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Assessment of Groundwater Quality for Drinking and Agricultural Purpose in Seven Districts, Rabigh Governorate, Saudi Arabia

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ABSTRACT

This study was conducted to analyze well waters in seven regions, Hajar, Mughynia, Nuweiba, Rabigh, Al-Abwa, Mastourah, and Kilayyah, which lie along the valleys that discharge in the Red Sea in the Western Region of Saudi Arabia. This is to evaluate and determine whether the water of these wells is suitable for drinking and agricultural use. The study included determination of the major elements Ca, Na, K, Mg, P, F, the heavy metals, Fe, Cu, Zn, Al, Mn, Ba, and the toxic metals, Ni, Pb, Cd, Cr, Ag, Mo, Co, Be, V, Ar, Sb, Ti, and U concentration in the water of these wells. The elements Na, K, P increased in the groundwater following the passage of water from upper valley to lower valley, and the elements Ca, Na, Mg, and Cl concentration in well water are affected by their nearness to the Red Sea water, and the wells of Hajar, El-nugemia and Nuweiba have the least concentrations of these elements while those near the coast, Mastourah, Rabigh, Kilayyah, and Al-Abwa contain water with high concentrations of these elements. As for the water content of the major elements, all well waters are acceptable for drinking, except Mastourah with a high concentration of Na and Mg, and Rabigh and Al-Abwa with a high concentration of Ca. All wells' water is acceptable for drinking as regards their content of the heavy and toxic metal.

Keywords: Well Water; Saudi Arabia; Agricultural; Heavy metals

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Introduction

No rivers are running in the Kingdom of Saudi Arabia so people depend on rainfall and groundwater for drinking water and agriculture. Wells are dug along water streams in valleys. Recently the groundwater has been subjected to many adverse factors and contaminants. The groundwater may be subjected to natural contaminants represented in the geological structure of the earth's layers through which water moves and the most important of these elements are (Al, Cr, Pb, Zn, Cl, Fe, Br, Ag, Na, Cu, Mn, Hg) [6]. Calcium concentration in groundwater depends on the type of soil and rocks in which water is found and its high concentration gives rise to water hardness [1]. Potassium (K) gets into groundwater through a dissolution of K salts in the soil and industrial residues, and its content in drinking water should not exceed 10 mg/L [16].

Magnesium (Mg) is one of the elements found in abundance in the earth's crust and it should not be more than 125 mg/L in drinking water. Sodium Na is one of the elements in natural waters and its concentration varies between 0.5 mg/L in rainwater and more than 1000 mg/L in salty waters, and its content increases in sewage water [16]. The World Health Organization [16] suggested that Na concentration in drinking water should not exceed 20 mg/L. Flouride (F) concentration in drinking water should be up to 1.5 mg/L and its increase causes damage to teeth [3]. It is found naturally and in groundwater due to release from geological formations [12]. Iron (Fe) content in groundwater is in the form of dissolved carbonate and bicarbonate and its concentration varies [13] and in the Kingdom, its concentration reaches up to 1.5 mg/L.Copper (Cu) compounds are considered toxic if exceeded permissible value in drinking water 1 mg/L [9, 16]. The reasonable concentration of manganese (Mn) in drinking water should not exceed 0.1 mg/L [13]. Zink (Zn) is found in natural water up to 50 microgram/L and its concentration in non-polluted water is less than 1mg/L [6].

This study will test the concentrations of the macro-elements Ca, Na, K, Mg, P, F, the heavy metals, Fe, Cu, Zn, Al, Mn, Ba, and the toxic metals, Ni, Pb, Cd, Cr, Ag, Mo, Co, Be, V, Ar, Sb, Ti, and U in the water of 49 wells distributed in 7 districts of the Western Region of Saudi Arabia (Hajar, Mughynia, Nuweiba, Rabigh, Al-Abwai, Mastourah, and Kilayyah) to see whether the concentration of these elements is below the standards put forward by the local and international bodies and whether they are suitable for drinking and agricultural use.

Materials and Methods

Water samples were collected from 49 wells in 7 districts in dry clean polyethylene bottles which were tightly closed, and all the required information was listed on each bottle. The samples were taken directly to the laboratories of the Faculty of Science in King Abdul Aziz University in Jeddah for the physical and chemical tests. The elements tested included (major elements Ca, Na, K, Mg, P, F, the heavy metals, Fe, Cu, Zn, Al, Mn, Ba, and the toxic metals, Ni, Pb, Cd, Cr, Ag, Mo, Co, Be, V, Ar, Sb, Ti, and U. Three instruments were used for examination of the anions and cations, instrument DR-4000 from Hach Co. Colorado- the USA, the atomic absorption spectrometer mod. Analyst 800 from Berkin Elmir- USA and the Metrohm Ion Chromatograph-USA. For the minor elements, the Inductivity Coupled Plasma Optical Emission Spectrophotometer from Berkin Elmir was used. The tests were carried out in the laboratories of the Faculty of Science – King Abdul Aziz University – Jeddah.

Results

Major Elements

Calcium – Ca

The statistical analysis (table 1) illustrated high significant differences (P≥0.01) between the wells regarding Ca concentrations in their water. Table (2) shows the continuance increase in Ca concentration in well waters during the passage of water from the upper valley toward the lower valley. Hajar, the high up in the valley witnessed the lowest Ca concentration (50.07-70,74 mg/L), seconded by Magenta with (57.16 – 107.3 mg/L), then comes Nuweiba with (84.9 – 424.22 mg/L) Ca concentration. The concentration of Ca reached its maximum in the district wells down the stream Mastourah –with an average of 661.28 and 790.54 mg/L

Sodium – Na:

Sodium is one of the elements that dissolve in water, and its increase in irrigation water is harmful to plants and turns the soil into alkaline soil. Table (1) shows high significant differences (P≥0.01) between wells as regards Na concentration in their water; it reached its lowest concentration in Hajar wells (22.8 – 41.61 mg/L) up the valley, and increased gradually, in Mughynia (34.19 – 122.92 mg/L), in Nuweiba (63.41 – 674.60 mg/L) and reached its highest in Rabigh (423.62 – 1184.14 mg/L) downstream. It also increased gradually in the other districts downstream from 114.63 – 666.73 mg/L in Al-Abwa to 1104.77 – 2226.52 mg/L in Mastourah well waters. Sodium concentration in water increased gradually with the running of water from the upper valley at Hajar up the stream to reach its maximum at Rabigh downstream.

Potassium – K:

The analysis of variance (table 1) illustrated high significant differences (P≥0.01) between the wells in their K concentration. Potassium is one of the most important nutritional elements in plant feeding. The average K concentrations (table 2) show a high rise in 5 of Rabigh wells (9,24 – 12.05 mg/L), 2 wells in El-Abwa, one well in each of Nuweiba and Kilayyah with 8.89 mg/L each. The rest of the wells gave less than 3 mg/L K concentration except one in Hajar, 3 in Nowabi, and one well in each of Rabigh and Kilayyah which gave K concentration between 5.15 – 6.23 mg/L. Rabigh wells have the highest K concentration because it is down streaming near the coast receiving water coming from districts of Hajar, Nuweiba, and El–Nugemia thus accumulating more K. Hajar and Mastourah have the least K concentration.

Chlorides – Cl:

There were highly significant differences (P≥0.01) in Cl concentration in wells in the different districts (table 1). Table (2) shows that the highest Cl concentration is in Mastourah reaching 2063.20 – 2989.50 mg/L, Rabigh 1025.20 – 1946.00 mg/L, Kilayyah 341 – 1382.54 mg/L and Al-Abwa i 211 – 918.80 mg/L, and the lowest was in Hajar with only 33.16 – 45.70 mg/L and then Mughynia and Nuweiba.

Magnesium – Mg:

There were highly significant differences (P≥0.01) in Mg concentration in wells in the different districts (table 1). Table (2) shows that the highest Mg concentration is in 2 wells of Kilayyah (322,8 and 261.83 mg/L), followed by 3 wells in Mastourah with 214.68, 212.28, and 211.98 mg/L. Wells with more than 180 mg/L are 5 in Mastourah, and 4 in Kilayyah, which is considered high. Mg concentration increased gradually when water is passing from Hajar (upper valley) to Rabigh (lower valley).

Phosphorus – P:

Phosphorus (P) is one of the major nutritional elements for plants. Its average values (table 2) illustrate a reduction in concentration in the water of all studied wells and none of it reached 1 mg/L. The wells with the highest P concentration compared to the others are 2 wells in Mastourah with 0.9836 and 0.4068 mg/L, and one in Nuweiba wit 0.5730 mg/L.

Flour – F:

There are significant differences in F water concentration between the different wells (Table 1). The average F concentration varies between 0.152 and 0.964 mg/L (table 2), where the highest values were attained in one well in each of Hajar, Nuweiba, Al-Abwa, and in 3 wells of Rabigh and 2 of Kilayyah.

The Heavy Metals:

The heavy metals studied are Fe, Cu, Zn, Al, Mn, and Ba. The analysis of variance (table 3) illustrated high significant differences ($P \geq 0.01$) between the wells in all regions as regards the concentration of Fe, Cu, Zn, Al, Mn, and Ba. Table (4) shows that Fe concentration is between zero and 0.1 mg/L, Cu between zero and 0.156 mg/L in all of the studied wells and are all below the permissible values stated by [10, 11], for drinking and agriculture, except one well in Rabigh, 2 in Al-Abwa, 3 in Mastourah and 4 wells in Kilayyah which have higher Cu concentration. The average Zn concentration is between zero and 0.002 mg/L and all wells have water with Zn concentration below the permissible levels. Aluminum concentration in water is very low between zero and 0.0007 mg/L, and Mn did not exceed 0.03 mg/L in all wells. Ba concentration did not exceed 0.31 mg/L which is only in one well, while all other wells have Ba concentration between 0.0006 and 0.09 mg/L, and all is below the permissible standards.

Toxic metals:

Statistical analysis (table 5) illustrates high significant differences ($P \geq 0.01$) between concentrations of these toxic metals in water of all wells except Cd and Ag. The average concentrations (table 6) of (Ni, Pb, Cd, Cr, Ag, Mo, Co, Be, Ti) are very low, while those of Ar, Sb, V, and U) showed an increase in some wells. Ar concentration increased in 4 of Hajar wells reaching up to 0.0202 – 0.0333 mg/L. Vanadium (V) increased in 4 wells of Mughynia (0.0194 – 0.0206 mg/L). Uranium concentration seems to be a little high compared to all other metals, and it ranged between 0.0113 and 0.0364 mg/L. The concentration of Sb is very low except in one well with 0.0222 mg/L.

Discussion of Results

Regarding the well water concentrations of major elements Rabigh, Mastourah and Kilayyah dominated all wells giving the highest concentrations of **Ca**, **Na**, **Mg**, **Cl,** and **K**. These are the coastal districts that receive water from other districts so these elements accumulate and seep into their soils and thus reaching their groundwater. And the districts with the least concentration of these elements are those of Hajar and Mughynia because they represent the upper valley. All wells of Hajar and Mughynia and 5 of each of Nuweiba and Kilayyah have Ca concentration less than the permissible standards put by [15, 16] which is 200 mg/L. Mastourah, Rabigh, and Al-Abwa Ca concentrations in their wells are above the permissible value, so their water is not permissible for drinking and agricultural use. Calcium concentration in groundwater depends on the type of soil and rocks in which water is found as mentioned by [1] and so these three districts may be affected by this factor. Ca concentration in other areas in the

Kingdom reached 84.6 mg/L in Wadi El-Morwani [8], and 66.7 mg/L in Abha wells [7]. **Na** concentration in well water did not exceed the permissible value declared by [10], thus the water of all wells can be used in drinking and agriculture, except those of Mastourah which have Na concentration above the permissible values. Compared to other regions in the Kingdom Na concentration in well water of south Makkah reached 427.6 mg/L [5], and 82.8 mg/L in Wadi Fatima [4]. Rabigh wells have the highest K concentration reaching in most wells above 10 mg/L compared to other districts, and thus water of these wells is not permissible for drinking. Mg concentration in the wells of Hajar, Mughynia, Nuweiba, Al-Abwa, and Rabigh is permissible for drinking and agriculture according to the standards of [11], but in the wells of Mastourah and 4 of Kilayyah Mg concentration exceeded the permissible value and is not suitable for drinking and agricultural use. [2] obtained 75.6 mg/L Mg concentration in Wadi El-Sufra wells water. The concentration of K and P is low in all wells studied, and their concentration is similar to studies carried out by others on well water in different regions in the Kingdom [7, 8, and 14]. The concentrations of the heavy and toxic metals in the water of all studied wells are below the permissible levels suggested internationally and locally, and accordingly, these wells' water can safely be used for drinking and agriculture.

Conclusions and recommendations

It seems that the concentration of major elements K, Na, P follow the trend of accumulation and increasing in the well's water with passage of water along the valley, thus seeping down enriching the groundwater, while elements Mg, Na, Cl and Ca presence in the wells is affected by their nearness to the Red Sea coast. So ground water of the coastal districts Rabigh, Mastourah, Al-Abwa, and Kilayyah receive a high concentration of these elements compared to the ones away from the coast Hajar, Mughynia, and Nuweiba. All studied wells have acceptable ware for drinking and agricultural use as regards concentration of the macro-elements Ca, Na, K, P, Cl, F, and Mg except Mastourah district with a high concentration of Na and Mg, and Rabigh and Al-Abwa with a high concentration of Ca. The concentration of the heavy and toxic metals in the water of all studied wells is negligible and below the permissible levels suggested for drinking water and water for agricultural use.

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Table 1. Analysis of variance of the major elements

Source of difference	DF	K mg/L	Ca mg/L	Mg mg/L	Na mg/L	P mg/L	F mg/L
Replicate	4	0.11 NS	141.08 NS	10.48 NS	110.35 NS	0.0002 NS	0.003 NS
ab	48	50.81**	280517.24**	29596.73**	1572523.21**	0.112**	0.309**
LSD	192	0.07	123.56	4.55	346.49	0.004	0.004

LSD: Least significant difference NS: not significant at P≥0.05 **: significant at P≥0.01

Table 2. Average values of major elements Ca, Na, K, Cl, Mg, P, F (mg/L) (Mean± SD).

Locations	Major elements						
	Ca	Na	K	Cl	Mg	P	F
Hajar	61.49±7.09	33.61±5.85	2.87±1.23	38.35±6.45	14.40±1.65	0.10±0.01	0.67±0.25
Mughynia	81.97±23.18	74.98±38.76	2.25±0.90	85.91±36.78	26.76±9.47	0.13±0.03	0.49±0.21
Nuweiba	176.53± 128.8	220.68±231.98	4.66±2.62	374.67±427.81	38.85±32.86	0.15±0.19	0.69±0.18
Rabigh	415.85±93.29	803.19±227.63	8.64±2.90	1027.35±628.66	99.54±40.05	0.09±0.02	0.69±0.31
Al-Abwa	212.06±71.99	430.44±199.24	5.29±3.88	526.95±211.70	61.85±13.85	0.11±0.014	0.64±0.21
Mastourah	750.53±42.42	1611.82±467.48	2.37±1.09	2659.29±363.33	190.74±23.98	0.25±0.35	0.35±0.13
Kilayyah	188.75±89.95	457.10±201.91	3.74±2.60	652.29±387.48	183.54±84.11	0.10±0.02	0.63±0.28

SD: Standard Deviation

Table 3. Analysis of variance of concentration of heavy metals

Source of difference	DF	Fe mg/L	Cu Mg/L	Zn Mg/L	Al Mg/L	Ba Mg/L	Mn Mg/L
Replicate	**4**	0.0009 NS	0.0002 NS	0.0001 NS	0.00001NS	0. 0001NS	0.00016NS
Wells	**48**	0.003**	0.0036**	0.00002**	0.00000**	0.012**	0.01577**
LSD	**192**	0.0002	0.00009	0.000002	0.0000001	0.0000001	0.0000018

NS: not significant at P≥0.05 **: significant at P≥0.01

Table 4. Average values of Heavy metals of well waters at different locations (mg/L) (Mean± SD).

Locations	Heavy metals					
	Fe	**Cu**	**Zn**	**Mn**	**Al**	**Ba**
Hajar	0.04±0.03	33.61±5.85	0.0003±.0004	0.0000±.000	0.0001±.0001	0.0322±.0599
Mughynia	0.05±0.02	74.98±38.76	0.0003±.0003	0.0001±.0014	0.0001±.0002	0.0149±.0088
Nuweiba	0.02±0.02	220.68±231.98	0.0012±.0007	0.0003±.0002	0.0005±.0003	0.0385±.0354
Rabigh	0.00±0.00	803.19±227.63	0.0012±.0006	0.0088±.0133	0.0005±.0001	0.0218±.0078
Al-Abwa	0.03±0.03	430.44±199.24	0.0002±.0003	0.0004±.0005	0.0000±.0001	0.0363±.0115
Mastourah	0.03±0.04	1611.82±467.48	0.0007±.0004	0.0002±.0004	0.0000±.0000	0.0451±.0076
Kilayyah	0.04±0.02	457.10±201.91	0.0004±.0004	0.0003±.0003	0.0000±.0000	0.0899±.0996

Table 5. Analysis of variance of minor-toxic metals.

Source of difference	DF	**Co**	**Pb**	**Be**	**Ni**	**Cr**	**Cd**	**Mo**	**Ar**	**Ag**	**Ti**	**Sb**
Replicate	4	0.000001NS	0.000006NS	0.000004 NS	0.00001 NS	0.0001 NS	2.55 NS	0.0001 NS	0.000 NS	0.000 NS	2.5 NS	0.00NS
Wells	48	0.0000024**	0.000001**	0.000003 **	0.000003 **	0.0000**	2.67	0.0003**	0.0005**	0.00006	1.4 **	0.003**
LSD	192	0.00000002	0.00002	0.0000002	0.0000001	0.00001	1.17	0.000001	0.00001	0.00	0.04	0.0001

NS : not significant at P≥0.05 **** : significant at P≥0.01**

Table 6. Averages of toxic metals Co, Pb, Be, Ni, Cr, Cd, Mo, Ar, Ag, Ti, Sb, V and U (mg/ l) (Mean± SD).

Locations	Toxic metals											
	Co	Pb	Be	Ni	Cr	Cd	Mo	Ar	Ti	Sb	V	U
Hajar	.0000±. 0000	.0001±. 0001	.0004±. 0001	0.0000±. 000	.0000±. 0000	.0000±. 0000	.0000±. 0000	.0000±. 0000	.0000±. 0000	.0012±. 0018	.0071±. 0014	.0196±. 0026
Mughynia	.0000±. 0000	.0001±. 0001	.0007±. 0004	0.0001±. 00014	.0000±. 0000	.0000±. 0000	.0000±. 0000	.0000±. 0000	.0000±. 0000	.0008±. 0010	.0101±. 0091	.0060±. 0051
Nuweiba	.0002±. 0003	.0001±. 0004	.0003±. 0002	0.0003±. 0002	.0033±. 0084	.0001±. 0001	.0026±. 0065	.0005±. 0008	.0003±. 0004	.007±.0 069	.0056±. 0012	.0233±. 0014
Rabigh	.0006±. 0002	.0008±. 0003	.0004±. 0002	0.0088±. 0133	.0004±. 0004	.0007±. 0001	.0005±. 0002	.0001±. 0001	.0001±. 0001	.0034±. 0032	.0030±. 0029	.0128±. 0015
Al-Abwa	.0000±. 0000	.0002±. 0002	.0005±. 0003	0.0004±. 0005	.0000±. 0000	.0000±. 0000	.0001±. 0001	.0000±. 0000	.0000±. 0000	.0000±. 0000	.0051±. 0023	.0137±. 0016
Mastourah	.0001±. 0002	.0008±. 0003	.0003±. 0002	0.0002±. 0004	.0000±. 0000	.0000±. 0000	.0002±. 0003	.0000± 0.0000	.0000± 0000	.0169±. 0210	.0014±. 0011	.0191±. 0122
Kilayyah	.0001±. 0002	.0004±. 0004	.0001±. 0001	0.0003±. 0003	.0000±. 0000	.0001±. 0001	.0004±. 0003	.0000± 0.0000	.0000±. 0000	.0053±. 0076	.0097±. 0021	.0233±. 0051