



Risk assessment of human exposure to lead and cadmium in maize grains cultivated in soils irrigated either with low-quality water or freshwater

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ABSTRACT

Maize is the third important cereal crop after wheat and rice, especially in Egyptian villages. It is used in baking as a substitution component in wheat products and a main component in snacks for children. The target of this study was to estimate the risk assessment of lead (Pb) and cadmium (Cd) in maize grains cultivated in the agricultural soil irrigated by the contaminated water in comparison with that irrigated by freshwater. Lead (Pb) and cadmium (Cd) levels in irrigation water, soils and maize grains collected from different sites in Egypt were determined using ICP-OES. The studied samples were collected from 5 agricultural sites irrigated with freshwater (Nile River water and groundwater) as well as 4 agricultural sites irrigated with low-quality water (contaminated by sewage and industrial wastewater). Results exhibited that the levels of Pb and Cd in soil and maize grains were significantly affected by their levels in irrigation water; where, the levels of Pb and Cd in soil and maize grains irrigated by low-quality water possessed the multiple concentrations in comparison with those irrigated by freshwater. Specific water sources such as Kafr-Dokhmais and Al-Nasiria sites, Kafr El-Sheikh governorate had the highest levels of metals in the samples of irrigation water, soil and maize grains ($p < 0.05$). Metals levels in water and soil samples were within the permissible limits except Cd in low-quality water samples. Levels of Pb in maize grains irrigated by low-quality water were above the permissible limits (0.20 mg kg^{-1}), while Cd levels were within the permissible limits (0.1 mg kg^{-1}) except Al-Nasiria samples. Levels of Pb and Cd in maize grains irrigated by low-quality water were 19–30 folds those of maize grains irrigated by freshwater. The risk assessment of Pb and Cd levels in maize grains was estimated by daily intake of metals (DIM) and health risk index (HRI). All determined HRI was < 1 indicating a non potential health risk for both adults and children.

1. Introduction

Maize (*Zea mays* L.) is an edible flowering plant belonging to family Poaceae grows during the spring and summer seasons in Egypt. Maize grains are used as food and feed sources for humans and animals, respectively, in different sites of the world. It contains carbohydrate (71.9 %), protein (8.8 %), fat (4.6), fiber (2.15 %), Ash (2.33 %), vitamins such as C, B₁, B₂, B₃, B₅ and B₆, carotenoids, phenolic compounds and phytosterols [1]. Maize grains are directly used in human nutrition as boiled or grilled. The maize flour is also extract and use in bread and manufacture of some types of pancakes. Maize oil is extracted from grain embryos and use in human nutrition.

Contamination of agricultural crops and their products by heavy metals such as Pb and Cd were reported by previous studies [2,3]. The

widespread contamination of agricultural crops by toxic metals during the last years is partly attributed to use low-quality water in plant irrigation as essential reason [4]. The other reasons of crops contamination by heavy metals are pesticides, agricultural fertilizers, traffic emissions and municipal waste [5]. Also, exhausts of automobiles as airborne pollutants are precipitated on agricultural soil [6].

Heavy metals in irrigation water are not degradable, then accumulate in agricultural soil and subsequently accumulate in plant crops [7]. In addition, heavy metals persist in agricultural soil and adsorbed with solid soil particles [8]. Also, Gupta et al. [9] reported that the regular use of wastewater for soil irrigation increased the heavy metals concentrations in cultivated crops and subsequently transferred through the food chain to human and animal causing potential health risk in the long term. Highly levels of toxic metals were found in Delta

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drains through the industrial and domestic wastewater [4]. They highlighted the potential health hazards caused by cultivation of agricultural crops in soils contaminated with heavy metals.

In this respect, Farrag et al. [10] studied the translocation of some heavy metals from wastewater irrigated soils to some crops such as cabbage, onion, garlic and wheat. They revealed that, Cd, Cr, Cu, Ni, Pb and Zn were accumulated in edible parts of the studied crops and their concentrations greatly varied according to the crop type. Also, Lu et al. [11] reported that, levels of Cr, Pb and Ni in maize grains cultivated in wastewater-irrigated soil were 0.23, 0.49 and 0.18 mg Kg⁻¹, respectively.

Levels of heavy metals in River Nile water and groundwater of Egypt were studied by many authors. In this respect, Malhat and Nasr [12] estimated the heavy metals in River Nile water and reported that the levels of Pb, Cu and Cd ranged from 0.0005 to 0.080 mg Kg⁻¹ for Pb, from 0.0002 to 0.017 mg Kg⁻¹ for Cu and from 0.0001 to 0.014 mg Kg⁻¹ for Cd. Meanwhile, levels of Cr, Ni, Cu, and Pb in groundwater collected from Samalout at Al Minya governorate, Egypt were 1.271, 0.041, 0.210 and 0.030 mg Kg⁻¹ as recorded by Bassioni et al. [13].

Increase of heavy metals levels above the permissible limits in agricultural crops leads to a serious ecological disaster [14]. They accumulate in human bodies and cause serious deterioration of human health especially for children [15]. In this respect, there are no available studies examined the risk assessment of toxic metals in Egyptian maize grains cultivated in soils irrigated with low-quality water. The low-quality water (contaminated with wastewater) considers the only source as irrigation water at some Egyptian sites. So, the overall targets of this study were to estimate the heavy metals contamination of agricultural soil irrigated by the contaminated water in comparison with that irrigated by freshwater. Also, investigating the risk assessment of heavy metals levels in maize grains cultivated in the studied agricultural soil was one of the main aims.

2. Materials and methods

2.1. Sampling

Samples of soil (0–30 cm), irrigation water and maize grains (27 samples each) were collected in August 2017 from different cultivated lands representing three Egyptian governorates, which are irrigated with different sources of irrigation water (Table 1 and Fig. 1). At each site, three different points (as triplicate) were chosen using cluster random sampling technique to collect the samples. Samples of irrigation water, soil and maize were collected in triplicate from the field at the same time when the maize was mature. Water samples were collected (about 20 cm below the water surface) in plastic bottles

Table 1
Sites of sampling and sources of irrigation water.

Site	Governorate	Irrigation water	Grade
Wadi El-Natron El-Nobarria (Abdel-Rakib)	El-Beheira	Nile River water	Fresh water
El-Nobarria (Abdel-Wahab)			
Al-Hawia	Kafr El-Sheikh		
Abdel-Rahman	Giza	Groundwater	
Kafr-Dokhmals	Kafr El-Sheikh	Contaminated by mixed wastewater*	Low-quality water**
Al-Nasiria			
Kafr-Hakem	Giza	Contaminated by sewage wastewater	
Abo-Roash			

* Mixed sewage and industrial effluents (Branch 62 - main canal pronged from Kitchener drain).

** Low-quality water is the irrigation water from freshwater sources but is contaminated inadvertently with wastewater.

containing 2 ml concentrated nitric acid to avoid microbial activity and maintain pH below 2 to prevent precipitation or adsorption of heavy metals to the plastic surface. The samples were taken directly to the laboratory for analysis.

2.2. Heavy metals analysis

2.2.1. Soil samples

The obtained samples of soil were digested according to Page et al. [16] by concentrated mixtures of HNO₃, HClO₄ and H₂SO₄ acids. The final solution was filtered using Whatman filter paper (ashless) and diluted to volume with distilled water until the determination of total heavy metals. Available heavy metals in soil samples were extracted by DTPA (diethylene triamine penta acetic acid) method as described by Soriano-Disla [17]. The total and available heavy metals (Cd and Pb) were measured using the Agilent 5100 Synchronous Vertical Dual View (SVDV) ICP-OES (Inductively Coupled Plasma - Optical Emission Spectrometry) according to APHA [18].

2.2.2. Water samples

About 250 ml of water samples were transferred to beakers, then 5 ml of HNO₃ were added in each sample. The samples were heated using hotplates to reach 80–85 °C to a final volume of about 10–20 ml before metal precipitation. The digestion procedure was repeated twice. The beaker walls were washed with de-ionized water, then transferred to 25 ml volumetric flask and filtered until the determination of total heavy metals [19]. Available heavy metals in water samples were directly determined after the filtration.

2.2.3. Samples of maize grains

About 5 g of maize grains were weighted into a crucible, then dried and digested using the dry-ashing procedure. The ash was dissolved using 1 ml HCl conc. on crucible walls, then transferred to volumetric flask (25 ml) by de-ionized water and filtered through ashless filter paper according to AOAC [20]. The final solution was stored in a refrigerator until the determination by ICP.

2.3. Risk assessment of heavy metals in maize grains

Daily intake of metals (DIM) and health risk index (HRI) were calculated according to the following formulas used by Farrag et al. [10].

2.3.1. Daily intake of metals (DIM)

$$\text{DIM} = \frac{C_{\text{metal}} C_{\text{factor}} D_{\text{food intake}}}{B_{\text{average weight}}}$$

Where C_{metal} is concentration of the metal (mg kg⁻¹) in maize grains, C_{factor} is the conversion factor (0.085) for conversion of fresh to dry weight crop, D_{food intake} is the daily intake of crops (0.345 and 0.232 kg person⁻¹ day⁻¹ for adults and children, respectively). B_{average weight} is the average body weight (70.0 and 32.7 kg for adults and children, respectively).

2.3.2. Health risk index (HRI)

$$\text{HRI} = \frac{\text{DIM}}{\text{RFD}}$$

Where RFD is the reference oral dose (mg kg⁻¹ day⁻¹) for each metal as 0.001 for Cd and 0.0035 for Pb. Humans are considered to be safe if HRI < 1.

2.4. Statistical analysis

Experimental results were subjected to one-way analysis of variance (ANOVA) at 0.05 of significance level. All statistical procedures were computed using statistical package [21].

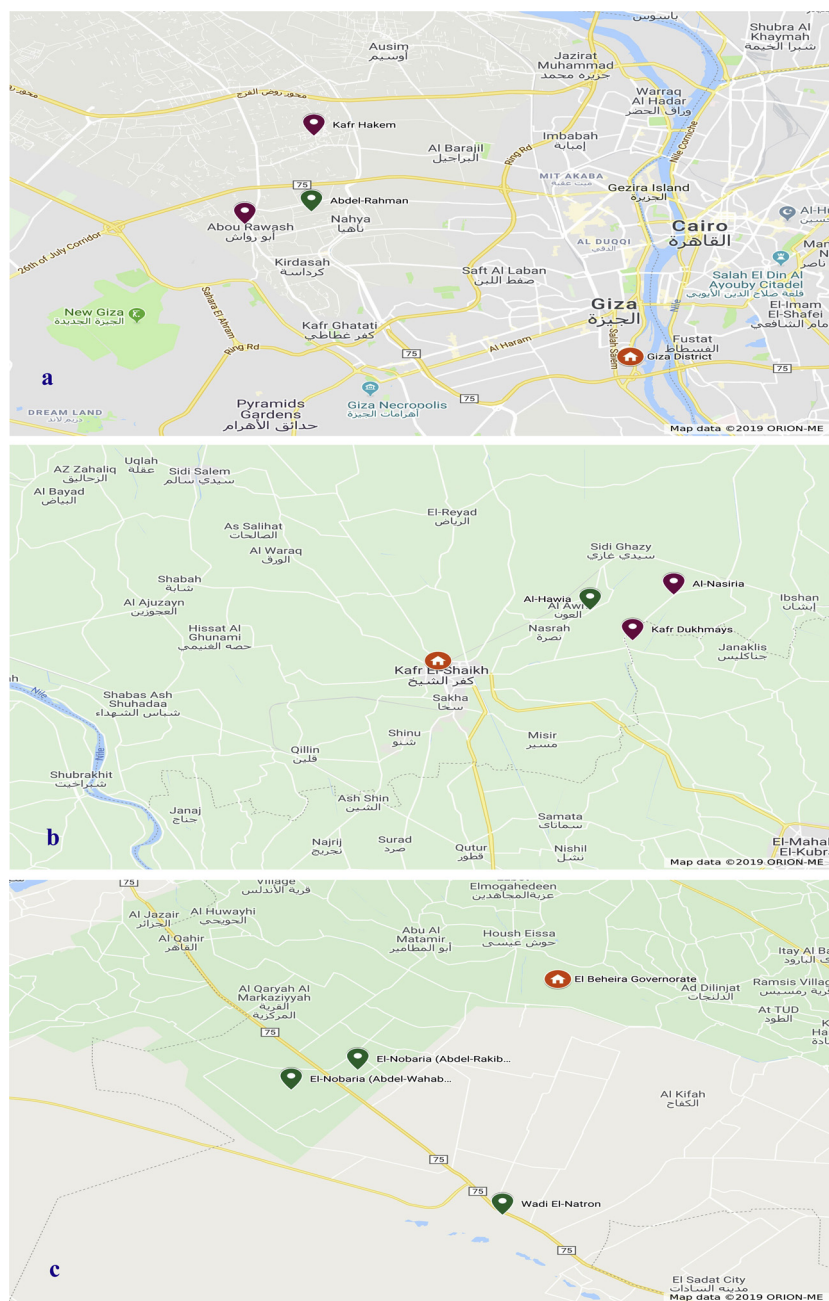


Fig. 1. Zones of sampling: Giza governorate (a), Kafr El-Sheikh governorate (b) and El-Beheira governorate (c); freshwater (green sign), low-quality water (red sign).

3. Results and discussion

3.1. Lead and cadmium in irrigation water

The total and soluble concentrations of Pb and Cd in the Egyptian irrigation water samples collected from different sites are shown in Table 2. The levels of total Pb and Cd in fresh water samples had the lowest values and ranged from 0.021 to 0.094 mg l⁻¹ for Pb and ranged from < 0.001 to 0.048 mg l⁻¹ for Cd. Meanwhile, the total Pb and Cd in low-quality water samples recorded the highest levels and varied from 0.151 to 0.317 mg l⁻¹ for Pb and from 0.094 to 0.106 mg l⁻¹ for Cd. This order was recorded also with the levels of the soluble Pb and Cd in irrigation water samples. The water samples of Kafr-Dokhmais site exhibited the highest levels of the total and soluble Pb ($p < 0.05$), while the water samples of Al-Nasiria site recorded the highest levels of the total and soluble Cd. The irrigation water of both sites was

contaminated by mixed sewage and industrial effluents.

Lead level in all water samples was below the permissible limit (5.0 mg l⁻¹) in irrigation water [22]. The Cd levels in all samples of low-quality water were above the permissible limit (0.01 mg l⁻¹), while the concentration of Cd in the freshwater samples was below the standard limit except Wadi El-Natron and Al-Hawia samples [22]. The continual use of such contaminated water in soil irrigation for long periods without any treatments may lead to harmful impacts for the agricultural soil.

The obtained results were in agreement with those determined by Mahmoud and Ghoneim [4] which varied from 0.05 to 1.05 mg l⁻¹ and from 0.001 to 0.07 mg l⁻¹ for Pb and Cd, respectively, in polluted water at El-Mahla El-Kobra site, whereas, these results were less than those recorded by El-Sayed et al. [23] which ranged from 4.15 to 5.01 mg l⁻¹ for Pb and ranged from 0.86 to 1.08 mg l⁻¹ for Cd in wastewater at Sharkia site. On the other hand, the determined concentrations of Cd

Table 2
Total and soluble lead and cadmium (mg l^{-1}) in different samples of Egyptian irrigation water collected from different regions.

Grade of irrigation water	Site	Lead		Cadmium	
		Total	Soluble	Total	Soluble
Fresh water	Wadi El-Natron	0.068 ^e ± 0.003	0.007 ^f ± 0.001	0.014 ^e ± 0.002	0.004 ^e ± 0.001
	Abdel-Rakib	0.021 ^f ± 0.001	0.008 ^f ± 0.002	< d.l.	< d.l.
	Abdel-Wahab	0.028 ^f ± 0.001	< d.l.	< d.l.	< d.l.
	Al-Hawia	0.094 ^d ± 0.002	0.016 ^e ± 0.001	0.048 ^d ± 0.003	0.009 ^d ± 0.001
	Abdel-Rahman	0.060 ^e ± 0.002	0.009 ^f ± 0.001	< d.l.	< d.l.
Low-quality water	Kafr-Dokhmais	0.317 ^a ± 0.004	0.088 ^a ± 0.002	0.098 ^{bc} ± 0.002	0.034 ^b ± 0.001
	Al-Nasiria	0.296 ^b ± 0.005	0.072 ^b ± 0.002	0.106 ^a ± 0.003	0.048 ^a ± 0.002
	Kafr-Hakem	0.151 ^c ± 0.003	0.036 ^d ± 0.001	0.094 ^c ± 0.002	0.025 ^c ± 0.001
	Abo-Roash	0.159 ^c ± 0.004	0.049 ^c ± 0.001	0.101 ^{ab} ± 0.003	0.037 ^b ± 0.002
LSD	0.009	0.004	0.006	0.004	

Means followed by different subscripts within column are significantly different at the 5 % level.
< d.l.: below detection limit LSD: Least Significant Difference.

Table 3
Total and available lead and cadmium (mg kg^{-1}) in different samples of Egyptian soil collected from different regions.

Grade of irrigation water	Site	Lead		Cadmium	
		Total	Available	Total	Available
Fresh water	Wadi El-Natron	2.65 ^f ± 0.07	0.234 ^f ± 0.019	0.527 ^e ± 0.023	0.074 ^f ± 0.007
	Abdel-Rakib	1.77 ^g ± 0.06	0.354 ^e ± 0.018	0.433 ^f ± 0.023	0.033 ^g ± 0.005
	Abdel-Wahab	1.93 ^g ± 0.06	0.192 ^f ± 0.014	0.400 ^f ± 0.025	0.049 ^g ± 0.005
	Al-Hawia	3.79 ^e ± 0.12	0.827 ^c ± 0.014	0.550 ^e ± 0.023	0.116 ^e ± 0.008
	Abdel-Rahman	2.53 ^f ± 0.08	0.569 ^d ± 0.014	0.553 ^e ± 0.020	0.095 ^f ± 0.007
Low-quality water	Kafr-Dokhmais	7.33 ^a ± 0.15	1.428 ^a ± 0.016	1.260 ^c ± 0.026	0.425 ^c ± 0.007
	Al-Nasiria	6.49 ^b ± 0.11	1.382 ^a ± 0.016	1.667 ^a ± 0.027	0.524 ^a ± 0.008
	Kafr-Hakem	4.56 ^d ± 0.06	1.227 ^b ± 0.013	0.853 ^d ± 0.020	0.235 ^d ± 0.008
	Abo-Roash	5.88 ^c ± 0.17	1.265 ^b ± 0.018	1.453 ^b ± 0.032	0.474 ^b ± 0.008
LSD	0.32	0.047	0.074	0.022	

Means followed by different subscripts within column are significantly different at the 5 % level.
< d.l.: below detection limit LSD: Least Significant Difference.

Table 4
Risk assessment of lead levels in maize grains.

Grade of irrigation water	Site	Pb level (mg kg^{-1}) LSD (0.04)	DIM* ($\text{mg kg}^{-1} \text{ person}^{-1} \text{ day}^{-1}$)		HRI*		Remarks
			Adults	Children	Adults	Children	
Fresh water	Wadi El-Natron	< d.l.	0	0	0	0	Safe
	Abdel-Rakib	0.04 ^d ± 0.01	1.68E-05	2.41E-05	0.004788	0.006892	Safe
	Abdel-Wahab	< d.l.	0	0	0	0	Safe
	Al-Hawia	0.03 ^d ± 0.01	1.26E-05	1.81E-05	0.003591	0.005169	Safe
	Abdel-Rahman	< d.l.	0	0	0	0	Safe
Low-quality water	Kafr-Dokhmais	0.55 ^a ± 0.03	0.00023	0.000332	0.065832	0.094766	Safe
	Al-Nasiria	0.52 ^a ± 0.01	0.000218	0.000314	0.062241	0.089597	Safe
	Kafr-Hakem	0.26 ^c ± 0.02	0.000109	0.000157	0.03112	0.044799	Safe
	Abo-Roash	0.39 ^b ± 0.02	0.000163	0.000235	0.046681	0.067198	Safe

Means followed by different subscripts within column are significantly different at the 5 % level LSD: Least Significant Difference.
< d.l.: below detection limit (0.001) DIM: Daily intake of metals HRI: Health risk index *Farrag et al. [10].

and Pb were higher than the observed in El-Saff wastewater canal [10]. The differences of metals concentration in water samples of different Egyptian sites may be ascribed to different anthropogenic activities and concentrations of urbanization at each site.

3.2. Lead and cadmium in agricultural soil

Total content of Pb and Cd in agricultural soil is important because it determines the size of contamination in the soil and thus availability forms for metal accumulation in cultivated crops [24]. Therefore, soil samples of the studied sites were analyzed for total and available concentrations of Pb and Cd. The data (Table 3) revealed that the total and available levels of Pb and Cd in the soil samples irrigated by low-quality water had the multiple concentrations (about 2.4–3.0 fold) as

compared with the soil samples irrigated by fresh water ($p < 0.05$). Similar finding was reported by Chen et al. [25], who reported that soils which were irrigated by polluted water had the highest levels of heavy metals.

Soil samples of Kafr-Dokhmais site exhibited high concentrations of total and available Pb as 7.33 and 1.428 mg Kg^{-1} , respectively. Meanwhile, the highest levels of total Cd (1.667 mg Kg^{-1}) and available Cd (0.524 mg Kg^{-1}) were recorded in soil samples of Al-Nasiria site. Increase of Pb and Cd in soil samples of Kafr-Dokhmais and Al-Nasiria sites were attributed to their higher levels in irrigation water (Table 2). These results are conformable with those of Abou-Shanab et al. [26] who reported that the levels of available metals in soil depends on total metal content, form and metal source as well as the soil properties.

The concentrations of Pb and Cd in the studied soils were below the

Table 5
Risk assessment of cadmium levels in maize grains.

Grade of irrigation water	Site	Cd level (mg kg ⁻¹) LSD (0.004)	DIM* (mg kg ⁻¹ person ⁻¹ day ⁻¹)		HRI*		Remarks
			Adults	Children	Adults	Children	
Fresh water	Wadi El-Natron	0.009 ^e ± 0.001	3.77E-06	5.43E-06	0.00377	0.005428	Safe
	Abdel-Rakib	< d.l.	0	0	0	0	Safe
	Abdel-Wahab	< d.l.	0	0	0	0	Safe
	Al-Hawia	0.010 ^e ± 0.001	4.19E-06	6.03E-06	0.004189	0.006031	Safe
	Abdel-Rahman	< d.l.	0	0	0	0	Safe
Low-quality water	Kafr-Dokhmais	0.076 ^b ± 0.002	3.18E-05	4.58E-05	0.031839	0.045832	Safe
	Al-Nasiria	0.112 ^a ± 0.002	4.69E-05	6.75E-05	0.04692	0.067543	Safe
	Kafr-Hakem	0.038 ^d ± 0.001	1.59E-05	2.29E-05	0.015919	0.022916	Safe
	Abo-Roash	0.063 ^c ± 0.002	2.64E-05	3.8E-05	0.026393	0.037993	Safe

Means followed by different subscripts within column are significantly different at the 5 % level LSD: Least Significant Difference. < d.l.: below detection limit (0.001) DIM: Daily intake of metals HRI: Health risk index *Farrag et al. [10].

permissible limits set by WHO [27] as 84 and 4 mg Kg⁻¹, respectively. Also, levels of Pb and Cd in the current soil samples are in agreement with the findings of Abdel-Hady [28] and Oladejo et al. [29]. Meanwhile, higher concentrations of Pb and Cd were recorded in wastewater-irrigated soil collected from different Egyptian sites such as El-Mahla El-Kobra [4], El-Gabal El-Asfar [30] and Kafr El-Zayat [31].

3.3. Risk assessment of lead and cadmium levels in maize grains

Maize grains are the third most important crop in the world after wheat and rice. Maize is grown in Egypt to produce grains, which is mainly used for bread, either alone or mixed with wheat. Levels of Pb and Cd in the maize grains cultivated in the different sites are presented in Tables 4 and 5. Concentrations of Pb and Cd in the maize grains cultivated in low-quality water-irrigated sites were significantly greater than those cultivated in the fresh water-irrigated sites (about 19–30 folds). The highest levels of Pb and Cd were recorded in the maize grains of Kafr-Dokhmais and Al-Nasiria sites ($p < 0.05$).

Levels of Pb in the maize grains samples cultivated in low-quality water-irrigated sites exceeded the permissible limits *i.e.* 0.20 mg kg⁻¹ according to WHO/FAO [32], while levels of Cd were within the permissible limits (0.1 mg kg⁻¹) except Al-Nasiria samples. Meanwhile, Pb and Cd levels in the maize grains cultivated in freshwater-irrigated sites were within the permissible limits. The present results are in accordance with those obtained by Lu et al. [11] who found that Pb accumulation in maize grains was 0.49 mg kg⁻¹. Also, Opaluwa et al. [33] reported that the uptake of Pb and Cd by maize grains ranged from 0.02 to 0.23 mg kg⁻¹ and from 0.04 to 0.11 mg kg⁻¹, respectively. The high content of heavy metals in the contaminated crops requires the post-harvest treatments until they decrease below the permissible limits [34].

The risk assessment of Pb and Cd accumulation from maize grains to human is achieved throughout estimation of DIM and HRI (Tables 4 and 5). The DIM and HRI values through the consumption of maize grains irrigated with low-quality water were higher than those irrigated with freshwater. Moreover, consumption of children for maize grains revealed the highest DIM and HRI values as compared to adults, so children are substantially exposed to health risks more than adults. The highest DIM and HRI values in both adults and children were calculated for maize grains obtained from Kafr-Dokhmais and Al-Nasiria sites for Pb and Cd, consecutively.

Conspicuously, all of the determined HRI values for both maize grains irrigated with low-quality water and freshwater were < 1. Humans are considered to be safe if HRI < 1 [35–37]. Therefore, in the present study, the maize grains irrigated with low-quality water which collected from the studied sites are safe for adults and children. The upper acceptable concentrations of Pb in maize grains are 8.354 and 5.803 mg kg⁻¹ for adults and children, respectively, while the upper acceptable concentrations of Cd are 2.387 and 1.658 mg kg⁻¹ for adults

and children, respectively (HRI = 0.99). These results are in agreement with the finding of Farrag et al. [10] who demonstrated that the HRI values of heavy metals levels in wheat were < 1.

4. Conclusion

The use of low-quality water for irrigation in agricultural soil increased in the developing and industrialized countries. The present study investigated the Pb and Cd concentrations in irrigation water, agricultural soil and maize grains as well as estimated the risk assessment of heavy metals levels in maize grains. Concentrations of metals increased in agricultural soil and maize grains irrigated with low-quality water in comparison with those irrigated by freshwater. Although Pb and Cd concentrations in maize grains irrigated with low-quality water were above the permissible limits, the studied maize grains was considered safe and no potential health risk for both adults and children was found (HRI was < 1).

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