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Chemical evaluation of treated sewage and brackish waters for irrigation

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ABSTRACT

Treated sewage water from the Al-Ardheyah sewage works and brackish water from two underground water well fields have been chemically evaluated for their suitability for irrigation. Chemical analyses involve determination of common cations, anions, boron, and trace elements. Suitability of irrigation water depends mainly upon salinity hazard, sodium adsorption ratio, and boron concentration. In addition, some trace elements such as Cu, Ni, Cd, Pb and Zn were determined and assessed. Although the salinity of treated sewage water appears to be less than that of brackish waters, both are rated as being of very poor quality. Because of the salinity hazard, continuous irrigation with such waters will increase the problem of substrate permeability. Although these waters are classified as 'medium sodium' waters, and hence would present an appreciable sodium hazard to fine textured soil, they have, nevertheless, been used successfully in irrigation in Kuwait where the soil is sandy. The water produced by tertiary treatment is also considered very saline, but has low concentrations of sodium, so it can be used for irrigation on almost all soils.

Boron concentration of treated sewage water ranges from 1·2 to 1·8 mg/l whereas that for brackish water is 1·5 mg/l, and does not exceed the permissible limit recommended for semi-tolerant and tolerant crops. It could also be used, with care, for semi-sensitive crops. Trace element concentrations in treated sewage water are lower than those in brackish water, and trace elements in both types of water are low enough to ensure their safe use in irrigation.

INTRODUCTION

The sewage works at Al-Ardheyah handles a volume of 130,000 m^3/day of raw sewage influent which undergoes secondary treatment. An amount of 50,000 m^3/day of effluent from secondary treatment is used to irrigate an area of 10 km^2 in Kuwait.

The sewage is treated by an activated sludge process. The first stage of treatment is the removal of large floating objects; it comprises screening and grit removal. Settled sewage is led to an aeration tank where oxygen is supplied by diffused aeration. It then passes into a first-stage settling tank where organic matter is oxidized and where sludge and effluent are separated. The process is again repeated using the effluent from the settling tank to the aeration tank inlet. Tertiary treatment water is an effluent which has received both primary (sedimentation) and secondary (biological) treatment. This process is most commonly used to remove any additional solids, and also reduces faecal coliform numbers by sand filtration.

Table 1. Characteristics of treated and untreated sewage water at Al-Ardheyah. T.D.S., cations and anions are expressed in mg/l

Date		pH	E.C. m.mhos/cm	T.D.S.	Cations Na^+	K^+	Ca^{++}	Mg^{++}	Fe^{++}	B	Anions Cl^-	SO_4^{--}	HCO_3^-	CO_3^{--}	NO_3^-	S.A.R.	Adj. S.A.R.
Jan. 83	A	7·60	2440	1562	310	29	96	70	0·44	–	515	165	–	–	–	5·88	27·63
	B	7·60	2370	1517	300	27	106	70	0·12	–	479	400	610	–	–	4·55	12·28
	C	7·30	2320	1485	310	25	113	70	0·23	–	462	900	488	–	–	5·65	15·25
Mar. 83	A	8·22	2780	1779	350	30	109	49	–	–	485	–	183	–	–	7·00	14·70
	B	8·44	2790	1779	357	29	101	52	–	–	473	–	244	–	–	7·20	16·25
	C	8·21	2800	1792	353	22	117	50	–	–	462	–	242	–	–	6·86	15·77
Apr. 83	A	7·57	2710	1734	220	40	180	45	–	2·1	621	200	976	–	–	3·80	11·04
	B	7·75	2580	1651	210	40	175	41	–	2·1	550	202	1006	–	–	3·72	11·16
	C	7·66	2590	1658	210	44	179	40	–	1·8	533	350	488	–	–	3·69	9·96
Jun. 83	A	7·30	1900	1216	170	15	59	22	3·0	1·8	390	320	356	84	–	6·20	14·88
	B	7·90	1870	1197	225	18	42	32	3·5	1·0	397	380	256	96	–	6·39	15·33
	C	7·95	1950	1248	240	20	84	38	3·5	1·5	327	380	244	48	–	5·48	13·15
Jul. 83	A	7·70	2480	1587	290	24	129	45	4·5	1·5	426	380	232	24	–	5·62	13·48
	B	7·90	2550	1632	295	24	133	47	4·5	1·5	447	400	280	–	–	5·62	13·48
	C	7·80	2610	1670	305	20	144	48	7·5	1·5	454	440	244	–	–	5·62	13·56
Aug. 83	A	7·50	2860	1830	335	23	166	60	8·0	1·5	511	500	305	–	–	5·66	14·15
	B	7·80	2770	1773	315	23	150	54	4·5	1·5	500	400	292	–	–	5·61	14·02
	C	7·70	2650	1696	320	23	148	54	5·0	1·2	511	440	305	–	–	5·74	14·35
Sep. 83	A	7·10	2600	1664	285	21	144	51	5·0	–	454	420	268	–	–	5·62	14·05
	B	7·30	2450	1568	270	22	140	49	6·0	1·5	440	440	281	–	–	5·01	12·53
	C	7·50	2450	1568	275	22	139	50	6·0	–	447	340	268	–	–	5·10	12·24
Oct. 83	A	7·50	2890	1850	270	22	126	50	3·5	0·1	430	400	512	–	–	5·16	13·41
	B	7·35	2650	1696	250	22	130	45	4·0	0·4	425	360	634	–	–	4·83	13·04
	C	7·54	2650	1696	255	21	135	45	8·0	–	420	340	354	–	–	4·85	12·12
Nov. 83	A	7·20	1500	960	260	28	124	42	4·0	–	–	360	547	–	–	5·15	13·40
	B	7·70	1410	902	300	27	143	52	4·1	–	–	280	577	29	–	5·47	15·34
	C	7·70	1410	903	170	18	88	30	4·2	–	–	220	296	15	–	3·99	8·78

Table 1. (*cont.*)

Date		pH	E.C. m.mhos/cm	T.D.S.	Cations					B	Anions					S.A.R.	Adj. S.A.R.
					Na^+	K^+	Ca^{++}	Mg^{++}	Fe^{++}		Cl^-	SO_4^{--}	HCO_3^-	CO_3^{--}	NO_3^-		
Dec. 84	A	7·60	2740	1753	158	30	126	47	0·15	1·2	440	724	470	–	19·8	2·15	5·59
	B	7·90	2580	1651	153	33	117	45	0.10	1·4	412	495	684	–	13·7	2·15	6·02
	C	7·80	2460	1574	150	28	113	40	0·08	1·1	403	757	426	–	11·7	2·19	5·69
	D	7·85	2490	1593	150	29	111	40	0·09	1·3	403	610	394	–	10·4	2·20	5·72

A = Influent raw sewage.
B = Effluent E-1 primary treatment.
C = Effluent E-2 secondary treatment.
D = Effluent E-3 tertiary treatment (started Nov. 84).

S.A.R. = Sodium adsorption ratio.
Adj. S.A.R. = Adjusted sodium adsorption ratio.
– = Not determined.

The brackish water is obtained from Al-Sulibiya and Al-Shagaya well fields, which have a salinity range from 2000–3000 mg/l. Daily production of brackish water depends on seasonal consumption. In July 1984, the daily production of brackish water was $2{\cdot}27 \times 10^5\,m^3/day$ of which $2{\cdot}04 \times 10^5\,m^3/day$ were used for domestic purposes and irrigation. In January 1985, daily production of brackish water was $6{\cdot}8 \times 10^4\,m^3/day$ of which $5{\cdot}2 \times 10^4\,m^3/day$ was consumed to meet domestic and irrigation demands. The purpose of this paper is to discuss the chemistry of treated and untreated sewage water, to compare treated water with brackish water, and to evaluate their suitability for irrigation use. The expected problems are also considered.

MATERIALS AND METHODS

Untreated and treated sewage water samples were collected through 1983 from the treatment plant at Al-Ardheyah, and brackish water samples were collected from the University Campus, and other sites. Complete chemical analyses of the common cations, anions and boron, along with trace elements such as copper, nickel, cadmium, lead and zinc (Tables 1–3), were carried out in the Department of Geology, University of Kuwait. Samples of the untreated and treated sewage water were filtered first, then analysed along with brackish water samples.

Table 2. Trace element concentration of treated and untreated sewage water (mg/l)

Date		Cu	Zn	Pb	Cd	Ni
Dec. 84	A	0·0098	0·0368	0·036	0·0034	0·0265
	B	0·0078	0·0225	0·039	0·0036	0·0287
	C	0·0057	0·0160	0·038	0·0035	0·0236
	D	0·0075	0·0257	0·039	0·0032	0·0285

The common cations, trace elements and iron, were determined by an atomic absorption spectrophotometer (Perkin Elmer 4000). Nitrate, sulphate and boron were determined by a spectrophotometer (Shimadzu-UV-240). Screening, turbidity and carmine methods were carried out according to Greenberge *et al.* (1980). Chloride was determined by titration against silver nitrate (Vogel 1961). Carbonate and bicarbonate were determined by titration with 0.1 M hydrochloric acid, using phenolphthalin and methyl orange as indicators.

Microbiologically, the Al-Ardheyah sewage works has a rich flora. Algal species are dominated by members of the Chlorophyceae, Bacillariophyceae and Euglenophyceae (Sallal & Al-Shihab 1983). Total bacterial count detected in the outflow from the works is 250×10^4 cells/ml which is a reduction of about 60% compared with the inflow (Sallal & Stewart 1981). Micro-organisms present in addition to bacteria and algae include fungi, protozoa and rotifers. The presence of coliforms ($0{\cdot}3–0{\cdot}7 \times 10^{16}$/100 ml) and *Salmonella* ($0{\cdot}1–0{\cdot}3 \times 10^6$/100 ml) in the treated effluent is viewed as a potential health hazard by Al-Eissa (1982). Direct microscopic counts showed that the organisms were present in all sewage effluents and sludges (Sallal & Babaa 1982). The

Table 3. Characteristics of typical brackish water from Shuwaikh district. T.D.S. and cations are expressed in mg/l

Date	pH	E.C. m.mhos/cm	T.D.S.	Na^+	Ca^{++}	Mg^{++}	HCO_3^-	S.A.R.	Adj. S.A.R.	Cu	Zn	Cd	Pb
12.1.84	7·7	3059	4190	474	317	124	120	4·05	9·72	0·0096	0·0438	0·0052	0·630
2.1.85	7·7	2960	4060	462	317	329	120	3·08	6·77				
5.1.85	7·7	3270	4490	497	340	135	120	4·07	9·76				
6.1.85	7·7	3066	4200	481	329	128	120	4·03	5·23				
7.1.85	7·8	3241	4440	494	337	141	110	4·04	9·69				
8.1.85	7·8	3179	4355	486	332	137	120	4·00	9·69				

range of (plate count) bacteria in brackish water samples is in the range of 40–140/ml at 35°C at Shuwaikh, 40–240/ml at 35°C at Doha and 80–140/ml at 35°C at Shuaiba (Water Resources Development Centre 1984).

DISCUSSION

The chemical suitability of an effluent for irrigation is judged mainly by its electrical conductivity, sodium adsorption ratio (S.A.R.), boron concentration, and trace element content (U.S. Salinity Laboratory Staff 1954).

ELECTRICAL CONDUCTIVITY (E.C.)

Electrical conductivity is a measure of dissolved salts, hence a measure of the salinity hazard to crops. Excessive salinity reduces the plant's osmotic activity and so interferes with absorption of both water and nutrients from the soil.

SODIUM ABSORPTION RATIO (S.A.R.)

Sodium adsorption ratio is a measure of the alkali or sodium hazard to the crop. When sodium concentration is high, sodium ions tend to become adsorbed onto the soil particles, displacing Mg^{++} and Ca^{++} ions. The exchange of Na^{+} for Ca^{++} and Mg^{++} results in a soil with poor internal drainage and restricted circulation of air and water when wet. Such soils usually form hard and unmanageable clods when dry. S.A.R. is defined as

$$\text{S.A.R.} = \frac{Na^{+}}{\sqrt{(Ca^{++} + Mg^{++})/2}} \quad \text{(Todd 1959)}$$

where Na^{+}, Ca^{++} and Mg^{++} are the concentration of these cations in meq/l.

The electrical conductivity and sodium adsorption ratios of the secondary and tertiary-treated sewage water and brackish water are plotted in Fig. 1 as suggested by the U.S. Salinity Laboratory Staff (1954). Most samples of effluent E-2 (secondary treatment) are located in the C_4–S_2 class, the samples of effluent E-3 (tertiary treatment) under C_4–S_1 class, while samples of brackish water are located in the extreme end of the C_4–S_2 class. According to the U.S. Salinity Laboratory scale, C_4 is considered very highly saline water and is not suitable for irrigation under ordinary conditions. S_2 corresponds to medium-sodium water and will present appreciable sodium hazard in fine textured soils. The effluent from tertiary treatment has a low concentration of sodium, and can be used for irrigation on almost any soil. Sewage water is lower in total dissolved solids (T.D.S.) than brackish water.

ADJUSTED S.A.R.

The older S.A.R. procedure is modified to include changes in soil water consumption that are expected to result from certain combinations of salts. Adjusted S.A.R. is calculated using the equation below.

$$\text{Adjusted S.A.R.} = \frac{Na^{+}}{\sqrt{(Ca^{++} + Mg^{++})/2}} \{1 + (8{\cdot}4 - \text{pHc})\} \quad \text{(FAO 1976)}$$

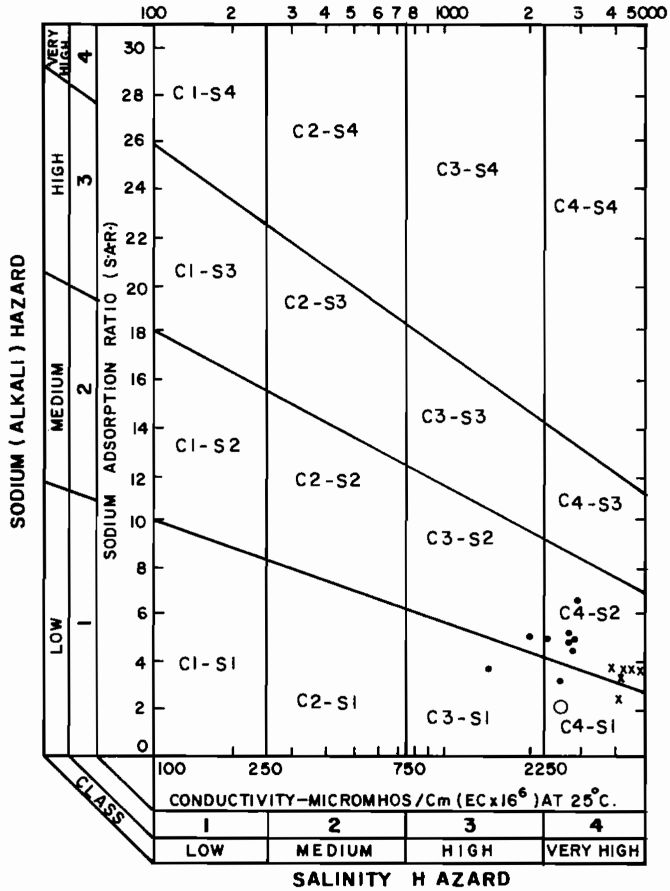

Fig. 1. Evaluation of secondary and tertiary-treated sewage water and brackish water (after the U.S. Salinity Laboratory Staff 1954). (●) Effluent E-2 (secondary treatment). (○) Effluent E-3 (tertiary treatment). (x) Brackish water.

where pHc = P(Ca + Mg + Na) + P(Ca + Mg) + P(CO_3 + HCO_3). This formula predicts the potential for a soil's permeability. Adjusted S.A.R. for effluent (E-2) ranges between 9·69 and 17·58, for effluent (E-3) is 5·7 and for brackish water from 5·23 to 9·76. According to the recommended values of FAO (1976), using an irrigation water with such high values will increase the problems of permeability with time. Nevertheless, although the adjusted S.A.R. for effluent of secondary treatment and brackish water is higher than the recommended values, in Kuwait such waters have been used successfully in irrigation, and have created no sodium hazard due to the sandy nature of the soil.

BORON CONCENTRATION

Boron is toxic at high concentrations. Scofield (1935) proposed the limits of boron concentration shown in Table 4.

The range of concentration of boron in effluent E-2 is 1·2 to 1·8 mg/l which places it on the border of class 4 and class 5 for semi-sensitive crops, in class 3 for semi-

Table 4. The permissible limits of boron for several classes of irrigation water

Boron class	Semi-semisitive crops (ppm)	Semi-tolerant crops (ppm)	Tolerant crops (ppm)
1	< 0·33	< 0·67	< 1·00
2	0·33–0·67	0·67–1·33	1·00–2·00
3	0·67–1·00	1·33–2·00	2·00–3·00
4	1·00–1·25	2·00–2·50	3·00–3·75
5	> 1·25	> 2·50	> 3·75

tolerant crops and in class 2 for tolerant crops. Effluent E-3 has boron concentrations of 1·27 mg/l, rating it in class 5 for semi-sensitive crops, class 2 for semi-tolerant crops and class 2 for tolerant crops. However, brackish water has a concentration of 1·52 mg/l, which makes it unsuitable for semi-sensitive crops. It is clear that the boron concentration of effluent sewage water and brackish water does not exceed the permissible limits of boron recommended for semi-tolerant and tolerant crops, but exceeds that for semi-sensitive crops. It is therefore suggested that it should be used carefully with such crops. Boron at concentrations > 0·5 mg/l is toxic to citrus and deciduous fruits, although concentrations < 2 mg/l are generally satisfactory for most crops (Mara 1978).

TRACE ELEMENTS

Irrigation water must not contain compounds toxic to the crop under cultivation. Trace elements causing growth reduction include copper, zinc, cadmium, lead, and nickel. These were determined for raw sewage, second-stage effluent, third-stage effluent and brackish water. Results are shown in Tables 2 and 3. Concentrations of trace elements in brackish water are slightly higher than those of sewage water, because sewage is mainly domestic and the original water supply comprises a mixture of brackish and fresh water. However, the concentration of trace elements of both sewage and brackish water is found to be lower than the recommended maximum concentration for irrigation water (FAO 1976). These levels will normally not have adverse effects on plant or soil. This is also indicated by the fact that these waters have been used successfully in Kuwait.

CONCLUSION

Treated sewage water and brackish water are considered a prime source for irrigation. Daily consumption of brackish water for irrigation and domestic purposes ranges between $5{\cdot}2 \times 10^4$ and $2{\cdot}04 \times 10^{-5}$ m^3/day and about 50,000 m^3/day of effluent from secondary treatment is used to irrigate an area of 10 km^2.

Secondary-treated sewage and brackish waters are considered highly saline on the basis of total dissolved solids and are not suitable for irrigation under ordinary conditions. These waters may also be described as 'medium sodium' and will develop an appreciable sodium hazard in fine textured soil. Secondary-treated sewage water appears to be lower in total dissolved solids than brackish water. The boron concentration in brackish water is slightly higher than that in sewage water. It would not cause a toxicity problem if a suitable selection of crops was made.

Trace element concentrations of treated sewage water are lower than those of brackish water, and the concentrations in both waters are below the recommended maximum limits.

Although brackish water is considered to be more or less on the same level of chemical quality as secondary-treated sewage water, it should be preferable to sewage water since it constitutes a much smaller potential health hazard. Second stage effluents should never be used to irrigate those crops which are eaten raw, due to health risk.

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التقييم الكيميائي لمياه المجاري المعالجة والمياه الجوفية قليلة الملوحة لاستخدامها في الزراعة

فوزية الرويح
قسم الجيولوجيا بجامعة الكويت

خلاصة

في هذا البحث تم اجراء تقييم كيميائي لمياه المجاري المعالجة من منطقة العارضية والمياه قليلة الملوحة من حقلين للمياه الجوفية ، وذلك لمعرفة مدى صلاحية كل منهما للاستخدام في الزراعة . وقد تضمن البحث تعيين مجموعة الكاتيونات ومجموعة الأنيونات وعنصر البورون وبعض العناصر النادرة .

إن تقييم صلاحية الماء للزراعة يعتمد على عدة معايير منها : خطر الملوحة ، ونسبة ادمصاص الصوديوم وتركيز البورون ، إلى جانب بعض العناصر الأخرى كالنحاس ، والنيكل ، والكادميوم ، والرصاص ، والزنك . لقد حللت كل هذه العناصر كيميائيا .

وقد ظهر ان مياه المجاري المعالجة أقل ملوحة من المياه الجوفية قليلة الملوحة . إلا أن كلا النوعين من المياه قد صنفا بأنهما من نوعية متدنية جدا .

إن الاستخدام المتواصل لهذه المياه في الري يسبب مشاكل تتعلق بمسامية الطبقة تحت السطحية من التربة . ومع ان مياه المجاري المعالجة والمياه قليلة الملوحة قد صنفتا بأنهما مياه ذات تركيزات متوسطة من الصوديوم ، مما يسبب مشاكل للتربة ذات النسيج الدقيق ، إلا أنهما قد استخدمتا بنجاح في الكويت وذلك لطبيعة التربة الرملية . وعلى الرغم من أن مياه المجاري التي خضعت للمعالجة الثلاثية تعتبر مياها ذات ملوحة عالية جدا ، فأنه يمكن استخدامها في ري جميع أنواع التربة ، نظرا لانخفاض تركيز الصوديوم بها .

يتراوح تركيز عنصر البورون في مياه المجاري المعالجة بين ١,٢ و ١,٨ ملجم في اللتر ، بينما تركيزه في المياه قليلة الملوحة ١,٥ ملجم في اللتر ، وهذه التركيزات لا تتجاوز الحد المسموح به لزراعة المحاصيل عالية التحمل ومتوسطة التحمل ، كما يمكن بشيء من الحرص استخدام هذه المياه لري المحاصيل نصف الحساسة . إن تركيز العناصر النادرة في كلا النوعين من المياه منخفض بالدرجة التي تسمح باستعمالها في الزراعة ، كما أن تركيز هذه العناصر في مياه المجاري المعالجة أقل منه في المياه قليلة الملوحة .