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ORIGINAL ARTICLE

Experimental study on accumulation of heavy metals in vegetables irrigated with treated wastewater

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Abstract
Treated sewage and industrial effluents are used for irrigation of crops in developing countries which may contain heavy metals in high concentration. It can contaminate soil and accumulate in vegetables. In the present study, the vegetables were irrigated with treated wastewater brought from a nearby full-scale sewage treatment plant. The concentration levels of the Cd, Co, Cu, Mn and Zn in the leaves were found below toxic limits as prescribed in the literature. Daily intake metals values suggest that the consumption of plants grown in treated wastewater and tap water is nearly free of risks, as the dietary daily intake limits of Cu, Fe, Zn, and Mn in adults can range from 1.2 to 3 mg, 10 to 50 mg, 5 to 22 mg and 2 to 20 mg, respectively. The enrichment factor for the treated wastewater irrigated soil was found to decrease in order of Zn > Ni > Pb > Cr > Cu > Co > Mn > Cd.

Keywords Heavy metals · Daily metal intake · Enrichment factor · Wastewater

Introduction

Due to rapid increase in population in urban area, high volume of waste water is generated every day. In many developing countries including India, farmers have initiated irrigation of their crops with industrial effluents due to non-availability of any other source. However, effluent from municipal sewage treatment plants often contains high levels of macro- and micro-nutrients along with heavy metals.

Contamination of soil with heavy metals in agricultural fields cultivated by industrial effluents has emerged as a new threat. The percolation of these pollutants through the soil causes degradation of soil. Soil pollution is caused mainly by spreading of pollutants on surface of soil. Surface pollutants come from many sources like waste (solid or liquid) disposal practices, spills, modern agricultural practices and percolation of surface pollutants through unsaturated soil (Patil et al. 2014).

Large areas of agricultural land are contaminated by heavy metals that mainly originate from mining activities, industrial discharges or the application of sewage sludge. Metals may exist in one of four forms in the soil: mineral, organic, sorbed (bound to soil) or dissolved. Sorbed metals represent the third largest pool and are generally very tightly bound to soil surface. Although mineral, organic and sorbed metals are not immediately absorbed by plants, they can slowly release metals into solution (Jones and Jacobsen 2009). The essential elements like Cr, Cu, Co, Fe, Mn, Mo, Ni, Se and Zn are required by organisms in trace amount and become toxic at higher levels. Non-essential elements including As, Sb, Cd, Pb, Hg, Sn and Ag are toxic and not required by organism (Mc Grath 2001). Most of the industrial effluents and wastes contain heavy metals in an amount sufficient enough to cause toxicity to crop plants (Naz et al. 2015).

The trace elements including Cu, Zn, Mn, Fe and B are essential micro-nutrients required for plant growth. These elements are also considered as heavy metals as they may be toxic to plants at high concentrations (Parveen et al. 2015). Wastewater treatment plant (WWTP) is a main concern for environmentalists, as it gives rise to environmental impacts

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due to its energy consumption, use of chemicals, emissions to the atmosphere and sludge production. Disposal of high amount of sludge generated from wastewater treatment plants is a big problem.

Agricultural land can be contaminated with heavy metals if it is irrigated with wastewater coming directly from urban areas or other polluted sources, constant application of fertilizers and agro-chemicals containing heavy metals. It has been shown that crops and vegetables cultivated in soil which is irrigated with water containing heavy metals may accumulate a greater quantity of heavy metals (Alrawiq et al. 2014). The ecological balance gets affected due to widespread contamination of soil. Most plants are unable to grow when chemistry of the soil changes in short period of time. In these conditions, fungi and bacteria found in the soil also begin to decline, creating an additional problem of soil erosion. Soils are able to accumulate heavy metals for many years without showing signs of their acute toxic effect. The purification capacity of soils is finite, as above a certain level, soils are no longer able to absorb these elements and become source of pollution themselves. Toxic elements are released from many sources into water and absorbed by cultivated crops and plants. Thereafter they are assimilated into vegetative, generative organs and also enter food chain. Sahito et al. (2016) assessed bioaccumulation of heavy metals in vegetables grown in soil amended with poultry waste as a fertilizer. A study conducted by Jamali et al. (2007) indicated increased danger of growing vegetables in soil irrigated and dressed with wastewater and sewage sludge. A typical range of metals in soil derived from normal and geochemically anomalous parent material in Britain is shown in Table 1.

Vegetables are considered to be an important component of human diet as they are rich sources of vitamins, minerals and fibers. However, the intake of the vegetables contaminated with heavy metals may pose a risk to human health (Parveen et al. 2015). Vegetables provide the human body with essential trace elements which are necessary for healthy life. Heavy metal pollution represents an important environmental problem due to its toxic effects and accumulation throughout the food chain.

Heavy metals may be absorbed and accumulate in edible and non-edible parts of vegetables in such a concentration that can cause adverse health effects in animals. Some metals present in vegetables are important biochemically and psychologically from health point of view. Heavy metals may also adversely affect growth of plants as they can influence biochemical processes such as photosynthesis and stomata opening.

Absorption and accumulation of metals in plant depend on many factors, such as pH, EC, clay content, organic matter content and physical and mechanical characteristics of soil. Plants take heavy metals from soil through different reactions, such as absorption, ionic exchange, redox reactions (El Zabalawy et al. 2015).

The study has been carried out by irrigating carrot, spinach and radish with different concentrations of treated sewage effluent in order to observe the effects on growth of plants and accumulation of heavy metals.

Materials and methods

In the present study, the vegetables were grown in premises of school of architecture, Gauatm Buddha University, Greater Noida, U.P., India. The soil was brought from village named Dankaur near the campus. Also, sample of treated sewage was brought for irrigation from 137 MLD sewage treatment plant located at village named Kasna near the campus. The vegetables selected for the study are carrot (Daucus

Table 1 Metals in soils derived from normal and geochemically anomalous parent material in Britain (Nriagu 1984)

Metals	Typical range (mg/kg)	Metals rich soil (mg/kg)	Sources	Possible effects
As	< 5–40	Up to 2500	Mineralization	Toxicity in plant and live stocks
		Up to 250	Metamorphosed rocks around Dart moor	Accumulation in food crops
Cd	< 1–2	Up to 30	Mineralization	Accumulation in food crops
		Up to 20	Carboniferous black shale	–
Cu	2–60	Up to 2000	Mineralization	Toxicity in cereal crops
Mo	< 1–5	10–100	Marine black shales of varying age	Molybdenosis or molybdenum induced hypocuprosis in cattle
Ni	2–100	Up to 8000	Ultra basic rocks in Scotland	Toxicity in cereal and other crops
Pb	10–150	1% or more	Mineralization	Toxicity in live stocks, excess in food stuffs
Se	< 1–2	Up to 7	Marine black shales in England and Wales	Chronic selenosis in horses and cattle
		Up to 500	Namurian shales in Ireland	
Zn	25–200	1% or more	Mineralization	Toxicity in cereal crops

Fig. 1 Image of 90 pots for growing vegetables used in the present study

Carota Subsp Sativus), radish (Raphanus Sativus) and spinach (Spinacea Oleracea). These vegetables were grown on pretreated soil filled in properly labeled pots as shown in Fig. 1.

Analysis of water, treated wastewater and soil

Samples of soil were collected from an agricultural area in village Dankaur. During preliminary study, physicochemical characteristics (pH, electric conductivity, Total N, P, K, Na, Mg and Ca) along with heavy metals (Cd, Ni, Mn, Cr, Pb, Co, Zn, Cu) in samples of soil, water and treated wastewater were determined as per the standard methods (American Public Health Association 2000). All the samples were pretreated by digestion with 1 mL nitric acid and 3 mL perchloric acid before analysis for heavy metals. Samples were filtered using whattman filter paper (No. 45). The filtrate obtained was used for analysis of heavy metals using atomic absorption spectrophotometer (Model GBC Avanta M). The heavy metals analyzed in the present study are Cd, Ni, Mn, Cr, Pb, Cu, Zn and Co.

Preparation of pots

The vegetables were grown in the pots by using a statistical approach (simple randomized block design method) suggested by Parveen et al. (2015). Study was carried out during January–April 2016. Ninety pots (with weight 1.8 kg each) of 20 cm diameter were filled with 5 kg of soil. Plants were harvested after 60 days time, being enough to construe the maturity which is known as days after sowing (DAS) period. Water and treated wastewater were used for irrigation of vegetables. The composition of water (control) and treated wastewater used for watering these pots was varied during the study. Vegetables were irrigated under five different conditions (1) 100% tap water, (2) 75% tap water with 25% treated wastewater, (3) 50% tap water with 50% treated wastewater, (4) 25% tap water with 75% treated wastewater and (5) 100% treated wastewater. Each set containing 6 pots and duplicates of plant samples were carefully uprooted at 60 DAS with minimum damage to the root and leaf.

Pretreatment of samples

Plant samples were driven out carefully from the pots and washed with tap water to remove soil particles. The plants were conserved in polypacks prior to analysis as shown in Fig. 2. The measurement of growth of plant and its parts as leaf (length and width), root (thickness, length) and stem was done using vernier calipers. Afterward roots and leaves were separated and dried in oven below 80 °C. The dried samples were digested with 1 mL nitric acid $\left(HNO_3\right)$ and 3 mL perchloric acid ($HClO_4$) as per the procedure given in the HACH Manual.

Daily intake of metals (DIM)

Daily intake of metal (DIM) was determined by using following equation (Eq 1):

$$\mathrm{DIM} = C_{\mathrm{metal}} \times C_{\mathrm{factor}} \times D_{\mathrm{food\,intake}} / B_{\mathrm{average\,weight}} \tag{1}$$

where $C_{\mathrm{metal}}, C_{\mathrm{factor}}, D_{\mathrm{food\,intake}}, B_{\mathrm{average\,weight}}$ represent the heavy metal concentrations in plants (mg/g), conversion factor, daily intake of vegetables and average body weight of humans, respectively. A conversion factor of 0.085 was used to convert weight of fresh vegetable to dry weight. The average daily vegetable intake for adults and children was taken as 0.345 and 0.232 kg/person/day, respectively, while the average body weight of adult and children was taken as 55.9 and 32. 7 kg, respectively (Khan et al. 2008).

Enrichment factor (Ef)

The term enrichment factor is defined as degree of contamination of soil in terms of accumulation of heavy metal in

Fig. 2 Samples of grown vegetables collected for analysis after washing with tap water

soil and plants growing on such a contaminated site with respect to soil and plants grown on uncontaminated site. The enrichment factor (Ef) for metals accumulated in soil and vegetables by irrigation using treated wastewater was calculated by following equation (Eq. 2)

$$\text{Enrichment factor (Ef)} = \frac{\text{mean content of metal in the sample}}{\text{mean content of metal in the control}} \quad (2)$$

The data obtained were analyzed statistically. The measurement is expressed in terms of mean values and standard errors for duplicates. Value of $0.5 \leq EF \leq 1.5$ suggests that the trace metal concentration may occur because of natural weathering processes (Zhang and Liu 2002). The enrichment factor close to unity ($EF = 1$) indicates that the element under consideration originated from the soil (Chiarenzelli et al. 2001), whereas enrichment factor of value more than 1.5 indicates that a significant portion of the trace metals was delivered from non-crustal material (Sutherland et al. 2000).

Results and discussion

The results obtained from analysis of samples of soil, water and treated wastewater in terms of physicochemical parameters are summarized in Table 2. The heavy metals analyzed are Pb, Zn, Cr, Cu, Ni, Mn, Co and Cd. The concentration of the heavy metals present in treated wastewater and soil was within the permissible limits. Also, the concentration of all heavy metals is found to be higher in treated wastewater than in the soil. Soil texture was loamy sand having great influence on growth of root and its ability to absorb water which ensures optimum growth for root vegetables.

Organic matter is an important source of plant nutrients. It also increases water holding capacity, ion exchange capacity and soil fertility as it regulates water and air supply in soil, which in turn controls rate at which nutrients are absorbed by roots. The average pH value of soil was observed to be 8.97, and the uptake of nutrients by various vegetables is dependent on pH. Result from the study indicates high pH values of soil as compared to the pH of treated wastewater (effluent) (Table 3).

Measurement of plant growth

The growth of different vegetables has been measured with respect to the total weight of plant, length of root, width of leaf and length of shoots in terms of plant height, leaf number and root diameter. The data for the same are summarized in Table 4. The growth of vegetables was affected by the concentration of treated wastewater used for irrigation. The growth was found to be maximum in plants irrigating with 100% treated wastewater as compared to the plants irrigated with 0, 25, 50 and 75% of treated wastewater.

The weight of the plants roots and leaves was found to be increasing with respect to time in a 60 days period. The presence of nitrogen and phosphorus along with potassium also enhances the growth of vegetables. In the present study, as sufficient concentration of potassium was present in the treated wastewater as well as in the soil, the growth of vegetable plants has been found to be enormous. In case of lower potassium concentration, the growth rate, cell size and water content of the tissues may be reduced. Another macro-nutrient, Ca which is found treated wastewater has an important role in the structure and permeability of cell membranes and division, thereby promoting growth.

The micro-nutrients, such as Cl, play most important role in opening and closing of stomata which is vital for gaseous exchange and increasing photosynthesis. It is also required for cell division in leaves and shoots. Another important micro-nutrient is iron which normally ranges between 50 and 250 mg/L in plants. Also, Cu acts as an electron carrier and a part of plastocyanin which has an important role in photosynthesis and accumulation of dry matter. The involvement of Mn in photosynthesis, particularly in the evolution of oxygen, is well known. Zinc concentration should range between 25 and 150 mg/L in plants, and its deficiency

Table 2 Physicochemical parameters of treated wastewater and soil

Parameter	pH	EC (μmho/cm)	N	P	K	Na	Ca	Mg	TOC (%)	NO_3–N	TSS
Soil[a]	8.97	420	5.5	0	11	27	12	468	3.6	3.24	–
Treated wastewater[a]	8.28	582	20	4.7	15	305	20	356	–	0.78	240

[a]Units: soil (mg/g); treated wastewater (mg/L) except pH, conductivity and TOC values

Table 3 Concentration of heavy metals in treated wastewater and soil (before irrigation)

Parameters	Cd	Ni	Cu	Zn	Mn	Pb	Cr	Co
Soil (mg/g)	0.0310	0.207	0.150	0.084	0.026	0.196	0.266	0.069
Treated wastewater (mg/L)	0.033	0.257	0.171	0.077	0.012	0.150	0.227	0.071

Table 4 Growth parameters of the vegetables

Concentration (%)		No. of crops	No of leafs	Weight of plant (gm)	Size of leave (cm)	Width of leave (cm)	Width of root (mm)	Length of root (cm)	Total height of plant (cm)
Tap water	Treated waste water								
Spinach									
100	0	1.	12	5.9	8–13.5	4.2	1	9.3	23
		2.	11	5.5	7–12	4.2	1	8.5	20.8
75	25	3.	16	11.86	8–15	5	1.5	17	27.3
		4.	12	8.4	7–14	4.3	2	14	29.8
50	50	5.	24	44.6	16–26	9	3	14	40
		6.	23	11.39	9–15	5.8	1.5	13	50
25	75	7.	23	35.5	9–17.8	5.5	2.5	11	28.5
		8.	17	6.48	6–11.5	4.5	1.5	8	19
0	100	9.	18	25.4	9–17	5.5	3	21	43
		10.	35	16.5	9–18	6	3.1	11	29.7
Radish									
100	0	1.	8	5.3	5–9	3.3	2	9	18
		2.	11	4.38	6–9.8	4	1	10.6	19
75	25	3.	12	14	10–13.3	5	1.6	10	24
		4.	6	5.87	6–8	4	2.1	12	20
50	50	5.	7	3.5	6–9	3.5	0.5	7	16
		6.	7	3.22	5–7.5	3.9	1	10	16.3
25	75	7.	8	3.62	5–8.5	3	1.1	11	19
		8.	9	3.33	5–7	3	0.7	8	15
0	100	9.	12	11	8–11	5	2	11	22
		10.	13	7.4	5.5–9	3.4	0.9	10.5	19
Carrot physical measurement									
100	0	1.	6	3.1	–	–	0.7	4	10
75	25	2.	8	3.62	–	–	0.92	3.8	11.8
50	50	3.	10	5.2	–	–	1	5	12.7
25	75	4.	7	4.1	–	–	0.98	3.7	9.4
0	100	5.	9	3.3	–	–	0.88	5	10.9

adversely affects the development of leaf as leaf margins are often distorted (Marschner 2002).

Heavy metal accumulation and translocation ratio in plants

In the present study, the heavy metals were determined in leaves and roots of radish, spinach and carrot grown in a 60-day period. Concentration of all heavy metals in different parts of different vegetable plants is tabulated in Table 5. The concentration of Cd varied from 20.5 to 39.5 mg/g, while concentration of Ni was found between 100 and 545 mg/g. The concentration of Cu was observed in the range of 22 to 324 mg/g, while the concentration of Zn was found between 152 and 259 mg/g. The concentration of Mn was observed in the range of 106.5 to 429 mg/g, while the concentration of Pb was found between 72.5 and 346 mg/g. The concentration of Cr was observed between 84 and 441 mg/g, and the concentration of Co was found between 12 and 77 mg/g.

Results from the study indicate that concentration of heavy metals Cd, Co and Pb in the root samples was found to be below the toxic limit. Concentration of heavy metals in leaves was found to decrease in order of Zn > Ni > Cr > Pb > Mn > Cu > Co > Cd, while in the roots it was in the order of Zn > Ni > Cr > Pb > Mn > Cu > Co > Cd. Concentration of Zn was found to be higher in plant samples irrigated with tap water. Also, the concentration of Zn was observed to be high in the roots than in the leaves, and it decreased with

Table 5 Concentration of heavy metals in various parts of vegetable plants

Concentration (%)			Concentration of heavy metals in radish (mg/g)							
Tap water	Treated waste water	Part of plant	Cd	Ni	Cu	Zn	Mn	Pb	Cr	Co
100	0	Root	0.033	0.062	0.05	0.302	0.106	0.092	0.1	0.002
		Leaf	0.039	0.138	0.07	0.256	0.148	0.12	0.068	0.046
75	25	Root	0.034	0.071	0.075	0.214	0.103	0.025	0.058	0.03
		Leaf	0.04	0.152	0.07	0.2	0.131	0.177	0.181	0.015
50	50	Root	0.037	0.094	0.108	0.226	0.063	0.098	0.221	0.023
		Leaf	0.039	0.184	0.05	0.225	0.15	0.161	0.207	0.001
25	75	Root	0.033	0.1	0.023	0.07	0.102	0.005	0.212	0.001
		Leaf	0.04	0.133	0.021	0.322	0.147	0.14	0.157	0.039
0	100	Root	0.038	0.093	0.054	0.3	0.1	0.117	0.065	0.039
		Leaf	0.041	0.125	0.101	0.243	0.173	0.15	0.134	0.035
Concentration (%)			Concentration of heavy metals in spinach (mg/g)							
Tap water	Treated waste water	Part of plant	Cd	Ni	Cu	Zn	Mn	Pb	Cr	Co
100	0	Root	0.042	0.18	0.01	0.237	0.15	0.176	0.223	0.028
		Leaf	0.02	0.197	0.129	0.318	0.195	0.234	0.275	0.087
75	25	Root	0.04	0.148	0.049	0.256	0.145	0.164	0.147	0.042
		Leaf	0.023	0.235	0.09	0.327	0.235	0.269	0.261	0.096
50	50	Root	0.043	0.17	0.076	0.246	0.145	0.264	0.338	0.029
		Leaf	0.02	0.204	0.071	0.213	0.299	0.174	0.092	0.045
25	75	Root	0.036	0.204	0.088	0.221	0.146	0.184	0.198	0.043
		Leaf	0.022	0.215	0.095	0.326	0.261	0.181	0.197	0.071
0	100	Root	0.017	0.213	0.112	0.213	0.14	0.21	0.36	0.001
		Leaf	0.024	0.218	0.058	0.227	0.126	0.112	0.209	0.005
Concentration (%)			Concentration of heavy metals in carrot (mg/g)							
Tap water	Treated waste water	Part of plant	Cd	Ni	Cu	Zn	Mn	Pb	Cr	Co
100	0	Root	0.021	0.225	0.066	0.152	0.273	0.104	0.283	0.077
		Leaf	0.019	0.235	0.067	0.234	0.235	0.112	0.208	0.086
75	25	Root	0.023	0.23	0.162	0.197	0.429	0.128	0.282	0.083
		Leaf	0.034	0.232	0.177	0.212	0.411	0.137	0.105	0.055
50	50	Root	0.024	0.228	0.085	0.215	0.198	0.234	0.235	0.083
		Leaf	0.027	0.219	0.105	0.238	0.217	0.256	0.229	0.088
25	75	Root	0.027	0.545	0.145	0.265	0.145	0.202	0.357	0.064
		Leaf	0.034	0.435	0.211	0.355	0.245	0.241	0.249	0.088
0	100	Root	0.026	0.465	0.324	0.259	0.163	0.346	0.441	0.052
		Leaf	0.031	0.343	0.298	0.287	0.137	0.424	0.398	0.055

respect to time as the plant attained growth. The variation in concentration of metals in these vegetables depends on physicochemical nature of the soil and absorption capacity for each metal by the plant. It is affected by the various factors like environmental condition, human interference and the nature of the plant.

Among the eight heavy metals, Cd and Co were found to be in lower concentration as compared to other heavy metals.

This may be due to their high dependability on solubility and pH of soil. The results from the present study indicated that concentration of heavy metal is higher in leaves and roots of the plants that are irrigated with 25%, 50%, 75% of treated wastewater as compared to the plants irrigated with 100% treated wastewater. It was not astounding because the metals uptake may be different in relation to external concentration and genotype of plant.

It may also be pointed out that uptake of heavy metals in plants is not linear in relation to treated wastewater concentration. The concentration of Zn was found to be maximum in spinach irrigated with 25% treated wastewater and radish irrigated with 75% treated wastewater after 60 days time.

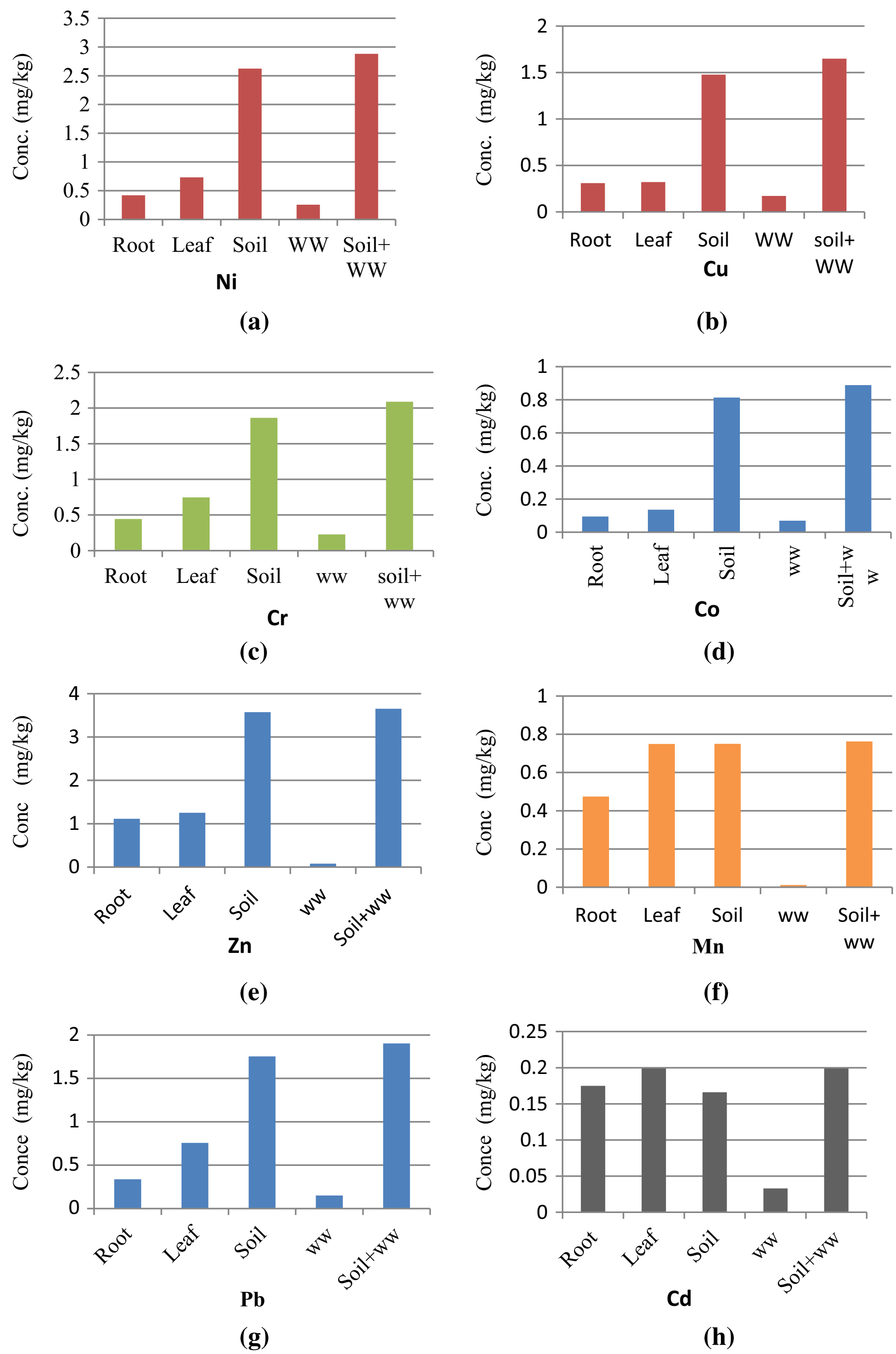

Fig. 3 Variation in concentration of heavy metals in various parts of radish **a** Ni **b** Cu **c** Cr **d** Co **e** Zn **f** Mn **g** Pb **h** Cd

The result also indicates that concentration of Zn is maximum in leaves than in roots. The concentration was found to normally decrease in roots with increased growth of plant. The concentration of Cd was found to be higher in roots of spinach then in leaves which is also in agreement with the work carried out by Demirezen and Aksoy (2004).

In the present study, the concentration of Cd was found between 20.5 and 39.5 mg/g. Figure 3 indicates that concentration of Cd, Co, and Cu is low and below the toxic levels in leaves and roots of all the vegetables. The concentration of Cu was found between 22 and 324 mg/g in all the plants. The concentration of Cr and Co ranged between 84 to 441 mg/g and 12 to 77 mg/g, respectively. Concentration of Cr was higher in the leaves of the spinach and carrot. However, in radish the concentration was high in roots as compared to the leaves.

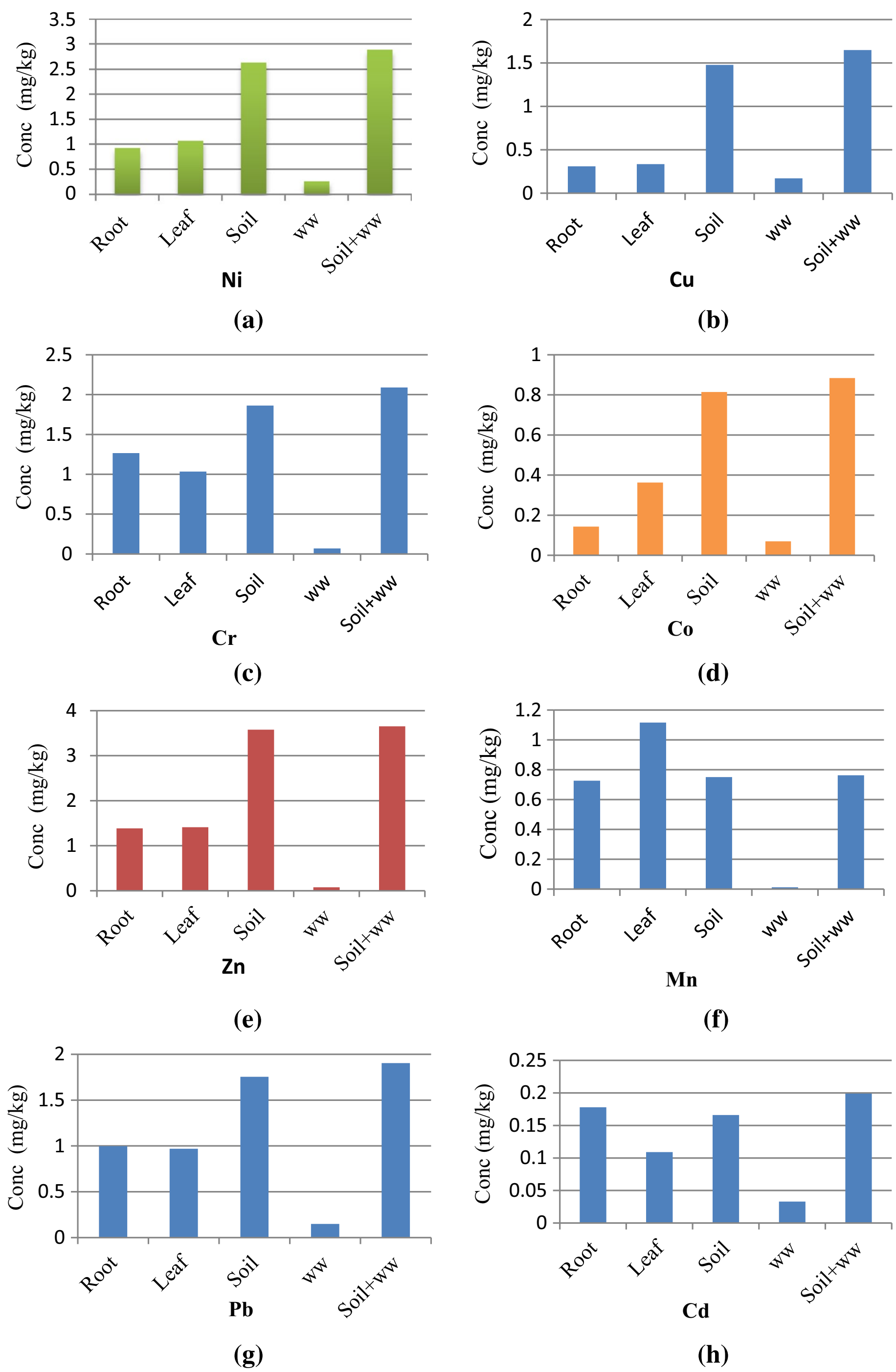

Fig. 4 Variation of heavy metals concentration in various parts of spinach vegetable **a** Ni **b** Cu **c** Cr **d** Co **e** Zn **f** Mn **g** Pb **h** Cd

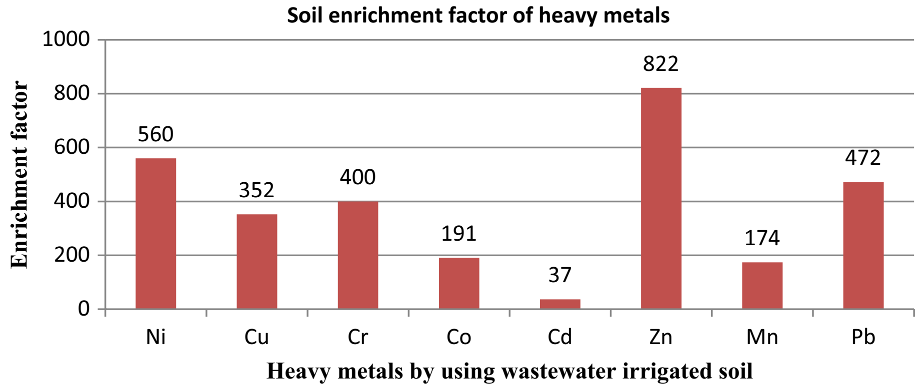

Fig. 5 Soil enrichment factor of heavy metals irrigated with treated wastewater

The concentration of Ni was higher in the leaves of all the vegetables plants ranging between 100 and 545 mg/g. The concentration of Mn in all vegetable plants was found to be in the range of 106.5 to 429 mg/g which is lower than toxic level. The concentration of Zn and Pb ranged from 152 to 259 mg/kg and 72.5 to 346 mg/kg, respectively. The translocation factor was analyzed from data, and it was found that heavy metals accumulate more in the shoots of the plants than in roots (Fig. 4).

The concentration of the heavy metals in the soil irrigated with mixture of treated waste water and normal ground water was in the order of Fe > Mn > Cr > Zn > Pb > Cu > Cd and Fe > Zn > Cr > Mn > Pb > Cu > Cd. The results indicated that the average concentration of heavy metals, except for Cd, was higher in the soil irrigated with treated water than in the soil irrigated with normal ground water. The concentration of heavy metals was higher in the soil except for Cd, Cu and Mn, which may be attributed to their weak adsorption in the soil.

Enrichment factor for soil

The enrichment factor for the soil irrigated with treated wastewater was found to decrease in the order of Zn > Ni > Pb > Cr > Cu > Co > Mn > Cd. The value for the same is shown in Fig. 5. The enrichment factor has been found to be maximum for Zn and is found to be minimum for Cd.

Daily intake of metals (DIM)

The daily intake of heavy metals was evaluated based on average consumption of vegetables for both adults and children. The daily intake of metals for adults and children through the consumption of plants irrigated with treated wastewater is summarized in Table 6. The daily intakes of metals were higher during consumption of plants gown in treated wastewater than those grown in control. Perusal of the data summarized in Table 6 regarding DIM suggests that consumption of plants grown in treated wastewater and tap water is nearly free of risks, as the dietary daily intake limits of micro-nutrients such as Cu, Fe, Zn, and Mn in adults can range from 1.2 to 3 mg, 10 to 50 mg, 5 to 22 mg and 2 to 20 mg, respectively (WHO 1996). The highest DIM values in both adults and children were measured in Zn followed by Cr, Ni Pb, Mn, Co, Cu and Cd.

Conclusion

The yield obtained was high in plants irrigated with treated wastewater because of the presence of more nutrients as compared to that of tap water. The concentration of heavy metals in vegetable plants irrigated with treated wastewater was at excessive levels at 60 DAS. The concentration of heavy metals in plants was found to be decreasing in the order of Zn > Ni > Cr > Pb > Mn > Cu > Co > Cd. The concentration of heavy metals is found to be higher in the edible parts of plant (leaves and roots). Consumption of plants grown in treated wastewater has shown high value of DIM as compared to those grown in tap water, but is nearly free from risks. The daily intake of metals (Zn, Ni, Mn, Cu, Pb, Cr, Co, Cd) for human with body weight (adults = 55.9 kg and children = 32.7 kg) indicates that intake of toxic metals from vegetables is not high. It can be inferred that excesses level of heavy metals accumulates in the plant root. The root of such plants may be considered as toxic for human or animal consumption and should be discarded from the plants if possible.

Table 6 Daily intake of metals (DIM)

Treatments 60 DAS		Cd		Ni		Cu		Zn		Mn		Pb		Cr		Co	
Water (%)	Treated waste water (%)	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children
Daily intake of metals (Radish (mg/kg))																	
100	0	0.010	0.020	0.050	0.066	0.031	0.036	0.146	0.168	0.066	0.076	0.055	0.063	0.044	0.050	0.012	0.014
75	25	0.019	0.021	0.058	0.067	0.038	0.043	0.108	0.124	0.061	0.070	0.052	0.060	0.062	0.072	0.011	0.013
50	50	0.019	0.022	0.070	0.083	0.041	0.047	0.118	0.135	0.055	0.064	0.067	0.077	0.112	0.129	0.006	0.007
25	75	0.020	0.022	0.060	0.070	0.011	0.031	0.102	0.118	0.065	0.075	0.038	0.043	0.096	0.111	0.010	0.012
0	100	0.016	0.023	0.057	0.065	0.040	0.046	0.142	0.163	0.071	0.082	0.070	0.080	0.052	0.060	0.019	0.033
Daily intake of metals (Spinach (mg/kg))																	
100	0	0.016	0.018	0.098	0.113	0.036	0.041	0.145	0.167	0.090	0.104	0.107	0.123	0.130	0.150	0.030	0.034
75	25	0.016	0.018	0.100	0.115	0.036	0.041	0.152	0.175	0.099	0.114	0.113	0.130	0.107	0.123	0.036	0.041
50	50	0.016	0.018	0.098	0.112	0.038	0.044	0.120	0.138	0.116	0.133	0.114	0.132	0.112	0.129	0.019	0.019
25	75	0.015	0.017	0.109	0.126	0.048	0.055	0.143	0.164	0.106	0.122	0.095	0.110	0.103	0.119	0.029	0.034
0	100	0.010	0.012	0.113	0.129	0.044	0.051	0.115	0.132	0.069	0.080	0.084	0.097	0.149	0.191	0.015	0.018
Daily intake of metals (Carrot (mg/kg))																	
100	0	0.011	0.012	0.118	0.135	0.034	0.039	0.079	0.091	0.143	0.164	0.054	0.062	0.148	0.170	0.040	0.046
75	25	0.012	0.013	0.120	0.138	0.084	0.097	0.103	0.069	0.225	0.258	0.068	0.077	0.147	0.170	0.043	0.050
50	50	0.012	0.014	0.119	0.137	0.044	0.051	0.112	0.129	0.103	0.119	0.122	0.141	0.121	0.141	0.023	0.027
25	75	0.014	0.016	0.285	0.320	0.076	0.087	0.139	0.159	0.076	0.087	0.105	0.121	0.187	0.215	0.033	0.038
0	100	0.013	0.015	0.240	0.280	0.169	0.195	0.135	0.156	0.085	0.098	0.181	0.208	0.231	0.265	0.029	0.034

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