GEO-STATISTICAL ASSESSMENT OF GROUND WATER QUALITY IN DHAMAR BASIN, YEMEN

ALLAM, M.[1,2] – MENG, Q. Y.[1*] – AL-AIZARI, H.[3,4*] – ELHAG, M.[5] – YANG, J.[6] – SAKR, M.[7] – WANG, Z.[1]

[1]*Aerospace Information Reseach Institute, Chinese Academy of Sciences, Beijing 100094, China*

[2]*Environment & Climate Change Research Institute, National Water Research Center, Cairo, Egypt*

[3]*Department of Chemistry, Faculty of Education, Thamar University, Yemen*

[4]*Laboratory of Biotechnology, Environment and Quality - UFR of process engineering, Faculty of Sciences, Ibn Tofail University, BP 133, Kenitra, 14000, Morocco*

[5]*Department of Hydrology and Water Resources Management, Faculty of Meteorology, Environment & Arid Land Agriculture, King Abdulaziz University, Jeddah 21589, Saudi Arabia*

[6]*Sanya Institute of Remote Sensing, Sanya 572029, China*

[7]*GIS and RS at King Mariout high Institute, Cairo, Egypt*

[*]*Corresponding authors*
e-mail: mengqy@radi.ac.cn (Meng, Q. Y.); Alaizari2@gmail.com (Al-Aizari, H.)

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Abstract. Groundwater quality in the Basin of Dhamar (Yemen) has been studied using geographic information system (GIS), principal component analysis (PCA) and correlation technique. A geographic information system is a tool for mapping and analyzing spatial data and is also used to retrieve groundwater quality information. For this study 26 wells were selected, for each well thirteen physicochemical parameters were analyzed including electrical conductivity, Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}), potassium (K^{+}), bicarbonate (HCO_3^-), Chloride (Cl^-), Sulphate (SO_4^{2-}), Nitrate (NO_3^-), Iron (Fe^{2+}), Fluoride (F^-) and Total Hardness (TH). The collected groundwater was evaluated for its suitability for both drinking and irrigation purposes. Correlation and PCA have been utilized to analyze the parameters. Cartographic maps of the study area have been generated using multivariate statistical tools and GIS approach Inverse Distance Weighting (IDW) for all the above parameters. The created maps can be used to visualize, analyze, and understand the relationship among all locations. Most of the wells are found to be within the permissible limit except one well and this is due to the anthropogenic pollution received by human activities. Correlation and principal component analysis can help in selecting the most significant parameters to determine the status of water quality. The tools available in the GIS environment supported the study in the integration of data with very different data structures, i..e. point, 2D and 3D, towards spatial modeling of processes relevant to the assessment of groundwater resources.
Keywords: *ground water quality, PCA, IDW, piper diagram, Yemen*

Introduction

Water is a source of life for life. This substance must be preserved from all influences: modern civilization, industrialization, urbanization, and an increase of the population (Kot et al., 2000; Rafiullah et al., 2012). The groundwater contamination in an urban environment is due to the infiltration of domestic untreated wastewater into the natural receiving environment, accentuated by favorable hydrogeological conditions (Ayad and Kahoul, 2016). Around the world, pressure on water resources and particularly on groundwater resources is on the rise, mainly due to increasing demand.

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The captured water may contain elements that may have adverse health effects, such as pathogenic microorganisms, unwanted substances or even toxic substances (Hartemann, 2000; Patil et al., 2012). Determining the quality of groundwater is important in deciding whether water is safe to drink, agriculture or industry. Water quality is a concept that refers to the chemical, biological and physical characteristics of water. The quality of the water required is determined by the purpose for which the water is to be used (domestic, urban, agricultural or industrial). Evaluation of water for uses is based on the characteristics of the water in relation to the quality required. In relation to drinking water, the required quality is defined by "standards" which define concentrations of constituents so that they have no adverse effect on the health of the consumer during the lifetime of consumption (Bakraji and Karajo, 1999).

Yemen is one of the countries most threatened by lack of water, it is already facing a serious water crisis: the annual consumption per individual is mediocre (135 m^3) compared to that recorded in the Middle East and North Africa (1250 m^3). Many cities face a serious water shortage, the prospect of sustainability of water resources, the main source of concern is the ever-increasing demand for water in water supply and irrigated groundwater agriculture in the same well field area (Glass, 2010; Whiting et al., 2011).

The aims of this study are to evaluate the groundwater quality of the Dhamar basin and its purposes for drinking and irrigation using GIS, correlation, and PCA, the second is to understand the variations in water quality in this reservoir.

Materials and Method

Study area

The governorate of Dhamar is situated in the middle of central highlands of Yemen with an area of 7.586 km^2 and 2700 m above sea level, it is divided into 12 administrative districts and 314 sub-districts (*Figure 1*). Dhamar has located 100 km to the south of Sana'a and north of Ibb city and west of Al-Beidha. Dhamar city is the capital of the governorate and it is situated on the main road that connects Sana'a with several other governorates. Dhamar basin is one of the largest water basins in Yemeni governorates and the most depletion one with over 6000 wells lastly reported in 2009 (Al-Aizari et al., 2017).

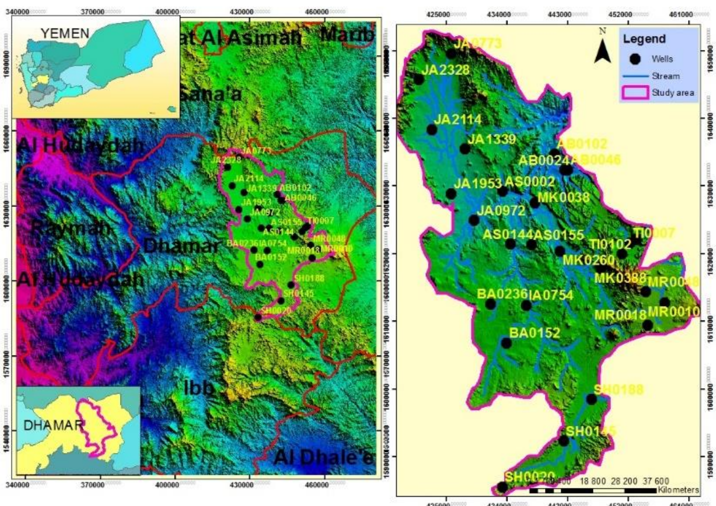

***Figure 1.** Study area and samples location*

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The climate of the study area is semi-arid. The annual rainfall is 407.8 mm, the maximum rainfall was 148.2 mm in June and the minimum was 88.2 mm in January during the period from 1999-2016. While the average monthly temperature varied from 21.4ºC in December -27.7°C in June for the same period (Al-Aizari et al., 2017). The geology of the study area comprises Quaternary alluvium, Tertry, Quaternary volcanic formations. Rhyolites, tuffs and ignimbrite ash-flow with occasional granite intrusions. The available hydrology data show that the main aquifers in Dhamar are Tertiary, Volcanic and Quaternary deposits. Groundwater subtraction through pumping wells in Quaternary deposits is more than Tertiary Volcanic. The outputs of this research are are identifying the productive aquifers and dominant fissure in the north-northeast of the study region (Geukens, 1966; Chiesa, 1983; Overstreet et al., 1985; Al-Kohlani, 2009).

Data sampling

A total of 27 well representing the Dhamar basin were selected in our study *Table 1*,14 groundwater samples were collected from each well in May 2009. These data have not been published earlier. The survey was carried out as part of a national program to monitor groundwater resources at a large number of locations nationwide. Since 2009 similar surveys have been carried out at other locations, which are not relevant for this study since samples were taken in different aquifers. It is not a common practice of this Government Department to publish the data they collect in response to governmental regulations. The samples were collected after pumping for 10 minutes, clean and dry polyethylene bottles are used for sample collection. The samples are tagged and stored in a refrigerator before the analysis (Girard, 1975). All samples were transported at temperature 4°C in portable coolers to the general agricultural research laboratory at Dahmer where the analyzes are carried out. Physio-chemical parameters were carried out EC, (Ca^{2+}), (Mg^{2+}), (Na^{+}), (K^{+}), (HCO_3^{-}), (Cl^{-}), (SO_4^{2-}), (NO_2^{-}), (Fe_2^{+}), (F^{-}) and (TH) and then compared with the guidelines admitted by the World Health Organization (WHO, 2003; Al-Asbahi, 2005).

Table 1. *The site and the name of the studied well*

No.	Well ID	Site name	No.	Well ID	Site name
1	AB0102	Abisiyah	15	JA1339	Jahran
2	AB0024	Abisiyah	16	JA1953	Jahran
3	AB0046	Abisiyah	17	JA2114	Jahran
4	AS0144	Aswad	18	JA2328	Jahran
5	AS0155	Aswad	19	MK0260	Makhderah
6	AS0002	Aswad	20	MK0038	Makhderah
7	BA0236	Balasan	21	MK0388	Makhderah
8	IA0754	Intervening	22	TI0102	Tinnan
9	MR0010	Maram	23	TI0049	Tinnan
10	MR0018	Maram	24	TI0007	Tinnan
11	MR0048	Maram	25	SH0020	Sherah
12	BA0152	Balasan	26	SH0188	Sherah
13	JA0773	Jahran	27	SH0145	Sherah
14	JA0972	Jahran			

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Chemical analysis

EC is measured in the field using conductivity meter (Medium Conductivity Session CEL/850 (HACH). PH is measured by pH-422. Ca^{2+} and Mg^{2+} are estimated titrimetrically using 0.02 N EDTA. HCO_3^- and Cl^- are estimated by H_2SO_4 and $AgNO_3$ titration (0.02 N), respectively. Na^+ and K^+ are measured by using a Flame photometer (PFP 7). F-, Fe^{2+}, and NO_2- are measured by the portable data logging spectrophotometer HACH DR/2400. This standard method is suggested by the American Public Health Association (WHO, 2003; APHA, 2005) (*Table 2*).

Table 2. *Average physiochemical analyses for the grounds water and compared with YEMEN standards, WHO and Irrigation*

Variable	Unit	Minimum	Maximum	Mean	STDEV	Yemen Standard	WHO Guideline
EC	µs/cm	312.7	1915.8	524	323.6	750-2000	1000-1500
pH	-	5.8	9.2	7.248	0.86	6.5-9	6.9-9.2
Ca^{2+}	mg/l	8	200	48.94	37.88	75-200	200
Mg^{2+}	mg/l	2.4	43.6	7.7	7.71	30-150	150
Na^+	mg/l	14.6	190	87.28	51.88	200-400	200
K^+	mg/l	0.8	10.7	4.27	2.597	8-12	8-20
HCO_3^{--}	mg/l	97.6	463.6	227.7	83.1	150-500	
Cl^-	mg/l	29	335	70.9	65.7	200-600	250
$SO4^{2-}$	mg/l	20	320	58.5	64.5	200-400	250
NO_3^{--}	mg/l	1.50	49.70	15.64	14.68	0 -50	0-50
Fe^{2+}	mg/l	0	1.07	0.2122	0.2409	0.3-1	0.3
F^-	mg/l	0	0.09	0.01556	0.0268	0.5-1.5	1.5
TH	mg/l	40	680	149.6	122.1	100-500	500

Geo-statistical analysis

Statistical analysis was carried out using statistical package for social sciences (Minitab17). The physicochemical analysis for all the samples was analyzed by Pearson’s correlation coefficient and principal component analysis. The PCA adopted in this paper is based on normalized and standardized data and exploits the correlation matrix between groundwater quality parameters rather than the covariance matrix (Sabnavis and Patangay, 1998; Van den Brink and Ter Braak, 1999; Singh et al., 2004; Joshi et al., 2009; Khatoon et al., 2013; Chaubey and Patil, 2015).

Interpolation methods fall into two categories, namely: the deterministic method and geostatistical method (Chen and Liu, 2012). Deterministic interpolation methods create surfaces from measured points, based on either the extent of similarity or the degree of smoothing. For instance, Inverse Distance Weighting (IDW), radial basis functions and splines function. The geostatistical interpolation methods such as Kriging method (Davis and Ierapetritou, 2007; Elhag and Bahrawi, 2017) can describe spatial patterns and interpolate the value of a primary variable at unmeasured locations, and quantify the uncertainty or error of estimated surface (Elhag, 2016a).

IDW assumes that the attribute value of unmeasured points is the weighted average of known values of the neighborhood. IDW will use the measured values surrounding the unmeasured locations to predict the values of the unmeasured ones. Those measured values closest to the prediction location will have more influence on the predicted value than those farther away. Thus, IDW assumes that each measured point has a local influence that diminishes with distance. It weights the points closer to the prediction location greater than

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those far away. Maps layout are generated used ARCGIS 13 and AquaChem 2014 (Elhag, 2016a,b; Elhag and Bahrawi, 2016).

Sodium Adsorption Ratio

Sodium adsorption ratio (SAR) a formula used to evaluate salinity hazard and whether the water quality of the Groundwater Suitable or not acceptability for irrigation uses Lesch and Suarez (2009) (*Table 3*). SAR is calculated from the Na^{+}, Ca^{++}, and Mg^{+} using the following equation.

$$SAR = Na/ [(Ca + Mg)/2]^{1/2} \quad \text{(Eq.1)}$$

where Na^{+}, Ca^{++}, and Mg^{++} are the concentrations expressed in milli-equivalents per litre (meq/L).

Table 3. *Irrigational Water Classification*

SAR (epm)	Classification
<10	Excellent
10-18	good
18-26	Permissible
>26	Unsuitable

It depend on the distribution of SAR as described in *Table 3* and *Figure 2* indicating that all wells suitable for irrigation. In relation to the hazardous effects of sodium adsorption ratio, the irrigation water quality rating is given in *Table 3*.

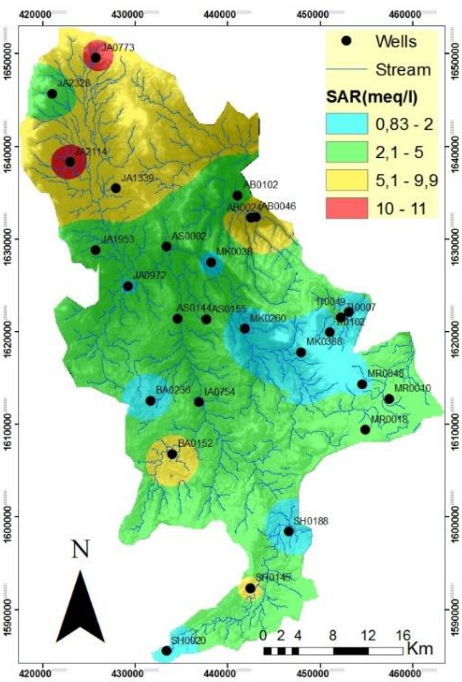

Figure 2. *Distribution of SAR*

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Result and Discussions

The physicochemical analysis of 27 well and evaluating suitability for drinking water and irrigation purposes are summarized in *Table 2*.

The tested physiochemical parameters of the designated water wells in accordance with Yemen Maximum Allowable Unit (MAU) and compared to the World Health Organization (WHO) are cross-referenced in *Table 2*. The range of variation in Yemen standards is quite wide which makes it more difficult to have a fair judge. Generally, one one hand, the tested variables are within or slightly above the MAU. On the other hand, the tested variables are poorly recorded according to WHO.

EC in the collected samples is ranged from 312.7 to 1915.8 µs/cm with an average value of 524± 323.6. The map shows that the values of EC are within the permissible level except for some areas, mainly (well no. IA0754), in which the EC recorded 1915.8 µs/cm. Therefore, it exceeds the WHO permissible level but it still within the level of Yemen standard as in *Table 2*. The high value of EC in that location is due to contamination from the effluent of wastewater treatment plans (WWTP) as this well located in Mawaheb village. The cartographic map showing the distribution of EC is given in *Figure 3*. The EC showed strong correlation with Cl^- and SO_4^{2-} (r = 0.94, 0.93, respectively) and good correlation between with Ca^{2+} Mg^{2+}, Na^+ and TH (r = 0.76, 0.8, 0.52 and 0.84, respectively).

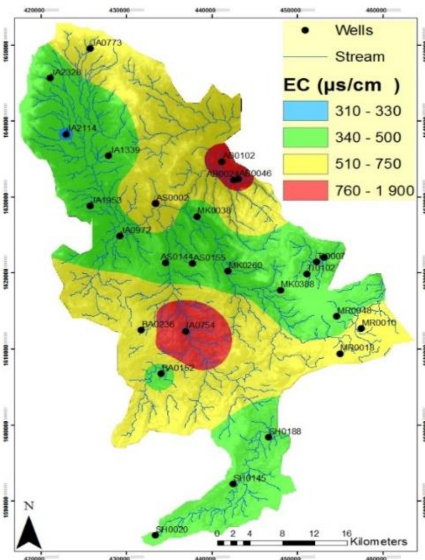

Figure 3. *Distribution of EC*

pH is considered as an important ecological factor that provides information on the types of geochemical equilibrium and solubility. From the thematic map (*Figure 4*), the pH is ranged from 5.8 to 9.2 so it is within the slandered of Yemen and WHO. The results show that three wells are basic and three well are acidic. The basic wells are Abisiyah (well no. ABS46, pH = 9.2), Balasan (well no. BB56, pH = 9.2) and Jahran (well no. QJB511, pH = 8.9). The three acidic wells are 6.3, 5.8 and 6.1 for the intervening area (well no. IA0754 pH = 6.3), Maram (well no. MR0018, pH = 5.8) and Jahran (well no. JA1953, pH = 6.1). pH showed negative correlation with all of parameters except Na^+ Cl^- and Fe^{2+} (r = 0.020, 00 and 0.34, respectively).

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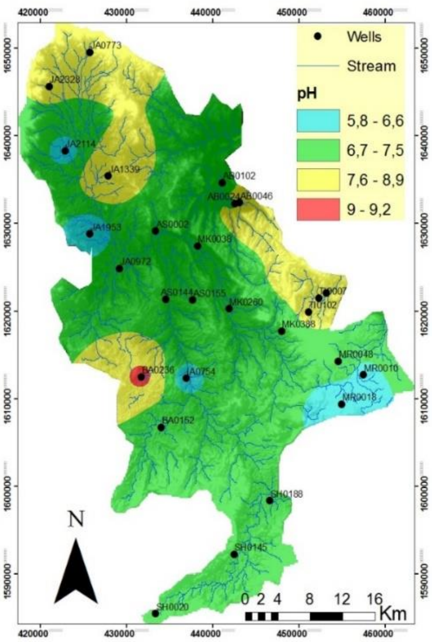

Figure 4. *Distribution of pH*

Na^+ varies from 14.6 to190 mg/l with an average value of 87.28 ± 51.88. The high concentration of sodium in water makes it unsatisfactory for use in irrigation purposes. The concentration of sodium in all samples are found to be within the permissible level of WHO and Yemen Standers *Table 2*. However, in well no AB0046, the concentration of sodium found to be near to the permissible level which is 190 mg/l. Na^+ has good correlation with Cl^- and SO_4^{2-} (r = 0.60, 0.53), demonstrated in *Figure 5*.

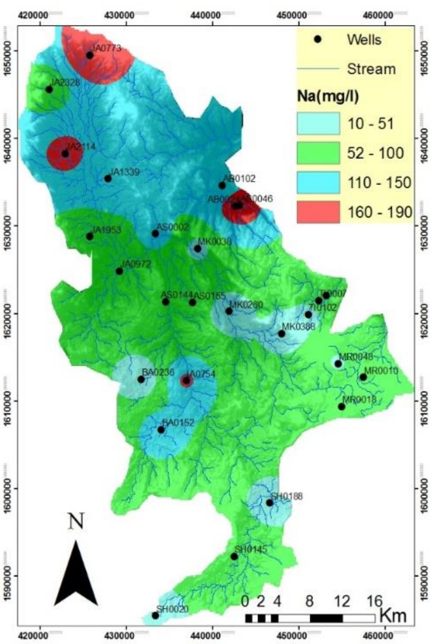

Figure 5. *Distribution of Na*

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The concentration of K^+ various from 0.8 to 10.7 mg/l with an average value of 4.27 ± 2.59. The concentration of potassium in all samples is found to be within the permissible level (*Table 2*). K^+ has good correlation with F^-, (r = 0.53), demonstrated in *Figure 6*.

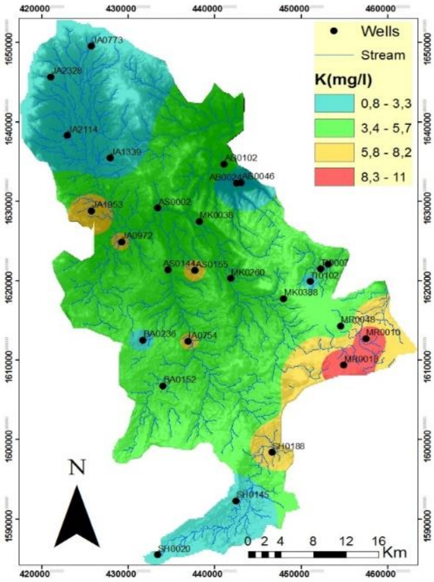

Figure 6. *Distribution of K*

The Mg^{2+} values range from 2.4 to 43.6 mg/l with an average value of 7.7 ± 7.71, the presence of Mg^{2+} in water generally does not have any health hazards to humans. The concentrations of Mg^{2+} in all samples are found to be within the permissible level in *Table 2* and *Figure 7*. Mg^{2+} is strong correlated with TH (r = 0.98) and with Ca^{2+} with Mg^{2+}, Cl^- and SO_4^{2-} (r = 0.81, 0.59 and 0.64), while it is good correlated with Cl^- and SO_4^{2-} (r= 0.78, 0.76) respectively.

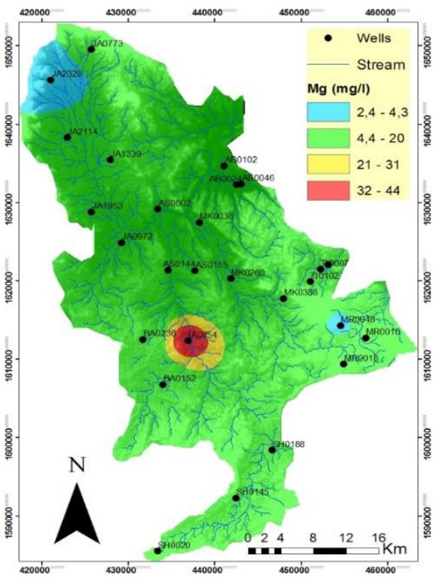

Figure 7. *Distribution of Mg*

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Ca^{2+} ranges from 8 to 200 mg/l with an average value of 48.94 ± 37.88. the presence of Ca^{2+} in water does not have health hazards to humans. Ca^{2+} values are within the permissible level in all samples except in the intervening area (well no. IA0754). This may be attributed to pollution by wastewater (*Figure 8*). Ca^{2+} shows strong correlation with TH, (r = 0.98) and good correlation with Mg^{2+}, Cl^- and SO_4^{2-} (r =0.81, 0.59 and 0.64) respectively.

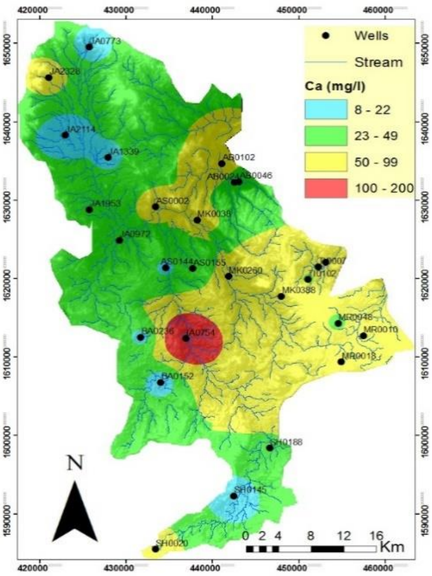

Figure 8. *Distribution of Ca*

SO_4^{2-} values various from 20-320 mg/l with an average value of 58.5 ± 64.5. The concentration of sulfate in all locations are within the permissible limit except the intervening area (well no. IA0754) where the sulfate value 320 mg/l. The SO_4^{2-} was has a good correlation between SO_4^{2-} with TH (r = 0.98) as is illustrated in *Figure 9*.

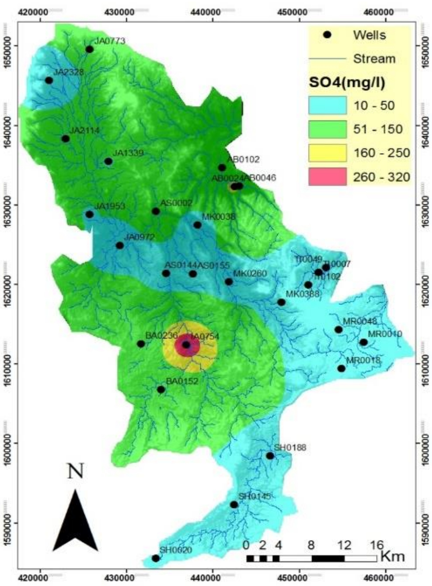

Figure 9. *Distribution of SO4--*

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The HCO_3^- varies from 97.6 to 463.6 mg/l with an average value of 227.7 ± 83.1. The concentration of bicarbonate in all samples are found to be within the permissible limit (*Figure 10*). The HCO_3^- has strong correlation with SO_4^{2-} (r = 0.98).

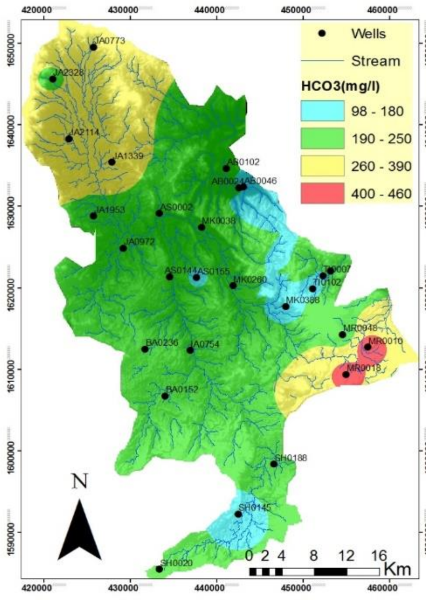

Figure 10. *Distribution of* HCO_3^-

WHO reported that atmosphere, legumes, plant debris, and animal excreta are the main source of water nitrate, alongside with the domestic water, sewage, septic tanks. Anionic and solubility of NO_3^{--} can also affect the concentration of NO_3^{--} in groundwater. In Yamen NO_3^{--} varies from 0.01 to 0.453 mg/l with an average value of 227.7 ± 83.1. The concentrations of nitrates in all samples are found to be within the permissible limit (*Table 2*), and its distribution in *Figure11*.

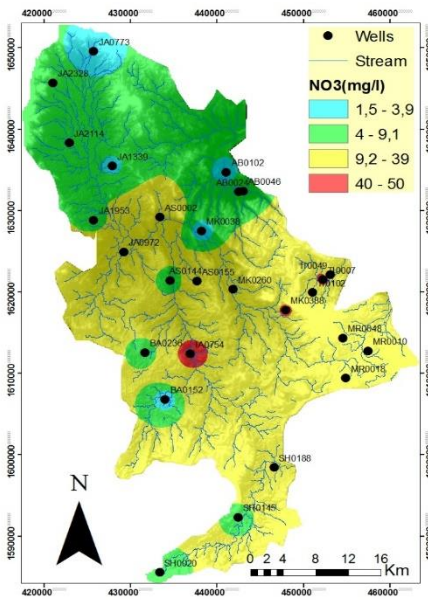

Figure 11. *Distribution of* NO_3^{--}

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The F^- values various from 0 to 0.09 mg/l with an average value of 0.01556 ± 0.0268. Fluoride concentration is within the permissible level in all locations. Fluoride above permissible level may cause mottled enamel of teeth and skeleton deformity. The cartographic map of F^- is given in *Table 2* and demonstrated in *Figure 12*.

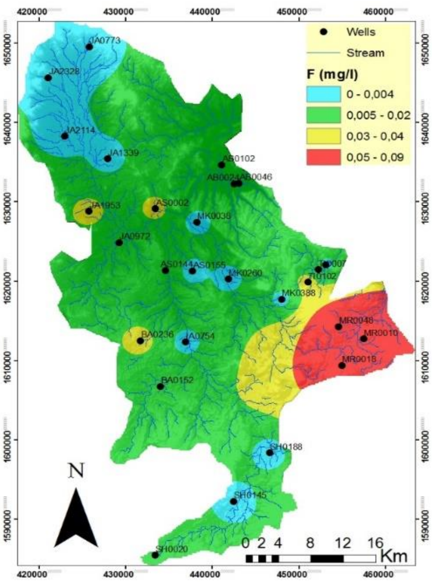

Figure 12. *Distribution of F*

Fe^{2+} concentration are varied from 0 to 1.07 mg/l with an average value of 0.2122 ± 0.2409. From the cartographic map (*Figure 13*), iron exceeded the permissible level in some wells Tinnan (TI0102), Tinnan (TI0007), Sherah (SH0188), and Jahran (JA1339). In the case of Tinnan (TI0102) and Jahran (JA1339) this may be attributed to strains of oxides and hydroxides on laundry, sanitary and plumbing textures. At concentration above 0.5 mg/l, iron cause an unpleasant taste (*Table 2*).

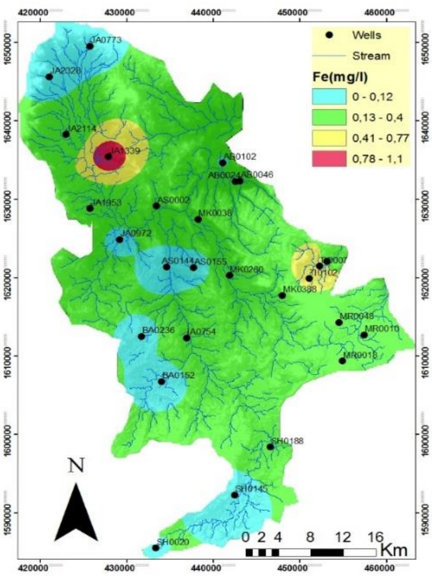

Figure 13. *Distribution of* Fe^{2+}

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The TH values range from 40 to 680 mg/l with an average value of 149.6 ± 122.1 (*Figure 14*). All samples are within the permissible values as in *Table 1* except well no. IA0754 has a comparatively high TH value of 680 mg/l.

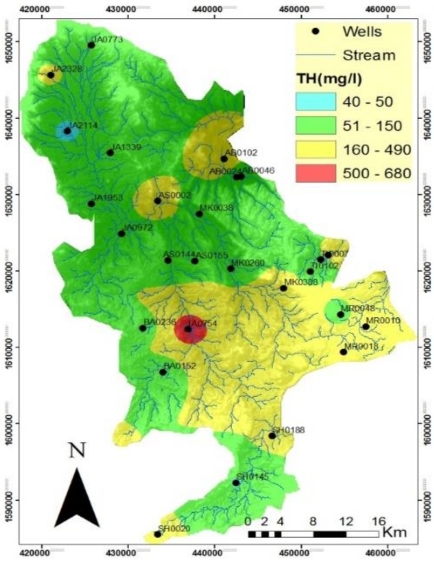

Figure 14. *Distribution of TH*

Cl^- is an important indicator of the contamination of groundwater by wastewater. The Cl^- values range from 29 to 335 mg/l with an average value of 70.9 ± 65.7. The permissible limit of Cl^- in drinking water for WHO guideline is 250 mg/l, while it is 600 mg/l for Yemeni Standards. The concentrations of Cl^- are within the permissible limit in all locations, except the intervening area (well no. IA0754) where the chloride value is 335 mg/l. The reason for high chloride in that well is due to the contamination of groundwater from effluent as discussed earlier. The cartographic map of Ca^{2+} is given in *Figure 15*. The Cl^- has a strong correlation with SO_4^{2-} (r = 0.98).

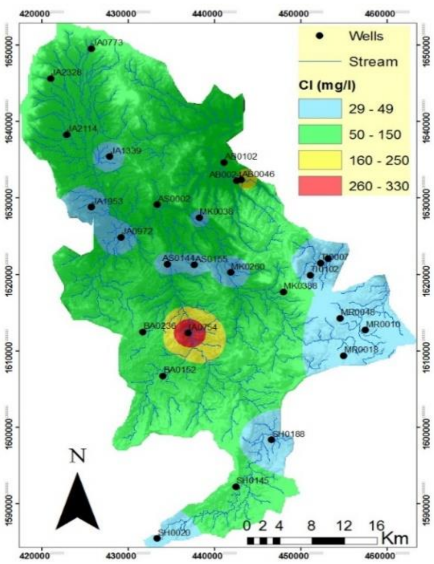

Figure 15. *Distribution of Cl^-*

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Correlation analysis a widely used between variable, the correlation between two variables is the simple correlation that indicates the sufficiency of one variable to predict the other one (Sedgwick, 2012). This coefficient s used to determine the correlation between variables when the dependent (x) is only influenced by the independent (y) and vice versa (Benesty et al., 2009). *Table 4* displayed the values of the correlation coefficients between the parameters. Strong correlations r> 0.9 and good r = 0.5-0.9.

Table 4. *Correlation matrix of all studied parameters*

	EC	pH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Fe^{2+}	F	TH
Ec	1.00												
pH	-0.16	1.00											
Ca^{2+}	0.76	-0.45	1.00										
Mg^{2+}	0.88	-0.35	0.81	1.00									
Na^{+}	0.52	0.02	0.01	0.29	1.00								
K^{+}	0.14	-0.56	0.44	0.33	-0.27	1.00							
HCO_3^-	0.10	-0.32	0.14	0.15	0.28	0.42	1.00						
Cl^-	0.94	0.00	0.59	0.78	0.60	-0.10	-0.13	1.00					
SO_4^{2-}	0.93	-0.09	0.64	0.76	0.53	-0.06	-0.06	0.91	1.00				
NO_3^-	0.29	-0.16	0.58	0.43	-0.24	0.38	-0.13	0.21	0.17	1.00			
Fe^{2+}	-0.07	0.34	0.04	-0.04	0.01	-0.12	0.07	-0.12	-0.04	0.27	1.00		
F	-0.01	-0.25	0.13	-0.02	-0.09	0.53	0.48	-0.18	-0.19	0.20	-0.02	1.00	
TH	0.84	-0.43	0.98	0.91	0.12	0.43	0.17	0.67	0.71	0.55	0.02	0.12	1.00

Principal Component Analysis

The principal component analysis is a multidimensional statistical method that can be used in the interpretation of a data matrix. This method, by looking for the reference directions of elongation of a multidimensional point cloud (eigenvalues), summarizes the information by projecting the point cloud on its preferential directions (factorial axes). Factors are linear combinations of the starting variables. Each variable contributing to the factor intervenes with a coefficient called "eigenvector" (Sabnavis and Patangay, 1998; Bahrawi et al., 2016; Elhag, 2016b).

Principal component analysis (PCA) for the groundwater allows determining its chemical characteristics, and their overall variations (factors). We select only the first two factors as they express 63.473% of the total variance. The analysis of the variables shows in *Tables 5, 6* and *Figures 16, 17*. The Factor 1 expresses 42.748% of the total factors and wells that correlated with the variables, these variables are conductivity, sodium, nitrates, chloride, calcium, sulfate, magnesium and Total hardens. While factor 2 expresses 20.725% of the total factors, these variables include bicarbonates, iron, fluoride, and potassium (*Figures 18 and 19*).

Table 5. *Total variation explained by all parameter*

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
Eigenvalue	5.557	2.6943	1.62	1.2571	0.654	0.4182	0.3071	0.2483	0.129	0.0832	0.023	0.008	0.0033
Proportion	0.427	0.207	0.12	0.097	0.05	0.032	0.024	0.019	0.01	0.006	0.002	0.001	0
Cumulative	0.427	0.635	0.76	0.856	0.906	0.938	0.962	0.981	0.991	0.997	0.999	1	1

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Table 6. *Coefficient of centered variables reduced in the linear equation of the principal axes*

Variable	PC1	PC2
EC	0.404	0.144
pH	-0.158	0.357
TH	0.403	-0.116
HCO_3^-	0.064	-0.292
Cl	0.356	0.296
F	0.027	-0.417
NO_3^-	0.198	-0.215
SO_4^{2-}	0.361	0.263
Ca^{2+}	0.379	-0.155
Mg^{2+}	0.4	-0.004
Na^+	0.155	0.311
K^+	0.14	-0.504
Fe^{2+}	-0.02	0.027

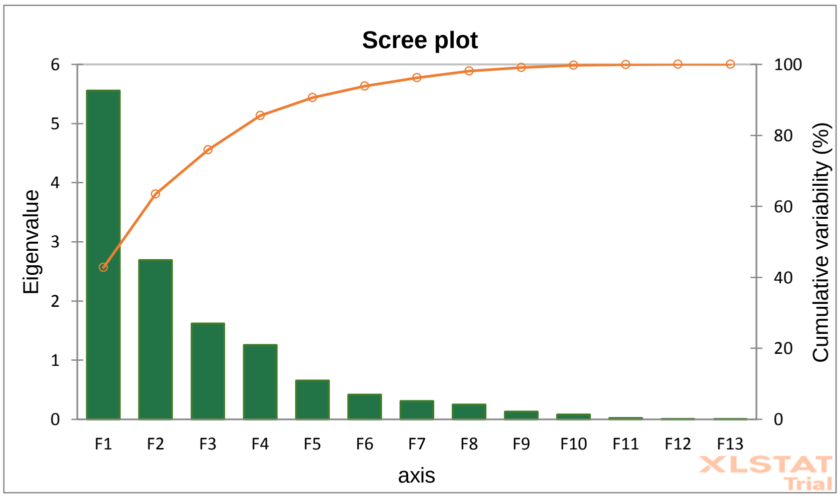

Figure 16. *Scree plot for all samples*

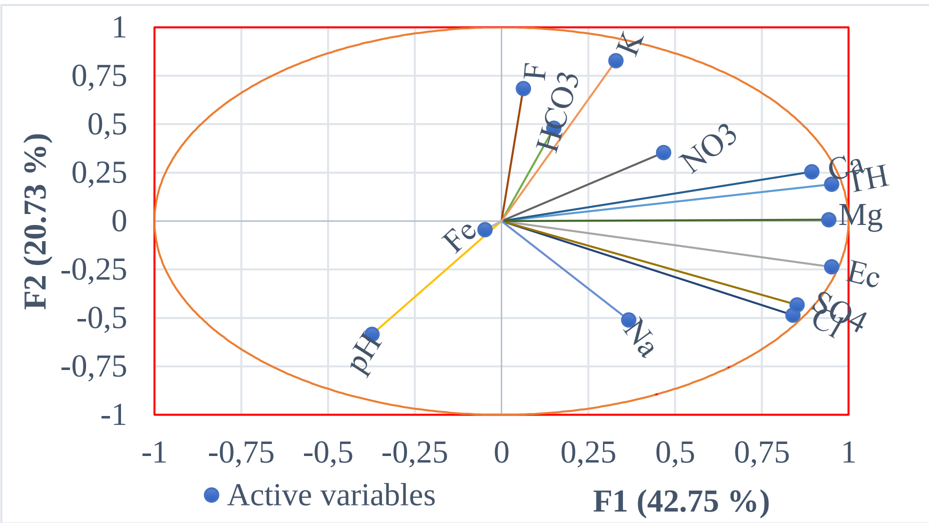

Figure 17. *PCA Variables (axes F1 and F2: 63.47%)*

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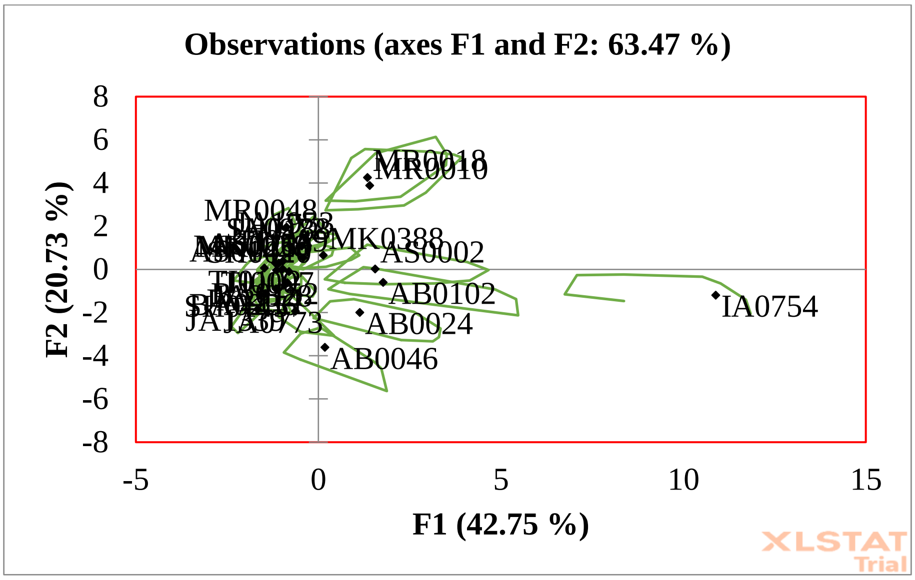

Figure 18. *Projection of wells on the F1-F2 factorial plane*

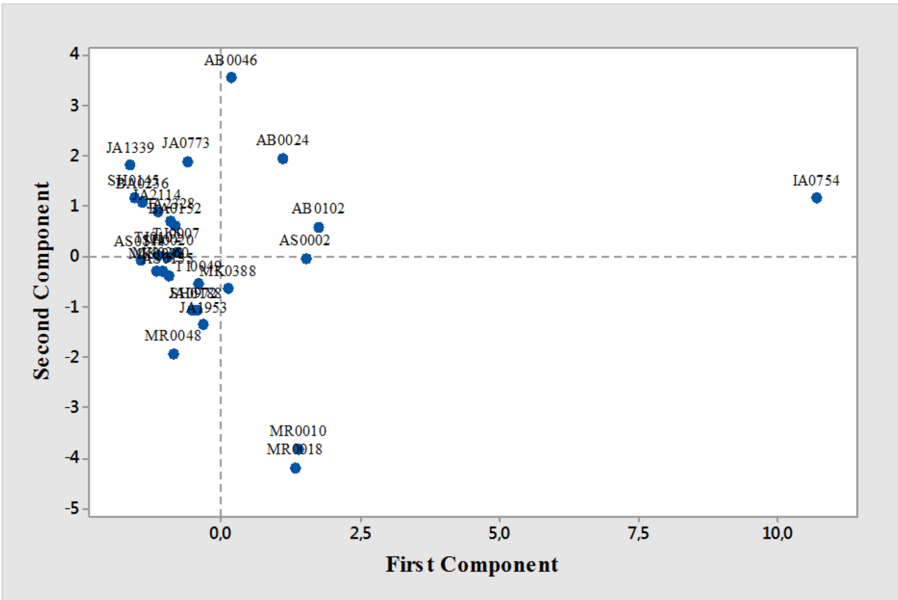

Figure 19. *A score of all the samples on the plan*

A piper diagram is a graphical representation of the chemistry of water samples. The cations and anions are shown by separate ternary plots. The apexes of the cation plot are calcium, magnesium, and sodium plus potassium cations. The piper diagram was preferred because of its accuracy in the identification of the water samples and the dominant component in the water chemistry (Piper, 1944; Elhag et al., 2019). Generally, the samples are showing different constituents of water as shown in *Table 7* and *Figure 20*. This indicates that the source's groundwater of these wells is different. The differences in compositions of the water are attributed to that the geology of the Dhamar area is generally volcanic and basaltic rock. However, some areas such as Jahran are having alluvial deposits.

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Table 7. *Chemical composition of water samples in various locations*

No.	Well ID	Site name	Chemical Composition
1	AB0102	Abisiyah	Na-Ca-HCO3-Cl
2	AB0024	Abisiyah	Na-Ca-SO4-HCO3
3	AB0046	Abisiyah	Na-Cl-SO4
4	AS0144	Aswad	Na-HCO3-Cl
5	AS0155	Aswad	Na-Ca-HCO3-Cl
6	AS0002	Aswad	Na-Ca-HCO3-Cl
7	BA0236	Balasan	HCO3-Cl-SO4
8	IA0754	Intervening	Ca-Na-Cl-SO4
9	MR0010	Maram	Ca-Na-HCO3
10	MR0018	Maram	Ca-Na-HCO3
11	MR0048	Maram	Ca-Na-HCO3
12	BA0152	Balasan	Na-HCO3-Cl-SO4
13	JA0773	Jahran	Mg-Na-HCO3
14	JA0972	Jahran	Ca-Na-HCO3
15	JA1339	Jahran	Na-HCO3
16	JA1953	Jahran	Na-Ca-HCO3
17	JA2114	Jahran	Na-HCO3-Cl
18	JA2328	Jahran	Na-Ca-HCO3-Cl
19	MK0260	Makhderah	Ca-Na-HCO3
20	MK0038	Makhderah	Ca-Na-HCO3-Cl
21	MK0388	Makhderah	Ca-Na-HCO3-Cl
22	TI0102	Tinnan	Ca-Na-HCO3-Cl
23	TI0049	Tinnan	Ca-Na-HCO3-Cl
24	TI0007	Tinnan	Na-Ca-HCO3-Cl
25	SH0020	Sherah	Ca-Na-HCO3-Cl
26	SH0188	Sherah	Ca-Na-HCO3
27	SH0145	Sherah	Na-HCO3-Cl

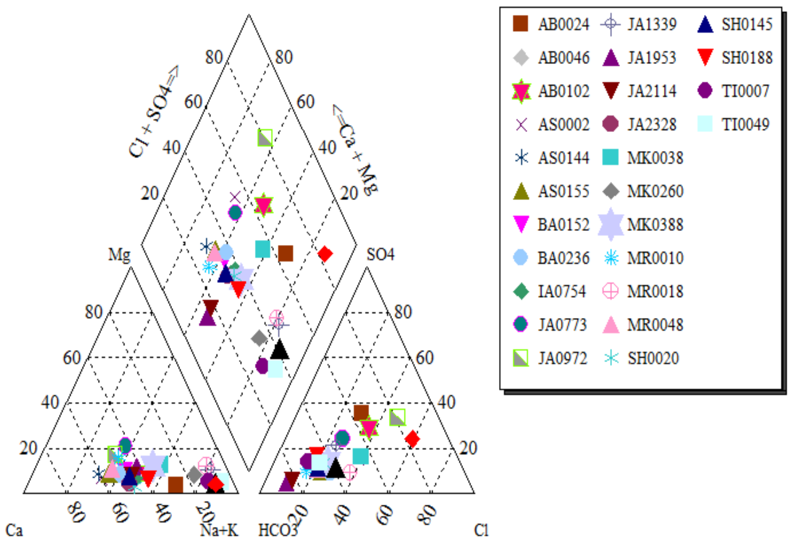

Figure 20. *Piper diagram of all samples*

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Groundwater is different wells of Abisiyah is a mixture of Na^+, Ca^-, Cl^- $SO4^-$ and HCO_3^-. The geological nature of this area is basaltic rocks. Generally, the groundwater aquifers of basaltic rocks have Na^- Ca^- HCO_3 composition and any change of this water are due to contamination from human activities or heavy exploitation. The high concentration of Cl and SO_4 without any natural sources indicate human contamination. However, the concentrations of Cl and SO_4 are within the permissible limit of WHO and standard Yamen illustrated in *Figure 21*.

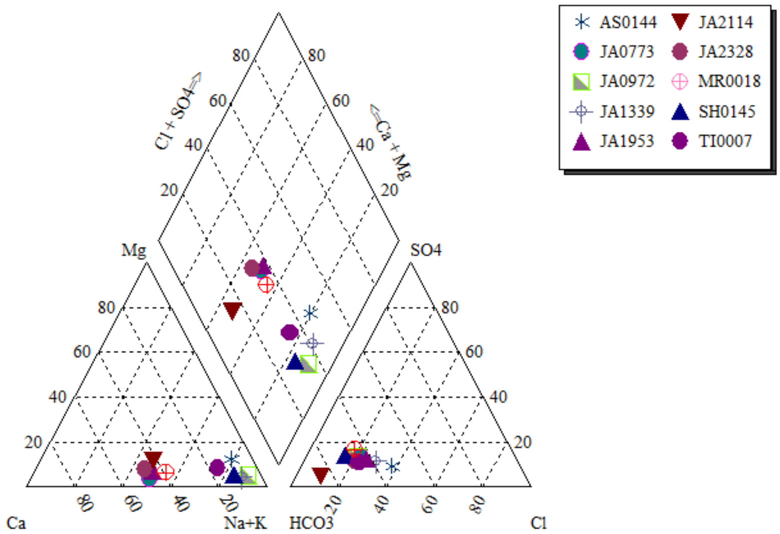

Figure 21. *Piper diagram of volcanic aquifer*

Predominantly, the water quality parameters used in the current research are varied based on the utilized sample in each rationing. Therefore, the categorization of different quality parameters using principal component analysis will help to examine the indices discrepancies (Yilmaz et al., 2018).

The dynamicity of the water quality monitoring process added further complications to designating mineral-affected wells in a systematic uniform perspective. The use of different quality parameters based on implementing different combinations and/or water samples in the form of water quality parameters evidenced to be more efficient to overcome wells' dynamicity problems (Elhag, 2016b; Bahrawi and Elhag, 2019; Elhag et al., 2019).

Earth is a forceful system that has been affected by natural and anthropological influences. One of the most substantial anthropogenic consequences on the earth are Land Use/Land Cover changes of (LULC) which take place over the earth surface. (Elhag, 2016c, Allam et al., 2019).

The water resources of the coastal region of the Gharb are susceptible to the pollution caused by the emergent industry and urbanization expansion. Certainly, the global economy growth, population density, and infrastructure developments stressed water quality and quantity (Elhag and Bahrawi 2014, Aremu, M. O. et al., 2017, Darwesh et al., 2019).

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Conclusion

Geographic Information System (GIS), correlation and Principal Component Analysis have been found to be a highly useful technique towards water quality management. The results of this study provide some information that can be useful with respect to groundwater studies. Salinity values are an acceptable level, in spite of the strong water abstraction from the wells in Dhamar plain except for the well no IA0754 that its salinity recorded 1900 μS/cm that is due to contamination from the effluent of wastewater treatment plans (WWTP) as this well located in Mawaheb village. The average salinity values are 524 μS/cm at 25°C. About 99% of the wells are classified as suitable for drinking water, and only 1% of total wells exceed the Yemeni standard for drinking water with respect to the Iron element. All wells are suitable for irrigation purposes. The low TDS was found in the groundwater of the Dhamar area because groundwater drains in igneous rocks (acidic rock), which release a low concentration of major elements. The lower concentrations of Cl^- and SO_4^{--} are due to an artificial source of pollution by human activities. Generally, groundwater quality is good in Dhamar plain. The presence of nitrates shows that the pollutant penetrates freely from the surface and that because of the hydrodynamic characteristics of the aquifers. The results of the good analysis of Dhamar plain indicates that the type of groundwater is Na-Ca-Cl/ $SO^{4-}HCO^{3-}$ and $Ca^{-}Na^{-}HCO_3^{-}Cl$, to mixed nature. The study recommended that modeling of groundwater quality in response to growing exploitation, particularly for irrigation. Irrigation leads to the percolation of water with higher salinity, thus potentially harmful for the long term sustainability of groundwater resources. Monitoring should be done more frequently and continuously to ensure timely detection of anomalies.

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