Accumulation and Translocation of heavy metals from soils to vegetables by sewage effluent application in territory of Rawalpindi

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Abstract

Application of sewage effluent for growing vegetables in peri-urben areas of big cities has become a common practice. A survey was conducted during 2008-2009 from 15 different sites of Rawalpindi, Pakistan to assess accumulation of heavy metals in soil and edible parts of vegetables by application of sewage effluents. Samples were collected randomly from sewage effluents, nearby soil and vegetables, and were analyzed for Zn, Ni, Mn, Pb, Fe, Cu, Co, Cr and Cd contents. Results revealed exceeding concentration of Ni (43%), Mn (71%), Pb (29%), Cu (29%) and Cr (43%) in sewage effluent. Fields (surface and in sub-surface soil) receiving sewage effluent were higher in metals contents than safe limits except Cd, Ni, Co and Pb. Vegetables (coriander, spinach, garlic, tomato and chili) grown in these field were found 100% contaminated and accumulation of heavy metals was higher than the WHO/FAO recommended permissible limits.

Keywords: Heavy metals, sewage effluent, contaminated soil, vegetables, peri-urban area

1. Introduction

Water is necessary for the survival and existence of all living organism on this planet. About 6% water is used for domestic, 3% for industrial and 90% of the total available water is used for irrigation purposes (Khan *et at*., 2013). Wastewater generated by domestic, industrial and commercial sources has increased with urbanization (Akram *et al*., 2006; Qadir *et al*., 2008). In urban areas of many countries wastewater is used as a source of irrigation water to some extent (Huibers *et al*., 2004). In Pakistan the shortage of surface water supply is being compensated by the conjunctive use of ground water and urban wastewater (sewage and industrial effluents) for irrigation to grow cereals and vegetables (Hussain *et al*., 2002). Farmers use sewage-contaminated municipal water for irrigation of crops earned more than those using freshwater (Ensink *et al*., 2004). However, wastewater contains large amount of organic material and inorganic elements essential for proper growth and development of crops (Mitra and Gupta, 1999). Rawalpindi is one of the over populated and polluted city which may cause soil pollution and contaminate the vegetables grown with it (Ullah *et al*., 2011). The heavy metals such as Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn have been identified from different industrial effluents (Asaolu, 1995). Some of the heavy metals are vital for proper plant growth but the others are not essential so after accumulating in the soil they could be shifted to food chain and caused detrimental effects (Ghafoor *et al*., 1995; Malla *et al*., 2007). Even low concentrations of heavy metals have damaging effects to man and animals because there is no established mechanism for their elimination from the body (Khan *et al*., 2013). Nowadays toxic heavy metals in wastewater are abundant because of their undue use in industrial applications (Singh *et al*., 2004; Chen *et al*., 2005). Long-term application of treated and untreated waste water resulted in significant buildup of heavy metals in soil, vegetables, cereals and their subsequent transfer to food chain causing potential health risk to consumers (Khan *et al*., 2008; Singh *et al*., 2010; Gupta *et al*., 2011; Ullah *et al*., 2011; Gosh *et al*., 2012). Heavy metal concentrations in plants were significantly higher grown in wastewater-irrigated soils than in the reference soil (Khan *et al*., 2008; Singh *et al*., 2010; Gupta *et al*., 2011; Meyer *et al*., 2016). Metal accumulation in soils, forage grass, milk from cattle, leafy and non-leafy vegetables was found more than the permissible limits (Sahu *et al*., 2007; Chary *et al*., 2008). Thus, the accumulation of such toxic compounds, especially of heavy metals having highly hazardous effect on living organisms, can cause undesirable changes in the biosphere with hazardous consequences (Ashwini *et al*., 2014). The present study was undertaken to assess the heavy metal content/status of the sewage-water-irrigated soil and vegetables and to correlate the heavy metal concentration of sewage water to that of the soil and plants.

2. Methodology

2.1. Sample Collection and preparation

The survey was conducted in 2009 in peri-urban area of Rawalpindi, Pakistan. Fifteen sites were selected and 3 samples in replicate from each site were collected for each soil, water and contaminated plants. Sewage effluent was collected in plastic bottles and added concentrated nitric acid to minimize microbial activity. Soil samples from two depths (0-15 cm and 15-30 cm) were taken from farmer field by using spiral auger where sewage-effluent was being used. Randomly collected samples were bulked together to make composite sample, passed through 2 mm mesh sieve and stored in plastic jars. Similarly Vegetables samples were collected from the same field, washed with distilled water then sun dried.

2.2. Soil, plant and water analysis

AB-DTPA method (Soltanpour and Workman, 1985) was used for the determination of heavy metals. Ten grams of well-prepared soil was weighed into 125 mL conical flask. Twenty milliliter of extracting solution was made by mixing ammonium bicarbonate and 0.005 DTPA. This solution was shaken on a reciprocal shaker for 15 minutes at 180 cycle's min^{-1}. Supernatant was obtained by filtering above solution through Whatman no.42 filter paper. Plant samples were dried in hot air oven at 65 ^oC for 24 hours, ground and stored in plastic jars. To estimate heavy metals, 1 g of plant material was transferred into 100 mL pyrex digestion tube, 10 ml of 1:2 HClO4 + HNO3 acidic mixture was added and allowed to stand overnight. After initial digestion, mixture was heated in block digester up to 235 ^oC and process was continued until the white fumes of perchloric acid start appearing. After cooling down the mixture, its volume was made to 100 mL with distilled water (Issac and Johnson, 1975). Prepared filtrates of plants and soil samples were used for determination of heavy metals (Zn, Cu, Mn,Cr, Cd, Ni, Pb, Fe & Co) by using Atomic Absorption Spectrophotometer and hallow cathode lamps were also changed for each metal. The metals present in sewage effluent were also analyzed by method of AOAC (1984).

2.3. Statistical Analysis

The data collected was subjected to statistical analysis for better interpretation by calculating means and standard deviation (Steel *et al*. 1997).

3. Results and Discussion

3.1. Heavy Metals Concentration in Sewage and Industrial Effluents

Descriptive statistics regarding the results of heavy metals concentration in effluents is given in the Table 1, which revealed that the concentration of iron, zinc, manganese and copper vary considerably. Iron concentration in sewage effluents varied from 0.42 to 3.04 mg L^{-1}, Zinc (0.003 to 0.084 mg L^{-1}) Manngnese (0.041 to 1.03 mg L^{-1}) and copper ranged from 0.04 to 0.84 mg L^{-1}. Zinc and iron were found 100% within the permissible limits, Cu 29% and Mn was recorded 71% above the critical levels presented by WWF (2007) Pakistan for irrigational water quality. The hıghest nickel concentration in sewage and industrial effluents was recorded 0.43 mg L^{-1} at Ali Abad. According to WWF (2007) Pakistan, for irrigational water quality the critical limit of nickel is 0.2 mg L^{-1} and 58% samples were observed safe limit and 42% found unsafe for irrigational purpose in Rawalpindi territory. The highest lead concentration was obtained (0.131 mg L^{-1}) at Dhhok Hasso in sewage water. According to limits given by WWF (2007) Pakistan for lead (0.1 mg L^{-1}) so analysed 71% water samples were observed safe and 29% found unsafe for irrigational purpose. The highest chromium concentration was obtained (2.21 mg L^{-1}) at Dhhok Hasso in sewage water and at the few of sites Cr was not found in sewage effluent. According to critical limit for Cr (0.01 mg L^{-1}) set by WWF (2007) 57% sewage and industriasl effluents samples were found fit and 43% were found unfit for irrigational purpose and cobalt was recorded 100% within the permissible limit. At different sites heavy metal ions were found beyond the permissible limits it's because the sources of effluents were from textile industry, ghee and oil industry and domestic sewage also contributes to load heavy metals in sewage water (Ansari *et al*., 1993). Jagtap *et al.* (2010) found higher contents of Zn, Cu, Pb, Ni, Cd and Cr in effluents samples from Rawalpindi Area. Gosh *et al.* (2012) reported sewage water contained Cd, Cr and Ni in amounts above the permissible limits for its use to irrigation water.

3.2 Heavy metals in soil

Heavy metals contents in surface and sub-surface soil samples has been presented in Table 2. The results showed that Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn content in surface soil ranged from 0-0.65, 0-0.21, 1.1-7.4, 4.2-14.7, 12.4-27.4, 2.11-15.41, 1.19-6.02, 2.39-21.32,and 2.3-25 mg kg^{-1} respectively with mean value 0.11±0.17, 0.03±0.05, 3.61±1.99, 9.41±3.57, 18.55±4.78, 7.96±4.15, 3.76±1.45, 8.48±6.42 and 6.57±5.94 mg kg^{-1}, similarly as in surface soil metals contents higher the metal contents in subsurface soil were founds in accordance to surface soil (table 2). According to the McLean *et al*. (1987) the permissible metal contents in soil the Cr, Cu, Fe, Mn and Zn were found 100% above the permissible limits. Same trend was observed in subsurface soil and where the metals contents were high in effluent the metals were founded higher in respective field. This might be due to the higher contents discharged from factories and long-run application of sewage effluent water for crop production. Similar results were reported by Khan *et al*. (1992) and Zhang *et al.* (2006) reported in occurdance to investigated results when sewage sludge was applied for crop irrigation. Untreated domestic waste and discharge from industries cause toxicity of heavy metals in soils reported by Ansari (1993). Ghafoor (2004) reported that the urban soils of Faisalabad irrigated with city effluents for growing vegetables for more than 30 years have attained concentration of Fe above the safe limit.

3.3 Plant Analysis

Vegetables are consumed as leaf like spinach, coriander, and chili where as tomato and garlic used as fruit and root. Therefor its necessary to investigate the level of heavy metals up taken by the vegetables by the application of sewage effluent is toxic to human shown in table 3 and 4. Therefore the concentration of heavy metals was investigated in both leaf and fruit of vegetables. The metal accumulation in vegitabel parts (Table 3 and 4) depicted that Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn were up taken

Table 1. Heavy metals in sewage and industrial effluents and classification on the basis of permissible limits given by WWF for irrigational purpose.

Heavy metals (mg L^{-1})	Range	Mean±SD	Permissible limits (mg L^{-1})	Within Permissible limits (%)	Above the Permissible limits (%)
Cd	0-0.01	0±0	0.01	100	0
Co	00	0±0	0.05	100	0
Cr	0-2.21	0.33±0.82	0.01	57	43
Cu	0.04-0.82	0.23±0.27	0.2	71	29
Fe	0.42-3.04	1.66±1.03	5	100	0
Mn	0.04-1.03	0.34±0.32	0.2	29	71
Ni	0-0.43	0.13±0.16	0.2	57	43
Pb	0-0.13	0.05±0.05	0.1	71	29
Zn	0-0.08	0.04±0.03	2	100	0

Irrigational Water Quality by Waste Water Forum Pakistan 2007.

The mean value against each metal is avrage value of 45 sample from 15 differnt sites

Table 2. Heavy metals in surface and sub-surface soil irrigated by industrial effluents and classification on the basis of permissible limits.

Heavy metals (mg kg^{-1})	Range	Mean±SD	Above the Permissible limits (%)	Range	Mean±SD	Above the Permissible limits (%)	Permissible limits (mg kg-1)
		0-15 cm			**15-30 cm**		
Cd	0-0.65	0.11±0.17	14	0-0.52	0.08±0.14	6	0.31*
Co	0-0.21	0.03±0.05	14	0-0.13	0.02±0.03	0	0.20*
Cr	1.1-7.4	3.61±1.99	100	0.7-3.33	2.07±0.99	80	1.00*
Cu	4.2-14.7	9.41±3.57	100	3.1-9.2	6.04±2.44	100	0.50**
Fe	12.4-27.4	18.55±4.78	100	9.52-20.21	14.7±3.72	100	5.00**
Mn	2.11-15.41	7.96±4.15	100	1.1-9.21	4.66±2.46	100	1.00*
Ni	1.19-6.02	3.76±1.45	0	0.82-4	2.49±0.97	0	8.10*
Pb	2.39-21.32	8.48±6.42	27	1.04-17.85	5.7±5.65	20	13.00*
Zn	2.3-25	6.57±5.94	100	1.8-20	5.6±4.71	100	1.50**

* Mclean *et al*. (1987), Availability of Zinc, Copper Nickel to plants grown in sewage treated soils.

** Sultanpur (1985). Use of AB-DTPA soil test to evaluate elemental availability and toxicity

at palnt affinity to metals that above the permissible levels. As in chili, coriander and garlic Co, Mn, Pb and Zn and exceptionally Cd in coriander were found 100% above the permissible limits provided by WHO (1996) and Asaolu (1995). Tomato and spinach were investigated highly accumulator for heavy metals, all investigated metals (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) were found 100% above the permissible levels given by WHO (1996) and Asaolu (1995). Metal accumulation by vegetables is affected by plant species and physicochemical activities, soil nature, temperature and rain fall also affect its uptake (Khan *et al*., 2013). Farid *et al.* (2003) collected spinach, bitter gourd, okra, and eggplant samples and found that they were contaminated with heavy metals similarly in accordance to current results. Ronaq *et al*. (2005) collected spinach samples from and found unsafe for eating due to higher accumulation of heavy metal concentration. Liu *et al*. (2006) and Barman *et al*. (2000) also reported higher concentration of heavy metals in waste water grown vegetables. Heavy metal accumulation in vegetable grown in wastewater-irrigated soils was significantly detected higher than cultivated in the reference soil (Meyer *et al*., 2016)

Table 3: Heavy metal accumulation in vegetables (mg kg^{-1})

	Chili			Garlic			
Heavy metals (mg kg^{-1})	Range	Mean±SD	Above the Permissible limits (%)	Range	Mean±SD	Above the Permissible limits (%)	Permissible limits (mg kg^{-1})
Cd	0-1.51	0.76±1.07	50	0.1-0.7	0.4±0.42	100	0.02*
Co	1.01-2.08	1.55±0.76	100	0	0±0	0	0.02*
Cr	0.75-1.27	1.01±0.37	0	0.89-1.17	1.03±0.2	0	1.30*
Cu	5.21-8.8	7.01±2.54	0	14.3-22.4	18.35±5.73	100	10.00*
Fe	95-120	107.5±17.67	0	55-114	84.5±41.71	0	150.0*
Mn	2.37-7.91	5.14±3.92	50	35.6-41.4	38.5±4.1	100	6.61*
Ni	2.92-3.4	3.16±0.34	0	8.4-12.3	10.35±2.76	67	10.00*
Pb	4.21-5.6	4.91±0.98	100	0-0.13	0.07±0.09	0	2.00**
Zn	5.62-13.4	9.51±5.5	100	42-57	49.5±10.6	100	5.00*
	Tomato			**Spinach**			
Cd	1.08-7.77	4.12±3.38	100	0.04-2.08	0.63±0.89	100	0.02*
Co	0.82-4.26	2.39±1.73	100	0-0.81	0.17±0.36	20	0.02*
Cr	4.5-10.35	7.45±2.92	100	0.86-3.41	1.85±1.02	60	1.30*
Cu	31-97	64.33±33	100	15.4-26.96	20.08±4.73	100	10.00*
Fe	177.32-215	194.89±18.9	100	160-297.4	226.78±58.99	100	150.0*
Mn	24.35-40	31.45±7.92	100	12.02-26.2	19.46±5.57	100	6.61*
Ni	12.25-20	15.83±3.9	100	2.52-4.55	3.49±0.8	0	10.00*
Pb	11.11-32.44	19.95±11.1	100	2.12-8.75	4.95±2.42	100	2.00**
Zn	19.4-32	25.73±6.3	100	13.21-24.5	18.18±4.39	100	5.00*

* WHO (1996) Critical levels of different metal ions in edible portion of vegetables

** Asaolu (1995) Critical levels of different metal ions in edible portion of vegetables

The mean value against each metal is avrage value of 45 sample from 15 differnt sites

Table 4: Heavy metal (mg kg^{-1}) accumulation in vegetables (Coriander)

Coriander				
Heavy metals (mg kg^{-1})	Range	Mean±SD	Above the Permissible limits (%)	Permissible limits (mg kg^{-1})
Cd	0.85-1.02	0.93±0.08	100	0.02*
Co	0	0±0	0	0.02*
Cr	0.45-1.02	0.78±0.29	0	1.30*
Cu	12.8-24.4	18.59±5.8	67	10.00*
Fe	85-120	102.04±17.51	0	150.0*
Mn	8.5-10.5	9.65±1.03	100	6.61*
Ni	1.58-4.6	2.82±1.57	0	10.00*
Pb	1.88-4.3	2.84±1.28	67	2.00**
Zn	19.2-55	34±18.6	100	5.00*

* WHO (1996) Critical levels of different metal ions in edible portion of vegetables

** Asaolu (1995) Critical levels of different metal ions in edible portion of vegetables

The mean value against each metal is avrage value of 45 sample from 15 differnt sites

4. Conclusion

This surveyed was conducted with aim to estimate the heavy metals content in soil and vegetable grown under sewage effluent in peri-urban area of Rawalpindi. The results revealed that in sewage effluent the contents of Zn, Cu, Mn,Cr, Cd, Ni, Pb, Fe and Co were higher than permissible limits. The accumulations of heavy metals in soil were higher than the permissible limits but in vegetables tomato and spinach were higher in metal accumulation than rest of investigated vegetables. Study revealed that specific plants species have its affinity to specific heavy metals and that may result in hyper accumulation.

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