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Review Article

Global evaluation of potentially harmful elements (PHEs) in potato and carrot irrigated by wastewater: A systematic review, meta-analysis, and health risk assessment

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Abstract

Background: We aimed to conduct a meta-analysis on the concentration of potentially harmful elements (PHEs) in carrots and potatoes irrigated by wastewater and estimate non-carcinogenic health risks among adult and children consumers.

Methods: The health risk of PHEs concentration, including Pb, Cd, total Cr, Ni, Zn, Cu, and Fe, in the edible parts of carrot and potato irrigated by wastewater was investigated by a meta-analysis using a random-effects model (REM). Accordingly, the related articles were screened from international databases such as Scopus, Medline, and Embase.

Results: The meta-analysis of 32 papers (38 studies) revealed that the rank order of the most accumulated PHEs in potato was Fe (86.54 mg/kg wet weight) > Zn (30.9 mg/kg wet weight) > Cu (13.7 mg/kg wet weight) > Ni (8.42 mg/kg wet weight) > Pb (5.56 mg/kg wet weight) > Cr (3.45 mg/kg wet weight) > Cd (0.58 mg/kg wet weight). This ranking for carrot was Fe (43.36 mg/kg wet weight) > Zn (36.29 mg/kg wet weight) > Ni (13.49 mg/kg wet weight) > Cu (9.79 mg/kg wet weight) > Pb (1.84 mg/kg wet weight) > Cr (1.05 mg/kg wet weight) > Cd (0.28 mg/kg wet weight). Total hazard quotient (THQ) of PHEs was higher than 1 for potato and carrot; its rank order for potato and carrot was Cu > Pb > Cd > Ni > Fe > Zn > Cr and Cd > Pb > Cu > Ni > Fe > Zn > Cr, respectively. The Cd, Pb, and Cu had also a considerable role for consumer health risk.

Conclusion: According to the results, continuous monitor and control of wastewater treatment plants are necessary.

Keywords: Wastewater, Food chain, Cadmium, Lead, Risk assessment

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Introduction

Nowadays, agriculture and crop production rate are negatively affected by growing the world population and food demand, decreasing and degrading of arable land, and especially water shortage (1). Lack of adequate accessibility to water resources often constrains crop planting (2). Some of the negative impacts of water shortage in agriculture/horticulture are increasing salinity (3), nutrient pollution (4), and degradation and loss of flood plains and wetlands. These public concerns have led to development of alternative management strategies and an increase in the wastewater reuse as an integral part of water demand management for crop irrigation (5,6). Wastewater reuse has some benefits such as providing the needed nutrients, conserving water resources, and reducing water contamination (7); on the other hand, it contains potentially harmful elements (PHEs) that can lead to water surface and soil contamination, transfer to vegetables, and finally, cause a health risk for consumers (8,9). It is estimated that up to 90% of exposure to PHEs has a direct association with using contaminated food and water by two major pathways: Soil-to-plant and direct soil ingestion by humans (10,11). Although PHEs are found in soil as trace elements, high concentrations of these elements are released into the environment by human activities (12,13).

Potentially hazardous elements such as Cd, Cu, Cr, Pb, Zn, Ni, and Fe are usually considered as serious pollutants and worldwide concern in the hydrosphere, lithosphere, and biosphere regarding ecological toxicity and permanence, and bioaccumulative potential (14,15). Long-term exposure to high levels of these elements can lead to severe problems in the lung (16), prostate (17), kidney (18), breast (19), bones (20), blood circulation (21), as well as endocrine (22), and immune system (23). Accumulation of PHEs in the soil also causes a decrease in the quality of the crops and long-term hazards by direct contacting with soil and skin, respiratory inhalation, and other pathways that cause serious problems for the human health through food chains (24). One of the major pathways for transferring PHEs into food chains is bioaccumulation in the leave, shoot, root, and edible parts of vegetables such as carrots and potatoes that are among the major food consumption sources for human nutrition (consumption rates of 388.2 and 46.3 million tons for potato and carrot in 2017, respectively) (25). As mentioned above, the main problem of PHEs is transferring into food chains and causing adverse impacts on the human health. Accordingly, health risk assessment is a beneficial and important instrument for estimating the potentially harmful impacts on the human health, now or in the future, and providing a systematic assessment of variables. Health risk assessment tools and methodologies help organizations recognize their risks in four steps: Hazard identification, hazard characterization, exposure assessment, and risk characterization (26).

Among the literature, bioaccumulation of PHEs in carrots and potatoes irrigated by different types of wastewater was investigated by Ahmad et al. The results of their study showed that the concentrations of Mn, Ni, Mo, Cd, and Pb were higher than the maximum permissible limits (27). In another study by Garrido et al, the concentration of PHEs in potato crops impacted by mining discharges was investigated. Similarly, the results of the study showed that the concentrations of heavy metals such as As, Cd, Pb, and Zn in potato tubers were above the concentration limit standards (28). Leblebici et al showed that the high concentrations of heavy metals in soil samples led to an increase in their concentration in potatoes as well. The rank order of PHEs concentrations in potato samples was Zn > Cu > Ni > Cd > Pb > Cr (29).

Although in several studies, the concentration of PHEs in carrots and potatoes irrigated by wastewater was investigated, the knowledge on reusing wastewater has developed with the history of humankind (30). Therefore, a systematic review can be helpful to provide a complete interpretation of the research results. Hence, the main aim of the present study was to conduct a meta-analysis on the concentration of PHEs in carrots and potatoes irrigated by wastewater based on the subgroup of countries. Also, non-carcinogenic health risk was estimated among adult and children consumers.

Materials and Methods

Search strategy

In the present study, the bibliography search was done according to the Cochrane's protocol (31,32) among some of the international databases such as Scopus, Medline, and Embase between May 1, 1977 and February 1, 2020 on the global scale. In this regard, the comprehensive searching was done in four steps: Identification, screening, eligibility, and finally, including articles based on PRISMA guideline shown in Figure 1 (33). The keywords used for searching were: ((TITLE-ABS-KEY ("Daucus carota") OR TITLE-ABS-KEY ("Solanum tuberosum") OR TITLE-ABS-KEY (potato) OR TITLE-ABS-KEY (carrot) OR TITLE-ABS-KEY (vegetables) AND DOCTYPE (ar)) AND ((TITLE-ABS-KEY ("Heavy metal") OR TITLE-ABS-KEY ("trace element") OR TITLE-ABS-KEY (metal) OR TITLE-ABS-KEY ("toxic elements")) AND DOCTYPE (ar)) AND ((TITLE-ABS-KEY (irrigation) OR TITLE-ABS-KEY (wastewater)) AND DOCTYPE (ar)).

Inclusion/exclusion criteria and data extraction

The papers were rigorously screened against a set of inclusion criteria *such as: 1)* Full-text papers were available; 2) Papers were published in English language; 3) Size of study area and number of sampling sites were expressed; 4) Type of studies was cross-sectional or descriptive; 5) Studies were done only on carrot and potato vegetables; 6) Type of irrigation source was wastewater; and 7) Mean value and value of standard deviation/range of PHEs concentration in carrots and potatoes were mentioned clearly. Moreover, the exclusion criteria for the papers were: 1) Books, review articles, and clinical trial; 2) Irrigation source was diluted wastewater or sludge/wastewater combined with each other; and 3) Papers with low-quality figures.

Finally, the parameters including year, country, sample size, mean, and standard deviation/error of PHEs concentration in carrots and potatoes were extracted. For the papers with graphical results, Graph Digitizer software version 2.24 was employed to extract the data as numerical.

Meta-analysis and statistical analysis

A meta-analysis was conducted for magnifying the size of samples to ameliorate the confidence of the conclusions

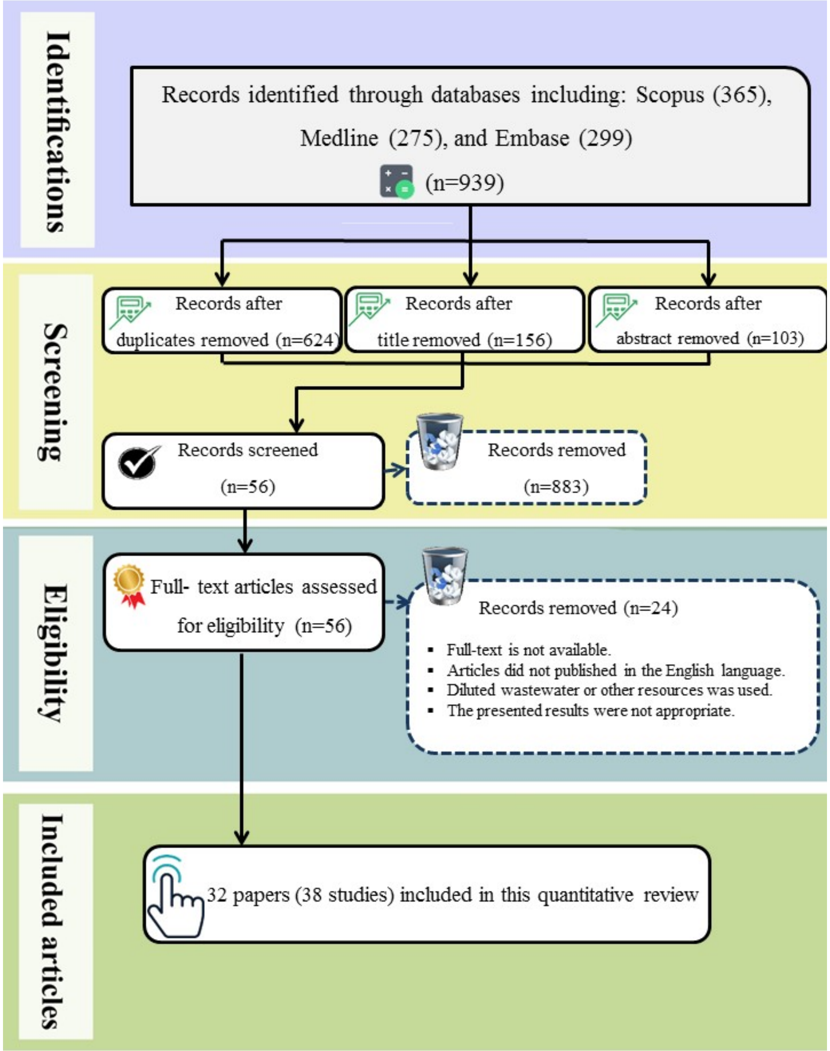

Figure 1. Selection process of the reviewed studies according to the Cochrane's protocols.

by combining the results from investigations by the mean and standard error (SE) of the PHEs concentration in the edible parts of the carrot and potato (34). Standard error was calculated according to the following equation:

$$SE = \frac{SD}{\sqrt{N}} \quad (1)$$

where *SD* is standard deviation and *N* is sample size.

In this study, the data were meta-analyzed in STATA 12.0 software (StataCorp, College Station, TX). Significant heterogeneity among studies was assessed using Cochrane's Q-test and chi-square (I^2) (35). A chi-square higher than 50% represents statistically significant heterogeneity (36). According to the analysis, I^2 percentage was higher than 50%, so random effect model (REM) was applied (37).

Health risk assessment

Estimating daily PHEs intake

The health risk assessment process initiates by estimating dietary intake of toxins. The estimated daily intake (EDI) of PHEs in carrots and potatoes was calculated based on the PHEs concentration (C, mg/kg), ingestion rate (IR, g/n-d) of carrots and potatoes (Table S1), exposure duration (ED, 6 years for children and 30 years for adults), exposure frequency (EF, 350 day/year), body weight (BW, 15 kg for children and 70 kg for adults), and average lifetime (AT = EF × ED, 2190 for children and 10 950 days for adults), as the following equation (37):

$$EDI = \frac{C \times IR \times EF \times ED}{BW \times AT} \quad (2)$$

To estimate the PHEs concentration in consumed vegetables, the dry-weight concentration unit (mg/kg-dry weight) was converted into wet weight unit (mg/kg-wet weight) using Eq. (3) (37), where *M* is water content of vegetables (87% for carrot and 78% for potato).

$$ww = \frac{dw \times (100 - \%M)}{100} \quad (3)$$

Non-cancer risk

Non-carcinogenic risks (n-CR) for individual PHEs were evaluated by hazard quotient (HQ). Indeed, HQ calculates the n-CR via comparing exposure level at a specified time (EDI) with the reference dose (RfD) or tolerable dietary intake (TDI) (38,39), as shown in Eq. (4).

$$HQ = \frac{EDI}{RfD \text{ or } TDI} \quad (4)$$

where *RfD* is the oral reference dose recommended by the EPA (As = 0.0003, Cd = 0.001, total Cr = 1.5, Ni = 0.02, Cu = 0.04, and Fe = 0.7 mg/kg.d) (40). TDI for Pb is 0.0036 mg/kg-d (41). An HQ higher than 1 represents the n-CR of a toxin, via the consumption of a certain food. To assess the n-CR when consuming several toxins from one food and several foods (potato and carrot), total hazard quotient (THQ) and total hazard quotient actual (THQ act) are used, respectively, as shown in Eqs. (5) and (6) (42).

$$THQ = \sum_{i=1}^{n} HQ \quad (5)$$

$$THQ_{act} = THQ_{carrot} + THQ_{potato} \quad (6)$$

Results

Study characteristics and selection process

Selection process of studies began by searching in Scopus, Medline, and Embase databases up to February 1, 2020. Initially, 939 articles were identified. Then, 624, 156, 103, and 24 papers were removed because of being duplicate or due to their title, abstract, and full-text, respectively. Finally, 32 papers (38 studies) as suitable studies were included in this review. Selection process of the reviewed studies according to Cochrane protocols is indicated in Figure 1. The main characteristics of the included papers are also presented in Tables S2 and S3 (See Supplementary file 1). These tables indicate parameters including mean, SD, SE, sample size, country etc. on PTEs in potato and carrot which entered in the study and analyzed.

Meta-analysis results

The rank order of countries based on the PHEs accumulation (mg/kg, wet weight) in potato and carrot is shown in Table 1. Among the countries, Pakistan, Nigeria, and India had the highest PHEs concentrations in both potato and carrot. Pakistan was ranked as the first country in terms of Zn and Ni concentration in potato and pb, Cu, and Ni content in carrot. Iran is also the first country with cadmium wet weight of 1.07 mg/kg in potato. Based on the meta-analysis results, the rank order of PHEs in potato was Fe (86.54 mg/kg wet weight) > Zn (30.9 mg/kg wet weight) > Cu (13.7 mg/kg wet weight) > Ni (8.42 mg/kg wet weight) > Pb (5.56 mg/kg wet weight) > Cr (3.45 mg/kg wet weight) > Cd (0.58 mg/kg wet weight); for carrot, it was Fe (43.36 mg/kg wet weight) > Zn (36.29 mg/kg wet weight) > Ni (13.49 mg/kg wet weight) > Cu (9.79 mg/kg wet weight) > Pb (1.84 mg/kg wet weight) > Cr (1.05 mg/kg wet weight) > Cd (0.28 mg/kg wet weight). As obtained by the results, Fe had the highest concentration among PHEs in both vegetables. However, the concentration of Fe in potato was two times higher than that of carrot. Zn was the second most abundant element in vegetables. The other PHEs concentration were similar in potato and carrot.

Health risk assessment results

The HQ of PHEs and their total amount (THQ) based on age group and vegetable type for the studied countries are given in Figure 2. According to the results, all the PHEs, except Cr, had an HQ higher than 1 for both vegetables. However, the related THQ was also obtained to be higher

Table 1. Rank order of countries for the PHEs (mg/kg, wet weight) in vegetables (potato and carrot)

	Potato
Pb	India (11.45) > Pakistan (6.78) > Iran (1.28) > Algeria (0.008)
Cd	Iran (1.07) > India (1.01) > Pakistan (0.69) > Turkey (0.26) > Germany (0.16) > China (0.004)
Cu	Algeria (65.65) > Pakistan (15.15) > Turkey (8.58) > India (5.18) > Iran (3.83)
Fe	Turkey (186.13) > India (121.87) > Pakistan (51.9) > Iran (48.32)
Cr	India (15.63) > Pakistan (1.41) > Iran (0.61) > Algeria (0.2)
Zn	Pakistan (64.08) > Turkey (45.6) > India (15.81) > Iran (4.82) > China (3.02) > Algeria (0.32)
Ni	Pakistan (11.62) > India (6.82) > Iran (4.44) > China (0.28)
	Carrot
Pb	Pakistan (17.31) > Nigeria (11.13) > India (8.83) > Ethiopia (0.15)
Cd	Nigeria (8.51) > Pakistan (1.86) > India (0.2) > Ethiopia (0.06)
Cu	Pakistan (20.02) > India (7.78) > Nigeria (5.22) > UAE (0.72) > Ethiopia (0.07)
Fe	India (187.92) > Pakistan (63.64) > UAE (2.48) > Ethiopia (0.29)
Cr	Nigeria (56.63) > Pakistan (4.72) > UAE (1.12) > Ethiopia (0.06)
Zn	Nigeria (72.47) > Pakistan (45.93) > India (24.86) > UAE (2.23) > Ethiopia (0.18)
Ni	Pakistan (15.06) > Nigeria (2.52)

than 1 in all the countries for each vegetable, which means a considerable n-CR for all age groups. India for consumption of potato and Nigeria for consumption of carrot had maximum THQ values for all age groups. THQs higher than 1 enhance the risk of long-term carcinogenic effect and it can be a health hazard. As shown in Table 2, the THQ related to the consumption of potato was more than that related to carrot in both age groups, which can be due to the higher capita consumption of potato than carrot. Figure 3 indicates the average THQ (%) of PHEs in both vegetables. India had the highest TTHQ of potato consumption in adult and children. Maximum TTHQ of carrot consumption in adult and children was related to Nigeria. The rank order of PHEs for potato was Cu > Pb > Cd > Ni > Fe > Zn > Cr; for carrot, it was Cd > Pb > Cu > Ni > Fe > Zn > Cr. So, it can be concluded that Cd, Pb, and Cu had a considerable role for consumer health risk.

Discussion

PHEs concentration among countries

PHEs accumulation in potato and carrot vary from country to country. As shown in Table 1, the highest PHEs concentration in both vegetables belongs to Pakistan, Nigeria, and India, respectively. Anthropogenic activities, especially development of urbanization and industrialization, can contribute to different levels of PHEs uptake in crops around the world (43,44). The wastewater used for irrigation purposes is generated by various sectors (domestic, industries, and mines) (45). In addition, factors like soil characteristics, climate, precipitation, soil minerals, atmospheric deposition rate, consumption of fertilizers and metal-based pesticides, and enforcement policies are different in various regions and affect the PHEs accumulation and uptake in the soil and vegetables (46).

Concentration of PHEs in potato and carrot

The concentration of each of the PHEs in potato and carrot is different. The order of PHEs concentration in potato was as Fe > Zn > Cu > Ni > Pb > Cr > Cd; and in carrot, it was as Fe > Zn > Ni > Cu > Pb > Cr > Cd. The earth's crust is a potential source of Fe which is transferred to vegetables via the soil. Fe which is a predominant and essential element in the root and leafy vegetables helps their growth and evolvement (47). In addition, high concentrations of this element can be related to its function of chlorophyll synthesis in plants. Fe accumulation in wastewater-irrigated soils was reported to be higher than others. The accumulation of higher than 300 mg kg^{-1} of Fe is toxic for the plants grown in soils with pH < 5 (48,49). Zn was the second most abundant element found in both vegetables. Similar to Fe, the high concentration

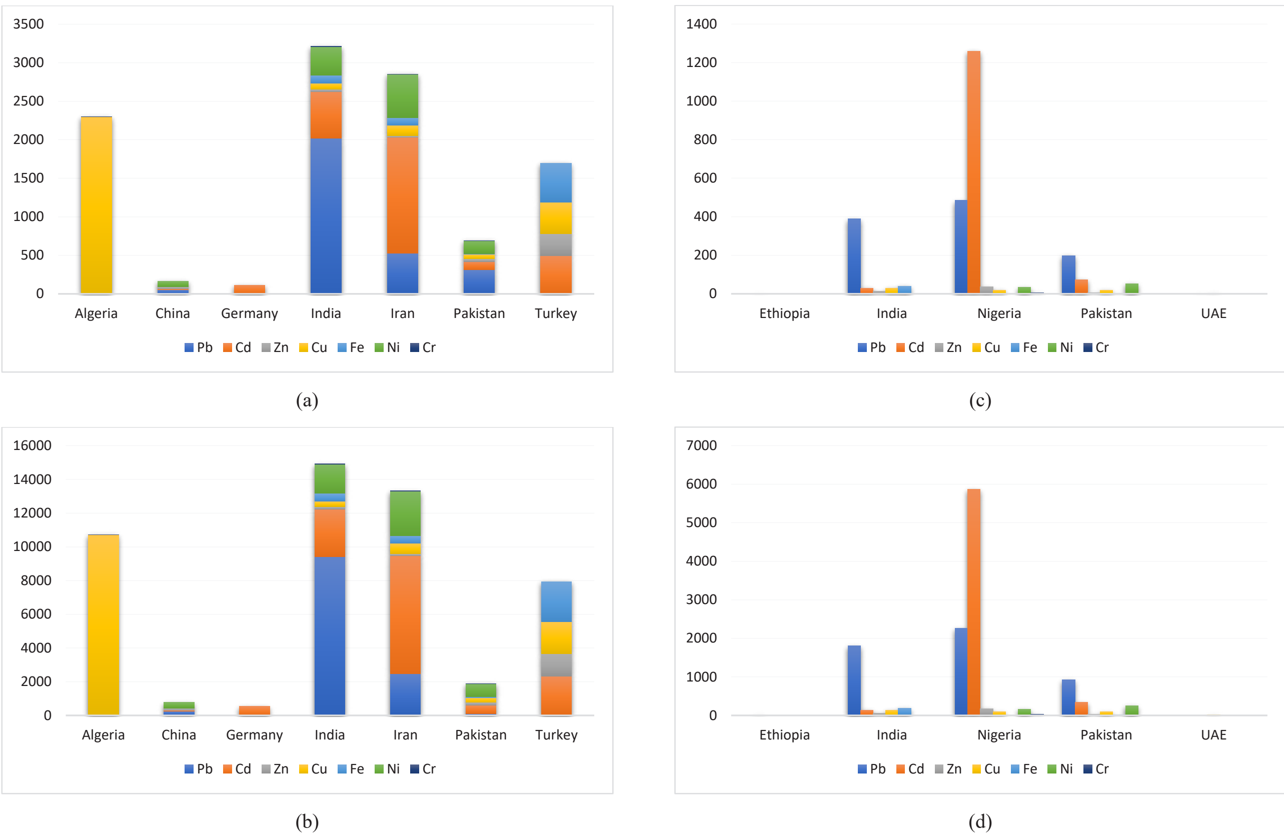

Figure 2. Non-carcinogenic risk due to ingestion of polluted vegetables based on countries. (a) Potato – adults, (b) Potato – children, (c) Carrot – adults, (d) Carrot – children.

Table 2. Actual non-carcinogenic risk due to ingestion vegetables (potato and carrot) content of PHEs

	Adults		Children		Adults	Children
	Potato	Carrot	Potato	Carrot	TTHQ act	TTHQ act
Algeria	2297.29		10720.79		2297.29	10720.79
China	164.24		766.56		164.24	766.56
Ethiopia		2.64		15.41	2.64	15.41
Germany	114.52		534.42		114.52	534.42
India	3214.92	500.49	14943.05	2335.73	3715.41	17278.78
Iran	2851.11		13305.28		2851.11	13305.28
Nigeria		1837.81		8586.56	1837.81	8586.56
Pakistan	688.92	353.99	1868.46	1652.07	1042.91	3520.53
Turkey	1698.59		7926.81		1698.59	7926.81
UAE		5.74		24.87	5.74	24.87

of Zn can be attributed to its relative abundance in the earth's crust in accordance with the rank of PHEs in topsoil (Zn > Cr > Pb > Ni > Cu > Cd) (50). Also, long-term irrigation by wastewater can reduce the soil pH and increase the content of Zn and other PHEs as bioavailable forms (51). Although Zn is an essential element for enzymatic activity and many biological processes at low concentrations, its high concentration can be toxic for the plant and human health (52). The third most abundant metals in potato and carrot was Cu and Ni, respectively. High contents of Cu in crops can be due to the possible contribution of wastewater pollution load and transport of sandy soil from the river to the farms (53). High levels of Cu reduce chlorophyll content in the leaf of vegetables and inhibit the photosynthesis and respiration rate (54). Nickel is a poisonous heavy metal for both humans and plants in high doses in certain forms (55). Possible source of Ni is discharge of untreated wastewater generated from nickel industries and combustion of fossil fuels (56). Ni decreases seed germination, root and shoot growth, and final production of crops. In addition, Ni toxicity causes chlorosis and necrosis. Nickel causes oxidative damage and inhibits photosynthesis and transpiration in plants (57). Pb concentration in potato was higher than that in carrot. Pb is an accumulative element that exists in the earth's crust, soils, water, and wastewater at trace levels (58). Soil pH, content of organic matter, and cation exchange capacity of the soil can enhance Pb uptake (59). Cr is another element which can be discharged into the environment using untreated wastewater of leather tanning, petroleum refining, electroplating, textile fabric, and other industries (60). The lowest absorbed PHE by the two vegetables was Cd. The main sources of Cd in soils are phosphatic fertilizers, irrigation wastewater, and atmospheric fallout from industries (61).

Effective factors for PHEs uptake

The accumulation and uptake of PHEs in the vegetables do not follow any pattern. Indeed, the order of accumulation is influenced by the properties of soil, PHEs, plant, and wastewater. However, other factors such as climate status, use of pesticides and manures, and harvesting time are also effective (62,63).

Soil nature

Nature of soil is a significant factor in the accumulation of PHEs. The physicochemical properties of the soil such as pH, cation exchange capacity, redox potential,

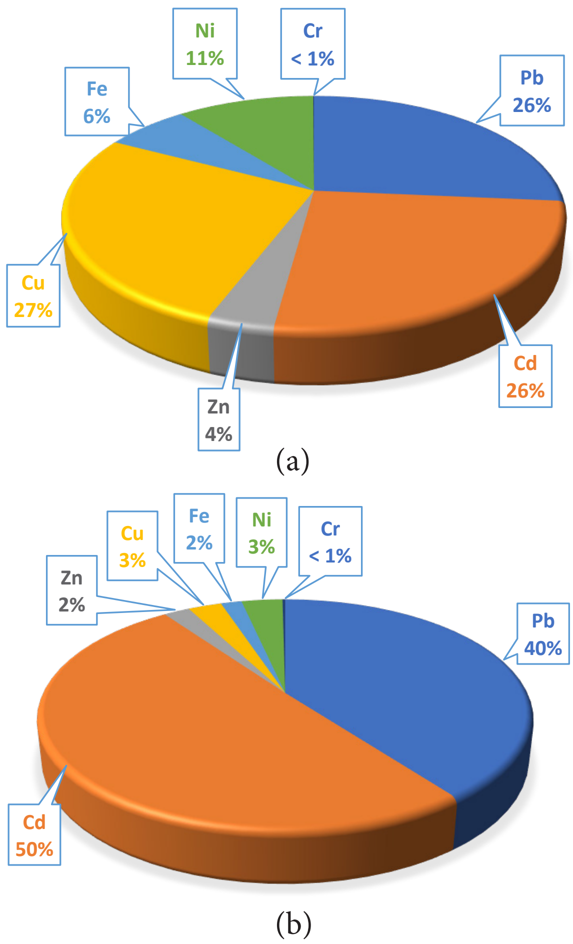

Figure 3. Non-carcinogenic risk due to ingestion of polluted vegetables based on the PHEs; (a) Potato, (b) Carrot.

and organic matter content can influence the solubility and bioavailability of PHEs in soils (64,65). Irrigation by untreated wastewater for a long time changes the soil physicochemical characteristics and elevates soil PHEs concentration (66). Acidic pH of soil increases the mobility of PHEs (67); reducing the redox potential in soil enhances bioavailability of PHEs and turns insoluble ions of PHEs into soluble forms. However, increasing cation exchange capacity enhances the adsorption of PHEs (63,68).

PHEs properties

The concentration of PHEs in various plants can be different depending on their solubility and bioavailability, distinctive uptake mechanism, and interaction between PHEs in the soil and within the plant (69,70). PHEs have two types of elements: Essential and non-essential elements. Cu and Zn are the essential types, but they are considered toxic at higher levels. Other metals such as Pb and Cd have no essential role in the organisms and are toxic even at low concentrations. Lead and cadmium ions disrupt the cell transport process by binding with cell membranes. Among PHEs, Cd and Zn have a higher transfer factor (concentration ratio of a specific PHE in the plant tissue to the soil) than Pb, due to their higher mobility from soil to the edible part (71). Cr, Cd, and Ni are transferred by going up of sap to plants and formed complexes with biomolecules. It is also reported that Cd, Zn, and Cu accumulate more in the shoot of plants. The interaction between PHEs changes their accumulation in the plant (72-74). For example, the antagonistic correlation between Zn and Cu causes more accumulation of PHEs (39,75).

Plant properties

Specie, age, and part of plants affect the rate of PHEs uptake (76). Plants uptake of water, nutrients, and PHEs via the root or aerial parts leads to different accumulation patterns between the root, shoot, and leaves (77,78). There are adsorption and physio-chemical mechanisms in plants which influence the concentration of PHEs in their parts (79). In our previous study (74), which was a meta-analysis on the accumulation of PHEs in different parts of onion and tomato, the results showed different orders of concentrations between the investigated parts for both species. In addition to the parts, the accumulation capacity is also different among species. Potato has a branched root system which develops from underground stems, while carrot has fibrous roots which extends from a taproot (80). Bioconcentration factor illustrates the rate of PHEs bioavailability for plants. Indeed, the plants with higher bioconcentration factor present higher affinity to accumulate the PHEs (81). The findings are also consistent with the results of our previous research (74,82). Based on the results, different orders of PHEs accumulation were found in onion, tomato, spinach, and radish vegetables. The roots were more likely to transport Cd to the aerial part, whereas Cu uptake was significantly higher in the roots than leaves (83).

Wastewater properties

Water shortage and high wastewater contents of organic matter and nutrient make it a valuable resource for irrigation and lead to wastewater irrigation as a common practice around the world. However, the existence of pathogens and other substances such as PHEs in raw and low-quality treated wastewater can threat the human health (84-86). Composition, source, volume, and type of wastewater are different in various areas, which influence the accumulation of PHEs in vegetables. Industrial wastewater with regard to its origin has more PHEs than the domestic ones. For example, tannery wastewater has high contents of chromium and reduced vegetable growth (87, 88). Long-term irrigation by wastewater elevates organic carbon content and reduces soil pH, which subsequently, increases PHEs mobility (89). As a general rule, it is proved that the soil irrigated by wastewater has higher concentrations of bioavailable PHEs than the soil irrigated by the groundwater (86).

Health risk assessment

PHEs accumulation and intake through the food chain could be a concern for the human health. Nowadays, many characteristics like acute and chronic toxicity, carcinogenicity, neurotoxicity, teratogenicity, or mutagenicity are attributed to PHEs due to their persistent and non-biodegradable nature (52,90). In the present study, the n-CR of PHEs via consumption of polluted potato and carrot vegetables was investigated by the HQ index. The HQ of all PHEs, except Cr, was more than 1 for both vegetables. The THQ was also more than 1 in all the countries for each vegetable, which means a considerable n-CR for all age groups. Health risk assessment of heavy metals was investigated and the individual hazard index of carrot for both children and adults was reported to be below 1, indicating no potential risk to the public except for cadmium, chromium, and manganese. Also, the hazard index of heavy metals studied were above 1, indicating non-acceptable level of non-carcinogenic adverse health effect (91). In accordance with our previous studies (74,82), children group was more susceptible to the adverse effects, which can be due to their lower body weight than adults. Alturiqi et al (18) found that HQs values in vegetables for Fe, Mn, Cu, Zn, and Ni were found to be less than 1, while the estimated HQs for Pb and Cd were higher than 1, posing a greater risk to the health of adults and children. THQ values were higher for children compared to adults (92).

Conclusion

In this study, the concentration of some PHEs in potato and carrot vegetables irrigated by wastewater via meta-analysis was assessed. Moreover, the n-CR due to the ingestion of polluted crops was investigated. In this regard, 32 papers published up to February 1, 2020 were included in the study. According to the meta-analysis results, the orders of Fe > Zn > Cu > Ni > Pb > Cr > Cd for potato and Fe > Zn > Ni > Cu > Pb > Cr > Cd for carrot were obtained as the most accumulated PHEs. In addition to the wastewater content of PHEs, the main reason for higher concentrations of Fe and Zn was attributed to their abundance in the earth's crust. The results associated with n-CR indicated the health risk for ingestion of all PHEs, except Cr. However, the consumption of each vegetable had a considerable health risk for both age groups in all the countries. Among PHEs, Cd, Pb, and Cu had the greatest effects on the health of consumers. In accordance with the n-CR results, it is not recommended to use the crops irrigated by untreated wastewater or low-quality treated wastewater.

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Ethical issues

The study protocols were approved by the Ethics Committee of Shahid Beheshti University of Medical Sciences, Tehran, Iran (Ethical code: IR.SBMU.RETECH.REC.1398.647).

Conflict of interests

The authors declare that they have no conflict of interests.

Authors' contributions

All authors equally contributed to the problem suggestion, experiments design, data collection, and manuscript approval.

Supplementary files

Supplementary file 1 contains Tables S1-S3.

References

1. Zhang Y, Zhang JH, Tian Q, Liu ZH, Zhang H. Virtual water trade of agricultural products: A new perspective to explore the Belt and Road. Sci Total Environ 2018; 622-623: 988-96. doi: 10.1016/j.scitotenv.2017.11.351.
2. Moussavi SP, Ehrampoush MH, Mahvi AH, Rahimi S, Ahmadian M. Efficiency of multi-walled carbon Nanotubes in adsorbing Humic acid from aqueous solution. Asian Journal of Chemistry 2014; 26(3): 821-6. doi: 10.14233/ajchem.2014.15609.
3. Ehrampoush MH, Moussavi G, Ghaneian MT, Rahimi S, Ahmadian M. Removal of Methylene blue (MB) dye from textile synthetic wastewater using TiO2/UV-C photocatalytic process. Australian Journal of Basic and Applied Sciences 2010; 4(9): 4579-85.
4. Malakotian M, Asadzadeh SN, Khatami M, Ahmadian M, Heidari MR, Karimi P, et al. Protocol encompassing ultrasound/Fe_3O_4 nanoparticles/persulfate for the removal of tetracycline antibiotics from aqueous environments. Clean Technol Environ Policy 2019; 21(8): 1665-74. doi: 10.1007/s10098-019-01733-w.
5. Malakootian M, Nasiri A, Khatami M, Mahdizadeh H, Karimi P, Ahmadian M, et al. Experimental data on the removal of phenol by electro-H2O2 in presence of UV with response surface methodology. MethodsX 2019; 6: 1188-93. doi: 10.1016/j.mex.2019.05.004.
6. Lorestani B, Merrikhpour H, Cheragh M. Assessment of heavy metals concentration in groundwater and their associated health risks near an industrial area. Environ Health Eng Manag 2020; 7(2): 67-77. doi: 10.34172/EHEM.2020.09.
7. Seid-Mohammadi A, Asgari G, Sammadi MT, Ahmadian M, Poormohammadi A. Removal of Humic acid from synthetic water using chitosan as coagulant aid in electrocoagulation process for al and fe electrode. Research Journal of Chemistry and Environment 2014; 18(5): 19-25.
8. Luo X, Ren B, Hursthouse AS, Jiang F, Deng RJ. Potentially toxic elements (PTEs) in crops, soil, and water near Xiangtan manganese mine, China: potential risk to health in the foodchain. Environ Geochem Health 2020; 42: 1965-76. doi: 10.1007/s10653-019-00454-9.
9. Radziemska M, Bęś A, Gusiatin ZM, Majewski G, Mazur Z, Bilgin A, et al. Immobilization of potentially toxic elements (PTE) by mineral-based amendments: Remediation of contaminated soils in post-industrial sites. Minerals 2020; 10(2): 87. doi: 10.3390/min10020087.
10. Antoniadis V, Golia EE, Shaheen SM, Rinklebe J. Bioavailability and health risk assessment of potentially toxic elements in Thriasio Plain, near Athens, Greece. Environ Geochem Health 2017; 39(2): 319-30. doi: 10.1007/s10653-016-9882-5.
11. Mousavi Khaneghaha A, Fakhri Y, Nematollahi A, Pirhadid M. Potentially toxic elements (PTEs) in cereal-based foods: a systematic review and meta-analysis. Trends Food Sci Technol 2020; 96: 30-44. doi: 10.1016/j.tifs.2019.12.007.
12. Jiang F, Ren B, Hursthouse A, Deng R. Wang Z. Distribution, source identification, and ecological-health risks of potentially toxic elements (PTEs) in soil of thallium mine area (southwestern Guizhou, China). Environ Sci Pollut Res Int 2019; 26(16): 16556-67. doi: 10.1007/s11356-019-04997-3.
13. McKinley K, McLellan I, Gagné F, Quinn B. The toxicity of potentially toxic elements (Cu, Fe, Mn, Zn and Ni) to the cnidarian Hydra attenuata at environmentally relevant concentrations. Sci Total Environ 2019; 665: 848-54. doi: 10.1016/j.scitotenv.2019.02.193.
14. Bilal M, Rasheed T, Sosa-Hernández JE, Raza A, Nabeel F, Iqbal HM. Biosorption: an interplay between marine algae and potentially toxic elements—a review. Mar Drugs 2018; 16(2): 65. doi: 10.3390/md16020065.
15. Timofeev I, Kosheleva N, Kasimov N. Contamination of soils by potentially toxic elements in the impact zone of tungsten-molybdenum ore mine in the Baikal region: A survey and risk assessment. Sci Total Environ 2018; 642: 63-76. doi: 10.1016/j.scitotenv.2018.06.042.
16. Ametepey ST, Cobbina SJ, Akpabey FJ, Duwiejuah AB, Abuntori ZN. Health risk assessment and heavy metal contamination levels in vegetables from Tamale Metropolis, Ghana. Int J Food Contam 2018; 5: 5. doi: 10.1186/s40550-018-0067-0.

17. Lim JT, Tan YQ, Valeri L, Lee J, Geok PP, Chia SE, et al. Association between serum heavy metals and prostate cancer risk–A multiple metal analysis. Environ Int 2019; 132: 105109. doi: 10.1016/j.envint.2019.105109.
18. Alturiqi AS, Albedair LA, Ali MH. Health risk assessment of heavy metals in irrigation water, soil and vegetables from different farms in Riyadh district, Saudi Arabia. Journal of Elementology 2020; 25(4): 1269-89. doi: 10.5601/jelem.2020.25.3.2016.
19. Romanjuk A, Lyndin M, Moskalenko R, Gortinskaya O, Lyndina Y. The role of heavy metal salts in pathological biomineralization of breast cancer tissue. Adv Clin Exp Med 2016; 25(5): 907-10. doi: 10.17219/acem/34472.
20. Karimi P, Baneshi MM, Malakootian M. Photocatalytic degradation of aspirin from aqueous solutions using the UV/ZnO process: modelling, analysis and optimization by response surface methodology (RSM). Desalin Water Treat 2019; 161: 354-64. doi: 10.5004/dwt.2019.24317.
21. Atamaleki A, Miranzadeh MB, Mostafaii GR, Akbari H, Iranshahi L, Ghanbari F, et al. Effect of coagulation and sonication on the dissolved air flotation (DAF) process for thickening of biological sludge in wastewater treatment. Environ. Health Eng Manag 2020; 7(1): 59-65. doi: 10.34172/EHEM.2020.08.
22. Vigneri R, Malandrino P, Gianì F, Russo M, Vigneri P. Heavy metals in the volcanic environment and thyroid cancer. Mol Cell Endocrinol 2017; 457: 73-80. doi: 10.1016/j.mce.2016.10.027.
23. Du C, Wu J, Bashir MH, Shaukat M, Ali S. Heavy metals transported through a multi-trophic food chain influence the energy metabolism and immune responses of Cryptolaemus montrouzieri. Ecotoxicology 2019; 28(4): 422-8. doi: 10.1007/s10646-019-02033-1.
24. Wang Z, Meng B, Zhang W, Bai J, Ma Y, Liu M. Multi-target risk assessment of potentially toxic elements in farmland soil based on the environment-ecological-health effect. Int J Environ Res Public Health 2018; 15(6): 1101. doi: 10.3390/ijerph15061101.
25. Atamaleki A, Yazdanbakhsh A, Fakhri Y, Gholizadeh A, Naimi N , Karimi P , et al. Concentration of potentially harmful elements (PHEs) in eggplant vegetable (Solanum melongena) irrigated with wastewater: a systematic review and meta-analysis and probabilistic health risk assessment . Int J Environ Health Res 2021; 31(1): 1-13. doi: 10.1080/09603123.2021.1887461 .
26. El-Harbawi M, Abd Raman AA, Al-Mubaddel F. Development of a chemical health risk assessment tool for health risk assessment from exposure to hazardous chemicals. Biomedical Journal of Scientific & Technical Research 2020; 28(3): 21715-26. doi: 10.26717/BJSTR.2020.28.004669.
27. Ahmad K, Iqbal Khan Z, Yasmin S, Ashfaq A, Noorka IR, Aisha N, et al. Contamination of soil and carrots irrigated with different sources of water in Punjab, Pakistan. Environ Earth Sci 2016; 75(5): 426. doi:10.1007/s12665-016-5348-4.
28. Garrido AE, Strosnider WH, Wilson RT, Condori J, Nairn RW. Metal-contaminated potato crops and potential human health risk in Bolivian mining highlands. Environ Geochem Health 2017; 39(3): 681-700. doi: 10.1007/s10653-017-9943-4.
29. Leblebici Z, Aksoy A, Akgul G. Accumulation and effects of heavy metals on potatoes (solanum tuberosum l.) in the Nevsehir, Turkey. Fresenius Environ Bull 2017; 26(12): 7083-90.
30. Jaramillo MF, Restrepo I. Wastewater reuse in agriculture: A review about its limitations and benefits. Sustainability 2017; 9(10): 1734. doi: 10.3390/su9101734.
31. Higgins J, Green S. Cochrane Handbook for Systematic Reviews of Interventions. UK: Cochrane Collaboration; 2011.
32. Atabati H, Abouhamzeh B, Abdollahifar MA, Sadat Javadinia S, Gharibian Bajestani S, Atamalek A, et al. The association between high oral intake of acrylamide and risk of breast cancer: An updated systematic review and meta-analysis. Trends Food Sci Technol 2020; 100: 155-63. doi: 10.1016/j.tifs.2020.04.006.
33. Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev 2015; 4: 1. doi: 10.1186/2046-4053-4-1.
34. Hill A, Clasen KC, Wendt S, Majoros AG, Stoppe C, Adhikari NK, et al. Effects of vitamin C on organ function in cardiac surgery patients: A systematic review and meta-analysis. Nutrients 2019; 11(9): 2103. doi: 10.3390/nu11092103.
35. Cohen JF, Chalumeau M, Cohen R, Korevaar DA, Khoshnood B, Bossuytc PM. Cochran's Q test was useful to assess heterogeneity in likelihood ratios in studies of diagnostic accuracy. J Clin Epidemiol 2015; 68(3): 299-306. doi: 10.1016/j.jclinepi.2014.09.005.
36. Alogaili A, Mannering F. Unobserved heterogeneity and the effects of driver nationality on crash injury severities in Saudi Arabia. Accid Anal Prev 2020; 144: 105618. doi: 10.1016/j.aap.2020.105618.
37. Daraei H, Conti GO, Sahlabadi F, Nam Thai V, Gholipour S, Turki H, et al. Prevalence of Cryptosporidium spp. in water: a global systematic review and meta-analysis. Environ Sci Pollut Res Int 2021; 28(8): 9498-507. doi: 10.1007/s11356-020-11261-6.
38. Singh A, Kumar Sharma R, Agrawal M, Marshall FM. Health risk assessment of heavy metals via dietary intake of foodstuffs from the wastewater irrigated site of a dry tropical area of India. Food Chem Toxicol 2010; 48(2): 611-9. doi: 10.1016/j.fct.2009.11.041.
39. Njuguna SM, Makokha VA, Yan X, Gituru RW, Wang Q, Wang J. Health risk assessment by consumption of vegetables irrigated with reclaimed waste water: A case study in Thika (Kenya). J Environ Manage 2019; 231: 576-81. doi: 10.1016/j.jenvman.2018.10.088.
40. Xue L, Zhao Z, Zhang Y, Liao Y, Naimi N, et al. Dietary exposure to arsenic and human health risks in western Tibet. Sci Total Environ 2020; 731:138840. doi: 10.1016/j.scitotenv.2020.138840 .
41. Mostafaii GR, Moravveji AR, Hajirostamloo B, Hesami Arani M, Dehghani M, Heidarinejad Z. The concentration and risk assessment of potentially toxic elements (PTEs) in unrefined salt: a case study of Aran and Bidgol Lake, Iran. Int J Environ Anal Chem 2020; 1-13. doi: 10.1080/03067319.2020.1734195.
42. Petroczi A, Naughton DP. Mercury, cadmium and lead contamination in seafood: a comparative study to evaluate the usefulness of Target Hazard Quotients. Food Chem Toxicol 2009; 47(2): 298-302. doi: 10.1016/j.fct.2008.11.007.
43. Sharma RK, Agrawal M, Marshall FM. Heavy metals in vegetables collected from production and market sites of a tropical urban area of India. Food Chem Toxicol 2009; 47(3): 583-91. doi: 10.1016/j.fct.2008.12.016.

44. Ali MH, Al-Qahtani KM. Assessment of some heavy metals in vegetables, cereals and fruits in Saudi Arabian markets. Egyptian Journal of Aquatic Research 2012; 38(1): 31-7. doi: 10.1016/j.ejar.2012.08.002.
45. Liaghati T, Preda M, Cox M. Heavy metal distribution and controlling factors within coastal plain sediments, Bells Creek catchment, southeast Queensland, Australia. Environ Int 2004; 29(7): 935-48. doi: 10.1016/S0160-4120(03)00060-6.
46. Sharma RK, Agrawal M, Marshall FM. Atmospheric deposition of heavy metals (Cu, Zn, Cd and Pb) in Varanasi city, India. Environ Monit Assess 2008; 142(1-3): 269-78. doi: 10.1007/s10661-007-9924-7.
47. Waheed H, Ilyas N, Iqbal Raja N, Mahmood T, Ali Z. Heavy metal phyto-accumulation in leafy vegetables irrigated with municipal wastewater and human health risk repercussions. Int J Phytoremediation 2019; 21(2): 170-9. doi: 10.1080/15226514.2018.1540547.
48. Yu L, Yan-Bin W, Xin G, Yi-Bing C, Gang W. Risk assessment of heavy metals in soils and vegetables around non-ferrous metals mining and smelting sites, Baiyin, China. J Environ Sci 2006; 18(6): 1124-34. doi: 10.1016/S1001-0742(06)60050-8.
49. Amin NU, Hussain A, Alamzeb S, Begum S. Accumulation of heavy metals in edible parts of vegetables irrigated with waste water and their daily intake to adults and children, District Mardan, Pakistan. Food Chem 2013; 136(3-4): 1515-23. doi: 10.1016/j.foodchem.2012.09.058.
50. Alloway BJ. Heavy metals in soils. Dordrecht, Netherlands: Springer; 2013. doi: 10.1007/978-94-007-4470-7.
51. Rattan RK, Datta SP, Chhonkar PK, Suribabu K, Singh AK. Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater—a case study. Agric Ecosyst Environ 2005; 109(3-4): 310-22. doi: 10.1016/j.agee.2005.02.025.
52. Bigdeli M, Seilsepour M. Investigation of metals accumulation in some vegetables irrigated with waste water in Shahre Rey-Iran and toxicological implications. Am Eurasian J Agric Environ Sci 2008; 4(1): 86-92.
53. Gupta S, Satpati S, Nayek S, Garai D. Effect of wastewater irrigation on vegetables in relation to bioaccumulation of heavy metals and biochemical changes. Environ Monit Assess 2010; 165(1-4): 169-77. doi: 10.1007/s10661-009-0936-3.
54. Påhlsson AM. Toxicity of heavy metals (Zn, Cu, Cd, Pb) to vascular plants. Water Air Soil Pollut 1989; 47: 287-319. doi: 10.1007/BF00279329.
55. Barceloux DG. Nickel. J Toxicol Clin Toxicol 1999; 37(2): 239-58. doi: 10.1081/clt-100102423.
56. World Health Organization. Guidelines for drinking-water quality. (cited 2020 Oct 12) Available from: https://apps.who.int/iris/bitstream/handle/10665/63844/WHO_EOS_98.1.pdf?sequence=1&isAllowed=y.
57. Hassan MU, Chattha MU, Khan I, Chattha MB, Aamer M, Nawaz M, et al. Nickel toxicity in plants: reasons, toxic effects, tolerance mechanisms, and remediation possibilities—a review. Environ Sci Pollut Res Int 2019; 26(13): 12673-88. doi: 10.1007/s11356-019-04892-x.
58. Kushwaha A, Hans N, Kumar S, Rani R. A critical review on speciation, mobilization and toxicity of lead in soil-microbe-plant system and bioremediation strategies. Ecotoxicol Environ Saf 2018; 147: 1035-45. doi: 10.1016/j.ecoenv.2017.09.049.
59. Bahmanyar MA. Cadmium, nickel, chromium, and lead levels in soils and vegetables under long-term irrigation with industrial wastewater. Commun Soil Sci Plant Anal 2008; 39(13-14): 2068-79. doi: 10.1080/00103620802135013.
60. Park D, Lim SR, Yun YS, Park JM. Reliable evidences that the removal mechanism of hexavalent chromium by natural biomaterials is adsorption-coupled reduction. Chemosphere 2007; 70(2): 298-305. doi: 10.1016/j.chemosphere.2007.06.007.
61. Qadir M, Ghafoor A, Murtaza G, Murtaza G. Cadmium concentration in vegetables grown on urban soils irrigated with untreated municipal sewage. Environ Dev Sustain 2000; 2(1): 13-21. doi: 10.1023/A:1010061711331.
62. Jafarian-Dehkordi A, Alehashem M. Heavy metal contamination of vegetables in Isfahan, Iran. Res Pharm Sci 2013; 8(1): 51-8.
63. Sinha S, Gupta AK, Bhatt K, Pandey K, Rai UN, Singh KP. Distribution of metals in the edible plants grown at Jajmau, Kanpur (India) receiving treated tannery wastewater: Relation with physico-chemical properties of the soil. Environ Monit Assess 2006; 115(1-3): 1-22. doi: 10.1007/s10661-006-5036-z.
64. Sharma RK, Agrawal M, Marshall F. Heavy metal contamination in vegetables grown in wastewater irrigated areas of Varanasi, India. Bull Environ Contam Toxicol 2006; 77(2): 312-8. doi: 10.1007/s00128-006-1065-0.
65. Xiao W, Ye X, Zhang Q, Chen D, Hu J, Gao N. Evaluation of cadmium transfer from soil to leafy vegetables: Influencing factors, transfer models, and indication of soil threshold contents. Ecotoxicol Environ Saf 2018; 164: 355-62. doi: 10.1016/j.ecoenv.2018.08.041.
66. Akoto O, Addo D, Baidoo E, Agyapong EA, Apau J, Fei-Baffoe B. Heavy metal accumulation in untreated wastewater-irrigated soil and lettuce (Lactuca sativa). Environ Earth Sci 2015; 74(7): 6193-8. doi:10.1007/s12665-015-4640-z-z.
67. Loska K, Wiechuła D, Korus I. Metal contamination of farming soils affected by industry. Environ Int 2004; 30(2): 159-65. doi: 10.1016/S0160-4120(03)00157-0.
68. Meng J, Tao M, Wang L, Liu X, Xu J. Changes in heavy metal bioavailability and speciation from a Pb-Zn mining soil amended with biochars from co-pyrolysis of rice straw and swine manure. Sci Total Environ 2018; 633: 300-7. doi: 10.1016/j.scitotenv.2018.03.199.
69. Chaoua S, Boussaa S, El Gharmali A, Boumezzough A. Impact of irrigation with wastewater on accumulation of heavy metals in soil and crops in the region of Marrakech in Morocco. Saudi Society of Agricultural Sciences 2019; 18(4): 429-36. doi: 10.1016/j.jssas.2018.02.003.
70. Islam F, Zakir HM, Rahman A, Sharmin S. Impact of industrial wastewater irrigation on heavy metal deposition in farm soils of Bhaluka Area, Bangladesh. Journal of Geography, Environment and Earth Science International 2020; 24(3): 19-31. doi: 10.9734/JGEESI/2020/v24i330207.
71. Bhatia A, Singh S, Kumar A. Heavy metal contamination of soil, irrigation water and vegetables in peri-urban agricultural areas and markets of Delhi. Water Environ Res 2015; 87(11):2027-34. doi: 10.2175/106143015X14362865226833.
72. Rana S, Bag SK, Golder D, Mukherjee S, Pradhan C, Jana BB. Reclamation of municipal domestic wastewater by aquaponics of tomato plants. Ecological Engineering 2011; 37(6): 981-8. doi: 10.1016/j.ecoleng.2011.01.009.

73. Sahu RK, Katiyar S, Tiwari J, Kisku GC. Assessment of drain water receiving effluent from tanneries and its impact on soil and plants with particular emphasis on bioaccumulation of heavy metals. J Environ Biol 2007; 28(3): 685-90.
74. Atamaleki A, Yazdanbakhsh A, Fakhri Y, Mahdipour F, Khodakarim S, Mousavi Khaneghah A. The concentration of potentially toxic elements (PTEs) in the onion and tomato irrigated by wastewater: A systematic review; meta-analysis and health risk assessment. Food Res Int 2019; 125: 108518. doi: 10.1016/j.foodres.2019.108518.
75. Nayek S, Gupta S, Saha RN. Metal accumulation and its effects in relation to biochemical response of vegetables irrigated with metal contaminated water and wastewater. J Hazard Mater 2010; 178(1-3): 588-95. doi: 10.1016/j.jhazmat.2010.01.126.
76. Al-Lahham O, El Assi NM, Fayyad M. Translocation of heavy metals to tomato (Solanum lycopersicom L.) fruit irrigated with treated wastewater. Sci Hortic 2007; 113(3): 250-4. doi: 10.1016/j.scienta.2007.03.017.
77. Ghosh AK, Bhatt MA, Agrawal HP. Effect of long-term application of treated sewage water on heavy metal accumulation in vegetables grown in Northern India. Environ Monit Assess 2012; 184(2): 1025-36. doi: 10.1007/s10661-011-2018-6.
78. Zhao JY, Jin XL, Shen ZL, Guo HM. Accumulation and risk assessment of heavy metals in vegetables in Wastewater Irrigation Areas. Adv Mat Res 2011; 183-185: 527-31. doi: 10.4028/www.scientific.net/AMR.183-185.527.
79. Solís C, Andrade E, Mireles A, Reyes-Solís IE, García-Calderón N, Lagunas-Solar MC, et al. Distribution of heavy metals in plants cultivated with wastewater irrigated soils during different periods of time. Nucl Instrum Methods Phys Res B 2005; 241(1-4): 351-5. doi: 10.1016/j.nimb.2005.07.040.
80. Johansen TJ, Thomsen MG, Løes AK, Riley H. Root development in potato and carrot crops – influences of soil compaction. Acta Agric Scand B Soil Plant Sci 2015; 65(2): 182-92. doi: 10.1080/09064710.2014.977942.
81. Ahmad K, Ashfaq A, Khan ZI, Bashir H, Sohail M, Mehmood N. Metal accumulation in Raphanus sativus and Brassica rapa: an assessment of potential health risk for inhabitants in Punjab, Pakistan. Environ Sci Pollut Res Int 2018; 25(17): 16676-85. doi: 10.1007/s11356-018-1868-7.
82. Atamaleki A, Yazdanbakhsh A, Fakhri Y, Salem A, Ghorbanian M, Mousavi Khaneghah A. A Systematic review and meta-analysis to investigate the correlation vegetable irrigation with wastewater and concentration of potentially toxic elements (PTES): a Case Study of Spinach (Spinacia oleracea) and Radish (Raphanus raphanistrum subsp. sativus). Biol Trace Elem Res 2021; 199(2):792-9. doi: 10.1007/s12011-020-02181-0.
83. Zhu Y, Yu H, Wang J, Fang W, Yuan J, Yang Z. Heavy metal accumulations of 24 asparagus bean cultivars grown in soil contaminated with Cd alone and with multiple metals (Cd, Pb, and Zn). J Agric Food Chem 2007; 55(3): 1045-52. doi: 10.1021/jf062971p.
84. Hussain A, Bukhari SM, Andleeb S, Rehman KU, Maqsood I, Javid A, et al. Heavy metal levels in vegetables and soil cultivated with industrial wastewater from different sites of Chunian and Jamber, District, Kasur. Journal of Applied Sciences and Environmental Management 2020; 24(2): 271-7. doi: 10.4314/jasem.v24i2.13.
85. Liu P, Zhao HJ, Wang LI, Liu ZH, Wei JL, Wang YQ, et al. Analysis of heavy metal sources for vegetable soils from Shandong Province, China. Agricultural Sciences in China 2011; 10(1): 109-19. doi: 10.1016/S1671-2927(11)60313-1.
86. Mahmood A, Malik RN. Human health risk assessment of heavy metals via consumption of contaminated vegetables collected from different irrigation sources in Lahore, Pakistan. Arabian Journal of Chemistry 2014; 7(1): 91-9. doi: 10.1016/j.arabjc.2013.07.002.
87. Kim HK, Jang TI, Kim SM, Park SW. Impact of domestic wastewater irrigation on heavy metal contamination in soil and vegetables. Environmental Earth Sciences 2015; 73(5): 2377-83. doi:10.1007/s12665-014-3581-2.
88. Alemu T, Mekonnen A, Leta S. Integrated tannery wastewater treatment for effluent reuse for irrigation: Encouraging water efficiency and sustainable development in developing countries. J Water Process Eng 2019; 30: 100514. doi: 10.1016/J.JWPE.2017.10.014.
89. Jan FA, Ishaq M, Khan S, Ihsanullah I, Ahmad I, Shakirullah M. A comparative study of human health risks via consumption of food crops grown on wastewater irrigated soil (Peshawar) and relatively clean water irrigated soil (lower Dir). J Hazard Mater 2010; 179(1-3): 612-21. doi: 10.1016/j.jhazmat.2010.03.047.
90. Schümann K. Safety Aspects of Iron in Food. Ann Nutr Metab 2001; 45(3): 91-101. doi: 10.1159/000046713.