

# Assessing of Groundwater Contamination by Toxic Elements through Multivariate Statistics and Spatial Interpolation, Wadi Fatimah, Western Arabian Shield, Saudi Arabia

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**Abstract**— Groundwater is present in the shallow alluvial and fractured bedrocks aquifers of wadi Fatimah, west central Arabian Shield, Saudi Arabia. The impact of human activities and natural processes on groundwater quality is one of the major serious problems for sustainable development in this area. 80 well-representative groundwater samples were analyzed for the total 17 water quality descriptors (variables) including toxic elements which are not considered in traditional techniques for water quality assessments. This study was to assess the levels of groundwater contamination of toxic elements and their spatial distribution in the region, and to identify possible anthropogenic and natural sources of contamination in the area. Multivariate statistical techniques were performed in this study. Cluster analysis in both R and Q modes was used. R-mode analysis is interpreted and there are three major groups. Q-mode shows three main groups related to the same geological formation. Factor analysis revealed that the first three factors account for 85% of the total variance. Factor 1 revealed high loading of Al, Li, B and Cd, suggested interaction between water and geological formation. The second factor represented high loading of As, Pb and Hg, suggested human and agricultural activities. Factor three represented high loading of Si and Fe, which may be resulted from water/weather rock interactions.

**Index Terms**— Groundwater pollution, Multivariate statistics, Wadi Fatimah, Saudi Arabia

## 1 INTRODUCTION

IN arid regions, groundwater is the main source of water uses, and it is subject to contamination due to long time of aridity, human and agricultural activities. The trace element composition of groundwater depends on many natural factors such as the lithology of the aquifer, the quality of recharge waters and the types of interaction between water and aquifer and also on human activities, which can alter these fragile groundwater systems, either by polluting them or by changing the hydrological cycle [1]. In recent years, with the increasing number of chemical and physical variables of water quality, there is a growing need for study and analysis of the groundwater chemistry variables. Multivariate statistical analysis is more rapid and cheap alternative method for assessment of water quality variables.

Multivariate statistical methods have been devised for proper analysis and interpretation of the water quality data [2], [3]. [4]. [5] used principal component analysis for identifying the chemical processes of groundwater quality in southwest of Saudi Arabia. [6] Characterized the

chemical facies of groundwater of Niger delta using factor analysis. [7] is also using factor analysis for identify the hydrochemical processes of groundwater in Wadi Na'man, western Saudi Arabia.

Groundwater contamination by toxic elements is significant problem especially in arid regions. Groundwater quality is subject of atmosphere, biosphere and lithosphere interactions and also by agriculture and human activities. The magnitude of hazards in groundwater depends on chemical composition, concentration of toxic elements and the water bearing formation and water pH.

Because of the groundwater is the main source of water in arid regions, the best planning of water resources management is to define water quality from the areal distribution and the generic aspects, in order to establish as far as possible the qualitative effects of the natural and human influence factors on the water quality. Hence, any fall off in groundwater quality may result in a big reduction in the percentage of resources that can be utilized or may create series problems for water users [8], [9].

Wadi Fatimah is shallow alluvial and fracture bedrock aquifer in western part of Saudi Arabia, and considered as one of the major source of water supplies in the area. Because of the rapid growth of population, long time of aridity and intensive exploitation of groundwater resources from this wadi has led to concern about potential

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water quality impacts. [10] studied the nitrate concentration in the upper reaches of Wadi Fatimah. His study shows that the nitrate concentration in the groundwater exceeded the maximum contaminant level due to the effects of cesspool system in the upper reach of the basin.

The main objectives of this study are to assess the level of groundwater contamination in respect the toxic elements. To determine the degree of associations between the different toxic elements and their areal distribution, and to identify the possible natural and anthropogenic sources of contamination in shallow alluvial aquifer of Wadi Fatimah, western Saudi Arabia.

## 2 GEOLOGICAL SETTING

### 2.1 Rock units

The study area is located in the west central part of Saudi Arabia (Fig. 1). It is occupied by Precambrian Arabian Shield igneous and metamorphic rocks with less frequent sedimentary rocks (Fig. 2). The exposed rock units of W. Ash Shumaysi-W. Fatimah area are classified by [11] into metamorphic, igneous and sedimentary rocks. According to the geologic map of [12], the rock units of the study area (Fig. 2) are subdivided into: i) Intrusive complexes as Makkah suite, Hashfate complex, Kamil suite and Rumayda Granite; ii) Layered metamorphic rocks of green schist- amphibolite facies of Jeddah/ Zibara group; and iii) The Cenozoic rocks which are represented mainly by the siliciclastic succession of Ash Shumaysi Formation.

The sedimentary rocks overlie nonconformably the crystalline rocks, mostly grano-diorite granite-granodiorite and diorite, granodiorite and red metasedimentary series (Fatimah Series). These rocks are represented by the Oligo-Miocene succession of Ash Shumaysi Formation and the Quaternary wadi sediments. Ash Shumaysi Formation is a clastic sedimentary succession forming brown intermittent hills preserved within faulted-down areas along the flanks of W. Ash Shumaysi and W. Fatimah and resting nonconformably on the crystalline rocks (Fig. 2). Ash Shumaysi Formation consists of conglomerates, sandstone, mudstone and carbonate-bearing succession just overlying the Precambrian Arabian shield rocks and the underlying the Oligo-Miocene volcanics (Harrate). The Quaternary deposits: which are represented by unconsolidated deposits occur widely toward the headwaters of the major tributaries. Terraces of alluvial gravel also cover large areas of the coastal plain. They are consisting of well rounded pebble to boulder size fragments and conglomerate.

### 2.2 Wadi Fatimah drainage basin

Wadi Fatimah basin comprises the most important drainage system in the western province of Saudi Arabia (Fig. 3). It considered the major important sources of ground-

water to the cities of Makkah, Jeddah and the surrounding villages and towns. The Red Sea escarpment (Hijaz Highlands) and Harrat Rahat are considered the recharge areas of these basins. Generally, the main course of the basin follow westerly to southwesterly directions towards the Red Sea coast. The drainage of the basins generally is well developed and the pattern is typically dendritic (Fig. 3). Although the local relief generally less than 400 meters above the wadi floor, the wadi networks have many small and large tributaries. They are deep and narrow and their longitudinal profiles are rather gentle and in some areas become irregular. They almost follow N-S, NW-SE and SE-NW directions, which probably controlled by major structures, and smaller faults that commonly control lesser drainage channels. The upper stream parts of the basin is rather narrow, where the width of the main wadi course vary from less than 100 m to more than 1.5 km further downstream, where the alluvium deposits are widespread and rather thicker.

### 2.3 Geomorphologic units of wadi Fatimah

The mountainous region comprises mostly folded and faulted Precambrian rocks (Hijaz Highlands) and Tertiary lave flows (Harrat Rahat). These are present along the northwestern and southeastern flanks of wadi Fatimah. They form a longitudinal block that extends from the northeast to the southwest (Fig. 1). However, this block is interrupted by several wadi courses i.e. wadi Dafin and wadi Al Sheib. The mountainous areas are highly fragmented into a relatively small isolated outcrop. It rises between 400 and 1960 meter above sea level. However, in the vicinity of the Hijaz Highlands, isolated summits over 600 m are observed. Steep-sided wadis in wadi Fatimah dissect the upland region, many of which reflect the faulting that has taken place throughout the area such as Al Yammaniyyah and Al Shamiyah sub-basins.

The pediments bound the mountainous from the west and are marked by their elongated features, which trend in a westerly direction and sometimes appear as small knobs. The pediments are marked by thin layer of alluvial and aeolian sediments resting on highly weathered surface of Precambrian rocks.

The coastal plain is the most westerly morphological unit, and it is quite different from the previous two. It has a width ranging from 5 km to more than 25 km. The predominant features are the recent alluvial plains built from sediments transported and laid down by the waters of the main wadis which run rapidly through mountainous and pediment regions. These deposits are widespread and relatively thicker. The dominant surface forms here are huge, gently sloping alluvial fans, aeolian deposits, and less extensive talus deposits at the base of the ridges. The alluvial deposits consist essentially of fine gravel, sand, silt and in some areas clay is observed.

## 2.4 Structural elements

The Precambrian layered rocks were intensively folded and faulted, while the plutonic rocks appear less

Samples were analyzed in the laboratories of the Faculty of Earth Sciences, Saudi Arabia. The accuracy of this analytical technique was controlled using appropriate standards. Statistical summary including the mean, standard

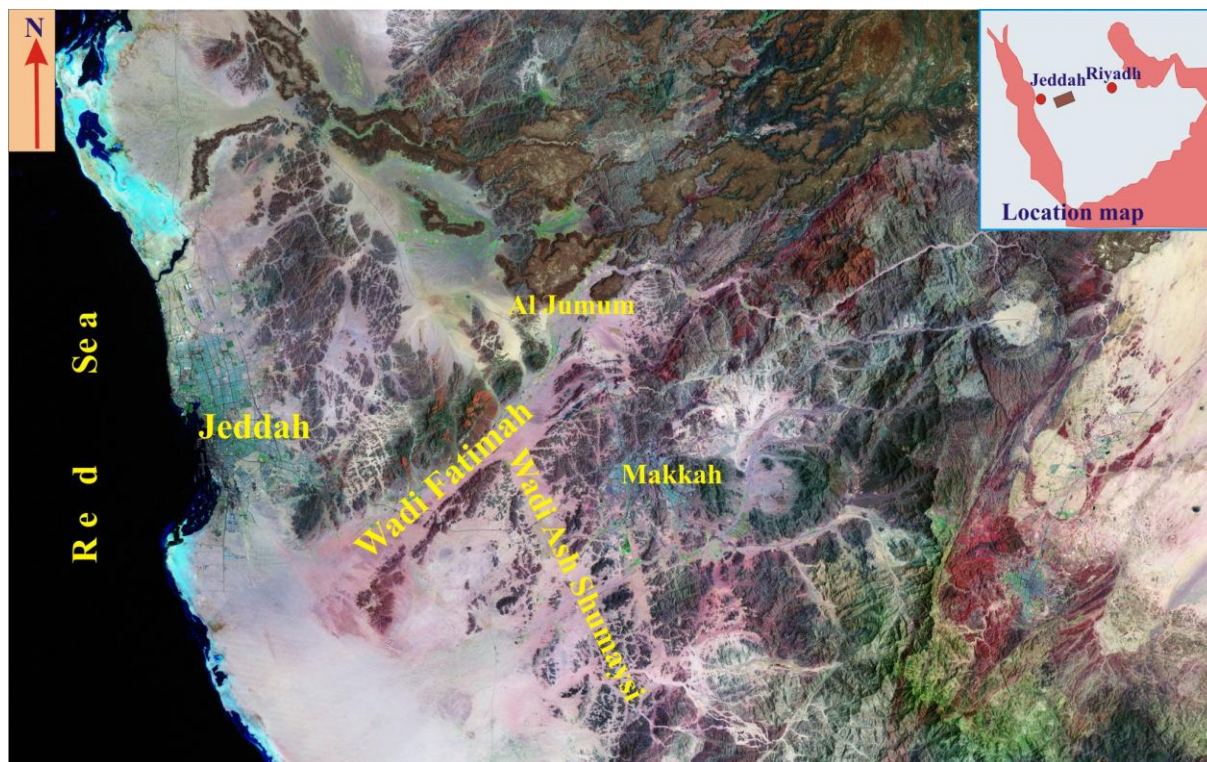


Fig. (1): Satellite image of wadi Fatimah area.

deformed. The Tertiary sedimentary rocks were faulted but not folded. The volcanic rocks of the Harrat Rahat are essentially undeformed. There are three main fracture sets, these are (i) north-northeasterly faults; (ii) east-northwesterly faults; and (iii) southeast trending faults of the Red Sea fracture system.

## 3 METHODOLOGY AND SAMPLING COLLECTION

A total of 80 water samples were obtained from shallow wells (<70 m) that tap the unconfined alluvial/fracture aquifer of Wadi Fatimah. These representative groundwater samples were collected from different tributaries in the Wadi catchments area to preserve the uniform distribution of sampling sites over the study area. The sampling locations of the study are shown in Fig. 4 [8]. Groundwater samples of the main stream were taken from the alluvial and fracture aquifer in winter, 2004. Trace elements were analyzed in each sample for a total of 17 water quality descriptors (variables), these elements are: As, Zn, P, Pb, Ba, B, Si, Al, Li, Cu, Fe, Hg, Mn, Cd, V, and Rb. Among these, only pH was measured in the field.

deviation, coefficient of variation, and skewness of trace elements are shown in Table 1.

### 3.1 Cluster Analysis

Cluster analysis is the name given to an assortment of techniques designed to perform classification by assigning observation to group so each is more or less homogeneous and distinct from other groups [13]. So there are two types of cluster analysis: R and Q-modes. In this study, R-mode and Q-mode were used such that R-mode depicts relationships between variables, while Q-mode identified relationships between samples [14], [15]. So the hydrochemical results of all samples were statistically analyzed. Generally, prior to cluster analysis data were normalized, the weight per group method was applied in Euclidean distance.

### 3.2 Factor Analysis

Factor analysis is a multivariate statistical technique that can be utilized to examine the underlying patterns or relationships for a large number of variables and summarize information in a smaller set of factors or components for



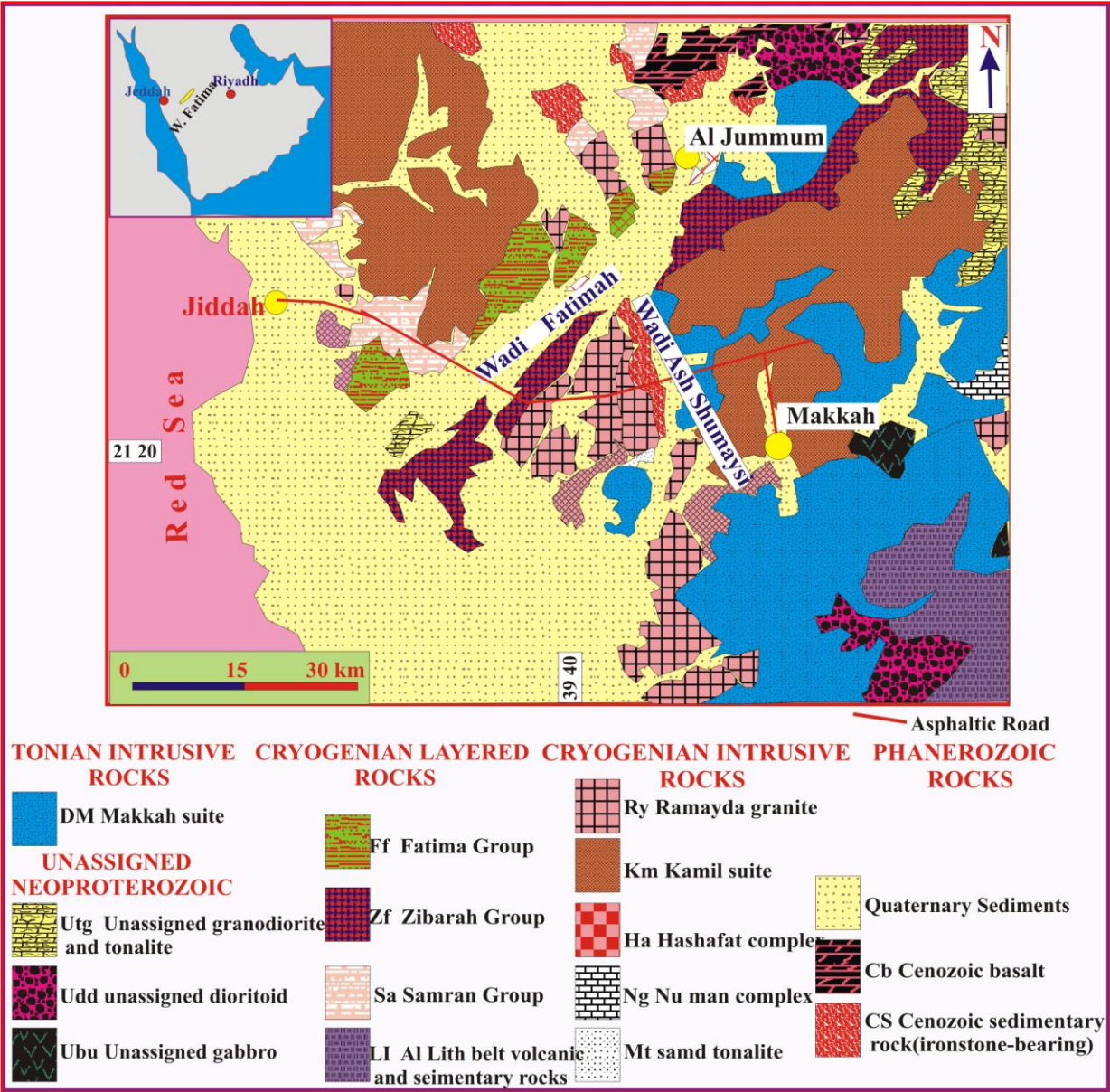


Fig. (2): Geologic map of Makkah district including wadi Fatimah area [12].

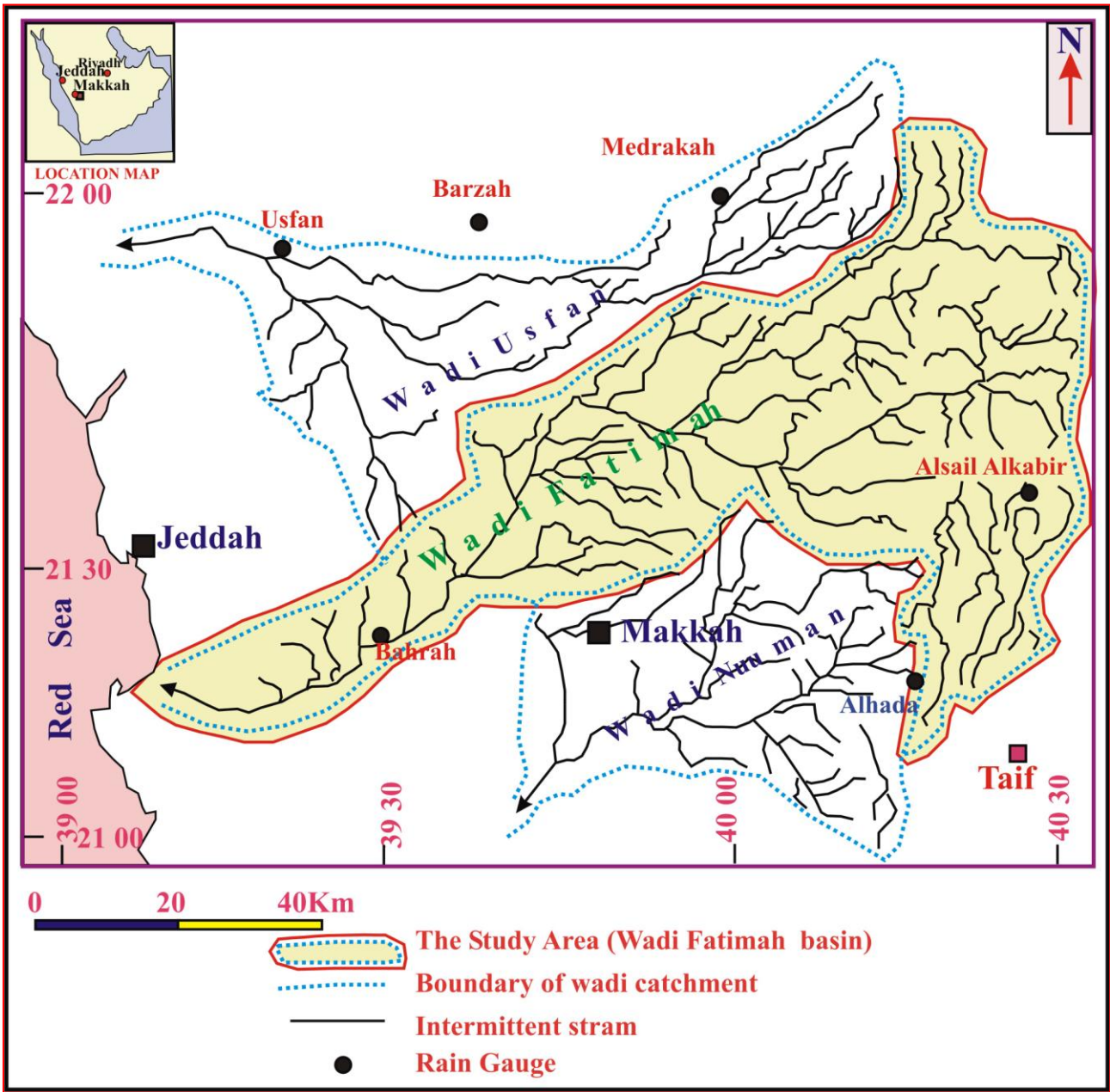


Fig. (3): Drainage basin map of wadi Fatimah

	Max	Min	Mean	St.Dev.	Skew	Co.Var.
As	0.09	0.00026	0.015	0.023	1.98	1.55
Zn	0.36	0.0001	0.044	0.069	3.32	1.59
P	4.16	0.046	0.626	0.540	3.35	0.86
Pb	0.07	0.001	0.020	0.020	1.41	1.00
Ba	0.56	0.037	0.208	0.088	0.64	0.42
B	8.54	0.372	1.612	1.390	2.45	0.86
Si	25.06	4.89	9.832	3.004	2.07	0.31
Al	0.90	0.00256	0.062	0.152	3.25	2.46
Li	0.60	0.002	0.089	0.145	2.35	1.62
Cu	0.06	0.0013	0.021	0.012	0.64	0.58
Fe	0.32	0.005	0.032	0.054	4.42	1.68
Hg	0.17	0	0.018	0.038	3.05	2.10
Mn	0.28	0.001	0.020	0.037	5.10	1.84
Cd	0.02	0.0001	0.004	0.004	1.71	1.06
V	0.70	0.00213	0.213	0.196	0.19	0.92
Rb	0.16	0.0046	0.097	0.055	-0.42	0.57
Ph	7.90	7.1	7.487	0.205	0.36	0.03

Table (1): Statistical summary for trace elements (mg/l).

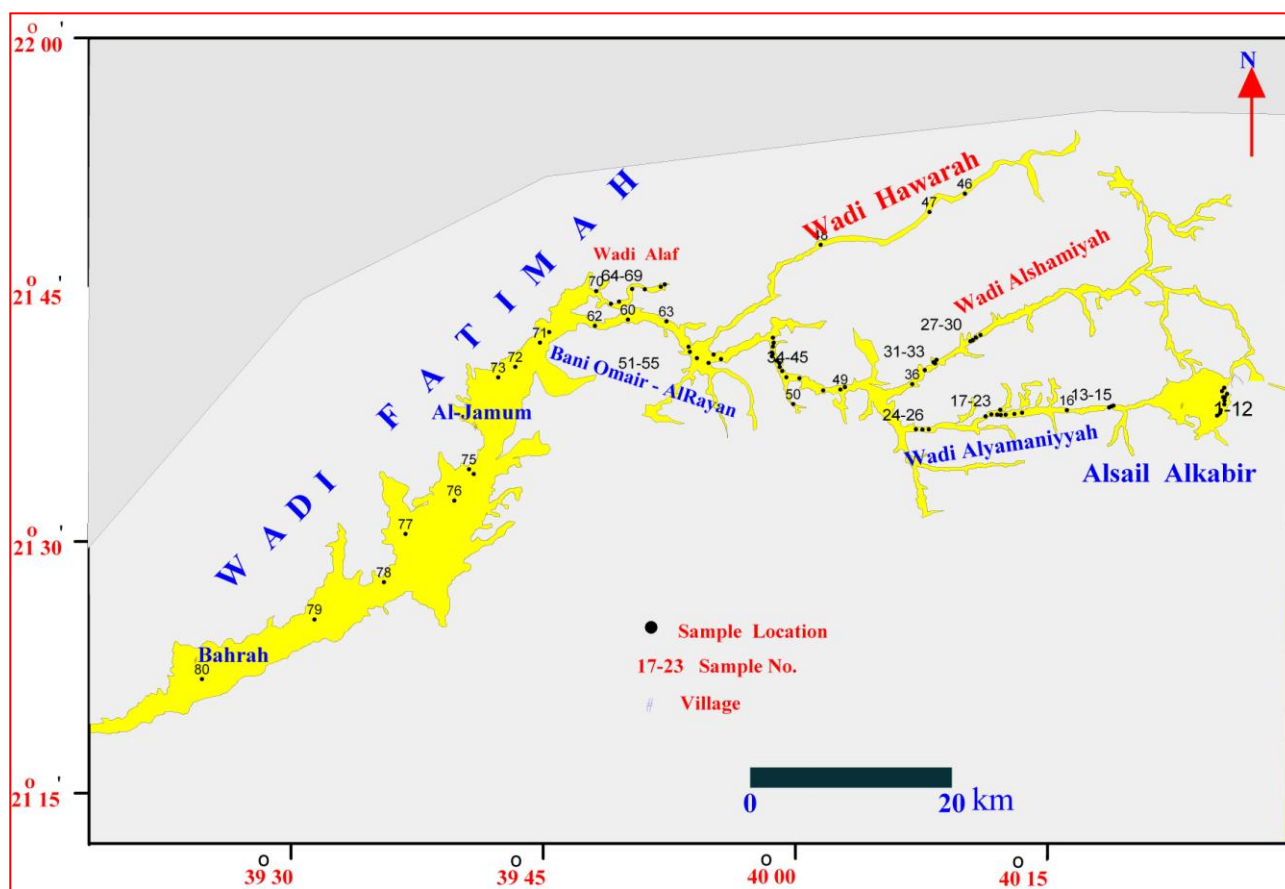


Fig. 4. Location map of groundwater samples.

	As	Zn	P	Pb	Ba	B	Si	Al	Li	Cu	Fe	Hg	Mn	Cd	V	Rb
Zn	0.07															
P	0.38	-0.10														
Pb	<b>0.74</b>	0.06	0.37													
Ba	0.31	0.04	0.36	0.37												
B	0.28	-0.05	<b>0.68</b>	0.19	0.37											
Si	-0.01	0.08	0.40	-0.00	0.15	0.25										
Al	<b>0.54</b>	0.05	0.41	0.27	0.28	<b>0.76</b>	0.13									
Li	0.35	0.05	<b>0.45</b>	0.28	0.27	<b>0.76</b>	0.12	<b>0.84</b>								
Cu	0.18	-0.05	<b>0.73</b>	0.16	0.35	<b>0.57</b>	0.24	0.36	<b>0.46</b>							
Fe	0.18	0.11	<b>0.45</b>	0.14	0.15	<b>0.40</b>	0.38	0.38	<b>0.42</b>	0.27						
Hg	<b>0.66</b>	0.02	0.27	<b>0.56</b>	0.11	-0.05	-0.04	0.00	-0.06	0.11	-0.07					
Mn	-0.06	-0.08	0.34	-0.00	0.08	0.16	0.35	0.07	0.15	0.26	0.34	-0.14				
Cd	<b>0.64</b>	0.12	0.38	<b>0.54</b>	<b>0.49</b>	<b>0.48</b>	0.05	<b>0.61</b>	<b>0.56</b>	0.22	0.27	0.16	-0.04			
V	0.10	-0.15	<b>0.56</b>	0.16	0.24	<b>0.55</b>	0.04	0.39	<b>0.56</b>	<b>0.60</b>	0.32	-0.25	0.38	0.29		
Rb	<b>0.49</b>	0.04	<b>0.45</b>	<b>0.44</b>	0.23	0.07	0.12	0.14	0.20	0.31	0.07	0.34	0.20	0.35	0.38	
Ph	0.12	-0.16	0.07	0.02	0.08	0.07	0.07	0.07	0.02	0.08	-0.03	0.01	-0.01	0.15	0.09	0.17

Table 2. Pearson correlation matrix for trace elements (Bold number significant with 95% confidence level).

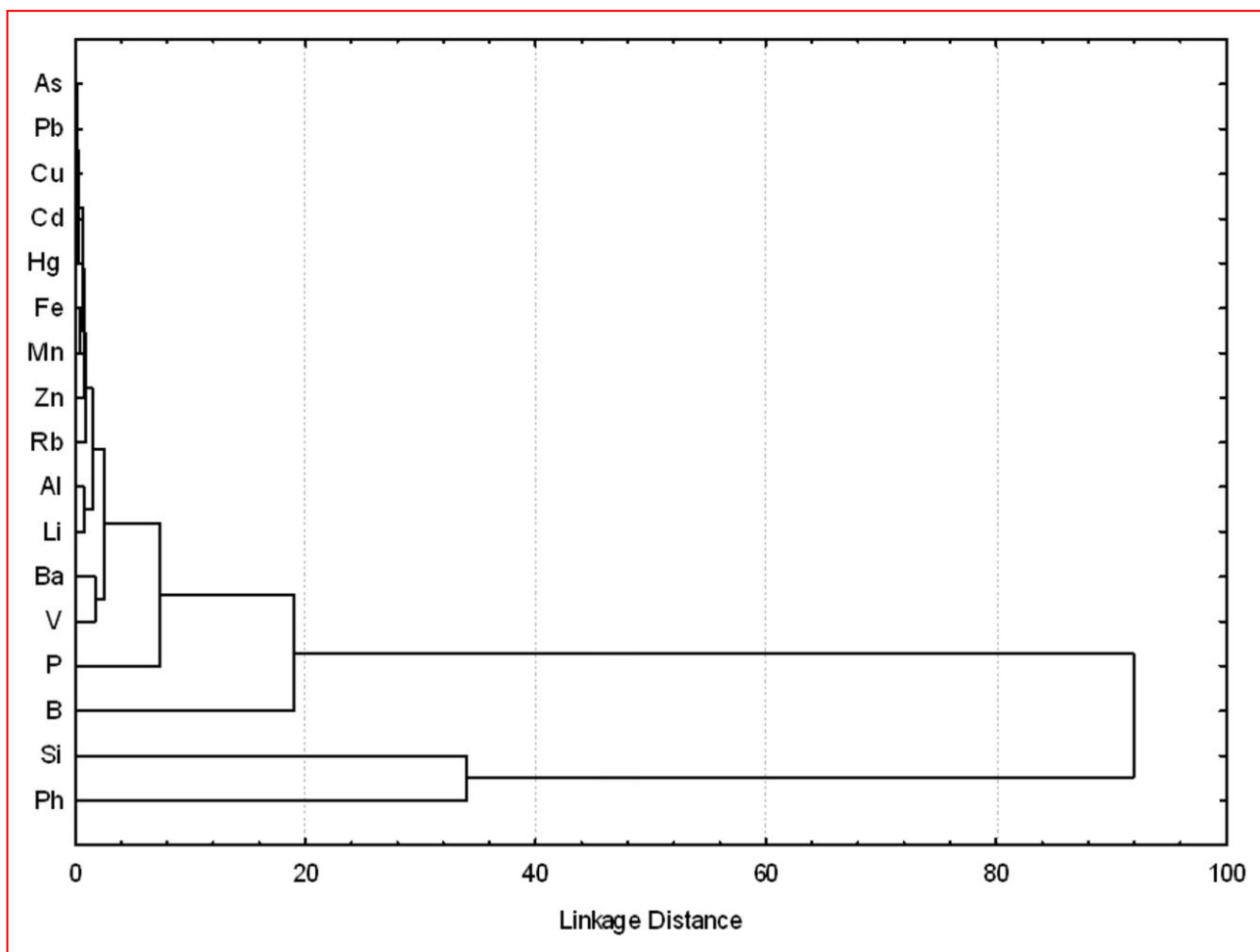


Figure 5. Dendrogram for 17 variables from cluster analysis in R-mode



prediction purposes [14]. Principle component analysis (PCA) is the most frequently employed factor analytic approach. PCA defined as an orthogonal linear transformation that transforms the variables to a new coordinate system such that the greatest variance by any projection of the variables comes to lie on the first coordinate (called the first principal component), the second greatest variance on the second coordinate, and so on. PCA is theoretically the optimum transform for a given data in least square terms [3], [16], [17], [15]. To determine the number of components to extract, data obtained from laboratory and field analysis were used as variable inputs. Prior to the analysis, the data were standardized to produce a normal distribution of all variables [18], [14]. The weights of the original variables in each factor are called loadings; each factor is associated with a particular variable. Communality is a measure of how well the variance of the variable is described by a particular set of factors [19].

## 4 RESULTS AND DISCUSSION

The Pearson correlation coefficients for 17 pairs of variables were computed and presented in Table 2. Some of these elements are medium to high positive correlated to each other, for example, Arsenic (As) is highly correlated with Lead (Pb), Aluminum (Al), Mercury (Hg) and Cadmium (Cd). On the other hand, Zinc (Zn) is totally uncorrelated with other elements.

The analytical results of multivariate analysis were performed for the set of 80 samples and 17 variables. Figure 5 shows the R-mode cluster analysis dendrogram of the 17 descriptors. The variables cluster into three major groups. From this dendrogram one can find the relationship between different variables, the dendrogram shows a high correlation between major ions (As, Pb, Cu, Cd, Hg), which indicated surface water recharge and releasing during the dissolution of the plutonic acidic and intermediate igneous rocks of the study area. Other group of phosphorous (P) and Boron are highly associated with each other indicated anthropogenic origin. The third cluster shows the strong association between silica and Ph values.

Figure 6 shows the clustering of the basins in Q-mode according the similarity. Three main groups can be verified in this figure. The first cluster shows a high similarity between the wells in the same geological formation of Wadi Alyamaniyyah and Wadi Alshamiyyah (see Fig. 1). The second cluster belong of Wadi Hawarah which originated from Basaltic formation. Third group belongs the main stream of Wadi Fatimah.

Factor analysis was also performed for this study. Figure 7 shows the scree plot with the successive eigenvalues in a simple line plot. The first three common factors

represent 85% of the total variance. Table 3 shows the R-mode analysis according to the loading of each variable on each factor and the percentage of the total variance accounted for by each factor in the rotated three factors model. The first rotated factor, representing 37% of the total variance, revealed high loading of Al, Li, B and Cd. These elements are most likely derived from water interaction with the acidic and intermediate igneous rocks. It is associated with aluminum forms during mineral weathering of an igneous rock composed primarily of alkali feldspar together with other minerals, such as orthoclase, anorthite, albite, and micas and the interaction of groundwater in the gabbroic and syenite rocks composition in addition to aluminum silicate minerals weathering from underlying geology.

The second component accounts for about 30% of the total variance with high loading of As, Pb and Hg, suggesting the effect of human and agricultural activities. The third factor contribute only 18 % of the total variance with high loading of Si and Fe. Other elements produced very low loading.

The distribution of samples with respect to the relationship between factor 1 and factor 2 is shown in Fig. 8. Most of the samples can be categorized into the three group, group A generally yielding positive values for factors 1 and 2. These samples were obtained from mixed waters located in the main stream. Group B contains most of samples around zero values for factors 1 and 2. Group C of six samples (wells 16-21) showed the highest positive scores with factor 2 and negative scores with factor 1. These samples were mainly located in high agricultural activities area. Figure 9 shows a plot of factor 1 versus factor 3, where 2 main groups are present in this figure. Group A represent samples of main stream of Wadi Fatimah, where group B represent the uperstream tributaries. In this figure, sample 12 has the highest values of concentration in all elements, where sample 53 has high value of Mn, These outlier samples were most likely subjected to poor well design and anthropogenic pollution [20].

## 5 TRACE ELEMENTS OF WADI FATIMAH GROUNDWATER

The analysed trace elements of wadi Fatimah show the following distribution:

*Aluminum (Al):* In the study area, the average Al content is 0.062mg/l which is very low when compared with WHO guideline of Al (0.2 mg/l, Table 4). The concentration of Al will depend on the availability and extent of weathering of the aluminosilicates such as clays, pyrophyllites, feldspars, micas and other related minerals. High concentration of Al in soils and groundwater may also be attributed to a number of factors including the availability of dissolved organic matter and fluoride [21].



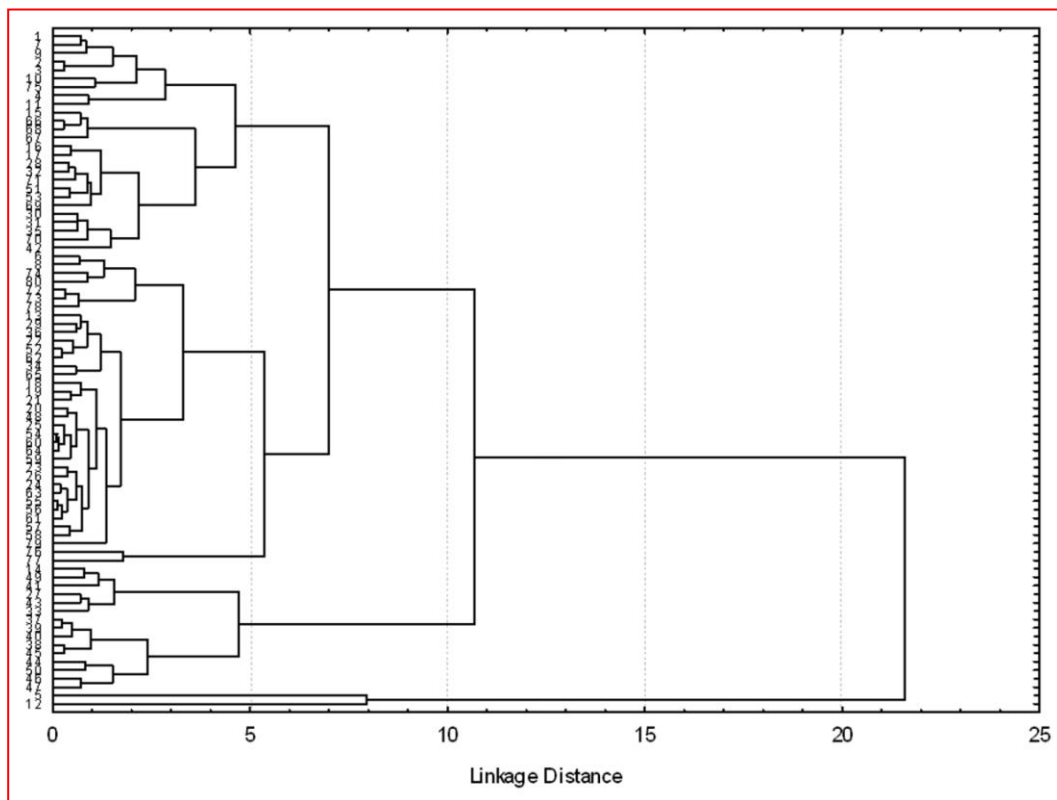


Figure 6. Dendrogram for 80 samples from cluster analysis in Q-mode.

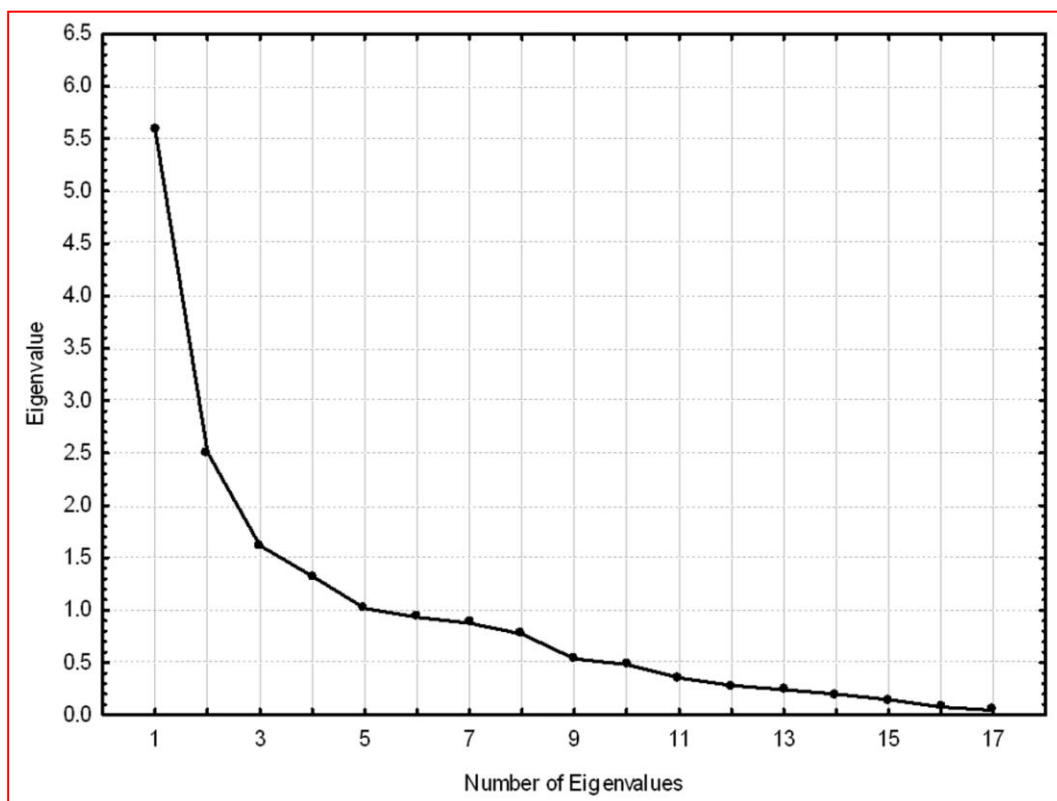


Figure 7. Plot of eigenvalue

Variable	Factor1	Factor 2	Factor 3	Cummunality
As	0.404446	0.830360	-0.036590	0.859210
Zn	0.143215	0.103864	0.339659	0.070604
P	0.347238	0.382198	0.391420	0.803943
Pb	0.249316	0.818113	-0.017190	0.721089
Ba	0.381428	0.332230	0.164360	0.300041
B	0.798648	0.004145	0.169554	0.802692
Si	0.035957	0.004841	0.855788	0.322952
Al	0.903019	0.120607	0.056186	0.837442
Li	0.867216	0.048121	0.069275	0.825639
Cu	0.325809	0.163486	0.209751	0.596453
Fe	0.415245	0.002976	0.615893	0.373123
Hg	-0.152917	0.849526	-0.062784	0.726998
Mn	-0.070497	-0.070475	0.552626	0.536709
Cd	0.709243	0.460103	0.030187	0.710235
V	0.433710	-0.039227	0.044310	0.599400
Rb	-0.004711	0.640180	0.130249	0.583430
Ph	0.061282	0.047950	0.037435	0.040608
Expl.Var %	37	30	18	

Table 3. Vraimax loading matrix.

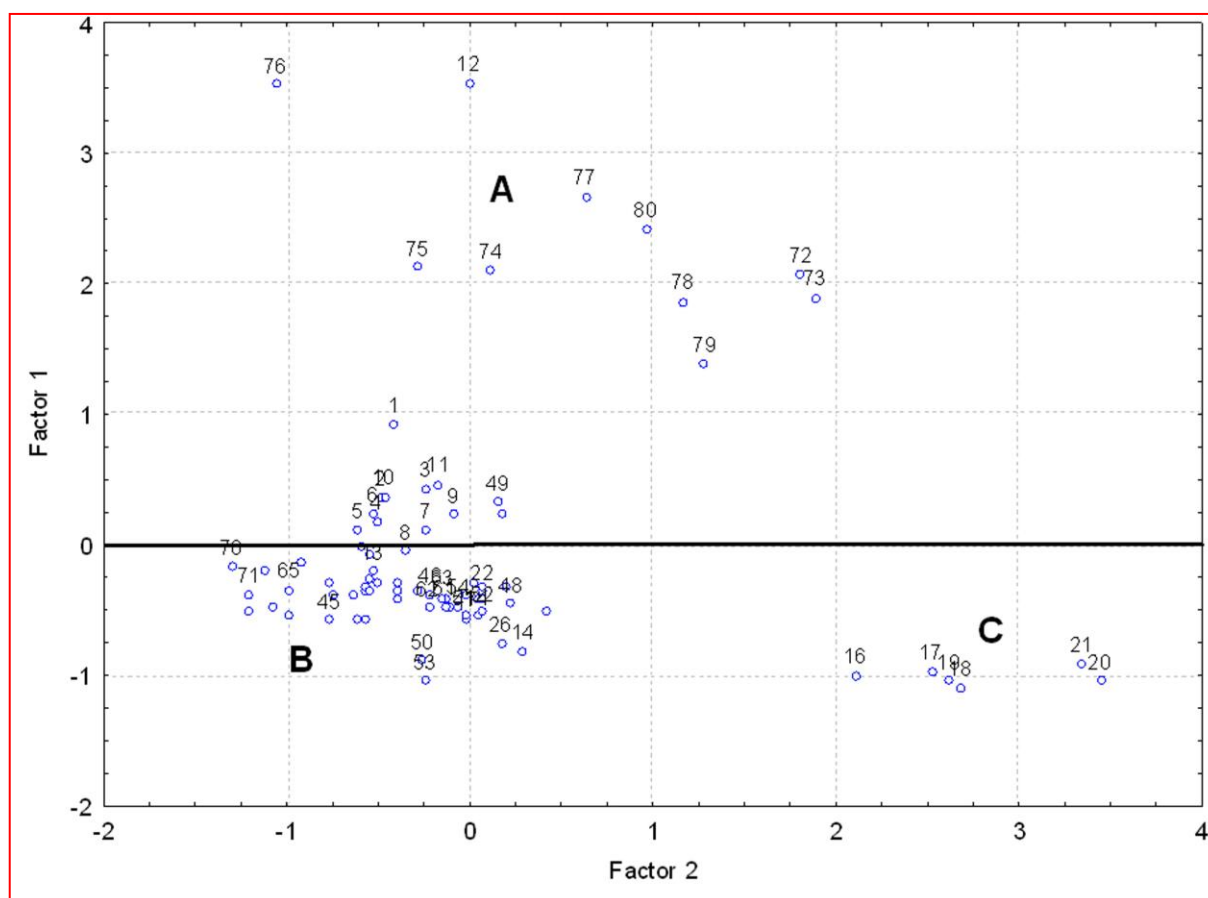


Figure 8. Plot factor 1 versus factor 2

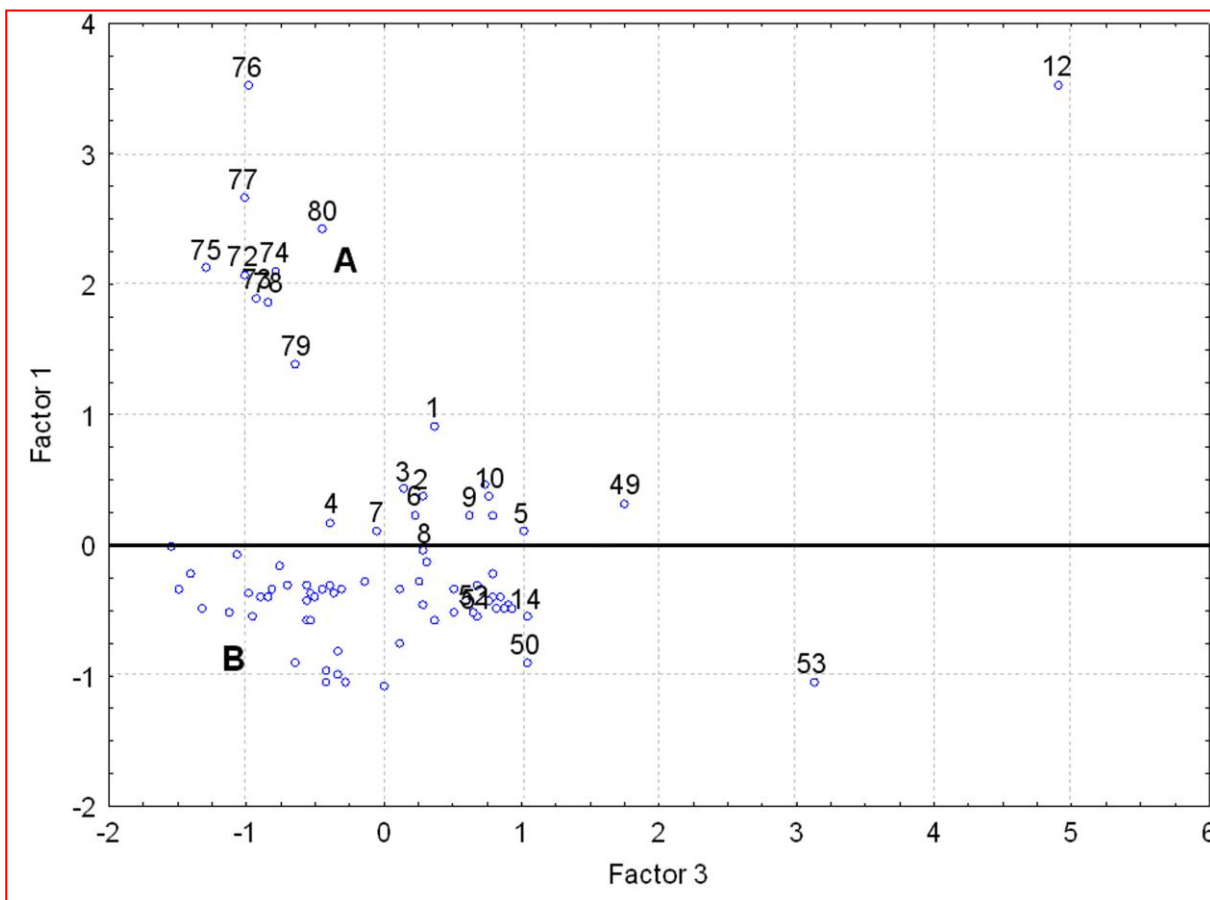


Figure 9. Plot factor 1 versus factor 3 scores

**Arsenic (As):** which is the most important element affecting the groundwater quality. The average value of arsenic is 0.015 mg/l which is similar to that recommended by the WHO (Table 4).

**Barium (Ba):** The average barium content of wadi Fatimah area is 0.208mg/l which is similar to the WHO (0.3 mg/l).

**Boron (B):** The maximum value of boron is 8.54 mg/l while its minimum value is 0.372 and the average is 1.6126mg/l which is higher than that recorded in the normal groundwater (Table 4) and also higher than the [22] recommended values (0.3 mg/l). The toxic effect for B in humans is found to occur above 20 mg /l<sup>-1</sup> [23]. Boron usually occurs as a nonionized form as H<sub>3</sub>BO<sub>3</sub> in soils at pH less than 8.5, but above this pH, it exists as an anion, B(OH)<sub>4</sub><sup>-1</sup> [24]. It is very soluble in soils and can be leached especially in sandy soils [25]. It is also dispersed in the environment through fertilizer application. Since the pH was less than 8.5 for all the samples, it is more likely that B would be in the nonionized than the ionized state.

**Cadmium (Cd):** The cadmium in wadi Fatimah groundwater is higher than that recommended by the WHO guideline. The average of Cd is 0.004 mg/l. Cadmium is used normally as a coating material, paint pigment, in plastics, fungicide and is a constituent of some fertilizers. Copper, Cd and Zn exist in aqueous form in the predominately +2 state. Generally, Zn exists as Zn<sup>2+</sup> state in pH below 7.7 (Liptrot, 1989). Cadmium (II) oxide occurs in some Zn ores which suggests that the two have identical properties such as that both have the +2 being the most stable oxidation state (Liptrot, 1989). In natural waters, Cu, Cd and Zn occur in the 2<sup>+</sup> form.

**Copper (Cu):** The average copper content of wadi Fatimah is 0.021 mg/l which is very low when compared with that of WHO (2 mg/l).

**Iron (Fe):** The average Fe content is 0.032 mg/l which is lower than the recommended WHO iron level (< 0.3mg/l). Iron dissolved in groundwater is in the reduced ferrous iron form. This form is soluble and normally does not cause any problems by itself. Ferrous iron is oxidized into ferric iron on contact with oxygen in the air or by the action of iron related bacteria. Ferric iron forms insoluble

Symbol/ formula	Normally found in fresh water/surface water/ground water	Health based guideline by the WHO	Wadi Fatimah Groundwater (Present study)
Al		0,2 mg/l	0.062
As		0,01 mg/l	0.015
Ba		0,3 mg/l	0.208
B	< 1 mg/l	0,3 mg/l	1.612
Cd	< 1 µg/l	0,003 mg/l	0.004
Cu	2mg/l	2 mg/l	0.021
Fe	0,5 - 50 mg/l	0.3 mg/l	0.032
Pb		0,01 mg/l	0.020
Mn		0,5 mg/l	0.020
Hg	< 0,5 µg/l	0,001 mg/l	0.018
Zn		3 mg/l	0.044
Li			0.089
Rb			0.097
V			0.213

Table (4): The average values of the trace elements of wadi Fatimah compared with those of the [22] guideline.

hydroxides in water. These are rusty red and cause staining and blockage of screens, pumps, pipes, reticulation systems etc. If the iron hydroxide deposits are produced by iron bacteria then they are also sticky and the problems of stain and blockage are many times worse.

*Lead (Pb)*: Lead (average 0.001 mg/l, Table 1) and it is relatively higher than the WHO (0.01, Table 4). Lead on the other hand is used in automobile industries in form of tetramethyllead.

*Manganese (Mn)*: which is present in wadi Fatimah by very low content (average 0.020 mg/l) and it is relatively lower than the WHO (0.01, Table 4).

*Mercury (Hg)*: Hg which is important for the water quality. The average Hg in wadi Fatimah area is 0.018mg/l (Table 3) which is relatively higher than the WHO values (Table 4).

*Zinc (Zn)*: The average Zn content of wadi Fatimah basin is 0.044 mg/l which is lower than that recommended by WHO guideline (3 mg/l). Zinc is used as an anticorrosion agent where it is coated on iron pipelines to protect them against corrosion. During the construction of the boreholes galvanised pipelines were used. Corrosion of pump parts could also lead to Zn being released into the groundwater.

*Lithium (Li)*: The average Li content of wadi Fatimah

groundwater is 0.089 mg/l. Li may be derived from granite rocks where minerals rich in Li could be found.

*Rabidium (Rb)*: The average Rb content of wadi Fatimah ground water is 0.097mg/l

*Vanadium (V)*: The average V content of wadi Fatimah ground water is 0.213mg/l.

### Source of Trace Elements

Oxidation and dissolution rocks of gabbroic composition will contribute trace elements such as, Cu, Zn, Li, Cd, V and Mn. The source of these trace elements will be associated with the major cations such as Ca<sup>2+</sup>, Mg<sup>2+</sup>, Fe, Na<sup>+</sup>, Al and Si which are considered the major cations in the rocks of gabbroic composition. Whereas, in the weathering granitic rocks will contribute trace elements of Cu, Ba, Rb, Pb and As, These elements will be associated with the major ions such as Na<sup>+</sup>, K<sup>+</sup>, Al and Si.

## 6. CONCLUSION

The distribution of trace elements in groundwater is mainly controlled by different processes. The groundwater has a large range of chemical composition [27], [28], [29]. The trace element composition of groundwater depends not only on natural factors such as the lithology of the aquifer, the quality of recharge waters and the types of interaction between water and aquifer, but also on hu-



man activities, which can alter these fragile groundwater systems, either by polluting them or by changing the hydrological cycle [1].

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