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Research Article

Iron and manganese concentrations of vegetables grown in soil irrigated with wastewater: Evaluation of health risk to the public

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Abstract

Aim of the present research was to determine the concentrations of iron and manganese in soil, vegetables grown at the areas which are usually irrigated with canal water and sewage water. The samples were analysed through atomic absorption spectrophotometer. The mean iron and manganese concentrations in soil samples varied from 16.425 to 32.835 mg/kg and 0.450 to 0.904 mg/kg, respectively. The highest Fe value was observed in *Raphanus sativus* irrigated with sewage water irrigation and the lowest content was noticed in *Capsicum frutescens* irrigated with canal water. In the same way as Fe, the highest Mn value was observed in *Raphnus sativus* irrigated with sewage water and the lowest content was noticed in *Capsicum frutescens* irrigated with canal water irrigation. In all vegetables, the daily intake of metal values for Fe and Mn were higher during sewage water irrigation as compared to the canal water irrigation. Bio-concentration factor values of heavy metals were less than 1 in all vegetables and these results specified that metal bioavailability was low at the two sites. Health risk index values of Fe and Mn fell under the safe limit of health risk index value and the vegetables were deemed fit for human consumption. But amid irrigation of wastewater, there are chances of further contamination upto levels that are hazardous to public health.

Keywords: Heavy metal; Iron; Manganese; Wastewater; Vegetables

Introduction

Industrialization is very important for developing nations [1]. But wastewater disposal has become a global concern as the industries are associated with the generation of high volumes of effluents and high cost of treatment technologies [2]. Even at the places where some treatment facilities occur, these are not working well. Resultantly the water resources are contaminated by these wastes and finally the cultivation area [3]. The peri urban and urban agriculture is using the untreated wastewater irrigation. About 11% of land used for vegetation is using the untreated wastewater around the globe [4].

The effluents emitted from industries and human settlements which are collectively called municipal waste (public waste) have been enhanced due to rapid population growth in cities and increased number of industries and because of this, pollution of the environment has been increased [5, 6]. In rivers or other water bodies, heavy metal contamination has caused problems in the species living in these habitats e.g. fishes are mostly susceptible to it and the people who eat these fishes suffer with many diseases [7, 8]. In this way the ecosystem gets affected with the pollution of heavy metals [9].

Enormous amounts of heavy metals are discharged to the soils, ground and surface water by many anthropogenic actions that include use of automobiles for transportation, cultivation, mining and production of industrial effluents from industries. These are emitted to the environment ultimately [10, 11]. By passing across the boundary of soil and root heavy metals increase in concentration in the crops [12, 13]. Trace metals like Fe and Mn are accumulated by plants upto poisonous levels although they are useful for the growth of plants [14]. Health of humans becomes vulnerable to the risks caused by heavy metal toxins when they consume the vegetables grown in the soil that is irrigated via industrial wastewater. The irrigation of soils with the wastewater for extended time period results in the enormous levels of the heavy metals beyond safe limits that hamper the soil fertility. Eventually, the heavy metals accumulate in the plants to hazardous levels after the increased concentration of metal content in the soil which plants are grown in [15].

In this direction, the main objective of the present research was to determine the concentrations of the Fe and Mn in soil samples irrigated with canal and sewage water to evaluate the fitness of these vegetables for human health.

Materials and methods

Study area

The present research was performed in Sargodha City, Punjab, Pakistan. This city has tolerable winter season and warm temperature from May to July 2017. The temperature differs from 24 to 50 °C in the summer. The main production of this city is citrus fruits. The areas irrigated with sewage and canal water in the Sargodha city were selected for this study. The land used in agriculture is saline in nature in this city. Mostly the areas surrounding the Sargodha are irrigated with the industrial wastewater. Two sites were selected for study i.e. site I, where canal water (CWI) is used for irrigation and site II, where industrial sewage water (SWI) is used.

Sample preparation

In this study, *Raphanus sativus* L. (roots), *Brassica rapa* L. (roots), *Zingiber officinale* Roscoe (roots), *Capsicum baccatum* L. (fruit), *Capsicum frutescens* L. (fruit), *Capsicum annuum* L. (fruit), *Solanum lycopersicum* L. (fruit) and *Curcuma longa* L. (rhizome) were chosen as vegetables samples. All these samples were collected at maturity.

Wet digestion process

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The procedure for sample arrangement and preparation involved the wet digestion process. This process involves following steps: Firstly, complete digestion of samples is done by using acid and hydrogen per oxide. After digestion, prepared samples are first filtered and then diluted with distilled water.

100 mL flask, 10 mL pipette, small size beakers, stirrers, Whatman filter paper, acid and hydrogen per oxide are required for wet digestion process. The wet digestion breaks down organic components of the sample and the organic content found in plant tissue is disintegrated into CO_2 by strong oxidizing agents such as H_2O_2.

Due to the disintegration of organic content into CO_2, a colourless transparent and clear solution is obtained. Firstly, soil is weighed, and 1 g sample is added in flask. The sample is placed on hot plate after the addition of 20 mL nitric acid. On hot plate sample is heated till it boils, and the volume gets reduced to 2 or 3 mL. After removing the sample from hot plate, the sample is allowed to cool down. Then 10 mL hydrogen per oxide which is strong oxidizing agent is added to the solution. All steps are repeated till the colourless, clear and transparent solution is obtained.

Similar digestion process was done for the digestion of the collected food crops. The food crops were converted to powdered form and then dried completely in oven for 24 h. The samples were then added to the digestion flask. Then hydrochloric acid and nitric acid were added in following proportion i.e. 1:3 and the solution was measured in measuring beaker and then 20 mL of this strong acid solution was added to the dried powdered sample grains. Heating and boiling of samples was done on hot plate in digestion flask. After that 10 mL mixture solution of acid was added to the cooled solution of sample and then again placed on hotplate till the clear and colourless solution was obtained. The next step after complete digestion was dilution of the samples that were prepared with distilled water. The volume of the solution was made 50 mL for each sample. After the samples were diluted, the samples were filtered through Whatman filter paper, labelled and made airtight in plastic bottles [22].

Iron and manganese analysis

The analysis of heavy metals requires the formulation of specific standard solution for the heavy metals that are under research. Before starting the analysis of iron (Fe) and manganese (Mn), the formulation of the standard solution was done. After formulation of specific standard solution, the heavy metal analysis was done with atomic absorption spectrophotometer (AAS-6300 Shimadzu Japan).

Preparation of the standard solution

The general method for analysis of metal can be used to prepare the standard solution in which the amount in ppm for stock solution preparation whose stock solution is to be prepared is divided by the volume of solvent such as distilled water and for metal stock solution preparation from metal salt weight of the test metal is multiplied by mole fraction concentration of metal and then divided by solvent concentration.

Statistical analysis

Among different plant (crops) and soil samples, the degree of variation was measured by using SPSS 22 (Statistical Package for Social Sciences). To measure the mean concentration values for soil and food crop samples, one-way ANOVA was conducted.

Daily intake of metals (DIM)

DIM stands for daily intake of metals. It is defined as the amount calculated to the intake of trace metals orally obtained by formula given by Sajjad et al. [16]. For humans, normal value of DIM is 0.242 kg. Human mean weight is taken as 55.9 kg.

DIM = Concentrations of metal x Daily consumption of vegetable (kg per person)/Average body weight of a person

Pollution load index (PLI)

The presence of heavy metals in soil is assessed by this factor. By relating the amount of trace element in the polluted soil under consideration with reference to the amount of the same trace element as mentioned by the reference value of that element in soil, PLI is measured. It is calculated by following formula:

PLI= metal concentrations in soils/metal concentration taken as reference

Health risk index (HRI)

Health risk index is calculated relative to DIM value and relative dose (RfD). The formula described by Cui et al. [17] is used to measure the relative measurement of HRI.

HRI= DIM/ food oral reference dose for the metal

Bio-concentration factor

The concentration of a substance in the tissue of organism is called bio-concentration factor (BCF). It is also known as enrichment factor or bio magnification factor. It is measured by the following formula:

BCF = Vegetable metals/Soil metals

Results and discussion

Iron and manganese concentrations in soil samples

The mean Fe concentration in soil varied from 16.425 to 32.835 mg/kg. Higher Fe values in soil were observed during sewage water irrigation and lower values were observed by canal water irrigation. The ANOVA results showed significant ($p \leq 0.05$) variation in Fe concentration with respect to the irrigated sites (Table 1). The mean Mn concentration in soil varied from 0.450 to 0.904 mg/kg. Higher Mn values in soil were observed during sewage water irrigation. The ANOVA results showed non-significant effect ($p > 0.05$) on Mn concentration with respect to the irrigated sites (Table 1). Soil serves as the most central component in agricultural environment and contents of heavy metals and various other minerals in soil determine the accretion of heavy metal in plant body. The Fe levels in the soil samples investigated in the present research were lower than the maximum permissible limit of Fe (2100 mg/kg) reported by WHO [18]. The level of Mn in present findings were below the permissible limit of 2000 mg/kg given by FAO/WHO [19]. This might be due to factors like soil pH, amount of organic matter, redox potential of soil and rate of addition of metals mainly affecting their adsorption and retention in soil [20].

Iron and manganese concentrations in vegetable samples

In different vegetables, the mean Fe concentrations (mg/kg) ranged from 1.16-2.318 (*Raphanus sativus*), 0.249-0.496 (*Brassica rapa*), 0.189-0.374 (*Zingiber officinale*), 0.606-1.211 (*Capsicum baccatum*), 0.159-0.316 (*Capsicum frutescens*), 0.416-0.829 (*Capsicum annuum*), 0.666-1.329 (*Solanum lycopersicum*) and 1.073-2.143 (*Curcuma longa*) (Table 1). Higher Fe values were observed in *Raphanus sativus* at SWI and lower Fe contents were noticed in *Capsicum frutescens* at CWI. According to the ANOVA results, the irrigation water had significant effect ($p \leq 0.05$) on the Fe contents in *Raphanus sativus*, *Capsicum annuum*, *Solanum lycopersicum* and *Capsicum baccatum*. Whereas non-significant effect ($p > 0.05$) was observed in *Zingiber officinale*, *Capsicum frutescens*, *Brassica rapa* and *Curcuma longa* (Table 1). The Fe levels in the vegetable samples investigated in the present research were lower than the maximum permissible limit of Fe (1000 mg/kg) reported by Chiroma *et al*. [21]. The values of Fe in present findings were lower than those recorded by Ahmad et al. [22]. The quantities of Fe in the leafy vegetables were higher than values in the other vegetables mainly in middle district. The reasonable clarification of this condition is that the Fe uptake is enhanced in leaves thereby leading to accumulation of Fe in leaves.

In different vegetables, the mean Mn concentrations (mg/kg) ranged from 0.769-1.535 (*Raphanus sativus*), 0.156-0.259 (*Brassica rapa*), 0.388-0.374 (*Zingiber officinale*), 0.833-1.653 (*Capsicum baccatum*), 0.369-0.316 (*Capsicum frutescens*), 0.3691-0.829 (*Capsicum annuum*), 0.551-1.100 (*Solanum *lycopersicum*) and 388-1.585 (*Curcuma longa*) (Table 1). Higher Mn values were observed in *Raphanus sativus* by sewage water irrigation and lower Mn contents were noticed in *Capsicum frutescens* by canal water irrigation. According to the ANOVA results the irrigation water had significant effect ($p \leq 0.05$) on the Mn contents in *Raphanus sativus*, *Capsicum frutescens, Curcuma longa and Capsicum baccatum* (Table 1). Whereas non-significant effect ($p>0.05$) was observed in *Zingiber officinale, Brassica rapa, Capsicum annuum* and *Solanum lycopersicum* (Table 2). The values of Mn were within the permissible limit of 500 mg/kg given by FAO/WHO [19]. Mn values in present investigation were similar to the findings of Ahmad *et al*. [23]. Various researches presented that the mineral contents of the vegetables are more in sites which were treated with sewage water as compared to canal water. The current study analysis is in good accordance with other studies [24, 25] which suggested that uptake of metals by plants is proportional to the compositional contents and bioavailability in soils. The Fe and Mn are considered as key elements for the production of chlorophyll and also regulate various respiratory enzymes present in plants.

Bio-concentration factor

Bio-concentration factor values of Fe and Mn in various vegetables are presented in Table 2. In different vegetables, the BCF values of Fe differed from 0.071-0.071 (*Raphanus sativus*), 0.015-0.015 (*Brassica rapa*), 0.011-0.011 (*Zingiber officinale*), 0.037-0.037 (*Capsicum baccatum*), 0.010-0.010 (*Capsicum frutescens*), 0.025-0.025 (*Capsicum annuum*), 0.041-0.040 (*Solanum lycopersicum*) and 0.065-0.065 (*Curcuma longa*). Higher BCF values were recorded for *Raphanus sativus* and lower Fe values were found in *Capsicum frutescens* by sewage water irrigation. On the other hand, the BCF values of Mn were: *Raphanus sativus* (0.071-0.071), *Brassica rapa* (0.015-0.015), *Zingiber officinale* (0.011-0.011), *Capsicum baccatum* (0.037-0.037), *Capsicum frutescens* (0.010-0.010), *Capsicum annuum* (0.025-0.025), *Solanum lycopersicum* (0.041-0.040) and *Curcuma longa* (0.065-0.065) (Table 2). Higher BCF values were recorded for *Raphanus sativus* and lower Fe values were found in *Capsicum frutescens* by sewage water irrigation. When the BCF is ≤1, this presents that the plant only absorbs but does not build up heavy metals; when BCF>1, this shows that plant gathers metals in it [26]. Bio-concentration factor values of heavy metals were less than 1 in all vegetables for Fe and Mn, and these results specify that metal bioavailability was low at CWI and SWI.

Daily intake of metal and health risk index

Daily intake of metal values for Fe and Mn are presented in Table 3. Among two irrigations, the DIM values for Fe were 0.007-0.013 (*Raphanus sativus*), 0.001-0.003 (*Brassica rapa*), 0.001-0.002 (*Zingiber officinale*), 0.003-0.007 (*Capsicum baccatum*), 0.001-0.002 (*Capsicum frutescens*), 0.002-0.005 (*Capsicum annuum*), 0.004-0.008 (*Solanum lycopersicum*) and 0.006-0.012 (*Curcuma longa*). In all vegetables, the DIM values for Fe were higher during sewage water irrigation as compared to the canal water irrigation. On the other hand, the DIM values for Mn were *Raphanus sativus* (0.007-0.013), *Brassica rapa* (0.001-0.003), *Zingiber officinale* (0.001-0.002), *Capsicum baccatum* (0.003-0.007), *Capsicum frutescens* (0.001-0.002), *Capsicum annuum* (0.002-0.005), *Solanum lycopersicum* (0.004-0.008) and *Curcuma longa* (0.006-0.012) (Table 3).

Table 1. Analysis of variance and mean values of iron and manganese (mg/kg) in soil and vegetables treated with canal and sewage water

	Fe Contents			Mn Contents		
	Mean ± S.E.		Mean Square	Mean ± S.E.		Mean Square
Soil	16.425±2.754	32.835±5.500	7.118*	0.450±0.102	0.904±0.184	4.638ns
Raphanus sativus	1.160±0.198	2.318±0.395	6.850*	0.769±0.019	1.535±0.040	302.795***
Brassica rapa	0.249±0.092	0.496±0.184	1.442ns	0.156±0.041	0.259±0.075	1.430ns
Zingiber officinale	0.189±0.113	0.374±0.227	0.533ns	0.388±0.077	0.774±0.155	4.966ns
Capsicum baccatum	0.606±0.049	1.211±0.098	30.336**	0.833±0.193	1.653±0.376	3.767*
Capsicum frutescens	0.159±0.038	0.316±0.075	3.509ns	0.369±0.052	0.734±0.104	9.842*
Capsicum annuum	0.416±0.063	0.829±0.126	8.538*	0.551±0.115	1.100±0.230	4.547ns
Solanum lycopersicum	0.666±0.063	1.329±0.126	22.024**	0.533±0.120	1.050±0.230	3.967ns
Curcuma longa	1.073±0.197	2.143±0.395	5.867ns	0.788±0.022	1.585±0.040	309.304***

*, ***= significant at 0.05 and 0.001 levels, ns = non-significant

Table 2. Bio-concentration factor for vegetable/soil system for iron and manganese

Vegetables	Iron		Manganese	
	CWI	SWI	CWI	SWI
Raphanus sativus	0.071	0.071	1.708	1.698
Brassica rapa	0.015	0.015	0.347	0.286
Zingiber officinale	0.011	0.011	0.861	0.856
Capsicum baccatum	0.037	0.037	1.850	1.828
Capsicum frutescens	0.010	0.010	0.819	0.812
Capsicum annuum	0.025	0.025	1.225	1.217
Solanum lycopersicum	0.041	0.040	1.183	1.162
Curcuma longa	0.065	0.065	1.750	1.754

Table 3. Daily intake of metals and health risk index of iron and manganese contents via intake of different vegetables from canal and sewage wastewater irrigated sites

	Iron		**Manganese**		**Iron**		**Manganese**	
Vegetables	**Daily intake of metal**				**Health risk index**			
	CWI	**SWI**	**CWI**	**SWI**	**CWI**	**SWI**	**CWI**	**SWI**
Raphanus sativus	0.007	0.013	0.004	0.009	0.0100	0.0186	0.0976	0.2195
Brassica rapa	0.001	0.003	0.001	0.001	0.0014	0.0043	0.0244	0.0244
Zingiber officinale	0.001	0.002	0.002	0.004	0.0014	0.0029	0.0488	0.0976
Capsicum baccatum	0.003	0.007	0.005	0.009	0.0043	0.0100	0.1220	0.2195
Capsicum frutescens	0.001	0.002	0.002	0.004	0.0014	0.0029	0.0488	0.0976
Capsicum annuum	0.002	0.005	0.003	0.006	0.0029	0.0071	0.0732	0.1463
Solanum lycopersicum	0.004	0.008	0.003	0.006	0.0057	0.0114	0.0732	0.1463
Curcuma longa	0.006	0.012	0.004	0.009	0.0086	0.0171	0.0976	0.2195

Table 4. Pollution load index of iron and manganese in soil

Sites	**Fe**		**Mn**	
	Reference soil value [17]	**PLI**	**Reference soil value [17]**	**PLI**
CWI	56.9	0.2887	25.5	0.0176
SWI	56.9	0.5771	25.5	0.0354

In all vegetables, the DIM values for Mn were higher during sewage water irrigation as compared to canal water irrigation. The results revealed that HRI of Fe and Mn was less than 1 in each vegetable which was lower than the permissible limit. To determine the health risk associated with heavy metal contamination of plants grown locally, estimated exposure and risk index were calculated. In all vegetables, the HRI values for Fe and Mn were higher during sewage water irrigation as compared to the canal water irrigation (Table 3). In the present study, the HRI values of Fe and Mn fell under the safe limit of HRI value and were considered fit for human consumption. The present study consequences were relatively identical to other researchers' observations [27].

Pollution load index (PLI)

The PLI values of Fe for soil samples were 0.2887 and 0.5771 for CWI and SWI treatment, respectively (Table 4). On the other hand, the PLI values of Mn for soil samples were 0.0176 and 0.0354 for CWI and SWI treatment, respectively. Contamination level in soil can be explored using PLI. This index provides a simple and comparative means for assessing the quality of different combinations of water irrigation. As described by Tomlinson et al. [28], a value of zero indicates no risk, whereas a value of one and values above one would indicate progressive deterioration of the site irrigated with this water quality.

Conclusion

Wastewater irrigation is common practice in many parts of the world. Wastewater contains surplus amount of toxic metals and micronutrients required for the growth of plants. The results revealed that the mean levels of iron and manganese in all vegetables were within the permissible limits given by FAO/WHO. The bioaccumulation of Mn in vegetable samples was quite high as compared to Fe. The values of HRI for both Mn and Fe were less than 1 indicated that these vegetables are safe for human consumption. Prolonged use of wastewater for irrigation may cause issues as elevetaed level of metals indicate accumulation which might reach toxic levels for humans.

Authors' contributions

Conceived and designed the experiments: ZI Khan, I Ugulu, K Ahmad & IR Noorka, Performed the experiments: A Nisar, H Bashir, M Munir, A Ashfaq, R Abdullah, S Iqbal & F Batool, Analyzed the data: K Wajid, M Nadeem, TM Qureshi & IS Malik, Contributed reagents/ materials/ analysis tools: K Nawaz, Mian Jahan Zaib Rasheed, H Memona, M Shehzadi & M Sana, Wrote the paper: N Mehmood, T Abbas, S Ullah, J Zaib, H Muqadas & S Siddique.

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