THE EVALUATION OF GROUNDWATER QUALITY AT AL-SAYYADAH AREA, IBB CITY, YEMEN

Esmail Al Sabahi1, Abdul Rahim S1,
Zuhairi WY1, Fadhl Al Nozaily & Fares Alshaebi1
1Geology Program, School of Environment and Natural Resource Sciences, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi Selangor, Malaysia.
2Water and Environment Center, Sana'a University, Republic of Yemen.

ABSTRACT

Groundwater samples were collected from Al-Sayyadah area in three different seasons to study the suitability of groundwater for drinking water. The objective of the study is to determine the physiochemical and microbiological parameters at Al-Sayyadah area, Ibb city, the Republic of Yemen. The concentrations of various physiochemical parameters include pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), and dissolved oxygen (DO), heavy metals (Pb, Zn, Ni, Cr, Cd, Cu), anions and nutrients (F-, Cl-, SO4-2, NO-2, NO3-, NH3-N), major cations (Fe, Na, K, Ca, Mg), and coliform group bacteria were measured from the groundwater samples. Seven boreholes were selected for this study. The results show that, all boreholes are suitable for drinking water compared to the standard acceptable levels which are required for drinking water adapted by Yemen's Ministry of Water and Environment (YMWE, 1999) and WHO (2004). The variations in concentrations of the physiochemical parameters can be attributed to the nature of the geological and chemical structure of the soil and rocks, the depth of the boreholes, and the dilution of the boreholes spatially in main wet season.

Key words: groundwater, pollution, bacteria, heavy metals.

INTRODUCTION

Pollution occurs when a product added to our natural environment adversely affects nature's ability to dispose it off. A pollutant is something which adversely interferes with health, comfort, property or environment of the people. Generally, most pollutants are introduced in the environment as sewage, waste, accidental discharge and as compounds used to protect plants and animals. There are many types of pollution such as air pollution, soil pollution, water pollution, nuclear pollution and oil pollution (Misra & Main, 1991).

Groundwater is that portion of subsurface water which occupies the part of the ground that is fully saturated and flows into a hole under pressure greater than atmospheric pressure. Groundwater occurs in geological formations known as aquifer. An aquifer (gravel/ sand) may be defined as a geologic formation that contains sufficient permeable materials to yield significant quantities of water to wells and springs; this implies an ability to store and transmit water (Chae, 2000). Groundwater is an important source of drinking water for humankind. It contains over 90% of the fresh water resources and is an important reserve of good quality water. Groundwater, like any other water resource, is not just of public health and economic value; it also has an important ecological function (Armon & Kott, 1994).

The objective of the study is to determine the physiochemical and microbiological parameters at Al-Sayyadah area, Ibb city, the Republic of Yemen.

MATERIAL AND METHODS

Ibb city (Figure 1) is located between Sana'a, the capital of Yemen, and Taiz governorates. Ibb city is located at latitude 13°58′48″ and longitude 44°10′48″. Ibb is situated in a fault controlled valley close to the main watershed of the Wadi Zabid at an elevation of about 2000 above sea level.

Groundwater samples are collected from seven boreholes from un agricultural area Al-Sayyadah area. The boreholes are distributed in different locations around the city Figure 2. Glass and polyethylene bottles are used to collect groundwater samples. A few drops of concentrated nitric acid are added to all the water samples collected for heavy metals analysis to preserve the samples. The samples were then transported in a cool box and to be stored under suitable temperature until analysis.

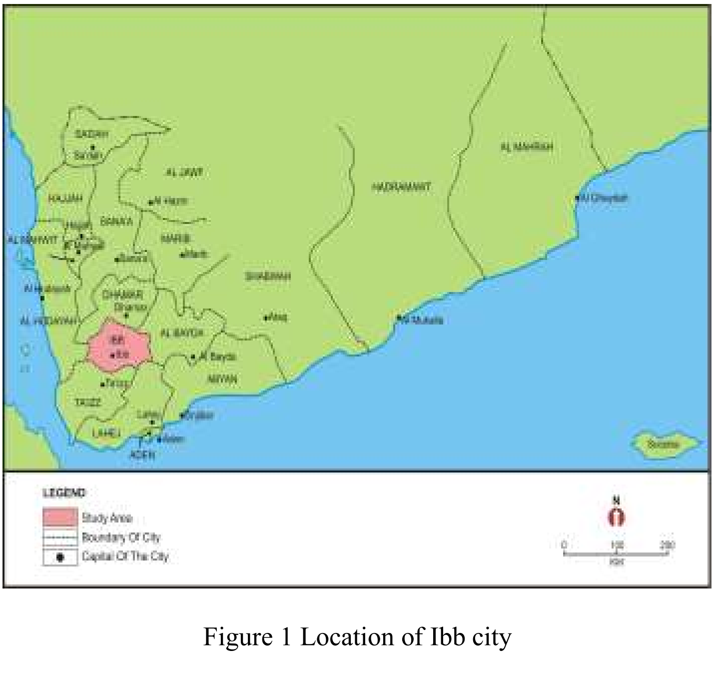

Figure 1 Location of Ibb city

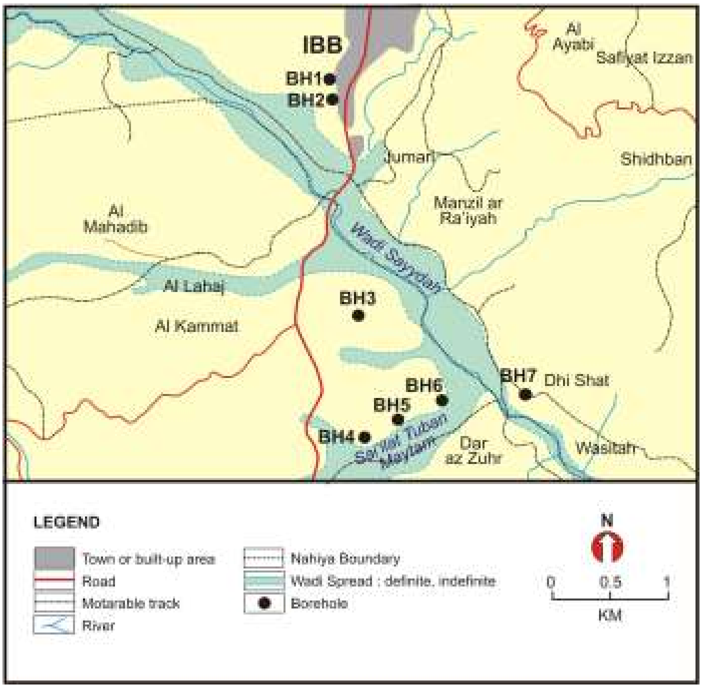

Figure 2 Location of the boreholes

The laboratory of Ibb Water and Sanitation Local Corporation (IWSLC) is used for analyzing of water samples. Spectrophotometer HACH (DR 4000 models 48000 and 48100) is used for measuring of PO_4, SO_4, NO_3, NO_2, F, and NH_3. Flame photometer (PFP 7) was used to determine Sodium (Na) and Potassium (K). The analyzing of heavy metals was by Inductively Coupled Plasma of Optical Emission Spectrometry (ICP-OES) model Vista MPX.

Chloride was measured by the Mercuric Nitrate Titrimetric Method. 25ml of water samples was placed in Erlenmeyer flask, and then Diphenylcarbazone regent was added to the sample. The solution was blue-green, when Mercuric Nitrate was added as a titrant, the solution was turned from blue-green to purple, making the end point of the titrant.

Calcium was measured by the EDTA titrimetric methods which involves the use of solutions of ethylene diaminetetra acetic acid. 25ml of water sample was placed in a conical flask, and then 2ml of buffer solution was added to the sample. Man Ver 2 Calcium indicator was also added to the sample. The solution was wine red, when EDTA was added as a titrant, the solution was turned from wine red to blue, making the end point of the titrant.

The hardness was measured by the EDTA titrimetric methods which involves the use of solutions of ethylene diaminetetra acetic acid. 25ml of water sample was placed in a conical flask, and then 2ml of buffer solution was added to the sample. Man Ver 2 Hardness indicator was also added to the sample. The solution was wine red, when EDTA was added as a titrant, the solution was turned from wine red to blue, making the end point of the titrant.

Magnesium was measured by calculation as the difference between total hardness and calcium hardness as follows:

Total hardness (as $CaCO_3$) = 2.497 [Ca^{2+}, mg/L] + 4.118 [Mg^{2+}, mg/L].

Then

4.118 [Mg^{2+}, mg/L] = Total hardness (as $CaCO_3$) - 2.497 [Ca^{2+}, mg/L]

Where

Ca hardness = Ca ion × 2.5

Mg hardness = Mg ion× 4.11

MICROBIOLOGICAL ANALYSIS

Nine tubes of lactose broth (Figure 3) were prepared according to the size of the water sample i.e.0.1ml, 1ml, and 10ml respectively for all water samples. The test tubes are placed in incubator at 35ºC for 24 hours for gas production. Table 3.17 shows the most probable number (MPN) of coliforms. Production of gas confirms the presence of coliform in the sample. To confirm the presence of coliform, Eosin Methylen Blue agar (EMB) was used in which contains methylene blue that inhibits coliforms. The plates of Eosin Methylen Blue agar (EMB) is placed in incubator after streaking at 35ºC for 24 hours. E.coli colonies on this medium are small with metallic sheen. A single colony from EMB agar plate was picked up and inoculated it into lactose broth. The lactose broth was showed a cid and gas production confirms the presence of coliform bacteria.

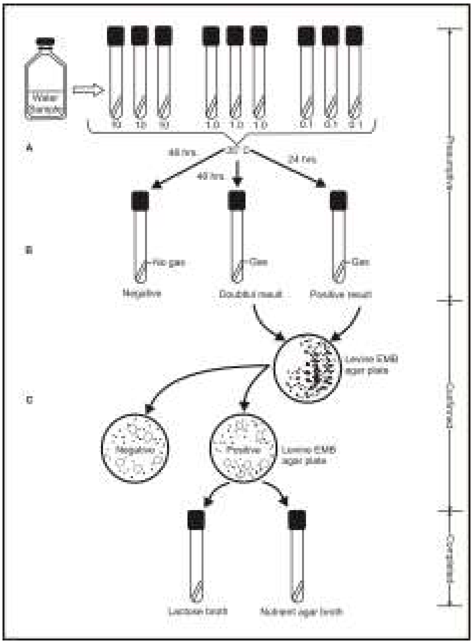

Figure 3 Bacteriological analysis of water for coliform bacteria

RESULTS AND DISCUSIONS

INSITU PARAMETERS

The results of the measured insitu parameters including pH, temperature (T), electrical conductivity (EC), total dissolved solids (TDS), and dissolved oxygen (DO) are shown in Table 1.

The pH values of all boreholes are shown in Table 1. The highest value of 8.22 is measured in BH2 at dry season, whereas the lowest value of 7.14 is measured in BH3 at wet season. The highest pH value is higher than the results 8.11 obtained by Matloub et al. (2001) and lower than the results 8.81 obtained by Kamal & Mohammed (2001). On the other hand the lowest pH value is also lower than the results 7.73 obtained by Matloub et al. (2001) and lower than the results 7.56 obtained by Kamal & Mohammed, 2001. These results are in agreement with the range values set by Yemen's Ministry of Water and Environment (YMWE, 1999) and WHO (2004). If the pH is above 7, this will indicate that water is probably hard and contains calcium and magnesium (David, 2004). Zajic (1971) stated that, natural waters generally range from pH 5.5 to 8.6. Water with lower pH tends to cause corrosion, and in many cases an upward adjustment to the neutral range (pH = 7.0) is necessary. Drinking water with pH range from 6.5 to 8.3 is necessary. At high pH values the effectiveness of chlorination decrease, i.e. the rate of kill of microbes decreases.

The temperature measurements between boreholes are very close. The highest value is measured in BH3 (24.9° C) at wet season, whereas, the lowest values in BH 7 (21.8° C) at dry season. These results are in agreement with the range values set by Yemen's Ministry of Water and Environment (YMWE, 1999).

Electrical conductivity (EC) values show different results between the boreholes. The highest value is recorded in BH3 (770 µS/cm), whereas the lowest value is recorded in BH4 (570 µS/cm). These results are lower than the results 1160 µS/cm obtained by Kamal & Mohammed, 2001. Conductivity was used to give an idea of the amount of dissolved chemicals in water, and presence of Na, K, and Cl. Conductivity is not a problem in itself and just because it is above certain level does not mean that the water will cause illness (David, 2004). These results are in agreement with the range values set by Yemen's Ministry of Water and Environment (YMWE, 1999).

Dissolved oxygen (DO) measurements are varied in three different seasons. The highest concentration of 7.5mg/l is measured in BH4, whereas the lowest concentration of 1.1mg/l is measured in BH1. At high pH values the effectiveness of chlorination decrease, i.e. the rate of kill of microbes decreases Zajic (1971).

The concentrations of total dissolved solids (TDS) are different between boreholes. The highest value of 5005.5 mg/l is measured in BH3 at main wet season, whereas, the lowest value of 388.7 mg/l is measured in BH6 at dry season. These results are lower than the results 754 mg/l obtained by Kamal & Mohammed, 2001. On the contrary, these results are higher than the results 430mg/l obtained by Matloub et al. (2001). On the other hand, the concentrations of total dissolved solids (TDS) in all boreholes did not pose any water quality problems because these results are in agreement with the range values set by Yemen's Ministry of Water and Environment (YMWE, 1999) and WHO (2004) which required for drinking water. The variations in concentrations of the above insitu parameters can be attributed to the nature of the geological and chemical structure of the soil and rocks, the depth of the boreholes, the dilution of the boreholes spatially in main wet season.

Table 1 Insitu parameters at Al-Sayyadah area

	Wet season					Main wet season					Dry season				
Parameters	pH	T	EC (μS/cm)	TDS (mg/l)	DO (mg/l)	pH	T	EC (μS/cm)	TDS (mg/l)	DO (mg/l)	pH	T	EC (μS/cm)	TDS (mg/l)	DO (mg/l)
BH1	7.40	23.1	731	475.15	3.3	7.25	23.8	728	473.2	3.8	8.12	23.4	731	475.15	1.1
BH2	7.25	24.0	671	436.15	3.4	7.38	23.8	688	447.2	5.2	8.22	23.9	688	447.2	1.6
BH3	7.14	24.9	664	417.1	4.3	7.56	25.1	770	500.5	4.4	8.09	24.1	769	500	1.3
BH4	7.61	23.2	607.5	394.88	4.1	7.52	22.8	570	370.5	3.8	7.81	22.7	696	452.4	7.5
BH5	7.30	23.5	674	438.10	3.3	7.60	24.0	682	443.3	3.8	7.74	22.8	704	457.6	6.1
BH6	7.58	23.0	736	478.4	3.1	7.56	23.9	598	388.7	3.9	7.77	23.8	598	388.7	5.7
BH7	7.65	24.0	639	415.35	3.2	7.30	24.5	720	468	4.2	7.74	21.8	720	468	6.1
YMWE 1999	6.5-9	25	450-1000	1500	-	6.5-9	25	450-1000	1500	-	6.5-9	25	450-1000	1500	-
WHO 2004	6.5-9.5	-	-	1200	-	6.5-9.5	-	-	1200	-	6.5-9.5	-	-	1200	-

MAJOR ANIONS AND NITROGENOUS COMPOUNDS

These include fluoride (F^-), chloride (Cl^-), sulfate (SO_4^{-2}), nitrites (NO_2^-), nitrates (NO_3^-), and ammonia-N (NH_3-N). The results are shown in Table 2.

The highest concentration of F^- is measured in BH1at dry season with the value of 0.943mg/l, whereas the lowest concentration is measured in BH6 at main season with the value of 0.24mg/l. These results are lower than the results 1.21 mg/l obtained by Kamal & Mohammed, 2001. On the contrary, the lowest concentration in BH6 is closed to the result 0.25 mg/l obtained by Matloub et al. (2001). The absence of fluorides in drinking water encourages dental caries or tooth decay; excessive concentrations of the chemical produce mottling of the teeth or dental fluorosis. Thus, managers and operators of water treatment plants must be careful that the exact concentrations of the fluorides are administered to the drinking water. Optimum concentrations of 0.7 to 1.2 mg/l are normally recommended, although the actual amount in specific circumstances depends upon the air temperature, since air temperature influences the amount of water that people drink (Arcadio & Gregoria, 2003). In general, the values of F^- in all boreholes are in agreement with the standard acceptable levels of drinking water set by YMWE (1999) and WHO (2004).

The concentrations of Cl^- are different between boreholes at three different seasons. The highest Cl^- concentration is found in BH3 at dry season with the value of 146 mg/l, whereas the lowest Cl^- concentration is found in BH4 at main season with the value of 85.2 mg/l. These results are high compared to the results 28.5 mg/l obtained by Matloub et al. (2001). On the contrary, these results are in agreement with range results 26.8 to 180.1 mg/l obtained by Kamal & Mohammed, 2001. In general, the values of Cl^- in all boreholes did not pose any water quality problems because they are in agreement with the standard acceptable levels of drinking water set by YMWE (1999) and WHO (2004).

The concentrations of SO_4 are different between boreholes at three different seasons. The highest SO_4 concentration is found in BH7 at wet season with the value of 42.4 mg/l, whereas the lowest SO_4 concentration is found in BH6 at main season with the value of 19.68 mg/l. These results are low in compared to the results 34.0 mg/l obtained by Matloub et al. (2001). On the contrary, these results are low in compared to the results 665 mg/l obtained by Kamal & Mohammed, 2001. In general, the values of Cl^- in all boreholes did not pose any water quality problems because they are in agreement with the standard acceptable levels of drinking water set by YMWE (1999) and WHO (2004).

The NO_2 and NO_3 levels in the boreholes are very low and did not pose any significant water quality problem. Nitrate is reduced to nitrite in the stomach of infants, and nitrite is able to oxidize haemoglobin (Hb) to methaemoglobin (metHb), which is unable to transport oxygen around the body. Guideline value for combined nitrate plus nitrite should not exceed 1 (WHO, 2004). In this study the combined of nitrate plus nitrite did not exceed 1.

The concentration of ammonia NH_3-N for all boreholes gave different values at three different seasons. The highest concentration of ammonia is recorded in BH4 at wet season with the value of 0.071 mg/l, whereas the lowest concentration of ammonia is recorded in BH3 at main wet season with the value of 0.008 mg/l. On the other hand, the ammonia concentrations in BH1 (dry season), BH7 (main and dry seasons) are not detected.

According to Atxotegi et al. (2003), ammonium ion NH_4 is transformed into ammonia NH_3 based on pH through the following reaction:

$NH_4 \longrightarrow NH_3 + H^+$ or

$NH_4OH \longrightarrow NH_3 + H_2O$

	Wet season						Main wet season						Dry season					
Parameters	F-	Cl-	SO4-2	NO2-	NO3-	NH3-N	F-	Cl-	SO4-2	NO2-	NO3-	NH3-N	F-	Cl-	SO4-2	NO2-	NO3-	NH3-N
BH1	0.63	124.25	33.7	0.024	22.0	0.032	0.56	100.11	34.1	0.02	19.33	0.043	0.943	138.45	33.48	0.021	13.0	ND
BH2	0.43	89.46	23.0	0.0085	11.3	0.035	0.505	93.01	33.4	0.043	16.5	0.058	0.098	125.1	37.4	0.11	9.0	0.03
BH3	0.623	110.76	34.05	0.061	17.0	0.021	0.627	127.8	42.3	0.025	29.67	0.008	0.695	146.3	39.3	0.02	30.25	0.063
BH4	0.645	102.0	27.65	0.017	13.0	0.071	0.477	85.2	23.92	0.001	13.83	0.009	0.493	115.02	34.47	0.022	15.0	0.056
BH5	0.505	105.16	33.35	0.023	16.0	0.033	0.66	110.1	33.2	0.007	20.5	0.083	0.523	115.02	35.83	0.014	16.0	0.04
BH6	0.442	110.0	19.68	0.029	14.17	0.031	0.24	88.04	24.8	0.064	13.0	0.052	0.46	125.67	35.6	0.001	12.0	0.041
BH7	0.487	114.7	42.4	0.012	11.67	0.051	0.678	123.54	40.2	0.005	6.67	ND	0.32	117.15	39.9	0.012	17.25	ND
YMWE 1999	1.5	250	250	0.1	50	0.5	1.5	250	250	0.1	50	0.5	1.5	250	250	0.1	50	0.5
WHO 2004	1.5	250	250	0.1	50	0.2	1.5	250	250	0.1	50	0.2	1.5	250	250	0.1	50	0.2

Table 2 Major anions and nitrogenous compounds at Al-Sayyadah area

MAJOR CATIONS

The major cations include Fe, Na, K, Ca, and Mg. The concentrations of cations are given in Table 3. The highest concentration of Fe is measured at main season in BH5 with the value of 0.124 mg/l, whereas the lowest concentration is measured at dry season in BH2 with the value of 0.01 mg/l. On the other hand, the highest concentration of Na is recorded at wet season in BH3 with the value of 68.0 mg/l, whereas the lowest concentration is recorded at main season in BH1 with the value of 22.17 mg/l. With regards to, the highest concentration of K is reported at wet season in BH1 with the value of 2.25 mg/l, whereas the lowest concentration is reported at also wet season in BH3 with the value of 0.6 mg/l. On the other hand, the highest concentrations of Ca and Mg are found in BH1 and BH5at dry season respectively, whereas the lowest concentrations of Ca and Mg are found BH4 at main wet season.

The presence of sodium in drinking water can affect persons suffering from heart, kidney, or circulatory ailments. It may elevate blood pressures of susceptible individuals. Sodium is plentiful in the common table salt that people use to flavor food to their taste (Arcadio & Gregoria, 2003). The distribution of Fe, Na, K and Mg in all boreholes did not pose any significant water quality problem, because these cations are within the standard acceptable levels of drinking water determined by YMWE (1999) and WHO (2004).

Among all the cations analysed, Ca showed high concentrations level in most boreholes at wet season, main wet season and dry season. These concentrations are higher than the results 72.0 mg/l obtained by Matloub et al. (2001) and also by Kamal & Mohammed, 2001. These results are not within the standard acceptable levels of drinking water determined by YMWE (1999) and WHO (2004).

Calcium is naturally present in water. It may dissolve from rocks such as limestone, marble, calcite, dolomite, gypsum, fluorite and apatite. Calcium is a determinant of water hardness, because it can be found in water as Ca^{2+} ions. Calcium is largely responsible for water hardness, and may negatively influence toxicity of other compounds.

On the contrary, among all the cations analysed, Fe showed low concentration level with the value of 0.01 mg/l at dry season in BH2. These results in all seasons did not pose any water quality problems because these results are within the standard acceptable levels of drinking water determined by YMWE (1999) and WHO (2004).

The variations in concentrations of the above cations parameters can be attributed to the nature of the geological and chemical structure of the soil and rocks, the depth of the boreholes, the dilution of the boreholes spatially in main wet season.

HEAVY METALS

Heavy metals include lead (Pb), zinc (Zn), nickel (Ni), chromium (Cr), cadmium (Cd), and copper (Cu). The concentrations of heavy metals are given in table 4. Pb concentration is the highest concentrations of heavy metals which are measured in wet season. Although, Pb concentrations are high in BH1 and BH2 at wet season in compared to the standard acceptable levels of drinking water determined by YMWE (1999) and WHO (2004) so that, they still under permissible limit. Ni, Cr, and Cd concentrations are not detected in most boreholes at different seasons.

BACTERIA

The results of microbiological analysis for three different seasons are shown in Table 5. The results show that all boreholes did not show any microorganism bacteria during three seasons. This means that all boreholes are suitable for drinking water in compared to APHA, 1998 standard.

Table 5 Microbiological analysis for all seasons

Parameter	3 of 10m each	3 of 1m each	3 of 0.1m each	MPN Index per 100m
BH1	ND	ND	ND	0
BH2	ND	ND	ND	0
BH3	ND	ND	ND	0
BH4	ND	ND	ND	0
BH5	ND	ND	ND	0
BH6	ND	ND	ND	0
BH7	ND	ND	ND	0
APHA, 1998	3	3	3	2400

ND: Not detected

Table 3 Major cations at Al-Sayyadah area

	Wet season					Main wet season					Dry season				
Parameters	Fe (mg/l)	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Fe (mg/l)	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Fe (mg/l)	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)
BH1	0.072	35.0	2.25	105.6	26.88	0.0104	22.17	0.867	99.2	24.24	0.020	31.5	0.8	121.2	27.82
BH2	0.031	39.0	1.7	82.4	18.9	0.06	31.67	0.917	83.2	22.63	0.01	41.25	0.93	85.6	9.12
BH3	0.023	68.0	0.6	71.2	15.6	0.019	45.83	0.9	80.8	22.56	0.012	63.0	0.8	87.6	15.84
BH4	0.036	41.0	1.3	78.0	16.56	0.093	51.0	1.15	55.2	8.18	0.025	34.5	1.25	84.0	25.21
BH5	0.025	35.0	1.3	86.8	25.68	0.124	32.0	1.5	83.2	23.04	0.023	37.0	1.23	88.8	28.8
BH6	0.061	52.67	1.15	68.0	10.56	0.043	44.0	0.9	73.6	21.6	0.034	39.0	0.9	99.6	24.74
BH7	0.039	54.0	0.733	86.4	23.76	0.082	46.0	0.817	83.6	22.32	0.03	39.25	1.1	96.0	24.24
YMWE 1999	0.3	200	-	75	300	0.3	200	-	75	300	0.3	200	-	75	30
WHO 2004	0.3	200	-	75	300	0.3	200	-	75	300	0.3	200	-	75	30

Table 4 Heavy metals at Al-Sayyadah area

	Parameters	BH1	BH2	BH3	BH4	BH5	BH6	BH7	YM WE 1999	WHO 2004
Wet season	Pb (mg/l)	0.06	0.04	0.01	0.01	0.01	0.003	0.003	0.01	0.01
	Zn (mg/l)	0.926	0.22	0.226	0.401	0.704	0.157	0.824	3.0	3.0
	Ni (mg/l)	0.01	0.01	ND	ND	ND	0.01	0.01	0.02	0.02
	Cr (mg/l)	0.01	0.01	ND	ND	ND	ND	ND	0.05	0.05
	Cd (mg/l)	ND	ND	ND	ND	ND	ND	ND	0.003	0.003
	Cu (mg/l)	0.33	0.049	0.112	0.81	0.164	0.163	0.199	1.0	1.0
Main wet season	Pb (mg/l)	0.01	ND	0.002	0.01	0.01	0.001	0.001	0.01	0.01
	Zn (mg/l)	0.543	0.147	0.167	0.55	0.945	0.082	0.574	3.0	3.0
	Ni (mg/l)	ND	ND	ND	ND	ND	ND	ND	0.02	0.02
	Cr (mg/l)	0.001	ND	ND	ND	ND	ND	ND	0.05	0.05
	Cd (mg/l)	ND	ND	ND	ND	ND	ND	ND	0.003	0.003
	Cu (mg/l)	0.187	0.259	0.120	0.172	0.234	0.125	0.236	1.0	1.0
Dry season	Pb (mg/l)	0.001	0.002	0.001	0.001	0.002	0.001	0.001	0.001	0.01
	Zn (mg/l)	0.678	0.124	0.092	0.475	0.345	0.128	0.675	3.0	3.0
	Ni (mg/l)	ND	ND	ND	ND	ND	ND	ND	0.02	0.02
	Cr (mg/l)	ND	ND	ND	ND	ND	ND	ND	0.05	0.05
	Cd (mg/l)	ND	ND	ND	ND	ND	ND	ND	0.003	0.003
	Cu (mg/l)	0.201	0.130	0.010	0.136	0.185	0.186	0.155	1.0	1.0

CONCLUSIONS

The results show that, all boreholes did not pose any water quality problems because the concentrations of all physiochemical and microbiological parameters are within the standard acceptable levels of drinking water determined by YMWE (1999) and WHO (2004). The aquifer in this area is considered alluvial deposits and Igneous rocks. The variations in concentrations of all parameters can be attributed to the nature of the geological and chemical structure of the soil and rocks, the depth of the boreholes, the dilution of the boreholes spatially in main wet season. These boreholes are suitable for drinking water.

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