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Drainage Water Quality Evaluation for Irrigation in Al-Ahsa Oasis, Saudi Arabia

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ABSTRACT

Saudi Arabia is facing an acute shortage of irrigation water because of limited and non-renewable groundwater resources coupled with a low annual mean rainfall and arid climatic conditions. Drainage water of different qualities is abundantly available in many regions of Saudi Arabia. The main objective of this study is to evaluate the drainage water quality for reuse to enhance the existing, inadequate irrigation supplies for sustainable agricultural production. Drainage water samples were collected from Al-Ahsa, Eastern Province, Saudi Arabia and analyzed chemically. The drainage water in D-1 is classified as C4S4 (very high salinity and very high sodium water), while D-2 drainage water is classified as C4S3 to C3S2 (very high salinity-high sodium water to high salinity-medium sodium water). The drainage waters of both D-1 and D-2 drains are free from sodicity hazards due to the low SAR values. Most of the drainage water is dominated by Na salts compared to other cations, such as Ca, Mg and K and has been classified as Na-Cl-HCO_3 water. The trace elements and heavy metal concentration in drainage water from both drains are within the permissible limits for irrigation purposes. The nitrate (NO_3) concentration is above the recommended limits for irrigation use. The bacterial contamination is very high in the drainage water of both drains and is not fit for irrigation without proper treatment. Based on the chemistry, the drainage water is not fit for irrigation due to the high total water salinity.

Key words: Water salinity, sodicity, ion relationship, water classification, cations, anions, total bacteria, *E. coli*

INTRODUCTION

Saudi Arabia is an arid country facing the acute problem of an irrigation water shortage due to high evaporative conditions and non-renewable groundwater resources. The agriculture sector is the main consumer of groundwater in the kingdom. Groundwater, specifically the deep aquifer, in Saudi Arabia is considered to be a non-renewable resource (fossil water). The cost of pumping water from the deep aquifer is increasing every year and in some areas, the aquifer is dried out or its quality has significantly deteriorated. Farmers facing this dilemma are forced to search for an alternate solution to irrigate their farms. Wastewater reuse is considered to be an important source of water to the agricultural sector in arid countries all over the world.

The production of wastewater is increasing manifold due to urban and rural expansion, resulting from the increased population of the country. The use of treated wastewater and in some areas, untreated wastewater is a known practice in Saudi Arabia. Wastewater contains not only a high salt content, it is polluted with different types of organic, inorganic and biological pollutants.

The sources of these pollutants are mainly from household and industrial uses and other waste effluents, such as hospitals and laundries which use different reagents types for cleaning and healthcare management.

According to a report, the standards for effluent reuse are not addressed properly due to the unnecessary limitations imposed on the disposal and reuse of wastewater (Abu-Rizaiza, 1999). In Bahrain, drainage water has high salinity and sodium and chloride contents with ranges of 4.0-46.0 ppt, 645-1480 and 1400-2669 mg L^{-1}, respectively. Elevated concentrations of bicarbonate, sulfate and calcium were also measured and ranged from 140-352, 1316-3617 and 512-990 mg L^{-1}, respectively. Additionally, the quality of drainage water reflected the quality of groundwater due to exclusive use of groundwater for irrigation purposes (Raveendran and Madany, 1991a, b; Madany and Akhter, 1990). However, El-Din *et al.* (1993) reported that seepage of sewage from septic tanks and cesspools was responsible for the deterioration of both the chemical and biological quality of well water in Saudi Arabia (Hejazi, 1989). Many investigators have evaluated the water quality in different regions of Saudi Arabia, such as Al-Hassa Oasis spring and drainage water (Hussain and Sadiq, 1991; Al-Hawas, 2002), Wadi Al-Yamaniyah (Bazuhair and Alkaff, 1989); the Al-Qassim Region (Faruq *et al.*, 1996); Saudi ground water chemistry (Mee, 1983) and the chemical composition of the ground waters of Saudi Arabia (WRD., 1985; El-Din *et al.*, 1993). Jun *et al.* (2005) applied a hydrogeological characterization and isotope investigation to identify the source location and to trace a plume of groundwater contamination by nitrate. Natural and fertilized soils were identified as non-point sources of nitrate contamination in the study area, while septic and animal wastes were identified as small point sources.

On a long-term basis, sewage water irrigation has been reported to be a potential source of carbon accumulation and the major and micronutrients in the soil (Yadav *et al.*, 2002). Previously, the concentration of nitrate (NO_3) in the groundwater varied from 50-130 mg L^{-1} in the croplands that were irrigated with wastewater. However, in well water irrigated croplands, the NO_3 concentrations were less than 35 mg L^{-1} (Tang *et al.*, 2004; Bae and Lee, 2008). Similarly, research has highlighted the potential contamination of groundwater from on-site domestic wastewater systems in the Wadi Fatimah basin, Western Saudi Arabia (Alyamani, 2007) at the Loess Plateau in Dongzhi, China (Wang *et al.*, 2007) and on the groundwater aquifer in arid regions of Southern Tunisia (Chamtouri *et al.*, 2008).

Kalavrouziotis *et al.* (2008) compared the effect of Treated Municipal Wastewater (TMWW) with ordinary irrigation water to determine the reuse of waste effluent for vegetable irrigation. They reported the careful use of treated effluent for vegetable irrigation to avoid biological contamination for human consumption. In another study, Ghafari *et al.* (2008) reviewed many studies on the biological denitrification of nitrate-containing water resources, aquaculture wastewaters and industrial wastewater for the remediation of different concentrations of nitrate. However, Ayers and Westcot (1985) classified irrigation water into three groups based on the salinity, sodicity, toxicity and miscellaneous hazards. They also reported phytotoxic threshold levels of toxic trace elements in the water used for crop irrigation.

Alaboud (2009) investigated a pilot scale MBR plant located in AlKhomra, Jeddah, Saudi Arabia, on the wastewater from a residential area and adjoining workshops. Irrespective of the applied Mixed Liquor Suspended Solids (MLSS) concentrations (10, 15 and 20 g L^{-1}), the MBR units had an excellent potential for the removal of organics, nutrients and pathogens. Selim (2008) highlighted the economic aspects of re-using secondarily treated wastewater in irrigation for the efficient utilization of the existing resources. Similarly, Massoudinejad *et al.* (2007) showed that water quality indicators of treated effluent from a Zamyard factory wastewater, such as the sodium adsorption ratio, sodium percentage, chloride content and electrical conductivity, were higher compared to the Food and Agriculture Organization (FAO) and Department of the Environment of Iran standards. Bouwer (2000) reported the increased use of sewage effluent for urban and agricultural irrigation. Tang *et al.* (2004) stated that in arid and semi-arid regions, wastewater as well as other low quality water resources, is an important source of water due to the shortage of irrigation water. Mahmood and Maqbool (2006) concluded that the application of untreated wastewater increased the levels of EC, TDS, SAR and RSC compared to the National Environmental Quality Standards (NEQS). Carr *et al.* (2004) stated that the use of wastewater in agriculture is occurring more frequently because of the water scarcity and population growth.

An extensive review of the literature indicated that there is an acute shortage of freshwater irrigation in Saudi Arabia due to the low annual mean rainfall, high arid climatic conditions and limited and non-renewable groundwater resource. Therefore, it is pertinent to explore alternative water sources to supplement the existing irrigation water resources for sustainable irrigated agriculture and to increase crop production for food self-sufficiency. The main objective of this study was to evaluate the drainage water quality that some farmers use for irrigation in Al-Ahsa, Eastern Province of Saudi Arabia and determine its reuse potential for irrigated agriculture expansion.

MATERIALS AND METHODS

The study was performed in Al-Ahsa Oasis, where high levels of free flowing wastewater are disposed through drainage canals (D-1 and D-2) in natural open lakes in the Al-Oyun and Al-Asfar areas, respectively.

Collection of water samples

Drainage water: A total of 25 drainage water samples were collected from the D-1 and D-2 main drainage canals. One liter drainage water samples were collected in sterile plastic bottles from selected sampling stations on the drainage channels. The water samples were stored in an icebox and then transported to an analytical laboratory for chemical analysis.

Microbiological analysis: Water samples were collected from both the D-1 and D-2 drainage canals for microbiological analysis to determine the contamination levels of fecal coliform and *E. coli* in the drainage water as well as their impact on the groundwater contamination from the seepage loss of drainage water collected from the canal beds or from the intrusion of wastewater from the main drainage canals that run across the Oasis to evaporation lakes.

Analytical study: All of the water samples were analyzed for different cations, anions, trace elements and heavy metals by following the standard procedures as described in APHA., AWWA. and WEF (1998). These include cations (Na, Ca, Mg and K), anions (CO_3, HCO_3, Cl, SO_4, NO_3 and PO_4), trace elements (Sr, Al, Be, Co, F, Mn, Mo, Fe, Se and B) and heavy metals (As, Cd, Cr, Cu, Pb, Hg and Zn) that can create possible health hazards when consumed by plants.

The physical parameters, such as the pH, EC, temperature, Dissolved Oxygen (DO), Total Suspended Solids (TSS) and turbidity, were measured immediately at the time of sample collection.

Table 1: Instruments used for water analysis

Name of the instruments	Company name	Made in	Analysis
ICP optima 200DV	Perkin Elmer	USA	Traces elements
Atomic absorption with furnace	Perkin Elmer	USA	Traces elements
TOC V_{CPH} analyzer	Shimadzu	Japan	TOC
GCMS2010	Shimadzu	Japan	Organic compounds
Ion chromatography	Dionex	USA	Cations
Ion chromatography	Ionex	USA	Anions
Multi element analyzer (HQ 40d)	HACH	USA	Field analysis

Additionally, 100 mL of each water sample was separately collected in a 100 mL capacity plastic bottle, acidified by adding approximately 1 mL of nitric acid and stored in an icebox for trace elements and heavy metal analysis.

In addition to the above water quality criteria, the SAR, adj.SAR and adj.R_{Na} were determined according to USDA (1954), Ayers and Westcot (1985) and Suarez (1981), respectively; we also determined the predicted Exchangeable Sodium Percentage (ESP) of the soil from different SAR's and the ion-interrelationship to evaluate the thermodynamic equilibrium occurring in soil solutions after irrigation. The drainage waters were classified according to the guidelines of Ayers and Westcot (1985) for agriculture use.

Data analysis: The data were statistically analyzed according to procedures of Snedecor and Cochran (1973) and SAS (2010).

Analytical procedures/methods: The drainage water samples were analyzed by following the standard analytical procedures for microbiological, physical and chemical analysis. The following instruments were used for the different analyses (Table 1).

RESULTS AND DISCUSSION

Water chemistry

Main drain D-1: The mean ranges of the different water quality parameters were 7.78-8.19 (pH), 6.88-8.85 (EC, dS m^{-1}), 1011-1358 (Na), 372-444 (Ca), 121-174 (Mg), 72-125 (K), 1618-2227 (Cl), 972-1321 (SO_4), 65-1321 (NO_3), 414-454 (HCO_3), 11.52-14.75 (SAR), 15.62-18.19 (adj.R_{Na}), 34.05-44.14 (adj.SAR) and 13.57-16.75 (ESP) at different locations in the D-1 main drain (Table 2). The drainage water from the D-1 drainage canal has high to very high salinity. The values of the Exchangeable Sodium Percentage (ESP) indicate that approximately 5% of the samples of drainage waters fall into the Na hazardous category and could create soil physical and chemical deterioration by replacing the Ca from the soil exchange complex with a high concentration of Na in water. However, according to the USDA (1954), the drainage water belongs to the C4S4 category of very high salinity and very high sodium water.

The mean ranges of micro-elements (expressed as micrograms per liter) were 3.03-6.54 (Co), 1.41-1.59 (F), 21.73-49.44 (Mn), 117.59-215.04 (Fe), 635.19-702.6 (B), 1.33-2.85 (As), 8.81-25.31 (Cu), 195.55-807.83 (Zn), 4.60-27.75 (Pb), 0.13-5.61 (Cd) and 13.65-20.82 (Cr) at different locations along the main drain (Table 3).

Main drain D-2: The mean ranges of the different water quality parameters were 7.75-8.10 (pH), 2.25-6.92 (EC, dS m^{-1}), 397-905 (Na), 162-352 (Ca), 64-153 (Mg), 29-88 (K), 606-1571 (Cl),

Table 2: Chemical analysis of the D-1 drain samples

Sampling	Parameters														
		EC	Na	Ca	Mg	K	Cl	SO_4	NO_3	HCO_3					
Station	pH	(dS m^{-1})	(mg L^{-1})								SAR	Adj.R_{Na}	Adj.SAR	ESP	Water class
M1	7.91	7.78	1135	409	121	115	1880	1023	75	423	12.80	18.09	37.95	14.88	C4S4
M2	7.90	7.95	1069	376	139	120	1811	978	82	414	12.15	16.27	35.84	14.15	C4S4
M3	7.89	7.91	1154	386	149	111	1923	1052	82	419	12.74	17.06	37.89	14.80	C4S4
M4	7.91	8.19	1232	402	154	109	2054	1086	83	427	13.28	17.73	39.87	15.35	C4S4
M5	8.00	8.10	1145	389	138	124	1912	1016	92	425	13.06	17.77	38.62	15.04	C4S4
M6	8.03	7.76	1187	401	145	106	1976	1056	81	434	13.24	18.19	39.48	15.24	C4S4
M7	8.01	8.85	1358	410	144	106	2227	1083	91	436	14.75	19.79	44.14	16.75	C4S4
M8	8.04	7.65	1079	392	143	101	1851	972	84	414	11.87	15.94	35.31	13.93	C4S4
M9	8.13	7.96	1157	414	167	72	1933	1114	108	421	12.27	16.31	36.89	14.32	C4S4
M10	8.13	7.55	1149	416	143	81	1947	996	97	437	12.56	17.24	37.67	14.66	C4S4
M11	8.19	7.44	1019	389	137	91	1688	1002	91	431	11.50	15.74	34.26	13.53	C4S4
M12	8.10	6.88	1013	378	133	89	1689	988	65	416	11.54	15.77	34.09	13.56	C4S4
M13	8.15	6.93	1011	372	135	98	1618	1058	91	419	11.54	15.72	34.05	13.57	C4S4
M14	7.85	6.94	1031	382	140	82	1637	1096	86	426	11.52	15.62	34.36	13.56	C4S4
M15	7.78	7.78	1114	419	158	81	1817	1173	89	435	11.79	16.01	35.75	13.86	C4S4
M16	7.94	8.53	1268	444	174	125	2056	1321	107	454	13.02	17.51	39.87	15.03	C4S4

Table 3: Micro-element analysis of the D-1 drain samples

Sampling	Parameters												
	EC	Co	F	Mn	Fe	B	As	Cu	Zn	Pb	Hg	Cd	Cr
Station	(dS m^{-1})	(µg L^{-1})											
M1	7.78	3.03	1.50	28.39	158.58	772.88	3.11	22.81	495.55	7.70	0	1.85	20.69
M2	7.95	4.01	1.43	30.94	128.31	688.99	2.55	14.00	231.73	22.03	0	0.13	14.98
M3	7.91	6.54	1.51	32.54	152.89	640.40	2.47	20.62	419.01	8.76	0	1.21	16.58
M4	8.19	6.00	1.53	35.42	199.04	807.93	2.75	22.96	485.10	8.32	0	0.86	20.82
M5	8.10	5.11	1.47	30.53	190.31	618.78	2.05	25.31	388.08	14.69	0	0.85	18.23
M6	7.76	6.09	1.44	30.35	122.48	744.94	2.31	23.19	545.69	6.18	0	0.97	17.01
M7	8.85	4.95	1.37	29.21	146.93	647.87	2.85	23.34	480.76	26.70	0	1.06	16.13
M8	7.65	5.56	1.45	31.36	118.94	702.68	2.57	16.49	807.83	7.61	0	1.40	16.50
M9	7.96	5.09	1.47	40.61	152.67	686.93	1.49	21.33	306.68	27.75	0	0.63	15.27
M10	7.55	4.54	1.41	49.44	137.18	661.30	1.79	16.02	249.58	5.28	0	0.56	16.73
M11	7.44	5.52	1.41	30.49	215.04	635.19	1.33	31.47	257.98	17.59	0	2.27	17.32
M12	6.88	4.42	1.42	28.49	127.56	653.96	1.76	19.10	275.28	5.84	0	1.59	15.02
M13	6.93	4.54	1.42	34.41	152.51	687.86	1.96	25.29	328.55	4.81	0	2.58	14.98
M14	6.94	5.22	1.40	29.30	132.27	635.64	1.29	10.38	321.61	4.91	0	1.33	13.65
M15	7.78	4.63	1.49	21.73	120.61	636.75	1.23	11.48	304.32	4.60	0	5.61	13.94
M16	8.53	3.83	1.59	38.00	117.59	567.45	1.71	8.81	328.15	4.67	0	2.70	13.59
Permissible limits		0.05	1.0	0.20	5.0	1.0	0.10	0.20	2.0	5.0	-	0.01	0.10

390-927 (SO_4), 30-99 (NO_3), 330-401 (HCO_3), 6.76-10.54 (SAR), 8.61-13.41 (adj.R_{Na}), 17.31-29.76 (adj.SAR) and 7.94-12.44 (ESP) at different locations in the D-2 main drain (Table 4). Based on the USDA irrigation water classification scheme, the drainage water falls in the category of C4S3 to C3S2 category with a very high salinity and high sodium water to high salinity and medium sodium water.

Table 4: Chemical analysis of the D-2 drain samples

Sampling Station	pH	EC (dS m^{-1})	Na	Ca	Mg	K	Cl	SO_4	NO_3	HCO_3	SAR	Adj.R_{Na}	Adj.SAR	ESP	Water class
			(mg L^{-1})												
M1	7.75	5682	785	305	123	85	1302	812	69	401	9.63	12.63	27.73	11.41	C4S3
M2	7.75	6256	905	352	153	88	1571	927	77	399	10.03	13.13	29.47	11.84	C4S3
M3	7.77	6923	816	283	109	70	1255	811	84	401	10.54	13.41	29.76	12.44	C4S3
M4	7.79	5332	776	294	119	79	1265	794	99	388	9.73	12.79	27.61	11.53	C4S3
M5	7.91	2575	397	162	64	29	606	390	30	330	6.76	8.61	17.31	7.94	C3S2
M6	8.10	2252	629	225	117	53	1055	594	68	343	7.66	9.76	20.94	8.87	C3S3

Table 5: Micro-elements analysis of the D-2 drain samples

Sampling Station	EC (dS m^{-1})	Co	F	Mn	Fe	B	As	Cu	Zn	Pb	Hg	Cd	Cr
		(µg L^{-1})											
M1	5682	5.72	1.44	21.36	126.94	686	2.87	9.23	414	5.79	0	1.07	11.50
M2	6256	4.19	1.43	59.80	132.83	701	2.83	9.98	202	5.17	0	0.92	12.76
M3	6923	5.55	1.51	26.33	130.38	588	1.49	9.15	225	3.40	0	0.85	11.85
M4	5332	5.76	1.42	23.82	126.01	627	1.67	10.64	218	4.98	0	1.00	13.46
M5	2575	3.32	1.31	20.07	115.99	571	0.76	9.35	199	2.47	0	0.71	12.33
M6	2252	6.46	1.22	22.75	131.48	552	0.72	10.28	204	2.00	0	1.16	14.76
Permissible limits		0.05	1.00	0.20	5.00	1.0	0.10	0.20	2.0	5.00	-	0.01	0.10

The mean ranges of micro-elements (expressed as micrograms per liter) were 3.32-6.46 (Co), 1.22-1.51 (F), 20.07-59.80 (Mn), 115.99-132.85 (Fe), 552-701 (B), 0.72-2.87 (As), 9.23-10.64 (Cu), 199-414 (Zn), 2.00-5.79 (Pb), 0.71-1.16 (Cd) and 11.55-13.46 (Cr) at different locations along the main drain D-2 (Table 5).

Ion interrelationship

Cl vs. Na, Ca, Mg and K: The data in Fig. 1 illustrate the relationship between Cl and the major cations. The relationship between Cl and Na is very strong as shown by the high value of the coefficient of determination ($R^2 = 0.951$) followed by a weak relationship between Cl vs. Ca ($R^2 = 0.423$), Cl vs. Mg ($R^2 = 0.200$) and Cl vs. K ($R^2 = 0.144$) in the drainage water. This indicates that the order of major salts in the drainage water is $NaCl>CaCl_2>MgCl_2>KCl$ due to the salt solubility constants. The solubility constants of Na salt are very high compared to all other cations.

SO_4 vs. Na, Ca, Mg and K ions: A regression analysis was performed to determine the relationship between SO_4 and other major cations (Na, Ca, Mg and K) in the drainage waters of the D-1 main drain (Fig. 2). The SO_4 ion has a strong relationship with Ca ($R^2 = 0.513$) and Mg ($R^2 = 0.608$) compared to the Na ($R^2 = 0.230$) and K ($R^2 = 0.006$) ions. This indicates that the SO_4 radical is strongly associated with Ca and Mg ions, making $CaSO_4$ and $MgSO_4$ salt ion pairs comparable to Na_2SO_4 and K_2SO_4 salts. In other words, D-1 drain drainage water is dominated by Ca and Mg salts, followed by Na and K sulfate salts. This may be due to the difference in the solubility constants of different salts in association with different major cations.

SO_4 vs. Na, Ca, Mg and K ions: A regression analysis was performed to determine the relationship between SO_4 and other major cations (Na, Ca, Mg and K) in the drainage waters of

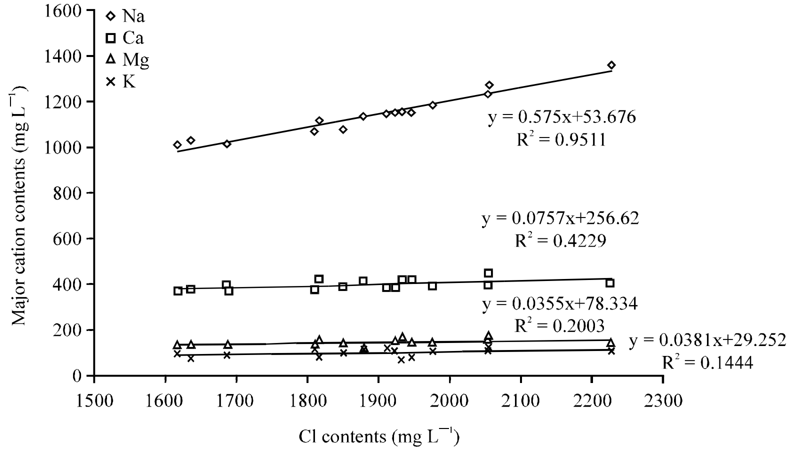

Fig. 1: Relationship between Cl and major cations of drainage water

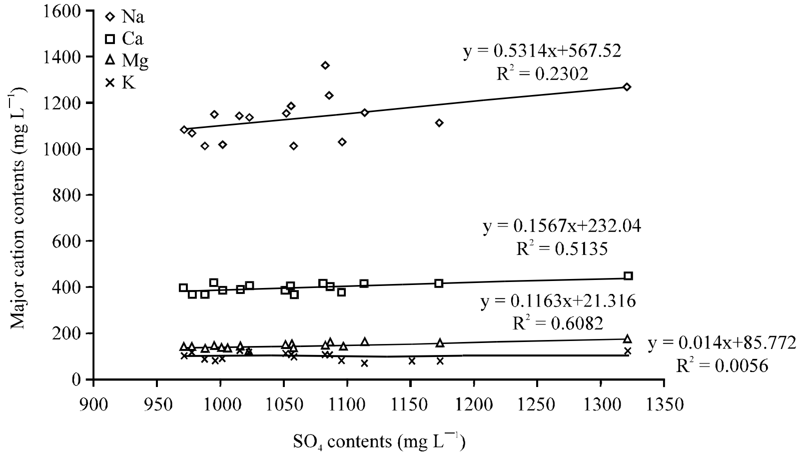

Fig. 2: Relationship between SO_4 and major cations of drainage water

the D-1 main drain (Fig. 2). The SO_4 ion has a strong relationship with Ca ($R^2 = 0.513$) and Mg ($R^2 = 0.608$) compared to the Na ($R^2 = 0.230$) and K ($R^2 = 0.006$) ions. This indicates that the SO_4 radical is strongly associated with Ca and Mg ions, making $CaSO_4$ and $MgSO_4$ salt ion pairs comparable to Na_2SO_4 and K_2SO_4 salts. In other words, D-1 drain drainage water is dominated by Ca and Mg salts, followed by Na and K sulfate salts. This may be due to the difference in the solubility constants of different salts in association with different major cations.

EC vs. Cl and SO_4 ions: The data in Fig. 3 indicated a linear increase in the Cl content ($R^2 = 0.832$) compared to the SO_4 content (0.167) and there was an increase in the total salinity of the drainage water in the D-1 drain. This variation may be due to the addition of the Na dominant salt (NaCl) in the drainage waters as the seepage water is collected from adjacent, high salt affected lands with high NaCl salts compared to SO_4 salts under the reclamation process. The data also indicate that most of the drainage water salinity is dominated by the Cl ion compared to the sulfate ion because of the difference in the solubility constant between the two anions (higher for the Cl ion than the SO_4 radical).

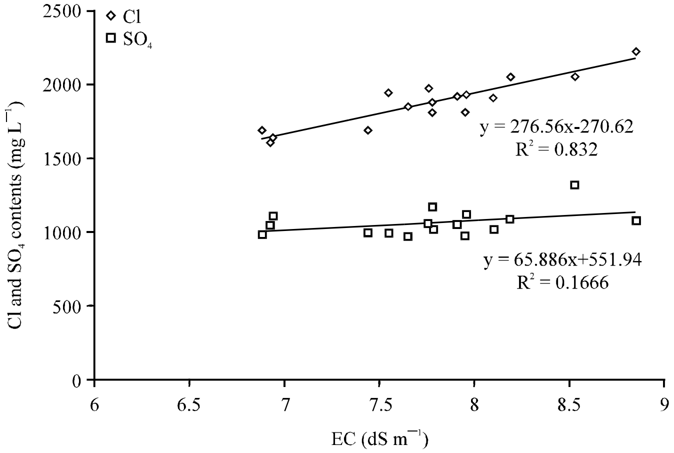

Fig. 3: Relationship between EC vs. CI and SO_4 of drainage water

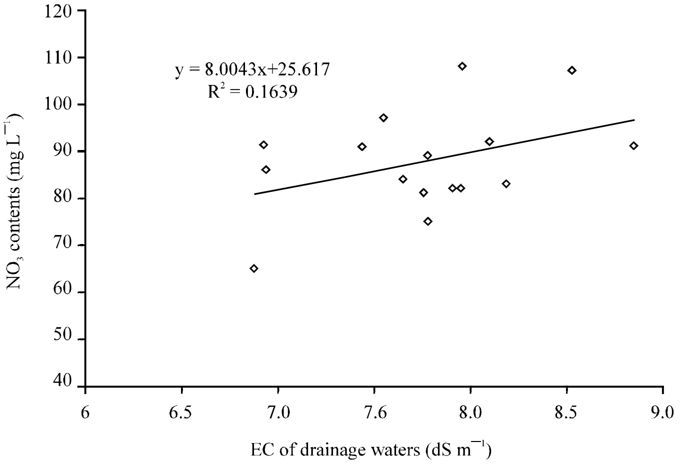

Fig. 4: Relationship between EC and NO_3 of drainage water

EC vs. NO_3 contents: The regression analysis showed a very poor relationship between the total water salinity and NO_3 content ($R^2 = 0.164$) of drainage water (Fig. 4). Although the NO_3 content of drainage water ranged between 60 and 110 mg L^{-1} which is considered to be high, the poor relationship indicated there was an insignificant relationship between the water salinity and NO_3 content. The high NO_3 concentration in the drainage water may be due to the seepage of nitrogen compounds from the adjacent fields that receive excessive nitrogen fertilizer to promote increased crop production.

HCO_3 vs. Na, Ca, Mg and K ions: The data in Fig. 5 shows a fairly strong relationship between Ca and HCO_3 ($R^2 = 0.648$) but the relationship was very poor between HCO_3 and Na ($R^2 = 0.351$), HCO_3 and Mg ($R^2 = 0.274$) and HCO_3 and K ($R^2 = 0.009$) at different sampling stations in the D-1 drain. The study results showed that the HCO_3 anion is strongly associated with Mg cation compared to Na, Ca and K cations.

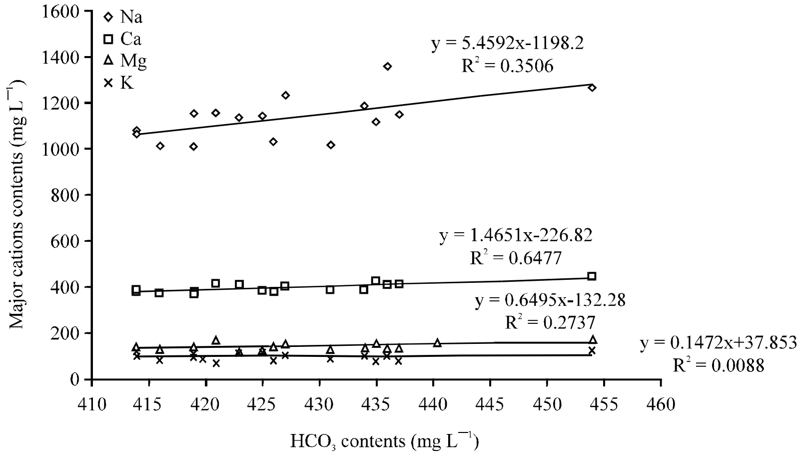

Fig. 5: Relationship between HCO_3 vs. major cations of D-1 drainage water

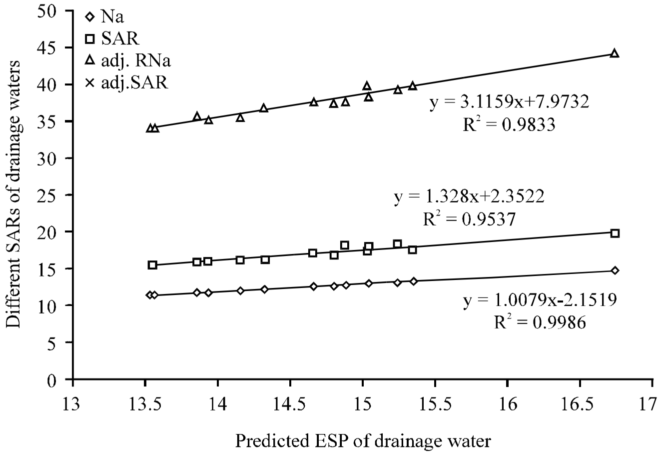

Fig. 6: Relationship between predicted ESP vs. different SARs of drainage water

Exchangeable Sodium Percentage (ESP) vs. SARs: The relationship between the predicted ESP and different sodium adsorption ratios of drainage water is very strong as indicated by the high value of R^2 values which were 0.983 for ESP vs. SAR, 0.954 for ESP vs. adj.R_{Na} and 0.998 for ESP vs. adj, SAR (Fig. 6). The data indicate that the values of the predicted ESP of the soil increased linearly with increasing SAR values of the drainage water. Overall, the ESP values were within acceptable limits, indicating that irrigation with these drainage waters will not pose any soil physical or chemical deterioration after irrigation.

EC vs. different SARs of drainage water: There is a good relationship between the EC and SARs of drainage water (Fig. 7). It is known that the SAR of water increases with the square root of the increasing total water salinity. The R^2 value was 0.750 for EC vs. SAR, 0.605 for EC vs. adj.R Na and 0.727 for EC vs. adj.SAR in different locations.

Cl vs. Na, Ca, Mg and K in the D-2 drain: The Cl content of drainage water had a strong relationship with Na (R^2 = 0.567), Ca (R^2 = 0.993) and K (R^2 = 0.619) ions but had a poor

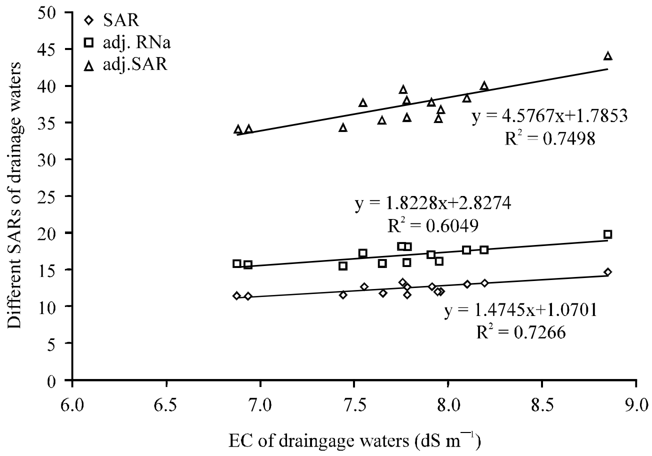

Fig. 7: Relationship between EC vs. different SARs of drainage water

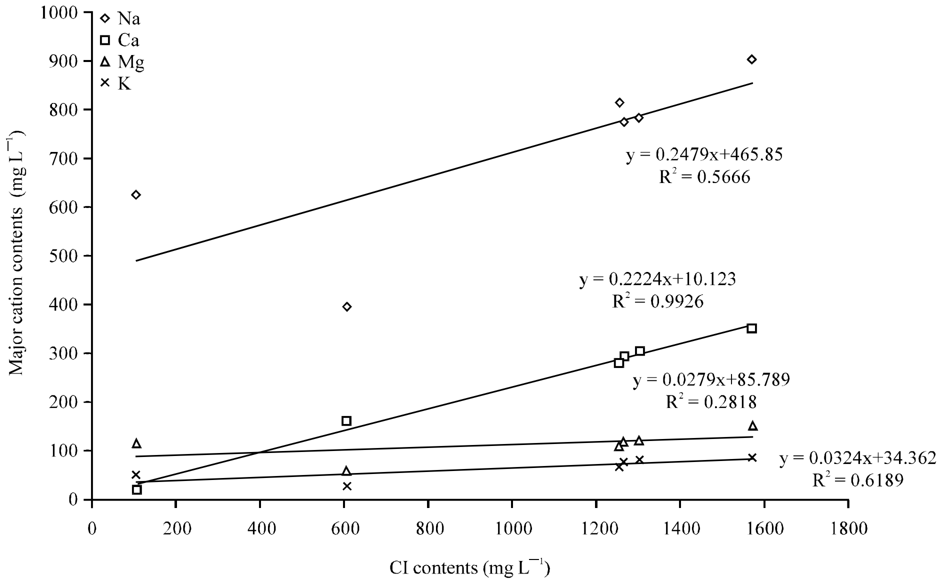

Fig. 8: Relationship between Cl vs. major cations D-2 drain

relationship with Mg ($R^2 = 0.282$) ions (Fig. 8). This indicated that the drainage water in the D-2 drain was dominated by Na, Ca and K salts compared to Mg salt.

SO_4 vs. Na, Ca, Mg and K ions: The regression analysis showed a strong SO_4 anion with all of the major cations (Fig. 9). The order of the strength of the relationship followed the trend of Na vs. SO_4 ($R^2 = 0.989$)>K vs. SO_4 ($R^2 = 0.949$)>Mg vs. SO_4 ($R^2 = 0.787$)>Ca vs. SO_4 ($R^2 = 0.572$) at different locations along the main drain D-2. The drainage water in the D-2 drain was dominated by Na_2SO_4, K_2SO_4 and Mg SO_4 salt ion pairs compared to the $CaSO_4$ salt ion pair which may be due to the low solubility constant of $CaSO_4$ salt compared to other highly soluble salts in the drainage water.

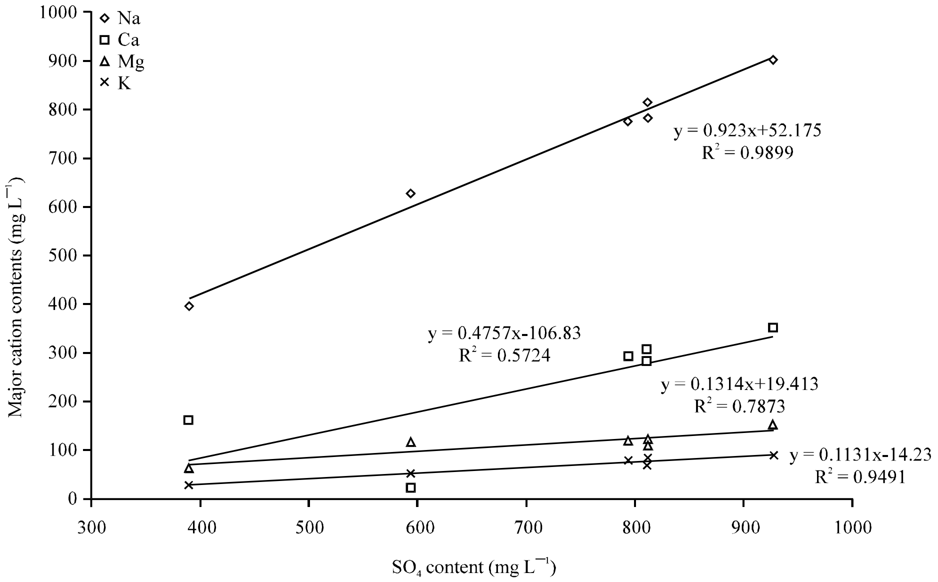

Fig. 9: Relationship between SO_4 vs. major cations D-2 drain

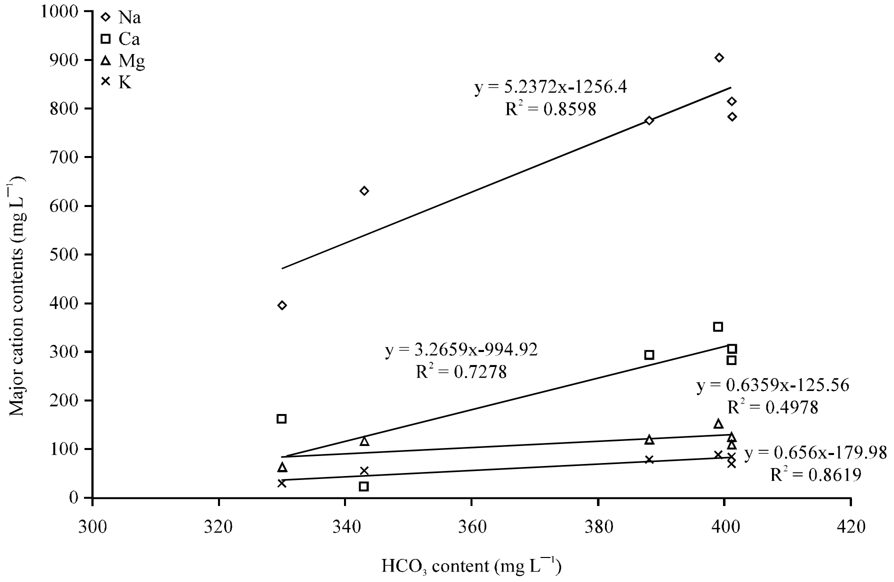

Fig. 10: Relationship between HCO_3 vs. major cations D-2 drain

HCO_3 vs. major cations (Na, Ca, Mg and K): Data in Fig. 10 showed a strong relationship between HCO_3 and Na ($R^2 = 0.860$) and Ca ($R^2 = 0.728$) and K ($R^2 = 0.862$), except Mg which had a low R^2 value of 0.498 in the drainage water. This weak relationship between HCO_3 and Mg may be because $Mg(HCO_3)_2$ is unstable and quickly converted to the more stable CO_3 form in the soil-water solution.

EC vs. different SARs of drainage waters: A very strong relationship was observed between the EC and different SAR values of drainage waters (Fig. 11). The values of the coefficient of

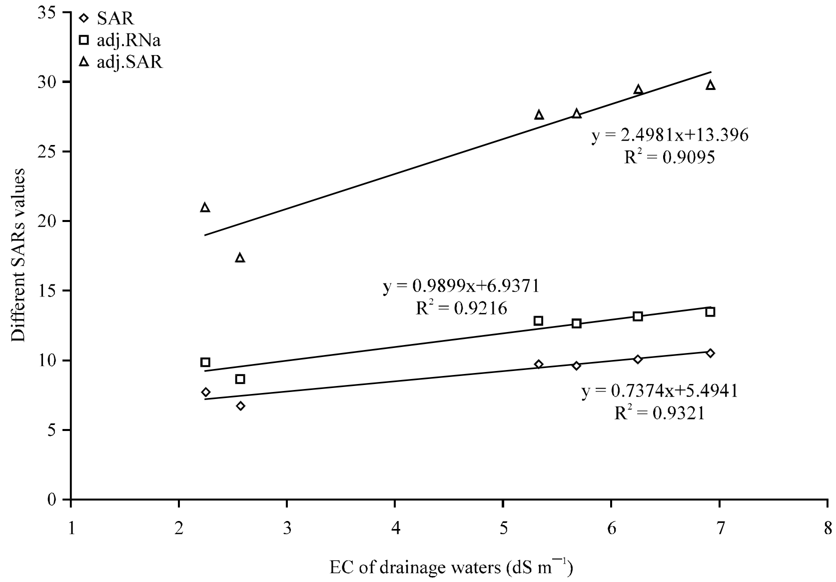

Fig. 11: Relationship between EC vs. different SARs of drainage waters

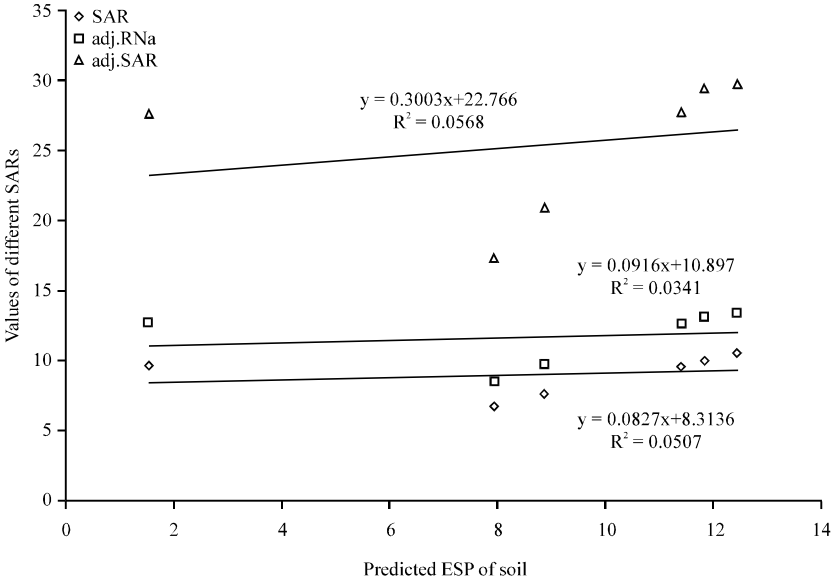

Fig. 12: Relationship between ESP vs. SARs of D-2 drainage waters

determination (R^2) were 0.909, 0.922 and 0.932 for EC vs. adj.SAR, EC vs. adj. R_{na} and EC vs. SAR, respectively, at different locations of the drain. The SAR values linearly increased with the corresponding increase in the EC (total water salinity).

ESP vs. different SARs of drainage water: The regression analysis showed a poor relationship between the ESP and different SAR values of the drainage water (Fig. 12). The R^2 values were 0.057, 0.034 and 0.051 for ESP vs. adj.SAR, ESP vs adj.R_{Na} and SAR, respectively. The predicted

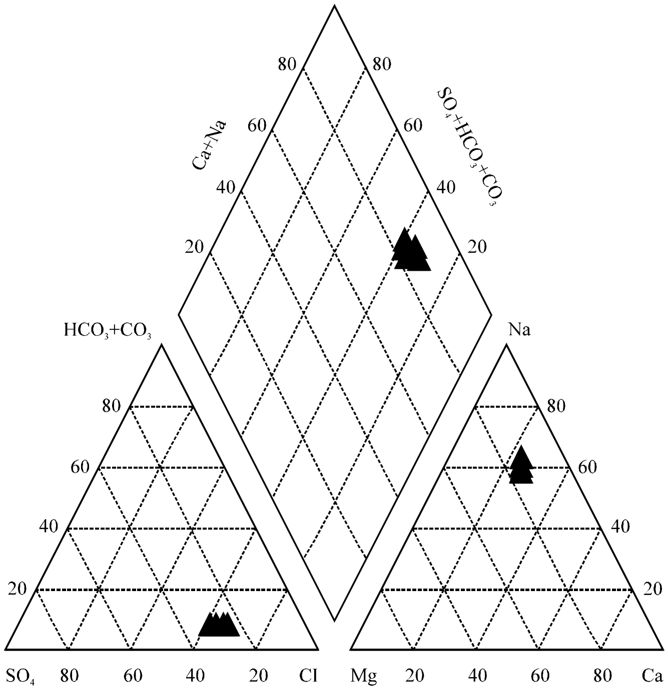

Fig. 13: Piper diagram for the classification of D-1 drainage waters

value of ESP from different SARs was well below the hazardous limit of 15 which can cause deterioration of the soil physical and chemical properties, resulting in loss of land productivity.

Classification of the drainage water: It can be seen from the piper diagrams (Fig. 13 and 14) that drainage water from both the D-1 and D-2 main drains is Na-Cl-HCO_3 water. The drainage water was dominated by the Na ion, followed by Ca, Mg and K in descending order as well as by different anions (Cl>HCO_3>SO_4). It is well known that the ion pairs formed in the drainage waters are NaCl>$CaCl_2$>$MgCl_2$>KCl due to the salt solubility constants.

Bacterial analysis

Main drain D-1: The count of the total coliforms bacteria ranged between 7.0 and 118 for the total bacteria count (MPN colonies/100 mL water sample) and the *E. coli* ranged between 0.0 and 56.3 (MPN colonies/100 mL water sample) at various locations of the main drain D-1 (Table 6). The main source of bacterial contamination, especially of *E. coli*, in the drainage water seems to be the household sewage effluent containing human waste (main source of *E. coli* bacteria) that flows into these drains. D1 samples show that the *E. coli* that are present are those collected downstream, after the wastewater treatment plant (WWP).

Main drain D-2: The count of the total coliform bacteria ranged between 4.0 and 62.0 (MNP) for the total coliform bacteria and the *E. coli* ranged between 4.0 and 41.0 (MNP) at various locations of the main D-2 drain (Table 7). As stated earlier, the presence of *E. coli* indicates the disposal of household sewage effluent containing human waste (main source of *E. coli*).

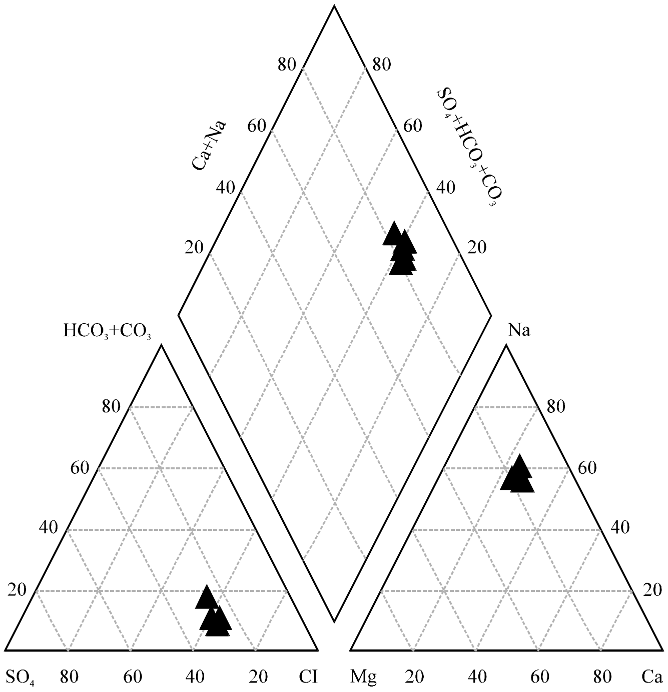

Fig. 14: Piper diagram for the classification of D-2 drainage waters

Table 6: Total coliform and *E. coli* count in the main drain D-1

D-length (km)	ID number	DO	BOD	COD	*E. coli*	Total plate	Total coliforms
0.00	M1	1.94	50	209	26.0	276	50.2
1.74	M2	1.77	35	198	7.1	414	118.6
2.87	M3	1.44	40	197	56.3	223	85.9
5.25	M4	1.69	60	287	13.0	141	28.2
8.37	M5	1.78	58	263	9.0	266	67.2
12.46	M6	1.97	65	289	16.0	287	79.0
14.64	M7	1.39	80	350	6.0	124	23.8
18.54	M8	1.82	67	319	11.0	195	56.3
22.78	M9	2.81	125	578	19.0	216	70.0
26.27	M10	4.59	43	182	13.0	116	41.1
27.49	M11	8.17	29	76	36.0	239	71.0
29.79	M12	9.30	40	73	2.8	56	19.2
30.73	M13	10.35	75	154	0.0	19	7.0
36.31	M14	3.90	70	148	4.6	51	13.8
40.14	M15	3.45	52	93	4.6	137	24.9
44.68	M16	4.23	45	118	0.0	83	15.0

Overall, the level of *E. coli* was significantly high in the main D-2 drain compared to the main D-1 drain. This significant difference in *E. coli* may be due to the disposal of sewage effluent from the main city of Hofuf into the main D-2 drain containing mostly human waste, the main source of *E. coli*. In D2, all of the samples showed the presence of *E. coli* because of the supply of untreated wastewater from the WWP at the beginning of D1.

Table 7: Total coliform and *E. coli* count in main drain D-2

D. length	ID	DO	BOD	COD	*E. coli*	Total plate	Total coliforms
0.00	D2M01	1.81	80	152	6.8	35	17.5
4.00	D2M02	1.79	67	150	4.0	51	8.0
11.42	D2M03	2.11	105	253	41.0	276	56.0
13.36	D2M04	2.67	55	141	4.8	71	18.6
21.75	D2M05	3.76	70	144	28.0	209	62.0
25.80	D2M06	2.60	40	155	4.0	28	4.0

DISCUSSION

The study results indicated that the drainage water of D-1 belongs to the C4S4 category of very high salinity and very high sodium water, while the drainage water of D-2 falls in the category of C4S3 to C3S2 category with a very high salinity and high sodium water to high salinity and medium sodium water. The relationship between Cl and Na was very strong followed by a weak relationship between Cl and other major cations (Ca, Mg and K in the drainage water. Most of the drainage water salinity is dominated by the Cl ion compared to the sulfate ion. The study results agree with the findings of many investigators who reported the effect of quality of groundwater for deteriorating the quality of drainage water due to excessive use of groundwater for irrigation (Raveendran and Madany, 1991a, b; Madany and Akhter, 1990). Also, El-Din *et al*. (1993) and Hejazi (1989) observed that seepage of waste effluent from septic tanks and cesspools was responsible for the deterioration of drainage water.

In this study, the NO_3 content of drainage water ranged between 60 and 110 mg L^{-1} which is considered to be high according to the safe limits for irrigation purpose. Previously, many researchers found the concentration of nitrate (NO_3) in the groundwater varied from 50-30 mg L^{-1} in the croplands irrigated with wastewater. On the other hand, the NO_3 concentrations were less than 35 mg L^{-1} in well water irrigated croplands according to Tang *et al*. (2004) and Bae and Lee (2008). The drainage water in the D-2 drain was dominated by Na_2SO_4, K_2SO_4 and $MgSO_4$ salt ion pairs compared to the $CaSO_4$ salt ion pair. The drainage water from both the D-1 and D-2 main drains is Na-Cl-HCO_3 water.

Overall, the level of *E. coli* was significantly high in the main D-2 drain compared to the main D-1 drain. The drainage water in D-1 is classified as C4S4 (very high salinity and very high sodium water), while D-2 drainage water is classified as C4S3 to C3S2 (very high salinity-high sodium water to high salinity-medium sodium water). The nitrate (NO_3) concentration is above the recommended limit for irrigation use. The bacterial contamination is very high in the drainage water of both drains and not fit for irrigation. Similar results were reported by Ghafari *et al*. (2008) who studied aquaculture wastewaters and industrial wastewater containing high levels of nitrate for groundwater contamination.

CONCLUSION

The drainage water in D-1 is classified as C4S4 (very high salinity and very high sodium water), while D-2 drainage water is classified as C4S3 to C3S2 (very high salinity-high sodium water to high salinity-medium sodium water). The order of abundance of different salts with respect to Cl in the D-1 drainage water was NaCl >$CaCl_2$>$MgCl_2$>KCl; with respect to SO_4 salt, it was $MgSO_4$>$CaSO_4$>Na_2SO_4>K_2SO_4 and for HCO_3, t was $Ca(HCO_3)_2$>$NaHCO_3$>$Ca(HCO_3)_2$>$KHCO_3$. The drainage waters of both D-1 and D-2 drains are free of sodicity hazards because of the low SAR values. The Na salts dominate in most of the drainage water compared to other cations, such as Ca, Mg and K.

All of the trace elements in the drainage water of both of the drains are within the permissible limits for irrigation purposes. The nitrate (NO_3) concentration is above the recommended limit for irrigation use. The bacterial contamination is very high in the drainage water of both drains and it was not fit for irrigation without proper treatment. The concentration of trace and heavy metal ions was within the permissible limits.

Based on the chemistry, the drainage water is not fit for irrigation due to the high total water salinity which could deteriorate the soil physico-chemical characteristics after irrigation. In conclusion, if drainage water is intended for reuse, certain precautionary measures, such as leaching requirements, selection of salt tolerant crop plants and advanced irrigation (drip irrigation), need to be considered to avoid the loss of land productivity.

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REFERENCES

APHA., AWWA. and WEF., 1998. Standard Methods for the Examination of Water and Wastewater. 20th Edn., American Public Health Association/American Water Works Association/Water Environment Federation, Washington, DC., USA., ISBN-13: 9780875532356, Pages: 1220.

Abu-Rizaiza, O.S., 1999. Modification of the standards of wastewater reuse in Saudi Arabia. Water Res., 33: 2601-2608.

Al-Hawas, I.A., 2002. Irrigation water quality evaluation of al-hassa springs and its predictive effects on soil properties. Pak. J. Biol. Sci., 5: 651-655.

Alaboud, T.M., 2009. Membrane bioreactor for wastewater reclamation-pilot plant study in Jeddah, Saudi Arabia. Res. J. Environ. Sci., 3: 267-277.

Alyamani, M.S., 2007. Effects of cesspool systems on groundwater quality of shallow bedrock aquifers in the recharge area of Wadi Fatimah,Western Arabian Shield, Saudi Arabia. J. Environ. Hydrol., 15: 1-11.

Ayers, R.S. and D.W. Westcott, 1985. Water Quality for Agriculture. FAO, Rome, ISBN: 9789251022634, Pages: 174.

Bae, S.K. and S.H. Lee, 2008. [Interaction between groundwater and surface water in urban area. J. Korea Water Resour. Assoc., 41: 919-927.

Bazuhair, A.S. and A. Alkaff, 1989. Evaluation of ground water quality in Wadi Al-Yamaniyah Saudi Arabia. Arab Gulf J. Sci. Res., 7: 21-38.

Bouwer, H., 2000. Groundwater problems caused by irrigation with sewage effluent. J. Eniron. Health, 63: 17-20.

Carr, R.M., U.J. Blumenthal and D.D. Mara, 2004. Guidelines for the safe use of wastewater in agriculture. Water Sci. Technol., 50: 31-38.

Chamtouri, I., H. Abida, H. Khanfir and S. Bouri, 2008. Impacts of at-site wastewater disposal systems on the groundwater aquifer in arid regions: Case of Sfax city, Southern Tunisia. Environ. Geol., 55: 1123-1133.

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

Faruq, I.M., M. Jahangir and A.S. Al-Shareef, 1996. Chemical characteristics of Saudi ground water, Al-Qassim. Biol. Sci. Saudi Biol. Soc. J., 4: 123-140.

Ghafari, S., M. Hasan and M.K. Aroua, 2008. Bio-electrochemical removal of nitrate from water and wastewater-a review. Bioresour. Technol., 99: 3965-3974.

Hejazi, R.F., 1989. Investigation of leachate from a sanitary landfill in Saudi Arabia. M.Sc. Thesis, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia.

Hussain, G. and M. Sadiq, 1991. Metal chemistry of irrigation and drainage waters of Al-Ahsa Oasis of Saudi Arabia and its effects on soil properties. Water Air Soil Pollut., 57-58: 773-783.

Jun, S.C., G.O. Bae, K.K. Lee and H.J. Chung, 2005. Identification of the source of nitrate contamination in ground water below an agricultural site, Jeungpyeong, Korea. J. Environ. Quality, 34: 804-815.

Kalavrouziotis, I.K., P. Robolas, P.H. Koukoulakis and A.H. Papadopoulos, 2008. Effects of municipal reclaimed wastewater on the macro-and micro-elements status of soil and of *Brassica oleracea var. Italica* and *B. oleracea var. Gemmifera*. Agric. Water Manage., 95: 419-426.

Madany, I.M. and M.S. Akhter, 1990. Assessment of the chemical and physical properties of Adari spring in Bahrain. Environ. Int., 16: 297-300.

Mahmood, S. and A. Maqbool, 2006. Impacts of wastewater irrigation on water quality and on the health of local community in Faisalabad. Pak. J. Water Res., 10: 19-22.

Massoudinejad, M.R., M. Manshouri and A.R. Yazdanbakhsh, 2007. Study on the reuse of Zamyad factory wastewater treatment plant effluent in irrigation. Iran J. Environ. Health Sci. Eng., 3: 285-288.

Mee, J.M., 1983. Saudi ground water chemistry and significance. Arab Gulf J. Sci. Res., 1: 113-120.

Raveendran, E. and I.M. Madany, 1991a. Characteristics of agricultural drainage water in Bahrain. Sci. Total Environ., 104: 239-247.

Raveendran, E. and I.M. Madany, 1991b. The quality of groundwater in Bahrain. Sci. Total Environ., 103: 177-184.

SAS., 2010. Base SAS. 9.2 Procedures Guide: Statistical Procedures. 3rd Edn., SAS Institute Inc., Cary, NC., USA., pp: 17-34.

Selim, M.M., 2008. Evaluation of the re-use of treated wastewater for irrigation. Acta Agron. Hungarica, 56: 477-484.

Snedecor, G.W. and W.G. Cochran, 1973. Statistical Methods. 6th Edn., Iowa State University Press, Ames, Iowa, USA.

Suarez, D.L., 1981. Relation between pHc and Sodium Adsorption Ratio (SAR) and an alternative method of estimating SAR of soil or drainage waters. Soil Sci. Soc. Am. J., 45: 469-475.

Tang, C., J. Chen, S. Shindo, Y. Sakura, W. Zhang and Y. Shen, 2004. Assessment of groundwater contamination by nitrates associated with wastewater irrigation: A case study in Shijiazhuang region, China. Hydrol. Processes, 18: 2303-2312.

USDA., 1954. Diagnosis and Improvement of Saline and Alkali Soils. Handbook No. 60, United States Department of Agriculture, Washington, DC., USA.

WRD., 1985. Water atlas of Saudi Arabia. Water Resources Department (WRD), Ministry of Agriculture and Water, Riyadh, Saudi Arabia.

Wang, J.F., G.X. Wang and H. Wanyan, 2007. Treated wastewater irrigation effect on soil, crop and environment: Wastewater recycling in the loess area of China. J. Environ. Sci., 19: 1093-1099.

Yadav, R.K., B. Goyal, R.K. Sharma, S.K. Dubey and P.S. Minhas, 2002. Post-irrigation impact of domestic sewage effluent on composition of soils, crops and ground water: A case study. Environ. Int., 28: 481-486.