Environmental Science and Pollution Research (2021) 28:50217–50229
https://doi.org/10.1007/s11356-021-14249-y

RESEARCH ARTICLE

Bioaccumulation and human health risk assessment of heavy metals in food crops irrigated with freshwater and treated wastewater: a case study in Southern Cairo, Egypt

Hanan Elsayed Mohamed Osman[1] · Enas Mohamed Wagdi Abdel-Hamed[2] · Widad Saleem Mubarak Al-Juhani[1,3] · Yaser Ayesh Omer Al-Maroai[1,3] · Mohamed Helmy El-Metwally El-Morsy[4,5]

Received: 16 February 2021 / Accepted: 29 April 2021 / Published online: 5 May 2021

Abstract

Food safety has often attracted attention worldwide. Few studies have investigated the heavy metal (HM) pollution and health risk assessment of crops and vegetables. The current work was conducted to evaluate the human risk assessment of HM (Cu, Cd, Cr, Pb, and Zn) in radish, lettuce, tomato, onion, turnip, squash, okra, sunflower, Jews mallow, and garden rocket cultivated in treated wastewater (TWW)-irrigated sites as compared with those cultivated in freshwater (FW)-irrigated sites. Irrigation water, soil, and different plants were collected from 6 farmlands irrigated with TWW and two agricultural sites irrigated with FW (Nile river). Heavy metal transfer factor (HMTF), chronic daily intake of metals (CDIM), health hazard risk (HR), and health hazard index (HI) were estimated. The results showed that the tested HM levels in FW and TWW were below the Food and Agriculture Organization (FAO) and Egyptian standards recommended for irrigation. In soil samples, HM levels were below the permissible limits for both tested sites. The HM in soil and plants grew in TWW-irrigated sites possessed multiple levels higher than those grown in FW-irrigated sites. Among different plants, HM levels in the edible parts of plants grown in TWW-irrigated sites followed in decreasing order: tomato > sunflower >Jew's mallow = turnip = squash > lettuce > okra = radish > onion > garden rocket. The mean CDIM and HR values of plants irrigated using TWW were higher than those irrigated using FW. Furthermore, HR values for all plants grown in polluted and unpolluted sites were < 1 except Cd in plants grown in the TWW-irrigated farmlands. The mean HI for radish, lettuce, tomato, onion, turnip, squash, okra, sunflower, Jews mallow, and garden rocket grown in TWW-irrigated sites were 2.08, 2.39, 1.76, 1.53, 2.08, 1.80, 2.03, 1.91, 1.82, and 1.44 (for adult), and 2.39, 2.75, 2.71, 1.75, 2.38, 2.06, 2.33, 2.69, 2.10, and 1.65 (for children). Plants irrigated with TWW showed a higher HMTF than plants irrigated with FW. Jew's mallow and okra irrigated with TWW had a maximum HMTF. Consequently, different practical measures can be taken to minimize the HM levels in agricultural foodstuffs. These measures include preventing the excessive application of pesticides and fertilizers for crop production and continuous monitoring of different foodstuffs in the market.

Responsible Editor: Lotfi Aleya

✉ Hanan Elsayed Mohamed Osman
heosman@uqu.edu.sa

Enas Mohamed Wagdi Abdel-Hamed
emabdelaal@zu.edu.eg

Widad Saleem Mubarak Al-Juhani
wsjuhani@uqu.edu.sa

Yaser Ayesh Omer Al-Maroai
Yamarwei@uqu.edu.sa

Mohamed Helmy El-Metwally El-Morsy
mhmorsy@uqu.edu.sa

1 Biology Department, Faculty of Applied Science, Umm Al-Qura University, Makkah, Saudi Arabia

2 Soil Science Department, Zagazig University, Zagazig 44519, Egypt

3 Research Laboratories Centre, Umm Al-Qura University, Makkah, Saudi Arabia

4 Deanship of Scientific Research, Umm Al-Qura University, Al Mukarramah, Makkah, Saudi Arabia

5 Plant Ecology and Range Management Department, Desert Research Center, Cairo, Egypt

Keywords Edible plants · Chronic daily intake of metals · Human risk assessment · Heavy metal transfer factor · Treated wastewater · Freshwater

Introduction

Water scarcity is a significant problem in many countries in North Africa and the Middle East. Owing to the high population and much-irrigated agricultural land, Egypt has moved to a water-scarce country. Egypt's primary water source is the Nile River, which receives about 55.5 billion m^3 of freshwater; it is about 97% of the renewable water sources (Elbana et al. 2013; El-Agha et al. 2020). In Egypt, wastewater production is about 2.4 billion m^3/year, representing a challenge to recycle; most raw wastewater is passing through farmlands. Owing to the limited availability of freshwater, farmers around drainages use it as an alternative source of irrigation for many crops (Egypt State of the Environment Report 2009).

Wastewater contains heavy metals (HM), and repeated irrigation of this water causes the accumulation of HM in agricultural soil. Plants uptake essential and non-essential metals from soil and accumulate in different plant parts. Increasing HM's content above the permissible food-safe levels contributes to the environmental crisis (Stavrides 2006). Consumption of crops and cereals grown in contaminated soil causes deterioration in human health, especially in children, and increases the possibility of cancer risk (Lu et al. 2015; Qu et al. 2016; Parihar et al. 2021). Heavy metals are non-biodegradable and have a long half-life, and can bioaccumulate in the human body. Exposure to such metals could cause many health problems like changes in blood pressure, dysfunction of the liver, lung, and kidney, and immune system defects (Ming-Ho 2005). In the human body, cadmium and lead have no physiological roles and are linked with disorders of the liver, kidney, and nervous system (Järup 2003). To sustain normal development and maintenance of human physiology, trace essential metals such as zinc and copper are required for living organisms at low concentrations, but excessive exposure to these elements poses human health risks (Nriagu et al. 2009).

From the last century, there is public concern about food safety, and many studies are concerned with the assessment of foodstuffs grown in polluted soil because it is associated with human health risks (Guadie et al. 2021; Haque et al. 2021; Kharazia et al. 2021; Natashaa et al. 2021; Román et al. 2021; Zakir et al. 2020). In Egypt, several studies have explored the assessment of human health hazard and detection of HM in fish (Issa et al. 2018; Masoud et al. 2007), different foodstuffs (Badwey et al. 2014; Farrag et al. 2016), squash (Galal 2016), wheat and maize (Farahat et al. 2017), fruits (Amer et al. 2019), meat from camel, cattle, buffalo, and sheep (Morshdy et al. 2018), and soft drinks (Ghuniem et al. 2020).

The aims of this work are the following: (1) to monitor the bioaccumulation and HM content in water, soil, and plant parts sampled from various treated wastewater and freshwater irrigated farmlands, (2) to evaluate the chronic daily intake (CDIM) of tested HM for children and adult residents via the intake of edible parts, and (3) to assess the non-carcinogenic risk and human health hazards linked by HM accumulation via consumption of foodstuffs irrigated with treated wastewater (TWW). The findings will provide valuable data for further examining HM contents in foodstuffs, thus improving residents' food safety and health. The outcome of this work is expected to afford an essential contribution to policymakers in Egypt concerning the use of TWW for irrigation foodstuff.

Materials and methods

Site descriptions

This study was performed during May 2018 and June 2019 in two sites. The first site was located in El-Saff city's cultivated area (Helwan, Cairo Governorate, Egypt). According to local farmers, this site has been exposed to TWW irrigation of crops for over 40 years. The water originates from the sewage treatment station at Helwan.

Helwan Sewage Treatment Plant (HSTP) was located near the industrial area of Helwan city (iron and steel factory, coke, weaving, and fertilizer industries). Those industrial activities produce a vast amount of wastes, which is usually dumped into HSTP for treatment. Also, the station receives domestic wastewater from Helwan and 15th May City. After secondary treatment, the effluent is pumped into the El-Saff canal. These areas are cultivated in violation of traditional crops by farmers. The governorate was planned to use this water for planting about 17,000 hectares of tree forest. The second site was located at El-Badrashin (Giza governorate, Egypt), where the fields in this location have been irrigated with water from the Nile River.

According to the Egyptian Meteorological Authority, the studied area climate is subtropical desert, with hot, sunny summer, and a very mild winter. The temperature ranged from 10 to 36 °C. The precipitation is scarce over most of the year, and the annual rainfall does not exceed 25 mm.

Sampling and analysis

Water sampling

Field sampling was conducted from May 2018 and June 2019. Treated wastewater (TWW) samples were collected regularly from six different sites of the TWW canal passing the studied farmlands. At the same time, the Nile River's water was taken as a control. Water samples were collected from each irrigation source that simultaneously supplies the studied agricultural farmlands as soil and foodstuff sampling. To avoid microbial activity, few drops of nitric acid (HNO_3) were added, and samples were taken to the laboratory for analysis.

Soil sampling

In a contaminated site, composite soil samples were collected from different farms (6 farms, covering 8 ha) irrigated with the El-Saff canal (TWW). Also, soil samples from a reference site (2 farms) were taken. Ten profiles were selected randomly within each farm for each soil sample, where soil samples were sampled at 0–30 cm. The soil was stored in polyethylene bags, air dried, sieved in 2 mm, and stored for analysis from each sampling point.

Plant samples

At the harvest stage, 24 composite samples from different plants were collected randomly from both studied sites. These plants are radish (*Raphanus sativus* L.), tomato (*Solanum lycopersicum* L.), lettuce (*Lactuca sativa* L.), onion (*Allium cepa* L.), turnip (*Brassica raba* L.), squash (*Cucurbita pepo* L.), sunflower (*Helianthus annus*), Jew's mallow (*Corchorus olitorius*), okra (*Abelmoschus esculentus* L.), and garden rocket (*Eruca vesicaria*). All the collected plants were thoroughly washed with double distilled water. The samples were cut to separate the roots, shoots, and fruits or seeds. The plant parts were oven-dried until constant weight and then grounded to a fine powder.

Water, soil, and plant analysis

Water samples were analyzed for their pH and electrical conductivity (EC). Nitrogen content was determined as described by Peach and Tracey (1956). Chloride anions (Cl^-), chemical oxygen demand (COD), and biological oxygen demand (BOD) were assessed according to APHA (2012). The phosphorous content was determined as described by Rowell (1993). Sodium (Na) and potassium (K^+) were determined using a flame photometer (PFP 7, Jenway, UK), according to AOAC (2000).

Soil extracts (1:2.5, w/v) were used to determine pH, EC, and chloride according to Richards (1954) and Jackson (1967). Total carbonate was determined according to Piper (1950). Soil texture was analyzed by the pipette method as outlined by Kilmer and Alexander (1949). Organic matter (OM) was determined following the method of Nelson and Sommers (1982). The total content of Cd, Cu, Cr, Pb, and Zn in the filtered extracts obtained from samples digested by concentrated HNO_3, concentrated H_2SO_4, and 60% $HClO_4$ was analyzed as outlined by Hesse (1971). The soil chemical-extractable contents of these elements were extracted using DTPA (diethylene triamine pentaacetic acid) to determine available HM content according to Lindsay and Norvell (1978).

Plant tissue powder (0.5 g) was digested according to Norvell (1984) using a mixture of H_2SO_4, HNO_3, and $HClO_4$ to quantify select essential elements and HM.

Heavy and essential metals Cd, Cu, Cr, Pb, and Zn in filtrate water, soil, and plant samples were analyzed using Inductively Coupled Argon Plasma (ICAP 6500 Duo, Thermo Scientific, England). A 1000 mg/L multi-element certified standard solution (Merck, Germany) was used as a stock solution for instrument standardization.

Data analysis

Soil Pollution Load index (SPLI) was evaluated using Eq. (1)

$$\mathrm{SPLI} = \mathrm{Cp}/\mathrm{Cup} \tag{1}$$

Whereas Cp and Cup is the HM content in polluted and unpolluted soil (Liu et al. 2005).

Heavy metal transfer factor (HMTF), the proportion of metal content in foodstuff ($C_{\mathrm{foodstuff}}$; D.Wt.) to metal contents in soil (C_{soil}), was determined (Mirecki et al. 2015) according to Eq. (2)

$$\mathrm{HMTF} = C_{\mathrm{foodstuff}}/C_{\mathrm{soil}} \tag{2}$$

Chronic daily intake of metals (CDIM) for each metal was assessed using Eq. (3)

$$\mathbf{CDIM} = (\boldsymbol{C}_{\mathbf{m}} \times \boldsymbol{C}_{\mathbf{f}} \times \boldsymbol{D}_{\mathbf{fi}})/B_{\mathrm{aw}} \tag{3}$$

C_m is the HM content in foodstuff (mg kg^{-1}), C_f is the conversion factor 0.085, D_{fi} is a daily intake of foodstuff with 0.232 and 0.345 kg^{-1} day^{-1} for children, and adults, respectively. B_{aw} is the average body weight with 32.7 and 55.9 kg for children and adults, respectively (Rattan et al. 2005).

Health risk (HR) was determined according to Eq. (4)

$$\mathbf{HR} = \mathbf{CDIM}/R_{\mathrm{fD}} \tag{4}$$

CDIM is calculated from Eq. (3), and oral reference doses (R_{fD}) are 0.001, 0.04, 1.5, 0.04, and 0.3 mg kg^{-1} day^{-1}, respectively, for Cd, Cu, Cr, Pb, and Zn, respectively (US EPA 2018). For HR less than 1, foodstuff are considered to be safe to the local people health.

Health hazard index (HI) is the sum of HR for all metals in each crop grown in the study area. The HI was predicated from Eq. (5) (Antoine et al. 2017; Weber et al. 2019).

$$\mathbf{HI} = \sum \mathbf{HR} \tag{5}$$

Statistical analysis

The Q-cluster analysis was performed on the tested HM in different plants (Fig. 1). In this analysis, the square Euclidean distance was considered a measurement interval, and the farthest neighboring element was applied.

Results and discussion

Treated wastewater and freshwater characteristics

Six water samples were obtained from TWW and FW sites for measuring different chemical quality indicators (Table 1). According to Egyptian governmental law and the Food Agriculture Organization (FAO), the pH and EC levels were below the permissible limits. The mean pH and EC for TWW were 7.87 and 1.53 dsm^{-1}, respectively, and those for FW were 7.40 and 1.14 dsm^{-1}, respectively. The obtained data were in line with the finding obtained by Osman et al. (2010) and Farrag et al. (2016) for the El-Saff canal. Total dissolved salts (TDS) ranged between 700–1900 and 137–350 mg L^{-1}, respectively, in TWW and FW. The mean TDS levels in TWW were below FAO guidelines while surpassing the limits recommended by Egyptian national law.

Chemical oxygen demand (COD) and biological oxygen demand (BOD) are essential quality indicators used to assess

Table 1 Physiochemical and HM characteristics of TWW and FW used for irrigation (mean ± stdv of 6 samples)

Quality indicator*	Effluent	Nile river	Recommended value			
	Range	Mean	Range	Mean	Egypt[a]	FAO[b]
pH	7.6–8.10	7.87 ± 0.22	7.4–8.3	7.83 ± 0.44	6.5–8.5	6.5–8.5
EC (mS/cm)	1.1–2.15	1.53 ± 0.45	0.52–1.5	1.14 ± 0.54	–	(0.7–3)
TDS (mg/L)	700–1900	1157.50 ± 521.43	137–350	225.75 ± 102.69	≤ 1000	(450–2000)
COD (mg O_2/L)	18–46	30.50 ± 9.29	2.90–10.5	5.18 ± 3.57	≤ 50	–
BOD (mg O_2/L)	9.5–37	23.88 ± 11.26	1.80–5.90	3.75 ± 1.92	≤ 30	–
Cl^- (mg/L)	120–300	201.50 ± 82.03	6.18–9.12	7.75 ± 1.32	–	0–1100
NO_3 (mg/L)	3.5–4.83	4.26 ± 0.56	3.00–4.12	2.40 ± 1.68	–	0–10
PO_4^{--} (mg/L)	2.5–7	4.70 ± 2.06	0.40–1.30	1.20 ± 0.96	–	0–2
K^+ (mg/L)	12–20	14.13 ± 4.63	0.50–1.67	1.14 ± 0.68	–	0–2
Na^+ (mg/L)	180–300	252.50 ± 55.00	11.25–14.92	12.56 ± 1.62	–	0–900
Cd^{++} (mg/L)	0.001–0.003	0.002 ± 0.001	0.0003–0.004	0.002 ± 0.0018	≤ 0.003	0.01
Cu^{++} (mg/L)	0.02–0.1	0.07 ± 0.04	0.008–0.016	0.012 ± 0.003	≤ 1.00	0.20
Cr^{+++} (mg/L)	0.002–0.004	0.003 ± 0.001	0.0001–0.0003	0.0003± 0.0001	≤ 0.5	0.10
Pb^{++} (mg/L)	0.002–0.04	0.02 ± 0.02	0.006–0.012	0.01 ± 0.003	≤ 0.10	0.1
Zn^{++} (mg/L)	0.007–0.01	0.01 ± 0.02	0.01–0.02	0.02 ± 0.004	≤ 2.00	2.00

[a] Egyptian Governmental Law 2013

[b] FAO 1985

the water quality and provide an index of the impact discharged wastewater will have on the receiving environment. Both quality indicators were within the permissible limits recommended by Egyptian standards (Table 1). The same findings were recorded by Farrag et al. (2016) and Gedamy et al. (2012). Among tested anions and cations, PO_4 and K were above the permissible levels recommended by FAO. The mean value of PO_4 and K in the El-Saff canal were 4.26 and 4.70 mg/L, respectively.

The tested HM content in both FW and TWW did not exceed the FAO and Egyptian standards recommended for irrigation (Table 1). In FW samples, HM contents had the lowest values and fluctuated between (mg/L) 0.0003 to 0.004 for Cd, 0.008 to 0.016 for Cu, 0.0001 to 0.0003 for Cr, 0.006 to 0.012 Pb, and 0.01 to 0.02 for Zn. In TWW samples, tested HM showed the highest levels and ranged (mg/L) between 0.001–0.003 for Cd, 0.02–0.1 for Cu, 0.002–0.004 for Cr, 0.002–0.04 for Pb, and 0.007–0.01 for Zn.

The reported values are in line with Farrag et al. (2016) and Gedamy et al. (2012). Farrag et al. (2016) found that the mean values of Cd, Cr, Cu, Pb, and Zn in the El-Saff wastewater canal were 0.002, 0.002, 0.033, 0.022, and 0.01 mg/L, respectively. Meanwhile, the detected data were less than those obtained by Osman et al. (2010), who found Cd and Zn contents in wastewater canals were 0.16 and 1.50 mg/L, respectively. Even though tested HM values were below the standards levels recommended for irrigation by FAO and Egyptian guidelines. The long irrigation period by such water may cause a detrimental impact on the agricultural soil and potential health risk.

Soil characteristics of tested agriculture sites

Physiochemical characteristics of soil samples taken from both tested sites are presented in Table 2. Soil pH, EC, OM, Cl, and $CaCO_3$ were significantly higher in TWW-

Table 2 Values of physiochemical and HM characteristics of TWW-irrigated and FW-irrigated sites (mean ± stdv of 6 samples)

Quality indicators	Site				SPLI
	TWW-irrigatedsites	FW-irrigated sites			
Coarse sand (%)	25.43	8.14			
Fine sand (%)	27.02	36.87			
Silt (%)	44.35	23.10			
Clay (%)	3.20	31.88			
Texture	Sandy loam	Clay loam			
pH	8.06 ± 0.33	7.47 ± 0.25			
EC)mS/cm(	3.67 ± 0.44	1.49 ± 0.11			
OM (%)	3.90 ± 0.69	3.15 ± 0.28			
Cl (%)	24.06 ± 1.04	8.73 ± 0.58			
$CaCO_3$ (%)	14.64 ± 0.65	4.63 ± 0.18			
Total N (mg kg^{-1})	110.81 ± 1.67	236.02 ± 21.91			
Total P (mg kg^{-1})	12.14 ± 0.28	21.92 ± 1.96			
Total HM (mg kg^{-1})			Limit according toFAO/WHO*	EU**	
Cd	2.40 ± 0.54	0.51 ± 0.03	3.00	3.00	4.71
Cu	77.55 ± 6.95	3.65 ± 0.48	140	100	21.25
Cr	7.00 ± 1.37	1.22 ± 0.22	150	100	5.74
Pb	53.75 ± 2.46	3.92 ± 0.58	300	100	13.71
Zn	83.90 ± 6.41	21.00 ± 3.20	300	300	4.00
DTPA-extractable metals (mg kg^{-1})					
Cd	0.22 ± 0.02	0.08 ± 0.01			
Cu	9.62 ± 3.39	0.26 ± 0.03			
Cr	0.09 ± 0.02	0.06 ± 0.02			
Pb	13.10 ± 4.80	0.24 ± 0.05			
Zn	1.14 ± 0.17	0.16 ± 0.02			

* FAO/WHO (2007)

** EU (2002)

irrigated sites than FW-irrigated sites. These findings are consistent with several studies indicated that prolonged irrigation with TWW causes such increases (Alghobar et al. 2014; El-Hassanina et al. 2020; Galal 2016; Rezapour et al. 2019; Gemeda et al. 2021).

Heavy metals values of Cd, Cu, Pb, Cr, and Zn in soil irrigated by TWW had multiple folds compared with soil irrigated with FW. Tested metal values in both tested sites had the following order: Zn> Cu> Pb> Cr> Cd. The metal values of Cd, Cu, Cr, Pb, and Zn in the TWW-irrigated sites were 2.40, 77.55, 7.00, 53.75, and 83.90 mg kg^{-1}, respectively, while in FW-irrigated sites were 0.51, 3.65, 1.22, 3.92, and 21.00 mg kg^{-1}, respectively (Table 2). Identical findings were recorded by Alghobar et al. (2014), Farahat et al. (2017), Farrag et al. (2016), and Guadie et al. (2021). El-Hassanina et al. (2020) reported that irrigation of agriculture soil by low-quality water significantly increased Pb and Cd many folds (2.4–3.0 folds) compared to those irrigated by FW.

The soil pollution load index (SPLI) of the tested metals was greater than 1, the maximum SPLI (21.25) was for Cu, and the minimum (4.00) was for Zn (Table 2). Relatively high HM levels in TWW-irrigated soils may be ascribed to anthropogenic activities, excessive usage of fertilizers and pesticides, and smelter deposition in more than 400 brick factories around the studied site. Meanwhile, in the FW-irrigated sites, slightly high Cu and Zn content may be due to chemical fertilizers and atmospheric deposition.

Tested HM levels for both tested sites (TWW-irrigated and FW-irrigated sites) were below the limit according to FAO/WHO (2007) and EU (2002). The safe limit values of tested metals in polluted agriculture soils could be attributed to the cultivation and rotation of different crops in such agricultural soils to remove such metal (Chauhan and Chauhan 2014).

Heavy metal contents in the cultivated plants

Tested HM contents in different parts of plants cultivated in both tested sites are presented in Table 3. In the TWW-irrigated sites, Cd, Cu, Cr, Pb, and Zn levels were higher than grown in the FW-irrigated sites. Levels in Cd, Pb, and Zn in the polluted site were surpassed the permissible limits, 0.5, 5.00, and 60 mg kg^{-1}, respectively, according to WHO/FAO (2007), while Cr and Cu contents were below the permissible levels, 5 and 40 mg kg^{-1}, respectively.

Q-cluster analysis was carried out on ten plant species grown in TWW-irrigated sites. The HM concentrations in the ten plant species were divided into two main groups: the first contained squash, Jews mallow, tomato, onion, and sunflower plants in ascending order. The second contained radish, lettuce, turnip, garden rocket, and okra plants in ascending order. This group could be classified into two subgroups: (radish–lettuce) and (turnip–garden rocket–okra). Cluster analysis showed that the highest HM contents were in tomato and sunflower among the studied foodstuffs (Fig. 1). The cluster analysis results were consistent with the content analysis conclusions.

For both sites, HM accumulation in various plant parts was in descending order Zn > Cu > Pb > Cd > Cr. Among plant parts, levels of HM in the edible parts grown in polluted site followed the order: tomato > sunflower > Jew's mallow = turnip = squash > lettuce > okra = radish > onion > garden rocket. Variation in HM levels in plants grown under identical environmental conditions could be attributed to differences in the growing cycle, morphological characteristics, and their ability to accumulate, retain, and exclude metals uptake (Kumar et al. 2009; Demim et al. 2013).

Among parts of plants grown in the polluted site, the highest levels Cd, Zn, and Cu were detected in sunflower shoot, and seed (5.34, 68.3, and 37.2 mg kg^{-1}, respectively), whereas the highest Cr and Pb were found in squash shoot (4.83 mg kg^{-1}) and tomato root (30.3 mg kg^{-1}), respectively. On the other hand, in the FW-irrigated site, the highest Cd and Cu were found in tomato root (0.71 and 2.18 mg kg^{-1}), while the highest Cr, Pb, and Zn were detected in radish root (0.33 mg kg^{-1}), okra root (2.27 mg kg^{-1}), and sunflower seed (12.4 mg kg^{-1}).

The obtained data were similar to those mentioned by Badwey et al. (2014), who reported that the mean HM contents in grains of maize and rice and fruits of guava, pepper, eggplant, palm, okra, and beetroot irrigated from the Bahr El-Baqar drain were 4.18–17.50 mg kg^{-1} for Cr, 2.75–34.7 mg kg^{-1} for Cu, and 65.1 mg kg^{-1} for Zn (on dry weight bases). On the other hand, the data obtained from this work are lower than those obtained by Galal (2016), who detected that Pb was 244.5–280.67, Cd was 4.62–61.6, Cr was 3.98–4.62, Cu was 75.7–132.5, and Zn was 1545–1686 mg kg^{-1} in squash irrigated by industrial effluents. Our results were also higher than those previously reported (El-Hassanina et al. 2020; Farrag et al. 2016).

Chronic daily intake of metals, health risk, and health hazard index

In Egypt, low-quality water is widely used for crop irrigation due to water scarcity. Assessment of human health risk is of vital importance. The mean calculated values of CDIM and HR for plants consumed by children and adults are presented in Tables 4 and 5. The mean chronic daily intake of metals (CDIM) values of plants irrigated by TWW water were higher than plants irrigated by FW. Guadie et al. (2021), Mahmood and Malik (2014), and Massaquoi et al. (2015) also documented higher CDIM values in wastewater-irrigated farmlands than in FW-

Table 3 HM contents (mg kg^{-1}) in different parts of plants grown in TWW-irrigated and FW-irrigated sites (mean ± stdv of 12 samples)

Foodstuff	Part	TWW-irrigated sites					FW-irrigated sites				
		Cd	Cu	Cr	Pb	Zn	Cd	Cu	Cr	Pb	Zn
Radish	Root	3.40 ± 0.33	21.16 ±1.05	3.34 ± 0.22	20.95 ± 7.12	50.13 ± 7.48	0.15 ± 0.12	2.15 ± 0.99	0.33 ± 0.24	1.43 ± 0.32	10.02 ± 3.46
	Shoot	2.70 ± 0.12	12.70 ± 0.29	1.12 ± 0.11	18.49 ± 1.18	53.80 ± 8.01	0.11 ± 0.04	1.61 ± 0.13	0.12 ± 0.04	1.06 ± 0.13	8.44 ± 0.44
Lettuce	Root	4.30 ± 0.30	19.36 ± 1.70	2.46 ± 0.15	25.81 ± 1.25	52.78 ± 6.26	0.14 ± 0.09	1.90 ± 0.15	0.28 ± 0.07	0.83 ± 0.15	6.88 ± 0.15
	Shoot	3.65 ± 0.21	12.73 ± 0.62	1.28 ± 0.05	16.01 ± 0.84	58.30 ± 1.71	0.12 ± 0.12	1.28 ± 0.12	0.18 ± 0.12	1.11 ± 0.12	12.13 ± 0.44
Tomato	Root	3.95 ± 0.18	37.03 ± 1.27	3.19 ± 0.31	30.30 ± 2.88	65.63 ± 3.90	0.19 ± 0.09	2.18 ± 0.22	0.18 ± 0.10	0.44 ± 0.09	10.93 ± 1.01
	Shoot	3.05 ± 0.19	13.28 ± 0.69	1.13 ± 0.21	17.35 ± 3.18	45.28 ± 5.78	0.07 ± 0.01	1.25 ± 0.34	0.13 ± 0.05	0.85 ± 0.14	7.55 ± 0.98
	Fruit	2.54 ± 0.22	34.45 ± 4.03	2.06 ± 0.27	22.41 ± 4.99	53.51 ± 9.10	0.14 ± 0.14	1.36 ± 0.41	0.04 ± 0.03	1.34 ± 0.23	8.38 ± 0.77
Onion	Root	3.84 ± 1.51	29.55 ± 5.01	1.17 ± 0.71	19.53 ± 6.07	63.30 ± 7.27	0.08 ± 0.16	1.17 ± 0.36	0.14 ± 0.08	1.06 ± 0.16	12.51 ± 0.79
	Shoot	1.89 ± 0.41	24.19 ± 5.09	0.98 ± 0.39	11.34 ± 3.69	39.90 ± 7.75	0.17 ± 0.03	1.43 ± 0.43	0.07 ± 0.05	1.20 ± 0.14	7.69 ± 0.56
Turnip	Root	2.66 ± 1.19	23.45 ± 4.86	1.55 ± 0.57	21.35 ± 1.19	50.91 ± 11.19	0.16 ± 0.10	2.19 ± 0.79	0.20 ± 0.11	1.15 ± 0.15	8.38 ± 0.48
	Shoot	1.85 ± 0.23	15.91 ± 4.12	2.15 ± 0.65	19.46 ± 5.24	54.96 ± 7.88	0.13 ± 0.09	1.60 ± 0.12	0.14 ± 0.03	0.45 ± 0.12	5.68 ± 0.94
Squash	Shoot	4.11 ± 0.65	24.79 ± 3.50	4.83 ± 1.22	23.09 ± 4.72	53.42 ± 5.26	0.10 ± 0.07	2.07 ± 0.12	0.22 ± 0.12	0.89 ± 0.15	9.87 ± 0.84
	Fruit	2.11 ± 1.44	26.43 ± 6.28	2.34 ± 1.37	19.34 ± 3.30	49.79 ± 8.38	0.14 ± 0.09	0.76 ± 0.11	0.32 ± 0.11	1.33 ± 0.11	5.88 ± 0.11
Okra	Shoot	4.99 ± 1.39	29.68 ± 5.61	1.08 ± 0.81	26.42 ± 6.24	51.55 ± 7.08	0.17 ± 0.10	1.35 ± 0.31	0.22 ± 0.07	2.27 ± 0.85	11.46 ± 1.11
	Fruit	3.96 ± 1.88	15.45 ± 4.06	2.10 ± 1.17	13.48 ± 5.21	54.20 ± 6.96	0.09 ± 0.04	2.17 ± 0.36	0.17 ± 0.06	1.65 ± 0.48	11.50 ± 1.38
Sunflower	Root	4.88 ± 2.66	36.70 ± 8.17	3.88 ± 1.95	22.20 ± 7.67	56.81 ± 6.79	0.07 ± 0.03	3.07 ± 0.78	0.23 ± 0.10	1.03 ± 0.15	7.31 ± 2.11
	Shoot	5.34 ± 1.78	29.81 ± 6.57	3.06 ± 1.93	17.70 ± 8.33	68.36 ± 7.48	0.02 ± 0.01	0.25 ± 0.08	0.17 ± 0.06	0.45 ± 0.12	8.53 ± 0.80
	Seed	1.97 ± 1.45	37.25 ± 7.90	1.41 ± 0.99	22.61 ± 8.51	45.33 ± 8.54	0.15 ± 0.09	0.14 ± 0.05	0.19 ± 0.06	1.54 ± 0.41	12.49 ± 1.04
Jews mallow	Root	2.26 ± 1.31	28.61 ± 5.40	4.09 ± 2.14	22.24 ± 6.39	47.94 ± 9.11	0.17 ± 0.06	0.36 ± 0.07	0.18 ± 0.08	0.56 ± 0.11	13.46 ± 0.92
	Shoot	3.63 ± 2.03	19.94 ± 6.07	2.08 ± 1.65	19.88 ± 7.97	53.57 ± 6.75	0.16 ± 0.05	0.08 ± 0.01	0.09 ± 0.02	0.62 ± 0.10	9.50 ± 0.99
Garden rocket	Root	2.96 ± 0.79	20.54 ± 4.08	1.27 ± 0.57	21.03 ± 7.21	65.08 ± 8.21	0.09 ± 0.06	1.57 ± 0.20	0.30 ± 0.08	1.46 ± 0.23	3.46 ± 0.56
	Shoot	1.79 ± 0.61	18.88 ± 4.40	0.84 ± 0.29	14.37 ± 5.00	36.03 ± 7.80	0.06 ± 0.03	0.62 ± 0.09	0.18 ± 0.03	0.95 ± 0.09	2.14 ± 0.26
Limits	WHO/FAO	0.20	40.0	5.0	5.0	60	0.20	40.0	5.0	5.0	60

irrigated farmlands. The highest CDIM in both children and adults were detected for Zn as 0.035 and 0.028, respectively (Table 4).

In TWW-irrigated site, the CDIM values in adults of Pb for radish, lettuce, tomato, onion, turnip, squash, okra, sunflower, Jews mallow, and garden rocket were 1.01E − 02, 8.40E − 03, 1.18E − 02, 5.95E − 03, 1.12E − 02, 1.01E − 02, 7.07E − 03, 1.19E − 02, 1.04E – 02, and 7.54E − 03, respectively. In children, the values were 1.16E − 02, 9.65E − 03, 1.35E − 02, 6.84E − 03, 1.29E − 02, 1.17E − 02, 8.13E − 03, 1.36E −

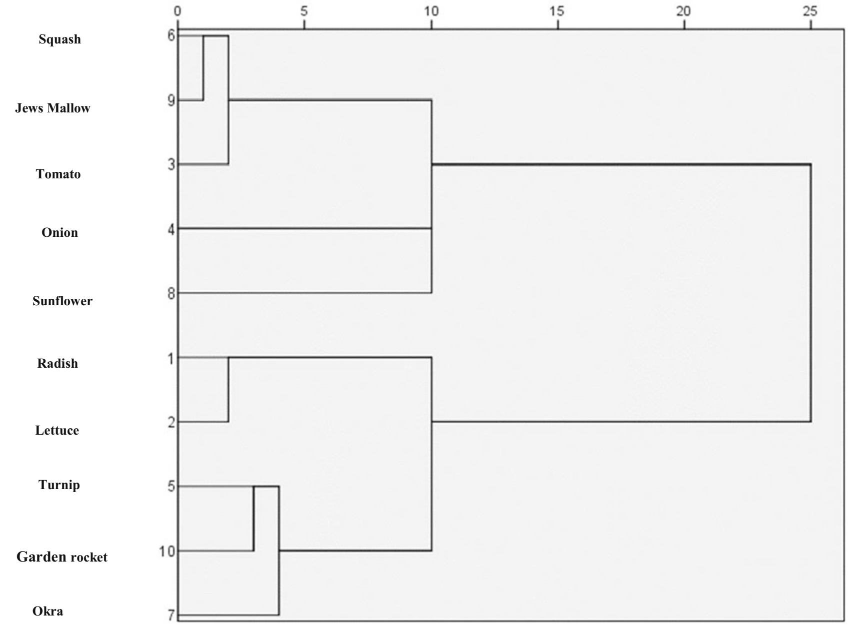

Fig. 1 Cluster analysis of ten plants grown in TWW-irrigated sites

02, 1.20E – 02, and 8.66E − 03, respectively. Children had higher risks than adults, and the CDIM values were higher for children than adults. The same finding was reported by Huang et al. (2018) and Hussain and Qureshi (2020). Among different plants, sunflower showed the highest risk to human health, followed by squash, turnip, and Jews mallow.

Table 4 Chronic daily intake of HM (CDIM; mg person^{-1} day^{-1}) from plants grown in TWW-irrigated and FW-irrigated sites

Foodstuff	Adult					Children				
	Cd	Cu	Cr	Pb	Zn	Cd	Cu	Cr	Pb	Zn
					TWW-irrigated sites					
Radish	1.52E − 03	8.61E − 03	1.11E − 03	1.01E − 02	2.66E − 02	1.74E − 03	9.90E − 03	1.28E − 03	1.16E − 02	3.06E − 02
Lettuce	1.91E − 03	6.68E − 03	6.72E − 04	8.40E − 03	3.06E − 02	2.20E − 03	7.68E − 03	7.73E − 04	9.65E − 03	3.52E − 02
Tomato	1.33E − 03	2.11E − 03	1.08E − 03	1.18E − 02	2.81E − 02	1.53E − 03	2.43E − 03	1.24E − 03	1.35E − 02	3.23E − 02
Onion	9 .92E − 04	1.27E − 02	5.16E − 04	5.95E − 03	2.09E − 02	1.14E − 03	1.46E − 02	5.93E − 04	6.84E − 03	2.41E − 02
Turnip	1.40E − 03	1.23E − 02	8.13E − 04	1.12E − 02	2.67E-02	1.61E − 03	1.41E − 02	9.34E − 04	1.29E − 02	3.07E − 02
Squash	1.11E − 03	1.39E − 02	1.23E − 03	1.01E − 02	2.61E − 02	1.27E − 03	1.59E − 02	1.41E − 03	1.17E − 02	3.00E − 02
Okra	1.55E − 03	8.11E − 03	1.10E − 03	7.07E − 03	2.84E − 02	1.79E − 03	9.32E − 03	1.27E − 03	8.13E − 03	3.27E − 02
Sunflower	1.04E − 03	1.95E − 02	7.38E − 04	1.19E − 02	2.38E − 02	1.19E − 03	2.25E − 02	8.48E − 04	1.36E − 02	2.73E − 02
Jews mallow	1.21E − 03	1.05E − 02	1.09E − 03	1.04E − 02	2.81E − 02	1.39E − 03	1.20E − 02	1.26E − 03	1.20E − 02	3.23E − 02
Garden rocket	9.37E − 04	9.91E − 03	4.39E − 04	7.54E − 03	1.89E − 02	1.08E − 03	1.14E − 02	5.05E − 04	8.66E − 03	2.17E − 02
					FW-irrigated sites					
Radish	6.82E − 05	9.88E − 04	1.15E − 04	6.53E − 04	4.85E − 03	7.84E − 05	1.14E − 03	1.33E − 04	7.51E − 04	5.57E − 03
Lettuce	6.30E − 05	6.71E − 04	9.18E − 05	5.82E − 04	6.36E − 03	7.24E − 05	7.72E − 04	1.06E − 04	6.69E − 04	7.32E − 03
Tomato	7.34E − 05	7.15E − 04	1.84E − 05	7.05E − 04	4.39E − 03	8.44E − 05	8.22E − 04	2.11E − 05	8.10E − 04	5.05E − 03
Onion	8.92E − 05	7.50E − 04	3.85E − 05	6.31E − 04	4.03E − 03	1.03E − 04	8.62E − 04	4.42E − 05	7.26E − 04	4.64E − 03
Turnip	6.82E − 05	1.53E − 03	1.07E − 04	6.02E − 04	4.40E − 03	7.84E − 05	1.76E − 03	1.23E − 04	6.92E − 04	5.05E − 03
Squash	7.34E − 05	3.99E − 04	1.68E − 04	6.98E − 04	3.08E − 03	8.44E − 05	4.58E − 04	1.93E − 04	8.02E − 04	3.55E − 03
Okra	4.72E − 05	1.14E − 03	8.92E − 05	8.66E − 04	6.03E − 03	5.43E − 05	1.31E − 03	1.03E − 04	9.95E − 04	6.94E − 03
Sunflower	7.87E − 05	7.52E − 05	9.97E − 05	8.06E − 04	6.55E − 03	9.05E − 05	8.64E − 05	1.15E − 04	9.27E − 04	7.53E − 03
Jews mallow	8.39E − 05	4.23E − 05	4.55E − 05	3.27E − 04	4.98E − 03	9.65E − 05	4.86E − 05	5.23E − 05	3.76E − 04	5.73E − 03
Garden rocket	3.15E − 05	3.25E − 04	9.27E − 05	4.98E − 04	1.12E − 03	3.62E − 05	3.74E − 04	1.07E − 04	5.73E − 04	1.29E − 03

Table 5 Health risk (HR; mg person^{-1} day^{-1}) from plants grown in TWW-irrigated and FW-irrigated sites

Foodstuff	Adult					Children				
	Cd	Cu	Cr	Pb	Zn	Cd	Cu	Cr	Pb	Zn
					Polluted sites					
Radish	1.52	0.22	7.43E − 04	0.25	8.87E − 02	1.74	0.25	8.54E − 04	0.29	0.11
Lettuce	1.91	0.17	4.48E − 04	0.21	1.02E − 01	2.20	0.19	5.15E − 04	0.24	0.12
Tomato	1.33	0.05	7.19E − 04	0.29	9.37E − 02	1.53	0.73	8.26E − 04	0.34	0.11
Onion	0.99	0.32	3.44E − 04	0.15	6.97E − 02	1.14	0.36	3.95E − 04	0.17	0.08
Turnip	1.40	0.31	5.42E − 04	0.28	8.90E − 02	1.61	0.35	6.23E − 04	0.32	0.10
Squash	1.11	0.35	8.20E − 04	0.25	8.70E − 02	1.27	0.40	9.42E − 04	0.29	0.10
Okra	1.55	0.20	7.35E − 04	0.18	9.47E − 02	1.79	0.23	8.45E − 04	0.20	0.11
Sunflower	1.04	0.49	4.92E − 04	0.30	7.93E − 02	1.19	1.07	5.66E − 04	0.34	0.09
Jews mallow	1.21	0.26	7.29E − 04	0.26	9.37E − 02	1.39	0.30	8.38E − 04	0.30	0.11
Garden rocket	0.94	0.25	2.93E − 04	0.19	6.30E − 02	1.08	0.28	3.36E − 04	0.22	0.07
					Unpolluted sites					
Radish	6.82E − 02	2.47E − 02	7.71E − 05	1.63E − 02	1.62E − 02	7.84E − 02	0.028	8.86E − 05	1.88E − 02	1.86E − 02
Lettuce	6.30E − 02	1.68E − 02	6.12E − 05	1.46E − 02	2.12E − 02	7.24E − 02	0.019	7.04E − 05	1.67E − 02	2.44E − 02
Tomato	7.34E − 02	1.79E − 02	1.22E − 05	1.76E − 02	1.46E − 02	8.44E − 02	0.021	1.41E − 05	2.03E − 02	1.68E − 02
Onion	8.92E − 02	1.88E − 02	2.56E − 05	1.58E − 02	1.34E − 02	1.03E − 01	0.022	2.95E − 05	1.82E − 02	1.55E − 02
Turnip	6.82E − 02	3.83E − 02	7.11E − 05	1.51E − 02	1.47E − 02	7.84E − 02	0.044	8.17E − 05	1.73E − 02	1.68E − 02
Squash	7.34E − 02	9.98E − 03	1.12E − 04	1.75E − 02	1.03E − 02	8.44E − 02	0.012	1.29E − 04	2.01E − 02	1.18E − 02
Okra	4.72E − 02	2.85E − 02	5.95E − 05	2.17E − 02	2.01E − 02	5.43E − 02	0.033	6.83E − 05	2.49E − 02	2.31E − 02
Sunflower	7.87E − 02	1.88E − 03	5.95E − 05	2.02E − 02	2.18E − 02	9.05E − 02	0.033	6.83E − 05	2.32E − 02	2.51E − 02
Jews mallow	8.39E − 02	1.06E − 03	3.03E − 05	8.18E − 03	1.66E − 02	9.65E − 02	0.001	3.48E − 05	1.88E − 02	1.91E − 02
Garden rocket	3.15E − 02	8.13E − 03	6.18E − 05	1.25E − 02	3.73E − 03	3.62E − 02	0.009	7.10E − 05	1.67E − 02	4.30E − 03

Health risk (HR) has been considered a valuable parameter for assessing the risk associated with consuming contaminated food crops (Sridhara Charya et al. 2008). One of HM's most notable exposure routes to humans is the food chain via vegetable intake (Muchuweti et al. 2006). In the plants irrigated with FW, HR values were lower than plants irrigated with TWW (Table 5). For adults and children, all HR values for all HM in foodstuff grown in farmlands irrigated with FW was <1, indicating that the foodstuff safe for consumption. Meanwhile, HR for plants irrigated with TWW were mostly <1, except for Cd> 1, suggesting possible exposure to Cd toxicity for local consumers (Table 5). Comparable results were reported following evaluation for a field irrigated with TWW in Dubi, UEA (Qureshi et al. 2016), and farmlands irrigated with TWW in western Azerbaijan province, Iran (Rezapour et al. 2019). Cadmium is a non-essential metal and, at very low content, had harmful impacts on human health. Exposure to Cd could cause chronic diseases like liver and kidney dysfunction, and human tissue accumulation causes cancer. In the present study, higher HR values were detected in children than adults, which could be attributed to children's behavioral habits that increase skin contact possibility (Huang et al. 2018).

The health hazard index (HI) has to be <1 to pose any health risk, while when HI is >1; there could be possible health hazards associated with overexposure (USEPA 2006). In this work, the order of HI for plants grown in TWW-irrigated sites was lettuce > radish = turnip > okra > sunflower > Jews mallow > squash > tomato > onion > garden rocket for adults, while the HI sequence for children was lettuce > tomato = sunflower > radish > Jews mallow > okra = turnip > squash > onion > garden rocket (Table 6).

The comparative contributions to the aggregated potential risk of radish, lettuce, tomato, onion, turnip, squash, okra, sunflower, Jews mallow, and garden rocket were 11.0, 12.6, 9.36, 8.12, 11.0, 9.54, 10.7, 10.1, 9.68, and 7.66, respectively. Garden rocket and onion have a low HI percentage revealed a low health hazard to consumers (Table 6).

Sanaei et al. (2021) found that the health hazard index HI in different foodstuffs consumed by the residents in Isfahan (Iran) was 2.98, 4.08, and 6.91 for adults, teens, and children, respectively. This reflects the potential threat for all communities, particularly children. In this context, regular observation of these metals in agricultural foodstuff in the studied sites is essential for preventing excessive accumulation of metals in the food web.

Table 6 Mean health index (HI) of plants grown in TWW-irrigated sites

Plant	Radish	Lettuce	Tomato	Onion	Turnip	Squash	Okra	Sunflower	Jews mallow	Garden rocket
HI Adult	2.08	2.39	1.76	1.53	2.08	1.80	2.03	1.91	1.82	1.44
HI childern	2.39	2.75	2.71	1.75	2.38	2.06	2.33	2.69	2.10	1.65

Heavy metal transfer factor

Plants irrigated with TWW showed higher HMTF than plants irrigated with FW, and Cd has the highest HMTF than other tested metals (Table 7). Among different plants grown in TWW-irrigated sites, the HM transfer factor was maximum in Jews mallow and okra. In Jews mallow, HMTF take the following order Cd (1.513) > Zn (0.638) > Pb (0.370) > Cr (0.297) > Cu (0.257). Meanwhile, among plants irrigated with FW, the highest HMTF was found in okra. In okra, HMTF was in order Cu (0.595) > Zn (0.548) > Pb (0.421) > Cd (0.176) > Cr (0.139).

Heavy metal transfer factor (HMTF) values were varied among various plants. It could be attributed to variations in soil metal levels, plant species, and metal (Cui et al. 2004). Extensively, HMTF values were varied among the edible parts of tested plants grown in TWW-irrigated sites and fluctuated between 0.120 and 1.650. Simultaneously, HMTF ranged from 0.022 to 0.600 in the edible parts of tested plants grown in FW-irrigated sites (Table 7). Rehman et al. (2019) found that heavy metal transfer factor (MTF) was higher in mustard, carrot, turnip, cabbage, spinach, and cauliflower grown in farmlands irrigated with wastewater than in farmlands irrigated with groundwater and was higher for Fe and Ni than for other tested metals (Pb, Cd, Cu, Zn, and Mn).

In all tested plants grown in both tested sites, the HMTF was a maximum in Cd followed by Zn (Table 7). It could be attributed to low retention and high metal mobility in the soil (Lokeshwari and Chandrappa 2006). The main module for human exposure to HM through the food chain is the metal transfer from soil to edible parts in the plant. HMTF is fundamental to examine risk index for human health (Cui et al. 2004)

Conclusion

The main objective of this work was to assess the levels of five HM (Cu, Cd, Cr, Pb, and Zn) in ten highly consumed plants (radish, lettuce, tomato, onion, turnip, squash, okra, sunflower, Jews mallow, and garden rocket) grown in a field farms irrigated with TWW and FW in Southern Cairo (Egypt). The HR and HI were also evaluated. The levels of tested HM in FW and TWW were below the FAO and the Egyptian standards. In soil samples, HM levels were below the permissible limits for tested sites. The HM levels in soil and plants grown in TWW-irrigated sites possessed multiple levels than those grown in FW-irrigated sites.

The most critical and worst scenario was considered: the consumption of all contaminated foodstuffs by local consumers. For the children, HR level was above the permissible limit only for Cd for all tested foodstuffs, and high HR levels were detected in lettuce, tomato, and sunflower. Simultaneously, for adults, these levels were less than detected in children.

According to this work, there is currently no health risk of HM toxicity resulting from human consumption of tested foodstuff irrigated with TWW, except for Cd. Routine monitoring of HM levels in TWW, soil, and foodstuff should be performed to prevent potential exposure and associated health hazards. Moreover, some suitable and practical solutions

Table 7 Metal transfer factor of plants grown in TWW-irrigated and FW-irrigated sites

Plant	Cd	Cu	Cr	Pb	Zn
			TWW-irrigated sites		
Radish	1.271	0.218	0.319	0.367	0.619
Lettuce	1.521	0.164	0.183	0.298	0.695
Tomato	1.058	0.444	0.294	0.417	0.638
Onion	0.788	0.312	0.140	0.211	0.476
Turnip	1.108	0.302	0.221	0.397	0.607
Squash	0.879	0.341	0.334	0.360	0.593
Okra	1.650	0.199	0.300	0.251	0.646
Sunflower	0.821	0.480	0.201	0.421	0.540
Jews mallow	1.513	0.257	0.297	0.370	0.638
Garden rocket	0.746	0.243	0.120	0.267	0.429
			FW-irrigated sites		
Radish	0.255	0.515	0.184	0.318	0.440
Lettuce	0.235	0.351	0.148	0.283	0.578
Tomato	0.275	0.373	0.033	0.342	0.399
Onion	0.333	0.392	0.057	0.306	0.366
Turnip	0.314	0.600	0.164	0.293	0.399
Squash	0.275	0.208	0.262	0.339	0.280
Okra	0.176	0.595	0.139	0.421	0.548
Sunflower	0.294	0.038	0.156	0.393	0.595
Jews mallow	0.314	0.022	0.074	0.158	0.452
Garden rocket	0.118	0.170	0.148	0.242	0.102

include the tertiary treatment of wastewater and management practices such as mixing TWW with fresh water. Implications refer to the need for actions for spreading public awareness, particularly concerning health risks are needed.

Abbreviations HM, Heavy metal; TWW , Treated wastewater; HMTF, Heavy metal transfer factor; CDIM, Chronic daily intake of metals; HR, Health risk; HI, Health hazard index; SPLI, Soil pollution load index; FW, Fresh water; HSTP, Helwan Sewage Treatment Plant

Author contribution H. E. M. O., E. M. W. A., W. S. M. A., Y. A. O. A., and M. H. E. E. carried out the study and written the manuscript. All authors read and approved the final manuscript

Funding Not applicable.

Data availability Not applicable.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent to publish Not applicable.

Competing interests The authors declare no competing interests.

References

Alghobar MA, Ramachandra L, Suresha S (2014) Effect of sewage water irrigation on soil properties and evaluation of accumulation of elements in grass crop in Mysore City, Karnataka, India. Am J Environ Prot 5:283–291

Amer MM, Sabry BA, Marrez DA, Hathout AS, Fouzy ASM (2019) Exposure assessment of heavy metal residues in some Egyptian fruits. Toxicol Rep 6:538–543

Antoine JMR, Fung LAH, Grant CN (2017) Assessment of the potential health risks associated with the aluminium, arsenic, cadmium, and lead content in selected fruits and vegetables grown in Jamaica. Toxicol Rep 4:181–187

AOAC (2000) Official methods of analysis of the Association of Official Analytical Chemist. 14th ed Washington

APHA (American Public Health Association) (2012) Standard methods for the examination of water and wastewater, 22nd edn. APHA, Washington

Badwey RK, Abd El-Gawad AM, Osman HE (2014) Health risks assessment of heavy metals and microbial contamination in water, soil and agricultural foodstuff from wastewater irrigation at Sahl El-Hessaniaarea. Egypt J Appl Sci Res 4:3091–3107

Chauhan G, Chauhan UK (2014) Risk assessment of heavy metal toxicity through contaminated vegetables from wastewater irrigated area of Rewa (M.P.), India. Inter. J Adv Technol Eng Sci 8:444–460

Cui YJ, Zhu YG, Zhai RH, Chen DY, Huang YZ (2004) Transfer of metals from soil to vegetables in an area near a smelter in Nanning. China Environ Int 30:785–791

Demim S, Drouiche N, Aouabed A, Benayad T, Dendene BO, Semsari S (2013) Cadmium and nickel: assessment of the physiological effects and heavy metal removal using a response surface approach by *L. gibba*. Ecol Eng 61:426–435

Egypt State of the Environment Report (2009) Ministry of state for environmental affairs. http://www.eeaa.gov.eg/English/main/about.asp. Accessed 15 Jan 2021

Egyptian Governmental Law No. 48/1982-Decision 92 (2013) The implementer regulations for Law 48/1982, Decision 92/2013 regarding the protection of the River Nile and water ways from pollution. Map Periodical Bull 21-30.

El-Agha DE, Molle F, Rap E (2020) Drainage water salinity and quality across nested scales in the Nile Delta of Egypt. Environ Sci Pollut Res 27:32239–32250. https://doi.org/10.1007/s11356-019-07154-y

Elbana TA, Ramadan MA, Gaber HM, Bahnassy MH, Kishk FM, Selim HM (2013) Heavy metals accumulation and spatial distribution in long term wastewater irrigated soils. J Environ Chem Eng 4:925–933. https://doi.org/10.1016/j.jece.2013.08.005

El-Hassanina AS, Samaka AR, Abdel-Rahmanb GN, Abu-Sreeb YH, Saleh EM (2020) Risk assessment of human exposure to lead and cadmium in maize grains cultivated in soils irrigated either with low-quality water or freshwater. Toxicol Rep 7:10–15. https://doi.org/10.1016/j.toxrep.2019.11.018

EU (European Union) (2002). Heavy metals in waste, Final Report, European Commission DG ENV. E3, Project ENV.E.3/ETU/2000/0058.

FAO (Food and Agriculture Organization) (1985) Water quality for agriculture. In: Ayers RS, Wescot DW (eds) Irrigation and drainage. FAO, Rome, p 174

FAO/WHO, Joint WHO (World Health Organization)/FAO (Food and Agriculture Organization) (2007) Food standard programme codex alimentarius commission, 13th session, report of the thirty-eight session of the codex committee on food hygiene, ALINORM 07/30/13. FAO/WHO, Houston, USA

Farahat EA, Galal TM, Elawa OE, Hassan LM (2017) Health risk assessment and growth characteristics of wheat and maize crops irrigated with contaminated wastewater. Environ Monit Assess 189:535. https://doi.org/10.1007/s10661-017-6259-x

Farrag K, Elbastamy E, Ramadan A (2016) Health risk assessment of heavy metals in irrigated agricultural crops, El-Saff wastewater canal, Egypt. Clean 44(9):1174–1183

Galal TM (2016) Health hazards and heavy metals accumulation by summer squash (*Cucurbita pepo* L.) cultivated in contaminated soils. Environ Monit Assess 188:434. https://doi.org/10.1007/s10661-016-5448-3

Gedamy YR, El-Aassar AM, Abdel-Gawad AM (2012) Pollutants detection in water resources at El Saff area and their impact on human health, Giza governorate. Egypt Int J Environ 1(1):1–14

Gemeda FT, Guta DD, Wakjira FS, Gebresenbet G (2021) Occurrence of heavy metal in water, soil, and plants in fields irrigated with industrial wastewater in Sabata town, Ethiopia. Environ Sci Pollut Res 28:12382–12396

Ghuniem MM, Khorshed MA, El-Safty SM, Souaya ER, MMH K (2020) Potential human health risk assessment of potentially toxic elements intake via consumption of soft drinks purchased from different Egyptian markets. Int J Environ Anal Chem 100(5):1–23. https://doi.org/10.1080/03067319.2020.1770742

Guadie A, Yesigat A, Gatew S, Worku A, Liu W, Ajibade FO, Wang A (2021) Evaluating the health risks of heavy metals from vegetables grown on soil irrigated with untreated and treated wastewater in Arba Minch, Ethiopia. Sci Total Environ 761:143302. https://doi.org/10.1016/j.scitotenv.2020

Haque MM, Niloy NM, Khirul MA, Alam MF, Tareq SM (2021) Appraisal of probabilistic human health risks of heavy metals in vegetables from industrial, non-industrial and arsenic contaminated areas of Bangladesh. Heliyon 7(2):e06309. https://doi.org/10.1016/j.heliyon.2021.e06309

Hesse PR (1971) A textbook in soil chemical analysis. William Glowe, London

Huang Y, Chen Q, Deng M, Japenga J, Li T, Yang X, He Z (2018) Heavy metal pollution and health risk assessment of agricultural soils in a typical peri-urban area in Southeast China. J Environ Manag 207: 159–168

Hussain MI, Qureshi AS (2020) Health risks of heavy metal exposure and microbial contamination through consumption of vegetables irrigated with treated wastewater at Dubai, UAE. Environ Sci Pollut Res 27:11213–11226

Issa AB, Yasin K, Loutfy N, Ahmed MT (2018) Risk assessment of heavy metals associated with food consumption in Egypt: a pilot study. J of Clin and Exper Toxico 2(1):15–24

Jackson ML (1967) Soil chemical analysis prentice hall, Inc Englewood Cliffs, N. J. laboratory of the Congress, M. A. S.

Järup A (2003) Hazards of heavy metal contamination. Br Med Bull 68(1):167–182. https://doi.org/10.1093/bmb/ldg032

Kharazia IA, Leilia M, Khazaeia M, Alikhanib MY, Shokoohia R (2021) Human health risk assessment of heavy metals in agricultural soil and food crops in Hamadan. J Food Compos Anal 2021:103890. https://doi.org/10.1016/j.jfca.2021.103890

Kilmer VJ, Alexander LT (1949) Methods of making mechanical analysis of soils. Soil Sci 68:15–24

Kumar A, Sharma IK, Sharma A, Varshney S, Verma PS (2009) Heavy metals contamination of vegetable foodstuffs in Jaipur (India). Electron J Environ Agric Food Chem 8(2):96–101

Lindsay WL, Norvell WA (1978) Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Sci Soc Am J 42:421–428

Liu WH, Zhao JZ, Ouyang ZY, Soderlund L, Liu GH (2005) Impacts of sewage irrigation on heavy metals distribution and contamination in Beijing, China. Environ Int 31:805–812

Lokeshwari H, Chandrappa GT (2006) Impact of heavy metal contamination of Bellandur Lake on soil and cultivated vegetation. Curr Sci 91(5):1–6

Lu Y, Song S, Wang R, Liu Z, Meng J, Sweetman AJ, Jenkins A, Ferrier RC, Li H, Luo W, Wang TY (2015) Impacts of soil and water pollution on food safety and health risks in China. Environ Int 77(1):5–15

Mahmood A, Malik RN (2014) Human health risk assessment of heavy metals via consumption of contaminated vegetables collected from different irrigation sources in Lahore, Pakistan. Arab J Chem 7(1): 91–99

Masoud MS, El-Samra MI, El-Sadawy MM (2007) Heavy-metal distribution and risk assessment of sediment and fish from El-Mex Bay, Alexandria, Egypt. Chem Ecol 23(3):201–216. https://doi.org/10.1080/02757540701339760

Massaquoi LD, Ma H, Liu XH, Han PY, Zuo SM, Hua ZX, Liu DW (2015) Heavy metal accumulation in soils, plants, and hair samples: an assessment of heavy metal exposure risks from the consumption of vegetables grown on soils previously irrigated with wastewater. Environ Sci Pollut Res 22:18456–18468

Ming-Ho Y (2005) Environmental toxicology: biological and health effects of pollutants, Chap. 12, 2nd edition, CRC Press LLC, Boca Raton, ISBN 1-56670-670-2.

Mirecki N, Agič R, Šunić L, Milenković L, Ilić ZS (2015) Transfer factor as indicator of heavy metals content in plants. Fresenius Environ Bull 24:4212–4219

Morshdy AMA, El Bayomi RM, Abd El Galil GM, AFA M (2018) Heavy metal concentrations and their risk assessment in marketed slaughtered animals in Sharkia governorate, Egypt. Slov Vet Res 55(20):103–112. https://doi.org/10.26873/SVR-635-2018

Muchuweti M, Birkett JW, Chinyanga E, Zvauya R, Scrimshaw MD, Lester JN (2006) Heavy metal content of vegetables irrigated with mixtures of wastewater and sewage sludge in Zimbabwe: implications for human health. Agric Ecosyst Environ 112:41–48

Natashaa N, Shahida M, Khalida S, Niazi NK, Murtaza B, Ahmad N, Farooq A, Zakira A, Imran M, Abbas G (2021) Health risks of arsenic buildup in soil and food crops after wastewater irrigation. Sci Total Environ 10:145266. https://doi.org/10.1016/j.scitotenv.2021.145266

Nelson DW, Sommers LE (1982) Total carbon, organic carbon, and organic matter. In: Page AL, editor. Methods of soil analysis, Part 2 (2nd). Madison, WI: Agron J: 539-79.

Norvell WA (1984) Comparison of chelating agents as extractants for metals in diverse soil materials. Soil Sci Am J 48:1285–1292

Nriagu J, Boughanen M, Linder A, Howe A, Grant C, Rattray R, Vutchkov M, Lalor G (2009) Levels of As, Cd, Pb, Cu, Se and Zn in bovine kidneys and livers in Jamaica. Ecotoxicol Environ Saf 72(2):564–571

Osman EH, Badwey KR, Ahmad FH (2010) Usage of some agricultural by-products in the removal of some heavy metals from industrial wastewater. J Phytol 2(3):51–62

Parihar JK, Parihar PK, Pakade YB (2021) Bioaccumulation potential of indigenous plants for heavy metal phytoremediation in rural areas of Shaheed Bhagat Singh Nagar, Punjab (India). Environ Sci Pollut Res 28:2426–2442

Peach K, Tracey MV (1956) Modern method of plant analysis, 1st edn. Springer-Verlag, Berlin, p 4

Piper CS (1950) Soil and plant analysis. Inter science Inc., New York

Qu C, Wei S, Jing G, Fang B, Shui W, Giesy JP, Holm PE (2016) China's soil pollution control: choices and challenges. Environ Sci Technol 50(24):13181–13183

Qureshi AS, Hussain MI, Ismail S, Khan QM (2016) Evaluating heavy metal accumulation and potential health risks in vegetables irrigated with treated wastewater. Chemosphere 163:54–61

Rattan RK, Datta SP, Chhonkar PK, Suribabu K, Singh AK (2005) Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops, and groundwater a case study. Agric Ecosyst Environ 109:310–322

Rehman KU, Bukhari SM, Andlee S, Mahmood A, Erinle KO, Naeem MM, Imran Q (2019) Ecological risk assessment of heavy metals in vegetables irrigated with groundwater and wastewater: the particular case of Sahiwal district in Pakistan. Agric Water Manag 226:105816

Rezapour S, Atashpaz B, Moghaddam SS, Damalas CA (2019) Heavy metal bioavailability and accumulation in winter wheat (*Triticum aestivum* L.) irrigated with treated wastewater in calcareous soils. Environ Sci Technol 656:261–269

Richards IA (1954) Diagnosis and improvement of saline and alkali soils. USDA, Washington, USA, Handbook No 60.

Román OY, Delgado GTC, Tejada TR, Yucra HR, Durand AE, Hamaker BR (2021) Heavy metal contamination and health risk assessment in grains and grain-based processed food in Arequipa region of Peru. Chemosphere 274:129792. https://doi.org/10.1016/j.chemosphere.2021.129792

Rowell DL (1993) Soil science: methods and applications. Department of Soil Science, University of Reading. Co-published in the US with John Wiley and Sons Inc., New York

Sanaei F, Amin MM, Alavijeh ZP, Esfahani RA, Sadeghi M, Bandarrig NS, Fatehizadeh A, Taheri E, Rezakazemi M (2021) Health risk assessment of potentially toxic elements intake via food crops consumption: Monte Carlo simulation-based probabilistic and heavy metal pollution index. J Environ Sci Eng 28:1479–1490

Sridhara Charya N, Kamalaa CT, Raj SDS (2008) Assessing risk of heavy metals from consuming food grown on sewage irrigated soils and food chain transfer. Ecotoxicol Environ Saf 69:513–524

Stavrides J (2006) Lung carcinogenesis: pivotal role of metals in tobacco smoke, Free Radical Bio. Med. 41(7):1017–1039. https://doi.org/10.1016/j.freeradbiomed.2006.06.024

USEPA (2006) United States, Environmental Protection Agency, Integrated Risk Information System. http://www.epa.gov/iris/substS. Accessed 15 Jan 2021

USEPA (2018) Risk assessment guidance for superfund Vol I: Human health evaluation manual (Part E, Supplemental Guidance for Dermal Risk Assessment).

Weber AM, Mawodza T, Sarkar B, Menon M (2019) Assessment of potentially toxic trace element contamination in urban allotment soils and their uptake by onions: a preliminary case study from Sheffield, England. Ecotoxicol Environ Saf 170:156–165

Zakir HM, Quadir QF, Mollah MZI (2020) Human health risk assessment of heavy metals through the consumption of common foodstuffs collected from two divisional cities of Bangladesh. Expo Health. https://doi.org/10.1007/s12403-020-00380-7