m/minute in the confined part, and about 1.6 x 10^{-2} in unconfined part. In general, Saq Aquifer has a storage coefficient value of 4.2 x 10^{-2}.

The groundwater in Qassim - Hail region flows toward northeast under an average hydraulic gradient of 0.0094. This groundwater flows in the western and southwestern directions around Tabuk and Al-Madinah area with average hydraulic gradient of 0.00065. While for Al-Jouf and Northern area, the average hydraulic gradient is 0.017 in the eastern and 0.00016 at the western parts. The movement of groundwater directed into northeastern part of the area. There is very limited local recharge in the unconfined part of the area.

The recharge study is one of the most important and complicated aspects of hydrology. Also the amount of water recharging the aquifer is dependent on the magnitude of the individual rainfall events which must satisfy the field capacity of the soil before it starts recharging the aquifer. The water infiltrates to the aquifers in the following phases: 1) Direct infiltration of rainfall that occurs on the outcrop of the aquifer; 2) Direct infiltration through the overlying superficial deposits on the outcrop areas; 3) Infiltration of the runoff through the stream beds or deposits which cross the outcrops of the aquifer to the aquifer and 4) Horizontal transfer of water within the aquifer from the areas adjacent to the study area.

Due to the greater depth of the Saq Aquifer throughout the study area, there is a limited rate of groundwater recharge. Infiltration in the Tabuk area was estimated to be 150 million cubic meters per year and in the Qasim area to be 80 million cubic meters per year. The recharge from runoff was insignificant; an estimated 20 million cubic meters per year in an area of Hail.

The statistical evaluation of the measured hydrochemical parameters reveals that, the total dissolved solids varies from 190.3 to 5073.5 mg/L, and the electrical conductivity has a mean of 1599.3 ohms/cm and maximum value of 7270 ohms/cm. The dominant cation is sodium, which has mean concentration of 171.04 mg/L, followed by calcium, which has mean of 106.93 mg/L, then followed by magnesium, with mean of 37.87 mg/l. Sulfate is the dominant anion, having a mean value of 242.41 mg/L. It has a wide range of concentrations, where the minimum value is 19.8

mg/L and the maximum is 2120 mg/L. Chloride and bicarbonate have mean concentrations of 278.42 and 153.56 mg/L, respectively.

The relationships between the hydrochemical parameters have been investigated through Pearson's correlation coefficients that are commonly used to measure the strength of the association between two variables. The results of Pearson's correlation matrix show positive relationship between the ions Na^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, $SO_4{}^{2-}$, except for the ions $SO_4{}^{2-}$ - Cl^{-} which shows weak positive correlation coefficients. Furthermore, the plot of EC-TDS shows typical positive relationship.

Multivariate statistical analysis are carried out using three techniques; 1) Principal Component Analysis (PCA); 2) Cluster Analysis (CA) and 3) Factor Analysis (FA). Using cluster analysis, the data was grouped into two clusters and six subgroups. Further classification by principal component and factor analysis, indicates three factors responsible for the variations within the data as follows; 1) High loading on Ca^{2+}, EC, Cl^{-}, TDS, $SO_4{}^{2-}$, Mg^{2+} and Na^{+}. This factor presents the contribution of these ions to the total mineralization of groundwater; 2) Medium loading of K^{+} and $HCO_3{}^{-}$ and 3) lower values of pH indicating its low contribution for the water.

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