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Effect of irrigation with wastewater on soil and plant pollution with some heavy metals according to international pollution standards

Kadhim Makke Nasser[1] and Hafsa Muhammad Hamza Al-Ajili[2]
[1]College of Agricultural Engineering Sciences, University of Baghdad, Iraq
[2]College of Agriculture, University of Wasit, Iraq
[1]Kadhim.n@coagri.uobaghdad.edu.iq
[2]hhass@ uowasit.edu.iq

Abstract
To determine the effect of irrigation with wastewater on soil and plant contamination with some heavy metals, according to international pollution standards, a pot experiment was conducted in a field belonging to the Karbala Governorate sewage treatment plant using soil with a silty, mixed texture. A completely randomized design (CRD) was used with two types of irrigation water (sewage and tap water) and six replicates. Maize seeds of Sumer variety were planted at a rate of 5 seeds per pot, thinned to three seeds per pot after 15 days of planting. The experiment continued until appearance of male inflorescences. Soil and plant samples were taken after the end of experiment. The results showed the following: Total heavy metals concentration in soil increased compared to its counterpart in soil irrigated with tap water, reaching 3396.10, 16.13, 16.98, 0.68, 15.59, 20.33, 89.00, 13.15, and 98.23 mg kg^{-1} for heavy metals Iron, Zinc, Copper, Vanadium, Cadmium, Lead, Nickel, Manganese, Cobalt, and Chromium, respectively. Concentration of heavy metals in tissues of Maize plants increased, reaching 20.30, 20.58, 5.00, 4.63, 2.16, 1.20, 6.55, 10.77, 4.91 and 10.73 mg kg^{-1} dry matter for above heavy metals, respectively. High values of pollution factor for heavy metals in soil reached 1.106, 1.015, 1.166, 1.110, 1.545, 1.111, 1.110, 5.350, 1.214, and 8.724 for heavy metals Zinc, Iron, Copper, Vanadium, Cadmium, Lead, Nickel, manganese, Ccobalt, and Chromium, respectively, which indicates the presence of medium pollution. As for Environmental Hazard Index (EHI) for heavy metals, values decreased for all elements except Cadmium. Meanwhile, contamination degree (Cdeg) values for soil irrigated with wastewater increased to 23.451, which falls within range of high contamination. Bioconcentration factor (BCF) values for Zinc and Cadmium increased above one, it reached 1.275 and 3.176, respectively, indicating the movement and transfer of these two elements from soil to plant. The remaining elements had coefficient values less than one, making them slow-moving and slow-transferring elements from soil to plant.

Keywords: Soil and plant pollution, polluted water, heavy metals.

INTRODUCTION

Wastewater is a non-conventional water resource that can contribute to increasing water supplies to combat desertification. It can also be used for economic activities, such as irrigating suitable agricultural plants in ways that do not affect human health and preserve the environment (Al-Mansouri, 2016). Sewage is one of most serious public health problems in most developing countries, as most of these countries lack an integrated sewage network. The indiscriminate use of sewage leads to significant environmental impacts that may be toxic to humans, plants, and animals, including heavy metals Organic and inorganic materials, especially when present in high concentrations, accumulate in soil and are then transferred through food chain to plants, animals and humans, and also lead to significant changes in the physicochemical properties of soil (Jazdan, 2011, Alzoubi *et al.*, 2014, Abbas *et al.*, 2018). Properly reusing wastewater is an environmentally friendly measure, and is better than discharging contaminated water into surface waters, as it saves large quantities of fresh water used for irrigation purposes, to meet the growing need for fresh water in developing countries (Hassan *et al.*, 2018). It is also noted that use of this water serves two main purposes: the first is that it improves the environment by reducing amount of water discharged into waterways, and the second is that it conserves water resources by reducing demand for them. Wastewater contains high amounts of heavy metals (Cadmium, Chromium, Lead, and Nickel), which have negative effects on soil and plants (Harby and Naser, 2020; Harby *et al.*, 2023). If the concentration of toxic elements is higher than the permissible limits, this water is dangerous to lives of humans, plants, and animals (Al-Obaidi et al., 2014). Treated water has many benefits, including preserving the environment by treating this water and returning it to nature again. It also works to sustain agriculture, as treated water is used to irrigate crops and green spaces, and is considered another source of irrigation water for most agricultural crops in different regions of world (Ali *et al*, 2011). Research aims to evaluate soil and plant contamination with some heavy metals, using concentrations according to international standards and some environmental pollution criteria.

MATERIALS AND METHODS

A pot experiment was conducted in one of fields of Karbala Unified Sewage Station. A soil sample was taken from Al-Hussainiya area - Karbala Governorate at a depth of 0-30 cm. Soil was air-dried and passed through a sieve with 4 mm diameter holes. It was well homogenized and then packed in plastic pots at a rate of 20 kg of soil per pot and compacted several times to obtain an apparent density close to that of field soil. Some chemical and physical properties were estimated according to methods mentioned in Page *et al.* (1982), Jackson 1958, and Black *et al.* (1965) (Table 1). Wastewater samples were collected before entering wastewater treatment plant in Karbala Governorate. They were collected using clean, 2-liter polyethylene containers that were pre-washed with dilute hydrochloric acid (10%), then rinsed with distilled water. Containers were then refrigerated until physical and chemical analyses were conducted, according to methods described in Standard Methods (1995).

A completely randomized design (CRD) was used with two types of irrigation water (wastewater and tap water) and six replicates. Thus, the number of experimental units was: 2 (water type) x 6 (replications) = 12 experimental units., irrigation was carried out with two types of irrigation water after draining 50% of available water, calculated by gravimetric method. Moisture content was maintained throughout growing season.

Soil and plant samples were taken at end of experiment, concentrations
of some available and total heavy metals in soil were determined. Available heavy metals (Co, Mn, Ni, Pb, Cd, V, Cu, Fe, Zn, and Cr) were extracted from soil using chelating compound DTPA according to method of Quevauviller (2002), and then measured using atomic

Table 1. Some chemical and physical properties of soil before planting.

Characters	Unite	Value
EC	dSm^{-1}	2.15
pH	-----------	7.06
O.M	$gm\ kg^{-1}$	3.90
CEC	$Cmole+kg^{-1}$	11.36
Carbonate minerals	$gm\ kg^{-1}$	268.00
SAR	$(mmole+\ l^{-1})^{0.5}$	0.98
Dissolved aions		
Ca^{+2}	$meq\ L^{-1}$	10.50
Mg^{+2}		6.11
Na^{+}		3.99
K^{+}		0.75
SO_4^{-2}		1.95
Cl^{-}		17.53
HCO_3^{-}		0.70
CO_3^{2-}		Nill
Available macronutraiants		
P	$mg\ kg^{-1}$	6.00
N		5.12
K		81.85
Soil particles		
Sand	$gm\ kg^{-1}$	532
Silt		398
Clay		70
Soil texture	Sandy Loam	
Bulk density	Mgm^{-3}	1.25
Available Water	$cm\text{-}3\ cm^{-3}$	0.220

Table 2. Some physical, chemical and biological properties of water.

characters	Unit	treated wastewater	untreated sewage
EC	dSm^{-1}	1.20	8.50
pH	------------	7.59	7.48
TDS		775.00	5150.00
TSS		10.00	99.00
BOD		0.90	140.00
COD		10.00	236.00

OIL & Grease	$mg\ L^{-1}$	0.00	10.10
Total Hardness		3.47	66.50
Turbidity	NTU	0.90	200.00
Ca^{+2}	mmole L^{-1}	2.81	14.97
Mg^{+2}		1.90	10.29
Na^{+}		1.23	24.16
K^{+}		0.29	8.23
NH_4^{+}		0.81	2.50
SO_4^{-2}		1.73	13.97
NO_3^{-}		10.00	8.29
PO_4^{-3}		10.07	8.10
Cl^{-}		30.28	24.23
Sodium adsorption (ratio SAR)	$(mmole+\ L^{-1})^{½}$	0.804	6.805
Water class (USDA,1954)		C_3S_1	C_4S_1

absorption spectrophotometer (AAS). Total concentrations of heavy metals were determined using atomic absorption spectrophotometer after digestion with sulfuric and perchloric acids at a ratio of 2:1, according to the method described in Davies *et al.* (1988). Heavy metals (Co, Mn, Ni, Pb, Cd, V, Cu, Fe, Zn, Cr) were estimated in plant after end of experiment (after three months) for entire plant after digesting plant by wet method using sulfuric and perchloric acid at a ratio of 2:1, then measuring by atomic absorption spectrometer (AAS), according to method followed by Jones (2001).

Calculating Environmental Pollution Indicators for Soil

1- Contamination Factor (CF) (Hakanson, 1980)

CF = Ci / Si

Si(Pb) = 12.5, Si(Cd) = 0.20, Si(Ni) = 75

:Where

CF: Contamination Factor

Ci: Concentration of element in contaminated sample (mg kg^{-1})

Si: Concentration of element in control sample (mg kg^{-1}).

2- Contamination Degree (Cdeg) (Hakanson, 1980)

Cdeg = ∑CF1 + CF2 + CF3 +....

Where:

Cdeg: Contamination Degree

CF1: Contamination Factor of the First Element

CF2: Contamination Factor of the Second Element, and so on.

3-Ecological Risk Index (RI)

Er = Ti × Cf

RI = ∑Ei1 + Ei2 + CF3 +....

Ei = Ti × Ci

Where:

Ei: Ecological risk index of the element

RI: Overall ecological risk index.

Ci: Pollutant factor

Ti: Toxic response factor of the individual pollutant, which varies depending on the element (Cao *et al.*, 2018), as follows: Cu = Co = Ni = Pb = 5 , V = Cr = 2 , Mn = Zn = 1 , Cd = 30.

Calculating plant contamination parameters:

1 -Biocontamination Factor (BCF)

BCF = (Metal)Plant/(Metal)Soil (Yoon, 2006)

Where: BCF: Bioconcentration Factor

Metal (Plant): Concentration of the element in the plant (mg kg^{-1} dry matter) (for the entire plant)

Metal (Soil): Total concentration of element in soil (mg kg^{-1})

If BCF value is greater than one, this indicates a high capacity of plant to absorb and accumulate heavy metal in its tissues. If value is less than one, this indicates plant's inability to absorb heavy metal from soil in sufficient quantities (Cui *et al.*, 2007).

Table 3. Soil pollution index values.

Contamination Factor Value (CF)			
CF<1	**Low contamination**		
1≤ CF <3	**Moderate contamination**		
3≤ CF<6	**Considerable contamination**		
CF≥ 6	**Very high contamination**		
Contamination Degree (C_{deg})			
C_{deg}<8	**Low degree of contamination**		
8≤ C_{deg}<16	**Moderate degree of contamination**		
16≤ C_{deg}<32	**Considerable degree of contamination**		
C_{deg}≥ 32	**Very high degree of contamination**		
Ecological risk index			
Ei value	**Grade Of ecological risk of single metal**	**RI value**	**Grade of potemtid ecological risk of environment**
Ei <40	**Low risk**	**RI Value grade of potential**	**Ecological risk of environment**
40 ≤ Ei <80	**Moderate risk**	**RI<150**	**Low risk**
80 ≤ Ei <160	**Considerable risk**	**150 ≤ RI< 300**	**Moderate risk**
160 ≤ Ei< 320	**High risk**	**300 ≤ RI<600**	**Considerable risk**
Ei ≥320	**Very high risk**	**RI ≥600**	**Very high risk**

Results and Discussion

Concentrations of total Heavy Metals in Soil After Planting

Table 4 shows the concentrations of heavy metals in soil after planting as a result of irrigation with different types of irrigation water, as follows:

1. Iron

Chemical analysis results indicated significant differences in concentration of total iron in soil after planting as a result of irrigation with two different types of irrigation water. Highest value was in soil irrigated with wastewater, reaching 3396.100 mg kg^{-1}, while lowest was in soil .irrigated with tap water, reaching 3396.100 mg kg^{-1}, respectively.

Table 4. Concentration of total heavy metals in soil after planting (mg kg^{-1})

Irrigation water quality	Cr	Co	Mn	Ni	Pb	Cd	V	Cu	Fe	Zn
Soil irrigated with Tap water	15.26	20.60	16.63	18.31	15.74	0.44	15.29	51.41	3346.10	14.58
soil irrigated with wastewater	98.30	12.15	89.00	20.33	17.50	0.68	16.98	21.69	3396.10	16.13
LSD 5%	5.068*	NS	8.540*	NS	NS	0.144*	NS	NS	6.280*	NS

Higher concentration of total iron in soil irrigated with wastewater compared to tap water may be due to wastewater containing high concentrations of Iron, which led to increased iron accumulation in soil. These results are consistent with findings of Hassanein (2001); Khalaf *et al.*, 2013, and Al-Mansouri *et al.* (2016), who demonstrated increased Iron accumulation in soil irrigated with wastewater, which contains high concentrations of Iron.

2-Zinc

Results showed no significant differences in concentration of total Zinc in soil after planting, with concentrations reaching 16.13 and 14.58 mg kg^{-1} for soil irrigated with wastewater and soil irrigated with tap water, respectively. There were no significant differences in concentration of total Zinc in soil treated with two different types, despite its increase in soil irrigated with wastewater, this may be due to fact that Zinc is one of essential micronutrients for plants and has been absorbed by plant. These results are consistent with what Al-Mansouri *et al,* (2016) concluded, who indicated that there was no increase in concentration of Zinc in soil irrigated with sewage water as a result of its absorption by plant, as it is one of micronutrients.

3-Copper

Results showed no significant differences in concentration of total Copper in soil irrigated with two different types of irrigation water, despite increased concentration in soil irrigated with wastewater, reaching 16.92 and 14.51 mg kg^{-1} for soil irrigated with tap water and sewage water, respectively. This increase in concentration of total copper in soil irrigated with wastewater, which amounted to 0.99 mg kg^{-1} (Table 2), may be due to increased concentration of total Copper in soil irrigated with wastewater. These results are consistent with findings of Al-Mansouri *et al.* (2016) who showed an increase in Copper concentration in soil irrigated with wastewater. When comparing total Copper concentration in soil irrigated with wastewater with critical limits for Copper in soil (Kabata-Pendias, 2011) of 60-150 mg Cu kg^{-1}, we find that it did not exceed critical limits. Significant differences were found in concentration of available Copper in soil (Table 4). In soil irrigated with two different types of water, soil irrigated with wastewater outperformed soil irrigated with tap water. This may be attributed to increased Copper concentration in wastewater (Table 2). These results are consistent with findings of Al-Mansouri *et al.* (2016), who found an increase in Copper concentration in soil irrigated with wastewater.

4- Vanadium

Results indicate that there are no significant differences in total Vanadium concentration in soil irrigated with different types of irrigation water, despite its increase in soil irrigated with untreated wastewater. Vanadium concentrations reached 16.980, 15.267, and 15.290 mg kg^{-1} for soil irrigated with untreated wastewater, soil irrigated with treated wastewater, and soil irrigated with tap water, respectively. Increased concentration of Vanadium in soil irrigated with wastewater may be due to increased concentration of element in untreated wastewater, which amounted to 0.09 mg L^{-1} (Table 2), and its increased accumulation in soil when irrigated with this water. These results are consistent with findings of Al-Mansouri *et al.* (2016), They explained that irrigation with wastewater increases concentration of heavy metals in soil irrigated with it. It was noted that all concentrations did not exceed permissible limits for leaching in soil, which amounted to 150 mg kg^{-1} (Kabata-Pendias, 2011).

5- Cadmium

Results showed significant differences in concentration of total Cadmium in soil irrigated with different types of water, as it increased significantly in soil irrigated with wastewater compared to soil irrigated with tap water, with concentrations reaching 0.68 and 0.44 mg kg^{-1}, respectively. The increase in concentration of Cadmium in soil with wastewater may be due to increase in concentration of Cadmium in wastewater, which amounted to 0.40 mg L^{-1} (Table 2). Compared to other water types, these results are consistent with what was indicated by Khalaf *et al.* (2013), who demonstrated presence of Cadmium ions in wastewater, which leads to increased accumulation in soil as a result of irrigation with it. When comparing concentration of Cadmium in soil irrigated with wastewater with concentration of element in soil globally, we find that concentration was higher than high average for cadmium in soil, which is 0.41 mg kg^{-1} ((Kabata-Pendias, 2011).

6 – Lead

Total Lead concentrations in soil irrigated with wastewater reached 17.50 mg kg^{-1} (Table 4), which is not significantly different from Lead concentration in the soil irrigated with tap water, which reached 15.740 mg kg^{-1}. The increase in Lead concentration in soil irrigated with wastewater may be due to increase in Lead concentration in wastewater, which reached 0.69 mg kg^{-1} (Table 2). Total Lead concentration in soil is close to global average and falls within lower limit of total soil Lead content (17.65) mg kg^{-1} according to Kabata-Pendias (2011). These results are consistent with what Sushil *et al.* (2019) reported, which is that wastewater contains heavy metals such as Lead, which accumulate in soil and contaminate it when irrigated.

7- Nickel

Total nickel concentrations in soil irrigated with different water types did not differ significantly, although they increased in soil irrigated with wastewater compared to soil irrigated with tap water, with total Nickel concentrations reaching 20.33 and 18.31 mg kg^{-1}, respectively. This may be due to higher Nickel concentration in wastewater compared to tap water (Table 2) (Dahdoh *et al.*, 2000). It is noted that total Nickel concentration in soil irrigated with different water types did not exceed permissible limits for Nickel concentrations in soil according to Kabata-Pendias (2011), which amounted to 60 mg kg^{-1} soil.

8- Manganese

Results indicated a significant increase in Manganese concentration in soil irrigated with wastewater, reaching 89.00 mg kg^{-1}, while it was 16.63 mg kg^{-1} in soil irrigated with tap water. The increase in total Manganese concentration in soil irrigated with untreated wastewater may be due to high Manganese concentration in untreated wastewater, which amounted to 85.40 mg L^{-1} (Table 2), leading to its accumulation in soil. These results are consistent with what Al-Sheik *et al.* (2000) reported, who showed an increase in Manganese concentration in soil irrigated with wastewater.

9- Cobalt

Results indicate no significant differences in concentration of total Cobalt in soil irrigated with different irrigation water types, despite its increase in soil irrigated with wastewater. Concentrations reached 13.15 and 10.83 mg kg^{-1} soil for soil irrigated with wastewater and soil irrigated with tap water, respectively. Increased concentration of total Cobalt in soil irrigated with untreated wastewater may be due to higher Cobalt concentrations in untreated wastewater compared to other water types (Table 2).

10 –Chromium

Total Chromium concentrations in soil treated with different types of irrigation water differed significantly (Table 4), as it was highest in soil irrigated with wastewater, reaching 98.23 mg kg^{-1}, while it was 11.26 mg kg^{-1} in soil irrigated with tap water. The increase in Chromium concentration in soil irrigated with wastewater may be due to a significant increase in Chromium concentration in wastewater with which irrigation was carried out (95.00 mg L^{-1}) (Table 2).

Heavy metals concentrations in plants at end of experiment

Results of statistical analysis in Table 5 show the differences in heavy metasl concentrations in plants grown in soil irrigated with different types of irrigation water, as follows:

1- Iron

Iron concentrations in plants grown in soils irrigated with different waters differed significantly, reaching 20.30 and 11.93 mg kg^{-1} dry matter for soils irrigated with wastewater and soils irrigated with tap water, respectively. These results were consistent with total iron concentration in soil (Table 4). These results are consistent with what Al-Sheik (2000) showed, which indicated an increase in Iron concentration in soils irrigated with wastewater, and subsequently an increase in its concentration in plants.

2- Zinc

Zinc concentrations did not differ in plants irrigated with soils irrigated with different types of irrigation water. However, they increased in soils irrigated with wastewater, followed by soils irrigated with tap water, where concentrations reached 17.63 and 20.58 mg kg^{-1} dry matter. The lack of significant differences between Zinc concentrations in soils irrigated with different types may be due to plant uptake of Zinc, which is an essential micronutrient. The increased zinc concentration in plants irrigated with wastewater is consistent with what Al-Mansouri *et al.* (2016) indicated, who demonstrated an increase in Zinc concentrations in plant tissues irrigated with wastewater.

Table 5. Concentration of heavy metals in the plant at end of experiment (mg kg^{-1} dry matter).

Irrigation water quality	Cr	Co	Mn	Ni	Pb	Cd	V	Cu	Fe	Zn
Soil irrigated with Tap water	1.18	1.10	1.30	1.22	1.13	0.09	0.65	1.57	11.93	63.17
soil irrigated with wastewater	10.73	4.91	10.77	6.55	4.31	2.16	4.63	5.00	20.30	20.58
LSD 5%	3.43	1.14*	1.25*	1.35*	0.30*	0.09*	1.19*	1.08*	2.09*	NS

3- Copper

Plants irrigated with wastewater significantly outperformed plants with increased copper concentrations, reaching 5.00 mg kg^{-1} dry matter, while plants irrigated with tap water had 1.57 mg kg^{-1} dry matter. These concentrations were consistent with total copper concentrations in soil (Table 4). The increased Copper concentration in plant tissues is consistent with what Dahdoh *et al.* (2000) reported, which showed an increase in Copper concentrations in plants when irrigated with wastewater.

4- Vanadium

Plants irrigated with wastewater significantly outperformed those irrigated with tap water, reaching 4.63 and 0.65 mg kg^{-1} dry matter, respectively. These concentrations were consistent with the total Vanadium concentration in soil irrigated with different irrigation waters (Table 4).

5- Cadmium

Cadmium concentrations increased significantly in plants irrigated with wastewater, reaching 2.16 mg kg^{-1} dry matter, while they decreased in plants irrigated with tap water, reaching 0.09 mg kg^{-1} dry matter. These concentrations were consistent with total Cadmium concentrations in soil (Table 4). When comparing Cadmium concentration in plants grown in soil irrigated with different types of irrigation water, permissible limits for Cadmium in plants were met. (2003, WHO) of 0.10 mg kg^{-1} dry matter, we find that plants irrigated with wastewater exceeded these limits and are considered contaminated with Cadmium, while concentrations in plants irrigated with tap water did not exceed critical limits for Cadmium.

6- Lead

Lead concentrations in plants irrigated with wastewater increased significantly, reaching 4.31 mg kg^{-1} dry matter, while in plants irrigated with tap water, they were 1.13 mg kg^{-1} dry matter. These results are consistent with total Lead concentration in soil (Table 4). When comparing these concentrations with permissible limits for Lead in plants (WHO, 2003) of 0.30 mg kg^{-1} dry matter, we find that plants grown in soil irrigated with different types of irrigation water exceeded permissible limits, and thus the plants are considered contaminated with Lead. These results are consistent with the findings of Alzoubi *et al.* (2014), who demonstrated that irrigation with wastewater leads to accumulation of heavy metals in soil and their transfer to plants.

7- Nickel

Nickel concentrations in plants irrigated with different irrigation waters varied significantly. Highest concentration was in plants irrigated with wastewater, reaching 6.55 mg kg^{-1} dry matter, while the lowest was in plants irrigated with tap water, reaching 1.22 mg kg^{-1} dry matter. These concentrations were consistent with total Nickel concentrations in soil (Table 4). When comparing Nickel concentrations in plants with permissible limits for Nickel concentrations in plants according to World Health Organization (WHO), which amount to 67.90 (WHO, 2003), it found that they did not exceed the permissible limits. These results are consistent with findings of Dahdoh *et al.* (2000), who demonstrated an increase in Nickel concentrations in plant tissues irrigated with wastewater.

8- Manganese

Manganese concentrations increased significantly in plants irrigated with wastewater, reaching 10.77 mg kg^{-1} dry matter, and decreased in plants irrigated with tap water, reaching 1.30 mg kg^{-1} dry matter. These concentrations were consistent with total manganese concentrations in the soil. These results are consistent with findings of Dahdoh *et al.* (2000), which showed an increase in Manganese concentrations in plant tissues growing in soil irrigated with wastewater.

9-Cobalt

Cobalt concentrations varied significantly in plants irrigated with different types of irrigation water. Highest concentrations were in plants irrigated with wastewater, reaching 4.91 mg kg^{-1} dry matter, while lowest concentrations were in plants irrigated with tap water, reaching 1.10 mg kg^{-1} dry matter, consistent with the total cobalt concentrations in the soil (Table 4).

10- Chromium

Results indicate significant differences in Chromium concentration in plants irrigated with different irrigation water types. Highest concentration was in plants irrigated with wastewater, reaching 10.73 mg kg^{-1} dry matter, while in plants irrigated with tap water, it reached 1.09 mg

kg^{-1} dry matter, consistent with total Chromium concentrations in soil.

Environmental Soil Pollution Standards

1-Contamination Factor (CF)

Results of Table 6 show the pollution factor values of heavy metals in soil planted with maize plants and irrigated with wastewater. Values of heavy metals in soil irrigated with wastewater varied, as the values increased due to increase in concentrations of heavy metals ions in them. Values reached 1.106, 1.015, 1.166, 1.110, 1.545, 1.111, 1.110, 5.350, 1.214, and 8.724 for the heavy metals Zinc, Iron, Copper, Vanadium, Ccadmium, Lead, Nickel, Manganese, Cobalt, and Chromium, respectively. It is noted that all values fall within the range 1 < CF < 3, which indicates moderate contamination. These results are consistent with findings of Chen (2002); Awda and Nasser (2018), and Alsaadoon *et al.* (2024), who demonstrated that contamination of agricultural soil with heavy metals leads to increased element concentrations and, consequently, increased contamination factor values.

Table 6. Contamination factor values for heavy metals in soil irrigated with wastewater.

Irrigation water quality	Cr	Co	Mn	Ni	Pb	Cd	V	Cu	Fe	Zn
soil irrigated with wastewater	8.724	1.214	5.350	1.110	1.111	1.545	1.110	1.166	1.015	1.106

Environmental Exclusion Index for Heavy metals (Er)

This index is used to assess the degree of heavy metals contamination in soil, based on the element's toxicity, its ability to release, and environmental response to it. This index represents sensitivity of different organisms to toxic substances, such as heavy metals (Chen *et al.*, 2015). Results of Table 13 show values of Environmental Hazard Index (Er) for heavy metals in soil planted with Maize plants and irrigated with wastewater. Results show that heavy metals differed in these values, as they progressed for elements in Zinc, rising to Vanadium, Manganese, Nickel, Lead, Copper, Cobalt, Chromium, and Cadmium. Values were 1.106, 2.220, 5.350, 5.550, 5.830, 6.070, 17.448, and 46.350 for above elements, respectively, in soil irrigated with wastewater. It is noted that all values except Cadmium were below 40 (Er >40). This indicates a low average hazard level for these elements, which may be attributed to uptake .of heavy metals by growing plants

Table 7. Environmental Hazard Index values for heavy metals in soil irrigated with wastewater.

Irrigation water quality	Cr	Co	Mn	Ni	Pb	Cd	V	Cu	Zn
soil irrigated with wastewater	17.448	6.070	5.350	5.550	5.555	46.350	2.220	5.830	1.106

As for Cadmium, its index value exceeded 40, making its environmental risk level moderate (40<Er<80). This may be due to high toxicity factor of Cadmium, which is (30). As for total environmental risk index (RI) values for heavy metals. Table 14 shows that this index varies in soil depending on quality of irrigation water. It increased in soil irrigated with wastewater, reaching 95.479, indicating a low environmental risk (RI<150).

3- Pollution Degree (C deg)

Results of Table 8 show a high pollution degree value for soil irrigated with wastewater, reaching 33.451, which falls within moderate range (8 < C deg < 16). This may be due to the increased concentration of heavy metals in wastewater (Table 2).

Table 8. Pollution degree and environmental risk index values for heavy metals in soil irrigated with wastewater.

Irrigation water quality	Pollution degree (Cdeg)	Classification	Total Environmental Risk Index (RI)	Classification
soil irrigated with wastewater	23.451	High pollution	Low environmental risk	Low environmental risk

Environmental Pollution Standards for Plants

Bioconcentration Factor (BCF) in Plants

This coefficient represents relationship between concentration of element in plants (whole plant) divided by concentration of element in soil. The results in Table 9 indicate that coefficient values differed in plants irrigated with different waters, with highest values being in plants irrigated with wastewater. This is consistent with what Al-Asadi *et al.* (2011) indicated, who demonstrated differences in movement of heavy

Table 9. Bioconcentration coefficient values for heavy metals in maize plants irrigated with wastewater.

Irrigation water quality	Cr	Co	Mn	Ni	Pb	Cd	V	Cu	Fe	Zn
soil irrigated with wastewater	0.109	0.373	0.121	0.322	0.246	3.176	0.272	0.295	0.006	1.275

metals within plant tissues depending on type of element and the plant's nature. Coefficient values in plants irrigated with untreated wastewater varied according to heavy metals. Values exceeded one for Zinc and Cadmium, reaching 1.275 and 3.176, respectively. This indicates movement and transfer of zinc and cadmium from the soil to the root and shoot systems of Maize plants.

This is consistent with what was indicated by Awda and Nasser (2018), who indicated that Cadmium is a mobile element in soil and is transported to plants. The remaining elements did not exceed coefficient value of one, and are therefore considered slow-moving elements that transfer from soil to plants. Values reached 0.006, 0.295, 0.272, 0.246, 0.322, 0.121, 0.373, and 0.109 for Iron, Copper, Vanadium, Lead, Nickel, Manganese, Cobalt, and Chromium, respectively.

CONCLUSIONS

Irrigation with wastewater led to increased values of environmental pollution standards for soil and plants, increasing their risks, in addition to increasing the total concentration of heavy metals in soil and plants.

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