IRRIGATION OF CROPS WITH RAW SEWAGE: HAZARD ASSESSMENT OF EFFLUENT, SOIL AND VEGETABLES

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Untreated sewage effluent containing heavy metals are applied to raise crops, mostly vegetables. Thus these metals enter human food chain and could cause health hazards. Therefore, a study was conducted to evaluate metals contamination in effluents, soils and plants being irrigated with such effluents. For this purpose, a field survey was conducted and a number of farmers' fields were selected near Kernailwala, Judgewala, Marzipura and Uchkera villages in the suburbs of Faisalabad city. Effluent samples were collected fortnightly during summer and winter to evaluate irrigation quality and metal contamination. Composite soil samples were drawn from all the sites at 0-15, 15-30, 30-60, 60-90 and 90-120 cm soil depths. Similarly, vegetables viz. spinach, eggplant, pumpkin okra and bitter gourd were sampled from each field to evaluate metal concentration in roots, shoots and fruits.

Effluent samples collected from drains were found unfit for irrigation with respect to EC, SAR and RSC. The Fe concentrations were maximum while that of Cd minimum. The concentration of Cr, Mn and Ni in all effluent samples while Cd at Kernailwala and Judgewala effluent samples was higher than the permissible limits. The EC and SAR of few soil samples were above the critical limits in 0-15 cm depth. The Fe contents were the highest and Cd the lowest in AB-DTPA extractable (plant-available) forms. The AB-DTPA extractable metals decreased with increasing soil depth. Almost all the metal ions were found above the safe limits in edible parts of above mentioned vegetables. Hence, untreated effluent irrigation will not only make the soil unproductive but also have adverse effects on human health through introducing toxic metals into the food chain.

Keywords: Untreated effluent; metal ions; vegetables; adverse effects

INTRODUCTION

Heavy metal is a term applied to a large number of trace elements, which are both industrially and biologically important. Although not completely satisfactory from the chemistry point of view, yet heavy metal is the most widely recognized and used term for a large group of elements with an atomic density greater than 6 Mg m^{-3} (Alloway, 1991). These metals normally have atomic number >22 and are good conductor of heat and electricity.

In developing countries, untreated sewage effluent is used for growing crops including vegetables (O'Riordan *et al.*, 1986). Around the cities in Pakistan, this is also a common practice (Khan *et al.*, 1994), as farmers consider it a source of irrigation and nutrients (Ghafoor *et al.*, 1994) while administrators think it a viable option for disposal. However, problems arise from such practices through the introduction of metal ions and their accumulation in bio-systems with continuous application to soils (Abdel-Saheb *et al.*, 1994; Wallace and Wallace, 1994). These metals could have toxic impact on biological systems if present beyond their respective safe limits in soils, waters and/or plants (Nriagu and Pacyna, 1988; Nriagu, 1990). Presently, there is a poor scientific data available in Pakistan pertaining to the concentration of metals in city effluents, and their accumulation in soils and plants receiving irrigation with these raw municipal sewage waters. Therefore, investigations were carried out to evaluate spatial and temporal variation in irrigation quality of city effluents and the degree of metal ion contamination in soils and plants receiving sewage effluents under farmers' fields.

MATERIALS AND METHODS

There are a number of open and covered channels spreading within and around the city area, which carry untreated city effluent. In Pakistan, including Faisalabad, the waste effluent from different sources and rain water flows/taken away by the same drainage systems. These channels pass through agricultural land from where farmers divert the effluent for irrigating vegetables. A number of farmers' fields were selected in the vicinity of Kernailwala, Judgewala, Marzipura and Uchkera villages, which falls within the Faisalabad municipal limits.

The effluent from irrigation channels at selected sites was sampled fortnightly in summer and winter. Five mL of concentrated HCl was added to each water sample to keep the pH of water below 2 to avoid metals precipitation. The effluent samples were analysed chemically (Table 1) following the methods described by Page *et al.* (1982). Composite soil samples were drawn from randomly selected fields at four sites at 0-15, 15-30, 30-60, 60-90 and 90-120 cm depths. These samples were processed for chemical analyses (Page *et al.*, 1982). Metal ions were extracted with NH_4HCO_3-DTPA (AB-DTPA) method (Soltanpour, 1985). Vegetables viz. spinach [*Spinacia oleracea* L.], eggplant [*Solanum melongena* L.], pumpkin [*Cucurbita* *moschata* (Duch) duch. ex Poir], okra [*Abelmoschus esculentus* (L.) moench] and bittergourd [*Momordica charantia* L.] were sampled from effluent irrigated fields. These were washed with 1 % HCl to remove aerial depositions followed by tap water and then with deionised water. Vegetable samples were air-dried and oven dried at 70 °C till the constant weight. Aliquots of sample were digested in HNO_3 + $HClO_4$ mixture (Anonymous, 1984). Finally metal ions were determined with the help of atomic absorption spectrophotometer (Varian SpectrAA 250 plus.).

RESULTS AND DISCUSSION

Chemical Composition of City Effluent

All the effluent samples were unfit for irrigation on the basis of EC, SAR and RSC (Table 1) according to the criteria of US Salinity Laboratory Staff (1954). The average EC for Kernailwala, Judgewala, Marzipura and Uchkera was 2.28, 4.03, 3.02 and 3.09 dS m^{-1}, RSC was 2.28, 6.23, 5.19 and 5.44 $mmol_c\ L^{-1}$ and SAR was 12.59, 20.79, 16.67 and 17.02 $(mmol\ L^{-1})^{1/2}$, respectively. The effluent at Judgewala was unfit for irrigation purposes due to maximum EC, SAR and RSC. High EC, SAR and RSC of the city effluent could be due to extensive use of poor quality groundwater, use of detergents in laundries, textile industries, cosmetics, ashes and wastes from factories. As regards the temporal changes in sewage composition, the EC and RSC remained almost similar during the study period at all the sites except at Kernailwala, where canal water flows through the same drains during some months of the year, caused dilution effect. Among metals in effluents, Fe concentration was maximum while that of Cd was minimum (Table 1). At Kernailwala, Judgewala, Marzipura and Uchkera sampling sites concentration of Fe, Pb, Cd and Zn were within permissible limits considering the classification of Ayers and Westcot, (1985). Copper concentration except that at Judgewala site was also within safe limits. However, Cr, Mn and Ni were above the permissible limits at all the sites.

High concentration of Cr, Mn, Ni and Cd appears because of the untreated effluents disposal from leather, textiles, metallurgy, paint, vegetable oil mills and chemical industries into sewage drains under investigation as has been reported by Ghafoor *et al.* (1994, 1995). Similar composition of sewage effluent by Mishra (1990) in India has been reported. It has been observed that the samples collected in afternoon contained higher concentration of metals, which might be due to increased anthropogenic activities during day-time.

Characteristics of Effluent Irrigated Soils

Chemical Characteristics: The pH_s ranged from 7.7 to 8.3 (Table 2) with mean pH_s being 7.9, 8.1, 8.2, 8.2 and 8.2 at 0-15, 15-30, 30-60, 60-90 and 90-120 cm soils depths, respectively. Generally, pH_s increased with an increase in soil depth which appears due to low calcium as much of it has been consumed in precipitation of lime at lower parts of soil profiles.

Maximum EC_e was observed in the surface layer (0-15 cm) of the fields at Marzipura (Table 2). The EC_e at other sites ranged from 1.7 to 3.6 dS m^{-1}. Only 8 % of the soil samples had EC_e above 4 dS m^{-1}. The EC_e of all the sampling sites was higher in the surface layer and decreased with an increase in soil depth due to irrigation imposed salts at the surface soil and evapotranspiration.

The soil SAR ranged from 9.4 to 16.7 (Table 2). About 20 % of the soil samples had SAR more than 15, and generally, SAR was higher at 0-15 cm depth than the lower depths. This might be due to the continuous use of city effluent having high SAR and RSC (Table 1). The results of Khan *et al.* (1994) are similar to our findings.

Toxic Metals: The plant available metals, Cd, Cu and Fe decreased with an increase in soil depth (Table 3). Cadmium remained below permissible limit of 0.31 mg kg^{-1} (MacLean *et al.*, 1987) at all the sites. Almost in all the soils, available Cu was found above the permissible limit of 0.5 mg kg^{-1} (Soltanpour, 1985). About 49 % of the soils contained available Fe below the permissible limit of < 5.0 mg kg^{-1} considering the criteria of Soltanpour (1985). Chromium showed inconsistent pattern with respect to available form at different depths in all the soil samples (Table 3). Khan *et al.* (1994) obtained similar results in the soils irrigated with city effluent near Faisalabad city.

Available form of Pb was less than 8.05 mg kg^{-1} (Table 4) but was maximum in the 0-15 cm soil depth. It was found below the permissible limit of 13 mg kg^{-1} (MacLean *et al.*, 1987). The high Pb accumulation in the surface layer might be due to the continuous irrigation of soils with metal-containing city effluent and also due to less mobility of Pb within soils, particularly under the alkaline soil conditions (McBride, 1994). In addition, industrial smoke, auto vehicle exhaust and fly ashes might also be contributing to the Pb concentration in the surface layer of soils, which condense on to the soil surface during relatively cold hours of night. Consistently, the soils at Uchkera site contained much higher Pb because the site is located quite close to a metalled road on which automobiles traffic continues round the clock producing smoke by burning the leaded mineral oil.

Available Mn, Ni and Zn were also higher in surface layers than that in the lower soil profiles (Table 4). About 11 % of the soil samples contained Mn less than the permissible limits of 1.0 mg kg^{-1} (Soltanpour, 1985). The Ni remained below the permissible limits in all the soils. Similarly, available Zn ranged from 0.40 to 19.49 mg kg^{-1} (Table 4) and 34 % of the soil samples had Zn above the permissible limit of 1.50 mg kg^{-1} considering the scheme of Soltanpour (1985). These results are similar to the earlier findings of Ghafoor *et al.* (1995).

Almost all the metals remained higher at Uchkera site (Table 3 and 4). It could be due to automobiles exhaust from the roadside and irrigation with industrial effluent alone.

The results indicate that almost all the soils at the surface layers contained higher amount of available metals and the content of each decreased with soil depth. Partly, this could be due to their complexation with other constituents of the soil matrix under neutral to alkaline soil reaction (McBride, 1994). Specific adsorption of metals onto organic matter, clay minerals, humic acid and fulvic acid has possibly restricted their movement into deeper horizons. Khan *et al.* (1994) recorded similar results in soils irrigated with city effluent at different villages near Faisalabad city. Singh and Singh (1994), Ghafoor *et al.* (1995) and Berrow and Mitchal (1980) also reported similar metal concentration (total and available) and their pattern of distribution in soil profiles.

Metal Ions in City Effluent Irrigated Vegetables

The concentration of Cd in vegetables ranged from 0.2 to 1.0 mg kg^{-1} (Table 5). Its maximum concentration was found in spinach followed by eggplant, okra, bitter gourd and pumpkin but critical level for human consumption is 0.01 mg kg^{-1}. The Cr ranged from traces to 106 mg kg^{-1}. Only 13 % vegetable samples contained Cr below the permissible limit (1.3 mg kg^{-1}). Copper was found from 16 to 30 mg kg^{-1}. Maximum Cu concentration was observed in eggplant followed by pumpkin, spinach, bitter gourd and okra. It was also above the permissible limit of 10 mg kg^{-1}. Iron concentration was the highest (up to 585 mg kg^{-1}) than all the metals determined. About 17 % of the vegetable samples had Fe contents below the critical level of 150 mg kg^{-1}.

There was an inconsistent pattern of Pb uptake by vegetables. It was higher in fruits of pumpkin sampled from Uchkera than the other sites as well as the other vegetables. Almost all the vegetable samples contained Pb above the permissible limit of 2 mg kg^{-1} (Asaolu, 1995). The concentration of Mn was generally higher in spinach followed by eggplant, bitter gourd, pumpkin and okra. In all the vegetable samples, Mn concentration was above the critical level of 6.61 mg kg^{-1}. Adhikari *et al.* (1998) in a similar study observed that samples of several vegetables contained Pb and Mn above the permissible limits. The concentration of Ni ranged from 4.4 to 20.0 mg kg^{-1}. Results show that about 39 % of the total vegetable samples had Ni below the permissible limit of 10 mg kg^{-1} set for food items. The concentration of Zn varied from 35.8 to 197.7 mg kg^{-1}. Maximum Zn was observed in pumpkin fruits sampled from Marzipura.

Almost all the vegetable samples collected from Uchkera had higher metal contents than other sites. It shows that there is a close correlation between metal ions present in soil in AB-DTPA extractable form and metals taken up by plants. Hence addition of metals in soil through anthropogenic activities could make the soils and vegetables harmful for human health.

CONCLUSION

Effluent samples collected from drains near Kernailwala, Judgewala, Marzipura and Uchkera villages were found unfit for irrigation with respect to EC, SAR and RSC. However, the effluent at Judgewala site was the worst for irrigation purpose. Among metals, Fe concentration was maximum while that of Cd was minimum. The Cr, Mn and Ni in effluent of all the four sampling sites while Cd at Kernailwala and Judgewala remained higher than permissible limits for irrigation waters. Iron was the highest and Cd remained the lowest in AB-DTPA extractable form (i.e., plant available). The AB-DTPA extractable metals decreased with increasing soil depth. Generally, concentration of metals was higher in leaves of leafy vegetable. Almost all the metals were found beyond safe limits in vegetables. It is inferred that the unwise use of raw sewage waters for irrigation will not only make the soils unproductive but also have adverse effects on animal and human health through introducing toxic metals in food chains.

Table 1. Chemical composition of raw city effluents from the sewer system of Faisalabad

Characteristic	Karnailwala	Judgewala	Marzipura	Uchkera	Critical levels
EC (dS m^{-1})	2.28±1.29	4.03±0.25	3.02±0.40	3.09±0.58	1.50*
RSC (mmol$_c$ L^{-1})	2.28±2.37	6.23±1.56	5.19±1.54	5.44±1.74	2.25*
SAR	12.59±5.13	20.79±4.90	16.67±5.09	17.02±4.44	10.00*
Cd (mg L^{-1})	0.01±0.00	0.01±0.00	0.01±0.00	0.01±0.00	0.01**
Cr (")	1.02±0.57	0.92±0.52	0.98±0.06	0.84±0.48	0.10**
Cu (")	0.20±0.12	0.21±0.05	0.18±0.04	0.18±0.06	0.20**
Fe (")	1.79±0.84	1.49±0.62	1.84±0.67	2.25±0.95	5.00**
Pb (")	0.22±0.04	0.19±0.07	0.21±0.04	0.21±0.05	5.00**
Mn (")	0.31±0.11	0.34±0.10	0.31±0.09	0.29±0.11	0.20**
Ni (")	0.48±0.07	0.47±0.07	0.46±0.06	0.47±0.06	0.20**
Zn (")	0.08±0.04	0.14±0.08	0.10±0.04	0.09±0.03	2.00**

(*US Salinity Lab. Staff, 1954; **Ayers and Westcot, 1985)

Table 2. The pH_s, EC_e and SAR of vegetable fields receiving raw city effluent

Site	Soil depth (cm)				
	0-15	15-30	30-60	60-90	90-120
			pH_s		
Kernailwala	*7.9	8.0	8.1	8.2	8.2
Judgewala	8.1	8.1	8.2	8.3	8.3
Marzipura	7.9	8.1	8.3	8.3	8.3
Uchkera	7.7	8.0	8.1	8.0	8.1
SD	0.30	0.31	0.26	0.29	0.30
			EC_e (dS m^{-1})		
Kernailwala	2.5	2.3	2.0	1.8	1.7
Judgewala	3.5	3.1	3.0	3.1	2.9
Marzipura	4.8	2.6	2.9	2.6	2.6
Uchkera	3.6	2.7	2.4	2.6	2.5
SD	1.67	0.96	0.90	0.95	0.72
			SAR		
Kernailwala	10.1	9.8	9.4	10.7	9.7
Judgewala	14.8	16.1	16.7	15.1	14.4
Marzipura	15.5	11.9	14.5	13.1	15.1
Uchkera	13.4	12.8	13.7	13.8	12.6
SD	3.67	3.89	4.61	3.39	2.49

*Figures are the average values of five samples. SD = Standard Deviation.

Table 3. The concentration of Cd, Cr, Cu and Fe in soils receiving untreated city effluent

Site	Soil depth (cm)				
	0-15	15-30	30-60	60-90	90-120
			Cd (mg kg^{-1})		
Kernailwala	0.060	0.019	0.008	0.011	0.013
Judgewala	0.033	0.021	0.019	0.013	0.019
Marzipura	0.069	0.022	0.011	0.006	0.004
Uchkera	0.109	0.067	0.025	0.015	0.012
SD	0.049	0.056	0.016	0.011	0.013
			Cr (mg kg^{-1})		
Kernailwala	0.397	0.866	1.595	0.597	1.416
Judgewala	1.255	2.005	2.032	2.141	1.171
Marzipura	0.762	0.233	0.814	0.921	0.305
Uchkera	0.801	2.608	0.679	0.980	1.322
SD	1.128	1.420	1.306	1.267	1.225
			Cu (mg kg^{-1})		
Kernailwala	9.023	2.577	1.962	1.620	1.323
Judgewala	4.061	2.533	1.809	1.513	1.323
Marzipura	16.945	7.075	3.708	2.400	1.558
Uchkera	22.918	6.912	3.817	2.463	1.565
SD	8.893	2.925	1.186	0.744	0.434
			Fe (mg kg^{-1})		
Kernailwala	9.820	5.033	3.477	3.295	4.620
Judgewala	10.186	4.996	5.147	4.530	3.641
Marzipura	19.450	6.995	4.198	2.975	3.595
Uchkera	36.300	35.488	8.752	8.030	6.505
SD	13.027	28.549	3.588	3.002	3.037

*Figures are the average values of five samples. SD = Standard Deviation

Table 4. The concentration of Pb, Mn, Ni and Zn in soils receiving raw city effluent

Site	Soil Depth (cm)				
	0-15	15-30	30-60	60-90	90-120
Pb (mg kg^{-1})					
Kernailwala	*4.730	0.753	0.628	0.537	1.583
Judgewala	2.560	0.561	1.027	0.397	0.159
Marzipura	6.778	2.360	1.373	0.870	0.650
Uchkera	8.048	2.767	1.210	0.283	0.580
SD	2.576	1.413	0.812	0.399	1.588
Mn (mg kg^{-1})					
Kernailwala	8.263	4.837	3.380	3.097	2.337
Judgewala	5.023	3.741	2.897	2.101	1.251
Marzipura	11.165	7.135	5.358	2.828	2.548
Uchkera	18.677	7.998	5.970	3.723	2.642
SD	6.916	3.460	2.21	1.601	1.090
Ni (mg kg^{-1})					
Kernailwala	0.552	0.248	0.240	0.223	0.217
Judgewala	0.403	0.250	0.279	0.213	0.213
Marzipura	1.145	0.423	0.378	0.248	0.165
Uchkera	3.260	0.927	0.383	0.222	0.227
SD	1.818	0.658	0.111	0.080	0.068
Zn (mg kg^{-1})					
Kernailwala	4.860	0.872	0.427	0.428	0.403
Judgewala	3.517	0.993	0.563	0.430	0.423
Marzipura	7.833	2.658	0.933	0.663	0.465
Uchkera	19.493	7.060	1.568	0.985	0.683
SD	9.999	4.170	0.707	0.425	0.223

*Figures are the average values of five samples. SD = Standard deviation.

Table 5. Metals ion concentration in edible portion of vegetables (mg kg^{-1} dry weight) irrigated with Faisalabad raw city effluent

Vegetable	Site	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
Spinach	Kernailwala	*0.9	27.4	23.3	520.5	5.9	176.2	17.0	44.0
	Judgewala	0.9	38.9	22.8	537.0	3.3	119.9	20.0	41.0
	Marzipura	0.6	60.0	16.0	409.0	30.4	60.7	7.4	76.0
	Uchkera	1.0	52.5	22.2	585.3	7.6	20.9	17.0	79.0
	SD	0.4	25.4	6.8	52.6	10.4	73.2	12.5	25.7
Eggplant	Kernailwala	0.5	0.0	23.0	119.0	13.0	44.0	3.0	43.0
	Judgewala	0.7	41.0	28.0	176.0	13.0	30.0	15.0	54.0
	Marzipura	0.6	39.0	30.0	171.0	28.0	20.0	15.0	37.0
	Uchkera	0.8	106.0	26.0	181.0	14.0	22.0	15.0	56.0
	SD	0.1	51.5	4.0	38.3	13.4	10.8	13.5	14.1
Okra	Judgewala	0.7	50.0	19.3	166.8	19.0	24.0	15.6	35.8
	SD	0.2	10.6	10.7	97.1	2.6	7.7	17.5	3.6
Bitter gourd	Kernailwala	0.6	24.7	22.7	237.2	21.2	33.1	16.9	57.7
	SD	0.4	13.7	2.9	55.6	17.3	5.5	17.8	23.5
Pumpkin	Kernailwala	0.2	47.5	19.3	68.9	16.4	28.4	4.5	67.3
	Judgewala	0.4	55.0	16.0	54.0	3.5	26.9	6.7	39.6
	Marzipura	0.4	Trace	27.1	56.7	16.1	30.6	4.4	97.7
	Uchkera	0.7	67.6	25.6	205.0	34.6	24.7	15.8	65.8
	SD	0.30	46.40	5.12	40.12	19.40	8.08	9.86	69.94

*The figures are average of six values and standard deviation (SD) is calculated from the same figures

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