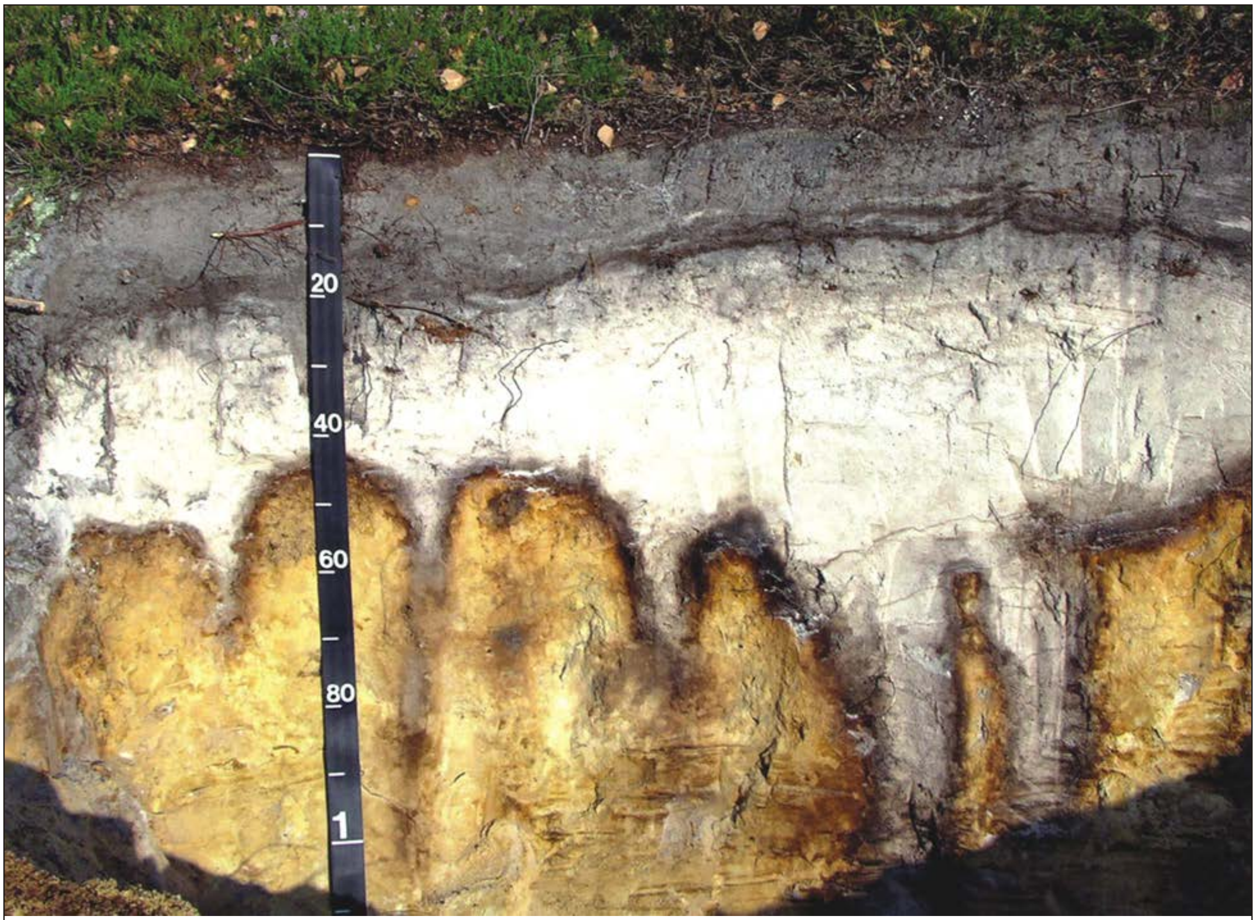

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Irrigation Water Quality Evaluation of Al-Mendasah Groundwater and Drainage Water, Al-Madenah Al-Monawarah Region, Saudi Arabia

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Abstract: Groundwater and drainage water samples were collected from Al-Mendasah area, North-West of Al-Madinah Al-Munawarrah for irrigation water quality evaluation. The well waters were classified as C4S2 to C4S4 waters i.e., very high salinity and medium sodium to severely saline and very high sodium waters. The drainage waters were classified as C3S2 to C4S3 i.e., high salinity and medium sodium to severely saline and high sodium waters. The groundwater is dominated by Na and Cl ions. The Saturation Indices (SI) showed that the groundwater is unsaturated with respect to anhydrite, halite, gypsum and fluorite; and saturated with respect to calcite and dolomite. The concentration of calcium is much higher than that of Mg. The nitrate contents are much higher than the recommended safe limits of 30 mg L^{-1} for drinking and other uses. The fluorite (F) concentration in 40% of well waters was higher than the recommended safe limits for drinking water. The strong correlation between SAR vs. adj. SAR and adj. R_{Na}, Na vs. Cl, Mg vs. Cl and Mg vs. SO_4 ions indicate the dissolution and precipitation reactions in the rock-water interface that affect groundwater chemistry. The soil infiltration rate will not be affected either by well water or drainage water irrigation. Only, 12% well waters are safe for irrigation directly without serious soil and crop production problems. The use of remaining 78% well waters requires the adoption of certain management practices such as adequate drainage, selection of salt tolerant crops and application of leaching requirements.

Key words: Water salinity, saturation indices, nitrate, fluorite, chloride, ion relationship, soil infiltration rate, management practices

INTRODUCTION

Rapid growth in urban and rural sectors not only increased the demand for water consumption but also caused significant increases in wastewater production (Anonymous, 1992). Wastewaters contain organic and inorganic pollutants. Its land disposal can influence the groundwater quality thus rendering it unfit for irrigation and other uses.

Saudi Arabia is an arid country with a total land area of 2.253×10^6 km^2. The total cropped area in the Kingdom has increased from 1.25 million ha in 1988 to 1.59 million ha by 1994 (Anonymous, 1992). As a result, the demand for irrigation water increased from 1.75 billion

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m^3 in 1975 to 22.93 billion m^3 in 1992 (Dabbagh and Abderrahman, 1997). Currently, more than 80% of water demand in agriculture sector is met from non-renewable groundwater sources (Anonymous, 1992).

To meet the growing demand for water in agriculture sector and to augment the existing irrigation supplies, evaluation of groundwater and drainage water quality is important. For example, from Capital City Riyadh about 100 million m^3 is discharged in Wadi Hanifah annually (Al-Degaither, 1992). Another 11.64 million m^3 per annum of drainage water in Al-Ahsa Oasis (Anonumous, 1984) is being disposed off in the open lakes, which can contaminate the groundwater easily due to sandy nature of the soil. In the study area more than 2 million m^3 $year^{-1}$ of treated and untreated sewage water is discharged in Wadi Al-Aqiaq.

Presently, there is a lot of awareness regarding groundwater pollution and environmental health hazards that may result from the use of treated and untreated wastewater. Thus, there is a growing concern regarding the reuse of wastewater. Presence of certain toxic elements such as Pb, Ni, Cd, Co, Cu, Mo, Hg etc. in the wastewaters may create some environmental problems and needs evaluation prior to its use in agriculture.

In Saudi Arabia, there are a number of sources, which have lead to the degradation of quantity and quality of the groundwater. Over-exploitation and excessive pumping causes salt-water intrusion in coastal areas and brine water transport to the surface deeper formations inland (Abdul-Fattah *et al*., 1978; Al-Ibrahim, 1991). Seepage of sewage from septic tanks and cesspools are responsible for the deterioration of both chemical and biological quality of some well waters (Allael-Din *et al*., 1992). Agricultural related sources such as irrigation water, pesticides, organic and inorganic fertilizers are also another source of groundwater contamination. Numerous severe cases of groundwater contamination have been documented worldwide (Fried, 1975; Jackson, 1980; Chalapati *et al*., 1986).

Allael-Din *et al*. (1992) stated that five percent of the well water samples in 1989 contained high level of nitrate, ammonium and fecal coliform in Saudi Arabia. They also concluded that human and animal wastes are primary continuous sources of pollution in the well water samples tested. Raveendran and Madany (1991) investigated the quality of groundwater and tape water throughout Bahrain. They highlighted the deterioration of groundwater in localized areas with respect to nitrite, nitrate, ammonia and phosphate. The concentration of nitrate (NO_3) ranged from 1.3-23.3 mg L^{-1} as NO_3-N with an average value of 4.4 mg L^{-1}. El-Arabi *et al*. (1997) studied the impacts of sewage-based irrigation on groundwater based on available monitoring data in Egypt. The main objectives of study were:

- To determine the groundwater chemistry of Al-Mendasah area
- To determine wastewater chemistry that is discharged into the Wadi stream
- To classify the groundwater and drainage water for agriculture

MATERIALS AND METHODS

Geomorphology and Geology of the Area

The study area is located in the North-West of Al-Madinah Al-Monawarah in the Arabian Shield and lies between latitude 24°00' and 24°40' N longitude 39° and 39° 20' E (Fig. 1).

Al-Mendasah area is a flat plain where three major wadis converge (Al-Aqiq, Malal and Boat). It is covered by alluvial deposits, belonging to the Quaternary period, which

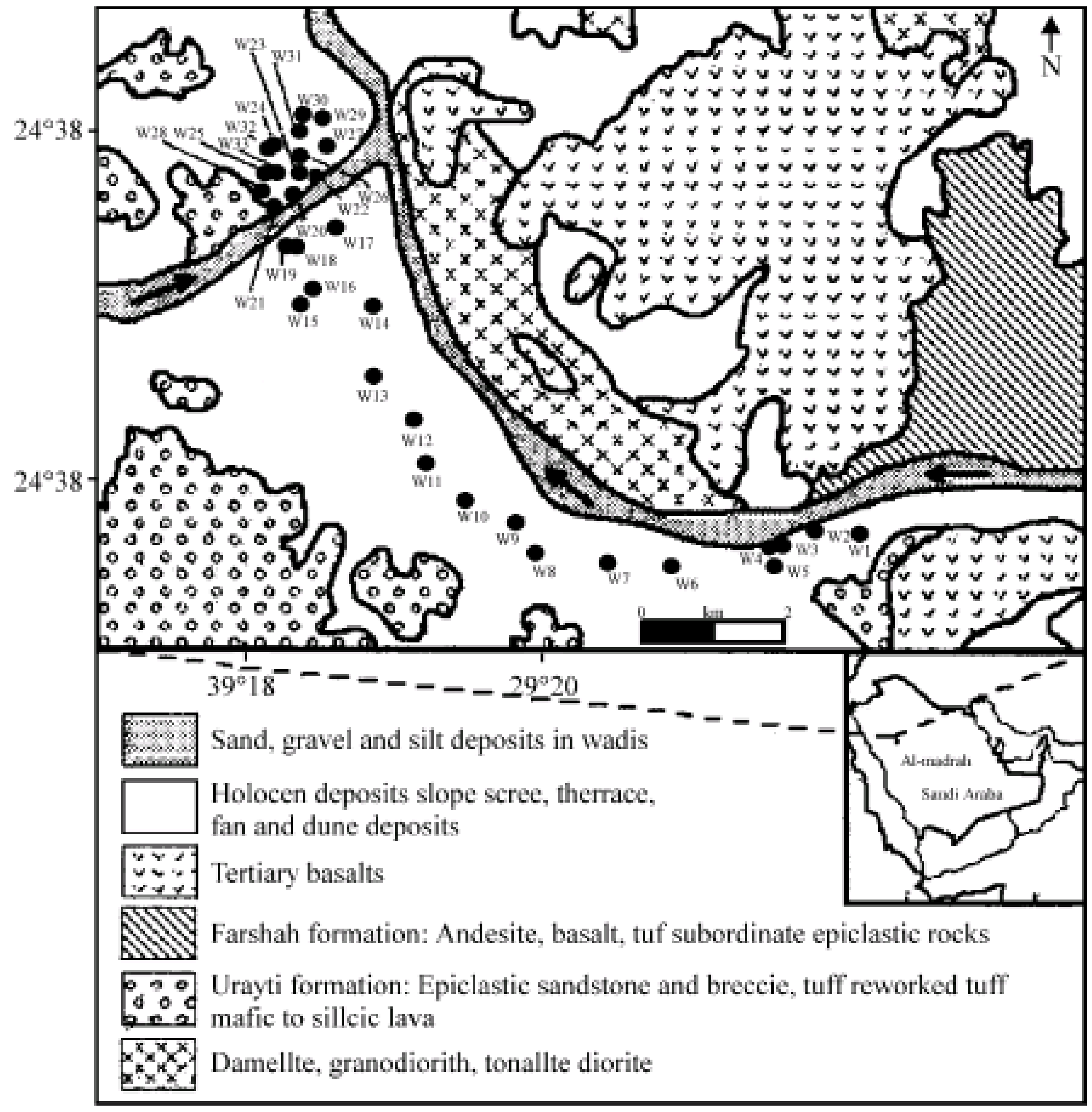

Fig. 1: Geological and sample location map (Pellaton, 1981)

constitutes the principal groundwater aquifer of the area. These deposits are gravel, sand, clay and sabkha deposits.

In the study area, the rocks of Arabian Shield represent the two main groups, Alys group and the overlying Furayh group (Fig. 1). The Alys group consists of intermediate mafic volcanic rocks, epiclastic volcanic rocks and tuff with numerous intercalation of silicic lava. The Furayh group, being an andesitic-basaltic formation, shows sporadic development of conglomerate and sandstone at its base. Non-volcanic terrigenous sedimentary rocks characterize the upper part of the group (Pellaton, 1981).

A total of 33 well water samples were collected from different locations in Al-Mendasah area. The samples location is shown in Fig. 1. One liter of water sample was collected in a sterile plastic bottle, then sealed properly and stored in an ice chest before transferring to the analytical laboratory. The water samples were analyzed for all cations, anions and other anions such as NO_3, PO_4 and fluoride (F) by following procedures given by Richards (1954).

The criteria used to evaluate quality of groundwater for irrigation are:

- Soil Salinity Development (SSD) after irrigation for its negative effects on plant growth according to Ayers and Westcot (1985)
- Sodium Adsorption Ratio (SAR) for its deleterious effect on soil physical properties (Bower *et al*., 1968)
- Residual Sodium Carbonate (RSC) for its effects on final soil water SAR value with the loss or gain in Ca and Mg concentration due to the precipitation or dissolution of alkaline earth carbonates (Bower *et al*., 1968)

- The Toxic effects of specific ions in irrigation water such as Na, Cl and B on plant growth and yield (Eaton, 1942)

In addition to the above water quality indicators for irrigation, some mathematical equations and models were applied to evaluate the data on water quality for its possible use in agriculture. Soil Salinity Development (SSD), adjusted sodium adsorption ratio (adj. SAR), adjusted Na Ratio (adj. R_{Na}) and Exchangeable Sodium Percentage (ESP) were calculated from the analytical data.

The SSD was calculated according to Ayers and Westcot (1985), the adj. SAR was calculated by following the procedure of Ayers and Westcot (1985), the adj.R_{Na} was determined according to Suarez (1981) and the ESP was predicted according to the procedure described by USDA (1954).

The salinity and sodicity hazards of the wastewaters were determined according to the classification given by USDA (1954).

RESULTS AND DISCUSSION

Chemistry of Groundwater

The order of abundance for cations was Na>Ca>Mg and that of anions was $Cl>SO_4>HCO_3$ mg L^{-1} (Table 1). The correlation was highly significant between Na and Cl ions (R^2 = 0.936) as the Na and Cl are the dominant cation and anion, respectively in the groundwater of Al-Mendasah wells. The groundwater of Al-Mendasah wells is mainly Na and Cl type water. A strong relationship existed between SAR and the corresponding calculated adj.SAR and adj. R_{Na} of the groundwater indicating that up to 79% of the total well waters in the study area can create soil sodicity hazard if used for irrigation (Fig. 2).

The groundwater was classified as C4S2 to C4S4 i.e., very high salinity and medium sodium to very high salinity and very high sodium waters according to USDA, 1954 (Fig. 3). Also, the groundwater of the study area can be used for crop irrigation if certain management practices such leaching requirement (depending on the total water salinity and soil type), cultivation of medium to high salt tolerant crops and the improved irrigation systems (drip or subsurface) are adopted.

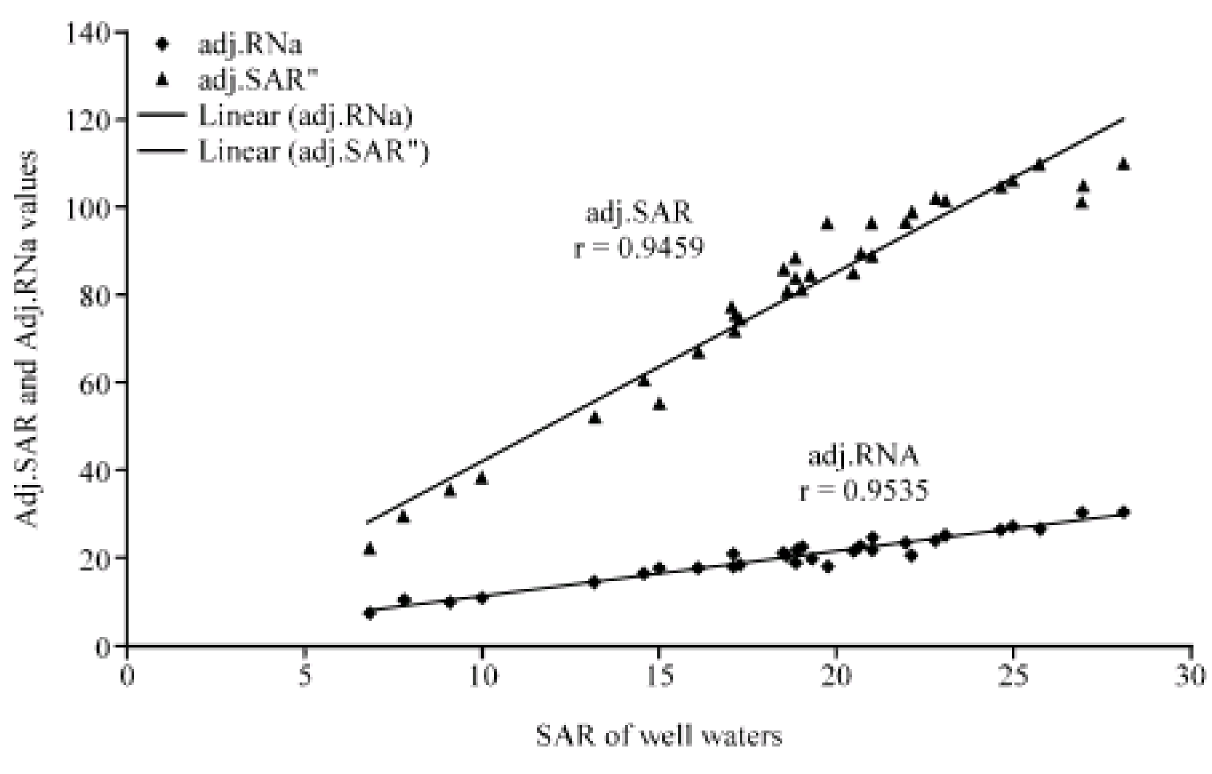

Fig. 2: Relationship between SAR vs. adj.SAR adj.RNa

Table 1: Chemical composition of groundwater (mg L^{-1})

Well No.	pH	TDS	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3	F	NO_3-N
W1	8.1	4510	178	118	1052	11.0	317	2150	683	97	2.20	22
W2	7.9	8210	184	319	1980	18.0	254	3966	1459	106	2.20	24
W3	8.0	10990	348	366	2584	28.0	317	5310	2000	132	2.20	30
W4	8.0	10080	226	309	2536	26.0	234	4916	1766	124	2.10	28
W5	7.9	9750	236	299	2420	28.0	293	4755	1667	127	1.10	29
W6	7.7	12570	611	427	2245	26.0	298	6773	2150	127	2.10	29
W7	8.0	11450	327	478	2765	28.0	268	5495	2010	142	2.10	32
W8	7.8	7720	140	159	2048	19.0	307	4069	1003	64	2.10	15
W9	7.8	9804	290	263	2440	22.0	273	5009	1512	87	2.10	19
W10	7.8	12860	610	426	2761	19.0	229	6184	2595	87	1.90	20
W11	7.7	10240	340	387	2496	26.0	244	5282	1475	72	1.90	16
W12	7.7	8412	341	347	2270	20.8	307	4218	932	81	1.70	21
W13	7.7	9045	520	359	2286	15.0	298	4412	1178	81	1.80	18
W14	7.5	4590	432	80	1136	7.0	83	2368	355	132	0.90	30
W15	7.9	5645	180	80	1728	8.0	171	1994	1478	59	1.10	14
W16	7.3	1816	147	68	398	9.0	146	744	293	55	1.10	11
W17	7.6	6058	257	72	1899	19.0	132	3012	650	62	1.20	14
W18	7.6	7380	438	170	2048	9.2	161	3621	912	66	1.20	15
W19	7.6	3650	384	80	824	6.2	88	1762	428	87	0.71	20
W20	7.6	7890	428	334	1962	16.0	171	3687	1255	71	1.10	16
W21	7.6	5872	432	200	1460	10.0	122	3130	482	64	0.90	15
W22	7.4	14302	1235	490	3243	16.0	215	6702	2334	123	1.20	28
W23	7.4	8260	488	356	2040	11.6	156	4195	988	73	1.00	17
W24	7.9	3290	432	58	648	5.2	185	1433	364	207	0.51	47
W25	7.6	9460	659	216	2561	5.2	88	5041	812	98	1.10	22
W26	7.6	7622	522	185	1988	12.0	176	3512	1175	97	1.20	22
W27	7.4	11512	975	357	2706	21.0	195	5612	1554	134	1.20	31
W28	7.6	6412	316	285	1640	12.7	161	3258	701	78	1.00	18
W29	7.9	6465	460	175	1702	10.1	195	3392	549	49	1.20	11
W30	7.7	7790	505	241	2032	11.0	98	4032	776	105	1.10	24
W31	7.5	8310	539	256	2173	12.3	122	4350	790	98	1.10	22
W32	7.5	3790	460	80	802	4.2	83	1946	305	116	0.62	26
W33	7.5	10388	957	265	2512	12.3	210	5653	719	78	1.10	23

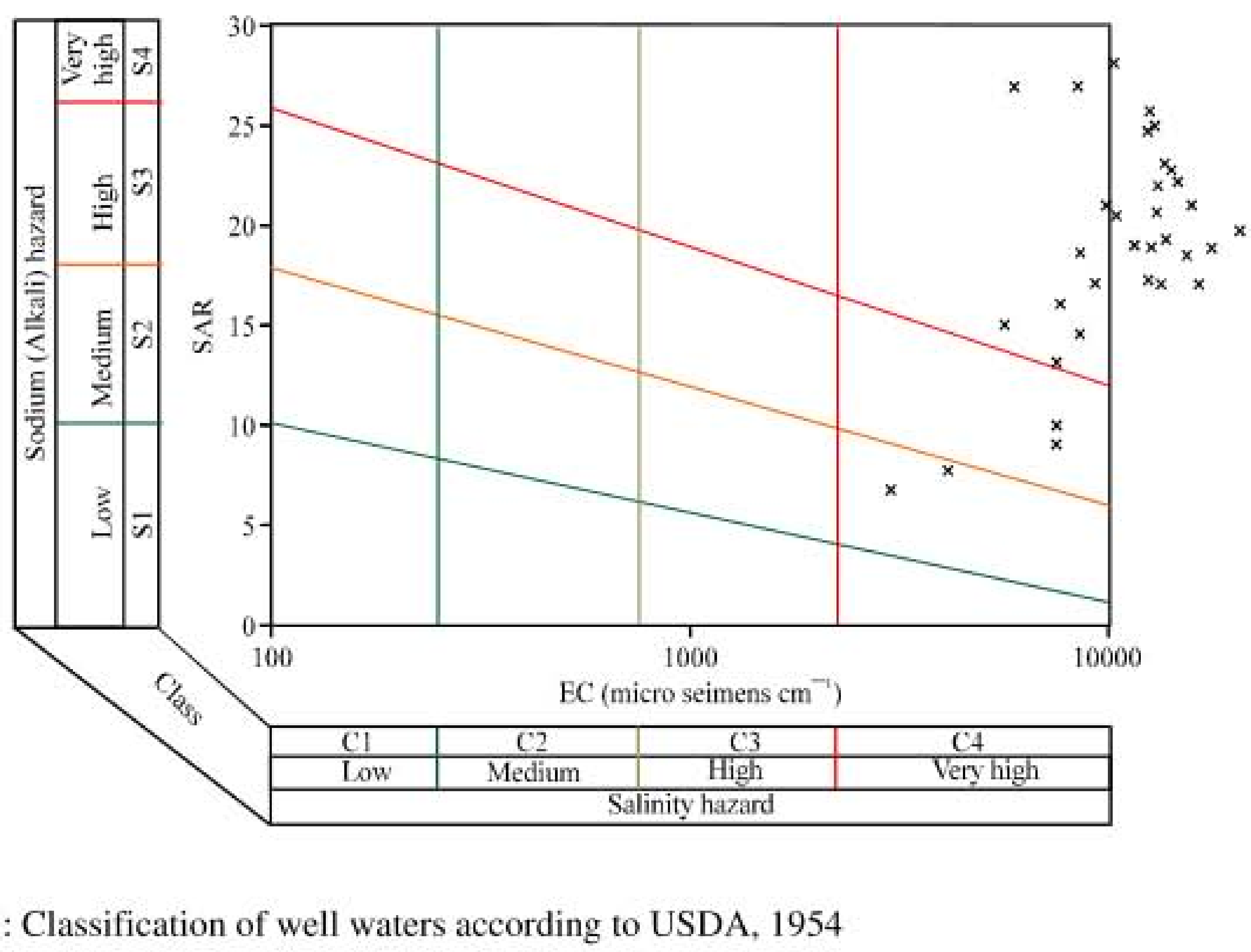

Fig. 3: Classification of well waters according to USDA, 1954

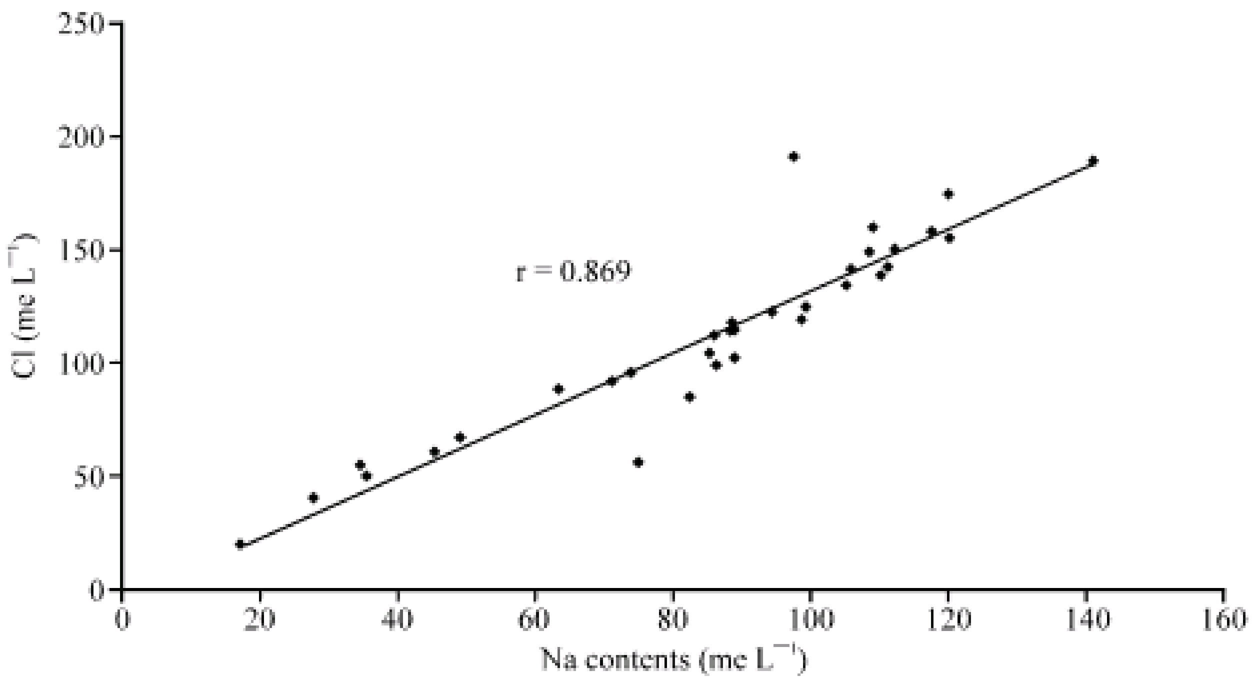

Fig. 4: Relationship between Na and Cl contents of well water

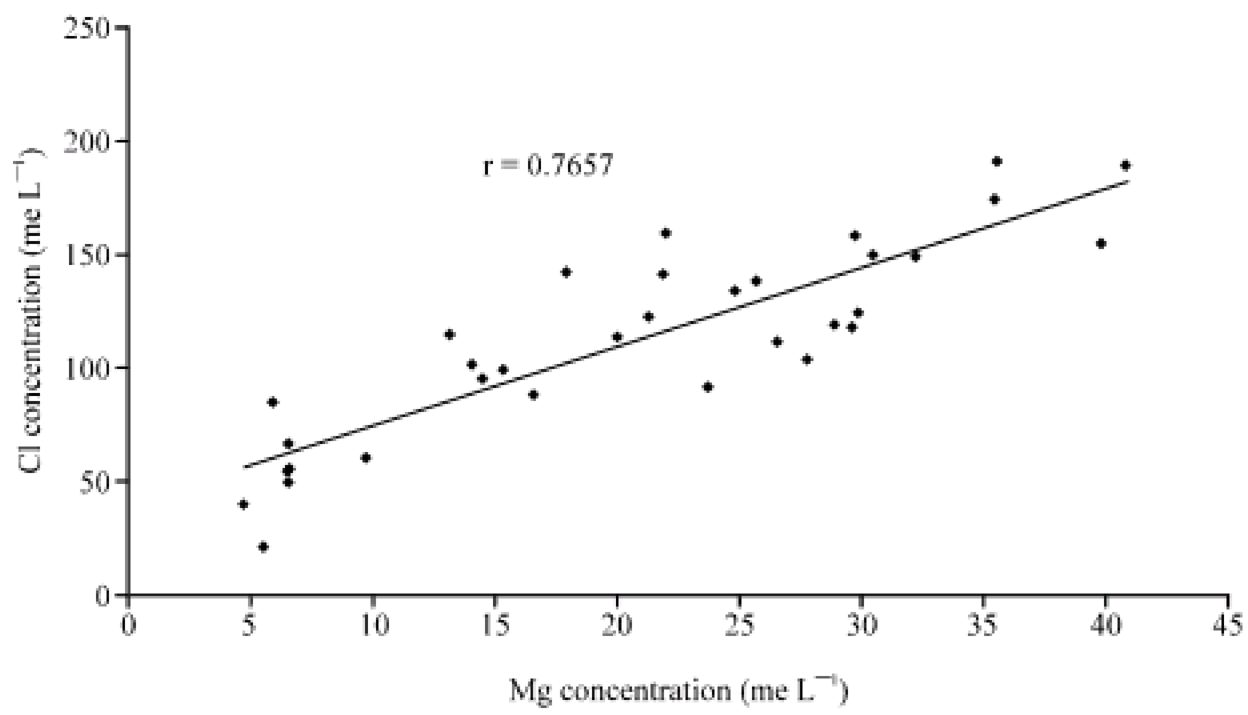

Fig. 5: Relationship between Mg vs. Cl

Ion Inter-Relationships

The regression analysis showed a strong relationship between Na and Cl ions (R^2 = 0.869) and Mg vs. Cl (R^2 = 0.766) followed by poor relation between Ca vs. Cl (R^2 = 0.288) ions in descending order (Fig. 4-6).

The relationship was poor between Ca and SO_4 (R^2 = 0.057) and strong between Mg and SO_4 ions (R^2 = 0.636) in the groundwater of Al-Mendasah wells (Fig. 7-8). With increasing SO_4 concentration, the Mg ion tended to increase whereas the Ca ion showed a decreasing trend indicating possible interactions between the aqueous and solid phases minerals due to gypsum ($CaSO_4$) precipitation.

The Ca/Mg ratio (0.35-4.52) showed that Ca concentration is 0.4-4.52 times higher than Mg in the groundwater of Al-Mendasah wells (Table 2). This indicated that Ca dominant soils are likely to develop with these waters after irrigation thus improving the soil structure.

The Cl/SO_4 ratio showed Cl as the dominant anion and ranged from 0.29-3.61 in the groundwater of Al-Mendasah. Besides, high Cl ion concentration can create chlorosis problem in some fruit tress (citrus and lemon) which could be overcome by applying leaching requirement to maintain its concentration within safe limits (Table 2). The high Cl

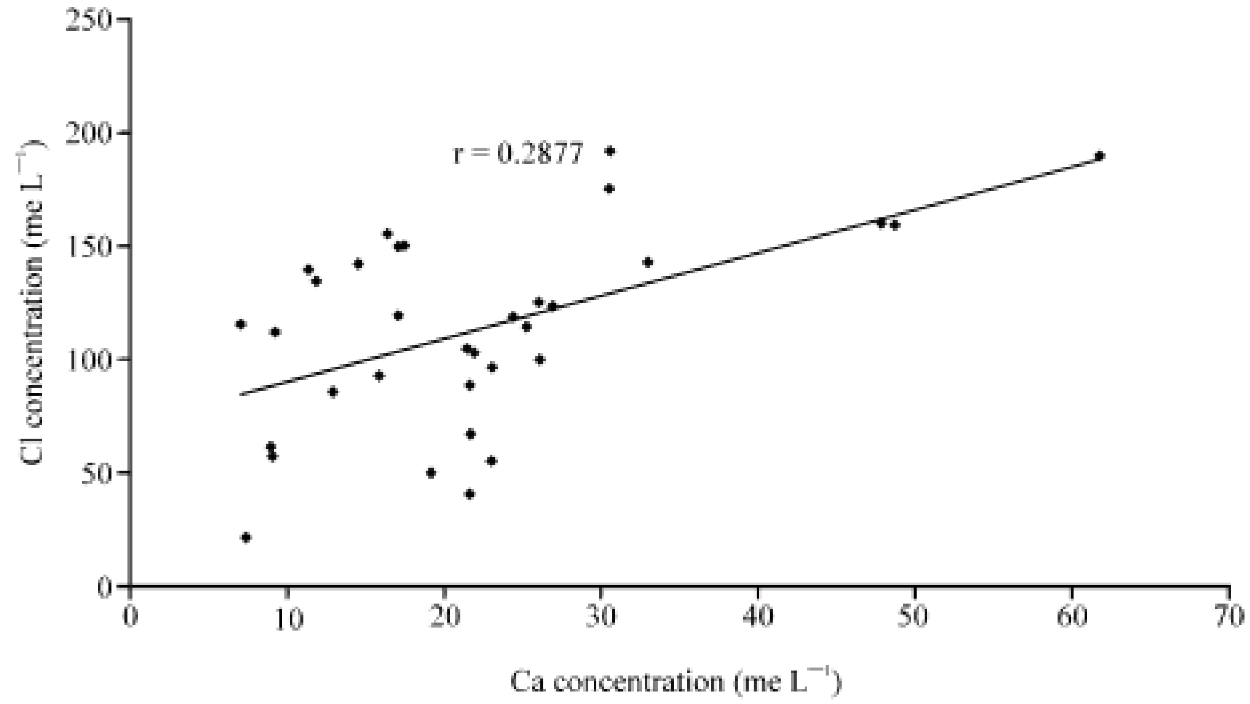

Fig. 6: Relationship between Ca vs. Cl

Table 2: Saturation indices and ionic ratios of well waters

Well No.	Anhy	Calcite	Dolo	Gyp	Halite	Fluo	SAR	Ca/Mg	Ca/SO_4	Na/Cl
MW01	-9.81	1.07	1.68	-7.86	-4.74	-1.29	7.77	4.52	2.84	0.70
MW02	-1.06	0.359	0.37	-8.68	-4.52	-1.13	9.08	3.49	3.61	0.64
MW03	-9.71	0.418	0.57	-7.82	-4.55	-1.09	9.99	2.91	2.15	0.72
MW04	-1.05	0.33	0.37	-8.63	-4.30	-8.86	13.17	3.27	2.91	0.74
MW05	-1.02	0.533	1.16	-8.27	-4.08	-1.01	14.57	1.31	2.15	0.72
MW06	-8.63	0.57	1.21	-6.86	-4.21	-1.19	26.94	1.36	0.29	1.34
MW07	-1.35	0.05	0.19	-1.17	-5.20	-1.00	6.80	1.31	1.20	0.82
MW08	-1.05	0.35	0.57	-8.59	-3.98	-8.89	26.98	2.16	0.95	0.97
MW09	-7.82	0.62	1.25	-5.96	-3.89	-7.85	21.04	1.56	1.15	0.87
MW10	-7.08	0.64	1.62	-5.41	-3.92	-1.03	17.26	0.78	0.82	0.82
MW11	-6.14	0.75	1.49	-4.46	-3.93	-7.78	19.03	1.71	1.06	0.87
MW12	-8.22	0.57	1.25	-6.43	-3.86	-8.70	18.62	1.27	1.56	0.78
MW13	-7.32	0.53	1.01	-5.61	-3.67	-7.95	22.13	1.85	1.94	0.78
MW14	-8.08	0.48	1.06	-6.26	-3.80	-8.51	19.30	1.28	1.63	0.77
MW15	-4.01	0.74	1.48	-2.15	-3.61	-6.43	18.84	1.66	1.50	0.74
MW16	-9.44	1.05	2.12	-7.66	-3.99	-7.59	17.13	1.59	2.01	0.77
MW17	-7.82	0.42	1.12	-5.93	-3.84	-1.02	17.13	0.83	1.18	0.75
MW18	-1.02	0.52	1.43	-8.41	-4.03	-1.15	16.10	0.67	1.08	0.78
MW19	-6.85	0.93	1.76	-5.10	-3.64	-6.83	18.53	2.19	3.19	0.69
MW20	-2.14	0.81	1.64	-2.08	-3.47	-6.19	19.76	1.53	1.27	0.75
MW21	-6.99	1.02	2.31	-5.23	-3.78	-5.36	18.88	0.88	1.06	0.80
MW22	-9.47	0.86	2.17	-7.64	-3.79	-7.25	20.68	0.60	0.88	0.83
MW23	-7.95	0.74	1.97	-6.22	-3.67	-7.02	21.97	0.53	0.55	0.73
MW24	-3.86	0.99	2.26	-2.16	-3.57	-5.24	20.98	0.87	0.56	0.69
MW25	-8.04	0.85	2.10	-6.41	-3.70	-6.35	24.97	0.67	0.46	0.75
MW26	-1.89	0.63	1.75	-1.02	-3.84	-8.11	28.12	0.53	0.33	0.78
MW27	-1.13	1.08	2.39	-9.40	-4.37	-5.12	15.01	0.91	0.62	0.75
MW28	-9.97	0.69	2.03	-8.11	-3.87	-7.37	20.46	0.35	0.30	0.77
MW29	-6.83	1.09	2.61	-4.97	-3.65	-5.40	23.07	0.58	0.42	0.75
MW30	-7.38	0.97	2.53	-5.50	-3.61	-6.59	22.80	0.41	0.39	0.78
MW31	-8.76	0.80	2.16	-6.93	-3.69	-7.25	25.79	0.44	0.31	0.80
MW32	-8.73	0.83	2.18	-6.88	-3.72	-1.25	24.68	0.48	0.34	0.78
MW33	-4.56	1.00	2.26	-2.71	-3.61	-3.87	17.64	0.87	0.68	0.51

Anhy: Anhydrite, Dolo: Dolomite, Gyp: Gypsum, Fluo: Fluorite

concentration in the groundwater could be attributed to the dissolution of chloride minerals from the outcrop of sabkha deposits surrounding the area during heavy rain storms thus recharging the aquifer through deep percolation.

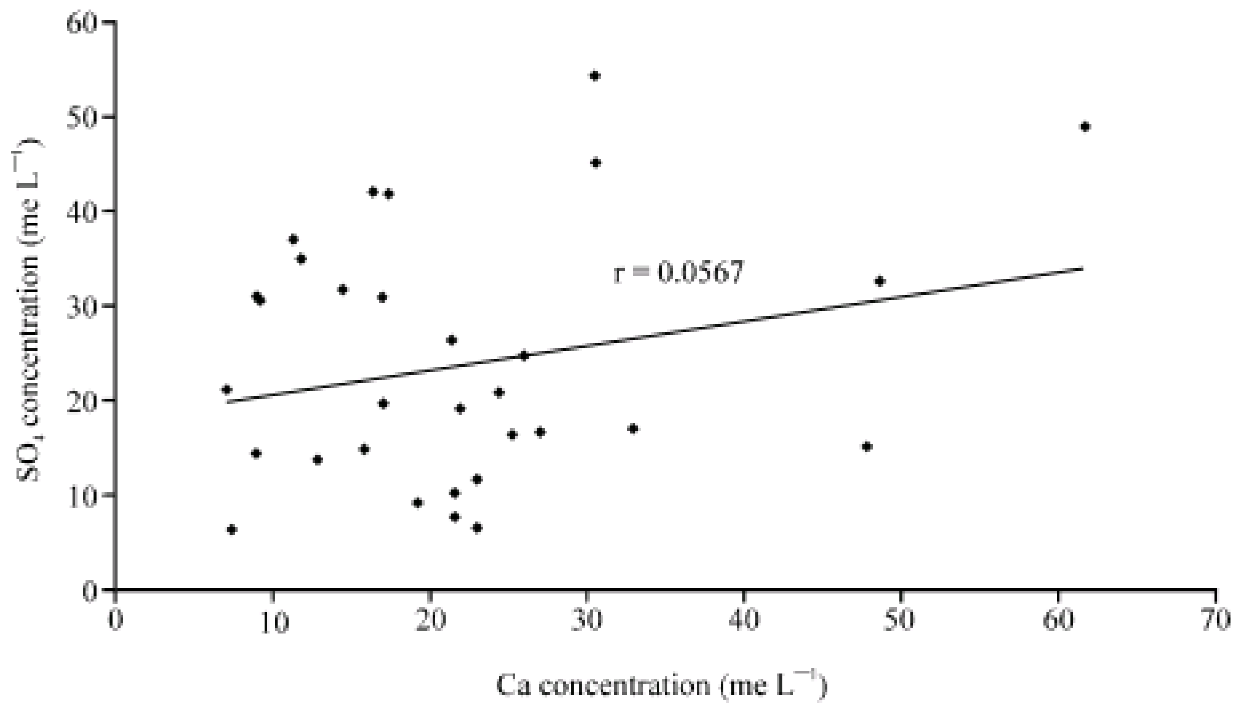

Fig. 7: Relationship between Ca vs. SO_4

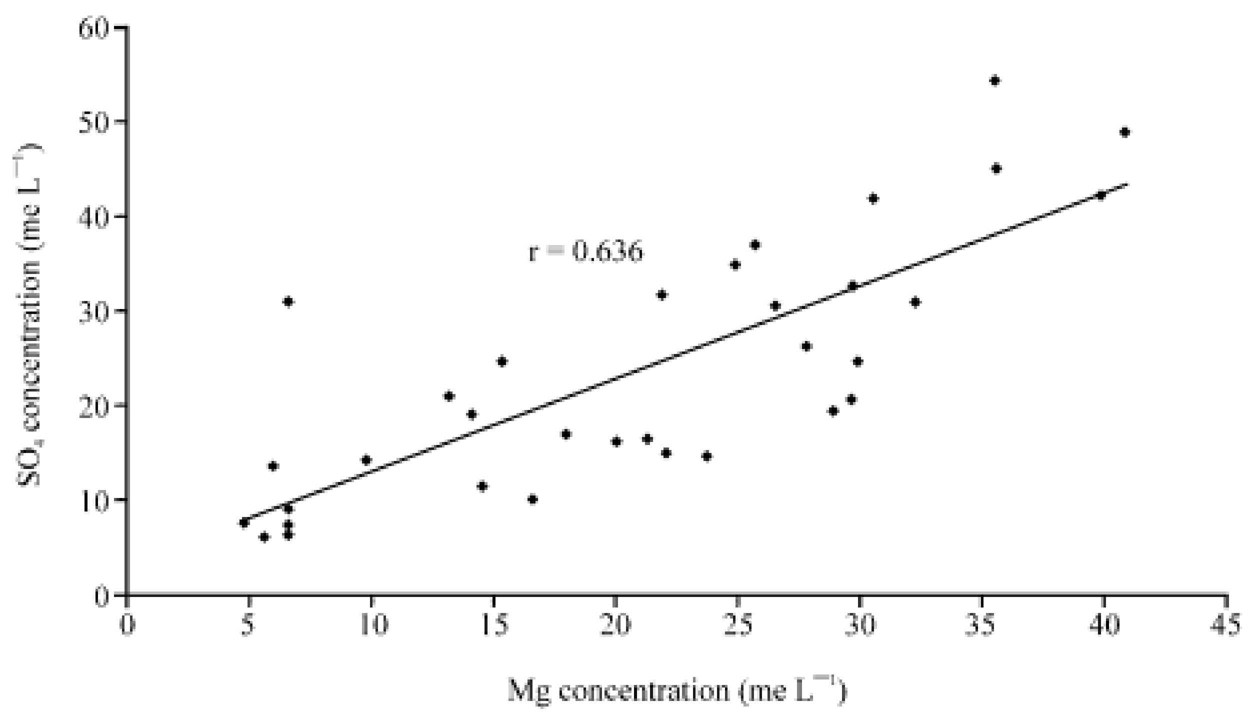

Fig. 8: Relationship between Mg vs. SO_4

Nitrate (NO_3) Concentration of Groundwater

Mean nitrate concentration (mg L^{-1}) ranged between 49-207 mg L^{-1} in the groundwater of Al-Mendasah wells (Table 1). The groundwater contains very high level of nitrate contents, which are beyond the permissible safe limits for drinking (30 mg L^{-1}) and other uses according to WHO (1984) drinking water quality standards and can cause serious health hazards for young humans and certain animals.

Fluoride (F) Concentration of Groundwater

The fluoride (F) concentration (mg L^{-1}) ranged from 0.51-2.20 in the groundwater of Al-Mendasah wells (Table 1). According to WHO (1984) guidelines, fluoride is an effective agent for preventing dental caries if taken in optimal amounts. Water is a major source of fluoride intake. The WHO (1984) guidelines suggested that in areas with a warm climate, the optimal fluoride concentration in drinking water should remain below 1 mg L^{-1}, while in cooler climate it could go up to 1.2 mg L^{-1}. The guidelines value (permissible upper limit) for fluoride was set at 1.5 mg L^{-1}. However, the F concentration of groundwater in about 60%

of water samples was within the permissible limits of WHO (1984). The SI value of fluorite mineral is negative in the groundwater of study area. This indicated more dissolution of F in water due to water-rock interaction especially during water flow through the fluoride bearing mineral rocks.

Chloride (Cl) Concentration of Groundwater

The Cl concentration in the groundwater is very high and ranged from 744-6773 mg L^{-1} (Table 1). Keeping in view the treated drainage water quality, the source of high Cl concentration in the groundwater could not be attributed to land disposal of treated or untreated effluent in Al-Mendasah area, but certainly there might be other sources of Cl ion intrusion into the groundwater of study area. The location map showed that the study areas is surrounded by many small and large tributaries entering the main Wadi and some sabkha areas. It seems that these sabkhas are saturated with chloride minerals which dissolve during the rainy season and contaminate the groundwater with brine seepage dominated by Na and Cl ions.

Saturation Indices

The chemical composition of natural waters is derived from many different sources of solutes including both gases and aerosols from the atmosphere and the weathering and erosion of rocks and soils. Dissolution and precipitation reactions of minerals occur below the soil surface where their concentration is influenced by many environmental factors, especially water-rock interaction (Lin and Clemency, 1980; Ronge and Claesson, 1982).

Saturation Indices (SI) were calculated for the groundwater of Al-Mendasah wells using the speciation code WATEQ4 (Ball and Nordstrom, 1992) and the PHREEQC model developed by Parkhurst (1995). Mean saturation indices of different minerals are given in Table 2. The groundwater is under-saturated (negative SI) with respect to certain minerals such as gypsum (SI = -9.4 to -1.02), anhydrite (SI = -9.97 to -1.02), halite (SI = -5.2 to -3.47) and fluorite (SI = -8.89 to -1.00) and oversaturated (positive SI) with respect to some other minerals such as Calcite (SI = 0.05-1.09) and dolomite (SI = 0.19-2.61). Actually, the SI is a measure of the thermodynamics state of a solution relative to the equilibrium with a specified solid-phase mineral. In the study area, most of the groundwater is under-saturated with respect to gypsum, anhydrite, halite, pyrite, fluorite and aragonite minerals. Therefore, the groundwater is capable of dissolving more minerals during rock-water interaction from the aquifer and simultaneously will increase both its porosity and the permeability.

Trace Elements and Heavy Metals

The concentration of the trace elements and heavy metals is very low in groundwater than the recommended safe limits for irrigation according to Ayers and Westcot, 1985 (Table 3). Therefore, there is no immediate concern of any environmental, health hazards and irrigation issues.

Effect of Water Quality on Soil Properties

Effect of groundwater was predicted on the soil salinity and sodicity hazards for crop production. The SAR of groundwater was calculated (Table 2). This information was used to calculate adj.SAR and adj.R_{Na}, which accounts for alkalinity hazards and the exchangeable-sodium-percentage (ESP) of soil. The predicted Exchangeable-Sodium-Percentage (ESP) of soils resulting from groundwater irrigation is presented in Fig. 9. The predicted ESP values

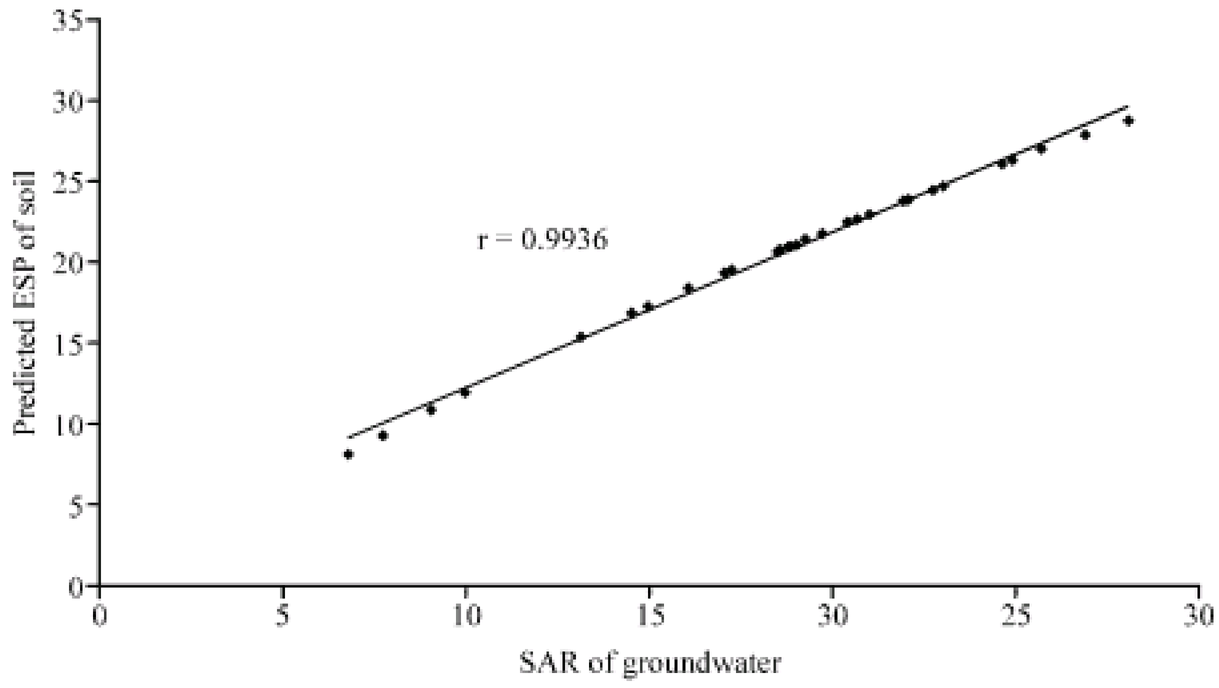

Fig. 9: Relationship between SAR vs. Predicted ESP of Soils

Table 3: Concentration of trace elements and heavy metals in groundwater (µg L^{-1})

Well No.	Al	Ba	Co	Cr	Cu	Fe	Mn	Ag	Se	Pb	As	Zn
W1	8.6	28.0	2.7	4.1	116.9	115.8	1.6	0.3	30.8	22.7	30.8	158
2	60.8	39.1	3.3	10.2	41.7	140.5	7.8	4	44.1	130.3	44.1	193
3	11.5	77.0	2.7	13.2	17.0	475.2	3.3	3.2	48.0	11.69	48.0	207
4	ND	48.0	1.1	7.9	38.8	82.86	3.4	4.7	57.6	27.3	57.6	187
5	54.1	48.6	1.2	9.4	21.0	148.1	3.1	ND	48.8	57.7	48.8	155
6	ND	67.4	1.2	13.8	23.3	272.2	1.7	2.7	71.0	67.7	71.0	178
7	ND	74.0	1.6	9.2	42.9	47.74	1.1	4.3	62.1	9.47	62.1	192
8	ND	43.7	1.3	3.2	41.1	29.95	1.0	4.6	26.0	19.61	26.0	169
9	ND	44.8	2.3	3.0	22.3	68.77	2.8	4.3	31.8	0.5	31.8	175
10	ND	42.8	0.8	1.2	34.3	59.32	2.6	4.2	30.14	ND	30.14	190
11	ND	35.5	2.2	1.2	20.6	39.24	2.7	4.2	29.3	16.84	29.3	153
12	28.9	38.8	0.5	2.0	0.3	46.05	1.0	4.9	40.4	3.37	14.2	244
13	ND	31.8	0.4	1.6	ND	102.5	0.5	0.5	40.1	0.54	18.7	303
14	ND	90.4	0.7	2.5	8.3	49.01	1.6	1.1	7.0	18.75	9.6	133
15	21.4	97.1	0.8	14.0	24.3	481.2	0.5	2.4	17.8	13.67	ND	131
16	14.3	42.5	ND	4.8	23	132.7	1.1	5.4	20.6	96.3	ND	105
17	37	99.4	1.8	6.0	58	368.0	1.4	6.5	21.3	ND	ND	145
18	ND	56.4	0.7	2.7	6.9	77.91	0.2	ND	32.1	92.6	ND	121
19	153.1	77.9	2.7	11.2	60	448.3	1.2	4.7	24.34	8.87	ND	431
20	ND	36.6	0.4	5.8	140.2	422.4	1.5	6.8	5.2	2.72	ND	98
21	288.8	78.0	0.5	2.8	37.1	274.0	2.7	0.8	12.8	2.87	ND	107
22	174	87.7	0.1	5.2	99.3	399.2	5.2	6.2	29.5	230.6	ND	268
23	120.8	77.8	0.1	28.2	11.5	1072	2.0	4.4	2.2	109.5	2.6	183
24	ND	101	ND	1.1	24.1	102.7	1.0	1.6	ND	22.0	0.5	473
25	109.4	55.4	ND	8.0	18.3	134.2	0.6	11.2	44.2	215.9	2.0	265
26	ND	31.8	0.5	3.8	16.7	115.2	1.1	6.8	9.2	50.7	ND	77
27	ND	107.8	0.9	10.5	23.3	519.9	1.8	1.1	39.8	76.7	ND	324
28	1072.3	81.6	1.8	6.6	204.6	450.8	3.2	ND	19.4	35.78	ND	195
29	75.7	43.2	1.0	7.1	29.4	341.5	1.1	3.0	13.4	196.5	ND	176
30	147.4	60.5	0.2	3.6	41.3	53.83	1.2	3.6	24.2	39.23	ND	142
31	ND	100	0.5	4.9	8.6	84.28	0.8	6.1	18.1	160.2	ND	199
32	ND	91.82	1.2	2.2	ND	137.8	1.8	0.4	0.2	48.3	ND	246
W33	176.4	91.6	1.7	6.4	113.3	465.8	7.6	9.1	10.1	63.4	ND	264

ND: Not deleted

from simple SAR of water were much higher and indicated the development of severe soil sodicity problems because the upper safe limit of ESP in soils is 15 according to USDA, 1954. In the case of long term irrigation practices, the development of severe soil sodicity problem could be minimized if improvement management practices such as provision of adequate soil

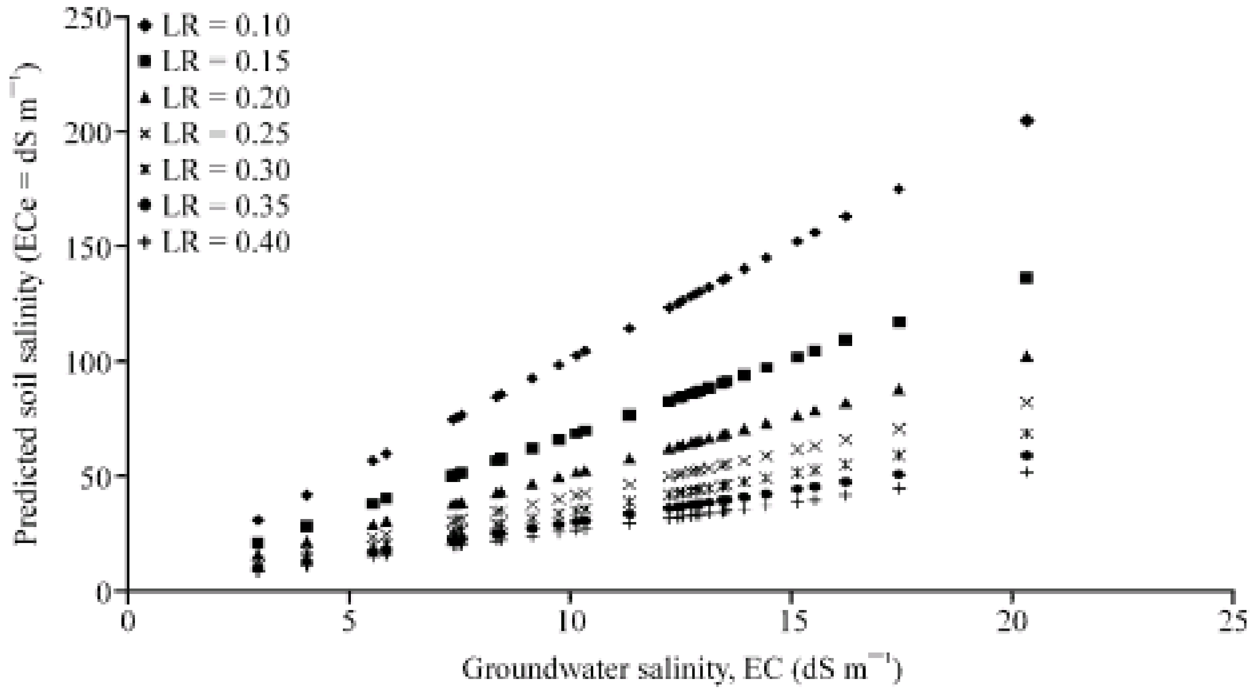

Fig. 10: Predicted soil salinity against hypothetical leaching requirements

drainage, application of leaching requirement (application of 15-20% excess water above crop ET requirements) and application of available calcium soil amendments are adopted to maintain soil salinity and sodicity within safe limits.

Development of soil salinity from groundwater irrigation was predicted using seven hypothetical leaching fractions ranging from 0.10-0.40 (Fig. 10). The data showed that up to 88% of well waters will develop soil salinity more than 8 dS m^{-1} which is considered as moderate to highly saline soil where the cultivation of moderate to high salt tolerant crops is possible without significant yield reduction provided 15% excess water above crop water requirements (ET) is applied as leaching requirement to maintain soil salinity within acceptable limits. The other suitable preposition is to use these waters on alternate basis i.e., one freshwater irrigation is followed by saline irrigation which will maintain soil salinity within safe limits for normal plant growth.

Infiltration Rate of Solis

The waters were classified for their effect on the infiltration rate of soils after irrigation (Fig. 11). It was found that these well waters will not affect the infiltration rate of soils upon irrigation as shown in the figure based on FAO Guidelines (Ayers and Westcot, 1985).

Chemistry of Treated Sewage Water

The order of abundance for cations was Na>Ca>Mg and that of anions was $Cl>SO_4>HCO_3$ mg L^{-1} (Table 4). The correlation was highly significant between Na and Cl ions ($R^2 = 0.979$) in the treated sewage water of Al-Mendasah area. The treated sewage water is classified as Na.Cl-SO4 type water except one sample where it was Na-Cl-HCO_3-SO_4 type water. The correlation was very high between SAR and the calculated adj.SAR ($R^2 = 0.781$) and adj. R_{Na} ($R^2 = 0.721$) of treated sewage water (Fig. 12).

The groundwater was classified as C3S2 to C4S3 i.e., high salinity and medium sodium to very high salinity and high sodium waters according to USDA, 1954. The use of this water for irrigation can create soil sodicity problems (Fig. 13). Furthermore, the treated sewage water can be used for crop irrigation if management practices such as leaching requirement based on total water salinity and soil type, adoption of improved irrigation systems (drip or subsurface) and selection of medium to high salt tolerant crops are considered.

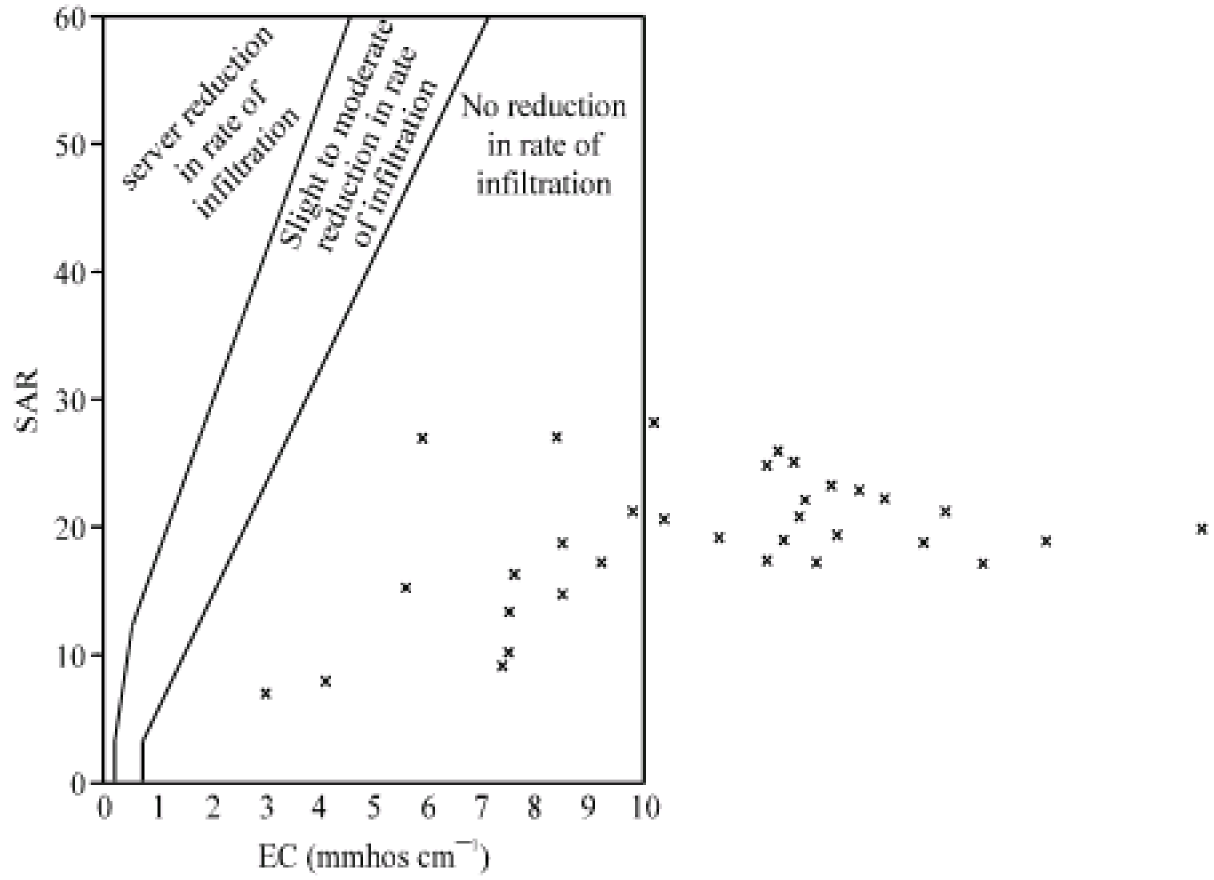

Fig. 11: Classification of well waters for infiltration hazards based on FAO guidelines

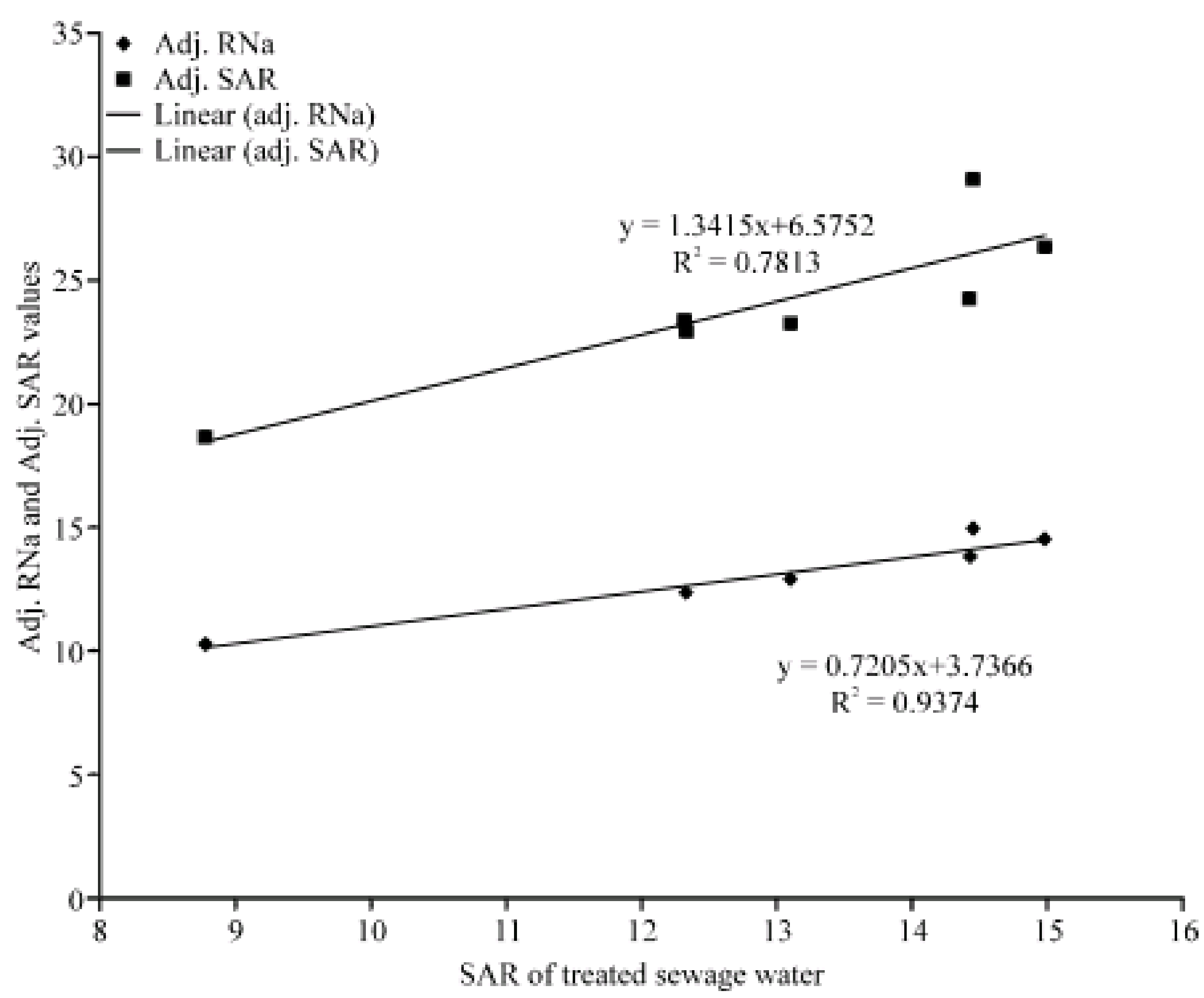

Fig. 12: Relationship between SAR vs. Adj.SAR and Adj.RNa of treated sewage water

Ion Inter-Relationships

The regression analysis showed a strong correlation between Na and Cl ions ($R^2 = 0.979$) and Na vs SO4 ($R^2 = 0.991$) (Fig. 14) as well as between Mg vs. Cl ($R^2 = 0.911$) and Mg vs. SO_4 ($R^2 = 0.943$) (Fig. 15). However, the correlation was poor between Ca vs. Cl ($R^2 = 0.253$) and Mg vs. SO_4 ($R^2 = 0.247$) (Fig. 16) in the treated sewage water of Al-Mendasah area. It was

Table 4: Chemical composition of treated sewage water Al-Mendasah

		EC	TDS			Ca	Mg	Na	K
Sample No.	Sample ID	(mS cm^{-1})	(mg L^{-1})	pH	Temp.	(mg L^{-1})			
M-1	M-1	3.22	2406	7.86	27.7	82.9	56.99	698	17.8
M-2	M-2	2.46	1830	7.77	28.3	40.7	38.93	557	16.9
M-3	M-3	2.50	1756	7.92	26.6	60	35	516	15.7
M-4	M-4	2.31	1640	7.8	26.9	33.3	34.86	499	15.5
M-5	M-5	1.79	1156	7.4	26.9	54	22	303	3
M-6	M-6	2.44	1720	7.87	27.8	57.2	39.84	496	18.9
M-7	M-7	2.44	1812	8.29	28.8	61.2	43.66	517	19.7

Sample No.	Cl (mg L^{-1})	SO_4 (mg L^{-1})	SAR	Adj RNA	Adj SAR	ESP	Ca/Mg ratio	Cl/SO_4 ratio	T.H (mg L^{-1})
M-1	947	478	14.5	14.9	29.0	16.7	0.88	2.68	441.7
M-2	699	360	15.0	14.6	26.2	17.2	0.63	2.63	261.9
M-3	693	324	13.1	12.9	23.2	15.3	1.04	2.90	293.9
M-4	618	318	14.4	13.8	24.2	16.7	0.58	2.63	226.6
M-5	301	178	8.80	10.3	18.6	10.5	1.49	2.29	226.0
M-6	656	326	12.3	12.5	23.2	14.5	0.87	2.72	307.0
M-7	703	348	12.3	12.3	22.9	14.5	0.85	2.74	332.6

				BOD	COD	F	PO4	NO_2	NO_3
Sample	Sample ID	DO (mg L^{-1})	Turbidity NTU	(mg L^{-1})					
M-1	M-1	5.58	10.4	5.0	23.9	0.76	Nil	0.033	39.3
M-2	M-2	5.44	24.7	5.5	27.5	0.71	Nil	0.032	39.7
M-3	M-3	7.54	19.4	4.5	16.4	0.71	Nil	0.048	34.4
M-4	M-4	6.70	29.7	3.0	24.6	0.72	Nil	0.058	38.6
M-5	M-5	6.34	26.7	7.0	22.9	0.39	179	ND	30.0
M-6	M-6	7.42	18.8	3.0	27.8	0.72	Nil	0.048	33.1
M-7	M-7	10.2		3.5	25.0	0.71	Nil	0.022	33.1

		Fe	Mn	Cu	Co	Zn	Pb	SiO_2	
Sample	HCO_3 (mg L^{-1})	(µg L^{-1})							T.Alk
M-1	136	15.2	5.2	9.5	1.87	198		16.9	112
M-2	122	12.9	2.7	9.5	1.96	120		13.6	100
M-3	112	14.8	2.1	8.7	2.12	165		14.9	92
M-4	116	11.1	2.0	8.5	3.77	12.8		15.4	95
M-5	300	46.9	25.2	10.7	1.8	264	1.3	40.1	246
M-6	140	73.2	5.7	11.2	0.91	14.7		15.3	115
M-7	122	71	4.9	9.3	0.78	13.2		16.2	100

also observed that with an increase in SO_4 concentration, the Mg ion tended to increase whereas the Ca ion showed a decreasing trend indicating possible interactions between the aqueous and solid phases minerals due to gypsum ($CaSO_4$) precipitation.

The Ca/Mg ratio with a range of 0.58-1.49 showed that Ca concentration is higher than Mg only in 29% of treated sewage water samples in Al-Mendasah area (Table 4). This indicated that Mg dominant soils are likely to develop with TSW irrigation and could result in ca deficiency in plants besides other related nutrient elements.

The Cl/SO_4 ratio ranged from 2.29-2.90 in the treated sewage water (Table 4). The significantly high Cl concentration in treated sewage water indicates that a heavy dose of chlorine is being applied during water treatment process killing and preventing growth of different microorganisms in the treated sewage water to avoid bacterial infection from treated sewage water irrigation. Also, high Cl ion concentration can create chlorosis problem in some fruit tress (citrus and lemon) after irrigation (Table 4). The high Cl concentration in the groundwater indicates possible recharge of groundwater with the land disposal of treated sewage water in Al-Mendasah area.

Nitrate (NO_3) and Phosphate (PO_4) Concentration of Treated Sewage Water

Mean nitrate concentration (mg L^{-1}) ranged from 30.00-39.70 (Table 4). The nitrate contents are within the permissible limits (45 mg L^{-1}) for crop irrigation according to Ayers

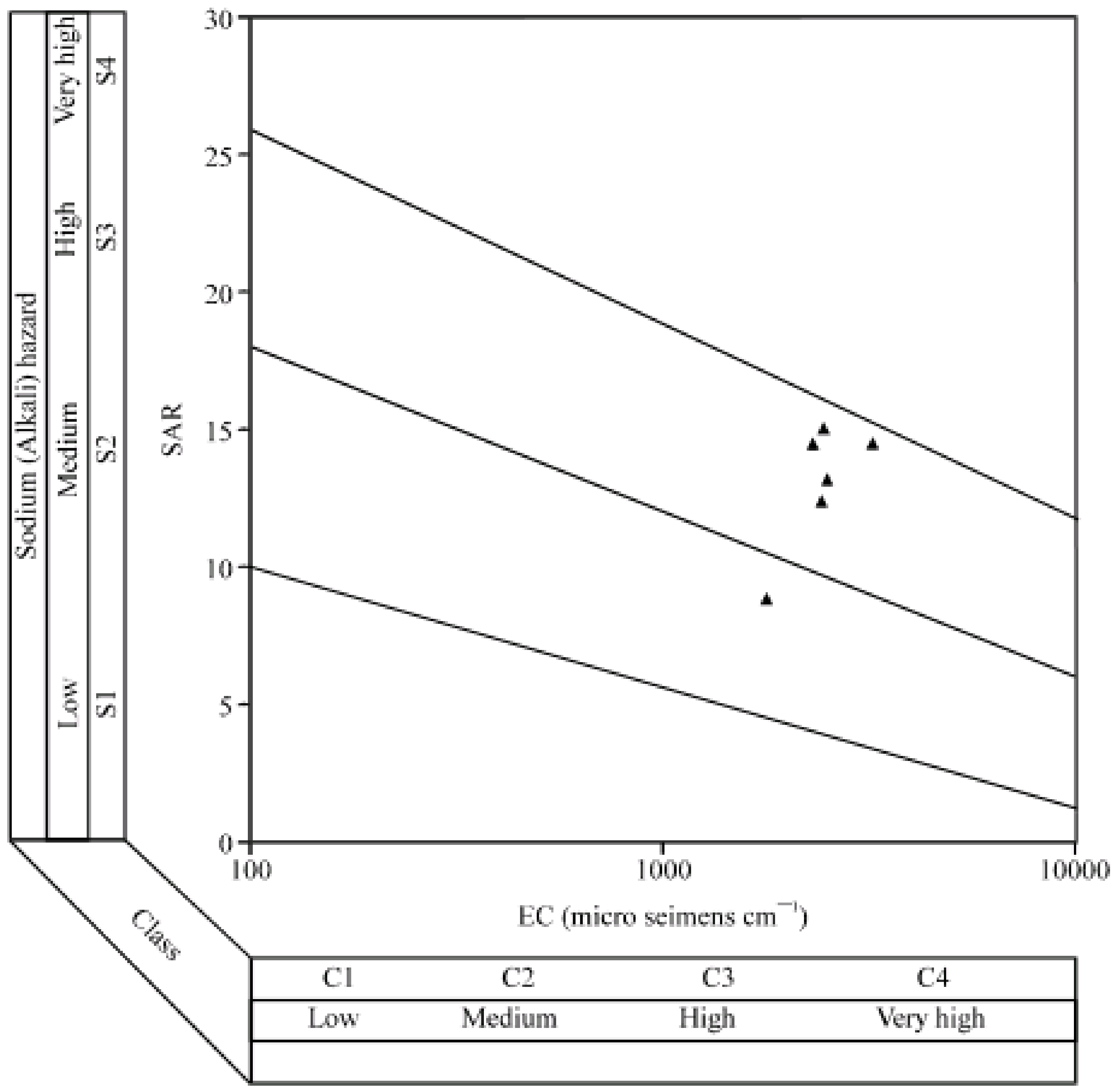

Fig. 13: Classification of treated sewage water for Irrigation based on USDA method of classification

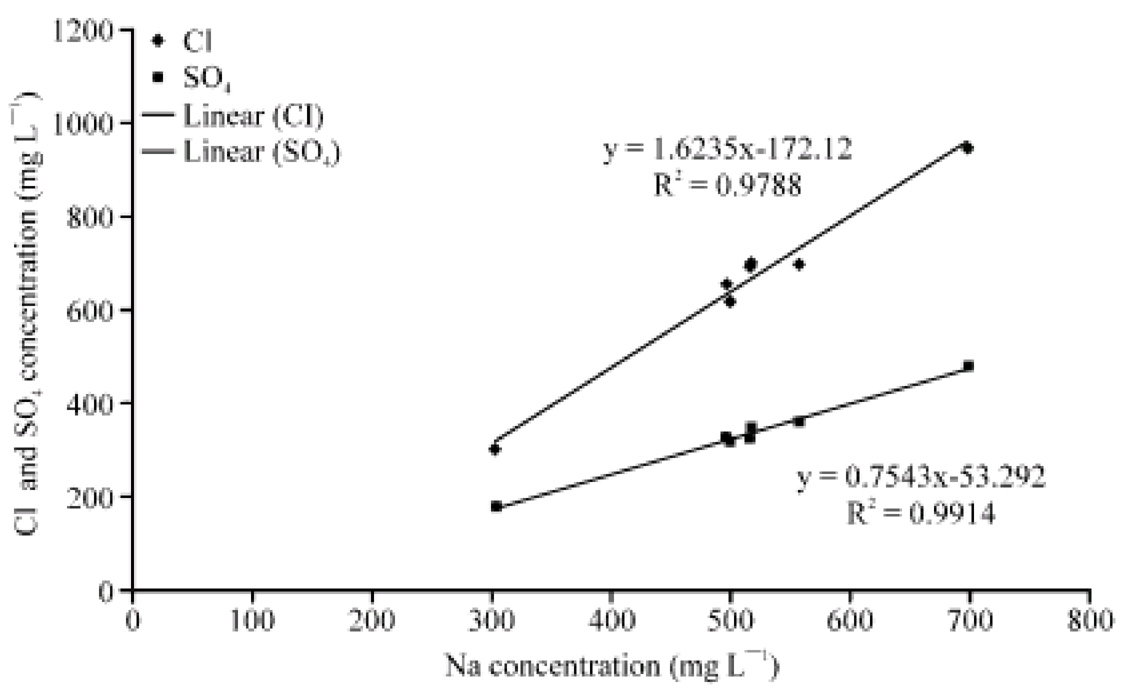

Fig. 14: Relationship between Na vs. Cl and SO_4 of Treated Sewage Water

and Westcot (1985). The PO_4 ion was absent the except in one sample of the treated sewage water where its concentration was 179 mg L^{-1}.

Fluoride (F) Concentration of Treated Sewage Water

The fluoride (F) concentration (mg L^{-1}) ranged from 0.39-0.76 in the treated sewage water and is within the recommended permissible limits of 1.0 mg L^{-1} for safe irrigation (Table 4).

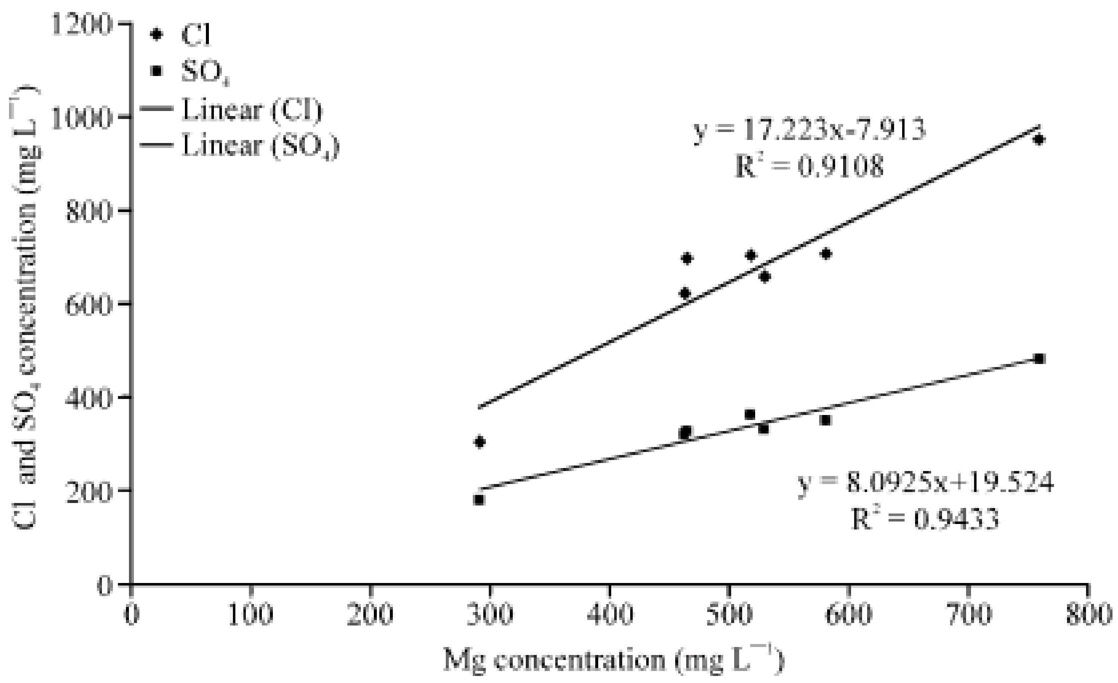

Fig. 15: Relationship between Mg vs. Cl and SO_4 of Treated Sewage Water

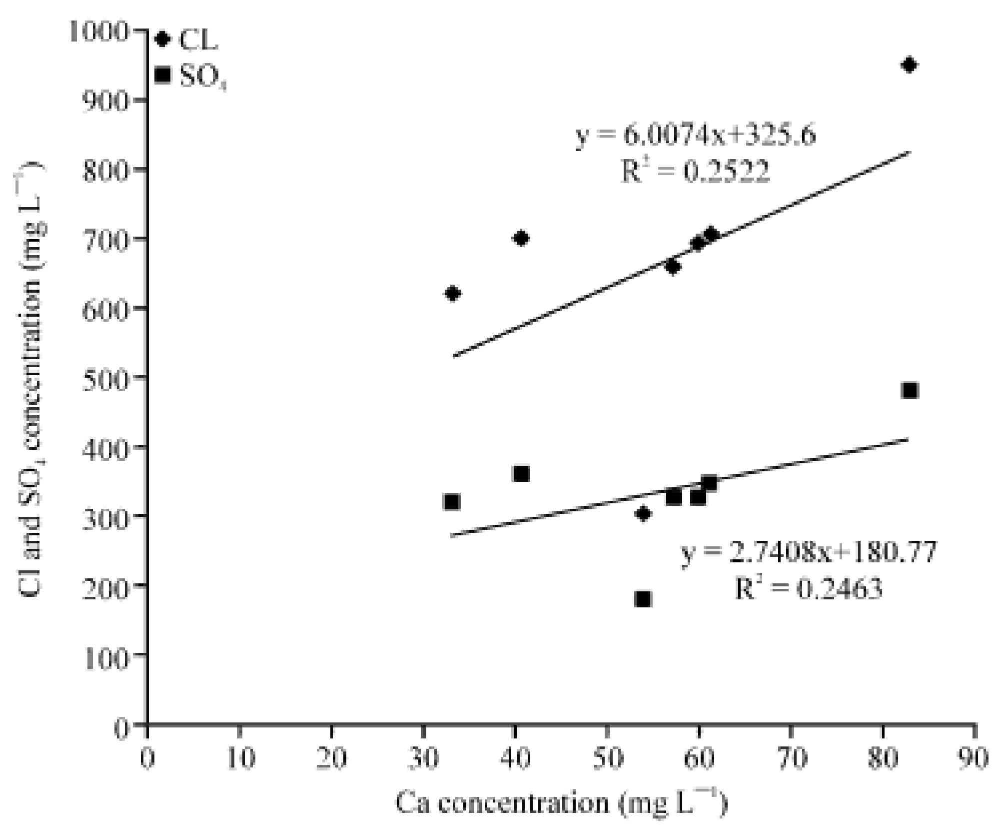

Fig. 16: Relationship between Ca vs. Cl and SO_4 of Treated Sewage Water

Chloride (Cl) Concentration of Groundwater

The Cl concentration ranged from 301-947 mg L^{-1} (Table 4). The high Cl concentration in the treated sewage water could be attributed to the addition of chlorine during the water treatment process which depends on the total load of microorganisms in the raw sewage water. This further confirmed the hypothesis that high Cl contents in the treated sewage water could be the major source of high Cl concentration in the groundwater of Al-Mendasah area.

Saturation Indices

The treated sewage water is un-saturated (negative SI) with respect to gypsum (SI = -1.230 to -1.678), halite (SI = -4.852 to -5.664) and aragonite (SI = -0.008 to -0.396) and over-saturated (positive SI) with Calcite (SI = 0.032-0.506) and dolomite (SI = 0.042-0.633) (Table 5). In the study area, the treated sewage water is un-saturated with respect to gypsum,

Table 5: Saturation indices of treated sewage water in Al-Mendasah area

Sample No.	Aragnonite	Calcite	Dolomite	Gypsum	Halite
S-34 (M-1)	0.070	0.211	0.633	-1.230	-4.852
S-36 (M-2)	-0.317	-0.175	0.008	-1.572	-5.066
S-37 (M-3)	-0.053	0.090	0.309	-1.438	-5.096
S-38 (M-4)	-0.396	-0.254	-0.123	-1.678	-5.157
S-15 (M-5)	-0.110	0.032	0.042	-1.632	-5.664
S-40 (M-6)	-0.008	-0.134	0.484	-1.458	-5.139
S-39 (M-7)	0.365	0.506	1.249	-1.420	-5.096

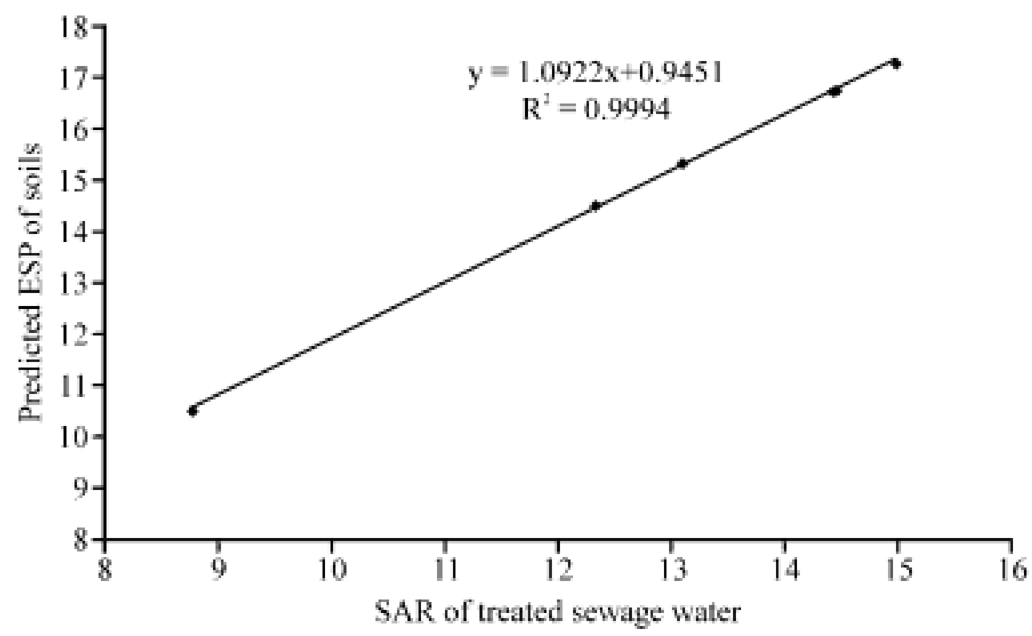

Fig. 17: Relationship between SAR and Predicted ESP of Soils

halite and aragonite minerals. Therefore, it is capable of dissolving more minerals by rock-water interaction during its flow in Wadi bed and percolation into the groundwater aquifer.

Trace Elements and Heavy Metals

The ranges for the concentration of different elements (expressed as parts per billion) were 11.1-71 (Fe), 2.1-25.20 (Mn), 8.5-10.70 (Cu), 0.78-3.77 (Co) and 12.80-264 (Zn) in the treated sewage water (Table 4). The concentration of all these elements was within the recommended upper limits for safe crop irrigation (Ayers and Westcot, 1985).

Effect of Water Quality on Soil Properties

Effect of irrigation with treated sewage water was predicted on the develop of soil salinity and sodicity hazards. The SAR of groundwater was calculated (Table 4). This information was used to calculate the exchangeable-sodium-percentage (ESP) of soil which accounts for alkalinity hazards. The predicted ESP values from simple SAR of water were much higher and indicated the development of severe soil sodicity problems because the upper safe limit of ESP in soils is 15 according to USDA, 1954 (Fig. 17). In the case of long term irrigation practices, the development of severe soil sodicity problem could be minimized if improvement management practices such as provision of adequate soil drainage, application of leaching requirement (application of 15-20% excess water above crop ET requirements) and application of available calcium soil amendments are adopted to maintain soil salinity and sodicity within safe limits.

Development of soil salinity was predicted from treated sewage water using five hypothetical leaching fractions ranging from 0.10-0.30 (Fig. 18). The data showed that irrigation with treated sewage water will develop soil salinity upto 8 dS m^{-1} and above which

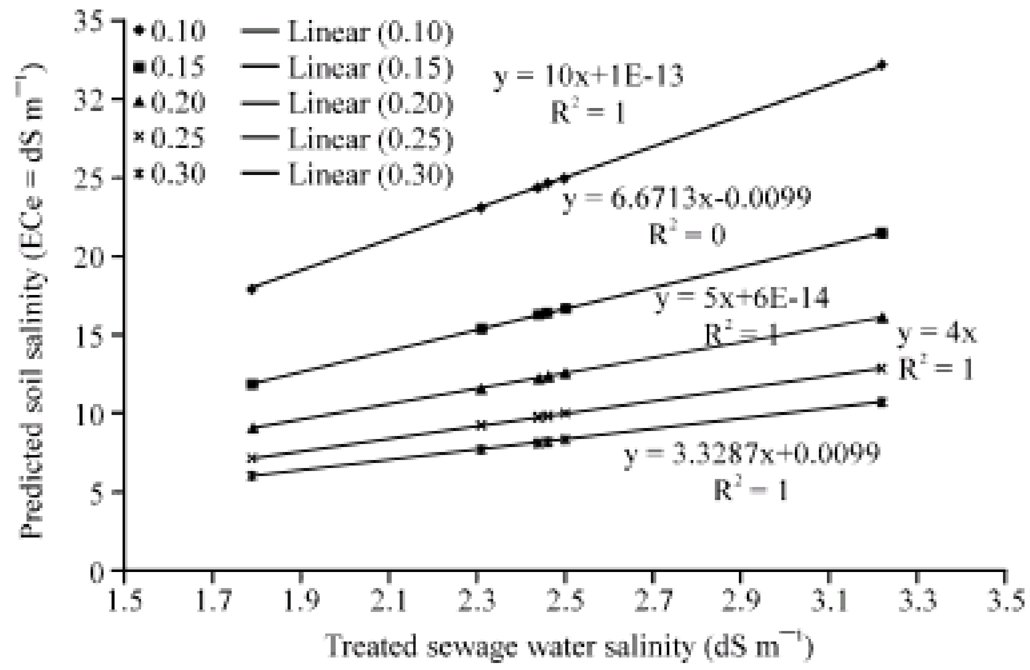

Fig. 18: Predicted soil salinity from treated sewage water salinity

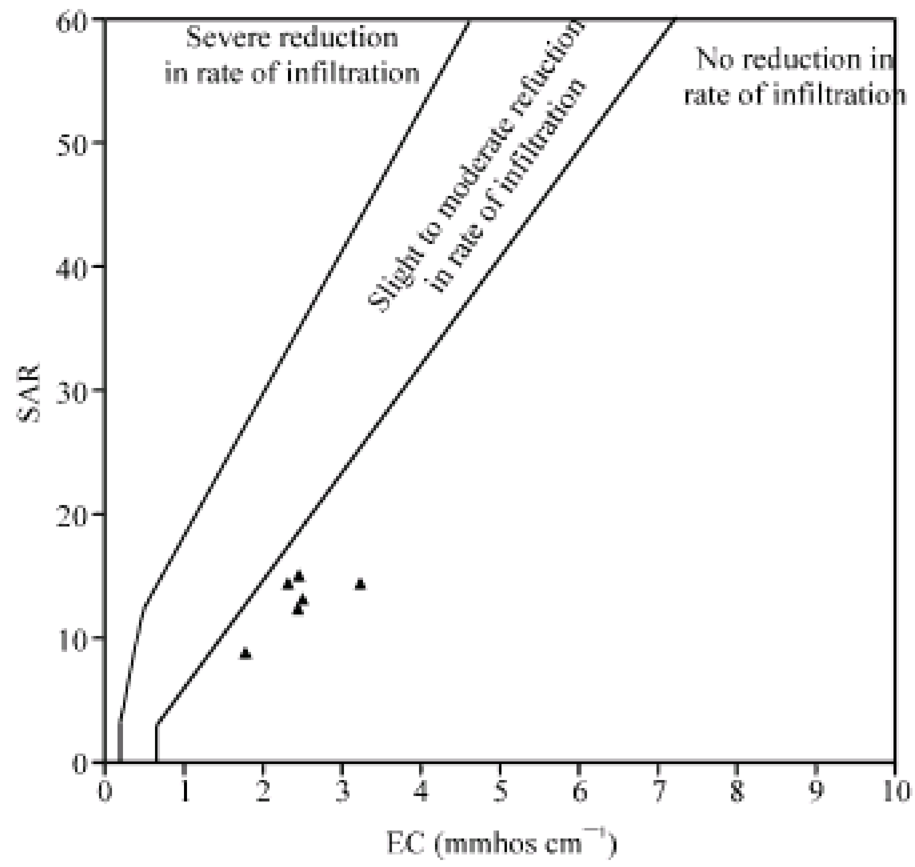

Fig. 19: Classification of treated sewage water for infiltration hazard based on FAO guidelines

is considered as moderate to highly saline soil. Only cultivation of moderate to high salt tolerant crops is possible without significant yield reduction provided 15% excess water above crop water requirements (ET) is applied as leaching requirement to maintain soil salinity within acceptable limits.

Infiltration Rate of Solis

The Treated Sewage Water (TSW) was classified for its effect on the infiltration rate of soils after irrigation (Fig. 19). It was observed that irrigation with TSW will not affect the soil permeability characteristics according to FAO Guidelines (Ayers and Westcot, 1985).

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