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Heavy metal accumulation in vegetables irrigated with water from different sources

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ABSTRACT

The present study was carried out to assess levels of different heavy metals like iron, manganese, copper and zinc, in vegetables irrigated with water from different sources. The results indicated a substantial build-up of heavy metals in vegetables irrigated with wastewater. The range of various metals in wastewater-irrigated plants was 116–378, 12–69, 5.2–16.8 and 22–46 mg/kg for iron (Fe), manganese (Mn), copper (Cu) and zinc (Zn), respectively. The highest mean levels of Fe and Mn were detected in mint and spinach, whereas the levels of Cu and Zn were highest in carrot. The present study highlights that both adults and children consuming vegetables grown in wastewater-irrigated soils ingest significant amount of these metals. However, the values of these metals were below the recommended maximum tolerable levels proposed by the [Joint FAO/WHO Expert Committee on Food Additives (1999). Summary and conclusions. In *53rd Meeting, Rome, June 1–10, 1999*]. However, the regular monitoring of levels of these metals from effluents and sewage, in vegetables and in other food materials is essential to prevent excessive build-up of these metals in the food chain.

1. Introduction

Industrial or municipal wastewater is mostly used for the irrigation of crops, mainly in periurban ecosystem, due to its easy availability, disposal problems and scarcity of fresh water. Irrigation with wastewater is known to contribute significantly to the heavy metals content of soil.

Heavy metals are very harmful because of their non-biodegradable nature, long biological half-lives and their potential to accumulate in different body parts. Most of the heavy metals are extremely toxic because of their solubility in water. Even low concentrations of heavy metals have damaging effects to man and animals because there is no good mechanism for their elimination from the body. Nowadays heavy metals are ubiquitous because of their excessive use in industrial applications. Wastewater contains substantial amounts of toxic heavy metals, which create problems (Chen, Wang, & Wang, 2005; Singh, Mohan, Sinha, & Dalwani, 2004). Excessive accumulation of heavy metals in agricultural soils through wastewater irrigation, may not only result in soil contamination, but also affect food quality and safety (Muchuweti et al., 2006).

Food and water are the main sources of our essential metals; these are also the media through which we are exposed to various toxic metals. Heavy metals are easily accumulated in the edible parts of leafy vegetables, as compared to grain or fruit crops (Mapanda, Mangwayana, Nyamangara, & Giller, 2005). Vegetables take up heavy metals and accumulate them in their edible (Bahemuka & Mubofu, 1991) and inedible parts in quantities high enough to cause clinical problems both to animals and human beings consuming these metal-rich plants (Alam, Snow, & Tanaka, 2003). A number of serious health problems can develop as a result of excessive uptake of dietary heavy metals. Furthermore, the consumption of heavy metal-contaminated food can seriously deplete some essential nutrients in the body causing a decrease in immunological defences, intrauterine growth retardation, impaired psycho-social behaviour, disabilities associated with malnutrition and a high prevalence of upper gastrointestinal cancer.

The present study was conducted with an aim to compare the heavy metals (copper, manganese, zinc and iron) accumulation potential of some of the commonly grown vegetables in Rajasthan, India. Irrigation of crops with wastewater is a very common practice in India. The effect of irrigation with wastewater is also studied in these crops to observe the concentration of accumulated metals to which human beings are exposed. Furthermore, the daily intake of these metals is calculated for both adults and children.

2. Materials and methods

2.1. Study area and sampling

All the experiments were conducted at the environmental science laboratory of Maharishi Dayanand College, Sri Ganganagar, Rajasthan, India. Samples of some commonly grown vegetables, i.e., radish (*Raphanus sativus*), spinach (*Spinacia oleracea*), turnip

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(*Brassica rapa*), brinjal (*Solanum melogena*), cauliflower (*Brassica oleracea* var. botrytis), lotus stem (*Nelumbium nelumbo*), mint (*mentha*), coriander (*Coriandrum sativum*), methi (*Trigonella foenum-graecum*), and carrot (*Daucus carota*), were collected from three different sites in Sri Ganganagar district, namely the vegetable market (unknown source of irrigation), and agricultural fields irrigated with fresh water and wastewater. For metal analysis, only the edible parts of vegetable samples were used.

2.2. Sample preparation

All the collected samples of various vegetables were washed with double distilled water to remove airborne pollutants. The edible parts of the vegetable samples were weighed and air-dried for a day, to reduce water content. All the samples were then oven-dried in a hot air oven at 70–80 °C for 24 h, to remove all moisture. Dried samples were powdered using a pestle and mortar and sieved through muslin cloth.

2.2.1. Digestion of the vegetable samples

For each vegetable, three powdered samples from each source of irrigation (0.5 g each) were accurately weighed and placed in crucibles, three replicants for each sample. The ash was digested with perchloric acid and nitric acid (1:4) solution. The samples were left to cool and contents were filtered through Whatman filter paper No. 42. Each sample solution was made up to a final volume of 25 ml with distilled water and analyzed by atomic absorption spectrophotometry (932AA, GBC Scientific Equipment, Dandenong, Australia).

2.3. Standards

Standard solutions of heavy metals (1000 mg/l), namely copper (Cu), zinc (Zn), manganese (Mn) and iron (Fe) were procured from Merck. Solutions of varying concentrations were prepared for all the metals by diluting the standards.

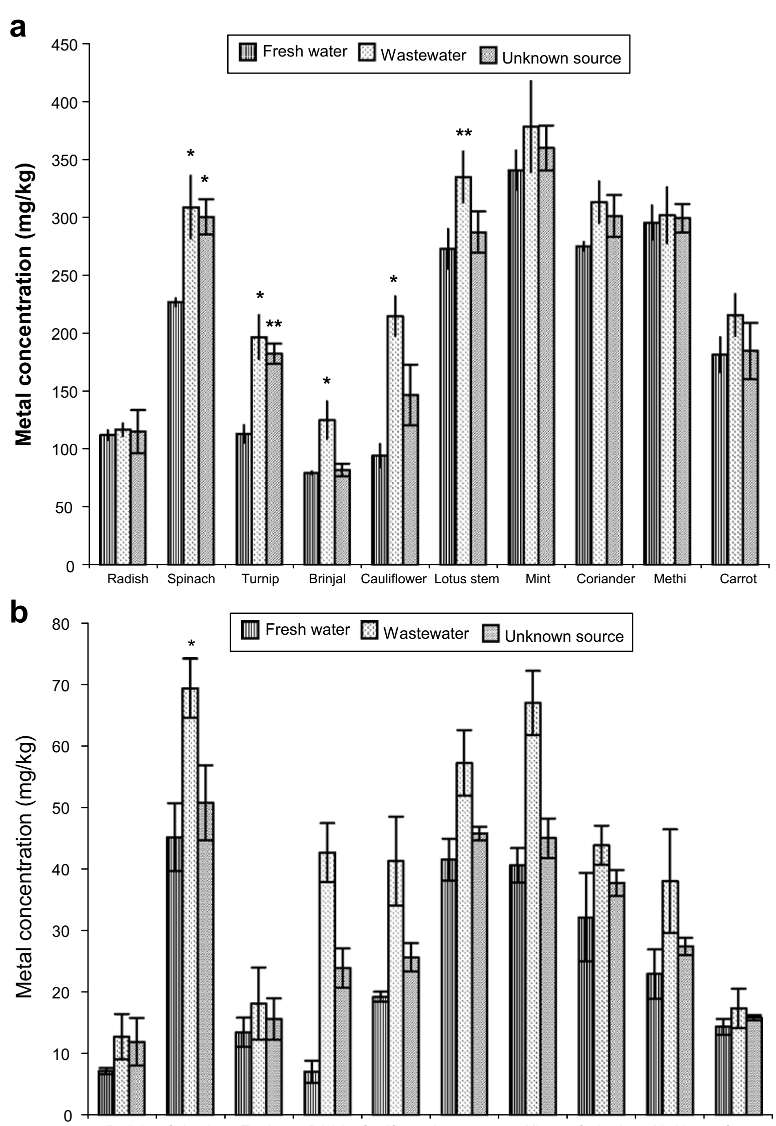

Fig. 1. Heavy metal concentrations in the edible parts of vegetables grown with fresh water, wastewater and with an unknown source of irrigation for (a) Fe and (b) Mn. The error bars indicate the standard deviation while the asterisks indicate significant differences in heavy metal concentrations between plants grown in wastewater or from an unknown source, with respect to fresh water, at $p < 0.05$ (*) and $p < 0.01$ (**).

2.4. Data analysis

The daily intake of metals (DIM) was calculated by the following equation:

$$\text{DIM} = \frac{[M]XKXI}{W}, \quad (1)$$

where [*M*], *K*, I and *W* represent the heavy metal concentrations in plants (mg/kg), conversion factor, daily intake of vegetables and average body weight, respectively. The conversion factor used to convert fresh green vegetable weight to dry weight was 0.085, as described by Rattan, Datta, Chhonkar, Suribabu, & Singh, 2005. The average adult and child body weights were considered to be 55.9 and 32.7 kg, respectively, while average daily vegetable intakes for adults and children were considered to be 0.345 and 0.232 kg/person/day, respectively, as reported in the literature (Ge, 1992; Wang, Sato, Xing, & Tao, 2005).

All the data are presented in terms of means and standard error of triplicates. Observations on heavy metal concentrations in response to different irrigation sources were tested for significance of difference using the *t*-test.

3. Results and discussion

3.1. Metal accumulation in plants

The application of wastewater generally led to changes in the physicochemical characteristics of soil and consequently heavy metal uptake by vegetables. The heavy metals concentrations in edible parts of vegetables in Sri Ganganagar District, Rajasthan are shown in Figs. 1 and 2. It can be clearly observed that the concentration of all the heavy metals is higher in wastewater-irrigated vegetables than freshwater-irrigated plants. Table 1 shows a very high concentration of heavy metals in vegetables irrigated with

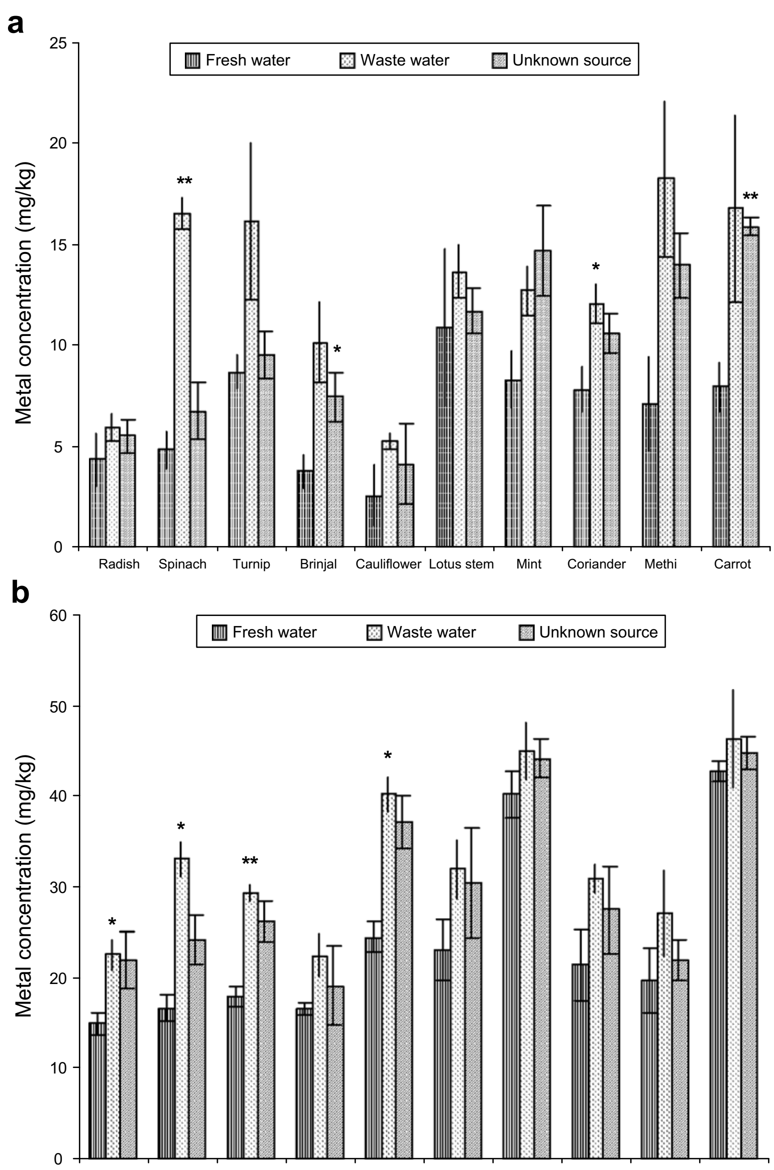

Fig. 2. Heavy metal concentrations in the edible parts of vegetables grown with fresh water, wastewater and with an unknown source of irrigation for (a) Cu and (b) Zn. The error bars indicate the standard deviation while the asterisks indicate significant differences in heavy metal concentrations between plants grown in wastewater or from an unknown source, with respect to fresh water, at $p < 0.05$ (*) and $p < 0.01$ (**).

wastewater. Heavy metals concentration was in the order of Fe > Mn > Zn > Cu for all the plants except radish, turnip and carrot; for these the trend was Fe > Zn > Mn > Cu. The concentrations of iron were in the range of 79–340 mg/kg, 116–378 mg/kg and 82–360 mg/kg in vegetable samples irrigated with fresh water, waste water and those of unknown treatment, respectively (Fig. 1a). Mint leaves were found to accumulate the maximum concentration of iron, in the range of 340–378 mg/kg, but no significant effects were observed. Wastewater-irrigated lotus stem showed a significantly ($p < 0.01$) higher accumulation of iron than freshwater-irrigated. Spinach, turnip, brinjal and cauliflower showed significantly ($p < 0.05$, $p < 0.01$) higher accumulation of iron when irrigated with wastewater or when the water treatment was not known. The concentrations of iron in most of the vegetables bought from the market were closer to those of vegetables irrigated with waste water than to samples irrigated with fresh water. This meant that the source of irrigation in market-bought samples was probably wastewater because of the scarcity of fresh water.

A similar trend was observed for the other metals, i.e., maximum accumulation in wastewater-irrigated vegetables and minimum in freshwater-irrigated samples. The differences of the metal contents in these vegetables depend on the physical and chemical nature of the soil and absorption capacity of each metal by the plant, which is altered by various factors like environmental and human interference, and the nature of the plant (Zurera, Moreno, Salmeron, & Pozo, 1989). For Mn, vegetables showed a range of 7–45 mg/kg with fresh water irrigation, 12–69 mg/kg with wastewater irrigation and 11–50 mg/kg where the source of irrigation was unknown (Fig. 1b). The concentration of Zn was 14–42 mg/kg, 22–46 mg/kg and 19–45 mg/kg in freshwater, wastewater and unknown source of irrigation, respectively (Fig. 2a). Copper concentration was 2.5–10.9 mg/kg, 5.2–16.8 mg/kg and 4.1–15.9 mg/kg in freshwater, wastewater and unknown source of irrigation, respectively (Fig. 2b). Table 2 shows that maximum Mn accumulation was in spinach (45–69 mg/kg), whereas carrot contained the maximum concentration of Cu but not at a significantly higher level than the freshwater one. Spinach showed a highly significant ($p < 0.01$) increase in copper accumulation when treated with wastewater. The concentration of Zn was significantly ($p < 0.05$) higher in wastewater-irrigated radish, spinach, turnip and cauliflower. All vegetables had lower levels of zinc and copper than the maximum permissible value (60 mg/kg and 40 mg/kg) in food proposed by FAO/WHO (Codex Alimentarius Commission, 1984) but still significantly higher than the plants irrigated with fresh water.

Our results show agreement with previous studies showing elevated levels of heavy metals in edible parts of food crops with continuous wastewater irrigation (Khan, Cao, Zheng, Huang, & Zhu,

Table 1
Heavy metal content (dry weight basis) in plants grown in wastewater-irrigated soils

Plants	Values	Fe	Zn	Mn	Cu
Radish	Range	111–122	21.1–24.3	10.0–17.0	5.21–6.42
	Mean ± S.E.	117 ± 5.4	22.5 ± 1.6	12.8 ± 3.7	5.96 ± 0.7
Spinach	Range	279–333	31.2–34.9	64.3–73.8	15.9–17.4
	Mean ± S.E.	309 ± 27.0	33.1 ± 1.9	69.4 ± 4.8	16.5 ± 0.8
Turnip	Range	176–212.4	28.8–30.3	11.8–23.3	12.4–20.1
	Mean ± S.E.	197 ± 19	29.3 ± 0.8	18.2 ± 5.9	16.1 ± 3.9
Brinjal	Range	113–144	20.7–25.1	38.1–47.7	7.92–11.8
	Mean ± S.E.	125 ± 16	22.5 ± 2.3	42.7 ± 4.8	10.2 ± 2.0
Cauliflower	Range	198–232	38.2–41.8	33.5–47.5	4.8–5.5
	Mean ± S.E.	215 ± 17.0	40.2 ± 1.9	41.3 ± 7.2	5.23 ± 0.4
Lotus stem	Range	311–353	28.7–35.2	52.6–63.0	12.8–15.2
	Mean ± S.E.	335 ± 22.0	31.9 ± 3.2	57.3 ± 5.3	13.7 ± 1.3
Mint	Range	335–412	41.4–47.4	61.0–70.8	11.8–14.1
	Mean ± S.E.	378 ± 39.0	45.0 ± 3.2	67.0 ± 5.2	12.7 ± 1.2
Coriander	Range	292–326	29.8–32.8	41.4–47.6	10.9–12.7
	Mean ± S.E.	313 ± 18.0	30.9 ± 1.6	43.9 ± 3.2	12.1 ± 1.0
Methi	Range	275–322	23.5–32.4	31.5–47.5	15.4–22.5
	Mean ± S.E.	302 ± 24.0	27.1 ± 4.7	38.0 ± 8.4	18.2 ± 3.8
Carrot	Range	200–235	40.4–50.7	14.0–20.4	12.5–21.6
	Mean ± S.E.	216 ± 18.0	46.4 ± 5.3	17.4 ± 3.2	16.8 ± 4.6

Table 2
Daily intake of metals (mg) for individual heavy metals in different vegetables grown in freshwater-rrigated soils

Plants	Zn		Cu		Fe		Mn	
	Adults	Children	Adults	Children	Adults	Children	Adults	Children
Radish	0.008	0.009	0.0023	0.0026	0.059	0.068	0.0038	0.0044
Spinach	0.009	0.0101	0.0025	0.0029	0.119	0.137	0.0237	0.0273
Turnip	0.009	0.0108	0.0046	0.0052	0.059	0.068	0.0071	0.0081
Brinjal	0.009	0.01	0.002	0.0023	0.042	0.048	0.0037	0.0043
Cauliflower	0.013	0.0147	0.0013	0.0015	0.05	0.057	0.0101	0.0116
Lotus stem	0.012	0.0139	0.0057	0.0066	0.143	0.165	0.0218	0.025
Mint	0.021	0.0243	0.0044	0.005	0.179	0.206	0.0213	0.0245
Coriander	0.011	0.0129	0.0041	0.0047	0.144	0.166	0.0169	0.0194
Methi	0.01	0.0119	0.0037	0.0043	0.155	0.178	0.0121	0.0139
Carrot	0.022	0.0258	0.0042	0.0048	0.095	0.11	0.0076	0.0087

Table 3
Daily intake of metals (mg) for individual heavy metals in different vegetables grown in wastewater-irrigated soils

Plants	Zn		Cu		Fe		Mn	
	Adults	Children	Adults	Children	Adults	Children	Adults	Children
Radish	0.012	0.014	0.0031	0.0036	0.0613	0.07	0.0067	0.0077
Spinach	0.017	0.02	0.0087	0.01	0.1621	0.186	0.0364	0.0419
Turnip	0.015	0.018	0.0085	0.0097	0.1033	0.119	0.0095	0.011
Brinjal	0.012	0.014	0.0053	0.0061	0.0657	0.076	0.0224	0.0257
Cauliflower	0.021	0.024	0.0027	0.0032	0.1128	0.13	0.0217	0.0249
Lotus stem	0.017	0.019	0.0072	0.0082	0.1757	0.202	0.03	0.0345
Mint	0.024	0.027	0.0067	0.0077	0.1985	0.228	0.0352	0.0404
Coriander	0.016	0.019	0.0063	0.0073	0.1644	0.189	0.023	0.0265
Methi	0.014	0.016	0.0096	0.011	0.1585	0.182	0.02	0.0229
Carrot	0.024	0.028	0.0088	0.0101	0.1133	0.13	0.0091	0.0105

Table 4
Daily intake of metals (mg) for individual heavy metals in different vegetables grown with irrigation water from an unknown source

Plants	Zn		Cu		Fe		Mn	
	Adults	Children	Adults	Children	Adults	Children	Adults	Children
Radish	0.012	0.013	0.003	0.003	0.06	0.069	0.0063	0.0072
Spinach	0.013	0.015	0.004	0.004	0.158	0.181	0.0266	0.0306
Turnip	0.014	0.016	0.005	0.006	0.096	0.11	0.0082	0.0094
Brinjal	0.01	0.012	0.004	0.004	0.043	0.05	0.0126	0.0144
Cauliflower	0.019	0.022	0.002	0.002	0.077	0.089	0.0135	0.0155
Lotus stem	0.016	0.018	0.006	0.007	0.151	0.173	0.024	0.0276
Mint	0.023	0.027	0.008	0.009	0.189	0.217	0.0236	0.0271
Coriander	0.014	0.017	0.006	0.006	0.158	0.182	0.0198	0.0228
Methi	0.011	0.013	0.007	0.008	0.157	0.181	0.0144	0.0166
Carrot	0.024	0.027	0.008	0.01	0.097	0.112	0.0083	0.0096

2007); (Liu, Zhao, Ouyang, Soderlund, & Liu, 2005). Results from present and previous studies (Liu et al., 2005; Muchuweti et al., 2006; Sharma, Agrawal, & Marshall, 2007) demonstrate that the plants grown on wastewater-irrigated soils are generally contaminated with heavy metals, which pose a major health concern.

3.2. Daily intake of metals (DIM)

In order to observe the health risk of any pollutant, it is very important to estimate the level of exposure, by detecting the routes of exposure to the target organisms. There are several possible pathways of exposure to humans but amongst them the food chain is the most important pathway. The daily intake of metals was estimated according to the average vegetable consumption for both adults and children (Tables 2–4). The DIM values for heavy metals were high when based on the consumption of vegetables grown in wastewater-irrigated soils. The highest intakes of Fe, Zn, Mn, and Cu were from the consumption of mint, carrot, spinach and methi, respectively, for both adults and children, grown in wastewater-irrigated soils. The findings of this study regarding DIM suggest that the consumption of plants grown in wastewater contaminated soils is high, compared to the other two treatments but is nearly free of risks, as the dietary intake limits of Cu, Fe, Zn, and Mn in adults can range from 1.2 to 3.0 mg, 10.0 to 50.0 mg, 5.0 to 22.0 mg and 2.0 to 20.0 mg, respectively (World Health Organization., 1996).

However, there are also some other sources of metal exposure, like dermal contact, dust inhalation, and ingestion of metal-contaminated soils, which were not taken into account in the present study. So further detailed studies are required to completely understand the problem and risk involved.

4. Conclusion

Heavy metals show a significant build-up with continuous irrigation with wastewater and long-term irrigation of farmlands with wastewater has led to contamination of food crops in the study area. Wastewater-irrigated spinach has shown significantly ($p < 0.05$, $p < 0.01$) higher accumulation of iron, manganese, copper and zinc, compared to the freshwater-irrigated spinach, indicating the highest metal absorption for this vegetable. All the vegetables contained heavy metals were lower than the recommended tolerable levels proposed by Joint FAO/WHO Expert Committee on Food Additives. The authors strongly recommend that people living in this area should not eat large quantities of spinach, so as to avoid excess accumulation of heavy metals in the body.

Dietary intake of food results in long-term low level body accumulation of heavy metals and the detrimental impact becomes apparent only after several years of exposure. Thus regular monitoring of these toxic heavy metals from effluents and sewage, in vegetables and in other food materials is essential, to prevent their excessive build-up in the food chain.

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