WASTEWATER IRRIGATION AND PHYSICO-CHEMICAL CHANGES IN SOILS

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ABSTRACT

Available information on chemical and physical characteristics of Saudi Arabia's wastewaters are reviewed. Data on wastewater characteristics are limited and, for the most part, are fragmented. The wastewater in Saudi Arabia contains high salt and sodium concentrations. The effects of salts, sodium, bicarbonate, and chloride concentrations in wastewaters on physical and chemical properties of wastewater-irrigated soils are discussed. The influence of organic matter on physical soil characteristics of soils is also evaluated. Phyto toxic metals are present in wastewater. Interactions of such metals in soils and the effects of wastewater composition on the mobility and plant availability of metals are discussed. Probable threats of groundwater contamination from wastewater irrigation under Saudi conditions are also explained.

KEYWORDS

Wastewater, salinity, groundwater contamination, sodium hazards, SAR, irrigation, and permeability.

INTRODUCTION

Water demands for the agricultural sector in Saudi Arabia have increased from 1.75 billion m^3 in 1975 (Ministry of Planning, 1985) to 22.93 billion m^3 in 1992 (Dabbagh and Aberrahman, in press) — an increase of over 13 fold. More than 80% of the agricultural demand is satisfied from non-renewable groundwater resources. To sustain agricultural growth, one has to find alternative irrigation water sources. One of the potential alternative water source for supplemental irrigation, which also increased from 0.1 to 0.5 billion m^3 in the same period (Al-Ibrahim, 1990), is treated wastewater. Because of the growth of wastewater treatment plants, a large quantity of wastewater is now available for irrigation. For example, according to an estimate (Ar-Riyadh Region Water and Sewage Authority, 1991), about 100 million m^3 of wastewater is available in Riyadh City alone.

A brief summary of municipal wastewater quantities available for irrigation in Saudi Arabia is given in Table 1. The use of treated municipal wastewater in agriculture has gradually been increasing (Al-Jaloud et al. 1995, 1993). The objectives of this paper are to review chemical characteristics of Saudi wastewaters, identify problems associated with high salts and sodium concentrations in wastewater, discuss metal uptake by plants, and investigate nutrient supply from treated municipal wastewaters in Saudi Arabia.

Table 1. Quantities of wastewater produced in Saudi Arabia.

City	Quantity (m^3 day^{-1})	Reference
Riyadh	420000	Riyadh SADA (1993)
Jeddah	668000	
Buraidha	10000	
Uniazh	7000	
Al-Hassa	293782	HIDA (1978)
Dammam	187143	Al-Elaiw et al. (1994)
Al-Khobar	96000	Al-Elaiw et al. (1994)
Al-Qatif	29571	Al-Elaiw et al. (1994)
Saihat	15717	Bader (1994)
Safwa	8021	Bader (1994)
Jubail	12639	Bader (1994)
Hufuf areas	104907	Bader (1994)
Al-Khafji	2963	Bader (1994)

CHEMICAL COMPOSITION OF SAUDI WASTEWATERS

Total dissolved salts, sodium, calcium, magnesium, chloride, sulfate, phosphates, nitrogen, organic carbon, and bicarbonate are major components of Saudi wastewaters. Information on these parameters were collected and are summarized in Table 2. It is obvious that even concentrations data for major ions in Saudi wastewaters are limited. Data were available for Riyadh, Dammam, Al-Khobar, Jubail, and Al-Hassa wastewater treatment plants. Except for the Riyadh wastewater treatment plant, the data in Table 2 represent a few samples only and may not be representative of the quality of wastewater around the year. Information regarding chemical characteristics of wastewaters in other cities were not available. Most of the data sets are old (although some have been re-published recently). For any planning for the reuse of wastewater in Saudi Arabia, one should collect new scientifically sound data on the wastewater quality.

Another important aspect of wastewater quality is the presence of trace metals, many of which are toxic to plants and humans. Efforts were made to collect available data on concentrations of trace metals in Saudi wastewaters. The collected data are summarized in Table 3. Like data on major elements, data on trace metal concentrations in wastewater are also limited. Moreover, quality of the data in several cases is questionable. The number of wastewater samples analyzed to collect these data are unknown.

Table 2. Concentrations of major elements in Saudi wastewaters. All concentrations are in mg/l except pH, which is unitless.

Parameters	[1]Wadi Hanifa	[2]Riyadh	[3]Wadi Hanifa	[4]Dammam	[5]Dhahran	[6]Al-Khobar	[7]Al-Hassa	[8]Jubail
Wastewater pH	7.5-7.8	7.3	7.2-8.4	6.2-7.7	7.2	7.4-8.7	7.5	6.6-7.1
Total dissolved solids	992-3982		973-2650	2560-6800	1955	3411-3857	2169-2438	530-795
Calcium	149-373	128	160-369					
Magnesium	52-110	28	39-116					
Sodium	149-639	140	155-533					
Potassium	5-16	15.1	7-17					
Bicarbonates	185-268	195.2	156-239					
Chloride	196-605	168	160-1775	1250-2400		1254-1694	869-1059	128-152
Sulfate	325-840	326				531-750		50-90
Ammonia		20.7	0.1-13	0-2.7			41	0-1
Total Kjeldahl nitrogen				0.-13.3	3.0-3.6	1.8-11.1		
Total organic carbon						5.5-47		
Phosphorus		7.0	0.1-12	5-21	2.5	1-3.9	18.9	

1 Wastewater samples from Wadi Hanifa (Jaloud et al., 1995)
2 Riyadh treated municipal wastewater (Jaloud 1994)
3 Wadi Hanifah Wastewater stream (Siddique and Al-Harbi, 1995)
4 Dammam Sewage Treatment Plant (Farooq, 1994)
5 Saudi Aramco, Dhahran Sewage Treatment Plant (Farooq, 1994)
6 Al Khobar Sewage Treatment Plant (Farooq, 1994)
7 Al-Hassa Wastewater Treatment Plant (Abderrahman and Shahlam (1991)
8 Wastewater Treatment Plant, Industrial City of Jubail (Abuhaimid, 1994)

EFFECTS OF TOTAL SALTS, SODIUM, AND CHLORIDE IN WASTEWATERS ON SOIL PROPERTIES

Total dissolved salts in the wastewater ranged from 530 to 3982 mg/l (Table 2). The lowest salts concentrations were found in the tertiary treated industrial effluent in the Jubail Industrial City. Because of the use of saline groundwater (Sadiq and Hussain, in press), Saudi wastewaters contained relatively higher salts concentrations in the world. Therefore, in Saudi Arabia, the primary factor in evaluating wastewater quality for agricultural applications is the quantity and kind of salt present in these waters. In general, the following guidelines are suggested for wastewater irrigation systems:

Salt Concentration (mg l)	*Comments*
<500	No salt injury to any types of crops, even salt sensitive crops can be irrigated.
500-1000	Sensitive crops may show slight salt injury problems.
1000-2000	Moderate problems with salt sensitive crops, slight to moderate problems with semi salt tolerant crops, and slight problems with salt resistance crops.
>2000	Very severe problems with salt sensitive crops, severe problems with semi salt tolerant crops, and moderate to severe problems with salt resistant crops.

Table 2 shows that salt concentrations in Saudi wastewaters are high enough to cause at least moderate to severe salt injury to semi-salt tolerant crops. The salt sensitive crops should not be grown if the source of irrigation is treated wastewater.

Since wastewaters contain high concentrations of salts, irrigation of crops with Saudi Wastewater will increase salt concentrations in soils. This is demonstrated by plotting data from Al-Jould et al. (1995) in Fig. 1. In this experiment, maize and sorghum crops were irrigated with wastewater of different salinities (expressed in terms of EC). It is obvious that with the increase in irrigation water salinity, salt concentrations in the saturated paste extract of soils from maize and sorghum pots also increased.

Salts are gradually added to the soil irrigated with wastewater. A problem of salts build-up should be expected if the quantity of salts added is higher than the quantity of salt removed from the soil. Therefore, the rate of salt accumulation in a soil profile depends on the rate of salt addition and removal. For the sustainability of agricultural sector over an extended period, the salts inputs must be equal or lower than the salts removal. One of the most practical and commonly used practices is to apply more wastewater than the crop requirements. This will assure that salts are being removed out of the plant root zone.

In addition to providing extra wastewater for leaching of salts, other management practices may have to be adopted to minimize salt accumulation in wastewater-irrigated soils. During periods with no crops cover on the fields, salts may be transported under capillary force from groundwater to the surface soil where these may form a crust. In such situations, the soil will become saline and salt concentrations may increase to levels sufficiently high for rendering such soils unfit for growing normal agricultural crops. The problem of salt injury to plants can be minimized by providing sufficient leaching water and by discouraging capillary formation in the surface soil layer.

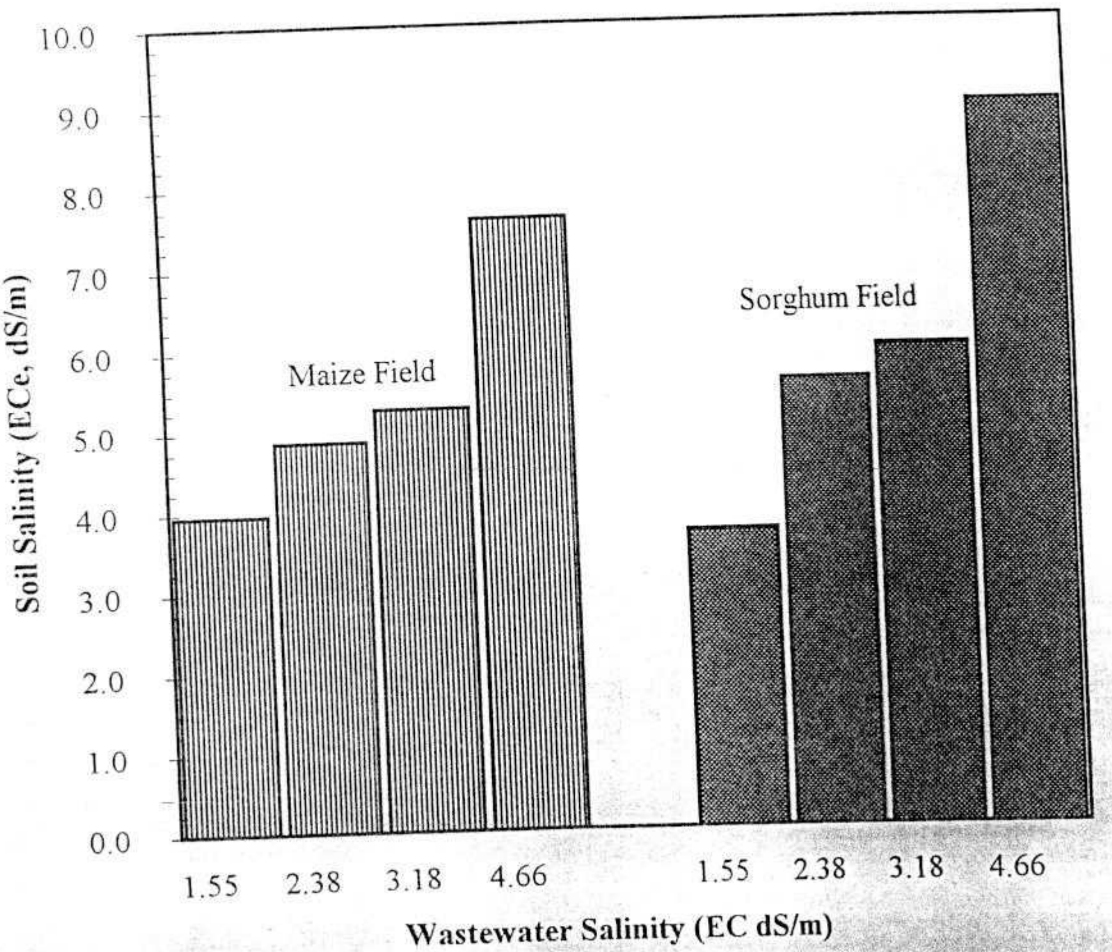

Fig. 1. Effect of wastewater salinity on salinity in soils cultivated with maize and sorghum.

Another concern of wastewater irrigation in Saudi Arabia is the high concentrations of sodium. The effect of sodium can be direct (plant accumulation) or indirect (nutritional imbalances and deterioration of soil physical properties). Sodium at very high concentrations in wastewater may induce toxicity to growing plants. Irrigation with waters containing sodium higher than 70 mg/l in wastewater, using a sprinkler system, may result in moderate sodium toxicity problems to the growing crops. Here, we are not concerned with the plant toxicity of sodium, but its deleterious effects on soil physical properties.

Sodium, if present in high proportion or concentrations in wastewater to be used for irrigation, can replace calcium from soil colloids, especially in clay minerals. During wetting and drying, the changes in sodium ion size exert pressure on the clay crystal, which as a result may ultimately break up. Breaking of clay structures deteriorates soil structure, water permeability, and aeration of sodium affected soils. Table 2 shows that Saudi wastewaters contain substantial quantities of sodium, therefore, one should expect an adverse effect on soil texture, permeability, and aeration. As stated above, the adverse effects of sodium are exhibited due to the breakdown of clay lattices, therefore, deleterious effects of sodium will be more pronounced in clayey soils and will decrease as sand content in soil increases.

In soils, it is not total sodium concentrations but sodium adsorption ratio (SAR) which is commonly used to assess deleterious effects of sodium on soil and crops. Wherever possible, we calculated SAR from the data in Table 1 by using the following formula:

$$\text{Sodium (meq/l)} / [0.5\{\text{calcium (meq/l)} + \text{magnesium (meq/l)}\}]^{0.5}$$

The values of SAR varied between 3 to 8 for Wadi Hanifa wastewater. One should expect even higher values in the Eastern Province because of high salinity of groundwater (Sadiq and Hussain, in press). However, in the western areas where groundwater is less saline, the values of SAR should be even smaller. The salinity of wastewater also affect soil SAR values. In an experiment, Al-Jaloud et al. (1995) determined chemical properties of soils under wastewater irrigation. Their data are plotted in Fig. 2. This figure shows that, in both maize and sorghum fields, wastewater salinity increased soil SAR, and the increase was more pronounced in treatments receiving the highest salinity wastewater.

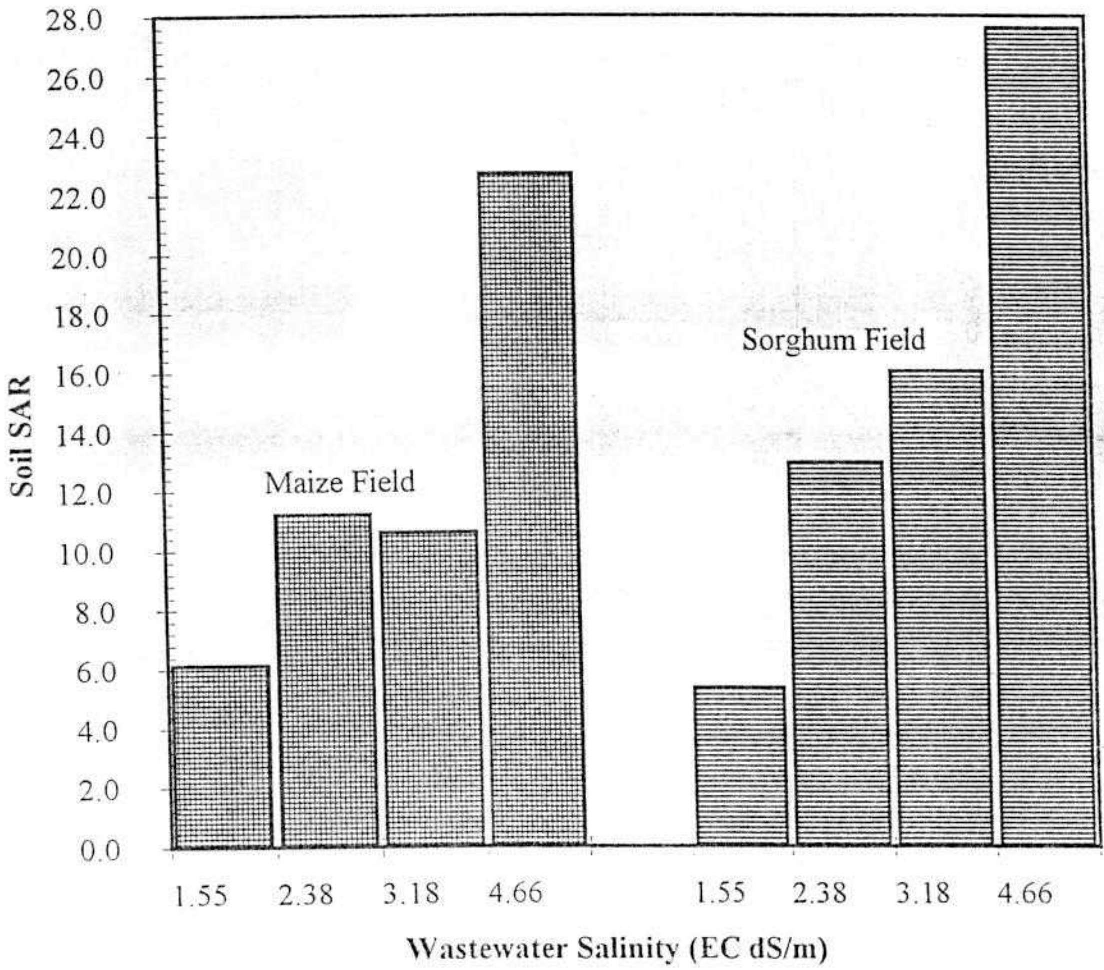

Fig. 2. Effect of wastewater salinity on soil SAR in maize and sorghum experimental plots.

As mentioned above, use of high SAR irrigation water may deteriorate soil texture and adversely affect soil permeability. We have developed a generalized diagram as an aid for assessing permeability problems in saline soils (Fig. 3). It appears that irrigation with recycled water from Riyadh and western region wastewater treatment plants should not develop a soil permeability problem. However, the quality of wastewater in the Eastern Province should further be evaluated.

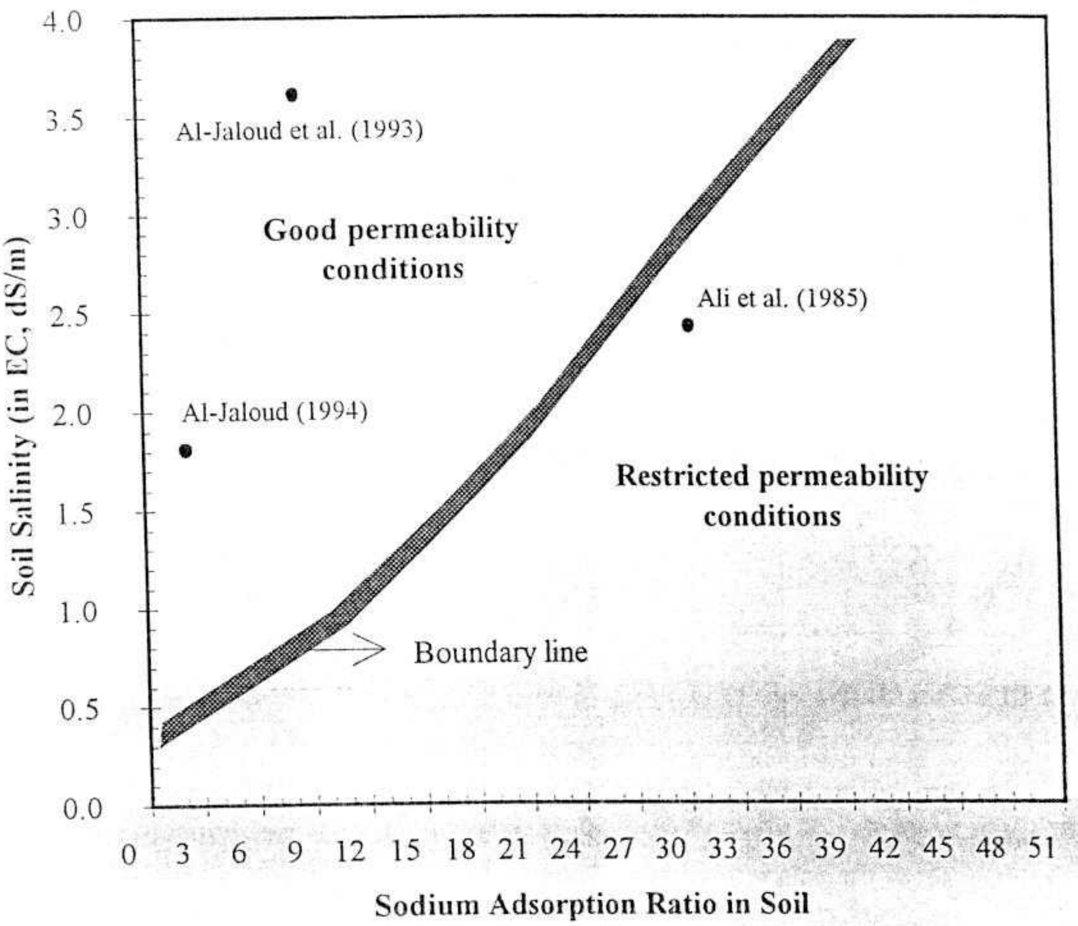

Fig. 3. Salinity and SAR boundary for predicting soil permeability conditions.

Calcium in wastewater and soil solution may chemically react with bicarbonate ions and form insoluble calcium carbonate minerals, such as calcite. If this reaction takes place, the value of SAR will increase further due to a decrease in calcium concentrations in the wastewater or soil solution. It has been recommended that the effect of bicarbonate ions in wastewater should be considered in evaluating sodium hazards of wastewater (Oster and Rhoades, 1985). The SAR which is adjusted for bicarbonates concentrations is referred to as adjusted SAR or adj. SAR, and is calculated as follows:

$$\text{adj. SAR} = \text{SAR}\,[1 + (8.4 - pH_c)]$$

and

$$pH_c = [pK + pK_{calcite}] + p[\text{Calcium} + \text{Magnesium}] + p[\text{Bicarbonate}]$$

where p refers to the negative logarithm, K is the second dissociation solubility constant for carbonic acid and its value is $10^{-10.3}$, $K_{calcite}$ is the equilibrium constant for calcite solubility, and concentrations of calcium, magnesium, and bicarbonate are to be in meq/l. Unfortunately, the available data are not enough from which to calculate adj. SAR for the Saudi wastewater.

Chloride can cause specific injury (leaf burn, chlorosis, twig dieback, etc.) in woody plants, but it is not toxic to vegetables and grain crops. However, chloride is known to form complexes with metals such as aluminum, lead, cadmium, calcium, etc. (Sadiq, 1992), and improves mobility of these metals in soil profile. Therefore, the potential for metal contamination of underlying groundwater is enhanced when the surface soil is irrigated with saline wastewater containing high concentrations of chloride.

Bicarbonate affects iron nutrition of crops and physical properties of soils through its effect on soil pH and calcium precipitation. Calcium precipitation reduces its concentrations in soil solution and thus increases SAR values. This increase in SAR causes sodium hazards to become more severe. The effects of high SAR have been discussed above. Table 2 shows that wastewaters in Saudi Arabia contain substantial quantities of bicarbonate and, therefore, that factor should be considered in quality evaluation of wastewaters for irrigation purposes. The following guidelines for bicarbonate concentrations in wastewater for sprinkle irrigation systems are suggested (Westcot and Ayers, 1985):

Bicarbonate concentration (mg/l)	*Degree of restriction on the use*
<90	None
90-500	Slight to moderate
>500	Severe

EFFECTS OF NUTRIENTS ON SOIL PROPERTIES

Irrigation with wastewater has some beneficial effects for crops and soils. Like other part of the world, Saudi wastewaters contain plant nutrients (Tables 2 and 3), such as phosphorus, nitrogen, and trace elements (iron, manganese, copper, and zinc). Many reports show that plant yield has increased with the application of wastewater (Ali et al., 1985; Al-Jaloud et al. 1995; 1993; 1992). As an example, the data from Ali et al. (1985) are shown in Fig. 4.

Nutrients in wastewater have no direct bearing on the physical properties of soils. However, nutrients can influence soil properties indirectly, such as by producing organic matter which may act as a cementing agent and, thus improve soil structure.

EFFECTS OF ORGANIC MATTER ON SOIL PROPERTIES

Organic matter is known for its cementing effects in soils and thus improves soil structure and permeability. Except for the Saudi Aramco wastewater treatment plant at Dhahran, no information on organic carbon concentrations in wastewater was available. It is, therefore, not possible to comment completely on the role of organic matter in Saudi wastewaters on soil properties.

EFFECTS OF TRACE METALS ON SOIL PROPERTIES

The available data on trace metals concentrations in Saudi wastewater are summarized in Table 3. Concentrations of trace metals in all wastewaters were below the guidelines recommended for wastewater if it has to be used for irrigation. Some studies have been

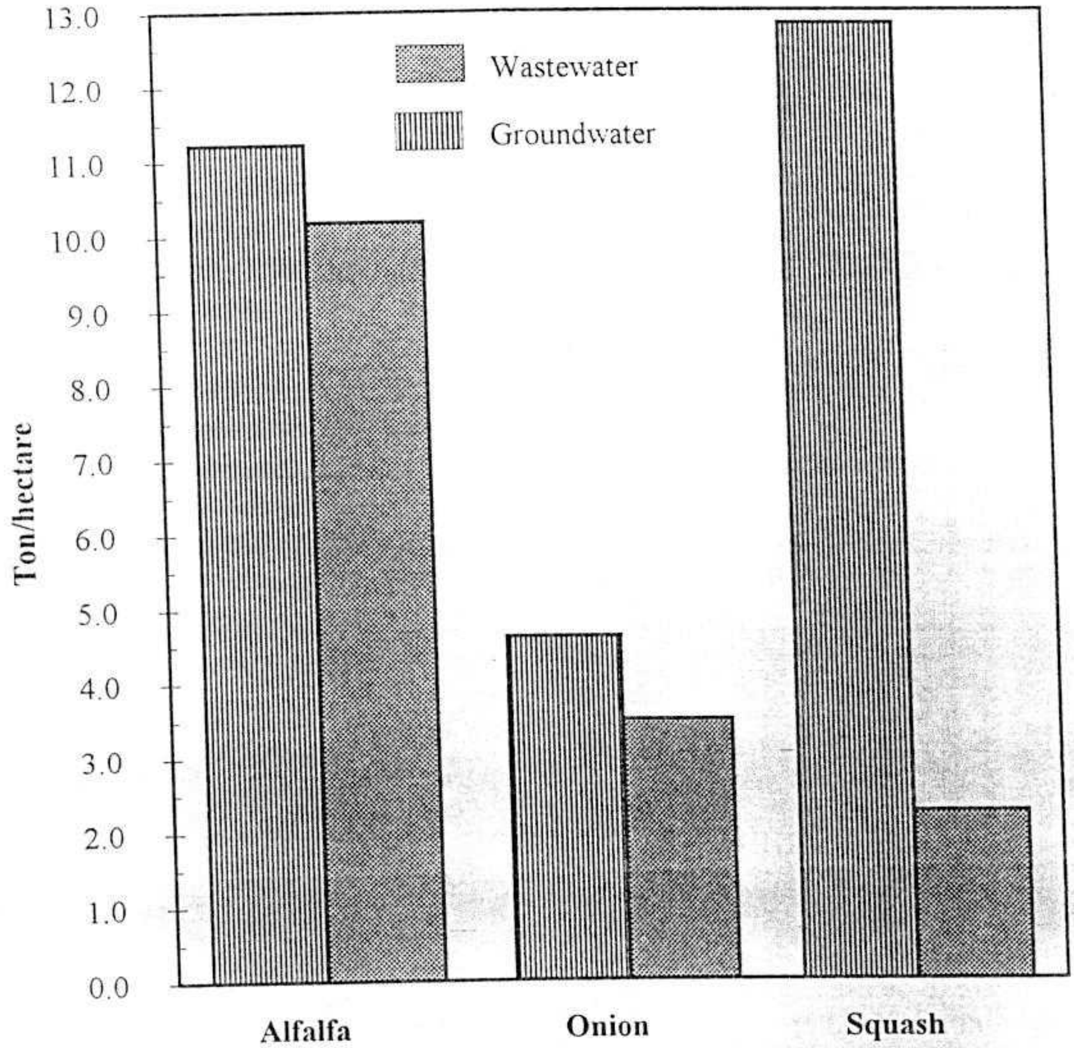

Fig. 4. Effect of wastewater irrigation on crop yields (on a fresh weight basis).

conducted in Saudi Arabia which show that crop plants did not accumulate trace metals when irrigated with wastewater. For example, Al-Jaloud et al. (1995) concluded from the results of a pot experiment that the use of treated municipal wastewater from Riyadh treatment plant did not increase metal concentrations in sorghum, corn, and soil. However, accumulation of metals in soils and plants from wastewater applications cannot be effectively evaluated from experiments of such a short duration.

Irrespective of trace metal concentrations in wastewater and their accumulation in plants, irrigation with wastewater is bound to increase metal concentrations in soils. Most of the trace metals become immobile in the soil profile and are not available to plants. These metals remain in soils almost forever. The use of wastewater for irrigation is relatively new in Saudi Arabia. It is, therefore, not possible to evaluate the impact of Saudi wastewaters on soil properties.

Table 3. Concentrations of trace metals (mg/l) in municipal wastewaters.

Metals	Wadi Hanifa[1]	Dammam[2]	Al-Khobar[2]	Qatif[2]	Permissible limits for Irrigation[3]
Aluminum		0.1	0.05	0.05	5.0
Copper	0.07	0.03	0.02	0.02	0.2
Arsenic		0.01	0.01	0.01	0.1
Iron	0.16	0.33	0.13	0.19	5.0
Manganese	0.01	0.02	0.02	0.02	0.2
Cadmium	bd	0.01	0.02	0.03	0.01
Mercury		0.02	0.02	0.01	0.01
Chromium	bd	0.05	0.05	0.05	0.1
Nickel	bd	0.02	0.02	0.02	0.2
Lead	bd	0.02	0.02	0.02	5.0
Zinc	0.05	0.13	0.08	0.04	2.0

1 Data taken from Al-Jaloud et al. (1995).
2 Data taken from Al-Elaiw et al. (1994).
3 Data taken from Westcot and Ayers (1985)
bd Below detection limit of the analytical method

WASTEWATER IRRIGATION AND GROUNDWATER CONTAMINATION

Table 2 shows that Saudi wastewaters are generally saline. Similarly, it has been reported that groundwaters in Saudi Arabia are also saline (Sadiq and Hussain, in press). If these waters are to be used for irrigation, a certain additional amount of water has to be applied to prevent salt build up or to leach already existing salts from the root zone. This means that there will always be surplus water to percolate through the soil profile and that water will ultimately join aquifers. Thus, groundwater can be contaminated if the irrigation wastewater contains pollutants. There are many reports showing groundwater contamination from irrigation (Benoit, 1973; NRC, 1986; Sadiq and Alam, in press. Yusop et al. 1984). Sadiq and Alam (this proceeding) suspect that irrigation with treated wastewater was one of the factors responsible for elevated concentrations of lead, iron, copper, and zinc in a shallow aquifer in the Jubail Industrial City. Contamination of deeper aquifers by the irrigation water may require several years. It is early, and data are also lacking, to investigate the influence of wastewater irrigation on deep aquifers.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the foregoing, the following is concluded:

- Data on wastewater characteristics are limited and, for the most part. are fragmented. Most of the available data are related to Riyadh City. A comprehensive study on wastewater characterization in all major Saudi cities should be carried out. The characterization effort should includ determination of trace metals in addition to the traditional parameters.

- Because of high salt concentrations in groundwater, the wastewater in Saudi Arabia is also saline. Such waters can be successfully used if appropriate cultural practices are adopted. There are several options available to chose from.

- The wastewater in Saudi Arabia contains high salt and sodium concentrations. Therefore, particular attention should be paid to these parameters and their influence on soil structure when deciding on the use of wastewater for irrigation.

- It is expected that wastewater will be less saline in the regions where groundwater is of good quality. The use of wastewater for irrigation in these regions should be encouraged.

- Comprehensive research studies should be conducted on government agricultural farms in each region to investigate interaction between wastewater irrigation and soil properties, and the effect of such irrigation on produce quality.

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