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Evaluation of heavy metal pollution in water wells and soil using common leafy green plant indicators in the Al-Kharj region, Saudi Arabia

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Abstract This study was performed to determine the levels of eight heavy metals in irrigation well water and soil and to assess the suitability of some leafy green plants that are commonly cultivated in the Al-Kharj region, Saudi Arabia, for human consumption using an atomic absorption spectrometer. The mean concentrations of metals ranged from 0.0001 to 0.436 mg/L in well water and from 0.248 to 164.52 mg/kg in soil. The heavy metal concentrations showed significant differences among the different leafy green plants studied. Parsley (4.98 mg/kg) exhibited higher levels of Pb than other leafy green plants, whereas mallow (0.097 mg/kg) revealed greater amounts of Cd than other plants. All of the leafy green plants retained essential metals (Cu, Zn, Fe and Mn) more than the toxic metals (Pb and Cd). The levels of some of the metals in the leafy green plants were found to meet the FAO/WHO-recommended limits. The monitoring of heavy metals in leafy green plants must be continued because these plants are the main source of food for humans in many parts of the world and are considered to be bio-indicators for environmental pollution.

Keywords Heavy metals · Leafy plants · Well water · Soil · Pollution

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Introduction

Heavy metals are important environmental pollutants, particularly in areas with high anthropogenic pressure. The presence of heavy metals in plants, atmosphere, soil and water, even trace amounts, can cause serious problems to all organisms (Ghosh et al. 2013). Heavy metals are not easily biodegradable and can consequently be accumulated in important human organs (Farooq et al. 2008).

Leafy green plants are an important part of the human diet. In addition to being a potential source of important nutrients, leafy green plants constitute an important functional food component by contributing protein, vitamins, iron and calcium, which have marked effects on human health (Farooq et al. 2008). Heavy metals in leafy green plants pose a direct threat to public health when plant-based foodstuffs are consumed. Several studies have indicated that plant species have different capacities for removing and accumulating heavy metals. The plants take up elements by absorption through their roots from contaminated soil, from the water used from irrigation and from deposits on different parts of the plant exposed to the air from a polluted environment (Shuaibu et al. 2013). However, the uptake of metals from the soil depends on different factors, such as the soluble content of the metal in the soil, the soil pH, the stages of plant growth, the types of plant species, the fertilizers that are used and the soil (Farooq et al. 2008).

Groundwater is a key resource, especially in the arid regions of Saudi Arabia where surface water and rainfall are scarce and evaporation rates are high. Hence, groundwater is a major resource that can supply domestic and agricultural needs throughout arid countries. In Saudi Arabia, the increasing need for water is because of the rapid growth of the population and the extension of agricultural activities around the country (Khanfar 2008).

Groundwater aquifers, which are critical sources of both drinking and irrigation water, suffer from pollution. The major causes of groundwater pollution are the leaching of pollutants from agriculture, industry and untreated sewage as well as saltwater intrusion caused by over pumping (Khanfar 2008).

The Presidency of Meteorology and Environment (PME 2001) has issued the Kingdom of Saudi Arabia National Environmental Standard to specify physical and chemical guidelines for ambient water quality, including well water, and carries out a water quality monitoring programme to maintain continuous surveillance of all of the relevant water quality parameters. In addition, the Saudi Arabian Standards Organization (SASO 1997) has set the maximum limits for contaminating metallic elements in foods.

Therefore, this study was carried out to determine heavy the metal content of well water samples used for irrigation and soil samples collected from a farm in the Al-Kharj region over 3 months to assess the quality and suitability of the environment for leafy green plants, as well as to determine the extent of compliance with the heavy metal specifications for some selected leafy green plants that are consumed regularly by inhabitants in this region.

Background information

Al-Kharj is located approximately 50 miles south of Riyadh. The small verdant farms and groves of date palm trees of Al-Kharj have flourished in fertile soil. Currently, Al-Kharj is an agricultural oasis and produces cereals, dates, vegetables and fruits, and Al-Kharj has become a modern centre for agriculture and related industries (Information Office, Royal Embassy of Saudi Arabia in Washington 1999).

Material and methods

Sampling and analysis

Twelve well water samples used for irrigation were collected weekly from a selected farm in the Al-Kharj region for a period of 3 months. The collection, preservation and physicochemical analyses of the water samples were performed in accordance with the Standard Methods for the Examination of Water and Wastewater (Eaton et al. 2005), and the findings were compared with local and international guidelines. The concentrations of heavy metals (lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), copper (Cu), zinc (Zn), iron (Fe) and manganese (Mn)) were determined using an atomic absorption spectrophotometer (Shimadzu model AA-6650 flame system) (Eaton et al. 2005).

The soil samples were air-dried, crushed, passed through a 2-mm mesh sieve and stored at ambient temperature prior to analysis.

Four leafy green plants (parsley, arugula, celery and mallow) were collected monthly from a selected field that was irrigated with well water for a period of 3 months. Three samples of each plant were washed with 20 % (*v*/*v*) nitric acid and then rinsed with distilled deionized water to remove the soil particles adhering to the surface of the plants. The leafy parts of the plants were cut into pieces with a knife and were air-dried in the laboratory for 4 days before being oven-dried at 105 °C for approximately 24 h. The samples were crushed into powder in a mortar with a pestle. The samples were then sieved through a 2-mm nylon sieve and transferred into a labelled polyethylene container for analysis. The common and botanical names of the leafy green plants selected for the study are shown in Table 1.

The dried soil and leafy green plant samples were digested according to the methods of Awofolu (2005). One gram of dry soil and leafy green plant samples was weighed into a 50-mL volumetric flask and digested

Table 1 Common and botanical name of leafy green plants selected in the study

Botanical name	Common name
Petroselinum crispum	Parsley
Eruca sativa	Arugula
Apium graveolens	Celery
Corchorus olitorius	Mallow

with the addition of 15 mL of a tri-acid mixture (HNO_3, H_2SO_4 and $HClO_4$ in a 5:1:1 ratio) at 80 °C until a transparent solution was obtained. After cooling, the digested samples were filtered using Whatman No. 42 μm filter paper and the filtrates were diluted to 50 mL with distilled water. The levels of Pb, Cd, Cr, Ni, Cu, Zn, Fe and Mn in the digestates were determined by the Shimadzu atomic absorption spectrophotometer. The concentrations were calculated on a dry weight basis.

Statistical analysis

Data were tabulated and analysed using the Statistical Package for Social Sciences (SPSS) version 11.0 computer software package (Forthofer and Lee 1995).

Pearson's correlation coefficient was performed at a confidence limit of 95 % to detect the relationship between the levels of heavy metals in the leafy green plants and their content in the irrigated soil samples. Additionally, Pearson's correlation coefficient was used to show the correlation between the heavy metal content in the water and the irrigated soil. One-way analysis of variance (ANOVA) was used to find significant differences in heavy metal concentrations among the different leafy green plants studied, considering a level of significance of less than 5 % ($p < 0.05$).

Results and discussion

Evaluation of heavy metals in well water

Irrigation water was a dominant factor for determining the concentrations of heavy metals in leafy green plants compared to the soil because irrigation water normally led to the accumulation of heavy metals in soil and consequently in leafy green plants. The heavy metal concentration may increase due to excessive groundwater abstraction, which allowed more sea water to seep through the soil and groundwater (Aweng et al. 2011).

In the study area, heavy metal concentrations in groundwater and soil are related with anthropogenic pressures especially agricultural practices. Irrigation return-flow; use of fertilizers, pesticides and herbicides; changes in vegetation through conservation tillage; and the application of waste effluents have all been caused changes in quality of well water and soil.

The heavy metal concentrations in the well water samples collected weekly over 3 months from a farm in the Al-Kharj region, KSA, are presented in Table 2.

Table 2 shows that the mean concentrations of heavy metals (mg/L) in well water used for irrigation were 0.002 for Pb; 0.001 for Cd; 0.014 for Cr; 0.025 for Ni; 0.038 for Cu; 0.157 for Zn; 0.436 for Fe; and 0.044 for Mn. According to the international standard guideline for irrigation water (FAO 1985), the mean values of all of the heavy metal concentrations in well water were in compliance with the recommended levels. Additionally, the results shown in Table 2 demonstrated that the heavy metal concentrations in well water were within the national permissible levels for the Saudi Arabia environmental standard, except Ni, Zn and Fe and some concentrations of Pb, Cd and Cu (Presidency of Meteorology and Environment 2001). The mean concentrations of Pb, Cr, Ni, Cu, Fe and Mn in the well water of the present study area were higher than the mean metal concentrations of irrigation water from other studies in the Al-Baha Region, Saudi Arabia (Zabin et al. 2008). Additionally, lower levels of Pb, Cd, Ni, Cu, Zn and Mn were determined by Rapheal and Adebayo (2011) in irrigation water in Nigeria, where the water used for irrigation had mean concentrations of 0.001, 0.00013, 0.0024 and 0.0022 mg/L for Pb, Cu, Zn and Mn, respectively. In addition, Cd and Ni were not detected in all of the water samples. This finding is consistent with a study conducted in India and reported by Brar et al. (2000). In their study, all of the mean heavy metal (mg/L) values (0.006 for Cr; 0.01 for Cu; 0.07 for Zn; 0.13 for Fe; and 0.004 for Mn) in water irrigation samples were below the FAO (1985) limits and were lower than those in the present study. However, in Morocco, higher field survey results were obtained by Al-Jaboobi et al. (2014), who evaluated heavy metal contamination in irrigated well water and showed wells with a mean of 0.520, 0.435, 0.251, 0.286, 0.0017 and 0.062 mg/L for Fe, Mn, Ni, Cr, Cd and Pb, respectively.

Heavy metal evaluation in soil

The range and mean concentration of heavy metals (mg/kg dry weight) in the agricultural soil of the study area are presented in Table 3.

Although the heavy metals in the agricultural soil of the Al-Kharj region were widely observed, the levels of the metals were acceptable according to the international permissible levels specified by FAO/WHO (2001) and

Table 2 Heavy metal concentrations in well water used for irrigation in Al-Kharj region, Saudi Arabia

Heavy metals $n = 12$	Unit	Well water samples			p value Sig. (2-tailed)	PME (2001)	FAO (1985)
		Min	Max	$\bar{x}$±SD			
Lead	mg/L	ND	0.008	0.002 ± 0.001	0.000*	0.005	5.0
Cadmium	mg/L	ND	0.006	0.001 ± 0.001	0.419	0.005	0.01
Chromium	mg/L	0.005	0.032	0.014 ± 0.009	0.854	0.1	0.1
Nickel	mg/L	0.009	0.069	0.025 ± 0.017	0.910	0.02	0.2
Copper	mg/L	0.026	0.489	0.038 ± 0.007	0.000*	0.05	0.2
Zinc	mg/L	0.013	0.921	0.157 ± 0.025	0.000*	0.02	2.0
Iron	mg/L	0.065	1.738	0.436 ± 0.072	0.000*	0.2	5.0
Manganese	mg/L	0.007	0.083	0.044 ± 0.006	0.000*	0. 1	0.2

ND not detected

*Significant at $p \leq 0.05$

were lower than the levels reported by Al-Jaboobi et al. (2014), with all of the heavy metals in the soil samples in Morocco within the permissible limits, except for Cr and Pb, which had averages of 276 and 107 mg/kg, respectively. The observed levels of heavy metal variation in soil samples could be attributed to the varying amount of metals in the irrigation water as well as other agronomic practices of the respective areas (Yadav et al. 2013). In India, lower results than those observed in the present study were obtained by Brar et al. (2000), indicating that all of the mean concentrations of the various elements in soil irrigated with groundwater (0.81 for Cr, 0.99 for Cu, 2.9 for Zn, 13.8 for Fe and 14.3 for Mn) were within the FAO/WHO (2001) limits. Among the eight heavy metals examined in the soil, Cd (0.248 mg/kg) had the lowest level, although Cd is found in phosphate fertilizers due to its presence as an impurity in all phosphate rocks. The low level of Cd can be attributed to its continuous removal by leafy green plants grown in the designated areas (Yadav et al. 2013). However, Fe (164.52 mg/kg) had the highest heavy metal concentrations. The highest deposition of Fe in soil could be due to its long-term use in the production of machine tools, paints, pigments and alloying in various industries of the study area that may contaminate soil (Yadav et al. 2013). This finding is consistent with the results reported by Rapheal and Adebayo (2011) in Nigeria and Türkdoğan et al. (2002) in Turkey, indicating that among the heavy metals studied in the soil, Cd (0.71 and 5.9 mg/kg, respectively) had the lowest concentration. In contrast, Cd (160 mg/kg) had the highest concentration in the soil samples from Kogi State

Table 3 Heavy metal concentrations in agricultural soil in Al-Kharj region, Saudi Arabia

Heavy metals $n = 12$	Unit	Soil samples			p value Sig. (2-tailed)	FAO/WHO (2001)
		Min	Max	$\bar{x}$±SD		
Lead	mg/kg	18.71	42.85	34.21 ± 4.76	0.934	100
Cadmium	mg/kg	0.194	0.475	0.248 ± 0.034	0.000*	3.0
Chromium	mg/kg	43.50	89.23	60.43 ± 5.71	0.376	100
Nickel	mg/kg	14.70	49.52	27.83 ± 3.91	0.491	75
Copper	mg/kg	21.87	91.34	68.78 ± 6.42	0.730	100
Zinc	mg/kg	38.45	174.52	82.90 ± 9.13	0.000*	300
Iron	mg/kg	53.75	316.28	164.52 ± 21.76	0.000*	No guideline
Manganese	mg/kg	33.52	94.83	73.19 ± 8.05	0.098	400

*Significant at $p \leq 0.05$

(Amune et al. 2012). Previous studies contradict our study, which found that Mn (105.9 and 171 mg/kg, respectively) exhibited the highest concentration in the soil samples, but its concentrations were below the recommended safe limit (400 mg/kg) of heavy metals by the FAO/WHO (2001) standards (Rapheal and Adebayo 2011; Türkdoğan et al. 2002). However, elevated levels of Fe (1537 mg/kg) and Cd (31.23 mg/kg) in agricultural soil samples (dry weight) were detected by Yadav et al. (2013) in India.

Heavy metal evaluation in leafy green plants

Table 4 and Figs 1 and 2 show the heavy metal concentrations in some selected leafy green plant samples collected from the Al-Kharj region, KSA.

Pb is a toxic element that can be harmful to plants, although plants usually show an ability to accumulate large amounts of lead without visible changes in their appearance or yield. In many plants, Pb accumulation can exceed several hundred times the threshold of the maximum level permissible for human consumption (Muhammad et al. 2008). The elevated levels of Pb in some leafy plants may be attributed to pollutants in the irrigation water or farm soil or due to pollution from highway traffic (Qui et al. 2000; Kananke et al. 2014).

Table 4 clearly shows that the mean Pb concentrations varied from 0.93 to 4.98 mg/kg, higher than the concentrations (0.0127–0.268, 0.078–0.134, 0.071–0.118 and 0.18–1.59 mg/kg) obtained from leafy green plants by Aweng et al. (2011) in Malaysia; Al Jassir et al. (2005) in Saudi Arabia; Shuaibu et al. (2013) in Nigeria; and Kananke et al. (2014) in Sri Lanka, respectively. These results contrasted with the findings of a survey conducted in Turkey (2002), indicating that leafy green plants contain high levels of Pb (409 mg/kg) (Türkdoğan et al. 2002). The observed mean concentrations of Pb were lower than the concentrations (9.5–19.2, 13.01–17.26 and 11.33–16.67 mg/kg) obtained by Shakya and Khwaounjoo (2013); Yadav et al. (2013); and Al-Jaboobi et al. (2014) for leafy green plants irrigated with groundwater in Kathmandu, India, and Morocco, respectively. The highest mean concentration of Pb was in parsley (4.98 mg/kg), followed by mallow (2.75 mg/kg), celery (1.14 mg/kg) and arugula (0.93 mg/kg). This finding is consistent with the results reported by Farooq et al. (2008), who found that parsley (2.652 mg/kg) grown in Pakistan contained the highest levels of Pb. The levels of Pb in all of the leafy green

Table 4 Mean concentrations of heavy metals in the four selected leafy green plants collected from a selected farm in Al-Kharj region, Saudi Arabia

Heavy metals $n = 12$	Unit	Leafy green plants samples				ANOVA F (p value)	SASO (1997)	FAO/WHO (2001)	FAO/WHO (2007)	EU(2006)
		Petroselinum crispum $\bar{x}$±SD	*Eruca sativa* $\bar{x}$±SD	*Apium graveolens* $\bar{x}$±SD	*Corchorus olitorius* $\bar{x}$±SD					
Lead	mg/kg	4.98 ± 1.657	0.93 ± 0.105	1.14 ± 0.652	2.75 ± 0.921	12.930 (0.000*)	0.3	0.3	5.0	0.10
Cadmium	mg/kg	0.082 ± 0.041	0.009 ± 0.0003	0.064 ± 0.007	0.097 ± 0.020	8.674 (0.000*)	0.2	0.2	0.2	0.20
Chromium	mg/kg	0.340 ± 0.039	0.195 ± 0.021	0.431 ± 0.065	0.396 ± 0.027	16.210 (0.000*)	1.0	0.5	No guideline	No guideline
Nickel	mg/kg	5.28 ± 1.430	1.57 ± 0.176	1.96 ± 0.401	3.47 ± 0.976	102.618 (0.000**)	10.0	67.0	No guideline	No guideline
Copper	mg/kg	5.07 ± 1.817	12.31 ± 4.064	7.94 ± 2.936	10.52 ± 3.419	22.345 (0.000*)	40.0	73.0	40.0	No guideline
Zinc	mg/kg	46.76 ± 5.908	38.84 ± 6.001	57.50 ± 12.470	50.32 ± 9.564	1.590 (0.000***)	60.0	99.40	60.0	No guideline
Iron	mg/kg	73.96 ± 18.531	45.09 ± 7.142	53.60 ± 10.890	66.13 ± 15.278	19.173 (0.000*)	No guideline	425	No guideline	No guideline
Manganese	mg/kg	48.23 ± 8.070	18.36 ± 1.361	36.52 ± 4.842	43.86 ± 6.654	28.258 (0.000*)	20.0	200	No guideline	No guideline

*Significant at $p \leq 0.05$; **significant at $p \leq 0.01$; ***significant at $p \leq 0.001$

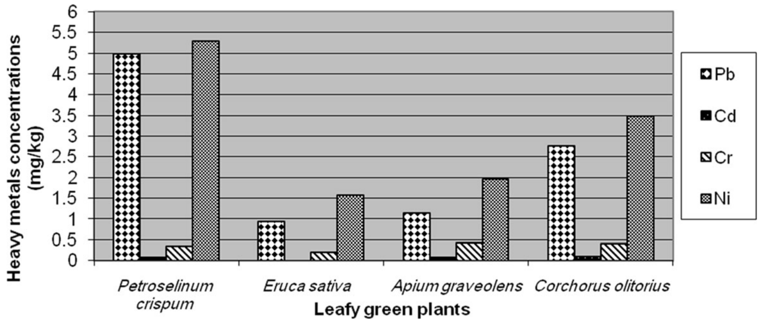

Fig. 1 Lead, cadmium, chromium and nickel concentrations in leafy green plants in Al-Kharj region, Saudi Arabia

plants studied were above the prescribed safe limit of SASO (1997), FAO/WHO (2001) and EU (2006), whereas its concentrations were below the allowable limits according to FAO/WHO (2007). Thus, we anticipate that the consumption of Pb through leafy green plants poses a substantial health risk to consumers, and therefore, these plants may be unfit for consumption, as mentioned by Al-Jaboobi et al. (2014).

Cd is not essential in foods and natural waters, and Cd accumulates principally in the kidneys, liver and lungs (Divrikli et al. 2006). Cd causes carcinogenic effects and teratogenic abnormalities in humans, even at very low concentrations. Phosphate fertilizers are the major source of soil contamination by trace metals, especially Cd, as Cd is naturally found as an impurity in phosphate rocks. Accumulation of Cd in plants affects the nutrient uptake; obstructs the respiratory enzymes, carbohydrate metabolism and photosynthesis; alters the antioxidant metabolism; and reduces the crop productivity (Kananke et al. 2014).

The maximum amount of accumulation of Cd was found in mallow (0.097 mg/kg), followed by parsley (0.082 mg/kg), as shown in Fig. 1. The mean concentrations of Cd (0.009–0.097 mg/kg) in leafy green plants were in agreement with the concentrations (0.033–0.073 mg/kg) observed in leafy green plants grown in Pakistan by Farooq et al. (2008), but were substantially lower than the Cd concentrations (0.0482–0.1123, 0.07–0.97, 0.45–4.1, 7.4–8.9, 2.97–18.92 and 12–35 mg/kg) in leafy green plants from Malaysia, Sri Lanka, China, Kathmandu, India and Turkey, respectively (Aweng et al. 2011; Kananke et al. 2014; Zhuang et al. 2009; Shakya and Khwaounjoo 2013; Yadav et al. 2013; Türkdoğan et al. 2002). This finding contradicts the results obtained by Al-Jaboobi et al. (2014) in Morocco and Shuaibu et al. (2013) in Nigeria, indicating that Cd was totally undetected in various leafy green plants. The Cd concentrations in all of the leafy green plants examined in the present study were below the permissible levels recommended by SASO (1997), FAO/WHO (2001), FAO/WHO (2007) and EU (2006).

Cr aids the breakdown of lipids in the body and increases high-density lipoprotein (HDL) cholesterols in the body, while reducing low-density lipoprotein (LDL) cholesterol. Ingestion of high doses of Cr can cause irregular heartbeat, stomach distress, itching and flushing in humans. In addition, chromium can cause ulceration and liver and kidney damage (Kananke et al. 2014).

The maximum uptake of Cr in celery (0.431 mg/kg), followed by mallow (0.396 mg/kg), parsley (0.340 mg/kg) and arugula (0.195 mg/kg), was within

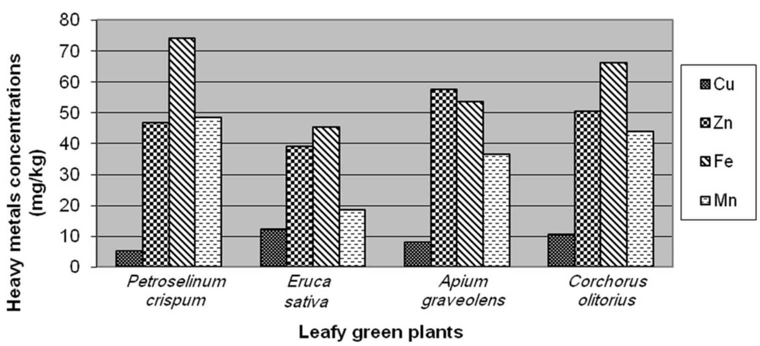

Fig. 2 Copper, zinc, iron and manganese concentrations in leafy green plants in Al-Kharj region, Saudi Arabia

the SASO (1997) and FAO/WHO (2001) limits (1.0 and 0.5, respectively). The present study revealed that the mean concentrations of Cr (0.195–0.431 mg/kg) measured in leafy green plants were consistent with the results reported from Pakistan (0.217–0.546 mg/kg) (Farooq et al. 2008). In contrast, none of the leafy green plants in Kathmandu had Cr concentrations in their leaves (Shakya and Khwaounjoo 2013). The mean Cr level detected in the leafy green plants studied was lower than the values reported from Sri Lanka, Morocco and India (0.18–5.05, 5.83–28.73 and 3.4–7.6 mg/kg, respectively) (Kananke et al. 2014; Al-Jaboobi et al. 2014; Brar et al. 2000).

The level of Ni in this study was found to be highest in the leaves of parsley (5.28 mg/kg) and lowest in the leaves of arugula (1.57 mg/kg), as presented in Fig. 1. The high mean concentrations of Ni reported in this study were lower compared to the high mean concentrations of Ni reported in Morocco and India (85 and 66.55 mg/kg, respectively) by Al-Jaboobi et al. (2014) and Yadav et al. (2013), but higher than those from Nigeria and India (0.77 and 1.3 mg/kg, respectively) (Rapheal and Adebayo 2011; Brar et al. 2000). The Ni contents of the leafy green plants in this study were lower compared to the FAO/WHO (2001) safe limit of 67.0 mg/kg and are within the permissible limit.

Cu is an essential micronutrient that functions as a biocatalyst and is required for body pigmentation (Shuaibu et al. 2013). Cu toxicity can induce lipid peroxidation, iron deficiency and membrane destruction within the body (Kananke et al. 2014).

The maximum mean concentration of Cu was exhibited by arugula (12.31 mg/kg), followed by mallow (10.52 mg/kg), which is in compliance with the acceptable level of FAO/WHO (2001) and FAO/WHO (2007) for Cu (73 and 40, respectively). The mean content of Cu (5.07–12.31 mg/kg) in leafy green plants was lower than the values (7.05–18.44, 6.1–28.47, 15.24–32.2 and 47–105 mg/kg) reported in Sri Lanka, Morocco, India and Turkey, respectively (Kananke et al. 2014; Al-Jaboobi et al. 2014; Yadav et al. 2013; Türkdoğan et al. 2002), but comparatively higher than the Cu (0.333–0.632, 0.252–0.923 and 1.220–5.220 mg/kg) levels reported from Nigeria, Pakistan and Nigeria, respectively (Shuaibu et al. 2013; Farooq et al. 2008; Rapheal and Adebayo 2011). In the present study, the mean Cu levels in mallow (10.52 mg/kg) and in parsley (5.07 mg/kg) were very close to the results (5.3 and 10.40 mg/kg) obtained by Brar et al. (2000) and Zhuang et al. (2009) in leafy green plants from India and China, respectively.

Zn is the least toxic of the heavy metals and an essential element in the human diet, as it is required to maintain the function of the immune system. A Zn deficiency in the diet may be highly detrimental to human health compared to too much Zn in the diet. However, the high concentration of Zn in leafy green plants may cause vomiting, renal damage, cramps and so on (Shuaibu et al. 2013).

The highest mean concentration of Zn shown by celery (57.50 mg/kg) complied with the recommended safe limit of FAO/WHO (2001) and FAO/WHO (2007) for Zn (99.40 and 60, respectively). This finding is similar to the results (58.77 mg/kg) obtained by Al-Jaboobi et al. (2014) for a high Zn mean value in leafy green plants irrigated with groundwater in Morocco. The mean Zn concentrations in leafy green plants varied from 38.84 to 57.50 mg/kg, which were lower than the data (31.6–107.6 mg/kg) reported by Shakya and Khwaounjoo (2013) in Kathmandu. However, the Zn concentrations were higher than the findings (0.163–0.32, 0.221–0.375, 0.461–1.893 and 4.590–9.350 mg/kg) reported by Aweng et al. (2011), Shuaibu et al. (2013), Farooq et al. (2008) and Rapheal and Adebayo (2011) in Malaysia, Nigeria, Pakistan and Nigeria, respectively.

Fe is essential for the synthesis of chlorophyll and activates a number of respiratory enzymes in plants. An Fe deficiency results in severe chlorosis of leaves in plants. High levels of exposure to iron dust may cause respiratory diseases, such as chronic bronchitis and ventilation difficulties (Shuaibu et al. 2013).

Among all of the heavy metals studied, Fe is the most abundant element, with the highest concentration of 73.96 mg/kg recorded in the leaves of parsley, as presented in Fig. 2. The lowest concentration of Fe (45.09 mg/kg) was recorded in the leaves of arugula. Moderate amounts of Fe were recorded in mallow and celery, which were 66.13 and 53.60 mg/kg, respectively. The observed high mean concentration of Fe in leafy green plants was lower than the concentrations (140, 292.35 and 601.9 mg/kg) obtained by Brar et al. (2000) in India; Yadav et al. (2013) in India; and Al-Jaboobi et al. (2014) in Morocco for leafy green plants irrigated with groundwater, respectively. The lowest mean concentration of Fe in leafy green plants was higher than the concentrations (0.260 and 0.65 mg/kg) found by Shuaibu et al. (2013) in Nigeria and Aweng et al.

Table 5 Pearson's correlation coefficients between heavy metal contents in irrigated soil and leafy green plants collected from a selected farm in Al-Kharj region, Saudi Arabia

Heavy metals in leafy green plants samples	Heavy metals in soil samples							
	Lead	Cadmium	Chromium	Nickel	Copper	Zinc	Iron	Manganese
Lead	1.00							
Cadmium	0.3844	1.00						
Chromium	0.7009**	0.0354	1.00					
Nickel	0.7951**	0.1278	0.2365	1.00				
Copper	0.3092	−0.3960	−0.3732	−0.2591	1.00			
Zinc	0.4861	−0.2406	−0.1852	−0.0247	−0.1230	1.00		
Iron	0.2725	−0.4831	−0.4331	−0.2762	−0.3464	0.9733***	1.00	
Manganese	0.4791	−0.2152	−0.1631	0.0054	−0.0871	−0.0005	0.5529*	1.00

*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$

(2011) in Malaysia, respectively. The contents of Fe in this study are within the permissible level of 425.00 mg/kg by the FAO/WHO (2001) in leafy green plants.

The Mn content was found to be highest in the leaves of parsley (48.23 mg/kg) and lowest in the leaves of arugula (18.36 mg/kg). Substantial amounts of Mn were recorded in the leaves of mallow and celery, which are 43.86 and 36.52 mg/kg, respectively, as exhibited in Fig. 2. The range of Mn means in the leaves of the test leafy green plants were far below those values (75.67–97.9, 108–237 and 121–389 mg/kg) recorded by Al-Jaboobi et al. (2014) in Morocco, Türkdoğan et al. (2002) in Turkey and Brar et al. (2000) in India, but they were far above those (0.04–1.2 and 2.0–7.8 mg/kg) measured by Aweng et al. (2011) and Rapheal and Adebayo (2011) in Malaysia and Nigeria, respectively.

Among the four different leafy green plants examined, parsley had the highest level of Pb, Ni, Fe and Mn: 4.98, 5.28, 73.96 and 48.23 mg/kg, respectively. Mallow had the highest level of Cd, 0.097 mg/kg; celery contained the highest Cr and Zn concentrations, 0.431 and 57.50 mg/kg, respectively; and arugula had the highest level of Cu, 12.31 mg/kg. The results showed significant differences in heavy metal concentrations among the leafy green plants studied. All leafy green plants have a higher uptake capacity for essential metals (Cu, Zn, Fe and Mn) than toxic metals (Pb and Cd), as also mentioned by Shuaibu et al. (2013).

Pearson's correlation was used to correlate between the heavy metal content in soil and the accumulation of the heavy metals in leafy green plants. The results of the statistical analysis indicated a significant correlation between the soil metal content and suitability of leafy

Table 6 Pearson's correlation coefficients between heavy metal contents in water and irrigated soil collected from a selected farm in Al-Kharj region, Saudi Arabia

Heavy metals in water samples	Heavy metals in soil samples							
	Lead	Cadmium	Chromium	Nickel	Copper	Zinc	Iron	Manganese
Lead	1.00							
Cadmium	−0.82143	1.00						
Chromium	−0.1532	−0.7921	1.00					
Nickel	0.3689	−0.08571	0.8333**	1.00				
Copper	−0.2350	−0.5432	−0.4373	−0.0541	1.00			
Zinc	0.5632*	0.9554***	−0.0543	−0.8631	0.9285***	1.00		
Iron	0.3691	−0.7652	−0.2606	0.4680	0.7620**	0.0651	1.00	
Manganese	−0.8765	−0.8642	−0.0084	0.3451	−0.0056	−0.0432	0.9761***	1.00

*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$

green plants for consumption at the level of $p < 0.05$, as shown in Table 5. This finding contradicts the results obtained by Rapheal and Adebayo (2011); they found that the metals in leafy green plants did not show any significant correlations with the metals in soils, where there is a combination of factors affecting metal uptake by plants, such as soil pH, organic carbon content, cation exchange capacity and soil texture. Table 6 shows the correlation between the heavy metal content in water and irrigated soil. Clearly, although several sources of heavy metals can contaminate soil and the lower level of heavy metals in well water used for irrigation, a significant correlation between levels of heavy metal in soil and the concentrations of heavy metals in irrigation water was detected.

Conclusions and recommendations

According to the findings of the present study, the following recommendations should be considered:

- Based on the water guidelines, the surveyed well water used for irrigating a selected farm located in the Al-Kharj region contained higher values of some heavy metals than the maximum allowable limits by PME and FAO. Therefore, a continued assessment of groundwater quality on a routine basis is imperative, and better management is warranted to reduce the deterioration of the aquifer water quality.
- Soil samples showed higher levels of some heavy metals, indicating that they accumulate in leafy green plants and become unfit for human consumption. Therefore, regular monitoring of the concentrations of potentially toxic trace metals in soil and leafy green plants is needed.

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