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EVALUATING THE EFFECT OF DIFFERENT TYPES OF IRRIGATION WATER ON LEVEL OF HEAVY METALS IN SOIL IN AL- HASSA OASIS, SAUDI ARABIA

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ABSTRACT

The present study is conducted to investigate the effect of irrigation water quality on heavy metals content in soil of Al- Hassa Oasis. The investigated irrigation water included groundwater (GW), mixture of groundwater and drainage water (GW+DW), mixture of groundwater and tertiary treated wastewater (GW+TTWW) and mixture of groundwater, drainage water and tertiary treated wastewater (GW+DW+TTWW). The results of this study indicate that the water types used in the present study may cause one problem or another according to the water type. By applying the criteria used for interpreting water quality for irrigation, the most domain problems are salinity hazard, potential salinity and soluble sodium percentage. Therefore, it is expected that continuous irrigation without good water management (leaching requirements) can led to severe problems from the salinity point of view. (GW+DW +TTWW) have the highest effect on elemental composition of soil followed by (GW+TTWW), (GW+DW) and then (GW). Generally, a significant difference in the heavy metals concentrations for both treated soil was found. The contents of the heavy metals in soil samples are compared with the worldwide standards. Based on these comparisons some recommendations are raised.

Keywords: - Al Hassa Oasis, Water Quality, Heavy metals, Water Resources, Environmental hazards.

INTRODUCTION

Water insufficiency is one of the most critical problems that confront the world particularly in the arid and semi arid regions. The water policy of any country is to use all water resources. The sources of irrigation water in Al-Hassa Oasis, Saudi Arabia are drainage water, tertiary treated wastewater and groundwater individually or mixed. The agriculture production of the country does not supply enough for the people demands. Most of the principal foods, such as wheat, oil, corn, soybeans, etc. are imported. The agriculture policy is planned to produce enough for local consumption. This policy will succeed by adding more arable land and increasing production per unit area.

The limiting factor for reclaiming and increasing the arable land is the available good quality water. Before using any source of water that mentioned before, it should be tested to find out its effect on soil chemical, physical, nutritional, fertility and toxicity properties. The effects on plant growth, yield and elemental analysis must be calibrated. Also, the hygienic and pathogenic effect on animal and human must be studied. The irrigation regime, the amount of applied water, the method of irrigation and, soil texture are some of the most important factors governing soil salinization.

Heavy metals are components of the biosphere, occurring naturally in soils and plants, but, as a consequence of industrialization. Heavy metals from various sources such as fossil fuel combustion, sewage sludge, industrial waste and fertilizer, contaminate the environment. Plants growing on polluted soils may contain elevated levels of heavy metals (Gallego *et al*., 2002; Zornoza *et al*., 2002). Heavy metal ions such as zinc, manganese and nickel are essential micronutrients for plants, but when present in excess, these, and also non-essential heavy metals such as cadmium, can accumulate in plant parts used for human or animal nutrition to undesirably high contents. At even higher levels, they can become toxic to the plant (Williams *et al*., 2000). The growing urbanization increases domestic water use while supplying wastewater that can be used for non-potable purposes, such as agricultural irrigation.

The wastewater is becoming a preferred marginal water source, since its supply is reliable and uniform, and is increasing due to population growth an increased awareness of environmental quality. In principle, the costs associated to this water source are low compared with those of other water sources (Bahri, 1999). In developed countries the predominant trend in agricultural wastewater reuse is to irrigate treated wastewater (Smith, 1996; Haruvy, 1997; Bahri, 1999,; Nicholson *et al*., 2003). In contrast, most developing countries such as Mexico, Peru, Chile and Argentina rely on raw wastewater for agricultural irrigation (Siebe and Cifuentes, 1995; Peasey *et al*., 2000).

The present study is conducted to investigate the effect of using different irrigation water qualities on some heavy metals content in soil of Al-Hassa Oasis, Saudi Arabia.

MATERIALS AND METHODS

Al-Hassa Oasis is one of the important agricultural regions in the Kingdom of Saudi Arabia. In the past, the ground water was the main source of irrigation water. Nowadays, other water resources are used to meet agriculture expansion due to the limited ground water resource. Drainage water (DW), tertiary treated wastewater (TTWW) and groundwater (GW) individually or mixed were used for long term to irrigate the soil of Al-Hassa Oasis.

The investigated irrigation waters include groundwater (GW), mixture of groundwater and drainage water (GW+DW), mixture of groundwater and tertiary treated wastewater (GW+TTWW) and mixture of groundwater, drainage water and tertiary treated wastewater (GW+DW+TTWW). Average characteristics of irrigation water quality used for irrigating the investigated soil are illustrated in (Table, 1).

Quality of irrigation water was determined according to the following parameters (Wilcox, 1958 and FAO, 1973& 1976).

1. The salt concentration of water, which can be expressed in terms of electrical conductivity (EC_{iw}, dS/m).
2. The chemical composition of water, by determining the concentrations of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^{-}, Cl^{-} and SO_4^{2-} ions (me/L).

Table (1): Average characteristics of irrigation water quality used for irrigation in the present study.

Characteristics	Irrigation Water			
	GW	GW+DW	GW+TTWW	GW+DW+TTWW
pH	7.37	7.41	7.44	7.55
EC (dS/m)	2.24	2.85	3.84	4.24
TDS (mg/L)	1433.6	1824.0	2457.6	2713.6
Soluble Cations, me/L				
Ca^{2+}	6.29	7.37	12.09	9.21
Mg^{2+}	4.56	4.58	5.63	6.12
Na^{+}	10.31	15.21	19.85	25.14
K^{+}	0.96	0.53	0.42	0.89
Soluble Anions, me/L				
CO_3^{2-}	-	-	-	-
HCO_3^{-}	3.38	4.59	3	5.57
Cl^{-}	8.12	11.61	25	21.11
SO_4^{2-}	10.42	11	9.16	14.58
NO^{-}_3 , mg/L	3.43	6.9	13.13	11.21
Micronutrients, mg/L				
Fe	2.29	3.05	2.31	4.43
Mn	0.34	0.43	0.38	0.39
Cu	0.11	0.09	0.08	0.17
Zn	0.18	2.12	2.34	3.31
B	0.23	0.42	0.33	0.41
Heavy metals, mg/L				
Cd	0.040	0.050	0.090	0.130
Co	0.012	0.015	0.017	0.021
Ni	0.010	0.014	0.020	0.026

The quality parameters were calculated from as follows:

a. Sodium Hazard:

Can be expressed in terms of Sodium Adsorption Ratio (SAR) or Soluble Sodium Percentage (SSP, %).

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

$$SSP = \frac{Na^{+}}{\sum Cations} \times 100$$

(The concentration of cations was expressed in me/L).

b. Magnesium hazard (SMgP):

It can be expressed by the value of Soluble Magnesium Percentage (SMgP, %),

$$SMgP = \frac{[Mg2+]}{[Ca^{2+} + Mg^{+2}]} \times 100$$

c. Bicarbonate hazard:

It can be expressed by the value of Residual Sodium Carbonate (RSC, me/L):

$(RSC) = [CO_3^{2-} + HCO^{-}_3] – [Ca^{2+} + Mg^{2+}]$

(The concentration of ions was expressed in me/L.)
3-The concentration of toxic compounds, can be expressed by the values of:
a. Potential Salinity (PS) PS (me/L) = $Cl^{-} + 0.5 *SO_4^{2-}$
b. The boron concentration (B, mg/L)
c. The nitrate concentration (NO_3^{-} , mg/L).

Table (2): Some physical and chemical characteristics of the experimental soil used in the present study.

NO.	clay, %	Silt,%	Sand, %	Texture	ECe (dS/m)	pH*	OM %	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
GW														
1	10.1	8.1	81.8	LS	1.68	7.66	0.25	8.83	6.51	1.24	0.15	1.59	1.86	12.74
2	8.1	6.1	85.8	LS	1.09	7.67	0.36	5.65	3.71	1.38	0.14	2.05	1.86	6.90
3	9.1	10.1	80.8	LS	1.50	7.70	0.24	5.39	4.00	5.00	0.46	2.77	3.75	8.38
4	4.5	4.0	91.5	S	2.56	7.60	0.37	12.27	10.37	2.45	0.22	1.88	1.93	21.31
5	12.1	8.1	79.8	SL	1.52	7.56	0.31	5.34	4.80	4.49	0.55	2.04	3.68	9.28
6	10.1	6.1	83.8	LS	1.26	7.41	0.58	6.40	4.53	1.26	0.17	1.81	1.76	9.00
7	10.1	10.1	79.8	SL	2.09	7.58	0.38	6.16	5.17	8.16	0.88	2.16	5.16	13.00
8	12.1	6.1	81.8	SL	1.39	7.48	0.36	4.52	3.61	5.39	0.34	1.28	3.43	8.99
9	12.1	8.1	79.8	SL	1.63	7.51	0.27	6.76	5.00	4.00	0.46	1.88	2.46	11.73
10	10.1	6.1	83.8	LS	2.58	7.62	0.23	13.14	6.33	5.18	0.88	1.55	3.49	20.53
GW+DW														
11	12.1	8.1	79.8	SL	1.54	7.77	0.49	6.55	5.44	2.58	0.69	2.90	3.59	8.85
12	10.1	8.1	81.8	LS	2.62	7.68	0.38	11.00	9.18	5.11	0.79	2.29	3.21	20.60
13	8.1	6.1	85.8	LS	2.04	7.75	0.60	9.43	7.38	3.07	0.47	1.72	2.26	16.35
14	10.1	8.1	81.8	LS	3.83	7.62	0.36	14.00	12.67	10.93	0.30	1.57	7.01	29.00
15	5.7	6.0	88.3	S	2.26	7.61	0.47	9.42	8.89	3.15	0.61	2.46	3.57	16.07
16	10.1	6.1	83.8	LS	2.02	7.66	0.36	8.43	7.00	4.07	0.47	1.68	2.30	16.00
17	6.1	8.1	85.8	LS	3.42	7.34	0.41	12.80	10.47	9.86	0.88	1.44	6.59	26.02
18	8.1	8.1	83.8	LS	1.89	7.25	0.57	6.86	4.77	6.86	0.20	1.31	5.47	11.69
19	10.1	10.1	79.8	SL	2.40	7.51	0.49	12.03	7.50	3.63	0.75	2.06	3.33	18.25
20	9.1	10.1	80.8	LS	2.56	7.50	0.31	12.44	10.24	2.54	0.22	1.93	2.02	21.44
GW+TTWW														
21	11.1	10.1	78.8	SL	1.59	7.46	0.38	7.08	5.00	3.21	0.58	2.75	3.67	9.45
22	8.1	6.1	85.8	LS	1.88	7.35	0.36	8.11	5.65	3.95	0.63	2.69	3.49	12.13
23	10.1	6.1	83.8	LS	1.38	7.41	0.34	6.31	3.74	3.39	0.34	2.28	3.43	7.99
24	10.1	8.1	81.8	LS	1.98	7.48	0.27	7.93	4.35	7.25	0.23	1.51	6.47	11.80
25	12.1	10.1	77.8	SL	2.17	7.74	0.36	9.91	3.51	7.92	0.32	1.49	8.31	11.65
26	12.1	6.1	81.8	SL	2.10	7.70	0.34	9.10	4.05	7.49	0.29	1.36	7.98	10.93
27	8.1	10.1	81.8	LS	2.24	7.66	0.31	10.70	8.28	3.11	0.27	1.58	2.16	18.44
28	9.1	6.1	84.8	LS	2.57	7.56	0.25	12.05	9.69	3.59	0.26	1.88	2.06	21.70
29	10.1	6.1	83.8	LS	1.83	7.47	0.34	8.85	5.91	2.87	0.58	2.67	3.58	11.91
30	12.1	10.1	77.8	SL	2.19	7.69	0.30	10.00	3.68	7.91	0.27	1.55	6.73	13.21
GW+DW+TTWW														
31	11.1	10.1	78.8	SL	3.26	7.53	0.40	13.53	9.16	9.38	0.22	1.31	6.33	24.45
32	16.2	8.1	75.7	SL	2.32	7.47	0.38	12.21	7.59	2.60	0.70	1.72	2.38	18.90
33	10.1	8.1	81.8	LS	2.43	7.58	0.28	11.96	7.88	3.72	0.72	2.04	3.28	18.80
34	11.1	12.1	76.8	SL	2.62	7.28	0.34	12.37	8.50	4.39	0.79	2.29	3.21	20.50
35	12.1	10.1	77.8	SL	3.70	7.54	0.32	14.00	12.49	10.00	0.35	1.57	6.01	28.81
36	6.5	4.0	89.5	S	3.48	7.42	0.40	13.80	10.67	9.86	0.31	1.44	6.63	26.45
37	10.1	6.1	83.8	LS	2.87	7.37	0.41	14.34	9.00	4.29	0.88	1.67	3.99	22.76
38	8.1	6.1	85.8	LS	2.25	7.35	0.40	11.27	7.49	3.07	0.58	2.42	1.11	18.70
39	10.1	8.1	81.8	LS	2.39	7.50	0.41	11.00	8.58	3.57	0.67	1.98	3.17	18.59
40	8.1	6.1	85.8	LS	2.65	7.56	0.37	12.21	9.00	4.32	0.80	2.43	3.32	20.31

SL = sandy loam LS = loamy sand S = sand *PH: in soil paste

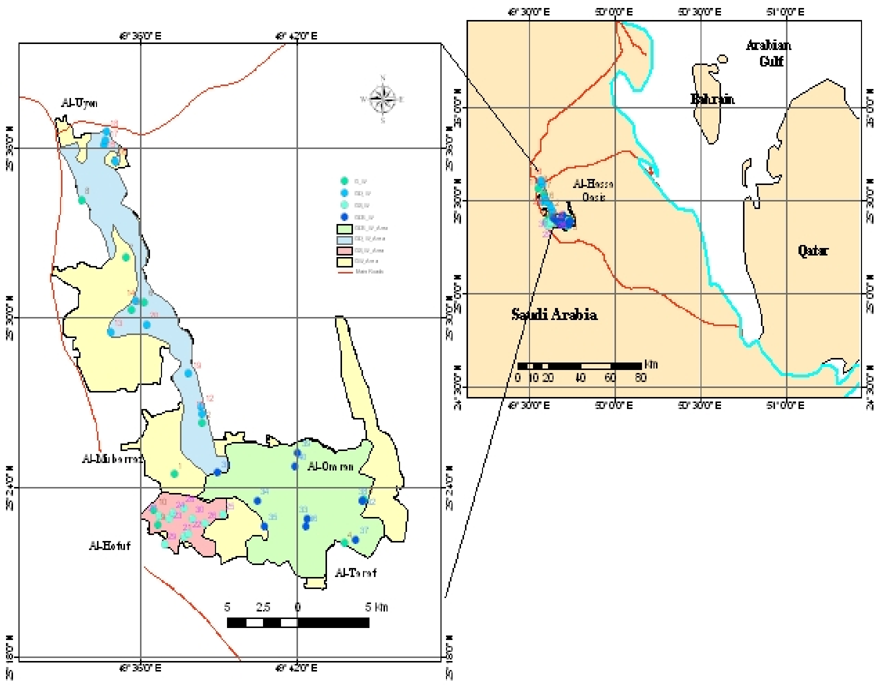

Figure1: The locations of plant and soil irrigated by different irrigation water types, Al- Hassa Oasis, KSA.

Forty sites (10 sites for each irrigation type) were selected to represent the irrigated soil with the above mentioned water types. From each site, three soil samples (0 – 30 cm) were collected and mixed to represent a composite sample. The sample position was recorded using Global Position System (GPS). All the collected soil samples were air dried, grounded and sieved through a 2 mm sieve and kept for analysis. Mechanical analysis was carried out according to the international hydrometer method using sodium hexametaphosphate as a dispersing agent (Richards, 1972). Organic matter content was determined according to Walkley-Black rapid titration method (Jackson, 1967). pH and total soluble salts were measured in the soil paste extract (Jackson, 1967). Fe, Mn, Cu, Zn, Cd, Co and Ni in the soil were determined by inductively coupled plasma optical emission spectrometer (Carter, 1993) after extraction with DTPA extracting solution. Some physical and chemical properties of the soil are presented in (Table, 2). Figure (1) illustrates the locations of plant and soil used in this study.

The data were arranged in a randomized complete block design with 10 replicates (one site represent a replicate) for each irrigation type. All collected data were subjected to statistical analysis of variance using SAS Software (SAS Institute Inc., 1996).

RESULTS AND DISCUSSION

1. Soil characteristics:

To make sure, that water type is the main factor in the heavy metals accumulation in soil, the relationship between all characterization of the investigated soil and all heavy metals determined in soil were statistically analyzed (Table, 3).The statistical analysis indicated that the correlation coefficient between all characterizations of the investigated soil were insignificant. This means that, accumulation of heavy metals in the soil are attributed to the water type not to soil properties.

Table (3): Correlation coefficient between soil characteristics and heavy metals in the investigated soil.

Soil parameters	Fe	Mn	Cu	Zn	Cd	Co	Ni
Clay (%)	0.10	0.22	0.04	0.08	0.16	0.14	0.15
Silt (%)	0.11	0.20	0.02	0.09	0.10	0.11	0.10
Sand (%)	-0.12	-0.25	-0.04	-0.10	-0.16	-0.15	-0.15
ECe (dS/m)	0.41	0.22	0.26	0.32	0.46	0.48	0.51
pH	-0.16	0.01	-0.09	-0.03	-0.33	-0.31	-0.34
OM (%)	-0.11	0.02	-0.14	-0.08	-0.04	0.01	0.01
Ca^{++} (me/L)	0.46	0.31	0.32	0.30	0.56	0.57	0.60
Mg^{++} (me/L)	0.31	0.10	0.22	0.19	0.34	0.36	0.40
Na^{+} (me/L)	0.23	0.11	0.08	0.30	0.20	0.22	0.20
K^{+} (me/L)	0.09	0.04	0.14	-0.08	0.17	0.17	0.21
HCO_3^{-} (me/L)	-0.04	-0.03	0.02	-0.08	0.00	0.00	-0.01
Cl^{-} (me/L)	0.23	0.16	0.08	0.35	0.22	0.24	0.19
SO_4^{2-} (me/L)	0.38	0.19	0.25	0.24	0.42	0.44	0.49

2. Quality of irrigation water:

The water quality parameters for the all investigated water types are presented in Table (4). From these data, it appears that for all types of water, the EC_{iw} ranged from 2.24 to 4.24 dS/m. The critical level of EC_{iw} to cause severe salinity problems is 3 dS/m as reported by FAO (1976). The values of EC_{iw} for (GW) and (GW+DW) are less than the critical limit and no problems of using these types of irrigation water. (GW+ TTWW) and (GW+ DW+TTWW) have EC_{iw} values more than the critical level. It could be considered as high salinity and may cause severe salinity problems. Therefore, it is expected that continuous irrigation without good water management (leaching requirements) can led to severe problems from the salinity point of view.

The data presented in Table (4) also revealed that the SAR value of all water sources is relatively low in comparing with the critical level of sodium hazard (less than 10) as reported by Richards (1972).

With respect to the SSP as indicator for sodium hazard, the values of SSP for all types of water were ranged from 46.61 to 60.78%. The data revealed that all values of SSP were less than the critical limit (< 60%) as reported by Wilcox (1958); accept SSP for (GW+DW+TTWW) were more than the critical limit (> 60%) as reported by Wilcox (1958).

Magnesium hazard is one of the criteria for suitability of water for irrigation. In this respect, the values of SMgP tabulated in Table (4) indicated that all types of water have a values ranged from 32 to 42%. The values are below the harmful level (> 50%). This means that no problem of magnesium hazard. The magnesium salts have toxic effects on the plant and the toxicity of Mg ion is higher than the toxicity of Na ion having the same concentrations.

The RSC value evaluates the tendency of irrigation water to form carbonates and to dissolve or to precipitate the calcium and to a less degree the magnesium carbonates. The precipitation of poorly soluble carbonates increases the sodium hazard of irrigation water and as a result increases the sodicity of irrigated soils. The present values of RSC have a negative values, this means that Ca^{2+} + Mg^{2+} is more than the CO_3^{2-} + HCO^-_3 resulted in no problem of sodium hazard.

Table (4): Water quality parameters used as irrigation water in the present study.

Irrigation water	EC_W dS/m	SAR	SSP %	Mg Hazard %	RSC me/L	Potential salinity me/L	Cl^- me/L	B mg/L	NO^-_3 mg/L
GW	2.24	4.43	46.61	42	-7.47	13.33	8.12	0.23	3.43
GW+DW	2.85	6.22	54.93	38	-7.36	17.11	11.61	0.42	6.90
GW+TTWW	3.84	6.67	52.25	32	-14.72	29.58	25.00	0.33	13.13
GW+DW+TTWW	4.24	9.08	60.78	40	-9.77	28.40	21.11	0.41	11.21

Potential salinity (PS) for all water types used was ranged from 13.33 to 29.58 me/L. The high values of PS over the critical level (5 me/L) as reported by Richards (1972) may be due to high chloride and sulphate content in the irrigation water.

Chloride ion (Cl^-) is extremely high and ranged from 8.12 to 25 me/L. According to the guidelines for interpreting water quality (FAO, 1976) this may also cause severe problems concerning Cl^- toxicity to plants.

The concentration of B for all the water types in the present study is < 1 mg/L. The palm trees are considered as semi-tolerant to boron, which the limit of boron in irrigation water is from 1 to 2 mg/L (Wilcox, 1958). This would put these waters in the range of no problem of toxicity with respect to palm trees.

The nitrate contents (NO_3^-) in this water varied from type to another, but it not exceed the critical limit (45 mg/L) that cause nitrate poisoning (Wilcox, 1958).

Generally, from the data previously presented, it appears that the water types used in the present study may cause one problem or another according to the water type. By applying the criteria used for interpreting water quality for irrigation, the most domain problems are salinity hazard, potential salinity and soluble sodium percentage.

4. Soil chemical analysis:

Table (5) illustrates the effect of different types of irrigation water quality on the chemical properties of soil cultivated with palm and squash. The results indicated that (GW+DW), (GW+TTWW) and (GW+ DW+TTWW) significantly increased available micronutrients (Fe, Mn, Cu, Zn, Cd, Co) and

Ni of the soil as compared with ground water. It is noticed that the effect of different types of irrigation water quality on the chemical properties of soil are in the following order: (GW+ DW+TTWW) > (GW+TTWW) > (GW+DW) > (GW). Also, the data showed that there were a positive significant correlation between soil micronutrients content (Fe, Mn, Cu, Zn, Cd, Co and Ni).

These results are in agreement with those obtained by Abdel-Nasser *et al* (2000), they found that available soil micronutrients (Fe, Mn, Cu and Zn) significantly increased as increasing the salinity of irrigation water. Also, these results are in agreement with those obtained by Hussein (1991), who found that sewage and drainage water significantly increased Fe, Mn, Cu and Zn in sandy clay loam soil, sandy soil and calcareous soil. These results are in harmony with those obtained by Shahin and Hussein (2005), they reported that (GW, DW &TTWW) have the highest effect on Cd content of soil followed by (GW&TTWW), (GW&DW) and then (GW).

Table (5): The chemical analysis of soil irrigated by different irrigation water types in the present study.

Irrigation water	Fe	Mn	Cu	Zn	Cd	Co	Ni
	mg/kg						
GW	2.13	2.94	0.37	1.18	0.10	0.26	0.28
GW+DW	2.95	6.02	0.56	2.31	0.13	0.41	0.39
GW+TTWW	3.95	9.06	0.84	4.48	0.17	0.53	0.48
GW+DW+TTWW	7.40	9.86	1.48	6.00	0.21	0.65	0.67
LSD (0.05)	1.14**	2.36**	0.41**	1.85**	0.01**	0.03**	0.05**

**** Significant at 1% probability level**

According to Follet and Lindsay (1970) the concentrations of Mn, Cu and Zn in the soil were adequate. Also, the concentration of Fe in soil irrigated with (GW, DW &TTWW) was adequate. The concentration of Fe in soil irrigated with (GW&TTWW) and (GW&DW) was marginal while, the concentration of Fe in soil irrigated with (GW) was deficient (figure 2).

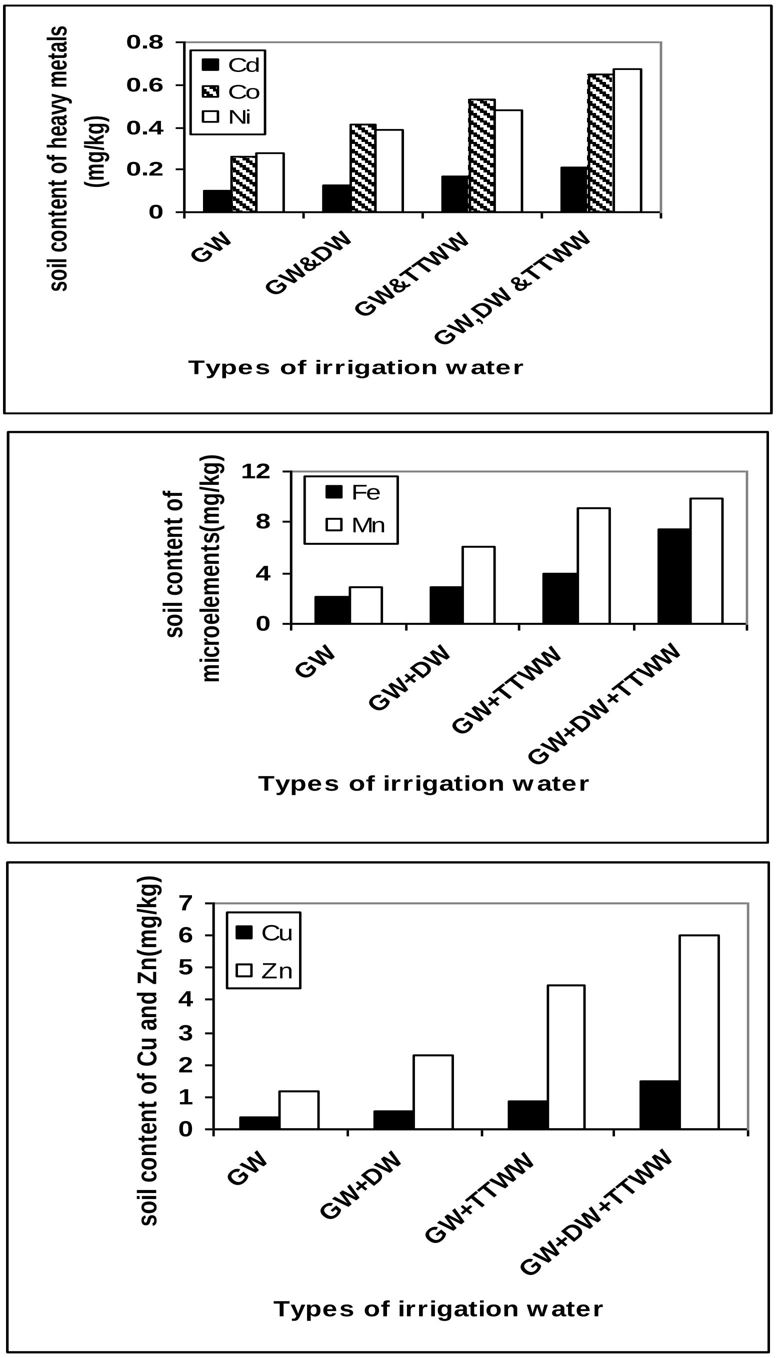

Figure 2: Effect of different types of irrigation water on Fe, Mn, Cu, Zn, Cd, Co and Ni contents of soil.

Conclusion

It can be concluded that the water types used in the present study may cause one problem or another according to the water type. By applying the criteria used for interpreting water quality for irrigation, the most domain problems are salinity hazard, potential salinity and soluble sodium percentage. Therefore, it is expected that continuous irrigation without good water management (leaching requirements) can led to severe problems from the salinity point of view.(GW+DW +TTWW) have the highest effect on elemental composition of soil followed by (GW+TTWW), (GW+DW) and then (GW). Heavy metals in the studied soil were in the range of the uncontaminated area.

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تقييم تأثير استخدام مياه مختلفة النوعية على محتوى التربة من العناصر الثقيلة في واحة الأحساء بالمملكة العربية السعودية

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تهدف هذه الدراسة للتحقق من تأثير نوعية مياه الري على محتوى التربة من المعادن الثقيلة في واحة الأحساء. وشملت مياه الري محل الدراسة المياه الجوفية (GW) ومزيج من المياه الجوفية ومياه الصرف الزراعي (GW+DW)، ومزيج من المياه الجوفية ومياه الصرف الصحى المعالجة ثلاثياً (GW+TTWW) ومزيج من المياه الجوفية ومياه الصرف الزراعي ومياه الصرف الصحي المعالجة ثلاثيا (GW+DW+TTWW). تشير نتائج هذه الدراسة إلى أن أنواع المياه المستخدمة هنا قد يسبب مشكلات متعددة تبعاً لنوع المياه. وبتطبيق المعايير المستخدمة لتفسير نوعية المياه لأغراض الري، تبين أن معظم المشكلات السائدة هي مخاطر الملوحة والملوحة المحتملة والنسبة المئوية للصوديوم القابل للذوبان. ولذلك، من المتوقع أن الاستمرار في عملية الري بهذه المياه ، وبلا إدارة جيدة لاستخدامها (تلبية احتياجات الغسيل - مثلاً) يمكن أن يؤدى إلى مشاكل حادة تتعلق بالملوحة. أن للمزيج الثلاثي (GW+DW+TTWW) أثراً كبيراً على محتوى التربة من العناصر يليه المزيج (GW+TTWW)، ثم المزيج (GW+DW) ثم المياه الجوفية منفردة (GW). ووجد عموما فرقا كبيرا في تركيزات المعادن الثقيلة للتربة –محل الدراسة. تمت مقارنة تركيزات المعادن الثقيلة في عينات التربة مع المعايير العالمية. واستناداً إلى هذه المقارنات طرحت التوصيات المناسبة.

قام بتحكيم البحث

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