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Full Length Research Paper

Groundwater investigation in Rabigh Governorate, West of Saudi Arabia

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Groundwater is generally presumed to be good for human consumption and is used as a potential source of drinking water. Agricultural development, urbanization and industrialization are the major causes for all changes in the quality of water. Saudi Arabia is an arid and the largest country in the Middle East. Recent urban and rural expansion has shown manifold increases in water use in various sectors. Water resources are limited and non-renewable coupled with unpredicted scanty rainfall. In order to meet the rising water needs, evaluation of water quality is important for allocation to various uses. The quality of 36 wells water in selected villages in Rabigh Region, West of Saudi Arabia used mainly for drinking was examined with respect to total dissolved salts (TDS), pH, total hardness, and concentrations of calcium, magnesium, potassium, sodium, chloride, fluoride, nitrate, and bicarbonate, beside coli form bacteria as an indicator of bacterial contamination. The TDS of tested water samples varied widely from 166 to 2400 mg/L. The chemical quality of well water of Rabigh has been studied in detail in order to demonstrate the potable groundwater zones without any deterioration by pollution. Water samples were analyzed for total salt concentration, pH, Ca, Mg, Po4, TDS, HC03, Cl, S04, N03, and NH4 contents. The EC of groundwater ranged between 230.0µs/cm to300.0 µs/cm. Magnesium was the most abundant cation. Chloride was the most abundant anion followed by HC03 and S04 in groundwater of Rabigh. The N03 concentration is more than the safe limits for drinking purpose according to WHO (2003) standards. PO4 values are within the permissible limits according to SASO (1993).

Key words: Groundwater, Water quality, Pollutants, Rabigh, Saudi Arabia

INTRODUCTION

Groundwater continues to be important for public supply, agricultural purposes, and industrial use, and in some regions in the world is the only or dominant source. Thus it is essential to protect this water source both in quality and quantity. Like most of the Arabian Gulf States, the Kingdom of Saudi Arabia depended until 1970 on groundwater as the only source of water supply for domestic as well as irrigation purposes. This led to overexploitation of groundwater in some areas which caused disturbance of the state of equilibrium of the reservoirs (Harter et al., 2002).

Groundwater is very important as the only source of water to supply human needs especially in arid regions like Saudi Arabia where there is scarce surface water and the rainfall is scarce, irregular and the evaporation rates are very high. Hence, the groundwater is a key resource for urban and rural supplies and it is considered as the

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only source, which can supply domestic and agricultural needs in town and villages. In Saudi Arabia, there are increasing needs of water as there is rapid growth of population and agricultural activities in increasing around the country (AlAhmadi, 2005).

The usage of groundwater has gradually increased because of the increase of water demand and the shortage of surface water during growth of population. In many cases groundwater is polluted by the inflow of pollutants such as sewage and industrial wastewater (Freeze and Cherry, 1979; Abctuyfzand, 1986). The residents who use contaminated groundwater as drinking water may suffer from health problems in the near future. But it is very difficult to elucidate or predict the pollution pattern because potential sources which include land disposal of solid wastes, sewage disposal on land, agricultural activities and other sources are various, and pollutants move through ground water (Fetter, 1994; Hwang *et al*., 1997). Surface waters like streams and lakes are not the only water sources that suffer from pollution. Groundwater aquifers, which are critical sources of both drinking and irrigation waters, are also affected. The major causes of groundwater pollution are leaching of pollutants from agriculture, industry and untreated sewage, as well as saltwater intrusion caused by over pumping. The quality of water for various uses is determined by its physical characteristics, chemical composition, biological parameters and the conditions of use. Because all the waters, surface or sub-surface, contain salts in different amounts and proportions and will increase the salt concentration of soil solution upon irrigation, because water will evaporate under highly evaporative environmental conditions thus leaving the salt into the soil.

Once pollutants enter a groundwater aquifer, the environmental damage can be severe and long lasting, partly because of the very long time needed to flush pollutants out of the aquifer (UNEP 1996). Because groundwater is primarily used for drinking water, pollution from untreated sewage, intensive agriculture, solid waste disposal, and industry can cause serious human health problems (Shiklomanov 1997). Due to the harmful health effect of excessive pollutants in human and animal food much research has been conducted on its accumulation in food plant and water resources. Even where available, data usually are not comparable because of the different measures and standards used, which vary by country (Shiklomanov 1997 and Scheidleder *et al*. 1999).

However, there is evidence that groundwater contamination from fertilizers, pesticides, industrial effluents, sewage and hydrocarbons is occurring in many parts of the world. As with surface waters, nitrate pollution is one of groundwater's most serious threats. In general, the risk of nitrate pollution for groundwater supplies is directly related to the amount of fertilizers or other nitrogen inputs to the land, as well as the permeability of the soil. For example, half the groundwater samples in a heavily fertilized region of northern China contain nitrate levels above the safe limit for drinking water (Zhang *et al*. 1996). In the United States, where groundwater supplies drinking water for more than half the population, a preliminary analysis of nitrate contamination found that high nitrate concentrations are widespread in shallow groundwater aquifers in agricultural areas (USGS 1999). Groundwater pollution in Europe is similarly widespread (Scheidleder *et al*.1999).

Variations in natural and human activities reflect spatial variations in the hydro-chemical parameters of the groundwater. The difference of dissolved ions concentration in groundwater are generally, governed by lithology, velocity and quantity of groundwater flow, nature of geochemical reactions, solubility of salts and human activities (Karanth, 1997 and Bhatt and Salakani, 1996). Suitable quantity and quality of groundwater become a more crucial alternative resource to meet the drastic increase in social, agricultural and industrial development and to avoid the expected deterioration of groundwater quality due to heavy abstraction for miscellaneous uses. The main objective of this paper is to study the physical chemistry and bacterial contamination of groundwater of Rabigh government, Saudi Arabia.

MATERIALS AND METHODS

Study area

The study was conducted in Rabigh government, Saudi Arabia area in the southwestern region of Saudi Arabia in the Province of Macca Almokaramah about 100 km to the south of capital Jeddah. It extends from 13º 38` south latitude and 42º 19` east longitude. Rabigh government, counted as one of the biggest centers of Macca Almokaramah and an estimated population of 70,000 distributed between many villages. It lies from the plains, mountains (Figure 1).

Sample collection

Groundwater quality is studied by systematic collection and analysis of samples, which enable us to properly manage the resources. A total of three water samples were collected from different wells located in Rabigh during the winter months of November and December in the year of 2011 about 5 L water was collected. The water samples were collected in plastic bottles, pH , EC, TDS were measured instantly and the samples were stored in an ice box during transportation. Each sample was divided into two portions; one for chemical cation analysis including Ca^{++}, Mg^{++} and K^{+} concentrations and the other for physical analysis.

Figure 1. Location map of the study site, Rabigh Governorate, West of Saudi Arabia

Physical and chemical analyses

In this work both physical and chemical methods of analysis were employed. Analytical grade BDH products (BDH Chemicals Ltd, Poole, England), unless otherwise stated, were used to prepare both reagents and calibration standards. Deionized water was used to prepare all reagents and dilution standards. The determinations were carried out according to the Standard Methods for the Examination of Water and Wastewater (APHA, 1985, 1992,) and Richards (1954). In these analyses, pH was measured by Meterohm pH-meter (Model 632) calibrated against two standard buffer solutions of known pH values (pH 7 and pH 9) produced by Wnlab Ltd. Maidenhead-Berkshire, England. Electric conductivity (EC) (dS/m at 25 ̊ C) was measured by a Beckman Solu Bridge type equipment calibrated using anhydrous KCL solution (0.01N) adjusted at 25 ̊ C . Na+ and K+ were determined by flame photometer (Corning Model M410 instrument). Ca++ and Mg++ were determined by titration with ethylenediamine tetra acetic acid (EDTA) disodium salt solution (0.01N). Total dissolved solids (TDS) were determined by multiplying the electrical conductivity value by 640 according to Rhoades, 1982).

Microbiological methods

The three-tube procedure using lactose broth (Difco) was used for estimating the most probable number (MPN) of coliform organisms. Tubes were incubated at 37 ̊ C for 48 h and the MPN was obtained according to the standard Methods for the Examination of Water and Wastewater (APHA, 1985; Geldreich, 1975). The confirmed coliform test was done by culturing positive tubes into brilliant green bile broth (Difco) and incubating at 37 ̊ C for 48 h.

Statistical analyses were performed using an IPM compatible 486 computer. The means obtained for the various water quality parameter measured were evaluated according to the current USEPA (1976), SASO (1984), G.C.C.S (1993) and WHO (1993) and drinking water standards and guidelines.

RESULTS

The total dissolved salts in 36 water samples ranged from 166 to 2400 mg L(Table 1) with an average value of 557 mgL-1 (S.D.=474). It is clear from the value of standard deviation that there is a wide variation among the samples with respect to their TDS. (Table 1) revealed that 7.5, 15., 15 and 32.5% of the studied samples were above the maximum salinity limits set by SASO, G.C.C.S, WHO and USEPA, respectively. The distribution of the TDS levels in the 40 water samples studied is shown in Table 2, which indicates that 67.5% of the water samples comprised the best quality water (TDS<500, set by USEPA), whereas 25% of the water samples (TDS = 501-1000 mgL-1 (17.5%) and TDS = 1001-1500 (7.5%)) comply with the maximum standards and guideline limits set by SASO, G.C.C.S and WHO for drinkable water. On the other hand, high salinity water samples (TDS>2000

Table 1. Physical and chemical quality of well water samples (n=36) in Rabigh region, west of Saudi Arabia. a= The lowest permissible level is around pH 6.5 , b= No Standard, NS= Not significant

Parameters	Mean (n=40)	Range	Standard Deviation (SD)	SASO standards (1984)	Percentage of samples above	G.C.C.S. standard (1993)	Percentage of samples above	WHO guidelines (1993)	Percentage of samples above	USEPA (1976)	Percentage of samples above
TDS mgL-1	557	166-2400	474	1500	7.5	1000	15	1000	15	500	32.5
pH	8.1	6.8-8.4	0.28	9.2a	0	6.5-8.5	0	<8	72	6.5-8.6	-
Total hardness (as $CaCO_3$)	132	29-348	76	500	0	500	0	NSb	-	NS	-
Ca^{++} mgL-	26.6		19.9	200	0	200	0	NS	-	NS	-
Mg^{++} mgL-	15.7		9.2	150	0	150	0	NS	-	NS	-
Na^+	90.6		96.9	NS	-	200	12.5	200	12.5	NS	-
K^+	3.6		1.7	NS	-	NS	-	NS	-	NS	-
Cl^-	147		160	600	5	400	12.5	250	17.5	250	17.5
NO_3^-	44.9		160.6	<45	36	<45	36	50	32.5	45	36
F^-	0.83		0.4	0.6-1	22.5	0.6-1	22.5	1.5	8.5	4	-
HCO_3^-	146		39.6	NS	-	NS	-	NS	-	NS	-
Total coliform (MPN100ml-1)				Negative	-	Negative	-	Negative	-	Negative	-

Table 2. Distribution of 36 well water samples in Rabigh region, west of Saudi Arabia according to their contents of total dissolved salts (TDS)

TDS Class (mgl-1)	No. of samples within class	% of total
< 500	24	67.5
501 - 1000	6	17.5
1001 - 1500	3	7.5
1501 - 2000	-	-
> 2000	3	7.5

mgL-1) comprised only 7.5% of the water samples.

Generally, all of the water samples studied have pH values falling within the limits of the standards and guidelines listed in (Table 1), with the exception of the WHO (1993) guideline limit for pH (pH < 8), where 72% of the examined samples were above this value.

Total hardness (as $CaCO_3$) ranged between

Table 3. Quantitative classification of 36 samples of well water samples in Rabigh region according to the level of hardness (Techobanglous and schreoder,1985)

Description	Hardness class (mgl-1) as CaCO3	No. of samples within class	% of total
Soft	< 50	2	5
Moderately hard	50 - 150	24	67.5
Hard	150 - 300	9	25
Very hard	> 300	1	2.5

Table 4. Distribution of 36 well water samples Rabigh region according to their content of NO3- (mgl^{-1}).

F- Class (mgL-1)	No. of samples within class	% of total
< 0.6	9	25
0.6 - 1	18	52.5
> 1	9	22.5

Table 5. Distribution of 36 well water samples Rabigh region according to their content of fluoride (F).

NO3 - (mgl-1)	No. of samples within class	% of total
< 45	23	65
45 - 90	10	27.5
> 90	3	7.5

29 and 348 mgL-1 with only 50% of the water samples studied being above the 100 mgL-1 optimum limit recommended by SASO 1984, however, none of the studied water samples exceeded the 500 mgL-1 maximum permissible level recommended. Quantitative classification of water according to their level of hardness showed that only 5% of the examined water samples are soft, 67.5% moderately hard, 25% hard , and 2.5% very hard (Table 3).

Cations including Ca++, Mg++ and K+ concentrations ranged between 2.8 and 78 mgL-1 , 1.2 and 49 mgL-1 and 1.2 and 12 mgL-1, respectively. Such concentrations are falling well water below the maximum limits set by the respective standards shown in (Table 1).

Nitrate (NO-3) concentrations as shown in (Table 1) ranged between 8.7 to 155 mgL-1 (mean 44.9 mgL-1). The distribution of the NO3- levels in the 40 water samples studied is shown in Table 4. It indicates that 65% of the samples comprised the best quality water with respect to NO-3 level (NO3-1 content < 45 mgL- 1) as recommended by SASO, G.C.C.S and USEPA standards, whereas 35% of the water samples [NO3-level = 45-90 mgL-1 (27.5%) and NO3-level > 90 mgL-1 (7.5%)] are violating the 45-50 mgL-1 maximum limit recommended by the respective standards listed in (Table 1).

The Flouride-concentration (F) in the samples studied ranged between 0.2 and 1.9 mgL-1 (Table 1) with only 22.5% of the water samples examined were above the SASO (1984) and G.C.C.S. (1993) maximum permissible limits of 1 mgL-1 while only 8.5% of the samples are above the WHO guideline limit of 1.5 mgL-1. None of the samples studied attained the relatively high limit of 4mgL-1 set by the USEPA standard (1976) . As shown in Table 5, 25% of the water samples examined contain F- levels below 0.6 mgL-1, while 52.5% of the samples are within the range between 0.6 and 1 mgL-1.

The HCO3- level as shown in (Table 1) ranged between 18 and 244 mgL-1 in the examined samples. The respective standards listed in (Table 1) have not set any standard or guideline limits for the HCO3 concentration.

Repeated bacteriological analyses of the studied water samples using the presumptive test indicated the presence (positive test) of coli form bacteria in 8 of the wells examined showing that 20% of the wells failed to meet the guide-lines (Negative test) set by SASO, G.C.C.S, WHO and USEPA . Confirmatory and IMViC tests revealed the presence of *Escherichia coli* (fecal coli form) in 3 (7.5%) of the water samples and *Entrobacter aerogenes* (nonfecal coli form) in 5 (12.5%) of the water samples.

DISCUSSION

The total dissolved salts and the distribution of the TDS levels in water samples studied is which indicates that 67.5% of the water samples comprised the best quality water (TDS<500, set by USEPA), It is well known that TDS affects taste, and waters above 500 mgL-1 can taste poor. Generally, TDS levels less than 500 mgL-1 are acceptable for household use (USEPA, 1976, 1986). According to the limits set by the various standards listed in (Table 1),

Water with salinity level beyond 1500 mgL-1 are considered unsuitable for drinking but could be used for irrigating some crops with high salt tolerance such as date palm trees (Clark et al, 1963; Raveendran and Madany , 1991; Abdel Magid,, 1997, Al-Redhaiman and Abdel Magid, 2002). There are several sources which might have contributed to this high salinity including excessive-exploitation, overpumping, runoff water, soil weathering and agricultural drainage water (Abdel-Aal et al., 1997; Moghazi and Al-Shoshan, 1999).

Total hardness (as CaCO3) ranged between 29 and 348 mgL-1 with only 50% of the water samples studied being above the 100 mgL-1 optimum limit recommended by SASO 1984, however, none of the studied water samples exceeded the 500 mgL-1 maximum permissible level recommended by SASO (1984) and G.C.C.S (1993). As stated by many authorities (Tchobanoglous and Schroeder 1985; Viessman and Hammer, 1985; Wilson et al. 1999 and Al-Redhaiman and Abdel Magid, 2002) water hardness of levels above 300 mgL-1 is considered excessive for a public water supply and results in a high soap consumption as well as objectionable scale in heating vessels and pipes. Moreover, many consumers object to water harder than 150 mgL-1, a moderate figure being 60-120 mgL-1 (Wilson et al. ,1999 and Al-Redhaiman and Abdel Magid, 2002) ; thus including the optimum limit of 100 mgL-1 recommended by SASO (1984).

Concentration of Na+ ranged between 17 and 455 mgL-1 with 12.5% of the water samples were above each of the G.C.C.S and the WHO standards and guidelines. However, USEPA (1976) standard did not set any limit for the Na + concentration. The Cl-1 concentration ranged between 28 and 709 mgL-1 (mean= of 147 mgL-1) with 5% and 12.5% of the water samples are above the SASO and G.C.C.S limits, respectively , 17.5% of the samples are above the limits of each of the WHO and USEPA standards and guideline limits. According to Raveendran and Madany (1991) the WHO guidelines for Na+ (200 mgL-1) and Cl-1 (250 mgL-1) are based on taste considerations rather than the impact on human health and thus higher values can be tolerated (for example: SASO has set the maximum limit for Cl- at 600 mgL-1).

Concerning Nitrate (NO-3) concentrations, previous evidence (Al-Abdula'aly et al., 2002 & 2003, Al-Turki and Abdel Magid , 2003) indicated the presence of high nitrate concentrations in some well water in Al-Qassim Region east of Saudi Arabia which exceeded the standards and guidelines set for the maximum permissible levels for NO3- in drinkable water. The wide variation of the NO3- among the studied well water samples examined could be attributed to the extent of depth of wells examined as well as human activity, specially the irrational use of nitrogenous fertilizers (El-Garawany and Al-eed, 1997; Al-Hindi, 1997). Moreover, Al-Turki and Abdel Magid (2003) indicated that a significant ($P<0.01$, $R2=0.293$) reciprocal relationship existed between well depth and its NO-3 concentration.

The F- concentration in the samples studied, SASO (1984) recommends that the level of F- of unbottled drinking water shall be between 0.6 mgL-1 amd 1 mgL-1; depending on the average maximum ambient temperature in community area. It may, therefore, be inferred from the data presented in Table 5 that 25% of the water samples examined have F- concentration below the recommended permissible level of SASO (1984) standard (0.6 mgL- 1), thus supplemental fluoridation to the optimum level is deemed necessary to avoid dental decay in such well water consumers (Al-Khateeb et al ,1991; Al-Abdula'aly, 1997 Al-Redhaiman and Abdel Magid, 2002; Van Netten et al. 2002). The USEPA (1986) standard indicated an aesthetic limit of 2 mgL-1 while Adachi et al., (1991), depending on the regional temperature, estimated the optimal level between 0.7 and 1.2 mgL-1.

The HCO3- level studied was above the recommended permissible level. However, the elevated level of HCO3 can probably be attributed to the presence of limestone formations in the groundwater bearing aquifers (Moghazi and Al-Shoshan, 1999).

Bacteriological analyses of the studied water samples indicated the presence of coli form bacteria. Thus indicating that pollution with human and animal wastes is evident, which may have contributed considerably to the deterioration of well water quality (Pritchard et al., 2007). This is expected since these wells do not receive any disinfection treatment before consumption in suburban areas. The Saudi standard (1984) requires a negative coliform test for every 100 m1 of water examined after treatment with chlorine to kill bacteria. The presence of coliforms may be attributed to contamination of the hoses used by humans, including farmers and livestock owners, and to the exposure of these delivery hoses to dust and storms(Pritchard et al., 2007). Previous workers, (Stephenson and Street 1978; Hammad and Dirar, 1982, Abdel Magid, 1997) indicated that dust storms and livestock activity in the vicinity of surface wells increase microbial levels and bacterial inputs. Moreover, the absence of microbial contamination in some of the wells tested may be attributed to the fact that the high salinity of water in some of the wells examined may have hindered proliferous bacterial growth in spite of the eminent contamination cited above (Abdel Magid et al., 1984 , Al-Redhaiman and Abdel Magid, 2002).

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