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Chemical Characteristics and Bacterial Contamination of Groundwater in Buraydah, Saudi Arabia

A. E. Abdelmonem* , M. A. El-Meleigi and A. A. Al-Rokaibah
College of Agriculture, King Saud University, Qassim branch, Saudi Arabia

Abstract. Chemical and microbial analyses were conducted on groundwater samples collected from 18 wells in Buraydah in 1986. Chemical analyses included pH, dissolved oxygen (DO), electrical conductivity (EC), total dissolved salts (TDS), and sodium adsorption ratio (SAR). Thirteen elements were determined of which some are toxic heavy metals. Chemical analyses for water quality of most wells showed high to very high salinity (TDS of 512-1664 mg/l), medium to high SAR (15.9-34.4), high concentrations of Cd and Pb (0.2-0.47 and 0.5-31.0), medium concentration of Hg (0.00-0.004), and low concentration of As, Fe, Zn, Cu. Eleven wells were contaminated, 4 with both or either *Escherichia coli* or *Salmonella sp.* The total bacterial count in various wells ranged from 10 to 4.6×10^{4} cfu/ml.

Introduction

The usable groundwater storage in Saudi Arabi is great and this vast reservoir is distributed across the nation in quantities determined primarily by precipitation, evapotranspiration, and geologic structure. In many groundwater basins, the amount of groundwater withdrawn for agricultural irrigation considerably exceeds the rate of recharge. Water supply development is concerned with both the quantity and quality of water required to meet the needs of man in an efficient and economical manner. Groundwater quality is influenced considerably by the quality of the source. Municipal and industrial wastes entering an aquifer are major sources of organic and inorganic pollution. The effects of such pollution may continue for indefinite periods since natural dilution is slow and artificial flushing or treatment is generally impractical or too expensive.

* Permanent address: College of Agriculture, Al-Azhar University, Plant Protection Department, Cairo, Egypt.

The protection of groundwater is not a simple matter because the potential sources of groundwater contamination are numerous and highly diversified, and they vary greatly from region to another due to climate, population density, intensity of industrial and agricultural activities, and the hydrogeology of the region. This complexity means that there is no uniform pattern to groundwater problems and each situation must be analyzed in the context of its particular circumstances. It is possible, in some instances, to alter the composition of the wastes in order to reduce or eliminate its undesirable effects on the environment. Water conservation is another strategy that may help to reduce the disposal of wastewater and thereby enhance the protection of groundwater [1, p. 315].

The number of harmful enteric organisms is generally reduced to tolerable levels by the percolation of water through 2 m fine textured soil [2]. However, as the water passes through the soil, a significant increase in the amounts of dissolved salts may occur. Salts are added by soluble products of soil weathering, erosion by rainfall and flowing water and the application of fertilizers. In that case, water may be too saline for satisfactory crop production. Depending on their concentrations, the effects of metals in groundwater range from beneficial through troublesome to dangerously toxic. At the same time, the presence of some metals is essential for production.

This work was carried out to identify and quantify the chemical and physical characteristics of groundwater of Buraydah and to determine its bacterial contamination.

Materials and Methods

Sample collection

Water samples were collected in November 1986, from 18 wells representing the whole city of Buraydah (Fig. 1). Water samples were collected by using the grab technique whereby a container was lowered into the water, rinsed, filled and capped. A Van Dorn-type sampler was used to obtain water from greater depths [3]. Two samples for each well were taken and triplicates determinations were made on each sample. Water temperature, pH, and dissolved oxygen were immediately measured after collecting using portable field kits (LaMotte chemical products company, Chestortwon, Md., U.S.A.). The collected samples were frozen at -20°C for the chemical analyses.

For microbial analysis, water samples of the same wells were taken in sterile glass bottles (100 ml), refrigerated at 5°C, and tested within 24 hr.

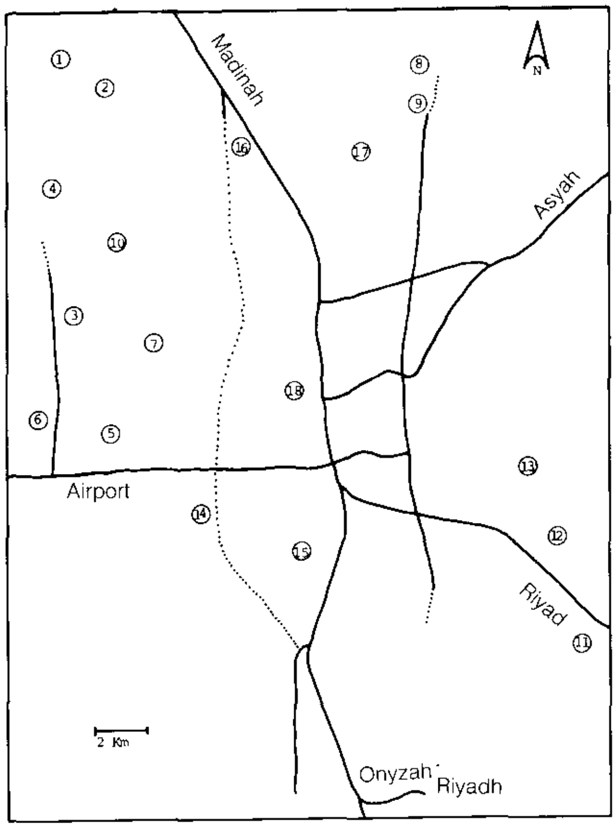

Fig. 1. **"Map of Buraydah" illustrating the location of the sampled wells**

Chemical analysis

A varian model AA-875 atomic absorption spectrophotometery was used to determine the minerals concentration. Because requirements for determining different metals vary with metal and/or concentration to be determined, four methods were used:

A- Determinations of Ca, Co, Cu, Fe, Pb, Mg, Mn, K, Na, and Zn were made by direct aspiration into an air-acetylene flame [3].

B- Determinations of low concentrations of Cd, Co, Cu, Fe, Pb, Mn, and Zn were made by chelation with ammonium pyrolidine dithiocarbamate (APDC), extraction into methyl isobutyl ketone (MIBK), and aspiration into an air-acetylene flame [3].

C- Determination of As was made by conversion to its hydrides and aspiration into a nitrogen - hydrogen flame [4].

D- Determination of Hg was made by the cold vapor technique [5].

Classification of groundwater

The classification of water of the 18 studied wells was based on the diagram which was taken from USDA handbook 60 [6, p. 160].

Microbiological analysis

Dilution series of water samples were made in autoclaved distilled water. Samples (0.1 ml) from each dilution were transferred into each of three plates of nutrient agar (NA) and/or sucrose peptone agar (SPA) media. The inoculated plates were incubated at 37°C for 24-48 hr. before bacterial colonies were counted. The multiple-tube fermentation test for detection of fecal coliform bacteria and the confirmation test were conducted as described by Greenberg *et al,* [3]. Water samples were tested for concentration with *Salmonella* sp. by plating on brilliant green agar media with agar concentration increased up to 2% [3]. Identification of *Salmonella* sp. was confirmed according to culture characteristics of the genus described in Cowan *et al.* [7, p. 1268].

Results and Discussion

Chemical analysis

Chemical and physical characteristics of the groundwater taken from 18 sampling wells are given in Table 1. The depth of these wells ranged between 35 and 720 m with an average of 312 ± 239.8 m. The average temperature and pH of the groundwater were 30.3 ± 3.5 C and 7.1 ± 0.3, respectively.

The total dissolved solids (TDS) of the groundwater in Buraydah area ranged between 512 and 1664 mg/l with an average of 1190.1 + 352 mg/l. The TDS levels in samples of wells no. 9 and 12 were extremely high (1664 mg/l), followed in a descending order by wells no. 8, 17, 16, 18, and 11 (1408 to 1600 mg/l). The acceptable level of TDS for drinking water according to WHO records should be less than 500 ppm (8,9). The electric conductivity (EC) of water samples ranged between 800 and 2600 decisiemens per meter (ds. m^{-1}) at 25°C. Because the electric current is transported by the ions in solution, the conductivity value increases as the concentration of ions increases. EC value of water is very important for plants; its lower value means lower osmotic pressure and subsequently a higher uptake of water by plants. The average of dissolved oxygen (DO) was 3.5 ±2.3 mg/l.

Table 2 presents the concentrations (mg/l) of heavy metals; As, Cd, Pb, Hg, Fe, Zn, Cu, and Co in the groundwater of 18 different wells. The highest heavy metal

Table 1. **Chemical and physical characteristics of irrigation water taken from 18 wells in Buraydah (1986).**

Sampling station No.	Depth (m)	Temp. °C	pH	E.C. mmhos/cm	T.D.S. mg/l	D.O. mg/l
1	180	34	7.4	0.8	512	5.8
2	144	33	7.3	1.3	830	4.5
3	160	30	6.8	1.8	1176	2.5
4	174	28	7.0	1.7	1088	10.1
5	270	33	6.5	1.5	960	2.3
6	150	29	6.6	1.6	1024	1.8
7	50	27	7.4	1.8	1176	2.4
8	700	36	7.1	2.5	1600	3.8
9	720	34	7.3	2.6	1664	1.2
10	35	22	7.6	1.2	768	5.6
11	675	32	6.8	2.2	1408	1.1
12	70	28	6.9	2.6	1664	3.8
13	638	30	6.6	1.4	896	2.2
14	170	27	7.1	1.3	832	4.8
15	190	32	6.8	1.9	1216	3.1
16	560	29	7.4	2.4	1536	1.0
17	380	34	7.6	2.5	1600	5.2
18	350	28	7.3	2.3	1472	1.5
$\bar{x}$	312	30.3	7.1	1.9	1190.1	3.5
S.d.	239.8	3.5	0.3	0.6	352	2.3

concentration was Zn (3.72 ± 1.55) followed in a descending order by Co (2.03 ± 0.50), Fe (0.56 ± 0.41), Cd (0.16 ± 0.13), Pb (0.16 ± 0.07), Cu (0.06 ± 0.01), As (0.04 ± 0.02), and Hg (0.001 ± 0.001). According to the international drinking water standards [10, 11], the concentrations of Cd and Pb in the studied wells were much higher than the acceptable maximum limits (0.01 and 0.05 ppm). The level of Cd in the tested wells varied from 0.02 to 0.47 mg/l (Table 2). Oppositely, the Hg concentration was lower than its recommended maximum limit (0.002). Except for Cd all the other heavy metals were within the limits [12]. Berg and Burbank [13], compared mortalities for 34 types of cancer with the incidence of 8 metals (As, Be, Cd, Cr, Co, Fe, Pb, and Ni) in surface water in the United states. No significant correlations were found for Fe, Co, or Cr, where the correlations for Pb were positive for kidney cancer, all lymphoma, leukemia, and intestinal cancer mortalities. In addition, epidemiological studies showed an increase of certain cancers and precancerous conditions in humans who are chronically exposed to As compounds by oral or respiratory routes, furthermore, Cd exhibited the strongest correlations with the most types of cancer [14, p. 226]. On the other hand, Pories *et al.* [15] indicated that low levels

Table 2. The concentration of heavy metals, As, Cd, Pb, Hg, Fe, Zn, Cu and Co in the groundwater taken from 18 wells is Buraydah.

Sampling station	Concentration (mg/l)							
No.	As	Cd	Pb	Hg	Fe	Zn	Cu	Co
1	0.01	0.15	0.16	0.002	1.38	5.98	0.05	1.91
2	0.02	0.21	0.27	ND*	0.68	7.33	0.04	2.52
3	0.02	0.08	0.05	0.001	0.37	6.82	0.06	2.06
4	0.01	0.47	0.31	ND	0.27	1.91	0.07	1.74
5	0.05	0.41	0.12	ND	0.29	2.80	0.06	1.92
6	0.03	0.06	0.14	0.003	0.35	8.40	0.05	2.05
7	0.04	0.07	0.21	0.001	0.17	6.35	0.04	2.08
8	0.06	0.07	0.15	0.002	1.43	3.32	0.04	1.66
9	0.07	0.18	0.12	ND	0.94	1.45	0.06	2.36
10	0.08	0.19	0.17	0.003	0.69	6.93	0.06	1.84
11	0.01	0.02	0.16	ND	0.67	1.33	0.05	0.35
12	0.02	0.02	0.09	ND	0.21	4.36	0.04	2.23
13	0.05	0.31	0.11	ND	0.38	1.39	0.05	2.31
14	0.03	0.21	0.23	0.002	0.29	1.08	0.03	2.46
15	0.03	0.08	0.21	0.003	0.08	1.37	0.06	2.58
16	0.05	0.25	0.13	ND	0.76	1.45	0.07	2.37
17	0.06	0.05	0.14	0.003	0.17	3.21	0.08	2.10
18	0.02	0.13	0.08	0.004	0.93	1.47	0.08	2.04
$\bar{x}$	0.04	0.16	0.16	0.001	0.56	3.72	0.06	2.03
S.d.	0.02	0.13	0.07	0.001	0.41	2.55	0.01	0.50

* ND - not detected

of certain metals may have a protective effect against cancer. They stated that As, Cu, Pt, Se, and Zn were the best inhibitors of experimental neoplastic growth. Additionally, Cu is known to potentiate the biological activity of certain anti-cancer agents. Thus, trace minerals are necessary to health but higher concentrations may be harmful. Also, it is possible that certain heavy metals in water may induce a protection against a broad spectrum of human tumors. This evidence is fragmentary and it deserves further investigations [15]. The lead levels in waters of wells no. 2, 4, 7, 14, and 15 were alarmingly higher (0.21 to 0.31 mg/l) than the acceptable level (below 0.1 mg/l) stated by Sachdev and West [16].

The concentration of Na, K, Ca, Mg, and Mn in the groundwater samples and the sodium adsorption ratio (SAR) are presented in Table 3. The overall average of Na concentration was the highest one (254.6 ± 44.5 mg/l) followed descendingly by Ca, Mg, K, and Mn; where their averages were 191.7 ± 58.9, 95.3 ± 24.9, 71.4 ± 52.6, and 1.40 ± 0.97 mg/l, respectively. The SAR ranged between 15.90 and 34.41 with an average of 21.73 ± 5.13.

To determine the suitability of groundwater of the 18 wells for irrigation purposes, Fig. 2 shows classification of irrigation waters according to the scheme of Richards [6]. Five wells (5,6,7,11 and 14) were fitted in section C3-S2 which was medium in medium hazard and high in conductivity, five other wells (1,2,3,4, and 10) belonged to section C3-S3 that was high in sodium hazard and high in conductivity. Four wells (9,12,16, and 18) were located in section C4-S3 which was high in sodium hazard and very high in conductivity. Wells No. 13 and 15 were placed in section C3-S4 (very high in sodium hazard and high in conductivity). Whereas, wells No. 8 and 17 were stationed in section C4-S4 that was very high in sodium hazard and very high in conductivity.

The values of SAR of irrigation water are correlated with particular soil characteristics and are often considered in conjunction with the electric conductivity. The suitability of water for irrigation purposes depends upon its salinity and permeability where water salinity has an influence on the availability of water in plants. Water salinity is affected by two parameters, EC and TDS. The values of these parameters specify the degrees of restriction of water use (none, slight to moderate and severe). When the values of EC (ds/m) and TDS (g/m^3), in that order, are 0.7 and 450 the degree of restriction of water use is none; 0.7-3.0 and 450-2000 degree of restriction of water use is slight to moderate; and > 3.0 and > 2000, degree of restriction of water use is severe [17, p. 768]. Permeability which affects the infiltrtion rate of water into soil, is affected by both SAR and EC values. When SAR and EC values are 12-20 and 2.9, respectively, none degree of restriction of water use for irrigation purposes is required. While degree of restriction of water use for irrigation is slight to moderate when SAR and EC values are 12-20 and 1.3 - 2.9, respectively, and it is severe when SAR and EC values are 12-20 and < 1.3, in that order [17, p. 768]. EC and SAR values of the eighteen wells averaged 1.9 ± 0.6 mmhos/cm (= ds/m) and 19.53 ± 2.74, respectively, (Tables 1 and 3). Thus, the degree of restriction of the use of their groundwater for irrigation was slight to moderate.

Bacterial contamination

Water in all tested wells were contaminated with diverse groups of bacteria at concentrations of 10 to 4.6×10^4 cfu/ml. Bacterial counts in 5 wells were over 10000 colony forming units cfu/ml (Table 4).

The results presented in Table 4 indicated that 38.9% of the tested wells were not contaminated with either *E. coli* or *Salmonella* sp. (wells no. 1, 6, 8, 11, 12, 13, and 15). One well was contaminated with *E. coli* only (no. 2), two wells were only contaminated with *Salmonella* sp. (no. 10 and 18), while eight wells were contaminated with both bacteria (no. 3, 4, 5, 7, 9, 14, 16, and 17). The fecal bacterial contamination of the groundwater is probably due to entering of municipal wastes into the groundwater aquifer, because all the supurbs of Buraydah use the septic tank system for municipal wastes which may allow the passing of the contaminated water

Table 3. **The concentration of Na, K, Ca, Mg, and Mn and SAR in the groundwater taken from 18 wells in Baurydah.**

Sampling Station No.	Concentration (mg/l)					SAR
	Na	K	Ca	Mg	Mn	
1	196.0	37.9	112.1	88.9	0.33	19.56
2	237.6	31.6	323.9	78.7	0.67	19.32
3	227.6	51.0	231.5	69.8	1.41	18.55
4	268.8	50.3	215.2	108.3	0.24	21.13
5	173.0	54.4	119.5	110.4	0.48	16.14
6	205.5	63.1	218.6	115.5	1.24	15.90
7	212.0	64.7	217.2	87.9	0.58	17.16
8	153.8	84.3	114.9	96.7	2.57	14.93
9	264.2	42.5	216.7	115.6	1.08	20.50
10	294.3	37.6	219.8	143.5	1.38	21.85
11	221.7	46.2	220.0	120.0	2.29	17.00
12	278.3	207.0	321.1	68.3	0.59	19.95
13	264.8	120.7	119.2	56.4	3.42	22.56
14	235.4	202.1	217.7	131.8	1.28	17.81
15	237.5	57.4	114.2	89.2	3.12	23.56
16	283.6	52.0	219.2	78.3	2.01	23.25
17	198.4	38.7	125.9	98.4	1.93	18.73
18	280.2	43.0	224.3	57.6	0.59	23.61
$\bar{x}$	254.6	71.4	191.7	95.3	1.40	19.53
S.d.	44.5	52.6	58.9	24.9	0.97	2.74

with fecal bacteria through the groundwater. Also, the differences in the geological structure of the ground could play an important role in occurring or preventing this contamination. However, the presence of *E. coli* and *Salmonella* sp. in groundwater could be accidental. Therefore, more samples should be collected at different times and tested for the occurrence of these bacteria before any recommendation on the use of the water of the tested wells.

In conclusion, previous data (Tables, 2 and 3) indicated that all heavy metal concentrations found in the tested wells did not affect the quality of water except that of Cd and Pb. Also, the SAR and EC values of the tested groundwater varied from medium to high. Therefore, the groundwater of these tested wells are suitable for irrigation of many plants, but it is suggested to be used for saline tolerant crops.

However, this study did not give a complete overview of all the problems that might be encountered, but it would serve as selected illustrations of a range of difficulties.

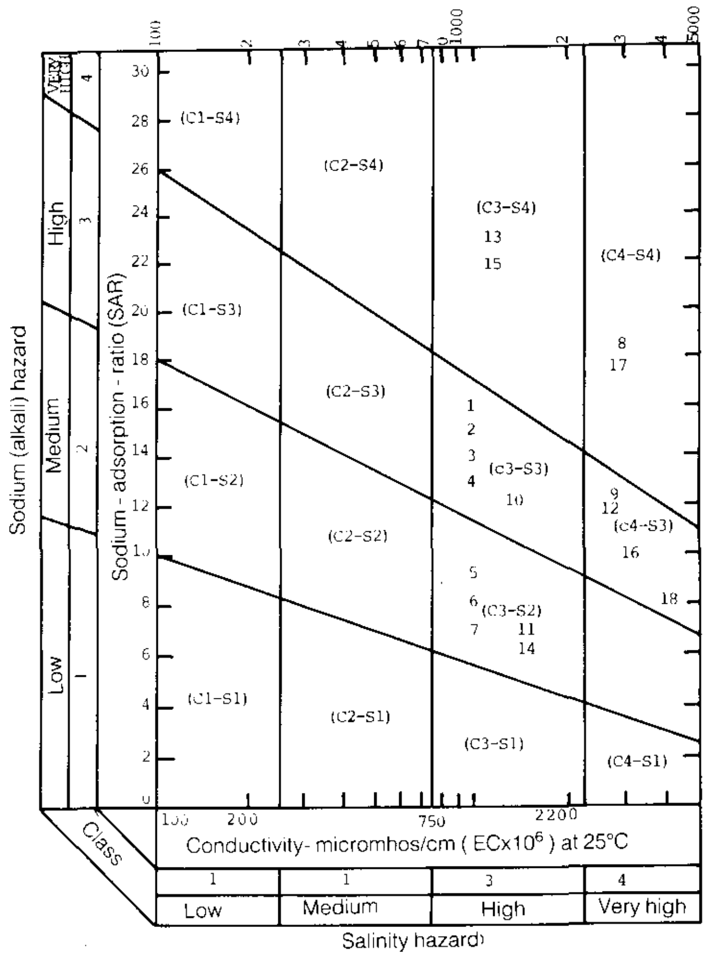

Fig. 2. The classification of irrigation waters of the 18 studied wells.

Table 4. Bacterial counts of wells water in Buraydah

Sample station No.	Bacteria		
	Total (cfu/ml)	E. coli	Salmonella sp.
1	130	−	−
2	14.000	+	−
3	46.000	+	+
4	3.580	+	±
5	40	+	+
6	10.000	−	−
7	10.000	+	+
8	16.000	−	−
9	5.000	+	+
10	50	−	+
11	960	−	−
12	1000	−	−
13	20	−	−
14	10	+	+
15	1000	−	−
16	230	+	+
17	3000	+	+
18	290	−	+

References

[1] Pye, V.I., Patrick, R. and Quarles, J. *Groundwater Contamination in the United States*. Pennsylvania: University of Pennsylvania Press 1983.

[2] Hirsheifer, J., Dettaven, J. and Milliman, J. *Water Supply-Economics, Technology, and Policy*. Chicago: University of Chicago Press, 1960

[3] Greenberg, A.E., Connors, J.J. and Jenkins, D. "Standard Methods for Examination of Water and Wastewater." *Am. Public Health Assoc.*, Wash. D.C. 20005(1981)

[4] Kopp, J.E., Longrottom, M.C. and Lobring, L.B. "Cold Vapor Method for Determining Mercury." *J. Amer. Water Works Assoc.*, **64** (1972), 20

[5] Fernadez, F.J. and Manning, D.C. "The Determination of Arsenic at Sub-microgram Levels by Atomic Absorbtion Spectrophotometery." *Atomic Absorption News-letter*, **10** (1971), 86

[6] Richards, L.A. *Diagnosis and Improvement of Saline and Alkali Soils*. U.S.D.A. Handbook No. 60, 1969

[7] Cowan, S.T., Holt, J.G., Liston, J., Murray, R.G., Niven, C.F., Ravin, A.W. and Stanier, R.Y. *Bergeny's Manual of Determinative Bacteriology.* Baltimore: The Williams & Wilkins Co. 1974

[8] Anonymous. "Water Atlas of Saudi Arabia." *Ministry of Agric. and Water,* (1984), 112

[9] Viessman, W., Jr. and Hammer, M.J. d. *Water Supply and Pollution Control.* 4th Ed. New York: Harper & Row 1985

[10] Anonymous. "Quality Criteria for Water." *U.S. Environmental Protection Agency* Wash, (1976).

[11] Taymaz, K., Yigit, V., Ozbal, H., Ceritoglu, A. and Muftugil, N. "Heavy Metal Concentrations in Water, Sediment and Fish from Izmit Bay, Turkey," *Environ. Anal. Chem.,* **16** (1984), 253-265.

[12] Hammer, M.J. *Water & Waste-Water Technology.* New York: Wiley,1977.

[13] Berg, J.W. and Burbank, F. "Correlations between Carcenogenic Trace Metals in Water Supplies and Cancer Mortality." *Annals of the New York Academy of Science,*, **199** (1972), 249-265.

[14] National Academy of Sciences (NAS). *Drinking Water and Health.* Vol 4. Washington, D.C.: National Academy Press. 1981

[15] Pories, V.I., Patrick, R. and Quarles, J. "Trace Elements that Act to Inhibit Neoplastic Growth." *Annals of the New York Academy of Science,* **199** (1972), 265-271.

[16] Sachdev, S.L. and West, P.W. "Concentration of Trace Metals by Solvent Extraction and their Determination by Atomic Absorption Spectrophotometery." *Environ. Sci. Technol.,* **4** (1970), 749

[17] Tchobanoglous, G. and Schroeder, E.D. *Water Quality.* Reading, Ma: Addison-Wesley Publishing Co., 1985.

الصفات الكيميائية والتلوث البكتيري للمياه الجوفية في مدينة بريدة ـ المملكة العربية السعودية

عبدالله الحسين عبدالمنعم*، محمد عبدالستار المليجي و أحمد علي الرقيبة
كلية الزراعة، جامعة الملك سعود، فرع القصيم، المملكة العربية السعودية

ملخص البحث. جمعت عينـات مياه الـري من ١٨ بئـرًا في مدينة بريدة، وأجري لها تحليل كيميائي وميكروبي. فمن ناحية التحليل الكيميائي والطبيعي تم تحليل وقياس الصفات التالية: إجمالي الأملاح الذائبة، التوصيل الكهربائي، درجة الحموضة، معدل إدمصاص الصوديوم، الأكسجين المذاب ودرجة الحرارة، وكذلك تم تقدير تركيز المعادن الثقيلة وبعض العناصر النادرة (مطيفات الامتصاص الذري).

وقـد أظهـرت التحليلات الكيميائية لمعـظم الآبـار أن إجمالي الملوحة كانت عالية إلى عالية جدًّا (٥١٢ ـ ١٦٦٤ جزء في المليون) ومعدل ادمصاص الصوديوم كان متوسط إلى عالي (١٥,٩ ـ ٣٤,٤). وكان تركيز كل من الكادميوم والرصاص أعلى من الحد المسموح به. أما تركيز باقي المعادن الثقيلة فقد كان في الحدود المسموح بها، إلا عنصر الزئبق فقد كان تركيزه متوسطًا.

تم اختيار تلوث مياه الآبار بكل من *E. coli* و*Salmonella* sp.ووجد أن إحدى عشر بئرًا كانت ملوثة بإحداهما أو الإثنين معًا، كما أجري تقدير الأعداد الكلية الميكروبية في جميع الابار فكانت تتراوح بين ١٠ إلى ٤,٦ × ١٠⁴ خلية/ مل.

* العنوان الدائم: كلية الزراعة، جامعة الأزهر، قسم وقاية المزروعات، القاهرة، جمهورية مصر العربية.