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Human health risk assessment: heavy metal contamination of vegetables in Bahawalpur, Pakistan

Hafiza Hira Iqbal[1], Raffia Taseer[2], Seham Anwar[1], Mehvish Mumtaz[1], Abdul Qadir[1], Naeem Shahid[3]*

1. *College of Earth and Environmental Sciences, University of the Punjab, Lahore, Pakistan.*
2. *Department of Life sciences, The Islamia University of Bahawalpur.*
3. *Department of Environmental Sciences, COMSATS Institute of Information Technology, Vehari, Pakistan.*

Abstract

Dietary exposure of toxic metals is a vital concern for human health through vegetable consumption, especially in developing countries. Aim of the current study was to determine the health risk related to vegetables contamination of heavy metals by irrigated with sewage and turbine water. Irrigation water sources, soils and vegetables were analyzed for selected metals viz: Pb, Cd, Cr and Ni. Heavy metals in water samples were within the permissible limits except Cd in sewage water. Concentration of heavy metals in soil and vegetables irrigated with turbine water were lower than the safe limits. In case of vegetables irrigated with sewage water, Cd was higher in soil while Pb, Cd and Cr were higher in most of the vegetables. Daily intake of metals, health risk index and Bio-concentration factor was also determined. Health risk index values for Cd, Pb and Ni were exceeded the permissible limits (European Union, 2002). Bio-concentration factor (BCF) found to be maximum (16.4 mg/kg) in *Coriandrum sativum* cultivated with sewage water. *Raphanus caudatus*, *Coriandrum sativum*, *Daucus carota*, *Allium sativum* and *Solanum tuberosum* showed Health Risk Index of Cd > 1 in adults and children. *Allium sativum* also showed HRI of Pb > 1 in children. We conclude that the quality of vegetables irrigated with sewage water is poor and not fit for human health, evident from the high concentration of Pb, Cd and Cr. Urgent measures are required to prevent consumption and production vegetables irrigated with of sewage water in the study area.

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***Correspondence:**

Naeem Shahid
COMSATS Institute of Information Technology, Vehari, Pakistan
naeemshahid@ciitvehari.edu.pk
Phone: +92 3450111117

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Introduction

Since the age of industrial revolution, food safety has become one of the forthcoming challenges worldwide. Recently, increasing food demands in developing countries is pushing farmers to adopt low cost methodologies but with highest crop yield interests. Among them, irrigation of wastewater has gained tremendous attention. According to an estimate, 10% of the total world's population depends on food irrigated with wastewater (Corcoran, 2010). Raschid-Sally and Jayakody (2009) reported that 200 million farmers in the world use different forms of wastewater (treated, partially treated, untreated) in agricultural irrigation. Although the wastewater possess considerable amount of valuable plant nutrients that can reduce the need for artificial fertilizers; however, it may also poses environmental and health risks due to the presence of wide array of contaminants, e.g., pathogens, synthetic chemicals, and heavy metals such as cadmium, chromium, nickel and lead, etc. Among them, heavy metals are of great environmental concerns (Shahid et al., 2015a, 2013) as many of them are extremely persistent in the environment and, hence their ignorance in handling can lead to bioaccumulation and/or bio magnification in the food web. These heavy metals are not only harmful for plants but can also cause significant damages to animal kingdom when consumed by secondary and tertiary consumers.

Heavy metals enter into plants mainly via roots from the soil and travel along the food chain (Shahid et al., 2015b). Once entered in the bodies of living organisms, heavy metals can pose serious threats due to their non-biodegradable nature, long biological half-lives and their potential to accumulate in different body parts, e.g., fatty tissues (Shahid et al., 2015a). Moreover, most of the heavy metals are extremely toxic because of their solubility in water. Even low concentrations of heavy metals have damaging effects on human and animal populations (Uzu et al., 2011a; Uzu et al., 2011b) by causing cardiovascular, kidney, nervous, mental impairment and bone diseases (Yargholi et al., 2008). It has been reported that the prolonged consumption of heavy metals contaminated food can impair liver, kidney, cardiovascular, nervous and/or cancers (Järup, 2003). For instance, acute and chronic exposure of As can cause dermal , respiratory, cardiovascular, gastrointestinal, hematological, hepatic, renal, neurological, developmental, reproductive, immunological, genotoxic, mutagenic and carcinogenic effect e.g. liver cancer (Lin et al., 2013). Another study reports that the dietary intake of Cd can increase the risk of postmenopausal breast cancer (Itoh et al., 2014). Internationally, several research projects have been conducted to evaluate the benefits and potential risk associated with wastewater irrigation as well as their possible remediation.

The current study was designed to assess the level of heavy metals in irrigation water, soil, vegetables and their transfer factors, and human health risk assessment. Unfortunately the comprehensive survey of heavy metals in market vegetables and their assessment of health risk to general population are lacking (Jamali et al., 2009; Jan et al., 2010a; Khan et al., 2010; Mahmood and Malik, 2014). To best of our knowledge, this is first study in the region reporting toxicity due to heavy metals in the vegetables along with the risk assessment for human health.

Materials and Methods

Sampling strategies and Locations

Two sites of Bahawalpur district, being irrigated with sewage water, were selected for sampling of commonly used vegetables *viz*: Fenugreek (*Trigonella foenum-graecum*), Radish (*Raphanus caudatus*), Coriander (*Coriandrum sativum*), Brinjal (*Solanum melongena*), Potato (*Solanum tuberosum*), Turnip (*Brassica rapa* var.), Red cabbage (*Brassica oleracea* capitata), Wild cabbage (*Brassica oleracea* var.), Carrot (Daucus carota), Radish (*Raphanus caudatus*), Spinach (*Spinacia oleracea*), onion (*Allium cepa*), and Garlic (*Allium sativum*). Vegetables were grown using turbine water in "Baghdad-ul-jaded campus, Islamia University Bahawalpur" for comparative study.

Soil Sampling

From each locality, a total of 10 soil samples were collected, dried and pass through 60 mm mesh sieve (Yu et al., 2006). Physical properties of soil such as pH and Soil organic matter was determined as described earlier (Ryan et al., 2007). Available phosphorus and potassium was also determined (Bao, 2000). Soluble and exchangeable potassium was checked with spectrophotometry. Exchangeable K + was calculated by using equation given as:

Exch. K^+= (CH_3COONH_4 – K^+ - soluble K^+) expressed in c mole kg^{-1}

For the determination of heavy metals, one gram of soil was digested with 5ml of aqua regia for 1 hour at 120°C, followed by for 3-4 hours heating at 160°C. By using Foss digestion system, per chloric acid was used for continuous digestion until soil became grey in color.

Water Sampling

Sewage water and turbine water was collected in pre-wash polystyrene bottles. Pre-washing of polyethylene bottles was done as described earlier (Chary et al., 2008); followed by preservation at 4° C. For digestion of water, 10 ml concentrated HNO_3 was added to 50ml of water sample. Blank was also prepared as same procedure without addition of sample (Yu et al., 2006).

Vegetables Sampling

The vegetables, mentioned earlier, were washed with distilled water in laboratory to remove dust and airborne particles. The aerial parts and roots of vegetables were separated and dried at 60° C followed by their conversion into powder (Jamali et al., 2009), and finally passed through a sieve of 40mm mesh size. Digestion of vegetables was performed by using nitric acid at 160°C. Heavy metals in soil vegetables and water samples were analyzed by using atomic absorption spectrophotometer. Standards were run to check the performance of atomic absorption spectrophotometer. Triplicate readings were noted to avoid error in results.

Bio-Concentration Factor (BCF)

Bio-concentration factor was determined by concentration of heavy metals in edible parts of vegetables with concentration present in soil. Following formula was used to calculate BCF,

$$\mathrm{BCF} = \frac{\mathrm{C}_{\text{Edible part}}}{\mathrm{C}_{\text{Soil}}}$$

Daily Intake of Metals (DIM)

Toxic heavy metals enter the human body through different pathways. It may be oral intake (by consuming food), inhalation, and/ or dermal contact (Shahid et al., 2015c). Following formula was used to calculate the daily intake of metals in human body.

$$\mathrm{DIM} = \frac{\mathrm{M} \times \mathrm{K} \times \mathrm{I}}{W}$$

where M represents concentration of heavy metals in plant tissue (mg/kg), I represents the amount of intake of vegetables on daily basis, W is average body weight and K is conversion factor. To convert fresh weight of vegetables into dry weight, 0.085 was used as conversion factor (Rattan et al., 2005). The average child and adult body weight was considered as 32.7kg and 55.9kg respectively; whereas, average intake of vegetables in children and adult was considered as 0.232 and 0.345kg /person/day (Chen et al., 2005).

Health Risks Assessment

In present study, health risk index was calculated by using metals concentration in vegetables irrigated by sewage and turbine water. Health risk index values depend on the daily intake of metals and oral reference dose (Rf_D). Health risk index was calculated by using following equation described by Jan et al. (2010b),

$$\mathrm{HRI} = \frac{\mathrm{DIM}}{\mathrm{Rf_D}}$$

Values of oral reference dose for selected metals were used by given US-EPA IRIS, 2006.

Statistical Analysis

Statistical analysis was performed by using SPSS. One way ANOVA was applied to determine the significant difference in concentration of metals present in vegetables irrigated with sewage and turbine water.

Results

Heavy Metals Concentration in Water and Soil

Heavy metals concentrations in water and soil samples are presented in Table 1. In turbine water samples, all of the heavy metals concentrations were lower than the maximum residual concentration (MRC) devised by Food and Agriculture Organization (FAO, 1985); however, in sewage water, Cd, Cr, and Ni were found to be high than the respective MRC values (Table 1a). Similarly, concentrations of heavy metals in turbine water irrigated (TWI) soil were lower than the MRC values whereas, in sewage water irrigated (SWI) soil, only Cd breached the upper limit (Table 1b). Although both of the soils types showed lower level of contamination compared to the MRC values, higher level of contamination was observed in soils irrigated with sewage water compared to the soil irrigated with turbine water.

Heavy Metals Concentration in Vegetables

The concentration of heavy metals in vegetables irrigated with turbine water was ranged from 0.04-0.08, 0.02-0.08, 0.03-0.42, 0.02-0.08 mg kg-1 for Pb, Cd, Cr, Ni respectively (Table 2). All of them were below the recommended maximum levels for vegetables (Commission, 2001). But the vegetables irrigated with wastewater showed higher level of concentrations ranging from 0.43-7.2, 0.05-.4.1, 0.34-4.6, 0.009-5.04 for Pb, Cd, Cr and Ni respectively. The trend observed was as follows (Table 3).

Pb > Ni > Cr >Cd

All of the vegetables sowed higher concentration of Pb, compared to the slandered value 2.0 mg kg^{-1} (MRC). In case of Cd, seven out of 10 vegetables *viz*: *Brassica rapa* var., *Brassica oleracea* capitat., *Raphanus caudatus*, *Coriandrum sativum*, *Spinacia oleracea*, *Daucus carota*, *Allium sativum*, *Trigonella foenum-graecum* and *Solanum tuberosum* showed higher concentration being deviated from the permissible limits. Levels of Cr concentrations were higher than the permissible limit in *Solanum tuberosum*, *Daucus carota*, *Allium sativum*, *Raphanus caudatus* and *Coriandrum sativum* while the concentration of Ni was within the permissible level in all of the vegetables.

Bio-concentration Factor (BCF)

Bio-concentration factors of metals in vegetables from studied area are summarized in Table 4. In case of vegetables irrigated with turbine water, BCF values were less than 1 for Pb and Ni whereas greater than 1 for Cd and Cr. In vegetables irrigated with sewage water, highest BCF value was observed for cadmium that was showed by *Spinacia oleracea* while the lowest value was showed by *Allium cepa*. Bio-concentration factors were in the range of 0.14-0.07, 0.66-2.66, 0.17-2.50 and 0.23-0.93 for Pb, Cd, Cr and Ni respectively.

BCF values for vegetables irrigated with sewage water were greater than 1 in most cases. Highest value of BCF for cadmium was 16.4 in *Coriandrum sativum*. Range of BCF for Pb, Cd, Cr and Ni were 0.20-3.51, 0.10-16.4, 0.18-2.54 and 0.01-6.00 respectively.

Daily Intake and Health Risk Index

The DIM through consuming vegetables was calculated for adults and children separately. Results of DIM are summarized in Appendix 01 and 02. Health risk index was calculated for children and adults on the basis of DIM values and given in Appendix 03 and 04. HRI of vegetables irrigated with turbine water for adults and children were lower than 01 that shows no risk.

Health risk index (HRI) of vegetables irrigated with sewage water for adults and children were greater than 1 in 50 % vegetables in case of Cd. *Raphanus caudatus*, *Coriandrum sativum*, *Daucus carota*, *Allium sativum* and *Solanum tuberosum* showed higher HRI values 1.6, 3.2735, 1.6026, 2.1508 and 1.7049 respectively for adults. For children, HRI of Cd via these vegetables was 1.83, 3.76, 1.84, 2.47 and 1.95 respectively. It was observed that the health risk for children was higher than the adults. In addition to Cd, Pb was statistically high in *Allium sativum* to cause health risk for adults with HRI value of 1.08.

Discussion

In pre-urban areas of developing countries, irrigation of vegetables with sewage water is a normal practice (Singh and Garg, 2006). As a result of sewage water irrigation, accumulation of heavy metals in vegetables may be increased (Devkota and Schmidt, 2000; Frost and Ketchum, 2000). Consumption of such contaminated vegetables can cause human health risks. In the present study, turbine water showed lower concentrations of metals and were safe according to MRC values but sewage water showed higher concentration of Cd exceeding the MRC limits.

Concentration of heavy metals in soil irrigated with turbine water was within permissible limits. Sewage irrigated soil also showed lower metal concentrations except Cd with deviating permissible level. Higher concentration of these heavy metals is the outcome

Table 1: Heavy metals in soil (mg kg-1) and water (mgL-1) samples.

Metals	Water Samples			Soil samples		
	Turbine Water	Sewage Water	MRC^{b}	TWI soil	SWI Soil	MRC^{b}
Lead	0.260	0.920	5.00	0.560	2.050	13.0
Cadmium	0.004	0.730	0.01	0.030	0.380	0.31
Chromium	0.090	0.120	0.10	0.170	1.810	8.00
Nickel	0.020	2.030	0.20	0.086	0.840	8.10

b = Maximum residual concentration (FAO, 1985)

Table 2: Heavy metals (mg kg^{-1}) in vegetables irrigated with turbine water.

Vegetables	Pb	Cd	Cr	Ni
Brassica oleracea var.	0.07	0.04	0.42	0.06
Brassica rapa var.	0.06	0.02	0.05	0.05
Brassica oleracea capitata	0.05	0.04	0.06	0.05
Raphanus caudatus	0.06	0.05	0.03	0.08
Coriandrum sativum	0.06	0.06	0.05	0.02
Allium cepa	0.04	0.02	0.04	0.05
Spinacia oleracea	0.06	0.08	0.05	0.04
Daucus carota	0.08	0.05	0.03	0.08
Allium sativums	0.08	0.07	0.07	0.03
Trigonella foenum-graecum	0.04	0.07	0.04	0.04
Solanum melongena	0.05	0.03	0.06	0.05
Solanum tuberosum	0.07	0.05	0.08	0.03
Permissible limits	**0.3**	**0.1**	**2.3**	**66.9**

industrial pollution, road runoff, food, wear of tires, hospital waste, atmospheric deposition and burning of fuels (Sörme and Lagerkvist, 2002). Bio-availability of metals in soil irrigated with contaminated water was higher as compared to soil irrigated with uncontaminated water as observed by Mahmood and Malik (2014). Previous studies conducted in Lahore (Pakistan) also reported higher concentration of metals in soil irrigated with waste water (Jan et al., 2010a; Jan et al., 2010b; Younas et al., 1998).

The higher concentration of metals in vegetables grown in sewage water was might be due to continuous irrigation with sewage water (Jan et al., 2010a). Resultantly, concentrations of Pb, Cd and Cr in sewage irrigated vegetables exceeded the permissible limits; however, only Ni concentration was according to the standards because its permissible value is very high as it is required by human body as trace element (Zhang and Gladyshev, 2010). Besides, high concentration of Pb could be due to increase in mobile metal fraction of lead (Siebe, 1995).With higher metal fraction, uptake and accumulation of metal in vegetables increased (Agrawal, 1999).

In human body, lead causes neurological, hematological and physiological disorders (Sörme and Lagerkvist, 2002). Accumulation of cadmium in human body leads to certain disorder including cardiovascular diseases, liver and nervous system (Tataruch and Kierdorf, 2003). Higher concentration of Chromium can cause heart problems, urogenital disorders, and carcinogenic effects heart problems, urogenital disorders, and carcinogenic effects (Costa and Klein, 2006). It was described in previous studies that leafy vegetables have higher concentration of metals as compared to bulbs and tuber vegetables due to smoke emit from industries present in vicinity of vegetables (Mahmood and Malik, 2014). In present study highest concentration was found in *Solanum tuberosum* which is tuber vegetable, the reason of this high concentration may be due to accumulation of metals through soil not from the atmosphere. Previous studies conducted in Pakistan reported higher concentration of metals in contaminated treated vegetables as compare to uncontaminated treated vegetables (Jan et al., 2010a; Khan et al., 2010).

In human, transfer factor of metals or bio-concentration factor is a key module to determine the level of exposure through food chain. In the following vegetables, i.e., *Allium sativum*, *Solanum tuberosum* and *Daucus carota*; BCF values was higher which were in line with previous study conducted in Lahore Pakistan (Mahmood and Malik, 2014). Higher transpiration rate to sustain the moisture level in plants in leafy vegetables may be due to high uptake of metals (Lato et al., 2012; Tani and Barrington, 2005). Nevertheless, the BCF values were higher for some vegetables compared to the previous studies (Jan et al., 2010b; Khan et al., 2010; Mahmood and Malik, 2014).

Health risk index (HRI) of vegetables irrigated with sewage water

Table 3: Heavy metals in vegetables irrigated with sewage water (mg kg^{-1}).

Vegetables	Pb	Cd	Cr	Ni
Brassica oleracea var.	1.6	0.08	0.42	0.03
Brassica rapa var.	2.8	0.47	1.00	0.09
Brassica oleracea capitat.	0.4	0.39	1.52	0.67
Raphanus caudatus	4.9	3.05	2.74	5.02
Coriandrum sativum	6.1	6.24	2.80	1.80
Allium cepa	1.0	0.04	0.34	0.07
Spinacia oleracea	1.9	0.14	0.77	0.10
Daucus carota	4.9	3.05	2.74	5.02
Allium sativum	7.2	4.10	4.60	4.33
Trigonella foenum-graecum	1.1	0.96	0.79	0.009
Solanum melongena	1.3	0.05	0.89	0.03
Solanum tuberosum	5.1	3.25	2.90	5.04
Permissible limits	**0.3**	**0.1**	**2.3**	**66.9**

Table 4: Bio-concentration factor for vegetables irrigated with uncontaminated and contaminated water.

Vegetables	Pb [a]	Cd [a]	Cr [a]	Ni [a]	Pb [b]	Cd [b]	Cr [b]	Ni [b]
Brassica oleracea var.	0.12	1.33	2.50	0.69	0.80	0.21	0.23	0.04
Brassica rapa var.	0.10	0.66	0.29	0.58	1.40	1.23	0.55	0.10
Brassica oleracea capitata	0.08	1.33	0.35	0.58	0.20	1.02	0.83	0.79
Raphanus caudatus	0.10	1.66	0.17	0.93	2.42	8.02	1.51	5.97
Coriandrum sativum	0.10	2.00	0.29	0.23	2.97	16.4	1.54	2.14
Allium cepa	0.07	0.66	0.26	0.58	0.50	0.10	0.18	0.08
Spinacia oleracea	0.10	2.66	0.29	0.52	0.92	0.38	0.42	0.12
Daucus carota	0.14	1.66	0.17	0.93	2.39	8.03	1.51	5.97
Allium sativum	0.14	2.33	0.41	0.34	3.51	10.7	2.54	5.15
Trigonella foenum-graecum	0.07	2.33	0.23	0.46	0.52	2.52	0.43	0.01
Solanum melongena	0.08	1.00	0.35	0.58	0.63	0.13	0.49	0.03
Solanum tuberosum	0.12	1.66	0.47	0.34	2.51	8.55	1.60	6.00

a = Vegetables irrigated with uncontaminated water
b = Vegetables irrigated with contaminated water

for adults and children were higher than 1 in most cases of Cd. It was observed that the health risk for children was higher than the adults which could be due to body weight. In addition to Cd, Pb was high in *Allium sativum* which may cause health risk for adults with HRI value of 1.09. All selected vegetables grown in turbine water almost safe for consumption.

Conclusions

Continuous irrigation with sewage or contaminated water may lead to the accumulation of heavy metals in food crops as compared to irrigation with uncontaminated water. In a nutshell, the concentration of metals in vegetables irrigated with sewage water was higher as compare to turbine water irrigated vegetables. Enrichment of metals in contaminated vegetable was in following order,

Pb > Ni >Cr > Cd

The concentration of metals was higher in tuber vegetables such as *Allium sativum* in case of Pb, Cd , Cr and in *Solanum tuberosum* for Ni. Some leafy vegetable such as *Coriandrum sativum* showed higher concentration of Pb. Health risk index values illustrate that vegetables irrigated with turbine water do not imparts any health

for Ni. Some leafy vegetable such as *Coriandrum sativum* showed higher concentration of Pb. Health risk index values illustrate that vegetables irrigated with turbine water do not imparts any health risk theoretically. HRI values of Cd from vegetables viz: *Raphanus cauhordatus*, *Coriandrum sativum*, *Daucus carota*, *Allium sativum* and *Solanum tuberosum* were higher than 1 and hence may cause potential human health risk. It is concluded that the vegetables grown by sewage irrigation are not safe for food. Furthermore, it is suggested that the usage of sewage water should not be used for irrigation.

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Conflict of Interest

The authors declare no conflict of interest.

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Appendix 1: DIM values for adults and children in uncontaminated vegetables

Vegetables	Adults				Children			
	Pb	Cd	Cr	Ni	Pb	Cd	Cr	Ni
Brassica oleracea var.	0.000037	0.000021	0.00022	0.000031	0.000000022	0.000000013	0.000000135	0.000000019
Brassica rapa var.	0.000031	0.000010	0.00003	0.000026	0.000000019	0.000000006	0.000000016	0.000000016
Brassica oleracea capitat	0.000026	0.000021	0.00003	0.000026	0.000000016	0.000000013	0.000000019	0.000000016
Raphanus caudatus	0.000031	0.000026	0.00002	0.000042	0.000000019	0.000000016	0.000000010	0.000000025
Coriandrum sativum	0.000031	0.000031	0.00003	0.000010	0.000000019	0.000000019	0.000000016	0.000000006
Allium cepa	0.000021	0.000010	0.00002	0.000026	0.000000013	0.000000006	0.000000014	0.000000016
Spinacia oleracea	0.000031	0.000042	0.00003	0.000024	0.000000019	0.000000025	0.000000016	0.000000014
Daucus carota	0.000042	0.000026	0.00002	0.000042	0.000000025	0.000000016	0.000000010	0.000000025
Allium sativum	0.000042	0.000037	0.00004	0.000016	0.000000025	0.000000022	0.000000022	0.000000010
Trigonella foenum-graecum	0.000023	0.000037	0.00002	0.000021	0.000000014	0.000000022	0.000000013	0.000000013
Solanum melongena	0.000026	0.000016	0.00003	0.000026	0.000000016	0.000000010	0.000000019	0.000000016
Solanum tuberosum	0.000037	0.000026	0.00004	0.000016	0.000000022	0.000000016	0.000000025	0.000000010

Appendix 2: DIM values for adults and children in contaminated vegetables.

Vegetables	Adults				Children			
	Pb	Cd	Cr	Ni	Pb	Cd	Cr	Ni
Brassica oleracea var.	0.00087	0.000042	0.000223	0.000020	0.00100	0.000048	0.00026	0.000023
Brassica rapa var.	0.00152	0.000247	0.000528	0.000047	0.00174	0.000283	0.00061	0.000054
Brassica oleracea capitat.	0.00023	0.000205	0.000797	0.000351	0.00026	0.000235	0.00092	0.000404
Raphanus caudatus	0.00261	0.001600	0.001437	0.002633	0.00300	0.001839	0.00165	0.003027
Coriandrum sativum	0.00320	0.003273	0.001469	0.000944	0.00368	0.003763	0.00169	0.001086
Allium cepa	0.00055	0.000021	0.000178	0.000037	0.00063	0.000024	0.00021	0.000042
Spinacia oleracea	0.00100	0.000077	0.000404	0.000053	0.00115	0.000089	0.00046	0.000061
Daucus carota	0.00257	0.001603	0.001437	0.002633	0.00295	0.001842	0.00165	0.003027
Allium sativum	0.00378	0.002151	0.002413	0.002272	0.00434	0.002473	0.00277	0.002611
Trigonella foenum-graecum	0.00057	0.000504	0.000414	0.000005	0.00065	0.000579	0.00048	0.000005
Solanum melongena	0.00068	0.000026	0.000467	0.000016	0.00078	0.000030	0.00054	0.000018
Solanum tuberosum	0.00271	0.001705	0.001521	0.002644	0.00311	0.001960	0.00175	0.003039

Appendix 3: Health risk index for adults and children in uncontaminated vegetables.

Vegetables	Adults				Children			
	Pb	Cd	Cr	Ni	Pb	Cd	Cr	Ni
Brassica oleracea var.	0.0092	0.021	0.00015	0.0016	0.0000055	0.0000127	0.000000090	0.00000095
Brassica rapa var.	0.0079	0.010	0.00002	0.0013	0.0000047	0.0000063	0.000000011	0.00000079
Brassica oleracea capitat	0.0066	0.021	0.00002	0.0013	0.0000040	0.0000127	0.000000013	0.00000079
Raphanus caudatus	0.0079	0.026	0.00001	0.0021	0.0000047	0.0000158	0.000000006	0.00000127
Coriandrum sativum	0.0079	0.031	0.00002	0.0005	0.0000047	0.0000190	0.000000011	0.00000032
Allium cepa	0.0052	0.010	0.00002	0.0013	0.0000032	0.0000063	0.000000010	0.00000079
Spinacia oleracea	0.0079	0.042	0.00002	0.0012	0.0000047	0.0000253	0.000000011	0.00000071
Daucus carota	0.0105	0.026	0.00001	0.0021	0.0000063	0.0000158	0.000000006	0.00000127
Allium sativum	0.0105	0.037	0.00002	0.0008	0.0000063	0.0000221	0.000000015	0.00000047
Trigonella foenum-graecum	0.0058	0.037	0.00001	0.0010	0.0000035	0.0000221	0.000000008	0.00000063
Solanum melongena	0.0066	0.016	0.00002	0.0013	0.0000040	0.0000095	0.000000013	0.00000079
Solanum tuberosum	0.0092	0.026	0.00003	0.0008	0.0000055	0.0000158	0.000000017	0.00000047

Appendix 4: Health risk index for adults and children in contaminated vegetables

Vegetables	**Adults**				**Children**			
	Pb	Cd	Cr	Ni	Pb	Cd	Cr	Ni
Brassica oleracea var.	0.2164	0.0420	0.0001	0.0010	0.2488	0.0482	0.0002	0.0011
Brassica rapa var.	0.3790	0.2466	0.0004	0.0024	0.4357	0.2834	0.0004	0.0027
Brassica oleracea capitat.	0.0564	0.2046	0.0005	0.0176	0.0648	0.2352	0.0006	0.0202
Raphanus caudatus	0.6531	1.6000	0.0010	0.1317	0.7508	1.8393	0.0011	0.1514
Coriandrum sativum	0.8000	3.2735	0.0010	0.0472	0.9197	3.7631	0.0011	0.0543
Allium cepa	0.1364	0.0210	0.0001	0.0018	0.1568	0.0241	0.0001	0.0021
Spinacia oleracea	0.2492	0.0771	0.0003	0.0026	0.2865	0.0886	0.0003	0.0030
Daucus carota	0.6426	1.6026	0.0010	0.1317	0.7387	1.8423	0.0011	0.1514
Allium sativum	0.9443	2.1508	0.0016	0.1136	1.0855	2.4725	0.0018	0.1306
Trigonella foenum-graecum	0.1416	0.5036	0.0003	0.0002	0.1628	0.5789	0.0003	0.0003
Solanum melongena	0.1705	0.0262	0.0003	0.0008	0.1960	0.0302	0.0004	0.0009
Solanum tuberosum	0.6767	1.7049	0.0010	0.1322	0.7779	1.9599	0.0012	0.1520