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Accumulation and Risk Assessment of Heavy Metals in Vegetables Irrigated with Wastewater in Giza Governorate, Egypt

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Abstract

The present study measured the concentrations of heavy metals (Zn, Ni, Pb, Cu, Cr, and Cd) in soils as well as vegetables (faba bean, cabbage, onion, garlic, zucchini, capsicum, eggplant, potato, okra and green bean) irrigated with wastewater in the western part of Giza governorate, Egypt. Human health risks to consumers of these vegetables were performed. The study revealed the considerable variations in metal contents of water, soil and vegetables samples. Generally, wastewater of the study drains was not suitable for irrigation purpose according to the bacteriological guidelines. Almost all the physico-chemical parameters and heavy metals concentrations of water and soil samples were compatible with the recommended permissible limits of irrigation and agricultural use, respectively. Vegetable species showed remarkable difference in metals concentrations of various plant portion, Zn showed highest tissue concentrations followed by Cu. Heavy metals concentrations in different edible portions decreased in a descending order as Zn > Cu > Pb > Ni > Cr > Cd with low translocation values (< 1) for studied vegetables except for faba bean. The health risk index (RI) for humans was low if edible portions from studied vegetables are consumed, in particular Cd, Cr, Pb, and Ni whose concentration values were relatively higher than the health based guidelines values. Considering the probable health risk associated with the consumption of contaminated vegetables, it is important to regularly monitor the levels of metals in wastewater, soils and vegetables in the studied area.

Keywords: Heavy metals, Risk assessment, Vegetables, Wastewater

1 Introduction

In arid and semi-arid areas where fresh water is a limited resource, wastewater is usually used for agricultural irrigation. Due to the shortage of good quality water, the application of raw wastewater for irrigation has been practiced although not legally allowed in most countries (Farrag et al 2016, Zhan and Shen 2019). Wastewater irrigation has many beneficial effects, such as supplying plant nutrients and soil organic matter, saving fresh water and decreasing water contamination (Zhang and Shen 2019). Therefore, wastewater irrigation can reduce the cost of production, fertilizers in particular, resulting in net cost savings up to 20% for poor farmers (Scott et al 2010). On other hand, wastewater irrigation can deteriorate the quality of soil, agricultural crops as well as human health due to the presence of heavy metals such as zinc, lead, nickel, cadmium, copper, and chromium in concentrations exceeding the safe limits (Khan et al 2008, Shahid et al 2017). Contamination of soils employed in agricultural purposes with heavy metals is considered a major pathway for possible health problems to humans via edible portion of vegetables consumption (Xiong et al 2016). The prolonged consumption of heavy metals contaminated vegetables has been recognized to cause disorders in various physico-biochemical processes, causing numerous diseases such as cardiovascular, bone, kidney, liver and nervous system (Dumat et al 2016). In less developed countries, very little attention has been paid towards the health risk assessment studies due to the consumption of vegetables contaminated with heavy metals (Khan et al 2008, Shahid et al 2017). Consequently, the current study aims to investigate the concentration levels of six global warning heavy metals (Cd, Cu, Cr, Ni, Pb and Zn) in soils and vegetables collected from wastewater irrigated farm lands, to assess their translocation behavior in vegetable species, and to evaluate the possibly associated health risks to humans via consumption of these vegetables edible portions.

2 Materials and Methods

2.1 Abu-Rawash study area and sampling locations

The chosen study area is located near Abu-Rawash wastewater treatment plant (30° 07′N, 31°08′E) and its surrounding agricultural lands in the western part of Giza governorate. The Abu-Rawash wastewater-treatment plant discharges 1.2 Mm^3 day^{-1} of primary treated wastewater which does not meet the legal requirements. The effluent from the plant moves through a network of drains until reaching the Rosetta branch of Nile River in the following sequence: Barakat, Abdel Rahman, Al-Ramal and El-Rahawy. In order to grow different seasonal vegetables crops, farmers illegally divert wastewater of these drains to soil surface using small diesel pumps. Based on farmer's interview where wastewater irrigation has been practiced for many years, twelve locations (**Table 1**) were selected to collect soil, wastewater and vegetables samples during the growing seasons 2018/2019 .The climate of the area is hot dry arid in summer and humid cold with very few rainfalls (< 10 mm $year^{-1}$) in winter.

2.2 Sampling and preparation

Samples of wastewater effluent were collected form twelve locations (**Table 1**) at regular intervals (70 days) throughout the period from October 2018 to September 2019. Wastewater samples were taken five times from Barakat, Abdel Rahman and Al-Ramal drains and from the surrounding agricultural fields the vegetable and soil samples were collected. Samples were collected in plastic bottles acidified with nitric acid and transported to the laboratory as quickly as possible to avoid microbial cross contamination and activity. Different vegetables samples were collected randomly from wastewater irrigated fields at the stage of harvesting during the respective growing seasons (2018/2019). Five types of vegetables such as i) Leafy, cabbage (*Brassica oleracea* L. var. capitata), ii) Fruity, zucchini (*Cucurbita pepo* L.), eggplant (*Solanum melongena* L.), okra (*Abelmoschus esculentus* L.) and capsicum (*Capsicum annuum* L.), iii) Tubers, potato (*Solanum tuberosum* L.), iv) Bulbs, onion (*Allium cepa* L.) and garlic (*Allium sativum* L.) and v) Seeds, green bean (*Phaseolus vulgaris* L.) were selected. Accordingly, three representative plant samples for each vegetable crop originating from same localities were collected. Vegetable samples were divided into different portions after uprooting. The divided portions (e.g. roots, stems, leaves, fruits, etc) were rinsed in tap and distilled water, dried in oven at 60 °C for 3 days till constant weight. Dried portions were ground in a mortar and pestle to pass through

Table 1. Wastewater sampling locations along with coordinates and corresponding growing vegetable crops

Points	Locations	Coordinates		Vegetables
		Latitude	Longitude	
1	Barakat	30° 5'1.40"N	31° 4'14.95"E	Green bean, Onion
2		30° 5'1.16"N	31° 4'31.12"E	Green bean, Eggplant, Garlic
3		30° 5'5.94"N	31° 4'46.62"E	Green bean, Capsicum
4		30° 5'12.00"N	31° 5'6.58"E	Eggplant, Faba bean, Onion
5	Abdel Rah-man	30° 5'16.10"N	31° 5'20.36"E	Cabbage, Garlic, Okra, Zucchini
6		30° 5'35.99"N	31° 5'13.64"E	Cabbage, Okra, Zucchini
7	Al-Ramal	30° 5'55.34"N	31° 5'24.59"E	Green bean, Capsicum, Potato
8		30° 5'58.93"N	31° 5'46.06"E	Capsicum, Potato, Zucchini
9		30° 6'2.86"N	31° 6'6.79"E	Eggplant, Garlic Potato
10		30° 6'8.38"N	31° 6'24.50"E	Cabbage, Onion
11		30° 6'14.94"N	31° 6'39.49"E	Green bean, Potato
12		30° 6'24.68"N	31° 7'0.41"E	Onion, Potato

40 mesh screens. The passed fine powdered mixed well and kept for analysis. From each sampling location, soils were taken from the top 20 cm in a mixture of five sub-samples maintaining a representative composite soil sample of each selected wastewater irrigated farm (S1). For comparison, three composite reference soil samples (S2) from uncultivated areas adjacent to the study area were collected.

2.3 Procedure of analysis

Wastewater samples were analyzed according to the procedures outlined in the Standard Methods (APHA 2017). Total dissolved solids (TDS) were measured by using the evaporating porcelain dishes and oven model HI-9321 at 105°C. Kjeldahl procedure was performed measuring ammonia by distillation unit, model UDK 130 (APHA 2017). The dissolved oxygen (DO) was determined by WTW Oxi 597 meter, with a dissolved oxygen self-stirring probe cell. Biological oxygen demand (BOD) was determined at range 0 - 4000 mgL^{-1} using respirometer (BOD-5days, model 606/2). Chemical oxygen demand (COD) was determined using a HACH 3900 spectrophotometer at 600 nm wavelength with access opening adapter for ampoule 25 mm tubes (APHA 2017). Density of total coliforms (TC) and fecal coliform (FC) as colonies forming units (CFU 100 mL^{-1}) were determined by applying the membrane technique (APHA 2017). The samples of soil were air dried in the laboratory at room temperature (25°C ±2), crushed and finely grounded, sieved through (0.2 mm) sieve and kept for mechanical analysis. Carbonate and organic matter contents, total and available metals were determined. A glass electrode was used to determine soil pH in distilled water suspension (1soil: 2.5 water). The electrical conductivity (EC) was measured using a scale of suspensions (1soil: 2.5 water) by conductivity meter in the filters. By the pipette method particle size and texture distribution were determined (Avery and Bascomb 1982). Available phosphorus (P_{ava}) has been determined according to the Olsen method using a UV/VIS spectrophotometer (Olsen et al 1954). The total and extractable metals concentration was determined using ICP-OES instruments (Perkin Elmer optima 3000). A microwave (Multiwave Perkin Elmer 3000) was employed to digest the soil and vegetables prepared samples with 5 HNO_3: 1 H_2O_2: 1 HCl mixture. The soil extractable-metals were estimated on soil extracts by DTPA (Diethylene teriamine penta-acetic acid) (Lindsay and Norvell 1978).

The ratio between the studied metals concentration in the vegetables above parts and that in the roots is a heavy metal transport factor (TF) as reported by Brooks (1998). The heavy metals displacement factor measures the efficiency of crops irrigated with wastewater to collect the studied minerals.

2.4 Estimation of daily intake of metals

Using equation (1) as follows, Daily Intake (DI) of metals was estimated. (Khan et al 2008):

$$\mathrm{DI} = \frac{(\mathrm{Cm} \times \mathrm{Cf} \times \mathrm{Dfi})}{\mathrm{Baw}} \ldots\ldots (1)$$

Where Cm = Concentrations of target metal in vegetables (mg kg^{-1}), Cf = conversion factor (0.085), Dfi = daily food intake (kg $person^{-1}$ day^{-1}) of vegetables (0.345 for adults and 0.232 for children) (Rattan et al 2005). Baw = body average weight (55.9 kg for adults and 32.7 kg for children (Wang et al 2005).

2.5 Estimation of health risk index

Using equation (2), the risk index (RI) was estimated (Khan et al 2008):

$$\mathrm{RI} = \frac{(1)}{\mathrm{Rfd}} \ldots\ldots (2)$$

Where Rfd = reference oral dose for target metal (mg kg^{-1} day^{-1}) as 0.001, 0.003, 0.04, 0.02, 0.03 for Cd, Cr, Cu, Ni and Zn, respectively (USEPA 2020) and 0.0035 for Pb (Cui et al 2004). The safety standard for humans is RI < 1.

2.6 Statistical analysis

Data obtained were subjected to variance analysis (ANOVA) and t-test analysis, means were separated at 0.05 level of significance by applying Fisher test using computer statistical package SAS ver. 9.1 (SAS institute Inc. Cary, NC, USA).

3 Results and Discussion

3.1 Characteristics of wastewater

Characteristics of the analyzed wastewater are given in **Table 2**. The pH values were moderately alkaline and within the national and FAO limits (6.5-8.5) for irrigation use. The EC values ranged from 0.936 to 2.28 with mean value 1.35 (dSm^{-1}), indicating that analyzed wastewater samples are within the allowable EC range (slight to moderate restriction) as stated by FAO guidelines (0.7-3.0 m^{-1}) for irrigation water. The pH and EC values of the wastewater samples are lower than the findings of Abdelkader (2013) in Barakt wastewater drain. The concentration of TDS in wastewater of studied drains was in the range of 618 and 1833 mg L^{-1}. The mean TDS concentration was found to be 815 mg L^{-1}, and it is within the limits of the Egyptian (1000 mg L^{-1}) and FAO (450-2000 mg L^{-1}) guidelines. However, lower value was reported by Abdelkader (2013) in Barakt drain. According to the Egyptian guidelines, concentration of NH_3^+ ions should not exceed 0.5 mg L^{-1}. The NH_3^+ value ranged from 3.05 to 19.35 mg L^{-1} in study drains with mean value 14 mg L^{-1}. High concentrations of NH_3^+ in drains discharge of study area were also recorded by Ezzat et al (2012). The concentrations of HCO_3^- in wastewater of study drains were higher than the CO_3^{2-} concentrations (**Table 2**), similar findings were reported in El Saff wastewater canal, eastern part of Giza governorate (Osman et al 2010, Farrag et al 2016). In general, the sequence of cations and anions was $HCO_3^- > Na^+ > Cl^- > SO_4^{2-} > Ca^{2+} > Mg^{2+} > K^+ > PO_4^- > CO_3^{2-}$. However, the mean concentrations values of the major cations and anions were lower than FAO guidelines (**Table 2**) except for PO_4^-, CO_3^{2-} and K^+. The mean value of DO in water was 3.5 mg L^{-1} which is lower than the Egyptian guidelines (≥ 5 mg L^{-1}). In general, the DO indicates the possibility of flora and fauna to live in the water system. However, the obtained mean value of DO was much higher than the mean value (0.16 mg L^{-1}) in effluent of Abu-Rawash wastewater treatment plant (Mostafa and Peters 2016).

Table 2. Water quality of wastewater drains used for growing vegetable crops (rang and mean ±STD of five samples)

	Effluent		Recommended values	
	Range	**Mean**	**Egypt (1)**	**FAO (2)**
Physico-Chemical (mg l^{-1})				
pH	7.04-8.28	7.74±0.36	6.5 - 8.5	6.5 - 8.5
CO_3	0-15	3.8±0.40	-	0-3
HCO_3	218-560	323.34±45.87	-	0-600
EC (dSm^{-1})	0.936-2.28	1.35±0.32	-	(0.7-3) SM
TDS	618-1833	815±176.10	≤1000	(450-2000) SM
NH_3	3.05-19.35	14.0±2.46	≤0.5	-
COD	219-399.40	290.49±65.95	≤50	-
BOD	17-180	119.95±28.22	≤30	-
DO	3.1-5.21	3.5±0.30	≥ 5	-
Major Cations (mg L^{-1})				
Ca	62.34-194	87.20±16.55	-	0-400
K	14-27	19.52±3. 50	-	0-2
Mg	11.67-51.27	19.85±5.48	-	0-60
Na	91-322	162.52±38.19	-	0-900
Major Anions (mg L^{-1})				
Cl	88.42-413.85	133±41.91	-	0-1100
NO_3	0.6-29.85	9.9±3.82	-	0-10
PO_4	4.25-14.69	8.15±2.82	-	0-2
SO_4	74.20-381.9	128.91±45.34		0-1000
Heavy Metals (mg L^{-1})				
Cd	0.001-0.002	0.002±0.001	≤0.003	0.01
Cr	0.002-0.039	0.03±0.02	≤0.05	0.10
Cu	0.021-0.154	0.05±0.03	≤1.00	0.20
Pb	0.001-0.002	0.002±0.001	≤0.10	0.01
Ni	0.003-0.048	0.014±0.012	0.10	0.20
Zn	0.003-0.924	0.23±0.17	≤2.00	2.00
Microbiological (CFU 100mL^{-1})				
TC	$480x10^4$ - $1600x10^4$	$1140x10^4$	5000	-
FC	$110x10^4$ - $700x10^4$	$520x10^4$	-	≤1000(3)

(1) (Egyptian Governmental Law 1982/2013), (2) (FAO 1985), (3) (WHO 1989).

The measured BOD mean value (119.95 mg L^{-1}) was much higher than the Egyptian guidelines (≤ 30 mg L^{-1}) and the value (78 mg L^{-1}) reported in Barakat drain (Abelkader 2013) and lower than 165 mg L^{-1} reported by Mostafa and Peters (2016) in effluent of Abu-Rawash wastewater treatment plant. The COD values (219–399.40 mg L^{-1}) were much higher than the Egyptian guidelines (≤ 50 mg L^{-1}). The COD maximum value (399.4 mg L^{-1}) was in accordance with the findings of Abdelkader (2013) in Barakt wastewater drain (403 mg L^{-1}). The mean COD (290.49 mg L^{-1}) was lower than those reported (332.5 mg L^{-1}) by Mostafa and Peters (2016). Results of wastewater samples as listed in **Table 2** showed that concentrations of all studied metals were below the standard limits, and a similar trend has been reported by Abelkader (2013) in water samples collected form Barakat drain.

The bacteriological results showed higher loads of TC and FC in all the examined wastewater samples of study drains (**Table 2**). High means of TC (1140x104 CFU 100mL^{-1}) and FC (520x104 CFU 100 mL^{-1}) were exceeded the Egyptian (1982/2013) and WHO (1989) regulations, respectively (**Table 2**) and were higher than the findings of Abdelkader (2013) in Barakt wastewater drain. Therefore, reusing wastewater of study drains for vegetable irrigation can potentially constitute a health risk to consumers and farmers.

3.2 Soils characteristics

Samples of wastewater irrigated soil (S1) and uncultured soil (S2) belonged to sandy loam and loamy sand classes of soil texture, respectively (**Table 3**). In comparison to the reference soils (S2), there was a slight increase in soil pH of wastewater irrigated soil (S1). These slight increase in soil pH as a function of the wastewater irrigation may be attributed to the alkalization effect of contained cations such as Mg, Ca, and Na in the water (Alghobar et al 2014). In addition, increases in values of OM, N_{tot} and P_{ava} in wastewater irrigated soils (S1) were recorded in comparison with the reference soil (S2). Similar findings were reported by Farrag et al (20116) in wastewater irrigated soils along El Saff wastewater canal eastern part of Giza governorate. Using wastewater in irrigation could enrich soils with OM, N_{tot} and P_{ava} (Abd-Elwahed et al 2018). In accordance with Farrag et al (2016), the irrigation with wastewater reduced soil salinity (EC) of cultivated lands along the study drains compared with the non-irrigated soil (S2). This reduction in EC values of wastewater irrigated soil (S1) is due to salt leaching by percolated waters after intensive furrow irrigation practiced by farmers in the study area. However, salinity of wastewater irrigated soils is impacted by soil type, climate, water use and irrigation routines, and crop management (Moreira Barradas et al 2015).

The concentrations of studied metals in soils were in sequence of Zn > Cu > Pb > Cr > Ni > Cd and were higher than their concentration in wastewater. Except for Cd, Cu and Zn, all soil samples were within the safe limits of metals contamination according to FAO/WHO (2007). The alkaline environment of study soils (pH >7) is the most important factor indicating the low mobility of studied metals (**Table 3**). pH is the key parameter influencing the mobility of heavy metals (McBride 1994). Furthermore, monitoring changes of heavy metal content of soils can be used to evaluate the inconsistent variations on the long term due to irrigation using wastewater (Mohammad and Mazahreh 2003).

3.3 Concentrations of metal in vegetables

Concentrations of metals in vegetables grown on soils irrigated with wastewater are represented in **Table 4**. The accumulation of studied metals in different portions of the studied vegetables exhibited the following trend: Zn > Cu > Pb > Ni > Cr > Cd. The examined vegetables accumulated heavy metals in the edible portions as follows: onion > garlic > green bean > zucchini > capsicum > potato > okra > faba bean > eggplant > cabbage. This variability in metal accumulation can be ascribed to the physiological and morphological characteristics of the studied vegetables and their mechanisms to deal with toxic levels of metals, in addition to growing conditions and stage of development (Kumar et al 2009). The obtained results showed that green bean shoots and onion stems accumulated greater amount of Zn (96.7 mg kg^{-1}) and Cu (60.9 mg kg^{-1}), respectively, than other grown vegetables. Similar values were recorded for both Zn (96.9 mg kg^{-1}) and Cu (60.3 mg kg^{-1}) respectively in leaves of peppermint been irrigated by El-Saff wastewater canal (Farrag et al 2016). However, the concentrations of Zn in both stems, bulbs and fruits of onion, garlic and green bean, respectively, were higher than the

Table 3. Soils physicochemical properties and concentrations of heavy metals (mg kg^{-1}, d.w) in studied locations

Parameters	Soils		
	S1	S2	
Coarse sand (%)	74.43	76.31	
Fine sand (%)	8.81	7.42	
Silt (%)	3.26	2.70	
Clay (%)	13.50	13.57	
Texture	Sandy loam	Loamy sand	
pH (H_2O)	8.00±018	7.29±0.24	
EC (ds m^{-1})	0.47±0.22	2.50±2.12	
$CaCO3_{tot}$ (%)	5.40±0.15	12.16±2.10	
OM (%)	3.88±0.46	1.22±0.18	
N_{tot} (mg kg^{-1})	197.8±29.48	81.32±6.10	
P_{ava} (mg kg^{-1})	0.69±0.20	0.18±0.03	
Total metals concentrations (mg kg^{-1})			Limits FAO/WHO (1)
Cd	4.40±2.66	0.06±0.002	3.00
Cr	66.20±12.15	0.21±0.02	150
Cu	219.20±30.33	0.60±0.12	140
Ni	22.60±8.06	0.05±0.001	75
Pb	99.40±10.12	0.15±0.03	300
Zn	557.40±47.97	15.20±0.06	300
Extractable metals concentrations (mg kg^{-1})			
Cd	0.02±0.002	0.02±0.001	3.00
Cr	0.04±0.001	0.05±0.01	150
Cu	0.35±0.02	0.14±0.02	140
Ni	0.04±0.001	0.02±0.001	75
Pb	0.9±0.02	0.04±0.001	300
Zn	2.28±0.03	1.20±0.002	300

(1) (FAO/WHO 2007), S1: Wastewater irrigated soil, values are mean ±STD (n=12), S2: Reference soil, values are mean ±STD (n=3).,

Table 4. Concentrations of heavy metals (mg kg^{-1}, d.w.) in different parts of study vegetables

Crop	Part	Concentrations (mg kg^{-1}, d.w.)					
		Cd	Cr	Cu	Ni	Pb	Zn
Faba Bean							
	Roots	0.18±1.57 a	0.48±4.71 a	4.90±40.50 a	1.05±7.42 a	0.39±9.82 a	9.50±160.81 a
	Stems	0.15±0.79 b	0.51±3.63 b	3.50±28.28 b	0.57±4.91 b	0.58±7.91 b	7.20± 74.77 b
	Leaves	0.58±0.06 c	2.88±0.27 c	23.68±2.72 c	3.69±0.53 c	5.87±0.47 c	30.62±3.63 c
	Seeds*	0.34±0.04 d	1.93±0.11 d	18.26±1.72 d	1.98±0.25 d	3.07±0.51 d	18.44±1.28 d
Cabbage							
	Roots	0.84±0.05 a	8.80±0.70 a	57.38±6.89a	5.51±0.72 a	4.91±0.30 a	55.90±7.00 a
	Stems	0.56±0.05b	6.19±0.42 b	40.87±8.38 b	3.50±0.47 b	3.41±0.59b	35.92±4.33b
	Leaves*	0.08±0.38 c	0.37±3.39 c	7.09±26.50 c	0.30±2.42 c	0.51±2.62c	1.38±22.81 c
Onion							
	Roots	1.37±0.29 a	5.30±0.74 a	92.30±5.68 a	10.92±0.71a	8.44±0.62 a	89.08±4.45 a
	Stems*	0.85±0.14 b	4.08±0.25 b	60.90±2.89 b	7.39±1.54 b	6.22±0.67 b	69.22±12.09 b
	Leaves*	0.54±0.19 c	2.30±0.24 c	28.67±4.54 c	5.18±1.90 c	4.22±0.64 c	48.24±13.43 c
Garlic							
	Roots	1.36±0.29 a	6.37±0.90 a	62.56±7.15 a	11.52±1.27a	9.60±1.39a	93.14±4.54 a
	Leaves	0.89±0.17 b	4.88±0.71 b	44.53±6.24 b	9.63±2.21 b	7.00±1.53 b	82.07±5.84 b
	Bulbs*	0.67±0.17 c	3.13±0.35 c	27.29±3.21 c	5.31±0.71 c	4.59±1.03 c	60.30±6.82 c
Zucchini							
	Roots	1.00±0.07 a	6.23±0.22 a	51.30±0.80 a	5.23±0.16 a	7.35±0.37 a	51.43±1.28 a
	Stems	0.78±0.08 b	4.28±0.15 b	40.83±1.49 b	3.11±0.20 b	5.33±0.19 b	46.33±1.60 b
	Fruits*	0.38±0.08 c	2.24±0.15 c	29.68±1.55 c	2.24±014 c	3.04±0.21 c	33.54±0.69 c
Capsicum							
	Roots	0.71±0.05 a	6.30±0.62 a	64.36±10.24 a	6.82±0.92 a	9.89±0.42 a	96.59±2.47 a
	Shoots	0.52±0.04 b	4.94±0.25 b	45.52±9.87 b	4.71±0.24 b	6.68±0.79 b	65.49±3.72 b
	Fruits*	0.31±0.02 c	3.14±0.57 c	26.69±2.66 c	2.71±0.63 c	3.98±0.34 c	31.40±1.00 c
Eggplant							
	Roots	0.90±0.08 a	4.07±0.67 a	41.70±2.76 a	6.82±0.41 a	8.24±0.77 a	78.26±5.10 a
	Stems	0.58±0.07 b	3.02±0.25 b	31.81±1.82 b	4.89±0.58 b	5.98±0.63 b	58.44±5.33 b
	Leaves	0.47±0.05 c	2.06±0.17 c	23.17±2.35 c	3.69±0.43 c	3.94±0.59 c	39.51±5.76 c
	Fruits *	0.28±0.06 d	1.59±0.33 d	17.00±2.71 d	2.43±0.36 d	2.94±0.42 d	19.34±1.27 d
Potato							
	Roots	0.81±0.06 a	8.82±0.51 a	45.80±4.75 a	5.01±0.27 a	6.74±0.50 a	38.83±5.86 a
	Shoots	0.58±0.06 b	4.73±0.39 b	31.16±2.24 b	3.78±0.45 b	5.02±0.44 b	29.02±3.65 b
	Tubers*	0.41±0.07 c	2.60±0.50 c	22.99±2.53 c	2.44±0.37 c	3.27±0.40 c	22.18±1.98 c
Okra							
	Roots	0.78±0.10 a	4.02±0.33 a	45.91±5.34 a	5.42±0.62 a	6.31±0.52 a	74.59±6.15 a
	Shoots	0.56±0.10 b	2.90±0.38 b	25.58±3.47 b	3.54±0.39 b	3.30±0.39 b	43.38±6.28 b
	Fruits*	0.36±0.06 c	1.69±0.20 c	18.62±1.31 c	1.84±0.22 c	2.12±0.33 c	27.79±.08 c
Green Beans							
	Roots	2.69±0.38 a	3.53±0.46 a	29.45±3.11a	7.78±0.79 a	11.12±0.66 a	149.36±10.64 a
	Shoots	1.95±0.29 b	2.85±0.83 b	19.16±1.26 b	5.59±0.66 b	8.42±0.59 b	96.66±12.63 b
	Fruits*	0.38±0.07 c	2.12±0.52 c	9.73±1.02 c	2.81±0.82 c	4.62±0.79 c	70.87±9.74 c
Guidelines							
FAO/WHO 2007		0.20	5.0	40.0	-	5.0	60.0
EU 2006		0.20	0.30	40.0	2.3	0.30	-

*: edible portion, For each vegetable crop means with the same letter are not significantly different (LSD test P<0).

threshold (60 mg kg^{-1}) set by FAO/WHO (2007). Whereas the Cu concentration (60.9 mg kg^{-1}) of onion stems was above the safe limits (40 mg kg^{-1}) of FAO/WHO (2007) and EU (2006). Contrarily, Cd showed minimum concentrations (0.08 -1.95 mg kg^{-1}) in all study vegetables. These values were higher than Cd concentrations (0.001-0.93 mg kg^{-1}) found in faba bean, garlic and onion, and lower than concentration (2.0 mg kg^{-1}) measured in the cabbage leaves grown in similar conditions (Farrag et al 2016). The content of Pb in the edible portions of studied vegetables ranged from 0.51 to 6.22 mg kg^{-1}. These values are greater than values (0.001 mg kg^{-1}) recorded by Farrag et al (2016) and regulated safe limits of foodstuffs (EU 2006, FAO/WHO 2007). The results showed that concentrations of Cr (0.37-4.08 mg kg^{-1}) in the edible portions of studied vegetables (**Table 4**) exceeded the recommended safety limits defined by the EU (2006) and the values reported in vegetables irrigated wastewater (Farrag et al 2016). Except for faba bean, cabbage, zucchini and okra (**Table 4**), Ni concentrations (0.30 -7.39 mg kg^{-1}) in the edible portions exceeded the EU (2006) standard limits (2.3 mg kg^{-1}) for foodstuffs. However, the recorded concentration of Ni (0.30 -7.39 mg kg^{-1}) was lower than values (8.3- 12.3 mg kg^{-1}) observed by Farrag et al (2016).

This variation in heavy metals accumulation and translocation to the edible portions (**Table 5**) showed the different uptake efficiency of study vegetables. Based on the efficiency of study vegetables to accumulate metals in consumed parts could be arranged following the order: Cd, faba bean > onion > potatoes > garlic > okra > green bean > zucchini > eggplant > capsicum > cabbage, Cr, faba bean > onion > green bean > capsicum > garlic > okra > eggplant > zucchini > potatoes > cabbage, Cu, faba bean > onion > zucchini > potatoes > garlic > capsicum = eggplant = okra > green bean > cabbage, Ni, faba bean > onion > potatoes > garlic > zucchini > capsicum > eggplant = green bean > okra > cabbage, Pb, faba bean > onion > potatoes > garlic > green bean > zucchini > capsicum > eggplant > okra > cabbage, and Zn, faba bean > onion > garlic = zucchini > potatoes > green bean > okra > capsicum > eggplant > cabbage. According to Cui et al (2004), this variation may be ascribed to the concentration of metals in the cultivated soil and the plant species. Considerably, the translocation factor (TF) of studied metals varied among the studied crops and ranged between 0.02 (Zn/leaves of cabbage) to 7.87 (Pb/seeds of faba bean) in the edible portions (**Table 5**). Except for Faba bean, all studied vegetables exhibited lower TF values (<1) in all studied metals, however, indicated ineffective metal transfer. High TF values (>1) in seeds and leaves of faba bean, suggesting that the TF of studied metals was substantial in this crop. According to the TF values, studied metals showed the greatest potential of food chain entry following the trend of Pb > Cr > Cu > Zn > Ni > Cd. The response of faba bean against study metals (TF >1), can be attributed to the metal efficient transportation systems and sequestration strategies (Zhao et al 2002).

3.4 Health risks of heavy metal consumption through study vegetables

Health risks of heavy metal consumption through study vegetables were assessed (**Table 6 A, B**) based on the daily intake of metals (DI) and health risk index (RI) for adults and children. The highest DI result measured for Zn was 0.0372 for adults and 0.04274 for children. Exposure to high levels of zinc may cause adverse health effects such as reduction of immune function and the levels of high-density lipoproteins (Rahman et al 2014). Whereas the lowest DI result for Cd was 0.00004 in adults and 0.00005 in children. Cadmium exerts toxicity in multiple human organs such as kidney, liver, lungs, spleen, thymus, heart and salivary glands (Huang et al 2017). However, the highest values of DI in adults for Cd, Cr, Cu, Ni, Pb and Zn were 0.00035 (garlic), 0.00165 (capsicum), 0.01557 (capsicum), 0.00279 (garlic), 0.00241 (garlic) and 0.0372 (green bean), respectively, and in children

Table 5. Calculated translocation factors of metals in the study vegetables

Crop	Part	Translocation factor (TF)					
		Cd	Cr	Cu	Ni	Pb	Zn
Faba Bean							
	Stems	0.83±.0.05	1.06±.0.08	0.71±.0.05	0.54±.0.08	1.49±.0.09	0.76±.0.04
	Leaves	3.22±0.02	6.00±0.02	4.83±0.03	3.51±0.06	15.05±0.03	3.22±0.01
	Seeds*	1.89±0.60	4.02±0.47	3.73±0.35	1.89±0.60	7.87±0.56	1.94±0.79
Cabbage							
	Stems	0.67±0.04	0.70±0.03	0.71±0.08	0.64±0.05	0.69±0.08	0.64±0.04
	Leaves*	0.10±0.07	0.04±0.02	0.12±0.07	0.05±0.03	0.10±0.08	0.02±0.03
Onion							
	Stems*	0.62±0.16	0.77±0.19	0.66±0.25	0.68±0.19	0.74±0.17	0.78±0.20
	Leaves*	0.39±0.18	0.43±0.18	0.31±0.26	0.47±0.22	0.50±0.18	0.54±0.20
Garlic							
	Leaves	0.65±0.27	0.77±0.29	0.71±0.42	0.84±1.32	0.73±0.43	0.88±0.50
	Bulbs*	0.49±0.23	0.49±0.18	0.44±0.25	0.46±0.68	0.48±0.26	0.65±0.40
Zucchini							
	Stems	0.78±0.14	0.69±0.17	0.80±0.10	0.59±0.21	0.73±0.16	0.90±0.05
	Fruits*	0.38±0.12	0.36±0.08	0.58±0.07	0.43±0.15	0.41±0.09	0.65±0.04
Capsicum							
	Shoots	0.73±0.05	0.78±0.05	0.71±0.06	0.69±0.08	0.68±0.07	0.68±0.03
	Fruits*	0.44±0.02	0.50±0.06	0.41±0.06	0.40±0.07	0.40±0.03	0.33±0.01
Eggplant							
	Stems	0.64±0.05	0.74±0.04	0.76±0.03	0.72±0.06	0.73±0.15	0.75±0.04
	Leaves	0.52±0.04	0.51±0.02	0.56±0.04	0.54±0.05	0.48±0.04	0.50±0.04
	Fruits*	0.31±0.05	0.39±0.05	0.41±0.05	0.36±0.04	0.36±0.03	0.25±0.01
Potato							
	Shoots	0.72±0.03	0.54±0.02	0.68±0.03	0.75±0.06	0.74±0.03	0.75±0.03
	Tubers*	0.51±0.17	0.29±0.11	0.50±0.18	0.49±0.19	0.49±0.21	0.57±0.26
Okra							
	Shoots	0.72±0.06	0.72±0.09	0.56±0.02	0.65±0.02	0.52±0.04	0.58±0.04
	Fruits*	0.46±0.04	0.42±0.30	0.41±0.03	0.34±0.03	0.34±0.05	0.37±0.03
Green Beans							
	Shoots	0.72±0.02	0.81±0.13	0.65±0.05	0.72±0.04	0.76±0.03	0.65±0.04
	Seeds*	0.14±0.01	0.60±0.08	0.33±0.01	0.36±0.07	0.42±0.05	0.47±0.04

*: edible portion, Values mean (±STD) of three samples per plant part.

Table 6A. Potential health risks of heavy metal consumption through study vegetables

Plant	Metal Mean mgkg^{-1}	Reference oral dose (1) mg kg^{-1}day^{-1}	DI Adults	DI Children	RI Adults	RI Children	Risks
Faba Bean	0.34	Cd, 0.001	0.00018	0.00021	0.178	0.205	Safe
Cabbage	0.08		0.00004	0.00005	0.042	0.048	
Onion	0.54		0.00028	0.00033	0.283	0.326	
Garlic	0.67		0.00035	0.00040	0.351	0.404	
Zucchini	0.38		0.00020	0.00023	0.199	0.229	
Capsicum	0.31		0.00016	0.00019	0.163	0.187	
Eggplant	0.28		0.00015	0.00017	0.147	0.169	
Potato	0.41		0.00022	0.00025	0.215	0.247	
Okra	0.36		0.00019	0.00022	0.189	0.217	
Green Beans	0.38		0.00020	0.00023	0.199	0.229	
Faba Bean	1.93	Cr, 0.003	0.00101	0.00116	0.337	0.388	Safe
Cabbage	0.37		0.00019	0.00022	0.065	0.074	
Onion	2.30		0.00121	0.00139	0.402	0.462	
Garlic	3.13		0.00164	0.00189	0.547	0.629	
Zucchini	2.24		0.00118	0.00135	0.392	0.450	
Capsicum	3.14		0.00165	0.00189	0.549	0.631	
Eggplant	1.59		0.00083	0.00096	0.278	0.320	
Potato	2.60		0.00136	0.00157	0.455	0.523	
Okra	1.69		0.00089	0.00102	0.296	0.340	
Green Beans	2.12		0.00111	0.00128	0.371	0.426	
Faba Bean	18.26	Cu, 0.04	0.00111	0.01101	0.239	0.275	Safe
Cabbage	7.09		0.00958	0.00428	0.093	0.107	
Onion	28.67		0.00372	0.01729	0.376	0.432	
Garlic	27.29		0.01504	0.01646	0.358	0.411	
Zucchini	29.68		0.01432	0.01790	0.389	0.447	
Capsicum	26.69		0.01557	0.01610	0.350	0.402	
Eggplant	17.00		0.01400	0.01025	0.223	0.256	
Potato	22.99		0.00892	0.01386	0.302	0.347	
Okra	18.62		0.01206	0.01123	0.244	0.281	
Green Beans	9.73		0.00977	0.00587	0.128	0.147	

(1) (US EPA 2005).

Table 6B. Potential health risks of heavy metal consumption through study vegetables

Plant	Metal Mean	Reference oral dose (1)	DI		RI		Risks
	$mgkg^{-1}$	$mg\ kg^{-1}day^{-1}$	Adults	Children	Adults	Children	
Faba Bean	1.98	Ni, 0.02	0.00104	0.00119	0.052	0.060	Safe
Cabbage	0.30		0.00016	0.00018	0.008	0.009	
Onion	5.18		0.00272	0.00312	0.136	0.156	
Garlic	5.31		0.00279	0.00320	0.139	0.160	
Zucchini	2.24		0.00118	0.00135	0.059	0.068	
Capsicum	2.71		0.00142	0.00163	0.071	0.082	
Eggplant	2.43		0.00127	0.00147	0.064	0.073	
Potato	2.44		0.00128	0.00147	0.064	0.074	
Okra	1.84		0.00097	0.00111	0.048	0.055	
Green Beans	2.81		0.00147	0.00169	0.074	0.085	
Faba Bean	3.07	Pb, 0.0035	0.00161	0.00185	0.460	0.529	Safe
Cabbage	0.51		0.00027	0.00031	0.076	0.088	
Onion	4.22		0.00221	0.00254	0.633	0.727	
Garlic	4.59		0.00241	0.00277	0.688	0.791	
Zucchini	3.04		0.00159	0.00183	0.456	0.524	
Capsicum	3.98		0.00209	0.00240	0.597	0.686	
Eggplant	2.94		0.00154	0.00177	0.441	0.507	
Potato	3.27		0.00172	0.00197	0.490	0.563	
Okra	2.12		0.00111	0.00128	0.318	0.365	
Green Beans	4.62		0.00242	0.00279	0.692	0.796	
Faba Bean	18.44	Zn, 0.30	0.00967	0.01112	0.032	0.037	Safe
Cabbage	1.38		0.00072	0.00083	0.002	0.003	
Onion	48.24		0.0253	0.02909	0.084	0.097	
Garlic	60.30		0.0316	0.03636	0.105	0.121	
Zucchini	33.54		0.0176	0.02023	0.059	0.067	
Capsicum	31.40		0.0165	0.01894	0.055	0.063	
Eggplant	19.34		0.0101	0.01166	0.034	0.039	
Potato	22.18		0.0116	0.01338	0.039	0.045	
Okra	27.79		0.0146	0.01676	0.049	0.056	
Green Beans	70.87		0.0372	0.04274	0.124	0.142	

(1) (US EPA 2005).

were 0.00040, 0.00189, 0.01610, 0.00320, 0.00277 and 0.04274, respectively. Therefore, the health risks impact in children is greater than in adults due to their estimated higher DI than in adults. However, prolonged intake of heavy metals through regular consumption of contaminated vegetables can cause deleterious health effects in humans. The health hazards caused by chromium are cancers, allergic reactions, bronchial asthma, reproductive and developmental problems, weakened immune systems, kidney and liver damage, cardiovascular and hematological problems (Teklay 2016). It has been concluded that copper can cause acute gastrointestinal symptoms, liver toxicity, DNA damage and reduced cell proliferation (Taylor et al 2020). Lead poisoning can cause brain and kidney damage, increase the oxidative stress and the neurological abnormalities, (Debnath et al 2019). Whereas the most serious harmful health effects from exposure to nickel are dermatitis, allergy, headaches, gastrointestinal and respiratory manifestations (Genchi 2020).

Additionally, the analysis showed that the RI values for studied metals were < 1 in all vegetables assessed. Accordingly, in the current investigation, the associated risk from metals contamination via consumed vegetables subjected to wastewater irrigation by children and adults suggested to be in general relatively safe. These results are in coincidence with the findings reported in faba been, onion, garlic, cabbage and peppermint been irrigated by wastewater of El-Saff canal (Farrag et al 2016). From this stand point, monitoring heavy metals in study vegetable crops is demanded to minimize their excessive augmentation in the food chain.

4 Conclusions

Heavy metals accumulation in agricultural lands has become an alarming issue that could threaten the food security and impact the environment safety. The results of this study demonstrate concentrations of Zn, Ni, Pb, Cu, Cr, and Cd in soils and vegetable crops associated with wastewater discharge from Abu-Rawash wastewater treatment plant, southern Giza governorate, Egypt. Generally, heavy metals concentrations in soils were higher than their concentrations in wastewater samples. Soil samples were under the critical limits for contamination except for Cd, Cu and Zn. The metals displacement factor indicated that Pb and Cr had the maximum potential for food chain entry followed by Cu, Zn, Ni and Cd. Heavy metals concentrations in edible portions decreased in a descending order following the trend Zn > Cu > Pb > Ni > Cr > Cd. The consumption of study vegetables poses relatively low risk from heavy metal toxicities due to the hazard indices that were below the limits of risk levels. Further studies are needed on microbial content of soil and vegetables for fecal coliform on serious threat to the health of the local population. In particular, the bacteriological results of wastewater samples were unfit to irrigation purposes.

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