INTERPRETATION OF GROUNDWATER QUALITY USING FACTOR ANALYSIS, WADI RABIGH AREA, WESTERN SAUDI ARABIA

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Groundwater is an important resource for people in the Wadi Rabigh area, which lies in the Western Saudi Arabia. It is necessary to assess its quality for suitable exploitation. For this purpose, physical and chemical analyses from 23 groundwater samples are carried out during this study to determine various groundwater quality parameters. After the collection of data, factor analysis (FA) is applied to identify and understand hydrochemical association and processes leading to the variability of groundwater quality without losing any information in the input pattern and avoiding limitations that are associated with classical methods. The FA includes R and Q modes, which are applied to groundwater samples collectively so as to identify significant factors leading to meaningful quality interpretations. Objective analyses led to two factors that explain 80% of the total variance in the groundwater quality data. The first factor reveals 48% of the total variance dominated by Ca, Mg, Na, SO_4, Cl, NO_3, EC, TDS and TH which suggest effects from water soil/rock interaction and agricultural activity. The second factor shows high loading of Na, and moderate loading of SO_4, Cl, Mg, EC, whereas TDS suggests chemical weathering processes in the study area.

INTRODUCTION

Groundwater is a very important for the people presently and it will be more precious with the present and future climate change impacts as a water supply in the world especially in the arid and semiarid area where there are no perennial surface waters like Saudi Arabia, where the population depends solely on groundwater as the major source for drinking water and irrigation supply like wadi Rabigh area. Water is essential to the existence of man and all living thing. Groundwater is the main source of potable and agricultural water in arid region. Due to population growth and increase of economic activities in Saudi Arabia water consumption has increased which has resulted in utilization of limited water resources. On the other hand, the groundwater resources decrease significantly with time due to extensive pumping for domestic and agriculture uses. The groundwater resources change by many factors such as rainfall, water-bearing formation composition, pH and the resident time within the formation (Olobaniy and Owyenmi, 2006). Early studies on the characterization of groundwater facies relied on graphical representation of the major ionic components. These graphical methods were used to describe the differences in major ion chemistry in groundwater and determined the water type group of groundwater (Piper, 1944; Hem, 1989; Freeze and cherry, 1979), which are usually of similar genetic history.

Recently, the studies have confirmed the usefulness of factor analysis (FA) techniques in groundwater chemistry to evaluate and interpretation of groundwater quality data and to provide insight into the processes (Ruiz et al., 1990; Subyani and Al-Ahmadi, 2010) and possible source of pollution. These methods have the ability to reveals hidden inter-variable relationships in addition to allowance of the use of virtually limitless number of variables like physical parameters and trace elements which can be part of the classification parameters. The effectiveness of FA in hydrochemical studies has been aptly demonstrated in many studies (Lawrence and Upchurch, 1983; Briz-Kishore and Murali, 1992; Subba Rao et al., 1996; Dalton and Upchurch, 1978).

The objective of this paper is to use FA to identify and describe the main processes affecting groundwater in unconfined shallow alluvial aquifer in wadi Rabigh, which is located in western part of Saudi Arabia.

STUDY AREA

Wadi Rabigh is located in Makkah region in the Western part of Saudi Arabia; about 150 km north of Jeddah city and it is accessible via Jeddah-Madina highway (Figure 1).

It extends from the Arabian Shield outcrops in the east to the Red Sea in the west. The total catchment is one of the largest in the western coastal plain of the Kingdom of Saudi Arabia of about 4570 km^2. The area is one of the densely populated locations in the western coast of Saudi Arabia. Rabigh City is planned to play an important role in the near future as one of the important cities in the Kingdom. A railway line from Jeddah to Madina is planned to pass through Rabigh, which is planned as one of the stations on the route. Additionally, Jeddah City is expanding north-wise, where the edge of the city has reached about 70 km south of Rabigh. Also the construction of the new King Abdullah Commercial City in the area, which received its first inhabitants and King Abdullah University for Science and Technology, received its students in September 2009, and it gives the area a special position and consideration.

However, the study area is confined to the lower part of the catchment, which lies between 39° 00', at the city of Rabigh, and 39° 30' E longitudes and 22° 45' and 23° 00' N latitudes as in Figure 1, where the potential of groundwater availability is the highest. The area covers about 2690 km^2 and is located between the Red Sea coast on the west and about 50 km east towards the Hijaz escarpments.
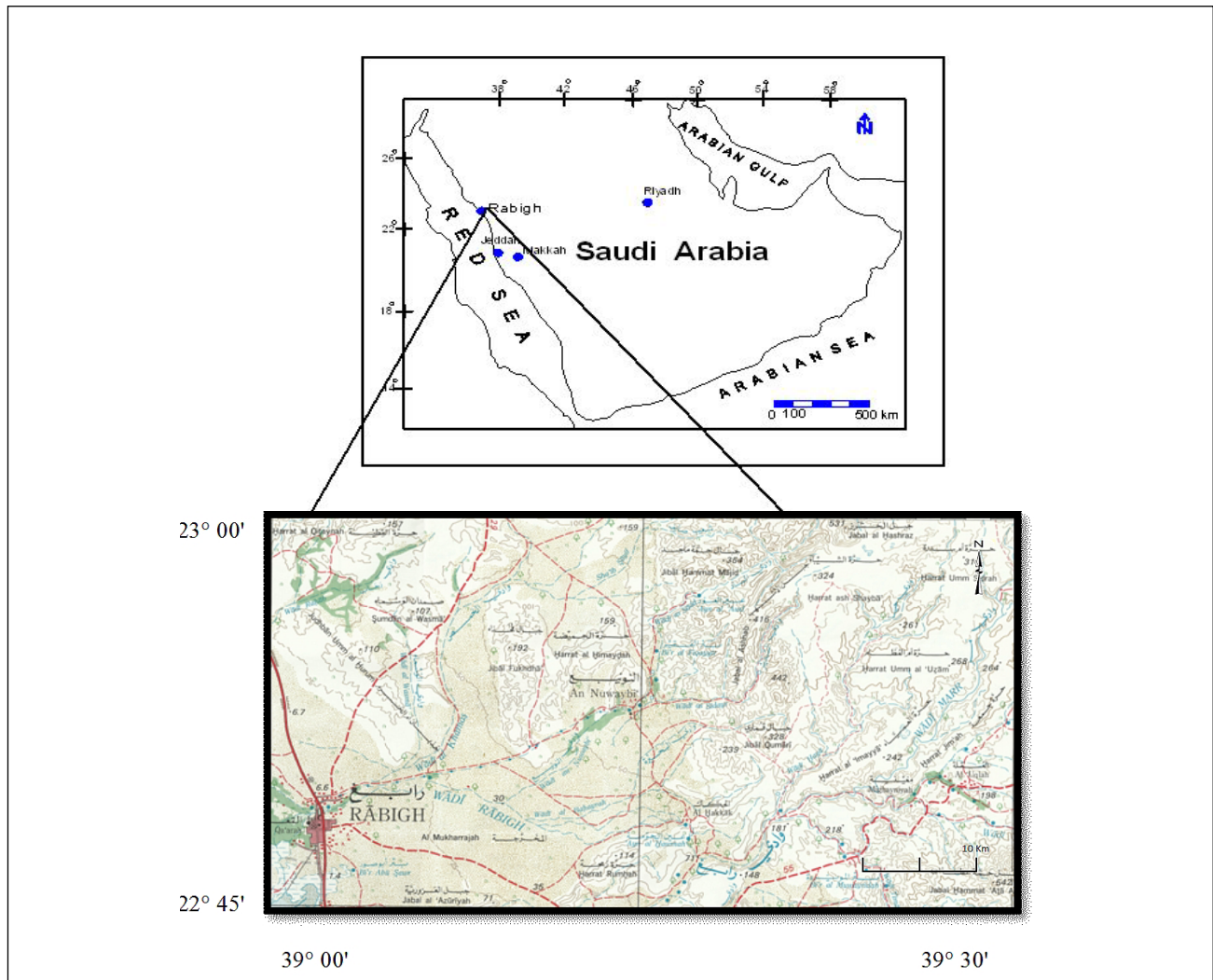
Figure 1. Location map of study area.

The climate of the study area is categorized as arid and has a desert climate, which is dry and hot throughout the year. However, transitional zones between Mediterranean and monsoon climates predominate in winter and early spring. Mean temperature ranges between 30°C and 34°C during summer and between 20°C and 24°C during winter (Bindagi, 1980). Rainfall occurs from October to April sporadically under the effects of moderate and high temporal and spatial variations. The average annual rainfall depth over the study area from 1966 to 2006 was estimated to be from 35 mm to 75 mm.

Geologically, Wadi Rabigh is located in the west-central part of the Arabian Shield, which extends from the north to the South in parallel with the Red Sea. The shield is composed of Precambrian crystalline, metamorphic and meta-volcanic sedimentary rock (Moore and al-Rehili, 1989). The geology of the study area may be divided into three main geological entities as (i) Late Proterozoic rocks, which are predominately lava and associated volcanic rocks , (ii) Tertiary rocks, which cover the western part of the area and they occur in low hills rising above the coastal plain and these rocks are generally horizontal but have been faulted, and (iii) Quaternary deposits that cover large areas of the coastal plain and consist of alluvial gravels, which range from few to several meters in thickness. The latter contains the main aquifer in the area. Also this Quaternary deposit contains reef limestone, which crops out in a strip along the coast (Ramsay, 1986). The shallow aquifer is unconfined, where the depth of the well reaches 2 m in the upstream of the study

area near the mountains at the stream edge. On the other hand, at Al Nuwabi village the depth of wells reach about 45 m below the surface in the alluvium deposits (well 15) where a great potential of groundwater is available. The major groundwater is pumped from alluvial deposits overlying the bed rocks. Most of the drilled wells are placed along and side of the main wadi. All wells are of large diameter with an average diameter of 3 m.

MATERIALS AND METHODS

Groundwater samples are collected during the field study in May 2010. The locations of the sampled well are shown in Figure 2.

About 23 water samples are collected from shallow wells (<50 m) that tap the unconfined alluvial/fracture aquifer of wadi Rabigh. Theses samples are taking after pumping for significant amount of time to get a representative sample, which was necessary to remove groundwater storage in the well. The samples are analyses in the laboratory of Faculty of Earth Sciences, King Abdulaziz University, for their chemical constituents such as calcium, magnesium, sodium, potassium, chloride, bicarbonate, sulfate and nitrate (NO_3^-). The tests are carried out according to standard methods as suggested by the American Public Health Association (APHA, 1998). All sampling bottles are washed with deionized water and again with filtered sample water before filling it to its capacity and then labeled accordingly. Hydrogen ion activity (pH) and Electrical Conductivity (EC) are measured in the field in order to acquire representative ambient aquifer condition. The concentration of the major cations and anions are also determined. Chloride (Cl^-) is determined by standard $AgNo_3$ titration; bicarbonate (HCO_3^-) by titration with H_2SO_4; sulfate (SO_4^{2-}) by gravimeter method using $BaCl_2$; sodium (Na^+) and potassium (K^+) by flame photometry; calcium (Ca^{2+}) and magnesium (Mg^{2+}) by titrimetrically using 0.05 N EDTA and 0.01 N.

All the concentrations of major and minor ions are presented in milligram per liter (mg/l), while the EC is listed in microsiemens per centimeter (μS/cm). The ion balance-error is found within the
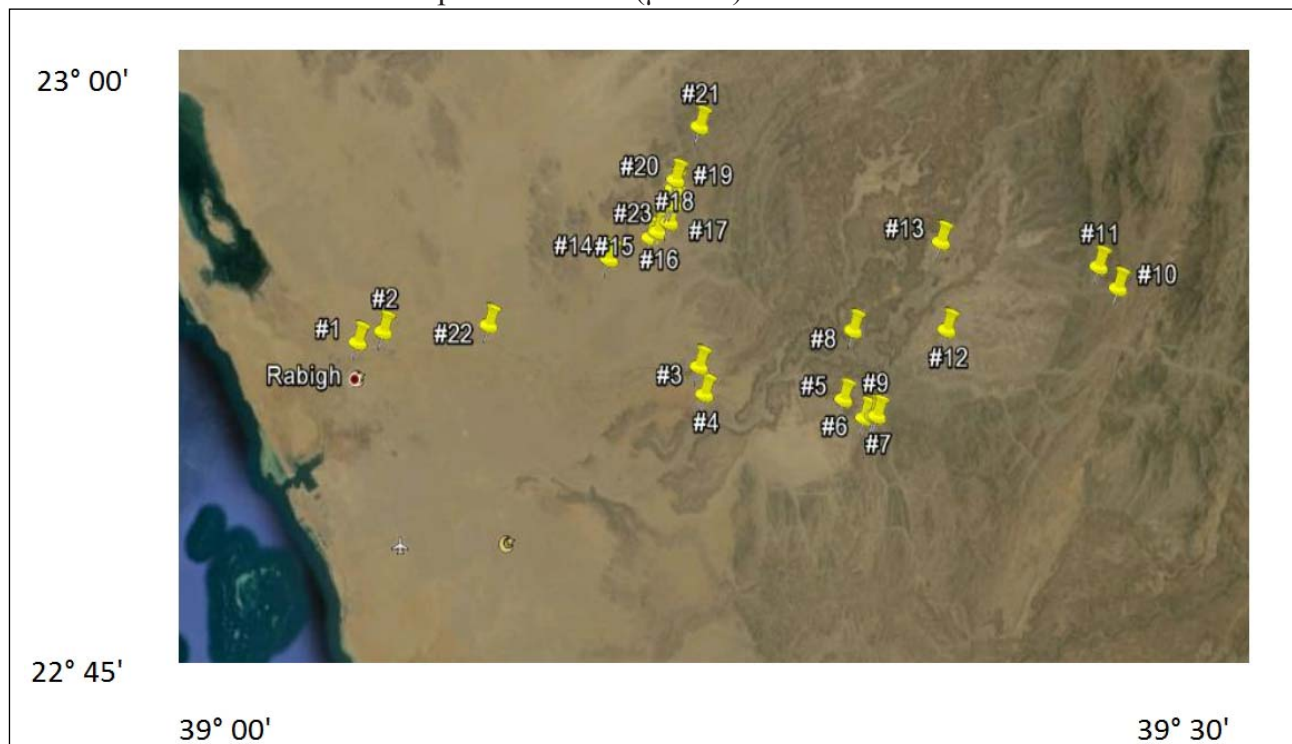

Figure 2. Location map of wells in the study area.

stipulated limit of 5 percent (Mandel and Shiftan, 1981). On the other hand, all mathematical and statistical computations are achieved by using Excel 2007. The details of the analysis data are given in Table 1.

Factor analysis (FA) is a generic term, which describes a variety of mathematical procedures applicable to the analysis of data matrices. It gets its important from in its ability to decrease the huge number of variables to small number of factors (Papatheodorou et al., 2007). On other hand, there are three main reasons that can be recognized for the application of FA on an original data set as 1) to observe and determine groups of well correlated original variables, 2) to decrease the number of variables under investigation, and 3) to create new combinations of original variables (groups) that can then be used as new variables in some further analyses (Davis, 2002).

In order to accomplish FA, there are three basic steps necessary to be done, as the first step is to compute a correlation matrix for all variables. This involves finding the correlation coefficient, which is a measure of interrelation, for all Paris of constituents. The second step in FA is to estimate the factor loading. The final step is to obtain easy interpretation of factors by factors rotation (Suk and Lee, 1999).

Hence, the FA was performed using the SPSS package described by Nie et al. (1975). It is very important to notice that the one step must be done prior to analysis, where the data are standardized to produce a normal distribution of all variables (Hussain et al., 2008; Davis 2002). The two types of FA, namely, R-mode and Q-mode, are used in this work, where R-mode investigates relationships between variables, while Q-mode determines the relationships among samples. Factors with eigenvalues of 1.0 or greater are considered significant as factors with the highest eigenvalues are the most significant (Kim and Mueller 1987).

RESULTS AND DISCUSSION

A statistical summary of the chemical parameters measured in the groundwater samples is already presented in Table 1. It was observed that the pH values of water samples in the study area are in the range of 7.2 – 8.3 with a mean values of 7.8 and standard deviation of 0.3 indicating that the water are generally neutral to slightly alkaline, so, the theses values were found to be in the permissible range of 6.5 to 8.5 according to WHO (2004) standards. The sodium ion concentration (Na^+) in the groundwater samples ranges from 40 to 4,800 mg/l with a mean value of 247.7 mg/

Table 1. Descriptive statistics of water quality parameters in study area.

Parameters	Minimum	Maximum	Mean	Standard Deviation	Coefficient of Variation	Skewness Coefficient.
Ca	35.27	2106.21	217.5	486.5	0.4	2.5
Mg	10.46	352.64	72.9	95.0	0.8	1.6
Na	40.00	4800.00	247.7	1133.6	0.2	2.7
K	1.85	72.39	9.6	17.7	0.5	2.1
HCO_3	135.97	316.83	183.9	56.1	3.3	-0.5
CO_3	7.79	47.48	20.1	11.2	1.8	0.0
SO_4	60.09	3026.91	417.1	761.4	0.5	1.9
Cl	181.51	7819.74	737.8	2206.5	0.3	2.1
NO_3	12.60	90.80	32.5	37.8	0.9	2.7
pH	7.16	8.32	7.8	0.3	30.7	-0.8
EC	1123.00	24500.00	3751.4	6783.4	0.6	1.9
TDS	612.00	16780.00	2405.1	4824.6	0.5	1.8

l and a standard deviation of 1,133.6 mg/l, so comparing this concentration of Na^+ with the recommended limit for sodium in natural water is 200 mg/l (WHO, 2004), it is found that 43% of the water samples fall above this limit.

On the other hand, the EC in groundwater in this study is found in the range from 1,123 to 24,500 µS/cm. The reason of high values of salinity may be due to long periods of aridity and intensive exploitation of groundwater from agricultural and domestic purposes with effective recharge from rainfall. The TDS in the water sample is found to vary from 612 to 16,780 mg/l with a mean of 2,405.1 mg/l and standard deviation of 4,824.6. The wide variations in these values reflect the change in water level, differential weathering and leaching of minerals into groundwater. So, the TDS may be attributed as mainly due to addition of ions by weathering and leaching of nonresistant minerals form rocks.

The order of abundance of the major cations is $Na^+ > Ca^{2+} > Mg^{2+} > K^+$. Totally, 9 samples are found exceeded the desirable limit of Ca for drinking water (200 mg/l), but only 26% of them exceed that of Mg (150 mg/l). The abundance of the major anions is $Cl^- > SO_4^{2-} > HCO_3^-$ and almost 13 % of the samples exceeded the desirable limit of Cl (250 mg/l), while about 35% the samples exceeded the desirable limit of sulfate (250) of the WHO standard (WHO, 2004).

Figure 3 shows Piper diagram of the collected groundwater samples in the study, which shows the hydrochemical characteristics of the plotted samples on the basis of major ions dominance. It indicates that all the groundwater samples are characterized by the dominance of strong acids, Cl and SO_4, over weak acids, HCO_3.

Correlation coefficient is commonly used to measure and establish the relationship between two variables. It is a simplified statistical tool to show the degree of dependency of one variable to the other (Belkhiri et al., 2011). There are two outliers, which may be related to different soil parent materials or geology of the sampling sites. In order to quantitatively analyze and confirm the relation among major ions contents in groundwater samples, Pearson's correlation matrices (Swan and Sandilands, 1995) are used to find relationships between two or more variables. The correlation matrix for the data at hand is shown in Table 2.

The term 'strong', 'moderate', and 'weak' as applied refer to values >0.75, 0.75 – 0.5, and 0.5 – 0.3, respectively. The correlation matrix of 11 variables has been presented in Table 2 where it gives an indication that EC has a strong positive and significant correlation with TDS, Cl^-, Na^+, Mg^{2+}, TH and SO_4^{2-}, while it is moderate with Ca^{2+}. In addition, TDS shows a strong positive and significant correlation with Cl^-, Na^+, Mg^{2+}, TH, and SO_4^{2-}, and low correlation with Ca^{2+}. The high correlation between SO_4^{2-} and EC indicates that sulfates tend to increase in concentration as the water salinity is increased due to evaporation of recharge water and also due to interaction between the groundwater and rocks. Also, the correlation between EC and TDS, TDS and Cl, TDS and Na, TDS and Mg, TDS and SO_4 show strong positive relationship (1.0, 1.0, 0.99, 0.97, 0.76), respectively. The relation between TDS and Ca^{2+} is low (r = 0.47), hence this suggests that the aquifer chemistry is mainly controlled be TDS, EC, Cl^-, Na^+, Mg^{2+} and SO_4^{2-}. The major exchangeable ions, EC and Na (0.97), Na and Cl^- (0.99), TDS and Na^+ (0.99), Ca and TH (0.75), are found to be correlated positively indicating the origin of major cations to be dissolution/ precipitation processes (Khatiwada et al., 2002). Cl and Na have a very good positive correlation (0.99) between each other. The high concentration of Na and Cl, which is noticed in some samples, may suggest the dissolution of chloride salts. The dissolution of halite in water releases equal concentrations of Na and Cl into the solution: $NaCl \rightarrow Na^+ + Cl^-$ (Belkhiri et al., 2011).
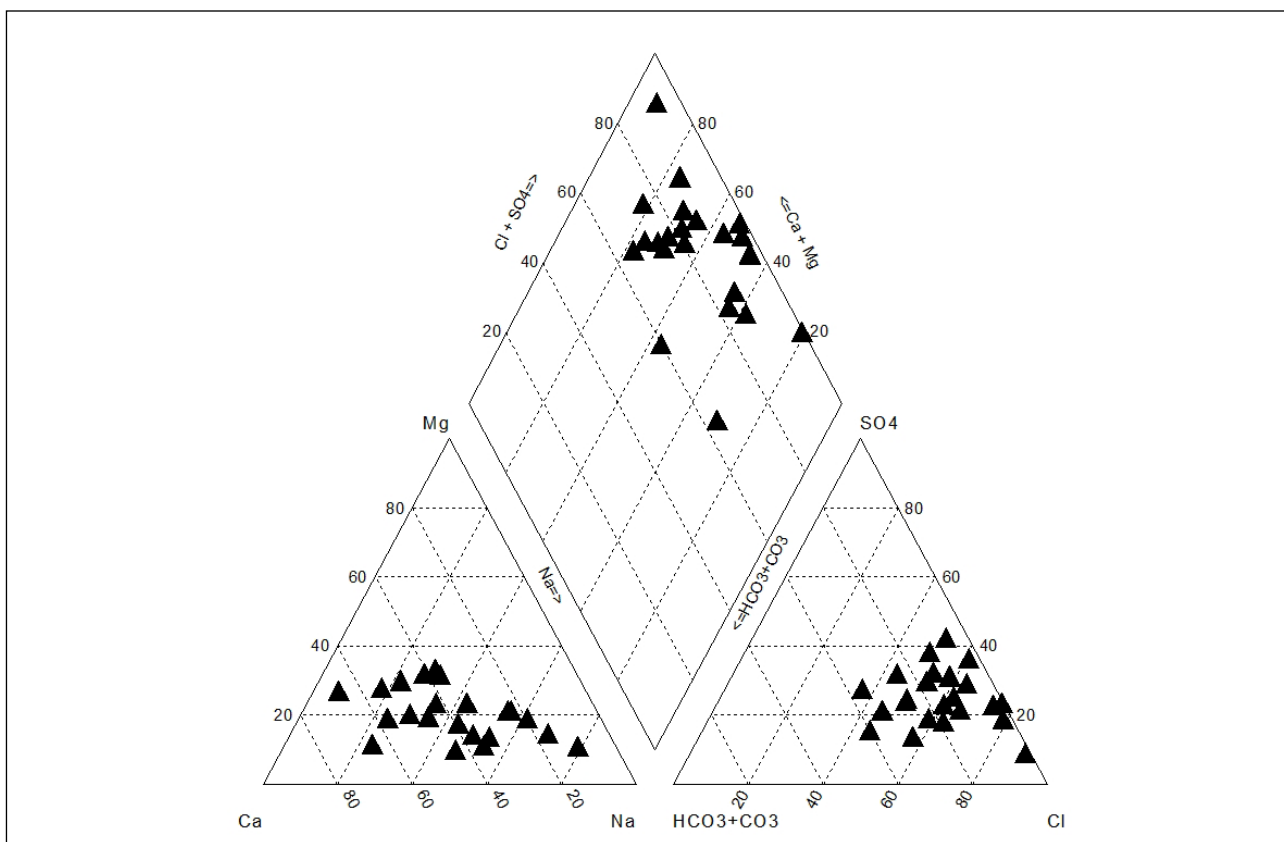
Figure 3. Piper diagram for groundwater samples in wadi Rabigh.

FA is applied separately to hydrochemical data to find the association between the chemical and physicochemical variables of groundwater. Factor extraction is done by principle component. Hence, Table 3 represents the eigenvalues and cumulative variances for each factor. It was necessary to establish Figure 4, which shows the scree plot with the successive eigenvalues in simple line plot. Only factors which has eigenvalues = 1 is accepted as possible sources of variance in the data. The first two common factors represent 80.6% of the total variance.

The factor loading are sorted according to the criteria of Liu et al. (2003), where strong factor loading refers to a absolute loading values >0.75, moderate loading is 0.75 – 0.50 and weak loading as 0.50 - 0.30. Tables 4 shows the results of FA based out on the most significant two factors, which clear that these two factors explain about 80.6% of the total samples variance and commonalities

Table 2. Correlation coefficient matrix for different water quality parameters in study area.

Parameter	pH	EC	TDS	TH	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3?	Cl^-	SO_4^2 ?
pH	1.0										
EC	0.18	1.0									
TDS	0.18	1.00	1.0								
TH	0.15	0.95	0.93	1.0							
Ca^{2+}	0.09	0.53	0.47	0.75	1.0						
Mg^{2+}	0.09	0.96	0.97	0.85	0.29	1.0					
Na^+	0.19	0.97	0.99	0.86	0.32	0.99	1.0				
K^+	0.03	-0.05	-0.07	0.14	0.45	-0.15	-0.14	1.0			
HCO_3?	0.01	-0.54	-0.52	-0.65	-0.20	-0.46	-0.44	-0.09	1.0		
Cl^-	0.18	0.99	1.00	0.92	0.44	0.98	0.99	-0.06	-0.61	1.0	
SO_4^2?	0.13	0.78	0.76	0.73	0.47	0.67	0.74	-0.20	-0.43	0.71	1.0

Table 3. Eigenvalues and cumulative variances.

Factor	Eigenvalues	Cumulative Variances
1	9.114055	70.10811
2	1.358269	80.55634
3	0.877721	87.30804
4	0.734291	92.95644
5	0.412089	96.12635
6	0.233756	97.92448
7	0.155593	99.12135
8	0.084544	99.77168
9	0.021221	99.93492
10	0.005757	99.97921

are generally more than 88%. In this way, these two factors can be use to explain the hydrochemical processes without losing any significant characteristics. Factor 1 represents about 48.1% of the total variance and has high absolute loading for Ca, Mg, K, NO_3 and TH, moderated loading for Na, SO_4, Cl, EC and TDS. This probably shows the results of mineral water reaction in the area, which may be due to the long residence time of the groundwater and increase of water-rock interaction Finally, the calcium and potassium enrichment may have occurred due to the weathering of country rocks through the water flow.

The NO_3 has no known lithologic source, and hence, it reveals pollution, which is attributed to the urban waste waters and agricultural practices involving chemical (nitrogenous) fertilizer applications (Penky et al., 1989; Subba Rao and Krishna Rao, 1990; Somasundaram et al., 1993; Uma, 1993; Ballukraya and Ravi, 1999). The strong negative factor loading pH on factor 1 shows that the decrease of pH emphasizes the weathering process. The strong association of Ca, Mg, Na, and Cl with EC on factor 1 can be explained by the control of groundwater EC with theses contents. The presence of Na and Cl could be interpreted as a signature of the evaporation.

Factor 2 contributes for 32.5% of the total variance of the variables, where it represents low eigenvalues and explains the greatest of the remaining variance and so forth (Table 4), which is characterized by strong positive loading of Na, and Moderate positive loading on SO_4, Cl, Mg, EC,
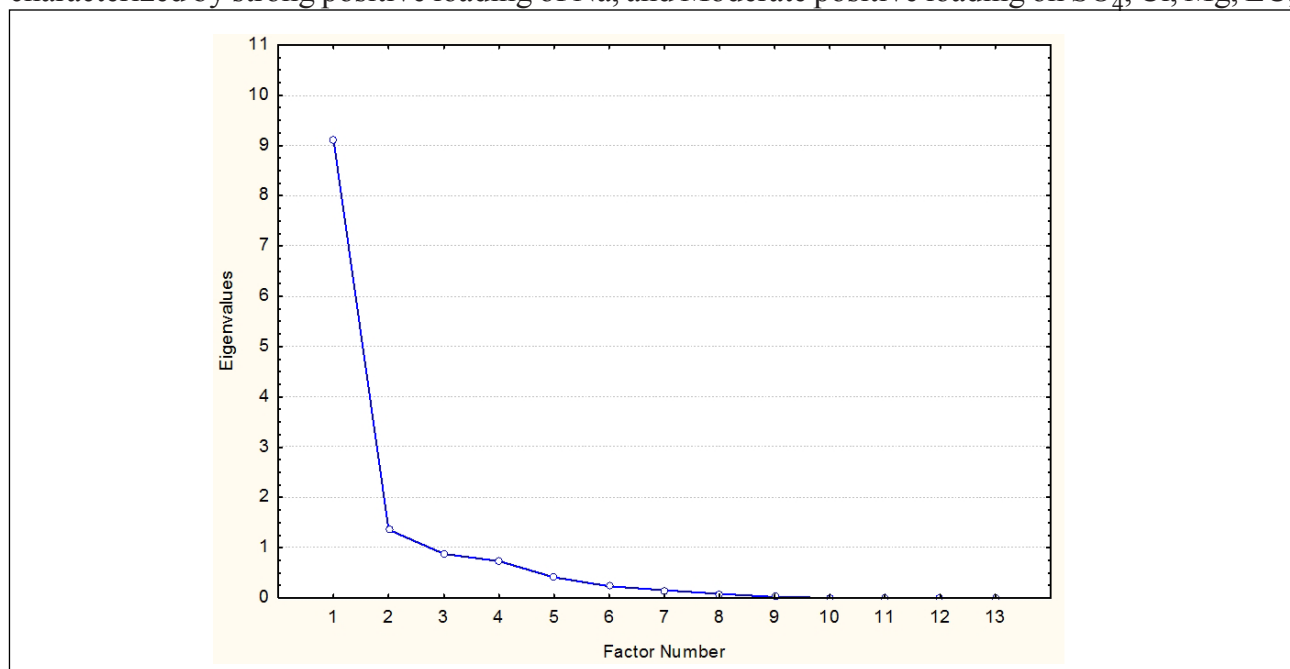

Figure 4. Plots of eigenvalues.

and TDS. The rest of the variables show very low or negative loadings. The loading on K, Cl and TDS are interpreted as representing the role of weathering of country rock, climate and anthropogenic sources (Subba Rao et al., 2001). The loading of bicarbonate could be attributed either to its release during the chemical weathering reaction of silicate minerals and/or resulted from calcite dissolution by recharge water (Alyamani et al., 1994).

On the other hand, the distribution of groundwater samples with respect to the relationship between factor 1 and factor 2 was represented by Figure 5, which shows that 15 water samples can be categorized into the lowest group, which generally yields to near zero values for factor 2 and less than zero for factor 1. So, theses samples are obtained from mixed waters located in the main stream. Seven samples (1, 2, 14, 15, 17, 22, and 23) showed the highest positive source with factor 1 and low scores with factor 2. These samples are collected from wells pumped through fractured bedrocks or downstream area. Sample 3 has high values of factor 2, which is distinct from other samples, and this sample is taken from fracture igneous rocks and has high concentration of major ions, in addition, this well has low rate of pumping compared with others wells.

Table 5 represents the Q-mode analysis for the data according to similarity between samples in this study, where factor 1 has high loading in wells No. 2, 15 and 22, and hence, it is clear that these wells have high salinity and bad well design, which may be leading to conclude that it could be because of anthropogenic pollution (Esteller and Andreu, 2005).

CONCLUSION

Interpretation of analytical data of the groundwater samples in wadi Rabigh shows that the abundance of the major ions in the sequence as $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $Cl^- > SO_4^{2-} > HCO_3^-$. A strong correlation is obtained between major cations (Na, Ca, Mg and K) and anions (Cl, HCO_3 and SO_4). The chemical data of groundwater in wadi Rabigh area is subjected to factor analysis (FA) and the results provide an insight into the underlying controlling hydrochemical processes in the area. The results show that a two-factor model is found suitable, where the first two factors explain 80.6% of the total variance; their loading allow the interpretation about the hydrochemical processes that take place in the area The first factor reveals 48.1% of the total variance and has loading include Ca, Mg, Na K, SO_4 , Cl, NO_3 , EC, TDS and TH. On the other hand,

Table 4. Varimax loading matrix.

Variable	Factor 1	Factor 2	Communality
Ca^{2+}	0.849463	0.316093	0.999855
Mg^{2+}	0.753587	0.631393	0.998371
Na^+	0.520019	0.814885	0.992614
K^+	0.764569	0.428105	0.920157
HCO_3?	0.159181	-0.887026	0.874100
CO_3?	-0.540733	-0.162551	0.771558
SO_4^{2}?	0.524194	0.689460	0.997640
Cl?	0.711921	0.676344	0.999732
NO_3	0.802561	0.036241	0.732635
PH	-0.782921	-0.127024	0.800954
EC(μs/cm)	0.700121	0.700125	0.995515
TDS	0.724985	0.676301	0.999898
T. Hardness	0.855578	0.408334	0.999917
% Variance	48.1	32.5	
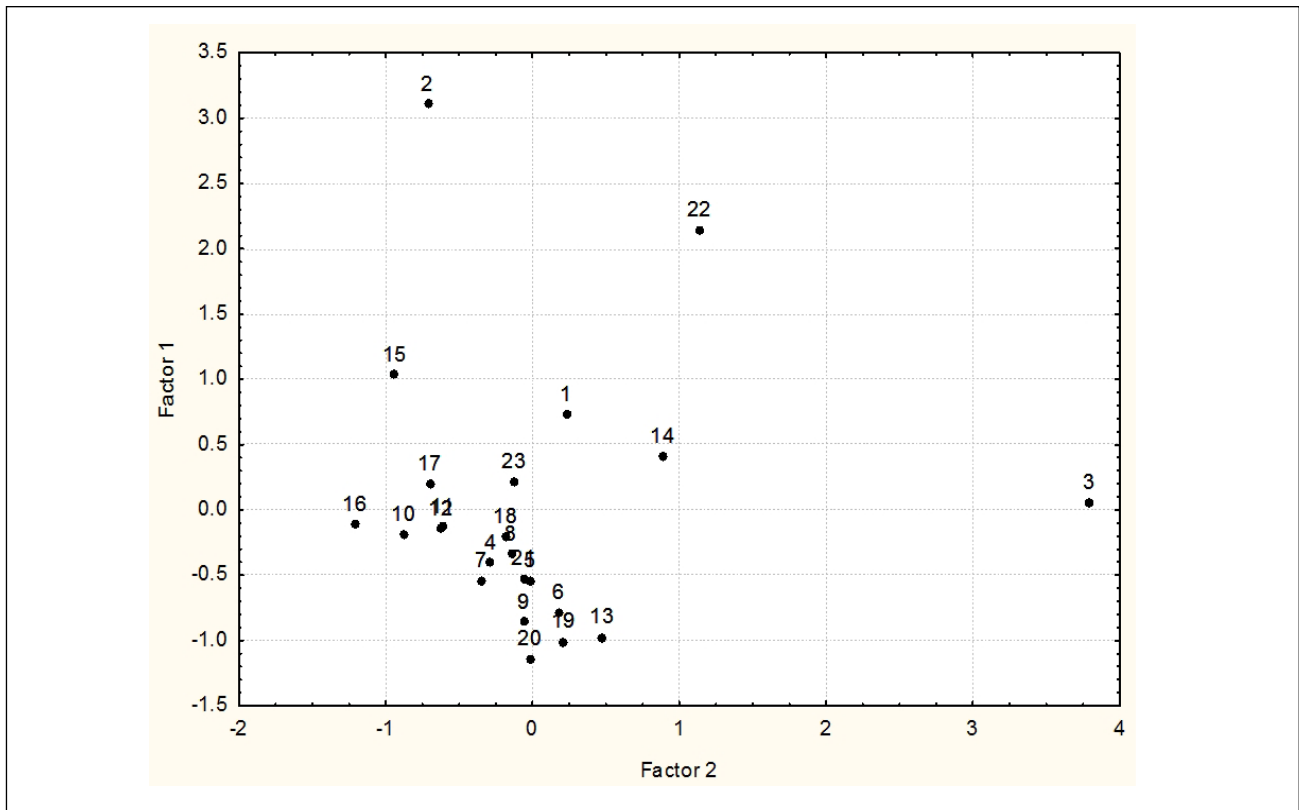
Figure 5. Plot of factor 1 versus factor 2.

Table 5. Varimax score matrix.

Sample No	Factor 1	Factor 2
1	0.73026	0.23203
2	3.10553	-0.71461
3	0.06006	3.79521
4	-0.40750	-0.28645
5	-0.54158	-0.01835
6	-0.78871	0.17713
7	-0.54074	-0.35160
8	-0.33973	-0.14297
9	-0.85853	-0.06030
10	-0.18622	-0.87561
11	-0.12519	-0.61187
12	-0.14838	-0.62247
13	-0.97368	0.47514
14	0.40886	0.88712
15	1.03317	-0.93934
16	-0.11369	-1.20962
17	0.20255	-0.70043
18	-0.20746	-0.18257
19	-1.00641	0.21376
20	-1.14109	-0.01744
21	-0.52569	-0.05964
22	2.14502	1.13778
23	0.21913	-0.12491

the second factor reveals 32.5% of the total variance and has high loading on Na, SO_4, Cl, Mg, EC, and TDS. Factors 1 and 2 represent ions with dominant concentrations, and therefore, the main contributions to the groundwater salinity. The results of this study show that there are many parameters that affect the chemical composition of groundwater in the area including aridity, water-soil-rock interaction and flow, human and agricultural activities. Finally, it is necessary to minimize the effect of human pollution and agriculture and domestic consumption. In conclusion, the FA is useful tool to characterize the study area, where hydrochemical and hydrogeological data area available.

ACKNOWLEDGMENTS

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