



Original Research Paper

Effect of Wastewater on the Soil and Irrigation Process: A Laboratory Study



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Abstract

Most of the industrial sewage effluents used for irrigation contains heavy metals which cause toxicity to crop plants as the soils are able to accumulate heavy metal for many years. The vegetables grown for the present study were irrigated with treated wastewater brought from a nearby full-scale sewage treatment plant at different compositions along with tap water as a control. The concentration levels of the Cd, Co, Cu, Mn and Zn in the soil were found to be below the toxic limits as prescribed in literature. Daily Intake Metals (DIM) values suggest that the consumption of plants grown in treated wastewater and tap water is nearly free of risks, as the dietary intake limits of Cu, Fe, Zn and Mn. The Enrichment Factor for the treated wastewater irrigated soil was found in order Zn > Ni > Pb > Cr > Cu > Co > Mn > Cd. Thus, treated wastewater can be effectively used for irrigation. This will have twofold significant environmental advantages: (1) helpful to reduce the groundwater usage for irrigation and (2) helpful to reduce the stress on surface water resources.

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1 INTRODUCTION

The continuous increase of the urban population and the increasing per capita water consumption has turned maximum amount of the fresh water to commercial, domestic and industrial sectors which generates a greater volume of waste water. In many developing countries including India, farmers are irrigating their crops with industrial effluents due to the non-availability of an alternative source. Effluent from municipal sewage treatment plants, apart from supplying water to plants, often contains high levels of macro and micro nutrients and heavy metals. Contamination of soil in cultivated fields by industrial effluents loaded with toxic heavy metals has emerged as a new threat to agriculture. The percolations of these surface pollutants through the soil

cause soil degradation. Pollution on the ground surface is the major cause of soil pollution. This surface pollution comes from many sources like waste (solid or liquid) disposal practices, spills, agricultural practices and percolation of surface pollutants through unsaturated soil, etc. (Patil et al., 2014).

Large areas of agricultural land are contaminated by heavy metals that mainly originate from former or current mining activities, industrial emissions or the application of sewage sludge. Metals 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 surfaces. Although mineral, organic and sorbed metals

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are not immediately absorbed by plants, they can slowly release metals into solution (Jones and Jacobsen, 2003). The essential elements including Cr, Cu, Co, Fe, Mn, Mo, Ni, Se and Zn are required by organisms at some level and become toxic at some higher levels of exposure. Non-essential elements including As, Sb, Cd, Pb, Hg, Tl, Sn and Ag are toxic and no one required by organism at any level (McGrath, 2001). Most of the 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 copper, zinc, manganese, iron and boron are essentially 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 ecological treatment system, as it gives rise to an environmental impact due to its energy consumption, use of chemical compounds, emissions to the atmosphere and sludge production. Sludge is the largest by-product from waste water treatment plants and its disposal is one of the most challenging environmental problems in waste water treating processes.

Agricultural land that is initially not affected can also be contaminated with heavy metals if it is irrigated with water coming directly from urban areas or from other polluted sources and also by the constant application of fertilizers and agro-chemicals this contained heavy metals. It has been shown that crops and vegetables cultivated in soils with heavy metals contamination accumulate a greater quantity of heavy

metals than those cultivated in uncontaminated soil (Alrawiq et al., 2014). The ecological balance of any system gets affected due to the widespread contamination of the soil. Most plants are unable to adapt when the chemistry of the soil changes so radically in a short period of time. Fungi and bacteria found in the soil that bind it together begin to decline, which creates an additional problem of soil erosion. Soils are able to accumulate heavy metals for many years without the obvious signs of their acute toxic effect. However, the filtering/purifying capacity of soils is finite and, above a certain level, soils are no longer able to absorb these elements and become sources of pollution themselves. Toxic elements from the environment are released into water and absorbed by cultivated crops and plants. Thereafter, they are assimilated into vegetative and generative organs and enter the food chain where they cause long term. The system of relation between heavy metals-soils-plants can be accurately and reliably studied in targeted field experiments (Fodor and Szabo, 2004). A typical range of metals in soils derived from normal and geochemically anomalous parent material in Britain is shown in the 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 excess heavy metals may pose a risk to the food chain and human health (Parveen et al., 2015).

Table 1. Metals in soils derived from normal and geochemically anomalous parent material in Britain (Nriagu, 1990)

Metals	Typical range (mg/kg)	Metals rich soil (mg/kg)	Sources	Possible effects
As	< 5- 40	Upto 2500 Upto 250	Mineralization Metamorphosed rocks around Dart moor	Toxicity in plant and live stocks excess in food crops
Cd	< 1- 2	Upto 30 Upto 20	Mineralization Carboniferous black shale	Excess in food crops
Cu	2- 60	Upto 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	Upto 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	Upto 7	Marine black shales in England and Wales	Chronic selenosis in horses and cattle
		Upto 500	Namurian shales in Ireland	
Zn	25- 200	1% or more	Mineralization	Toxicity cereal crops

Vegetables take up heavy metals and accumulate them in their edible and non-edible parts at quantities high enough to cause clinical problems to both animals and human beings. Vegetables acts as buffering agents acid generation during digestion and some metals present in vegetables are even important biochemically and psychologically from health point of view. Metals like cobalt (Co), copper (Cu), iron (Fe), manganese (Mn) and selenium (Se) but some elements like lead (Pb), cadmium (Cd) and arsenic (As) are very toxic for human (Jolly *et al.*, 2013). Heavy metals may also adversely effects plant growth as they can influence biochemical processes such as metabolism, photosynthetic and stomata opening.

Metal absorption and accumulation in a plant depends on many soil factors, such as- pH, EC, clay content, organic matter content and physical and mechanical characteristics of soil. Plant takes heavy metals from soil through different reactions such as: absorption, ionic exchange, redox reactions, etc. (Zabalawy *et al.*, 2015). Considering these facts in view the study has been carried out by irrigating the vegetables with different concentration of Sewage Treatment Plant (STP) treated wastewater/effluent in order to observe the effects on heavy metals accumulation and growth on some selected vegetables. Also, the physiochemical characteristics of soil medium and heavy metals concentration in soil and sewage treatment plant effluent have been assessed in the present study.

2 METHODOLOGY

In present study the vegetables grown in School of Architecture premises inside Gauatm Buddha University campus, Greater Noida, U.P., India. The soil for the same was brought from nearby fields of the Dankaur village near the campus. However, the treated effluent was brought from a 137 MLD capacity Sewage Treatment Plant located at Kasna Village near the GBU campus for the irrigation of vegetables. The vegetables selected for the study on seasonal basis are Carrot (*Daucus Carota Subsp Sativus*), Radish (*Raphanus Sativus*) and Spinach (*Spinacea Oleracea*). These



Figure 1: Image of 90 pots for growing vegetables used in the present study

vegetables were grown pretreated, equally filled soil and properly labeled 90 pots as shown in Figure 1.

2.1 Water, Treated Wastewater and Soil Analysis

Soil samples were collected from the agricultural land of Dankaur area of Gautam Buddh Nagar District, Greater Noida. Prior to the study the physicochemical characteristics (pH, Electric Conductivity, total N, P, K, Na, Mg and Ca) and heavy metals (Cd, Ni, Mn, Cr, Pb, Co, Zn, Cu) of the collected soil, water and treated wastewater samples were determined. All the analysis was carried out as per the standard method suggested by APHA (2005). The pretreatment of all the samples was carried out before heavy metals analysis by digesting each sample with 1 mL nitric acid and 3 mL perchloric acid. The samples were filtered through Whatman 45 filter paper. The obtained filtrate was used for heavy metals analysis using Atomic Absorption Spectrophotometer (Model GBC Avanta M). The heavy metals analysed in the present study are cadmium (Cd), nickel (Ni), manganese (Mn), chromium (Cr), lead (Pb), copper (Cu), Zinc (Zn) and Cobalt (Co).

2.2 Pots Preparation

The vegetables grown in the pots by using a statistical approach of simple randomized block design method suggested by Parveen *et al.* (2015). In order to carry out the study 90 pots were prepared and study was carried out during the period of January-April, 2016. Pots of size 20 cm diameter filled with 5kg soil and each pot weighted around 1.8 kg. Vegetables and plants were harvested after 60 days time interval as the time is enough to construe the maturity and is known as days after sowing (DAS) period. The experimental study was being planned by using five pot sets and the water and treated wastewater was used for irrigation. The composition of water (control water) and treated wastewater used for watering these pots was varied accordingly. Vegetables were grown under five different conditions as (i) 100% tap water with 0% treated wastewater (ii) 75% tap water with 25% treated wastewater (iii) 50% tap water with 50% treated wastewater (iv) 25% tap water with 75% treated wastewater and (v) 0% tap water with 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.

2.3 Daily Intake of Metals (DIM)

In the present study the daily intake of metal (DIM) was also determined by using following equation (equation 1):

$$DIM = C_{metal} \times C_{factor} \times D_{food\ intake} / B_{average\ weight} \quad (1)$$

where, C_{metal} , C_{factor} , $D_{food\ intake}$ and $B_{average\ weight}$ represent the heavy metal concentrations in plants (mg/g), conversion factor, daily intake of vegetables and average body weight of humans, respectively. The conversion factor 0.085 is used to convert fresh green

vegetable weight to dry weight. The average daily vegetable intakes for adults and children were considered to be 0.345 and 0.232 kg/person/day, respectively. While the average adults and children body weight were considered to 55.9 and 32.7kg, respectively (Rattan *et al.*, 2005; Arora *et al.*, 2008; Khan *et al.*, 2008).

2.4 Enrichment Factor (EF)

The term enrichment factor is the degree of soil contamination and heavy metal accumulation in 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 treated wastewater irrigated soil and vegetables were calculated by following equation (equation 2)

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

The data were analyzed statistically as per the method prescribed by Panse and Sukhatme (1985). The measurement is expressed in terms of mean values and standards errors of duplicates. Value of $0.5 \leq EF \leq 1.5$

suggest that the trace metal concentration may come entirely from natural weathering processes (Zhang and Lui, 2002).

The enrichment factor close to unity (EF=1) indicate, that the element considered did originate from the soil (Chiarenzelli *et al.*, 2001). The enrichment factor EF>1.5 indicates that a significant portion of the trace metals was delivered from non-crustal material (Sutherland *et al.*, 2000).

3 RESULTS AND DISCUSSIONS

The results obtained from the analysis of soil, water and treated wastewater samples in terms of physicochemical parameters are being summarized in Table 2. The heavy metals lead, zinc, chromium, copper, nickel, manganese, cobalt and cadmium analysis were carried out for the same. The concentration of the heavy metals present in treated wastewater and soil were within the permissible limits as per standards prescribed for land disposal (Pescod, 1992). The concentration of all heavy metals is found to be higher in treated wastewater than in the soil. Soil texture was loamy sand. It has great influence on root growth and its ability to absorbed water for optimum growth for root vegetables.

Table 2. Results of Physicochemical parameters of treated wastewater and soil

Para meter	pH	EC (µmho/cm)	N	P	K	Na	Ca	Mg	TOC (%)	NO ₃ -N	TSS
Soil (mg/g)	8.97	420	5.5	0	11	27	12	468	3.6	3.24	-
Treated wastewater (mg/L)	8.28	582	20	4.7	15	305	20	356	-	0.78	240

Table 3. Concentration of heavy metals before irrigation of vegetables (Soil and Treated wastewater)

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

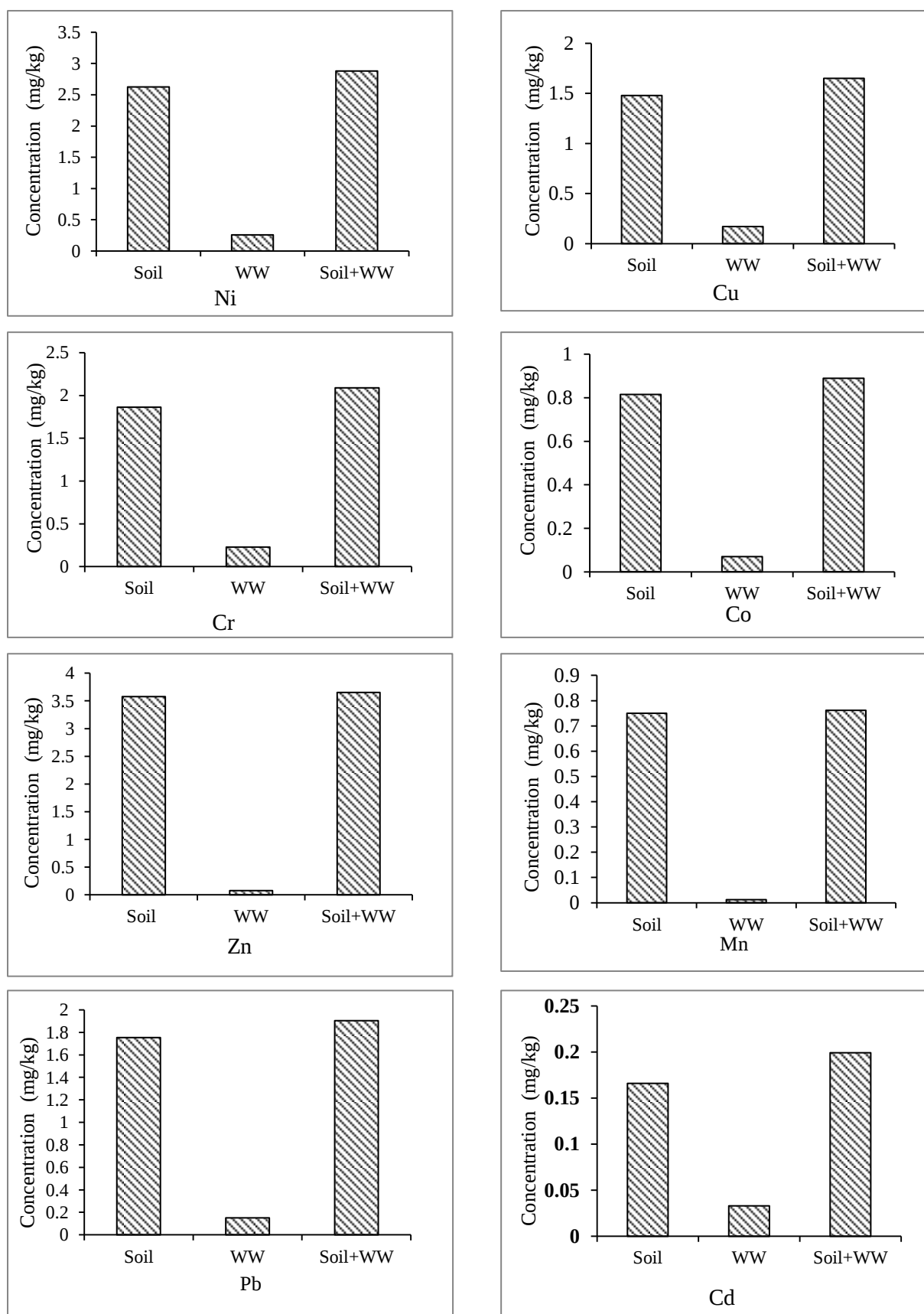


Figure 2. Variation of heavy metals concentration in various parts of radish vegetable (a) Ni, (b) Cu, (c) Cr, (d) Co, (e) Zn, (f) Mn, (g) Pb and (h) Cd

The organic matter is an important source of plant nutrients in addition to its role of providing organic colloidal of soil. It has water holding capacity, ion exchange capacity and soil fertility as its regulates the soil water and air supply, which in turn control the rate at which nutrients are absorbed by the roots. The average pH value of soil is observed to be 8.97 and the nutrients uptake by various vegetables is pH dependent. Result from the present study indicates high pH values of soil as compared to the treated wastewater (effluent).

Among the eight heavy metals, the Cd and Co is found to be in lower concentration as compared to other heavy metals. This may be due to their high dependability on solubility and soil pH. The experiments from present study indicates that the heavy metals concentration is found to be higher in leaves and roots of the plants that are grown with 25%, 50%, 75% treated wastewater as compared to the plants grown in irrigating with 100% treated wastewater. It was not astounding because the metals uptake may be different in relation to external concentration and genotype.

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

wastewater at 60 days interval. The result indicates that the Zn concentration is found to maximum in leaves than roots. The concentration is found normally decreased in plant roots with increased growth of plant. The Cd concentration 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 range of Cd concentration varied from 20.5 to 39.5 mg/g. The results of the present study as shown through [Figure 2](#) indicates that the concentration of Cd, Co and Cu is found low and below the toxic levels in leaves and roots of all the vegetables. The concentration of Cu varied from 22 to 324 mg/g in all the plants. The Cr concentration ranged from 84 to 441 mg/g and Co concentration is found in the range of 12 to 77 mg/g. However, the Cr concentration was greater in the leaves of the spinach and carrot but in radish the concentration was high enough as compared to the leaves.

The Ni concentration was generally greater in the leaves of all the vegetables plants. The concentration of Ni in all plants varied from 100 to 545 mg/g. The concentration of Mn in all vegetable plants is found in the range of 106.5 to 429 mg/g which is lower than the toxic levels as its concentration normally decreases with time as the plant grows. The concentration of

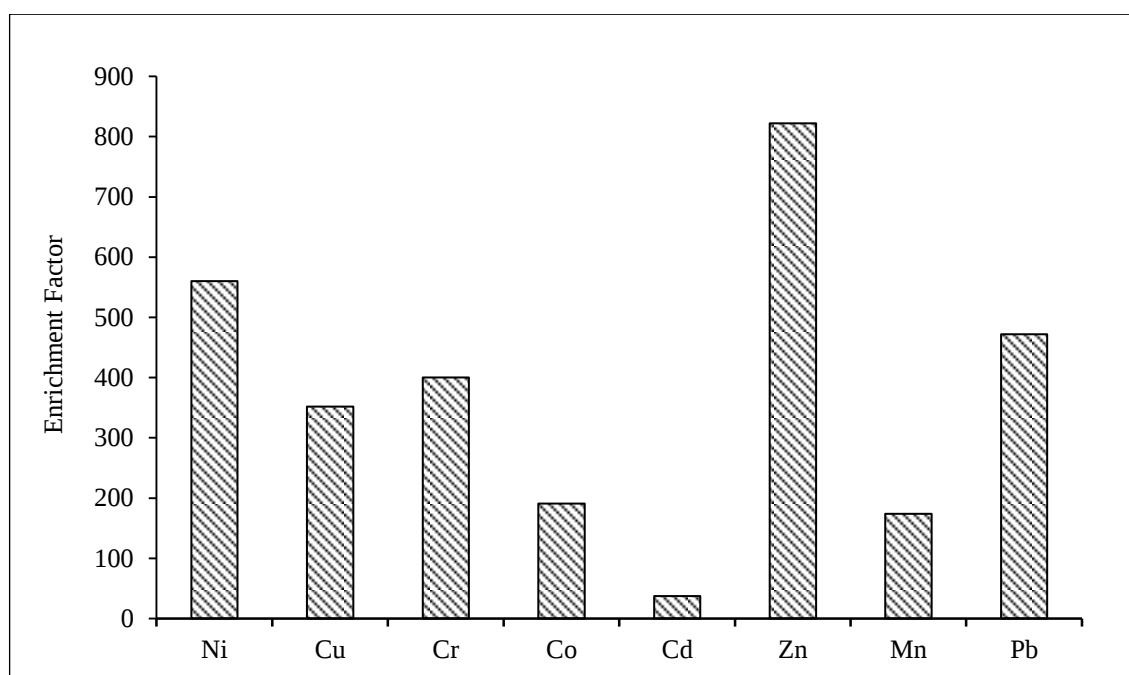


Figure 3. Soil Enrichment Factor of heavy metals irrigated with treated wastewater

Table 4. Daily Intake of Metals (DIM) calculated from the analyzed results of 60 days study period

1. Daily intake of metals of Radish (mg/kg)

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
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

2. Daily intake of metals of Spinach (mg/kg)

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
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

3. Daily intake of metals of Carrot (mg/kg)

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
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

Zn varies from 152 to 259 mg/kg and Pb concentration varied from 72.5 to 346 mg/kg. The translocation factor from the analyzed data has been evaluated and the values for the same has been found to be more in the shoots of the grown plants than in root part of the plants.

The concentration of the heavy metals in the soils irrigated with treated water and normal ground water were in the order of Fe > Mn > Cr > Zn > Pb > Cu > Cd and Fe > Zn > Cr > Mn > Pb > Cu > Cd, respectively. 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. Zhao et al. (2012) showed detection limit for heavy metals: Cd, Co, Ni, Pb, Zn, and Cu as 0.01, 0.04, 0.01, 0.34, 0.05, 0.04 $\mu\text{g L}^{-1}$, respectively. The heavy metals concentration was higher in the soil except for Cd, Cu and Mn, which may be attributed to their weak adsorption in the soil.

3.1 Enrichment Factor for Soil

The Enrichment factor for the treated wastewater irrigated soil was found in order Zn > Ni > Pb > Cr > Cu > Co > Mn > Cd. The value for the same is shown through Figure 3. The enrichment factor has been found maximum value of Zn and is found minimum value of Cd.

3.2 Daily Intake Metals (DIM)

The daily intake of heavy metals was evaluated based on average vegetables consumption 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 4. The daily intakes of metals were higher when waste on the consumption of plants grown in treated wastewater than those grown control water. Perusal of the data summarized in Table 4 regarding DIM suggests that the consumption of plants grown in treated wastewater and tap water is nearly free of risks, as the dietary 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.

4 CONCLUSIONS

The yield is high in plants irrigated with treated wastewater because of the presence of more nutrients as compared to that of tap water. Metal contamination in soil persists because of the two major pathways for human exposure to soil contamination: soil-plant-human (food chain pathways) and soil-human (incidental soil ingestion). 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 is found to be in the order of Zn > Ni > Cr > Pb > Mn > Cu > Co > Cd. Result analysis for daily intake of heavy metals suggests that the consumption of plants grown in treated wastewater is high compared to

these grown in tap water, but is nearly free from risks. The daily intake of metals (zinc, nickel, manganese, copper, lead, chromium, cobalt and cadmium) for human with body weight (adults = 55.9 kg and children = 32.7 kg) have been calculated and indicates that intake of toxic metals from vegetables is not high. In the present study, it can be inferred that water used for irrigation can be replaced by wastewater containing these heavy metals. There are certain limitations in the present study as the improper water soil ratio can affect the growth of plants. Moreover, under lab scale study, the variation in time of sowing the seasonal vegetable plants can also affect the study and can lead to time delays. Sometimes the mixing of manure and presence of nutrients in wastewater and soil can affect the growth of plants to a certain extent.

CONFLICT OF INTEREST

Authors proclaimed no conflict of interest.

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ABBREVIATIONS

Ag: Silver; **As:** Arsenic; **Ca:** Calcium; **Cd:** Cadmium; **Co:** Cobalt; **Cr:** Chromium; **Cr:** Chromium; **Cu:** Copper; **DAS:** Days After Sowing; **DIM:** Daily Intake Metal; **EC:** Electric Conductivity; **EF:** Enrichment Factor; **Fe:** Iron; **Hg:** Mercury; **K:** Potassium; **Mg:** Magnesium; **MLD:** Million Litres Per Day; **Mn:** Manganese; **Mo:** Molybdenum; **N:** Nitrogen; **Na:** Sodium; **Ni:** Nickel; **NO₃-N:** Nitrate Nitrogen; **P:** Phosphate; **Pb:** Lead; **Sb:** Antimony; **Se:** Selenium; **Sn:** Tin; **STP:** Sewage Treatment Plant; **Tl:** Thallium; **TOC:** Total Organic Carbon; **TSS:** Total Suspended Solid; **WWTP:** Waste Water Treatment Plant; **Zn:** Zinc.

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