INTERNATIONAL JOURNAL OF ENVIRONMENT

Volume-6, Issue-4, Sep-Nov 2017 **ISSN 2091-2854**

Received: 14 Aug 2017 *Revised: 2 Oct 2017* *Accepted: 15 Nov 2017*

QUALITY ASSESSMENT OF GROUND WATER IN DHAMAR CITY, YEMEN

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Abstract

Chemical and statistical regression analysis on groundwater at five fields (17 sampling wells) located in Dhamar city, the central highlands of Yemen, was carried out. Samples were collected from the ground water supplies (tube wells) during the year 2015. Physical parameters studied include (values between bracket s represents the measured mean values) temperature (T, 25°), total dissolved solids (TDS, 271.47), pH (7.5), and electrical conductivity (EC, 424.18). The chemical parameters investigated include total hardness (TH, 127.45), calcium (Ca^{2+}, 32.89), magnesium (Mg^{2+}, 11.03), bicarbonate (HCO_3^-, 143.84), sulphate (SO_4^{2-}, 143.84), sodium (Na^+, 35.11), potassium (K^+, 6.28) and Chloride (Cl^-, 22.69). The results were compared with drinking water quality standards issued by Yemen standards for drinking water. Except for T° and pH, all other measured parameters fall below the minimum permissible limits. The correlation between various physio-chemical parameters of the studied water wells was performed using Principal Component Analysis (PCA) method. The obtained results show that all water samples are potable and can be safely used for both drinking and irrigation purposes. This comes in agreement with the public notion about groundwater of Dhamar Governorate. Sodium Absorption Ratio (SAR) values were calculated and found below 3 except for one drill. The results revealed that systematic calculations of correlation coefficients between water parameters and regression analysis provide a useful means for rapid monitoring of water quality.

Keywords: Groundwater, physio-chemical parameters, correlation, Dhamar.

DOI: http://dx.doi.org/10.3126/ije.v6i4.18910

Introduction

Yemen suffers from limited drinking water supplies, and groundwater is the main source of water supply for domestic uses, drinking, and irrigation purposes (Aqeel et al., 2017). Therefore, insuring the quality of surface and groundwater is of profound importance. Natural waters' content of major ionic components is greatly affected by two main sources; the first source is atmosphere, with ions dissolving in rainwater and the other is the weathering processes of soils and base rocks in the catchment (Cey et al., 1998). Groundwater pollution is one of the most common environmental problems. Research outcomes of the last several decades have shown that groundwater sources are susceptible to contamination, and that once contaminated, water bodies are almost always difficult to clean up. This situation has drawn researcher's attention to the risk of contaminants transport to groundwater resources, as prevention has been far more effective than remediation or treatment (Letterman, 1999).

Quality of groundwater is affected by several factors such as climate, landscape, parent material of the area, land use and management at field or farm level. Other significant sources of groundwater contamination include uncontrolled hazardous waste sites, uncontrolled industrial effluents disposal and leachates from landfills (Gailey and Gorelick, 1993; Kjeldsen et al., 1993). The fact that Dhamar city has been witnessing a substantial growth in agricultural, industrial and municipal activities imposes equivalent governmental and social efforts to protect groundwater against contamination.

The quality of groundwater depends to some extent on a variety of chemical constituents at different concentrations. The greater part of the soluble constituents in groundwater comes from soluble minerals in soils and sedimentary rocks and play important roles as indicators of groundwater contamination (Ariqi and Ghaleb, 2010; Sundaram et al., 2009). Unfortunately, assessment of groundwater quality in Yemen has received insufficient attention and only a few studies have been conducted and fewer results have been publicized, e.g., Sana'a (Alhababy, 2016; Ariqi et al., 2010), Almukkala (Daraigan et al., 2011), Ibb (Sabahi et al., 2009; Sabahi et al., 2009), and Shabwa (Alamry, 2008). Generally, ground and surface water pollution has been attributed to the direct discharge of domestic wastes, industrial effluents, and poor management of farm wastes (Environmental Protection Agency), 2001). In Yemen, rapid depletion of groundwater has been an alarming crisis and if the same rate of water consumption continues, delivering safe water will not be available to all people in the near term (Glass, 2010). Nasher et al., (2013) studied the hydrogeochemical processes of the lower part of Wadi Siham catchment area, and Tihama plain, Yemen and found that the majority of pore waters investigated in the target area were unsuitable for irrigation purposes because of their very high salinity and sodium hazard. Dhamar city is characterized by high population density with a very large-scale irrigation rate. Dhamar area was considered to have sufficient groundwater source to cover the needs of its inhabitants. However, the magnitude of the problem of groundwater depletion was not well understood until the groundwater levels began to fall significantly, which served to increase pumping costs and in some cases wells just dried up or farms became unprofitable and were abandoned (FAO- the United Nations, 2009).

The main objective of this study was to determine the hydrochemistry of the groundwater of Dhamar city. The study examined the quality of groundwater in order to figure out the possible water contamination within the study area and also to identify the sources of ground water contamination.

Study area

Dhamar city (14°33'08" N.; 44 023'50" E.) is located about one hundred kilometres to the south of Sanaʼa (the capital city of Yemen), Figure 1.

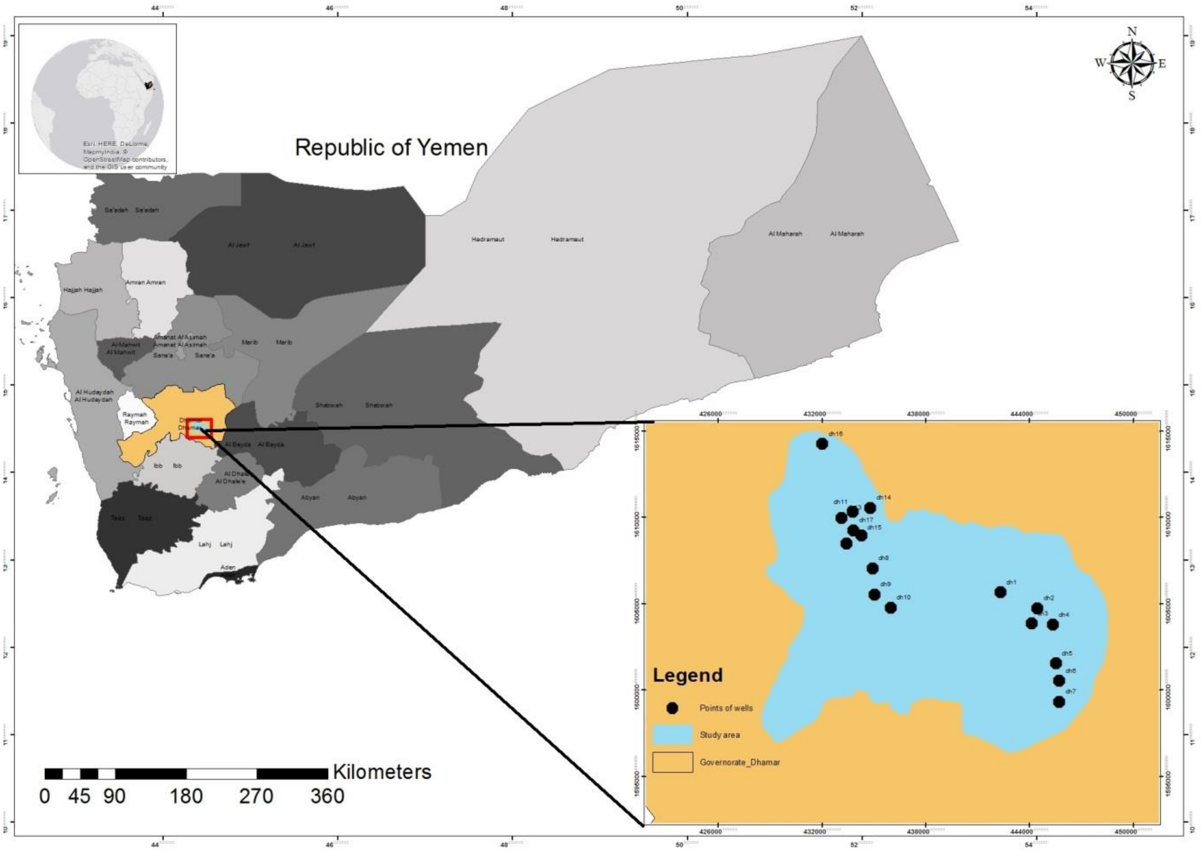


Figure 1. Location map of the study area showing sampling sites with black dots

Dhamar governorate is the largest agricultural area in the central highlands of Yemen, with the average elevation of 2400 – 2450 mast. In Dhamar city and neighbouring areas, groundwater is the only source of drinking water and the main source of irrigation. This city has a sewerage collection network and wastewater treatment station.

Dhamar City (the main city of Dhamar governorate) is part of Dhamar basin which has a both urban and pert-urban. Population of the study area has 175159 inhabitants (based on 2004 Census) (Rapport et al., 2008).

The geology of the study area is very complex, because the major outcrops in this area are quaternary basaltic lavas and ignimbrite ash flows. Also, there are volcanic cones of basalt and rhyolite. The western and northern part of Dhamar basaltic plateau is marked with obscured normal fault. The study area consists of two parts, viz; Qa’a Qaʾblasan and Qaʾa Samah. Qa’a Balasan consists of quaternary deposits formed by alluvial sediments of the streams and the weathered basaltic material. Young quaternary volcanoes are scattered and frequently formed the top layer mixed with alluvial sediments. The gap between consecutive basaltic lava flows is occupied with laterite, volcanic tuff, and ash. (Abdullah, 2006). However, Qa'a Samah is placed in the middle tertiary basalt and quaternary ignimbrites units, which represents quaternary basaltic lava, where some of the volcanic cones were formed in separate forms (Minissale et al., 2013).

The area is affected by a humid front generated from the Indian Ocean. During the months May-June (summer time), humidity is between 40% to 50% and declines down to less than 40% in the winter (October- February) with average rainfall over the surface water catchment of Dhamar depression in the range of 200- 400 mm /year (Al-Dobaee, 2016; Bruggeman, 1997).

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. Only 10% of the total rainfall infiltrate into groundwater recharge and forms the run-off portion (Bruggeman, 1997).

Dhamar area has a moderate weather where the average maximum annual temperature measured during the period 1999-2015 was about 24°C (Al-Dobaee, 2016).

Materials and Methods

Water samples for chemical analyses were collected during the year 2015 from 17 drilled wells in Dhamar city. The samples were collected after pumping for 10 minutes. Clean and dry polyethylene bottles were used for samples collection. Bottles were properly tagged and stored in the refrigerator until analysis. Immediately after sampling, temperature and total dissects solution was measured *in situ*, water acidity expressed as pH was measured by pH meter (LE422, Belgium), and electrical conductivity was measured using Conductivity Meter (model CEL/850, HACH, USA). Subsequently, the samples were analysed in the laboratory for their chemical constituents, such as Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, HCO_3^{-}, and SO_4^{2-}. Concentrations of Ca^{2+} and Mg^{2+} were estimated titrimetrically using 0.02 N EDTA and those of HCO_3^{-} and Cl^{-} were quantified by H_2SO_4 and $AgNO_3$ titration, respectively. Concentrations of Na^{+} and K^{+} were measured using a Flame Photometer (PFP 7) as stated in the Standard Methods for the Examination of Water and Wastewater (Rice et al., 2012). Laboratory facilities were provided by the Renewable Natural Resources Research Centre (RNRRC), Dhamar, Yemen.

Statistical Analysis

Statistical analysis was carried out using SPSS. The systematic calculation of Pearson's correlation coefficient (r) between water quality variables and regression analysis provides indirect means for rapid monitoring of water quality (Heydari et al., 2013). In order to calculate the correlation coefficients, the correlation matrix was constructed by calculating the coefficients of different pairs of parameters and correlation for significance was further tested by applying p-value. The variations are significant if $p<0.05$, $p<0.01$, and non-significant if $p>0.05$. The significance is considered at the level of 0.01 and 0.05 (2- tailed analysis) (Goon et al., 1968). Principal Component Analysis (PCA) is a technique for variable reduction, which helps in avoiding the consequences of non-homogeneity in sampling data, missing value and periodic trends in data. PCA also identifies temporal variation in water quality and extracts the most important parameter in the polluted site (Razmkhah et al., 2010).

Table 1. Physio-chemical parameters of 17 drilled wells located in the area of Dhamar city**.**

Drill well no.	**Mean concentrations of the target constituents (n=3)**											
	T	**pH**	**EC**	**TDS**	**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**HCO^{3-}**	**SO_4^{2-}**	**Cl^{-}**	**TH**
	C°		µs/cm	mg/L								
dh1	24.5	7.5	378	241.9	40.1	7.3	23.0	2.7	140.3	48.0	17.0	130.1
dh2	23.5	7.8	383	245.1	38.1	8.5	27.6	2.0	123.9	52.8	24.8	130.1
dh3	29.5	7.6	365	233.6	31.5	6.1	20.7	3.1	134.2	40.8	21.3	103.6
dh4	25	7.5	427	273.3	44.1	12.2	29.9	3.9	183.0	48.0	9.6	160.1
dh5	25	7.6	387	247.7	42.1	10.9	16.1	2.7	126.9	57.6	20.9	150.1
dh6	24	7.5	360	230.4	30.1	9.7	21.9	1.2	140.3	52.8	10.6	115.0
dh7	25	7.3	347	222.1	26.1	6.4	17.9	1.6	128.1	57.6	6.0	91.6
dh8	25.3	7.5	424	271.4	36.1	14.6	18.9	19.6	132.4	67.2	16.3	150.0
dh9	23	7.4	400	256.0	24.1	14.6	36.8	4.3	122.0	52.8	31.9	120.0
dh10	26	7.1	430	275.2	40.1	14.6	26.5	5.1	145.2	96.1	7.5	160.0
dh11	27	7.6	329	210.6	12.0	2.4	55.2	4.7	115.9	40.8	19.2	40.0
dh12	26.6	7.6	413	264.3	20.0	10.9	55.2	3.5	140.3	52.8	35.5	95.0
dh13	25	7.5	630	403.2	50.1	25.5	24.6	23.5	231.8	62.4	42.6	230.0
dh14	31	7	350	224.0	20.0	6.1	44.9	7.8	125.1	48.0	16.0	75.0
dh15	25	7.7	750	480.0	57.5	15.7	64.4	15.6	211.7	120.1	54.3	208.1
dh16	27	7.8	330	211.2	25.3	12.2	39.8	2.0	104.9	52.8	17.0	113.0
dh17	25	7.5	508	325.1	22.0	9.7	73.6	3.5	139.1	86.5	35.5	95.0

Results and Discussion

The mean results of analysis of groundwater samples collected from 17 drilled wells located in the target area of Dhamar city are summarized in Table 1 and Table 2. The closeness between the mean and median indicates the normal distribution of the obtained experimental values among the studied drilled wells. In Table 3, these values are compared with Yemen's standards and previous studies conducted on different areas in Yemen, and one area in Pakistan. The comparison confirms the unique physio-chemical properties of groundwater of Dhamar city, which is known of its healthy water. Also, the table reveals that groundwater in Dhamar city has almost similar physio-chemical properties to groundwater in Sana’a basin and far different physio-chemical properties with groundwater in other compared areas. This observation could be attributed to the fact that Sana’a basin is located about only 50 km north of Dhamar governorate where the current study was conducted.

Table 2. Comparison of the obtained experimental values of the studied parameters for the present study with Yemen's Standards for drinking water quality.

Parameter	Unit	Data Range	Mean	Median	Yemen's Standards
T	C°	23 – 31	25.73	25	25.00
pH		7 - 7.8	7.50	7.5	6.9-9.2
EC	µs/cm	329 – 750	424.18	387	750-3500
TDS	mg/L	211 – 480	271.47	247.68	500-1500
Ca^{2+}	mg/L	12.02 - 57.51	32.89	31.46	75-200
Mg^{2+}	mg/L	2.43 - 25.54	11.03	10.94	30-150
Na^{+}	mg/L	16.1 - 73.6	35.11	27.6	200-400
K^{+}	mg/L	1.17 - 23.46	6.28	3.52	12
HCO_3^{-}	mg/L	104.94 - 231.84	143.84	134.22	200-600
SO_4^{2-}	mg/L	40.83 - 120.08	61.03	52.83	150-500
Cl^{-}	mg/L	6.03 - 54.25	22.69	19.15	200-400
TH	mg/L	40.03 - 229.95	127.45	119.95	100-500

Table 3. Comparison of physio-chemical parameters of groundwater in Dhamar city with groundwater in some other areas of Yemen and Pakistan.

Parameter	Unit	Dhamar city, Yemen	Maytam, Ibb, Yemen	Adhban, Sana'a, Yemen	Wadi Siham, Yemen	Mardan, Pakistan
T	C°	25.73	22.87	-	20	26.5
pH		7.50	7.37	7.51	7.2	7.2
EC	µs/cm	424.18	1368	410	2,676	1297.8
TDS	mg/L	271.47	887.5	267	1617	777
Ca^{2+}	mg/L	32.89	169.5	38.5	134	37
Mg^{2+}	mg/L	11.03	44	7	81	69
Na^{+}	mg/L	35.11	81.87	56	352	-
K^{+}	mg/L	6.28	2.65	4.21	4.3	-
HCO_3^{-}	mg/L	143.84	582.5	239	277	393
SO_4^{2-}	mg/L	61.03	98.65	35	239	-
Cl^{-}	mg/L	22.69	179	22	596	-
TH	mg/L	127.45	606	-	669	387
Cited Reference		This study	(Mayas et al., 2015)	(Ariqi et al., 2010)	(Nasher et al., 2013)	(Khan et al., 2013)

The water temperature is an important quality, as many of the physical, biological and chemical functions of aquatic organisms are directly affected by temperature (Fondriest

Environmental Inc., 2017), and the amount of dissolved oxygen (DO) becomes lower as the water becomes warmer. High water temperature enhances the growth of microorganisms and may increase problems related to taste, odour, colour and corrosion. In addition, pollutants can become more toxic at higher temperatures, which could be attributed to the increase of their water solubilities (Fondriest Environmental Inc, 2017; Patra et al., 2015). On the other hand, several bacterial pathogens survived well for 22 weeks in cold groundwater or unchlorinated tap water (Schulze, 1986). Water temperature of the tested 17 wells was in the range of 23 °C to 31°C with a mean value of 25.00 °C, Figure 2. The correlation between water temperature and other parameters presented in Table 4 shows a weak positive relationship with Na^+ (0.155), and negative relationships with the rest of the parameters. However, there is no health related guideline value has been internationally set for the optimal temperature for dinking and irrigation water.

Table 4. Correlation coefficients between various measured parameters

	T	**pH**	**EC**	**TDS**	**Ca^{2+}**	**Mg^{2+}**	**Na^+**	**K^+**	**HCO_3^-**	**SO_4^{2-}**	**Cl^-**	**TH**
T	1.00											
pH	-0.32	1.00										
EC	-0.25	0.15	1.00									
TDS	-0.25	0.15	1.00	1.00								
Ca^{2+}	-0.37	0.18	0.68	0.68	1.00							
Mg^{2+}	-0.37	0.04	0.69	0.69	0.63	1.00						
Na^+	0.15	0.13	0.38	0.38	-0.30	-0.09	1.00					
K^+	0.00	-0.04	0.69	0.69	0.49	0.71	0.02	1.00				
HCO_3^-	-0.20	0.04	0.86	0.86	0.75	0.71	0.08	0.68	1.00			
SO_4^{2-}	-0.23	-0.06	0.77	0.77	0.51	0.45	0.40	0.39	0.47	1.00		
Cl^-	-0.16	0.39	0.79	0.79	0.30	0.48	0.58	0.49	0.54	0.47	1.00	
TH	-0.40	0.14	0.76	0.76	0.93	0.86	-0.24	0.65	0.81	0.53	0.41	1.00

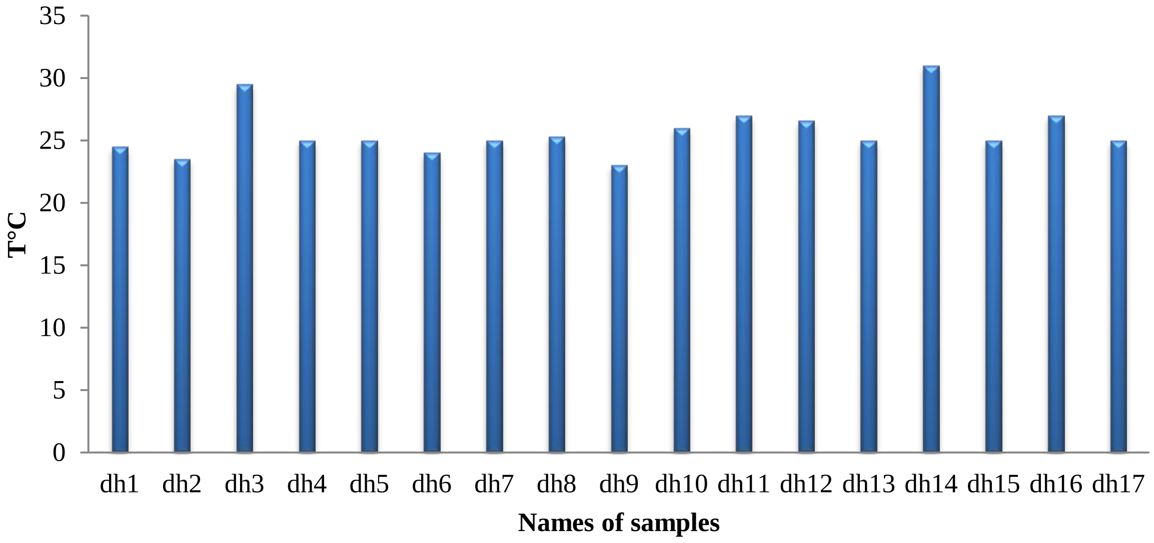


Figure 2. Variation of temperature degrees among the studied drilled wells of Dhamar city.

The potential of hydrogen (pH) was also measured. Change of water pH greatly influences biological activities of most of the aquatic organisms (Sasamura and Manglallan, 2017). Acidic waters can cause toxic heavy metals to be released into the water. Although extreme pH values (<4 and >11) may adversely affect health, there are insufficient data to set a health guideline value, and the value range of pH 6.5 to pH 8.5 has been set for aesthetic reasons. The pH values obtained for our samples showed significant differences among the studied wells and ranged from pH 7.0 to pH 7.8 with a median value of pH 7.5 indicating alkaline nature of groundwater in the studied area, Figure 3. Acidity expressed as pH value has positive correlations with most of the measured parameters

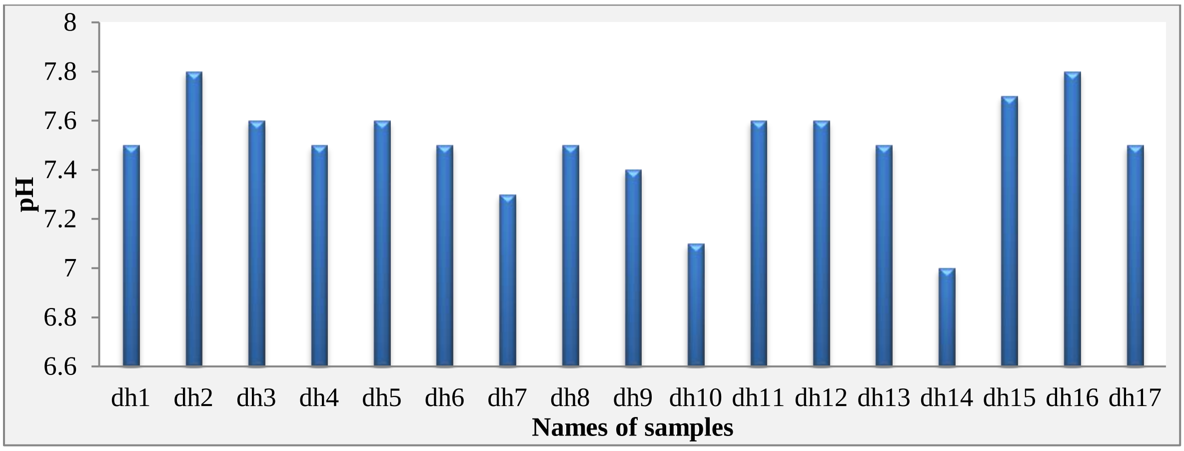


Figure 3. Variation of potential of hydrogen (pH) values among the studies drilled wells in Dhamar city

The electrical conductivity (EC) is related to the concentrations of ions capable of carrying the electrical current. Therefore, EC represents an estimation of the TDS, and no particular concentration has been set as an optimal value and usually EC values up to 800 µS/cm are acceptable in drinking water. EC levels in the tested drilled wells were found in the range of 329–750 µS/cm with a median value of 387 µS/cm. Distribution of the values of EC in groundwater of the entire study area is shown in Figure 4.

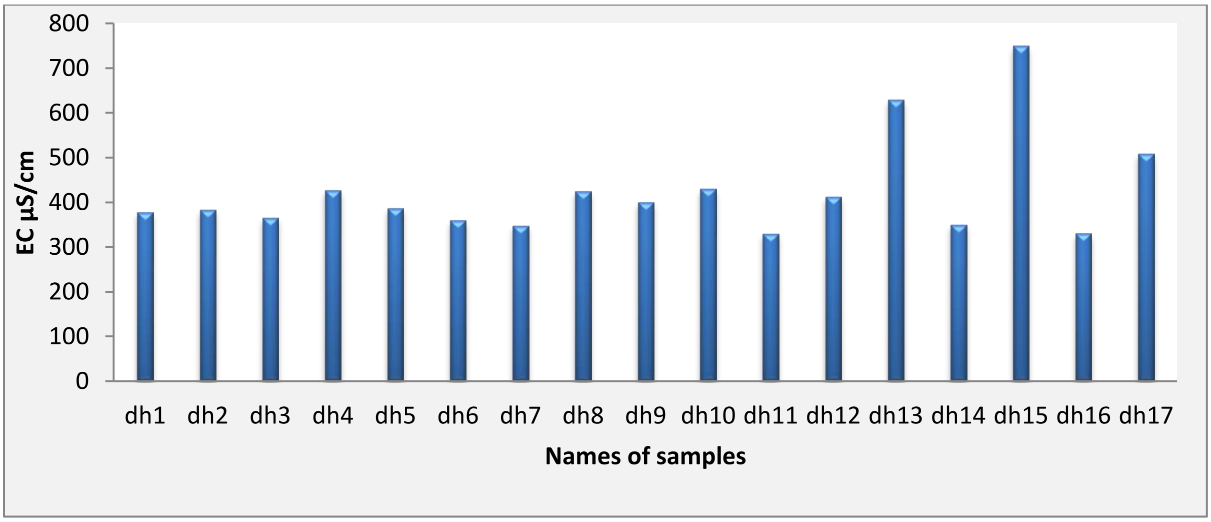


Figure 4. Variation of EC values among the studies drilled wells in Dhamar city

The concentrations of major cations, viz; Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} and major anions, viz; HCO_3^{-}, Cl^{-}, and SO_4^{2-} measured in the 17 groundwater samples are presented in Table 1. Variations in the concentrations of these inorganic constituents among the tested drilled wells and this variation is represented in Figure 5.

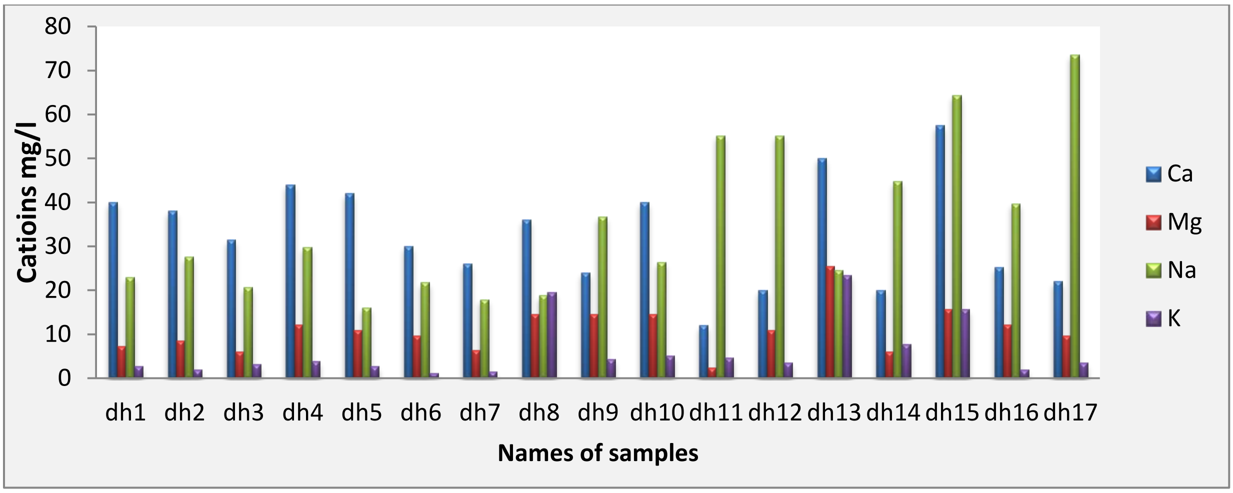


Figure 5. Variation of concentrations of major cations (sodium, potassium, calcium and magnesium) among the studies drilled wells in Dhamar city.

Calcium is an important element for good health and levels between 20 – 30 mg/L are desirable in drinking water. There is currently no health-based standard for calcium in drinking water. Very high levels of calcium, however, will produce scale and clog up water pipes. The concentration of calcium (Ca^{2+}) in the tested samples was found in the range of 12.02 to 57.51 mg/L with a median value of 31.46 mg/L. Positive correlation was observed between Ca^{2+} and some other parameters with a maximum correlation value with TH (0.933), and negative relationship with Na^{+} (-0.302), and K^{+} (-0.177).

The concentration of magnesium (Mg^{2+}) was found in the range of 2.43 to 25.54 mg/L with a median value of 10.94 mg/L, Fig. 5. A positive correlation was observed between Mg^{2+} and some other parameters with a maximum correlation value with TH (0.864), and negative correlations with Na^{+} (-0.094).

The concentrations of Na^{+} in groundwater are dependent on several factors such as local geological conditions and the level of contamination in wastewater. In addition, other sources such as mineral deposits and sewage effluents can contribute significantly to the level of sodium ions in groundwater. There is no health-related guideline value for sodium in groundwater. However, Na^{+} concentrations above 135 mg/L will affect water taste. Concentrations of sodium (Na^{+}) in the tested drilled wells was in the range of 16.1-73.6 mg/L with a median value of 27.6 mg/L. the concentration of Na^{+} exhibited positive correlations with some other parameters with a maximum correlation value with SO_4^{2-} (0.581), and a negative relationship with TH (-0.238).

The concentration of potassium (K^{+}) was found in the range of 1.17 to 23.46 mg/L with a median value of 3.52. The concentrations of K^{+} exhibited positive correlations with some other parameters with a maximum correlation value with SO_4^{2-} (0.413).

Bicarbonate ion (HCO_3^-) contributes to water alkalinity. The concentration of HCO_3^- in the tested water samples was found in the range of 104.94 to 231.84 mg/L with a median value of 134.22 mg/L, Figure 6. The concentration of HCO_3^- exhibited positive correlations with TH (0.807), SO_4^{2-} (0.545), and Cl^- (0.471).

Chloride (Cl^-) occurs naturally in waters from minerals and salt. Although, no health related guideline value has been set for chloride, a concentration exceeding 250 mg/L is not recommended for aesthetic reasons (taste). The concentration of Cl^- was found in the range of 6.03 to 54.25 mg/L with a median value of 19.15. The variation in the levels of Cl^- in the tested water wells could be attributed to the type of rock the ground water moves through and how long the ground water is in contact with these rocks. It is expected that higher Cl^- content may be found in deeper wells (this correlation was practically investigated by the current study). The concentration of Cl^- exhibited positive correlations with TH (0.534), and SO_4^{2-} (0.468).

Sulphate (SO_4^{2-}) occurs naturally in surface and underground waters. For aesthetic reasons SO_4^{2-} levels should not exceed 250 mg/L. The concentration of sulphate (SO_4^{2-}) in the tested wells was found in the range of 40.83 to 120.08 mg/L with a median value of 52.83 mg/L. The concentration of SO_4^{2-} exhibited positive correlations with EC (0.77), TDS (0.77), Ca^{2+} (0.51), Mg^{2+} (0.45), Na^+ (0.40), K^+ (0.39), HCO_3^- (0.47), and Cl^- (0.47).

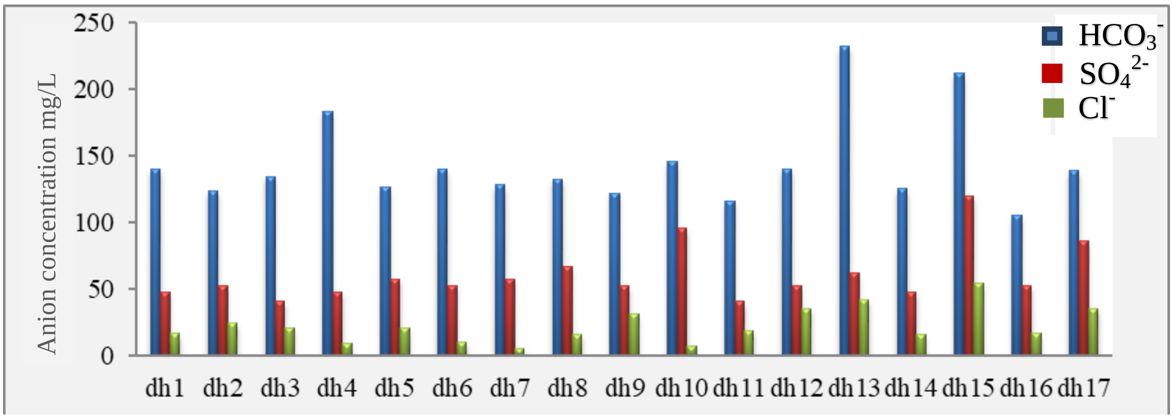
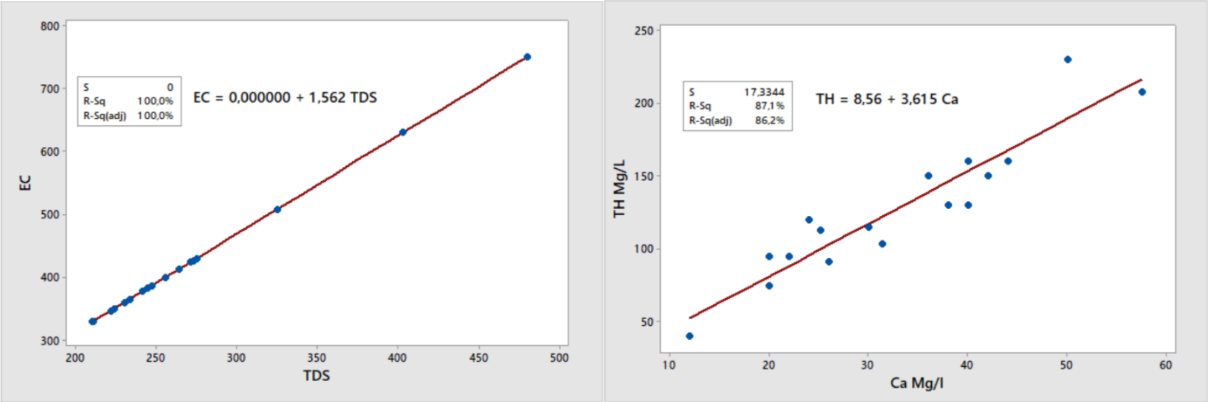


Figure 6. Variation in the concentration of the major anions (chloride, bicarbonate, and sulphate) among the tested wells.

The concentration of TH was found in the range of 40.03 to 229.95 mg/L with a median value of 119.95 mg/L. A highly positive correlation was observed between TDS and EC (R = 1.000), Figure 7-a and between TH and Ca^{2+} (R = 0. 871), Figure 7-b.



a b

Figure 7. (a) Regression between EC and TDS. (b) Regression between TH and Ca^{2+}.

Sodium Absorption Ratio (SAR): The SAR is a parameter relevant to irrigation use and is a measure of the ratio of Na^{+} to Ca^{2+} and Mg^{2+}. When the ratio of sodium to calcium and magnesium is high, water is regarded unsuitable for low salt-tolerant crops. Elevated SAR has an adverse effect on soil structure and permeability, which can reduce crop yields and growth rates. SAR is calculated using the following relation:

$$SAR = \frac{meqNa^{+}}{\sqrt{\frac{meq(Ca^{2+} + Mg^{2+})}{2}}}$$

SAR values calculated for the investigated drilled wells using the mean values are represented in Table 5.

Table 5. *SAR values calculated for the investigated drilled wells using the mean values*

	Ca^{2+}	Mg^{2+}	Na^{+}	SAR
dh1	40.08	7.3	23	0.88
dh2	38.08	8.51	27.6	1.05
dh3	31.46	6.08	20.7	0.88
dh4	44.09	12.16	29.9	1.03
dh5	42.08	10.94	16.1	0.57
dh6	30.06	9.73	21.85	0.89
dh7	26.05	6.44	17.94	0.82
dh8	36.07	14.59	18.86	0.67
dh9	24.05	14.59	36.8	1.46
dh10	40.08	14.59	26.45	0.91
dh11	12.02	2.43	55.2	3.79
dh12	20.04	10.94	55.2	2.46
dh13	50.1	25.54	24.61	0.71
dh14	20.04	6.08	44.85	2.25
dh15	57.51	15.69	64.4	1.94
dh16	25.25	12.16	39.79	1.63
dh17	22.04	9.73	73.6	3.28

There is no Yemeni guideline value for SAR. However, studies showed that SAR values less than 3 mean that there is no sodium problem and the water is regarded as of good quality, suitable for a wide range of crops. SAR values from 3 to 6 indicate low Na concentration causing few problems to Na sensitive crops e.g. pecan nut, avocado, papaw, strawberry (Swistock, 2017). It is clear that the groundwater sites analysed in this study have SAR values less than 3 (except for dh17) indicating that water causes no sodium problem to crops.

PCA analyses performed on the entire set of measured physicochemical parameters showed differences among the sampling sites. Principal components represent axes PC1 and PC2 together represent 70.54% of the variation in the physicochemical parameters of all sampling sites and the data clearly show that the sampling sites are consistently different in their characteristics, irrespective of the month of sampling. The scree plot (Table 6 & Figure 8a) of the principal component analysis showed that the eigenvalues of the two first principal components represent up to PC1 54.23% and PC2 16.31% of the observations.

Table 6. Total variance explained by each parameter

Component	**Rotation Sums of Squared Loadings**		
	Total	**% of Variance**	**Cumulative %**
1	6.51	54.23%	54.23%
2	1.96	16.31%	70.54%

However, to, correctly, interpret this graph, the factor loadings for each variable on the unroasted components must be taken into account, as shown in (Table 7 & Figure 8b). The twelve parameters shown in Table 7 are well represented on the plane under consideration either by the first component (Ca^{2+}, Mg^{2}, HCO_3, TDS, EC, SO_4^{2-}, and TH) or by the second component (T, Cl^-, Na^+ and pH).

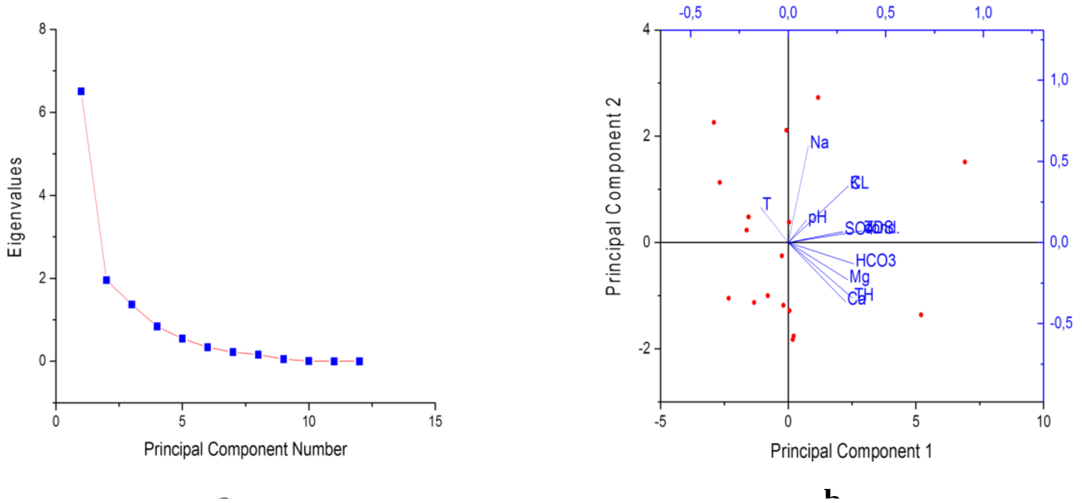


Figure 8. Scree plot of the 12 experimental variables (a) and Loadings of all samples on the plane defined by principal components 1 and 2 obtained by the12 experimental variables (b).

Table 7. Loadings of the principal components 1 and 2 of 12 experimental parameters.

Parameter	**T**	**pH**	**EC**	**TDS**	**Ca^{2+}**	**Mg^{2+}**	**Na^+**	**K^+**	**HCO_3^-**	**SO_4^{2+}**	**Cl^-**	**TH**
PC1	-0.14	0.07	0.38	0.38	0.31	0.32	0.07	0.29	0.35	0.28	0.28	0.35
PC2	0.22	0.10	0.16	0.16	-0.32	-0.20	0.68	-0.05	-0.06	0.19	0.39	-0.30

Conclusion

Based on the criteria specified in the Yemeni Guideline for drinking water quality, groundwater of all wells analysed in this study is considered suitable for drinking, irrigation purposes and domestic uses. However, the low concentrations of hardness indicates that drinking of such waters may result in low consumption of calcium and magnesium which requires further investigations of any consequences for health. It could be concluded that all the parameters investigated in this study are more or less correlated with each other. PCA statistical method could define spatial variations, explaining 70 % of total variances with two latent factors. Values of the correlation study and correlation coefficient can help in selecting a few parameters, which could be measured to determine the status of water quality regularly.

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