THE APPLICABILITY OF THE LOCAL AND INTERNATIONAL WATER QUALITY GUIDELINES TO AL-GASSIM REGION OF CENTRAL SAUDI ARABIA

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Abstract. The quality of 109 water samples, comprised of 70 drinking water and 39 irrigation water samples, in Al-Gassim Region of Saudi Arabia was investigated with respect to total dissolved salts (TDS), electric conductivity (EC), pH, total hardness and the major cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and anions (Cl^-, SO_4^{2-}, NO_3^-, F^- and HCO_3^-) beside coliform bacteria as an indicator of faecal contamination. The concentrations of TDS varied widely, from 109 to 6995 mg L^{-1}, with a mean of 1427 mg L^{-1}. Of the 109 water samples examined, 81 (74.3%) comply with the maximum permissible drinking water limits set by the local and international standards and guidelines and 28 (25.7%) were above the limits of these standards. The concentrations of the cations and anions (with the exception of NO_3^- and F^-) follow, more or less, a trend similar to TDS. NO_3^- concentrations (range 0–30 mg L^{-1}) comply with the limit of 50 mg L^{-1} NO_3^- as the highest tolerable NO_3^- content. The concentrations of F^- in drinking water (range 0.2–1.5 mg L^{-1}) are alarming since 88% of samples were below the lower permissible limit of 0.6 mg L^{-1} set by SASO (1984), the guideline of the WHO is 1.5 mg L^{-1} while the EEC maximum concentration lies within the range 0.7–1.5 mg L^{-1}. Microbiological analyses showed negative coliform tests, which confirms that they are devoid of any faecal contamination.

Keywords: guidelines, Saudi Arabia, quality, water

1. Introduction

Saudi Arabia is a fast growing country with limited drinking water supplies. Beside the challenge of supply there is also a problem of groundwater quality which makes it unsuitable for drinking without proper treatment. Groundwater constitutes the main source of water supply in the Kingdom and contributes to nearly 79% of the total supply, 82% of which is treated (Saudi Arabian Ministry of Agriculture and Water, 1984; Kabbara, 1987; Abdula'aly and Chammem, 1994).

Like in most regions of the Arabian Penninsula, groundwater continues to be the main source of water supply for drinking, irrigation and other domestic uses in Al-Gassim Region of Central Saudi Arabia. Consequently, it is important to protect this vital source both in quality and quantity.

In the Kingdom of Saudi Arabia, the quality of drinking water is currently receiving some attention (Saudi Arabian Standards Organization (SASO), 1984;

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Hashim, 1990; Garawi and Al-hendi, 1993; Gulf Cooperation Council Standard (G.C.C.S.), 1993; Abdel Magid, 1997; Moghazi and Al-Shoshan, 1999). SASO (1984) developed drinking water standards for both bottled and unbottled (municipal) water to define a quality of water that is safe and acceptable to the consumer. These standards set limits for the permissible and the maximum contaminant level of chemical elements and indicator organisms that endanger the health of consumers. A substantial number of these standards are based on the World Health Organization (WHO, 1971) international guidelines for drinking water.

This study examined the applicability of the SASO (1984), G.C.C.S. (1993), United States Environmental Protection (USEPA) (1976) standards, the EEC standards (1992) and the WHO (1993) guidelines to Al-Gassim Region of Central Saudi Arabia by investigating 109 water samples used for all purposes, including drinking, domestic, cooking as well as irrigation purposes.

2. Materials and Methods

2.1. Sample collection

Water samples were mainly obtained from water coolers used for drinking in mosques and public places and from wells located in farms throughout Al-Gassim Region of Saudi Arabia. Many of these wells water is used for drinking, domestic as well as agricultural purposes.

Water samples for chemical analysis were collected in polyethylene bottles whereas samples for bacteriological analysis were collected in 250 mL sterile glass bottles. The water samples were taken to the laboratory (Ambient temperature 25 °C) and analysis was carried out immediately.

Physical, chemical and bacteriological analysis were performed according to the following protocol as outlined by Abdel Magid (1997):

2.2. Physical and chemical analyses

The analyses were carried out according to the Standard Methods for the Examination of Water and Wastewater (APHA, 1971, 1985) and Richards (1954).

In these analyses, pH was measured by a Meterohm pH-meter (Model 632). Electric conductivity (EC) (dS m^{-1} at 25 °C) was measured by a Beckman Solu Bridge type equipment. Na^+ and K^+ were determined by flame photometer (Corning Model M410 instrument). Ca^{2+} and Mg^{2+} were determined by titration with EDTA – disodium salt solution (0.01 N). F^- was determined by the SPADNS [Sodium 2-(parasulfophenylazo)-1,8 dihydroxy-3,6 naphthalene disulfonate] colorimetric method using NaF for preparation of the standard solution. Cl^- was determined by titration using standard silver nitrate solution and potassium chromate (5% solution) as an indicator. SO_4^{2-} was determined turbidimetrically using Model ANA-14A turbidimeter (Tokyo Photo-electric Co. Ltd., Japan). NO_3^- was determined by the phenoldisulphonic acid method using Spectronic 2000 spectrophotometer. HCO_3^- was determined by titration against 0.02 N sulfuric acid to pH 4.5 using methyl orange as an indicator. Total hardness was obtained by calculation from Ca^{2+} and Mg^{2+} determined concentrations. Total dissolved salts (TDS) were determined by multiplying the conductivity value by 640 according to Rhoades (1982).

2.3. 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 hr 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 hr.

Statistical analysis were performed using an IBM compatible 486 computer. The means obtained for the various water quality parameters measured were evaluated according to the current SASO (1984), G.C.C.S. (1993), EEC (1992), WHO (1993) and USEPA (1976) drinking water standards and guidelines.

3. Results and Discussion

Analysis of the 109 water samples for TDS (Table I), showed a wide variation in concentration. TDS ranged from 109 to 6995 mg L^{-1} with an average value of 1427 mg L^{-1}. Comparison with the recommended standards and guidelines for salinity of drinking water (Table I) revealed that 26, 31, 31 and 91% of the samples studied are above the limits set by SASO, G.C.C.S., WHO and USEPA, respectively. The lowest value of TDS was recorded for drinking water whereas the highest value was recorded for surface well water used for irrigation. The levels of TDS in the water samples investigated varied significantly (large standard deviation value of 1349 mg L^{-1}). The distribution of the TDS levels in the 109 water samples examined is shown in Table II. It indicates that only 9.2% of the samples comprised the best quality water (TDS $<$ 500 mg L^{-1}, set by the USEPA) whereas 65.1% of the water samples [TDS = 501–1000 mg L^{-1} (60.5%) and TDS = 1001–1500 mg L^{-1} (4.6%)] comply with the 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 = 1501–2000 mg L^{-1} (3.7%) and TDS $>$ 2000 mg L^{-1} (22%)) comprised 26% of the water samples studied. Therefore, according to the standards and guideline limits for drinking water listed in Table I, such high salinity water is considered unsuitable for drinking but could be used for irrigating crops with good salt tolerance such as date palm trees (Clark, 1963; Raveendran and Madany, 1991; Abdel Magid, 1997). Nevertheless, in some areas of the Gulf such water is used for

TABLE I

Physical, chemical and microbiological quality of water samples (n = 109) in Al-Gassim Region of Saudi Arabia

Constituent/ property	Mean (n = 109)	Range	Standard deviation	SASO standard (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, mg L^{-1}	1427	109–6995	1349	1500	26	1000	31	1000	31	500	91
EC, mmhos cm^{-1}	2.2	0.2–10.9	2.1	2.3	26	1.6	29	NS[c]	–	NS	–
pH	7.6	6.2–8.6	0.6	9.2[a]	0.0	6.5–8.5	0.0	<8	43	6.5–8.6	0.0
Total hardness (as $CaCO_3$)	619	65–2893	646	500	29	500	29	NS	–	NS	–
Ca^{2+}, mg L^{-1}	163	16–820	177	200	21	200	21	NS	–	NS	–
Mg^{2+}, mg L^{-1}	54	4.9–257	61	150[b]	12	150	12	NS	–	NS	–
Na^{+}, mg L^{-1}	217	2.5–1502	231	NS	–	200	24	200	24	NS	–
K^{+}, mg L^{-1}	25	4.3–121	14.5	NS	–	NS	–	NS	–	NS	–
Cl^{-}, mg L^{-1}	363	18–1737	357	600	16	400	41	250	41	250	41
SO_4^{2-}, mg L^{-1}	457	48–2846	580	400	28	250	28	250	33	250	33
NO_3^{-}, mg L^{-1}	6	0–30	13	<45	0.0	<45	0.0	50	0.0	45	0.0
F^{-}, mg L^{-1}	0.5	0.2–1.5	0.3	1(0.6–1)	7	1(0.6–1)	7	1.5	0.0	4	0.0
HCO_3^{-}, mg L^{-1}	180	30–395	71	NS	–	NS	–	NS	–	NS	–
Total Coliform: (MPN 100 mL^{-1})	Negative		–	Negative	–	Negative	–	Negative	–	Negative	–

[a] The lowest permissible level is around pH 6.5.
[b] Not more than 30 mg L^{-1} if there are 250 mg L^{-1} of sulfate; if there is less sulfate, magnesium up to 150 mg L^{-1} may be allowed.
[c] NS = No Standard.

TABLE II

Distribution of 109 water samples in the Central Region of Saudi Arabia according to their contents of total dissolved salts (TDS)

TDS class ($mg\ L^{-1}$)	Number of samples within class	Percentage of total within class	Mean	Range	SD	Water use[a]
<500	10	9.2	214	109–493	112	D
501–1000	66	60.5	795	614–979	57	D + 1
1001–1500	5	4.6	1148	1043–1389	139	1
1501–2000	4	3.7	1751	1594–1907	151	1
>2000	24	22	367	2067–6995	1204	1

[a] D = Drinking water samples, 1 = irrigation water samples.

human consumption (Raveendran and Madany, 1991; Zubari *et al*., 1996). There are several sources which might have contributed to this high salinity, including over-exploitation, excessive pumping, soil weathering, runoff water, agricultural drainage water and holes found in the casing of pumping wells from which high salinity water enters the wells from the upper aquifers (Alaa El-Din *et al*., 1994; Abdel-Aal *et al*., 1997; Moghazi and Al-Shoshan, 1999). Conductivity, generally, reflects salinity and ranged from 0.2 to 10.9 mmhos cm^{-1} with an average of 2.2 mmhos cm^{-1} (Table I). With the exception of the WHO (1993) guideline limit for pH (pH < 8) all of the water samples studied have pH values falling within the limits of the respective standards included in Table I. Total hardness (as $CaCO_3$) ranged between 65 and 2893 mg L^{-1} with 29% of the water samples being above the 500 mg L^{-1} standard limit set by SASO and G.C.C.S. According to Viessman and Hammer (1985) water hardness of more than 300–500 mg L^{-1} is considered excessive for a public water supply and results in high soap consumption as well as objectionable scale in heating vessels and pipes. Moreover, many consumers object to water harder than 150 mg L^{-1}, a moderate figure being 60–120 mg L^{-1}, thus including the optimum limit of 100 mg L^{-1} recommended by SASO (1984). Ca^{2+} concentrations ranged between 16 and 820 mg L^{-1}, with 21% of the water samples studied falling above the standard limit of 200 mg L^{-1} set by SASO and G.C.C.S.; Mg^{2+} concentrations ranged between 4.9 and 257 mg L^{-1} with 12% of the water samples are above the standard limit of 150 mg L^{-1} set by both SASO and G.C.C.S., Na^{+} concentrations ranged between 2.5 and 1502 mg L^{-1} with 24% of the samples falling above each of the G.C.C.S. and WHO standard and guideline limits, K^{+} concentrations ranged between 4.3 and 121 mg L^{-1}. Cl^{-} concentrations ranged between 18 and 1737 mg L^{-1} with 16% of the water samples are above the SASO standard limits and 41% of the water samples above each of the G.C.C.S., WHO and USEPA standard and guideline limits. According to Raveendran and

Madany (1991) the WHO guidelines for Na^+ (200 mg L^{-1}) and Cl^- (250 mg L^{-1}) are based on taste considerations rather than the impact on human health and thus higher values can be tolerated. SO_4^{2-} concentrations ranged between 48 and 2846 mg L^{-1} with 28% of the water samples studied falling above each of the SASO and G.C.C.S. standard limits and 33% above the WHO and USEPA standards. Viessman and Hammer (1985) indicated that the taste threshold for SO_4^{2-} lies between 300–400 mg L^{-1} for most persons. NO_3^- concentration ranged between 0–30 mg L^{-1} with all of the water samples studied thus falling below the limit of 50 mg L^{-1} set by the WHO and EEC standards. F^- concentrations ranged between 0.2 and 1.5 mg L^{-1} with only 7% of the samples above each of the SASO and G.C.C.S. standards limits but falling within the limits of both the WHO and USEPA stanards. Elevated levels of HCO_3^-, ranging from 30 to 395 mg L^{-1} can be attributed to the presence of limestone in deep soil layers and consequently in groundwater (Moghazi and Al-Shoshan, 1999).

Large standard deviation values (Table I) indicated that significant variations exist among the 109 water samples examined. To get rid of this high variability and to make the picture more apprehensive rather than comprehensive the data in Table I were categorized into two categories viz. 70 drinking water samples (Table III) and 39 irrigation water samples (Table IV). Comparison of the values for the various parameters measured, to assess the quality of drinking water, with the EEC standards and guidelines depicted in Table III indicated that, except for a few instances, viz. pH (WHO guidelines), Cl^- (G.C.C.S., WHO, EEC and USEPA guidelines), SO_4^{2-} (WHO guidelines and F^- (SASO and G.C.C.S. guidelines) all the values are within the maximum permissible limits for drinking water. For the 39 water samples categorized as irrigation waters (with the exception of pH and NO_3^- values) almost all of the parameters determined are well above the maximum permissible limits of the respective standards and guidelines (Table IV) and are, therefore, considered unsuitable for drinking but could be used for irrigating salt-tolerant crops. Nevertheless, in some areas of the Gulf such water is used for human consumption (Raveendran and Madany, 1991; Zubari *et al*., 1996). In view of the WHO and EEC standards and guidelines, which suggested the limit of 50 mg L^{-1} NO_3^- as the highest tolerable NO_3^- content in drinking water, all of the water samples examined in this work (Tables III and IV) fall within this limit and, therefore, pose no health hazards with respect to their NO_3^- content. There are several sources which might have contributed to the comparatively elevated level of NO_3^- in irrigation water (average 14.6 mg L^{-1} (Table IV)), including agricultural related sources such as nitrogen rich fertilizers and manures applied at liberal rates by farmers in the region (Amr, 2000). On the other hand, F^- concentrations ranged between 0.2 and 1.5 mg L^{-1} for both drinking and irrigation water samples (Tables III and IV) with 3 and 17% of the water samples examined fall above the SASO and G.C.C.S. maximum permissible limit of 1 mg L^{-1}, respectively. The distribution of F^- in the samples examined is shown in Table V. It shows that 88% of the drinking water samples and 41.7% of the irrigation water sample examined

TABLE III

Physical, chemical and microbiological quality of drinking water samples (n = 70) in Al-Gassim Region of Saudi Arabia

Constituent/ property	Mean (n = 70)	Range	Standard deviation	SASO standard (1984)	Percentage of samples above	G.C.C.S. standard (1993)	Percentage of samples above	WHO guidelines (1993)	Percentage of samples above
TDS, mg L^{-1}	713	109–909	211	1500	0.0	1000	0.0	100	0.0
EC, mmhos cm^{-1}	1.1	0.2–1.6	0.30	2.3	0.0	1.6	0.0	NS[c]	–
pH	7.9	6.5–8.6	0.45	9[a]	0.0	6.5–8.5	0.0	<8	66
Total hardness (as $CaCO)_3$)	274	65–465	77	500	0.0	500	0.0	NS	–
Ca^{2+}, mg L^{-1}	74	16–144	21	200	0.0	200	0.0	NS	–
Mg^{2+}, mg L^{-1}	22	5–47	8	150[b]	0.0	150	0.0	NS	–
Na^{+}, mg L^{-1}	122	2.5–173	48		–	200	0.0	200	0.0
K^{+}, mg L^{-1}	28	5.5–56	9	NS	–	NS	–	NS	–
Cl^{-}, mg L^{-1}	196	18–259	74	600	0.0	250	16	250	16
SO_4^{2-}, mg L^{-1}	160	48–360	56	400	0.0	400	0.0	250	2.8
NO_3^{-}, mg L^{-1}	2	0–23	4	<45	0.0	<45	0.0	50	0.0
F^{-}, mg L^{-1}	0.4	0.2–1.5	0.2	1(0.6–1)	3	1(0.6–1)	3	1.5	0.0
HCO_3^{-}, mg L^{-1}	156	30–304	42	NS	–	NS	–	NS	–
Total coliform: (MPN 100 mL^{-1})	Negative		–	Negative	–	Negative	–	Negative	–

[a] The lowest permissible level is around pH 6.5.
[b] Not more than 30 mg L^{-1} if there are 250 mg L^{-1} of sulfate; if there is less sulfate, magnesium up to 150 mg L^{-1} may be allowed.
[c] NS = No Standard.

TABLE IV

Physical, chemical and microbiological quality of irrigation water samples (n = 39) in Al-Gassim Region of Saudi Arabia

Constituent/ property	Mean (n = 109	Range	Standard deviation	SASO standard (1984)	Percentage of samples above	G.C.C.S. standard (1993)	Percentage of samples above	WHO guidelines (1993)	Percentage of samples above
TDS, mg L^{-1}	2710	493–6995	1567	1500	69	1000	85	1000	85
EC, mmhos cm^{-1}	4.2	0.8–11	2.4	2.3	72	1.6	85	NS[c]	–
pH	7	6.2–7.8	0.3	9.2[a]	0.0	6.5–8.5	0.0	<8	0.0
Total Hardness (as $CaCO_3$)	1248	250–2893	747	500	82	500	82	NS	–
Ca^{2+}, mg L^{-1}	324	60–820	218	200	59	200	59	NS	–
Mg^{2+}, mg L^{-1}	113	18–257	70	150[b]	33	150	33	NS	–
Na^{+}, mg L^{-1}	392	66–1502	318	NS	–	200	67	200	67
K^{+}, mg L^{-1}	19	4–121	20	NS	–	NS	–	NS	–
Cl^{-}, mg L^{-1}	668	124–1737	456	600	46	250	87	250	87
SO_4^{2-}, mg L^{-1}	991	48–2846	703	400	80	400	80	250	85
NO_3^{-}, mg L^{-1}	14.6	0–30	10	<45	0.0	<45	0.0	50	0.0
F^{-}, mg L^{-1}	0.7	0.2–1.5	0.33	1(0.6–1)	17	1(0.6–1)	17	1.5	0.0
HCO_3^{-}, mg L^{-1}	224	101–395	89	NS	–	NS	–	NS	–
Total coliform: (MPN 100 mL^{-1})	Negative		–	Negative	–	Negative	–	Negative	–

[a] The lowest permissible level is around pH 6.5.
[b] Not more than 30 mg L^{-1} if there are 250 mg L^{-1} of sulfate; if there is less sulfate, magnesium up to 150 mg L^{-1} may be allowed.
[c] NS = No Standard.

TABLE V

Distribution of drinking water samples (n = 67) and irrigation water samples (n = 24) according to their content of F^- (mg L^{-1})

F^- (mg L^{-1})	No. of samples within class	Percentage of total within class
<0.6:		
Drinking water	59	88
Irrigation water	10	41.7
0.6–1:		
Drinking water	6	9
Irrigation water	10	41.7
>1:		
Drinking water	2	3
Irrigation water	4	16.6

contain F^- levels below 0.6 mg L^{-1}, only 9% of the drinking water samples and 41.7% of the irrigation water samples are within the range between 0.6 and 1 mg L^{-1}. Currently, SASO (1984) recommends that the level of fluoride in unbottled drinking water shall not be less than 0.6 mg L^{-1} but not greater than 1 mg L^{-1} depending on the average maximum ambient temperature in community area. The WHO guideline for fluoride is 1.5 mg L^{-1}, the EEC range for fluoride is 0.7–1.5 mg L^{-1}. It may be inferred from the data presented in Table V that 88% of the drinking water samples examined have fluoride concentration lying well below the recommended lower permissible level of SASO standard (1984), which means that supplemental fluoridation to the optimum level is deemed necessary to avoid dental decay in water consumers (Al-khateeb *et al.*, 1992; Abdula'aly, 1997).

Repeated bacteriological analyses of the 109 water samples under study, using standard procedures, failed to give any indication for the presence of the coliform bacteria (Tables I, III and IV), which confirms that they are devoid of any faecal contamination. This is expected since drinking water receives chlorination treatment before distribution to consumers and that the elevated salinity of irrigation water hinders the growth of bacterial colonies.

4. Conclusions and Recommendations

Based on the results of the present investigation, the following conclusions may be drawn:

1) Comprehensive analyses of 109 water samples used for all purposes, in Al-Gassim Region of Saudi Arabia, including drinking, domestic, cookig as well as irrigation purposes revealed that there are considerable variations among the examined samples with respect to their constituents which mostly fell above the maximum permissible levels set by SASO, G.C.C.S., WHO, EEC and USEPA standards and guidelines.
2) NO_3^- concentrations of the water samples examined pose no health hazards to the public health since they fall well below the maximum permissible limit of the respective standards used in this study.
3) The concentrations of F^- in drinking water is alarming since 88% of the water samples studied have F^- concentrations below 0.6 mg L^{-1} (the lower permissible limit of F^- suggested by the SASO and G.C.C.S. guidelines).
4) Bacteriological analysis indicated that the water samples under study are free from coliform bacteria and consequently are devoid of any faecal contamination.
5) Continuous assessment of groundwater quality on routine basis is imperative and a better management is warranted to reduce the deterioration of aquifer water quality.

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References

Abdel-Aal, S. I., Sabrah, R. E., Rabie, R. K. and Abdel Magid, H. M.: 1997, 'Evaluation of groundwater quality for irrigation in Central Saudi Arabia', *Arab Gulf J. Sci. Res.* **15**, 361–377.

Abdel Magid, H. M.: 1997, 'Assessment of drinking water quality in Al-Gassim Region of Saudi Arabia', *Environ. Internat.* **23**(2), 247–251.

Abdula'aly, A. I.: 1997, 'Fluoride Content in Drinking Water Resources in the Central Region of Saudi Arabia', Presented in the *Development and Environmental Impact Conference held in Riaydah*, Saudi Arabia, pp. 21–23.

Abdula'aly, A. I. and Chammem, A. A.: 1994, 'Groundwater Treatment in the Central Region of Saudi Arabia', *Desalination* **96**, 203–214.

Alaa El-Din, M. N., Madany, I. M., Al-Tayaran, Al-Jubair, A. and Gomaa, A.: 1993, 'Quality of water from some wells in Saudi Arabia', *Water, Air, and Soil Pollut.* **66**, 135–143.

Alaa El-Din, M. N., Madany, I. M., Al-Tayaran, Al-Jubair, A. and Gomaa, A.: 1994, 'Trends in water quality of some wells in Saudi Arabia, 1984–1989', *Sci. Tot. Environ.* **143**, 173–181.

Al-khateeb, T., Farsi, J., Clarkson, J. and O'Mullane, D.: 1991, 'Enamel mottling in Saudi Arabia children in communities with different levels of fluoride in drinking water', J. King Abdulaziz University, *Medical Sci.* **2**, 41–49.

Amr, A.: 2000, 'Nitrate and nitrite content of some vegetables grown in Central Jordan Valley', *Agricultural Sciences Studies* **37**(3), 410–419.

APHA (American Public Health Association): 1971, *Standard Methods for the Examination of Water and Wastewater*, 13th ed., New York, U.S.A.

APHA (American Public Health Association): 1985, *Standard Methods for the Examination of Water and Wastewater*, 16th ed., New York, U.S.A.

Clark, J. W., Viessman Jr., W. Jr. and Hammer, M. J.: 1963, *Water Supply and Pollution Control*, 2nd ed., International Textbook Company, New York, N.Y., U.S.A., pp. 235.

EEC (Economic European Community): 1992, *Standards: In Hach Water Analysis Handbook*, 2nd ed.

Garawi, M. S. and Al-hendi, H. A.: 1993, 'Spectroscopic study of the metallic constituents in some underground water in Al-Gassim area, Saudi Arabia', *Arab Gulf J. Sci. Res.* **11**, 47–56.

G.C.C.S. (Gulf Cooperation Council Standard): 1993, *Unbottled Drinking Water Standards*, Standardization and Metrology Organization for the Gulf Cooperation Council Countries #GS 149/193, Riyadh, Saudi Arabia.

Geldreich, E. E.: 1975, *Handbook of Evaluating Water Bacteriological Laboratories*, 2nd ed., Cincinnati, OH, U.S. Environmental Protection Agency.

Hashim, A. R.: 1990, 'Analysis of water and soils for Ashafa Toraba Wahat and Wehait', *J. King Saud. Univ. (Science)* **2**, 87–94.

Kabbara, S. A.: 1987, 'Water Recycling and Reuse Plants', in *Developing World Water*, Grosvenor Press International, pp. 226.

Kadaj, R.: 1991, *U.S. Interests in Middle East Rely upon Averting Looming Water Crisis in the Region. Arab Water World*, Journal (Published by Shatilla Press House, P.O. Limasol, Cyprus), Vol. 5 (September–October issue), pp. 19.

Lamb, J. C.: 1985, 'Water Quality and its Control', John Wiley & Sons Inc., New York, U.S.A.

Moghazi, H. M. and Al-Shoshan, A. A.: 1999, 'A Study of Increasing Salinity of Water Wells in Al-Gassim Region, Saudi Arabia', A paper presented in *the 4th Gulf Water Conference, Manama, The State of Bahrain*, 13–17 February, 1999.

Raveendran, E. and Madany, I. M.: 1991, 'The quality of groundwater in Bahrain', *Sci. Tot. Environ.* **102**, 177–183.

Rhoades, J. D.: 1982, 'Soluble Salts', in A. L. Page, R. H. Miller and D. R. Keeney (eds), *Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties*, 2nd ed., American Society of Agronomy, Inc. Madison, Wisconsin, U.S.A., pp. 167–179.

Richards, L. A.: 1954, *Diagnosis and Improvement of Saline and Alkali Soils*, Handbook No. 60, Washington, D.C., U.S. Department of Agriculture.

SASO (Saudi Arabian Standards Organization): 1984, *Bottled and Unbottled Drinking Water*, SSA 409/1984, 2nd ed., 1996-03-13, ISSN: 1319-2302: 1984. Available from: SASO Information Center, P.O. Box 3437, Riyadh, 11471, Saudi Arabia, pp. 1–8.

Saudi Arabian Ministry of Agriculture and Water: 1984, *Water Atlas of Saudi Arabia*, pp. 45–78.

USEPA (U.S. Environmental Protection Agency): 1976, *National Interim Primary Drinking Water Regulations*, Publication EPA/S 70/9-76-003. Washington, D.C., Government Printing Office.

Viessman Jr., W. Jr. and Hammer, M. J.: 1985, *Water Supply and Pollution Control*, 4th ed., Harper and Row, Publishers, New York, U.S.A., pp. 797.

WHO (World Health Organization): 1971, *International Standards for Drinking Water*, 3rd ed., Geneva.

WHO: 1993, *Guidelines for Drinking-Water Quality, Vol. 1, Recommendations*, 2nd (ed.), Geneva.

Zubari, W. K., Madany, I. M., Al-Junaid, S. S. and Al-Manaii, S.: 1994, 'Trends in the quality of groundwater in Bahrain with respect to salinity, 1941–1992', *Environ. Internat.* **20**, 739–46.