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Assessment of hydrochemical quality of groundwater in Wadi Almawaheb and Qa'a asawad area, Dhamar city (Yemen)

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Abstract

The main objective of this study was to assess the quality of groundwater for irrigation at Wadi Almawaheb and Qa'a Asawad, in Dhamar city-Yemen, where the study was conducted in May 2016, Thirty Six groundwater samples were collected from different wells of the study area for the physico-chemical analysis. The results revealed that Potential Hydrogen (pH) of groundwater samples ranged from 6.7 to 8.6, the Electrical Conductivity (EC) ranged from 380-6327 µS/cm, the Total Hardness (TH) from 59.88 to 2224 $mg.L^{-1}$ and Sodium Adsorption Ratio (SAR) 0.54-7.1. The Water quality was classified according to USDA and FAO systems (Guides). According to USSL 1954, the classes were C2-S1, C2-S2, C3-S1, C4-S1, and C4-S2 with 62%, 3%, 22 %, 8% and 5% of the wells, respectively. Based on FAO 1985, the classes were severing problem, slight-moderate and none problem and according to FAO 1992, they were moderate saline water, primary drainage water and groundwater. However, according to the above mentioned classification systems, there are no risk for SAR to affect soil permeability. A various physicochemical parameters of groundwater have been studied and analyzed by calculating the correlation coefficients and principle component analysis (PCA) between them. A chemical and physical analysis showed that there is a significant difference among the types of used water in some chemical properties. The results revealed that all water samples analyzed were very suitable for irrigation except two samples that have a highly saline which will effect on planted crops.

1. Introduction

Water quality analysis is one of the more important issues in groundwater studies. The hydrogeochemical study reveals the zones and the quality of water that are suitable for drinking, agricultural and industrial purposes. Further, it is possible to understand the change in quality due to rock-water interaction or any type of anthropogenic influence. Groundwater often consists of seven major chemical elements Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, Cl^{-}, HCO_3^{-} and SO_4^{-2} [1-3]. This is becoming increasingly important throughout the world. They are considered today as one of the major sources of drinking water supply to the population. This groundwater is cleaner (non-polluted) and do not require very large treatments compared to the surface waters. The variation of chemistry in groundwater in a so-called natural environment is mainly due to the interaction between these waters and the mineral composition of the aquifer material in which they circulate. Thus, such waters will have an acceptable quality and a relatively low level of chemical elements. However, groundwater is constantly exposed to the pollution risks, the degree and intensity of which are dependent on several parameters, whether natural or anthropogenic. Yemen is one of the most populous countries in the world [4]. It is already facing a severe water crisis. Mostly due to high population growth, misguided agricultural development and a vulnerable climate to climate change, this crisis may soon reach catastrophic levels [5]. Many towns are facing a serious water shortage. The water resources sustainability perspective, the major source of concern is the continuously increasing demand for water in water supply and the groundwater irrigated agriculture in the same well field area [6, 7]. Soil scientists use the following categories to describe irrigation water effects on crop production

and soil quality are salinity hazard - total soluble salt content, sodium hazard - relative proportion of sodium (Na^+) to calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions, pH, Alkalinity - carbonate and bicarbonate, and specific ions chloride (Cl^-), sulfate (SO_4^{2-}), boron (B), and nitrate nitrogen (NO_3 -N)[8].
Water sources in the study area start to deteriorate due to the presence of wastewater treatment plant (WWTP) in the city of Dhamar in the down up region and the flow of WWTP into the agricultural areas, according to studies not published in 2004 by Haidar and another study in 2007 by Alkadasi and also according to reports of the Center for Agricultural Research in Dhamar, in addition to the field visit by the researcher.Where a lack of sewage disposal and solid waste disposal systems is threatening water resources in Wadi AlMawaheb and Qa, in Aswad. The lack of organization of solid waste collection in these areas is a problem that leads to wasteful dumping of waste In Dhamar city, there are no domestic garbage collection. For example, waste disposal can create serious groundwater and surface water pollution, especially when there is no control of waste disposal in or near the water. In our study area, a lack of adequate sanitation facilities continues to threaten water resources in Wadi AlMawaheb and Qa, in Aswad.
Where the aim of this works is to evaluate groundwater quality at wadi Almawaheb and Qaʾa Aswad Area in the city of Dhamar, Yemen by using the Physico-chemical analysis and to discuss the major ions chemistry of in this case the methods proposed by correlation and PCA.

2. Study Area

The study area represents wadi Al mawaheb and Qaʾa Aswad is located in the northeast of Dhamar city between 16º 09'00" to 16º 29' 00" north latitude and 43º 40' 00" to 43º 80' 00" East longitude and covers an area of 74.5 km^2 with a total population of 20,000 inhabitants [9].

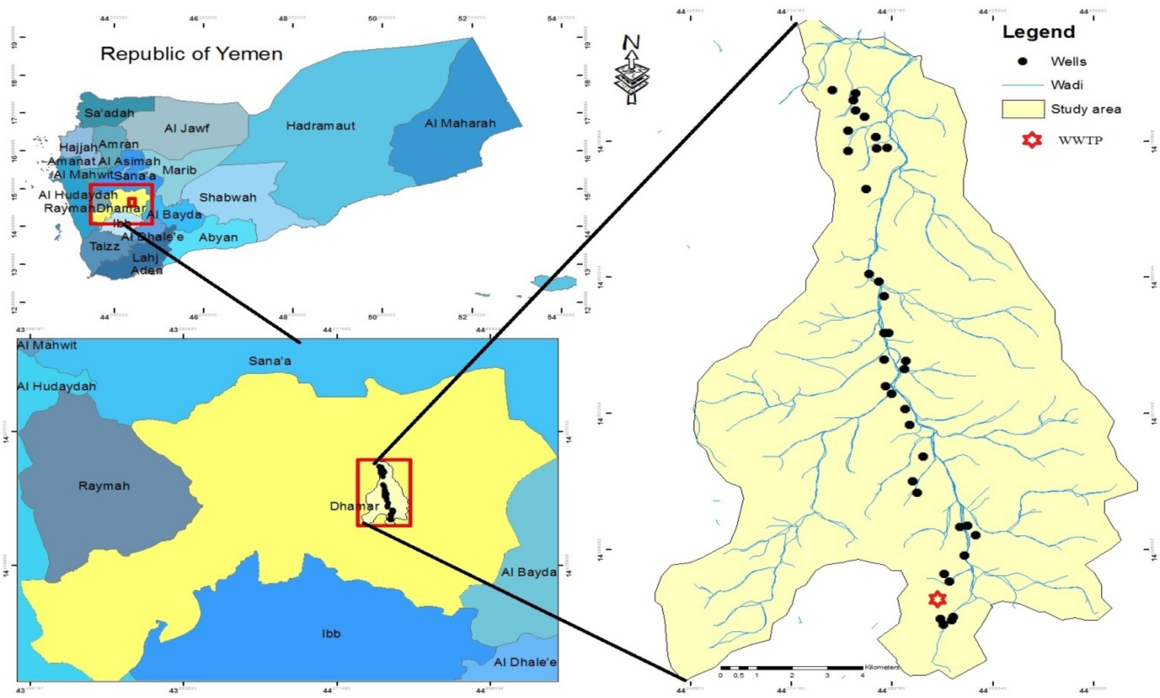

Figure 1: The location of the study area

The geology of the study area contains of Quaternary alluvium, Tertiary and Quaternary volcanic formations consisting of Basalts, Rhyolites, and ignimbrite ash flows with occasional granite intrusions. These rocks have been intersected by obscured thrust faults generally running in southern-northern direction. Tertiary basalts in the northern zones in the northern parts of a study area, there are outcrops of tertiary basalts. This tertiary ash flows and Rhyolite/Dacite are also encountered. In the southern parts of the study area, there are outcrops of basalts lavas [9,10].
The climate of the study area is arid and dry arid, it has two distinct rainy seasons, separated by a distinct dry interval (mid May-mid July). The first rainy period starts in mid March - beginning of April, the second rainy period starts mid July - beginning of August and stops abruptly at the end of August. The months September through to February are generally dry, although occasional thunderstorms may bring some rain during these months [11,12].

Average rainfall during 1999-2015 is about 431.1 mm /year. As for the wide depressions in the east and northeast ward. The mean annual rainfall over the surface water catchment of Dhamar depression is found to be 200- 400 mm. The monthly rainfall distribution shows that most of the rainfall amounts precipitate within five months of which most part occurs in March, April and May and the other higher amount occurs in July and August. It is affected by moderate weather, the average maximum annual temperature is during 1999-2015 about 24°C, as much as the surface water potential relay by direct mean on the rainy season, and while most of the rain water Evapotranspiration (about 90%), to the atmosphere. only 10% of the total rainfall infiltrate into groundwater recharge and forms the run-off portion according by national Water Resources Authority (NWRA,2015).

3. Material and Methods

3.1. Sampling

Groundwater samples were taken in May 2016 from thirty-six wells and surface water.All samples represent at wadi Almawaheb and Qa'a Asawad north east of Dhamar city. Some samples are located at the down up of the wastewater treatment plant. The samples were collected after pumping for 10 min. Clean and dry polyethylene bottles were used for samples collection. Following the standard procedures properly tagged and stored in a refrigerator before analysis for various quality parameters [13,14]. The water samples taken for analysis were transported at low temperature (4 ° C) in portable coolers to the general agricultural research laboratory at Dhamar where the analyzes were carried out. These samples are hermetically sealed and protected from light, and refrigerated in the laboratory prior to analysis in the laboratory in Dhamar, Yemen.

3.2. choice of Physico-chemical parameters

Directly after taken sampling were measured electrical conductivity (EC, TDS &T), in the field using a (session Conductivity Meter medal CEL/850 (HACH). After sampling temperature taken in laboratory, and the pH were evaluated by pH-422. Subsequently, the samples were analyzed for their chemical constituents such as Ca^{2+}, Mg^{2+}, Na^{+}, k^{+}, Cl^{-}, HCO_3^{-} and it was using the standard methods proposed for American Public Health Association [15].Concentrations of Ca^{2+} and Mg^{2+} were estimated titrimetric ally using 0.02 N EDTA and Concentrations of HCO_3^{-} and Cl^{-} by $H_2SO_4$and $AgNO_3$ titration (0.02 N), respectively. Concentrations of Na^{+} and K^{+} were measured using a Flame photometer (PFP 7) [16].

3.3. Statistical data analysis

Statistical analysis was carried out using statistical package for social sciences (SPSS Version22, Originlab2017 and AquaChem2014.4). The Physico-chemical parameters for all the study samples were analyzed by calculating Pearson's correlation coefficient and principle component analysis provides indirect means for rapid monitoring of water quality [17,18]. In this study, the results of the Physico-chemical parameters for all samples are summarized in Table-1, where it has been compared with Yemen standards for irrigation water quality samples were assessed for suitability irrigation water in Table-1.

Table 1: Statistical analysis of all samples for study area

Parametres	Unity	Mean	S.D	Min	Max	Yemen Standars
T	°C	26.625	4.72	20.00	41.5	-
pH	-	7.62	0.36	7.00	8.6	6.5-8.4
EC	µS/cm at 25°C	1168.25	1346.54	380.00	6327.00	700-4000
TDS	mg/l	747.68	861.79	243.2	4049.28	450-3000
Na^{+}	mg/l	89.60	96.25	17.25	460.00	70-207
K^{+}	mg/l	5.16	3.52	2.346	19.55	-
Mg^{2+}	mg/l	96.53	134.70	4.008	591.18	-
Ca^{2+}	mg/l	38.14	46.72	7.296	231.04	
Cl^{-}	mg/l	295.64	345.28	48.81	1531.36	140-350
SO_4^{2-}	mg/l	143.68	135.31	49.64	537.93	-
HCO_3^{-}	mg/l	133.48	216.93	9.61	1104.69	90-500
TH	mg/l	397.67	521.61	59.88	2224.81	-
SAR		2.13	1.35	0.54	7.10	9

4. Results and discussion

4.1. Physical and chemical Characteristics of water used for Irrigation:

The validity of water for irrigation depends on some physicochemical parameters to effects on crop production and soil quality. These include Electrical Conductivity, Sodium hazard - relative proportion of sodium to calcium and magnesium ions, pH - acidic or basic, Alkalinity - carbonate and bicarbonate, specific ions: chloride, and another potential irrigation water quality parameter that may affect its suitability for an agricultural system is microbial pathogens, which has often been neglected [19].

The laboratory analytical results (Table-1) indicated that the pH values ranged between 7.0– 8.6 in all water samples, with a mean value of 7.62 ± 0.36 according to Yemen standards of irrigation, most of water samples have a good quality for irrigation, where optimal limits of 6.5 and maximum permissible limit of 8.4 and only two of the samples (well 5 and well 16) in village mankatha have a higher pH values >8.4 (Figure 2).

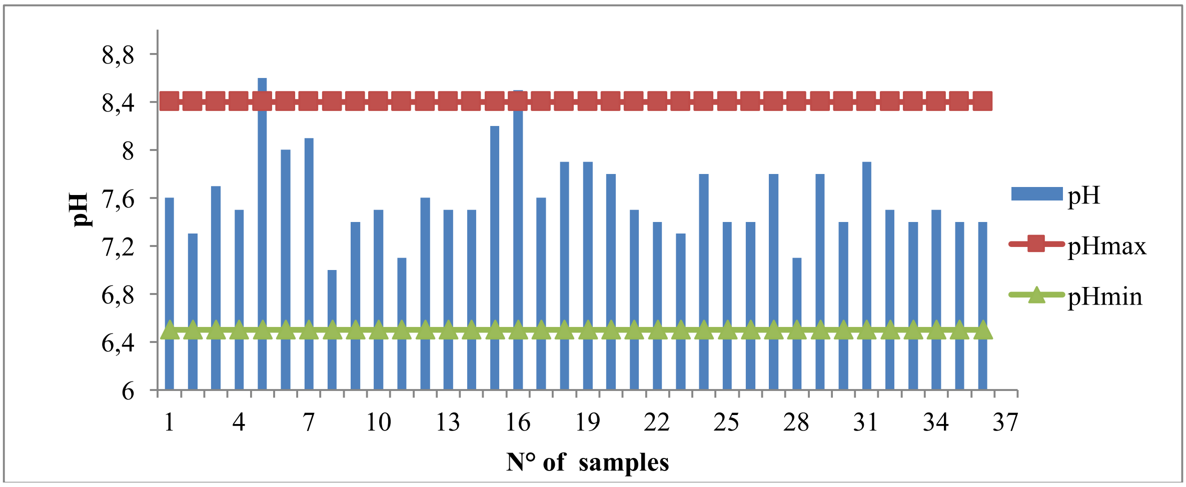

Figure 2: Variation of pH as in function of all samples

The correlation between physical and chemical parameters shown in Table 2, it was as follows:

- The correlation between the chemical standards with each other was positive.
- The correlation between physical correlations with each other was negative.
- While the correlation between physical and chemical parameters was positive with electrical conductivity, TDS and TH. and negative with pH, T and good with SAR.

Table 2: Correlation coefficients among various water quality parameters around study area

	T	pH	EC	TDS	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	HCO_3^-	TH	SAR
T	1.00												
pH	0.40	1.00											
EC	-0.35	-0.17	1.00										
TDS	-0.35	-0.17	1.00	1.00									
Na^+	-0.22	-0.02	0.93	0.93	1.00								
K^+	-0.15	-0.01	0.78	0.78	0.87	1.00							
Mg^{2+}	-0.41	-0.21	0.99	0.99	0.89	0.74	1.00						
Ca^{2+}	-0.38	-0.22	0.96	0.96	0.91	0.80	0.95	1.00					
Cl^-	-0.39	-0.16	0.98	0.98	0.95	0.81	0.97	0.95	1.00				
SO_4^{2-}	-0.24	-0.16	0.93	0.93	0.82	0.64	0.93	0.89	0.88	1.00			
HCO_3^-	-0.35	-0.16	0.97	0.97	0.91	0.77	0.95	0.90	0.94	0.84	1.00		
TH	-0.40	-0.21	0.99	0.99	0.91	0.77	0.99	0.98	0.98	0.93	0.95	1.00	
SAR	0.36	0.48	0.33	0.33	0.57	0.45	0.22	0.26	0.33	0.26	0.34	0.24	1.00

The temperature was in the range of 20 to 41.5°C with a mean value of 26.63 ± 4.72 (Table-1). This results show that the temperature of most samples is suitable for irrigation beyond one well, and its temperature is very high. The correlation between water temperature with all parameters in Table-2 shows a significant positive relationship with pH (0.41) & SAR (0.37) and significant negative relationship EC (-0.35), TDS (-0.35), Na^+ (-0.23), K^+ (-0.15), Mg^{2+} (-0.41), Ca^{2+} (-0.38), Cl^- (-0.39) SO_4^{2-} (-0.24), HCO_3^- (-0.35), TH (-0.40).

The electrical conductivity is found between 380–6327 µS/cm with a mean value of 1168.25 ± 1346.54 in Table 1. The figure 3 shows that most of the samples of the study are of good quality for irrigation according to Yemen standards of irrigation (optimal limits of 700 µS/cm and maximum permissible limit of 4000 µS/cm).

The electrical conductivity distribution of groundwater in the entire study area is shown in that lower EC values (<3000 µS/cm) were found in most samples, only two samples (well-1 & well-2), they are the higher EC values (>4000 µS/cm), its located in the passage of wastewater treatment plant down up. The correlation between electrical conductivity and all samples show in the table.3, significant positive relationship with TDS (1.000), Na^{+} (0.94), K^{+}(0.78), Mg^{2+}(0.99), Ca^{2+} (0.96), Cl^{-}(0.98), SO_4^{2-} (0.93), HCO_3^{-} (0.97), TH (0.99), and SAR (0.33).

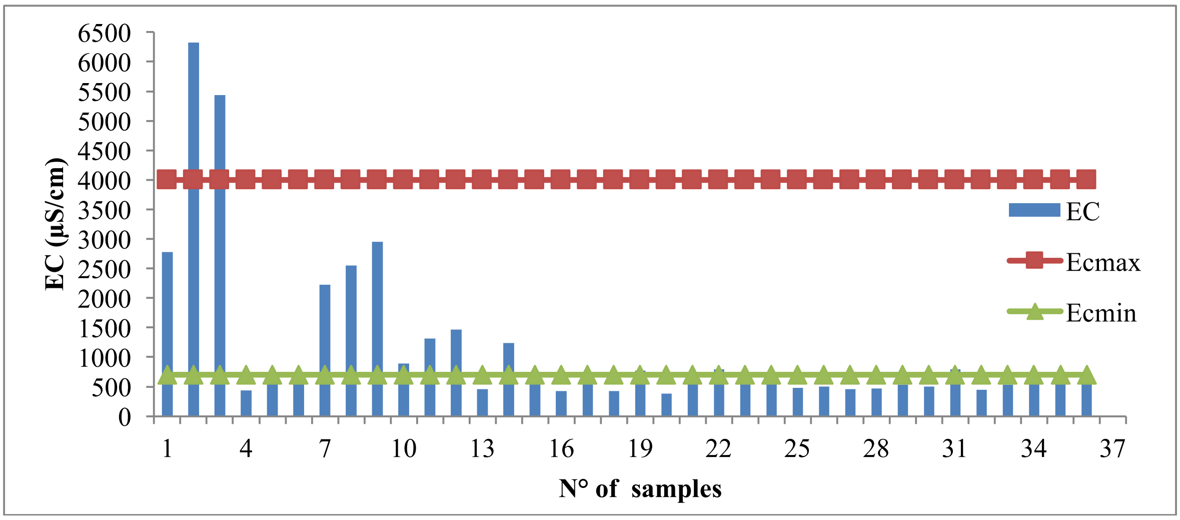

Figure 3: Variation of electrical conductivity as a function of all samples

The total dissolved soled is found in the range of 243.20–4049.28 mg/l with a mean value of 747.68 ± 861.79 (Table-1). The figure 4 shows that most of the samples of the study are of good quality for irrigation according to Yemen standards for irrigation (optimal limits of 450 mg/l and maximum permissible limit of 300 mg/l). The total dissolved soled distribution of groundwater in the entire study area is shown in that lower TDS values (<1500 mg/l).

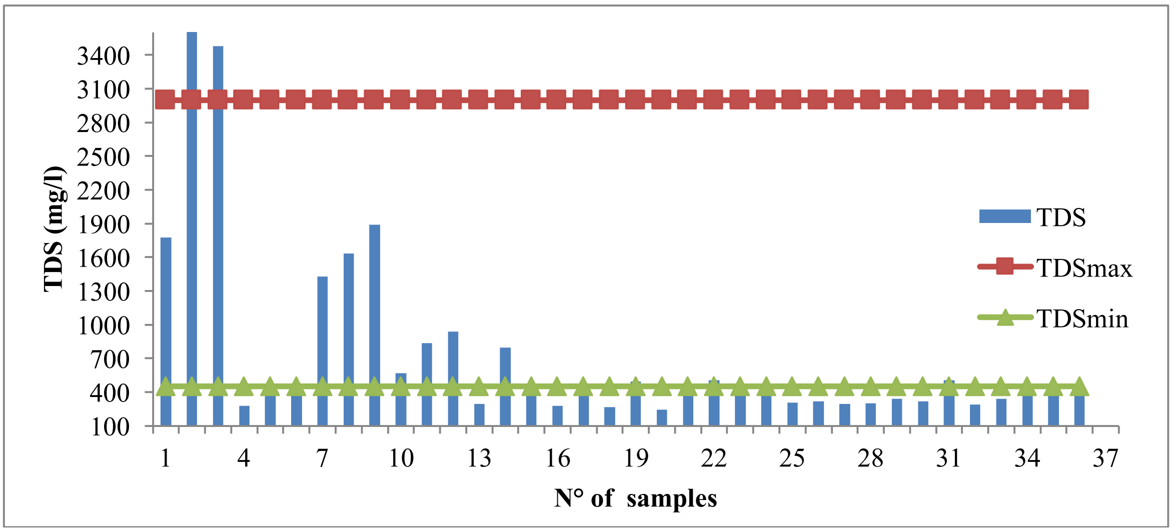

Figure 4: Variation of TDS as in function of all samples

Were found in most samples, only two samples are the higher EC values (>3000 mg/l), its located in the passage of wastewater above wastewater station. The correlation between TDS with all samples show in the table 3, significant positive relationship with Na^{+} (0.94), K^{+} (0.78), Mg^{2+} (0.99), Ca^{2+} (0.96), Cl^{-} (0.98) SO_4^{2-} (0.93), HCO_3^{-} (0.97), TH (0.99), and SAR (0.33).

The sodium is found in the range of 17.25-460.00mg/l with mean value of 89.60 ± 96.25 (Table 1). The figure 5 shows that most of the samples of the study are of good quality for irrigation according to Yemen standards of irrigation (optimal limits of 70 mg/l and maximum permissible limit of 207 mg/l). The sodium distribution of groundwater in the entire study area is shown in that lower values (<200 mg/l) were found in most samples, only two samples are the higher values (>200 mg/l), its located in the passage of wastewater above wastewater station. The correlation between all samples shows significant positive relationship with K^{+} (0.87), Mg^{2+} (0.89), Ca^{2+} (0.91), Cl^{-} (0.95) SO_4^{2-} (0.82), HCO_3^{-} (0.91),TH (0.91), and SAR (0.57),(the table 2).

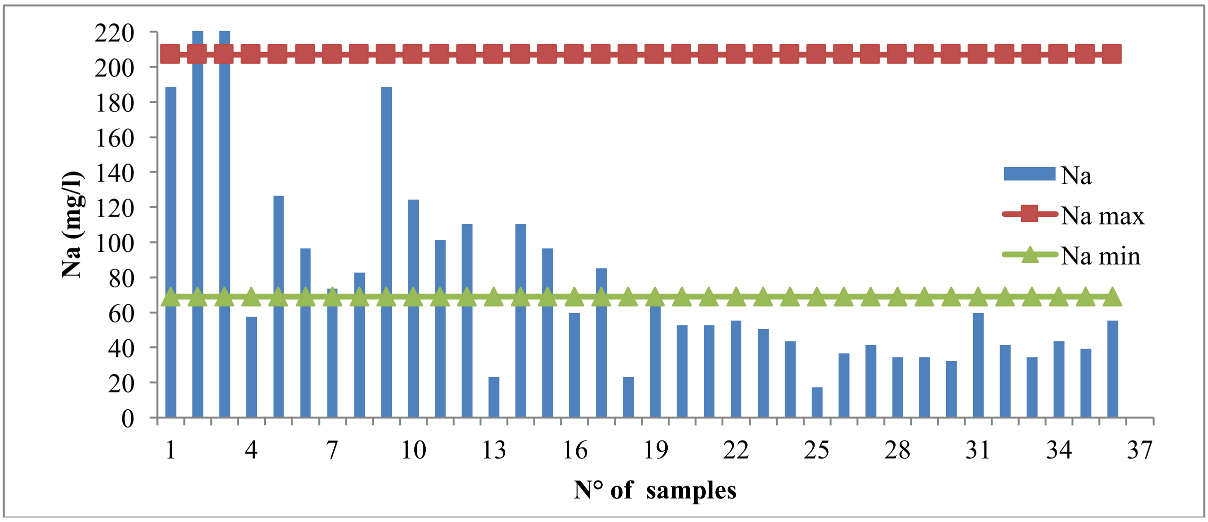

Figure 5: Variation of sodium as in function of all samples

The chloride is found in the range of 48.81-1531, 35mg/l with mean value of 295.64 ± 345.28 (Table-1). The figure 6 shows that most of the samples of the study are of good quality for irrigation according to Yemen standards for irrigation (optimal limits of 141.84 mg/l and maximum permissible limit of 354.6 mg/l). The chloride distribution of groundwater in the entire study area is shown in that lower Cl values (<250 mg/l) were found in more samples, only fife samples are the higher EC values = 354, 6 mg/l and three samples (>355 mg/l), fife samples higher pollution located in the passage of wastewater above and near wastewater station. The high chloride concentrations can cause toxicity to sensitive crops at high concentrations.

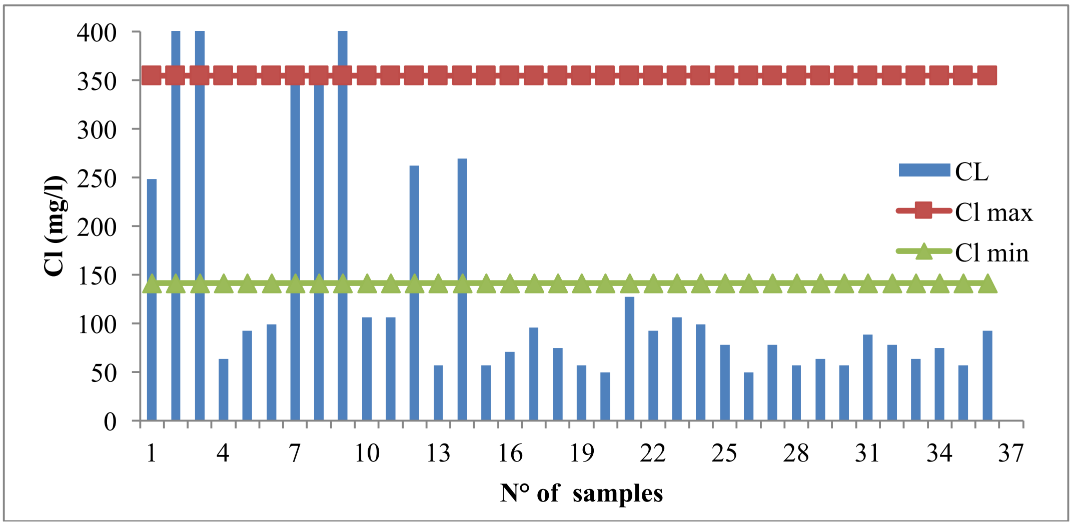

Figure 6: Variation of chloride as in function of all samples

The correlation between Cl with all samples show in table 2, significant positive relationship with K^+ (0.80), Mg^{2+} (0.95), Ca^{2+} (0.95), SO_4^{2+} (0.88), HCO_3^- (0.94),TH (0.98), and SAR (0.34).
The bicarbonate is found in the range of 9.61-1104.69mg/l with mean value of 133.48 ± 216.93 (Table-1). The figure-7 shows that most of the samples of the study are of good quality for irrigation according to Yemen standards for irrigation (optimal limits of 92mg/l and maximum permissible limit of 519mg/l). The electrical conductivity distribution of groundwater in the entire study area is shown in that lower HCO_3^- values (<500 mg/l) were found in more samples, only four samples are the higher HCO_3^- values (>519 mg/l). Only four samples higher pollution located in the passage of wastewater above and near wastewater station. The correlation between HCO_3^- with all samples show in the table 2, significant positive relationship with K^+ (0.77), Mg^{2+} (0.95), Ca^{2+} (0.90), SO_4^{2-} (0.845), TH (0.95), and SAR (0.34).
The SAR is found in the range of 0.54-7.10meq/l with mean value of 2.13 ± 1.35 (Table-1). The figure-8 shows that most of the samples of the study are of good quality for irrigation according to Yemen standards for irrigation (optimal limits of 3meq/l and maximum permissible limit of 9meq/l). The SAR of all samples distribution of groundwater in the entire study area is shown in that lower SAR values (<9 meq/l), it's are considered excellent. In the table-2 the correlation between SAR with all samples show significant positive relationship with K^- (0.45), Mg^{2+} (0.22), Ca^{2+} (0.26), SO_4^{2-} (0.83) and TH (0.24).

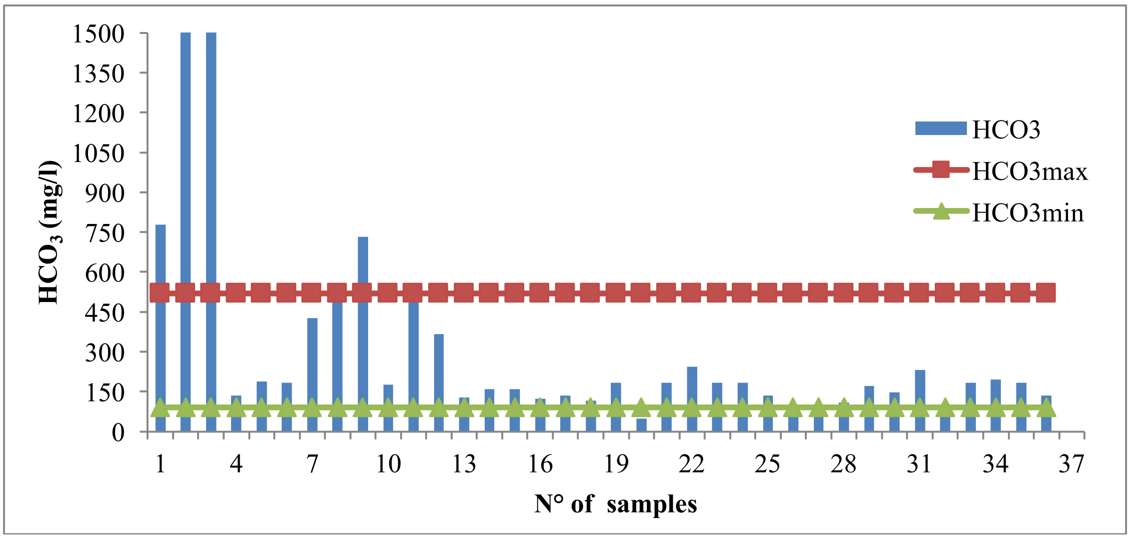

Figure 7: Variation of bicarbonate as in function of all samples

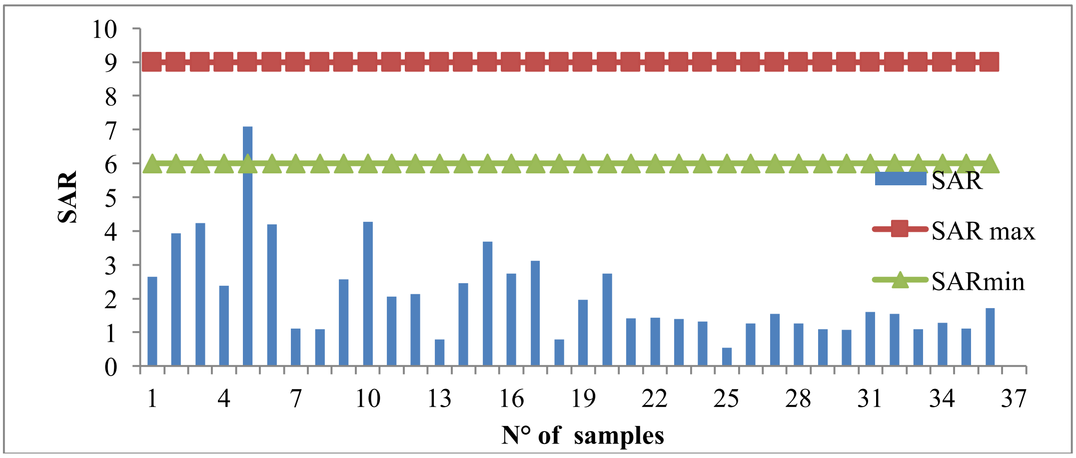

Figure 8: Variation of SAR as in function of all samples

4.2. Relationship between EC and SAR

The classification of SAR (alkali hazard) and EC (salinity hazard) data are plotted in a USSL (1954) diagram to determine the suitability of water for irrigation (Figure 9) [20]. The most of the wells fall within the medium salinity hazard zone, which shows a substantial amount of the total dissolved salts in the water. Following the classification system, the water from 65% of the wells fall in the salinity class C2, including four solicits classes about 22% of the wells are in the C3 while the most salinity hazard zone contains about 14% of the wells are in the C4 class. On the other hand, all the wells have SAR values below 9, which is of a medium quality for irrigation waters. The percentage of sodium is not very high in the groundwater throughout the aquifer, but the overall EC with SAR determines whether groundwater can be used for agricultural purposes. The water samples in categories of C2-S1, C2-S2, C3-S1, C4-S1, and C4-S2 classes with 62%, 3%, 22 %, 8% and 5% of the wells, respectively. The most of samples are suitable for irrigating, but the samples in C3-S1, C4-S1 and C4-S2 are unsuitable according to the USSL. This type of irrigation water is considered to be high water - low sodium and this type of water cannot be used in Irrigation of saline sensitive crops, particularly citrus, can be used for high tolerant salinity crops with a network Effective sludge and in soils where there are no hard layers to prevent leaching [21,22].

4.3. Piper Diagram

The chemical compositions of the all samples were plotted by using piper diagram trainer diagram show in the figure 10, [23]. The most of the groundwaters cluster mixt between cations and anions, a few show Mg^{2+} Na^{+} Cl^{-} and Na^{+} Cl^{-} HCO_3^{-} water type. Some of the surface waters and a few hand-dug wells plot mainly in the mixed water type where there is neither dominant cation nor anion. The ionic dominance pattern of the groundwater samples were $Mg^{2+} > Na^{+} > K^{+} > Ca^{2+}$ and $HCO_3^{-} > Cl^{-} > SO_4^{2-}$.

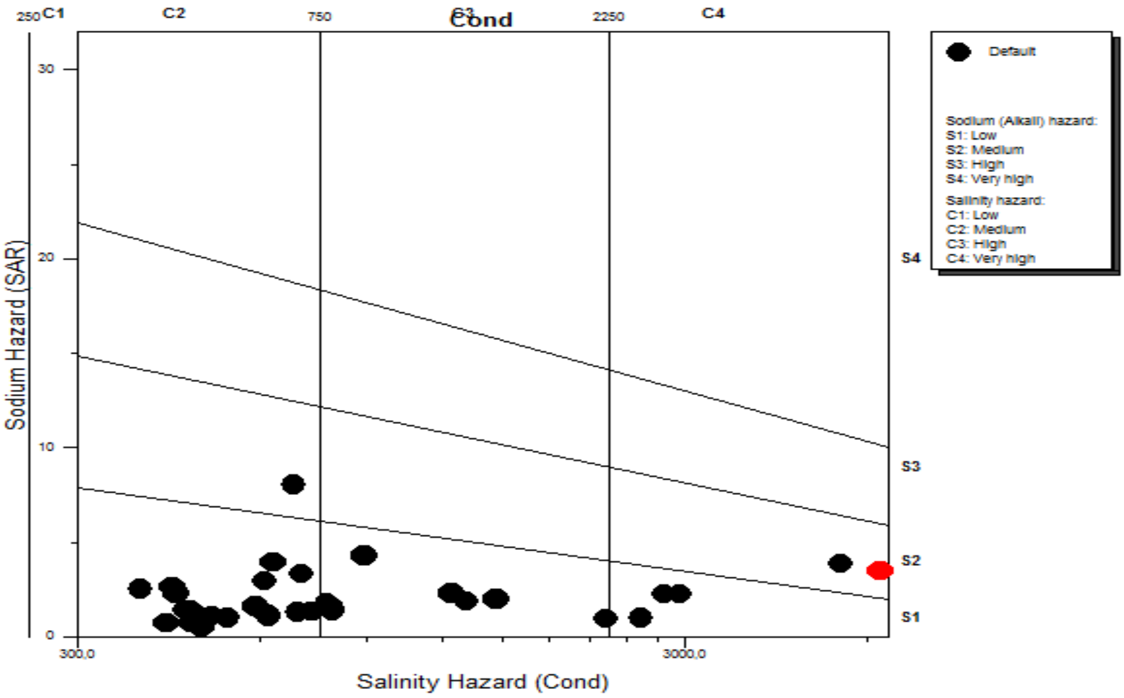

Figure 9: Variation of EC&SAR as in function of all samples

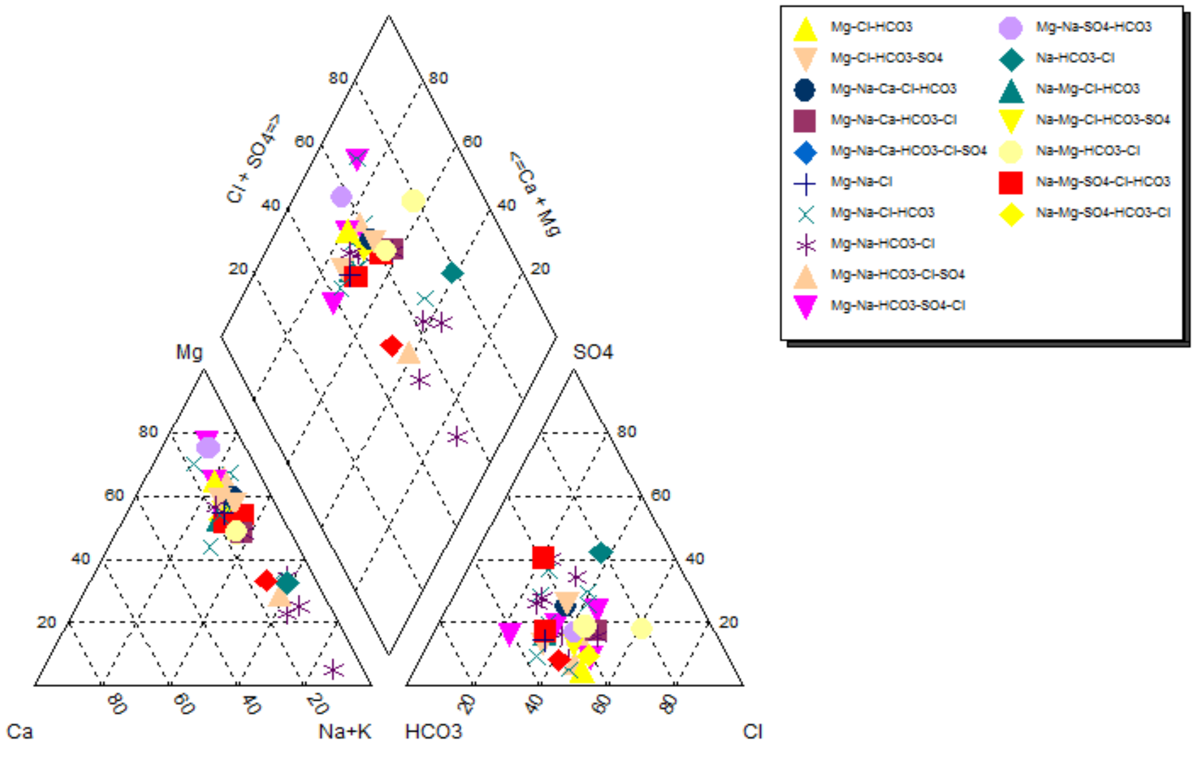

Figure 10: Piper Diagram of all samples

The Principal Component Analysis (PCA) which is a method complementary to classical approaches of hydrogeochemical research provides quick visualization and shows correlation among different water quality variables [24]. It was carried out on a data matrix consisting of 36 lines representing prospected wells and 13 columns representing physicochemical variables measured or analyzed (Table 3).

The aim of the analysis is to obtain a small number of linear combinations that account for most of the variability of the data.

The numerical results of this PCA show that the first component, which accounts for 69.19% of the captured variability, contrasts with positive coordinates (EC), (TDS), (Ca^{2+}), (Mg^{2+}), (Na^{+}), (K^{+}), (HCO_3^{-}), (Cl^{-}), and (SO_4^{2-}). The second component, with 13.66% of the captured variability, opposes mainly T, pH, and SAR which contribute positively to the expression of this axis. In contrast to the pH that correlates negatively with this axis (Figure 11, Table 3 and 4). The pollution is localized at high load on the two samples well2 & well3, compared to the other samples with most parameters

Table 3. Total Variance Explained by each vary factor

Component	Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %
1	9.00	69.19%	69.19%
2	1.78	13.66%	82.85%

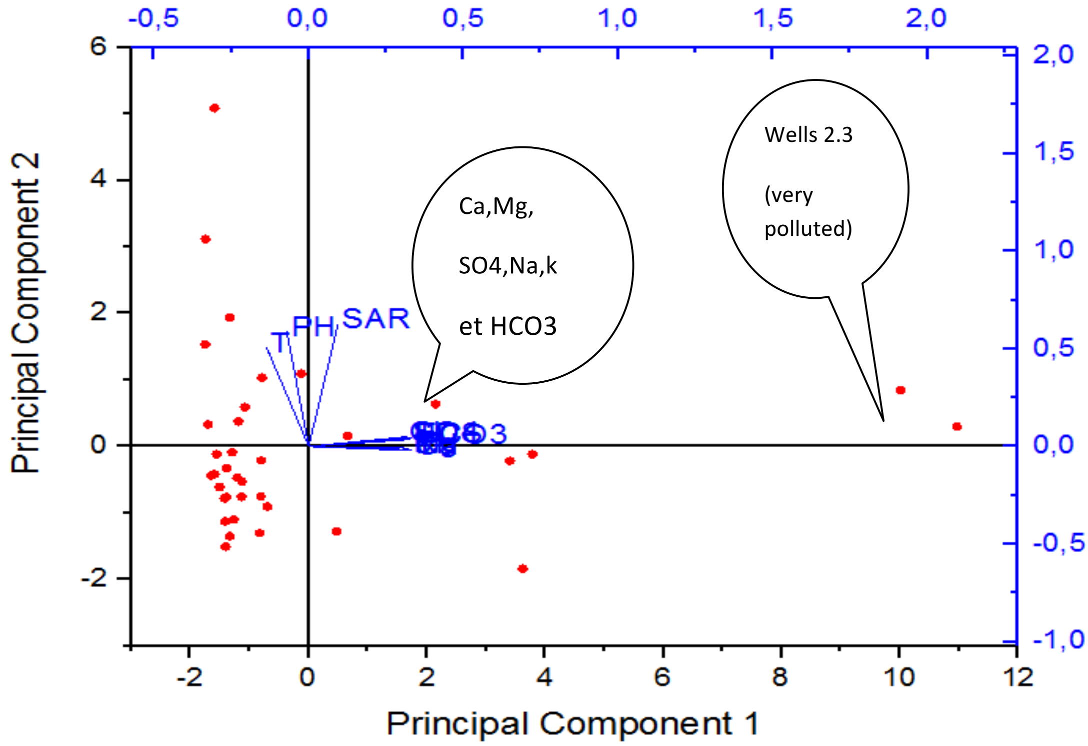

Figure 11: and Loadings of all samples on the plane defined by principal components 1 and 2 obtained by the13 experimental variables

Table 4. Loadings of the principal components 1 and 2 of 13 experimental variables.

	Coefficients of PC1	Coefficients of PC2
T	-0.16	0.51
pH	-0.03	0.58
EC	0.33	-0.00
TDS	0.33	-0.00
Na^{+}	0.33	-0.08
K^{+}	0.32	-0.04
Mg^{2+}	0.32	0.17
Ca^{2+}	0.17	0.03
Cl^{-}	0.33	-0.02
SO_4^{2-}	0.30	0.04
HCO_3^{-}	0.32	-0.02
TH	0.33	-0.06
SAR	0.12	0.60

Conclusion

The results of this study provide information that can be useful for the irrigation in study area water resources in with respect to water pollution. The salinity of the wells was observed higher than the sewage plant and the proximity of the plant compared to the Yemen standards for irrigation and FAO (1985) However. The samples in C3-S1. C4-S1 and C4-S2 according to the USSL can be used for saline and medium tolerant crops. While the other wells were slightly salty to medium. Contain the study area on relatively high concentrations of magnesium ions and calcium compared to sodium which indicates the lack of danger of sodium ions in the future on the qualities of soil irrigated with these types of water. The type of irrigation water quality studied according to the FAO system is (increase in the problem) for the index of salinity and both types (no problem and increase in the problem) for soil permeability index and filtration in the two categories (no problem and increase in the problem) for the toxicity index by sodium and chloride within the category (increase in problem) for the indicator of the various effects of irrigation water based on the bicarbonate ion. It was also noted that the pH of the irrigation water studied within normal rates**.** Interpretation of hydrogeochemical analyses reveals that the water resources in study area is fresh water type and is fall in the mixed water type where there is neither dominant cation nor anion. The ionic dominance pattern of the groundwater samples were $Mg^{2+} > Na^{+} > K^{+} > Ca^{2+}$ and $HCO_3^{-}>Cl^{-} >SO_4^{2-}$. The PCA results confirm that the impacts of wastewater .The proximity of the wells near the wastewater treatment plant are more important than the wells far from the sewage plant. Where the effect was more pronounced in the two wells (2-3) of the surface water. They are point in untreated wastewater catchments.

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