ACCUMULATION AND BIOAVAILABILITY OF Cd, Co AND Mn IN SOILS AND VEGETABLES IRRIGATED WITH CITY EFFLUENT

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Untreated city effluent is used for growing vegetables around big cities in most parts of the country. We determined the irrigation quality of city effluent and its impact on soils and vegetables' quality. This study was conducted at sites: Kernailwala (site I) and Judgewala(site II) within the Municipal limit of Faisalabad. Effluent samples were collected from the sites fortnightly from June 1998 to June 1999. Soil samples were drawn from 0.00-0.20, 0.20-0.40, 0.40-0.60, 0.60-0.80 and 0.80 to 1.00 m depths and were analysed for physical and chemical properties, and for heavy metals like Cd, Co and Mn. Associated vegetable samples (leaves and fruits separately) were collected from the same fields for their heavy metal contents. Quality of the effluent was marginal at site I [EC 1.1-1.7 dS m^{-1}, SAR 5.9-17.4 (mmol $L^{-1})^{1/2}$ and RSC 1.0-2.1 $mmol_c$ L^{-1}] and unfit for irrigation at site II (EC 3.7-4.1 dS m^{-1}, SAR 16.1-21.9, RSC 4.0-9.1 $mmol_c$ L^{-1}). Concentration of AB-DTPA extractable Cd, Co and Mn for 0-20 cm soil depth was 0.080, 0.057 and 216.62 mg kg^{-1} at site I while the corresponding values were 0.104, 0.077 and 176.96 at site II. In soils irrigated with city effluent, Cd and Co were found within safe limits but Mn was found above permissible limits. The concentration of Cd, Co and Mn tended to decrease with an increase in soil depth. Higher accumulation of metals was observed in plant leaves than their respective fruits. Manganese concentration in plants was much higher than those of Cd and Co. Edible parts of vegetables (fruits or leaves) grown with city effluent accumulated metals beyond permissible limits in spite the soils contained metals within permissible range, particularly where leaves are consumed. This is a continuous and serious hazard to soils and plants and ultimately to human health suggesting that either the practice must be discouraged or must be followed with appropriate/scientific management. Specific disorders due to toxic levels of different metals have also been highlighted.
Key words: city effluent; heavy metals; soils; vegetables; permissible limit; salination; sodication

INTRODUCTION

Environmental pollution is a global problem, more serious in industrialized societies. The problem is more serious in countries like Pakistan where we have uncontrolled disposal of untreated sewage resulting from domestic uses, industrial wastes containing a variety of pollutants, effluent from animal husbandry and drainage of irrigated lands and run off.

Disposal of sewage water is a big problem. Untreated city effluent is generally disposed off onto agricultural lands around big cities in developing countries, i.e. to establish urban agriculture (Hernandez *et al.*, 1991; Qadir and Ghafoor, 1997). Usually, the city effluent is a potential source of metals but still used for growing vegetables around the cities (Qadir *et al.*, 1998). These sewage effluents are considered not only a rich source of organic matter and other plant nutrients (Ahmad *et al.*, 1994) but also contain heavy metals like Fe, Mn, Cu, Zn, Pb, Cr, Ni, Cd and Co in considerable concentration. Continuous use of untreated city effluent for crop production, particularly vegetables, may result in accumulation of metals in phytotoxic concentrations (Qadir *et al.*, 1999) which ultimately enters food chain and prove hazardous to man and animals. The farmers are not aware of the toxicity of metal ions that is being introduced into the food chain by growing vegetables with city effluent. Since the farmers consider it a potential source of irrigation and plant nutrients (Bouwer *et al.*, 1999) while the administrators take this practice as a viable option for disposal of waste water. Therefore, severe contamination of soils and crops could result because of this practice if continued for longer periods.

Presently, insufficient data are available for metal ion contamination of soils and vegetables being irrigated by city effluent in Pakistan. The present studies were carried out with the objectives to evaluate quality of city effluent for irrigation with respect to EC, SAR, RSC and heavy metals and its impact on soils and vegetables characteristics in urban agricultural lands near Faisalabad, Pakistan.

MATERIALS AND METHODS

Location of studies

To determine the metal ion contamination in the effluent-irrigated vegetables and soils, ten farmers' fields which had been irrigated with city effluent for more than 20 years were selected in the vicinity of Kernailwala (site I) and Judgewala (site II) villages within Faisalabad Municipal Corporation limits, i.e. a typical urban agriculture area. The sole criterion for the selection of sampling sites was that a variety of vegetables had been grown with untreated sewage irrigation for about 20 years. Samples of city effluent, soils and plants were collected from these sites and analysed. The experiment sites have several open and covered drainage channels that spread within and around the urban land and carry untreated city effluent.

Effluent collection and analysis

The effluent being used by the farmers for irrigation at a particular site was sampled fortnightly from the channels that supplied the effluent to fields from June 1998 to 1999. One set of these samples was treated with 0.1% sodium hexametaphosphate with one drop per 25 mL and were analysed within 20 days of collection. These samples were analysed for pH, electrical conductivity (EC), carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), chloride (Cl^-), sulphate (SO_4^{2-}), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) following methods described by the U.S. Salinity Lab. Staff. (1954). Some parameters were computed, viz. sodium adsorption ratio(SAR) = $Na^+/[(Ca^{2+}+Mg^{2+})/2]^{1/2}$ and residual sodium carbonate (RSC) = $(CO_3^{2-}+HCO_3^-)-(Ca^{2+}+Mg^{2+})$. A second set of effluent samples was treated with concentrated HCl with 0.5 mL per 100 mL and Cd, Co and Mn were determined within 20 day of sample collection by atomic absorption spectrophotometer (Model Varian Spectr AA 250 plus).

Soil sampling and analysis

Composite soil samples were collected from randomly selected four sub samples at 0.00-0.20, 0.20-0.40, 0.40-0.60, 0.60-0.80 and 0.80 to 1.00 m soil depths from each of the 3-5 selected fields. The samples were air-dried, ground, mixed and sieved. Particle-size analysis (Table 1) was carried out following the method of Bouyoucos (1962). Saturated paste pH (pH_s), saturation paste extract EC (EC_e), soluble calcium plus magnesium ($Ca^{2+}+Mg^{2+}$), sodium (Na^+), potassium (K^+), lime ($CaCO_3$), and cation exchange capacity (CEC) were determined according to methods of the U.S. Salinity Lab. Staff (1954). Organic matter was determined by the method of Walkley (1947). Ammonium bicarbonate-diethylene triamine pentaacetic acid (AB-DTPA) extractable Cd, Co and Mn were determined by following the procedure described by Soltanpour (1985). Atomic absorption spectrophotometer (Model Varian Spectr AA 250 plus) was used for determining metal ion concentrations.

Plant sampling and analysis

The vegetables viz. bitter gourd (*Momordica charantia* L.), okra (*Abelmoschus esculentus* L. Moench), spinach (*Spinacia oleracea* L.) and mint (*Mentha spicata*) were growing in the field during the study period. Either fruit or mature leaves or both were collected randomly from 2-4 effluent irrigated fields during 1998-99. Plant samples were washed with 1% HCl, followed by 3-4 washings with distilled water to remove foreign material. These were then spread on clean paper and air-dried and finally oven-dried at 60-70°C. The oven-dried plant material was ground in Wiley mill and digested in diacid mixture (HNO_3+$HClO_4$). Metal ions were determined following the methods of the AOAC (1990). The results for soils and vegetables are presented on dry weight basis.

RESULTS AND DISCUSSION

Irrigation quality of effluent

The EC of effluent samples at site I ranged from 1.1 to 1.7 dS m^{-1} and at site II from 3.7 to 4.1 dS m^{-1} (Table 2). The sources of high EC in Faisalabad city effluent could be the use of poor quality ground water, detergents in laundries, cosmetics and textile mills, ashes and factory wastes (Ibrahim and Salmon, 1992b). The SAR values at site I ranged from 5.9 to 17.4 and that at site II from 16.1 to 21.8. On SAR basis it is considered of moderate hazard to most of the soil textures and plants according to the U.S. Salinity Lab. Staff. (1954) and Ayers and Westcot (1985). The RSC values ranged from 1.0 to 2.1 $mmol_c\ L^{-1}$ at site I and from 4.0 to 9.1 $mmol_c\ L^{-1}$ at site II. It was observed that the effluent samples were of moderate quality at site I while the effluents were both saline and sodic (high EC, SAR and RSC) at site II.

Cadmium concentration at site I and site II ranged between 0.03-0.10 and 0.02-0.10 mg L^{-1}, respectively (Table 2). Cobalt concentration was between 0.001-0.009 mg L^{-1} for site I and 0.002-0.010 mg L^{-1} for site II while the concentrations of Mn for the same sites were observed between 0.28-0.51 and 0.30-0.48 mg L^{-1}, respectively, i.e. only the Co concentration was within permissible limits. The permissible limits for Cd, Co and Mn in irrigation water are 0.01, 0.05 and 0.20 mg L^{-1}, respectively (Ayers and Westcot, 1985). There was no consistent effect of winter and summer season on the concentration of metals in the effluent. It was observed that continuous use of such effluent for irrigation over long periods may cause accumulation of these metals in soils leading toxic levels for plants and animal health (Kirkham, 1983; Adhikari, 1998).

Characteristics of soils irrigated with effluent

Soil reaction (pH_s)

The pH_s ranged from 7.4 to 8.0 in the top 0.00-0.20 m soil depth (Table 3). There were inconsistent changes in pH_s at various soil depths at both the sites. On an average, the pH_s was not problematic most probably due to regular addition of organic matter along with the sewage water. In addition, the effluent contained ≈ 0.20 % organic matter by weight (Ibrahim and Salmon, 1992a) and also because of the calcareousness of soils and canal water irrigation along with the sewer water.

Table 1. Physico-chemical characteristics of the soils in study area.

Site/Field under vegetable	Characteristic	Depth (cm)	
		0-20	20-40
Site I			
Bittergourd	Sand (%)	69.73	67.56
	Silt (%)	15.10	16.09
	Clay (%)	15.17	16.35
	Textural class	Sandy loam	Sandy loam
	Lime (%)	1.10	2.20
	Organic matter (%)	0.65	0.55
	CEC ($cmol_c\ kg^{-1}$)	7.55	7.05
Okra	Sand (%)	67.52	66.55
	Silt (%)	14.31	16.23
	Clay (%)	18.17	17.22
	Textural class	Sandy loam	Sandy loam
	Lime (%)	1.20	2.10
	Organic matter (%)	0.70	0.65
	CEC ($cmol_c\ kg^{-1}$)	7.65	7.15
Spinach	Sand (%)	66.12	69.30
	Silt (%)	15.77	14.66
	Clay (%)	18.10	16.04
	Textural class	Sandy loam	Sandy loam
	Lime (%)	1.10	1.80
	Organic matter (%)	0.70	0.63
	CEC ($cmol_c\ kg^{-1}$)	7.95	7.45
Site II			
Mint	Sand (%)	63.87	66.35
	Silt (%)	16.83	16.16
	Clay (%)	19.30	17.49
	Textural class	Sandy loam	Sandy loam
	Lime (%)	2.10	2.90
	Organic matter (%)	0.95	0.50
	CEC ($cmol_c\ kg^{-1}$)	8.30	7.85
Spinach	Sand (%)	62.40	66.72
	Silt (%)	16.55	14.79
	Clay (%)	21.05	18.50
	Textural class	Sandy clay loam	Sandy loam
	Lime (%)	2.00	3.00
	Organic matter (%)	0.80	0.45
	CEC ($cmol_c\ kg^{-1}$)	8.70	7.60

Soil salinity (EC_e)

The EC_e ranged from 1.9 to 4.8 dS m^{-1} (site I) and 3.1 to 6.1 dS m^{-1} (site II) at 0.00-0.20 m depth (Table 3). In almost all the fields, EC_e decreased with an increase in soil depth. Higher EC_e at the top layer (0.00-0.20 m) than the lower ones might be due to salts in effluents (Table 2) as well as evaporation through capillary action (Sandhu and Qureshi, 1986).

Table 2. Irrigation quality and metal ion concentration in the city effluent at different sites of Faisalabad city.

Site	Characteristic	Range	Mean	S.D.	Permissible limit	
Site I					*	**
	EC (dS m^{-1})	1.1-1.7	1.4	0.2	1.5	0.7
	SAR (mmol $L^{-1})^{1/2}$	5.9-17.4	10.9	2.8	10.0	3.0
	RSC ($mmol_c$ L^{-1})	1.0-2.1	1.6	0.3	2.0	-
	pH	7.2-7.7	7.5	0.1	-	-
	Cd (mg L^{-1})	0.03-0.10	0.06	0.030	-	0.01
	Co (mg L^{-1})	0.001-0.009	0.006	0.003	-	0.05
	Mn (mg L^{-1})	0.28-0.51	0.39	0.065	-	0.20
Site II						
	EC (dS m^{-1})	3.7-4.1	3.9	0.1	1.5	0.7
	SAR (mmol $L^{-1})^{1/2}$	16.1-21.8	18.3	1.7	10.0	3.0
	RSC ($mmol_c$ L^{-1})	4.0-9.1	5.6	1.1	2.0	-
	pH	7.4-8.1	7.8	0.2	-	-
	Cd (mg L^{-1})	0.02-0.10	0.068	0.022	-	0.01
	Co (mg L^{-1})	0.002-0.01	0.007	0.002	-	0.05
	Mn (mg L^{-1})	0.30-0.48	0.382	0.071	-	0.20

* U.S. Salinity Lab. Staff (1954).

** Ayers and Westcot (1985).

Soil sodicity (SAR)

The SAR ranged from 6.3 to 20.7 (Table 3). In general, the SAR decreased with increasing soil depth with the use of sewage water for irrigation for ≈ 2 decades (effluent EC 1.1 to 1.7 dS m^{-1}, SAR 5.9 to 17.4 and RSC 1.0 to 2.1 $mmol_c$ L^{-1} for site I and EC 3.7 to 4.1 dS m^{-1}, SAR 16.1 to 21.8, RSC 4.0 to 29.1 $mmol_c$ L^{-1} for site II (see Table 2).This reflects that in spite of all the farmers management, soils are being salinated/sodicated. Although, at the observed levels of EC_e, SAR and pH_s, most of the crops could yield satisfactorily because of their potential tolerance (Ayers and Westcot, 1985) but serious problems may result if this source of irrigation is continued for prolonged periods.

Metal concentration in soils

Cadmium

AB-DTPA extractable Cd detected in soils irrigated with the city effluent (Table 4) was below the permissible limit of 0.31 mg kg^{-1} (MacLean *et al.*, 1987). This could be due to low mobility or bioavailability of Cd due to formation of chelates with humates and clay in neutral to alkaline soils (Farid, 1998). There was inconsistent pattern of distribution of Cd in the soil profile but in all the samples, Cd was higher in top soil and decreased with depth in some cases. Khan et al. (1994) have reported similar concentration of Cd in the sub-urban soils of Faisalabad city.

Manganese

AB-DTPA extractable manganese in soils ranged from 5.4 to 560.4 mg kg^{-1} (Table 4). Maximum concentration of Mn was found in the top 0.20 m soil which decreased with an increase in depth. Similar results have been reported by Kuhad *et al.* (1989) and Adhikari *et al.* (1998). Concentration of Mn in most of the samples was above permissible limit of 12 mg kg^{-1} (WHO, 1996).

Cobalt

AB-DTPA extractable Co in the soil samples ranged from 0.010 to 0.099 mg kg^{-1} in the top 0.20 m soil depth (Table 4) which decreased with increasing soil depth. It may be due to markedly decreased solubility of Co at alkaline pH of experimental soils. Similar results were reported by Azad et al. (1986) Cobalt was below the permissible limits in all the soil samples. In general, the concentration of these three metals decreased with soil depth suggesting a little chance to contaminate ground water if well below surface (>8 m) but shallow ground water (<2 m) must get contaminated when sewage used continuously for longer periods.

Table 3. Chemical characteristics of soils irrigated with city effluent at Faisalabad.

Site	Characteristic	Soil depth (cm)				
		0-20	**20-40**	**40-60**	**60-80**	**80-100**
Site I						
pH_s	Range	7.5-8.0	7.3-7.8	7.4-8.0	7.4-7.9	7.3-8.0
	Mean	7.8	7.6	7.7	7.6	7.6
	S.D.	0.18	0.22	0.20	0.18	0.24
EC_e (dS m^{-1})	Range	1.9-4.8	1.5-3.9	1.4-2.8	1.6-2.3	1.4-3.0
	Mean	2.8	2.2	1.9	1.9	1.9
	S.D.	0.95	0.78	0.45	0.24	0.52
SAR	Range	7.2-13.5	6.3-12.0	7.2-9.4	7.2-9.4	6.3-10.7
	Mean	10.1	8.3	8.4	8.4	7.7
	S.D.	2.32	1.81	0.77	0.77	1.45
Site II						
pH_s	Range	7.4-7.9	7.3-7.9	7.4-7.8	7.6-7.9	7.5-7.8
	Mean	7.7	7.7	7.7	7.8	7.7
	S.D.	0.22	0.27	0.19	0.13	0.13
EC_e (dS m^{-1})	Range	3.1-6.1	2.9-4.2	2.9-3.7	2.9-3.9	2.7-5.1
	Mean	4.6	3.6	3.4	3.2	3.5
	S.D.	1.34	0.57	0.39	0.46	1.11
SAR	Range	13.1-16.0	12.8-20.7	10.6-15.5	10.8-14.3	7.8-12.8
	Mean	14.37	16.87	13.60	12.42	10.45
	S.D.	1.33	3.73	2.26	1.73	2.38

*Means are average of 8 observations for Site I and 4 for Site II.

Table 4. Concentration of metal ions (mg kg^{-1}) in soils irrigated with city effluent at Faisalabad.

Site	Characteristic		Soil depth (cm)				
			0-20	20-40	40-60	60-80	80-100
Site I							
	Cd	Range	0.052-0.108	0.059-0.089	0.053-0.076	0.054-0.113	0.056-0.115
		Mean	0.080	0.079	0.065	0.070	0.078
		S.D.	0.018	0.008	0.008	0.017	0.021
	Co	Range	0.010-0.099	0.010-0.068	0.002-0.089	0.030-0.086	0.011-0.083
		Mean	0.057	0.045	0.051	0.052	0.051
		S.D.	0.028	0.0 17	0.027	0.018	0.022
	Mn	Range	72.6-560.4	47.3-233.1	42.6-157.4	40.2-71.3	32.1-68.4
		Mean	216.6	120.5	80.7	52.8	47.2
		S.D.	135.2	65.8	34.3	10.9	11.5
Site II							
	Cd	Range	0.099-0.107	0.064-0.098	0.076-0.097	0.078-0.099	0.056-0.091
		Mean	0.104	0.086	0.085	0.089	0.077
		S.D.	0.004	0.015	0.009	0.009	0.015
	Co	Range	0.057-0.099	0.066-0.086	0.057-0.090	0.028-0.076	0.027-0.050
		Mean	0.077	0.078	0.073	0.062	0.043
		S.D.	0.018	0.009	0.015	0.023	0.011
	Mn	Range	108.1-261.4	40.4-78.7	48.9-130.2	35.3-47.6	5.4-48.1
		Mean	176.9	67.2	86.9	44.4	33.9
		S.D.	70.72	18.07	40.12	6.05	19.34

*Means are average of 8 observations for Site I and 4 for Site II.

Metals in vegetables

Cadmium

The concentration of Cd in vegetables ranged from 0.049 to 0.068 mg kg^{-1} (Table 5). Maximum concentration was found in leaves of spinach. Boon and Soltanpour (1992) observed maximum concentration of Cd in leaves of vegetables. Cadmium in the leaves was found in the order of mint<bittergourd<okra<spinach. While in fruits this order was okra<bittergourd. In all the plant samples, metal concentration was found above the critical limit of 0.01mg kg^{-1} in leaves as well as in fruits (WHO, 1996) from both the sites . In a similar study, Adhikari (1998) observed that available cadmium in soils was below permissible limits but plants grown there had Cd in high concentration for unknown reasons.

Cobalt

The concentration of Co in various parts of plants varied from 0.012-0.069 mg kg^{-1} (Table 5). The highest concentration (0.021-0.069 mg kg^{-1}) was found in bittergourd fruit and the lowest concentration (0.012-0.060 mg kg^{-1}) was in okra leaves. Overall means indicated that Co in leaves was in ascending order as okra<bittergourd<spinach<mint and for fruit the order was okra<bittergourd. In all the plant samples, Co was found higher than the permissible limit of 0.01mg kg^{-1} (WHO, 1996).

Table 5. Concentration of metal ions (mg kg^{-1}) in vegetables irrigated with city effluent at Faisalabad.

Site	Vegetable	Leaf			Fruit		
		Range	Mean	S.D.	Range	Mean	S.D.
Site I	**Cd**						
	Bittergourd	0.056-0.061	0.058	0.002	0.066-0.083	0.071	0.008
	Okra	0.055-0.106	0.074	0.022	0.006-0.069	0.052	0.031
	Spinach	0.049-0.113	0.073	0.028	-	-	-
	Co						
	Bittergourd	0.024-0.057	0.035	0.015	0.021-0.069	0.040	0.021
	Okra	0.012-0.060	0.034	0.020	0.015-0.051	0.035	0.019
	Spinach	0.013-0.045	0.035	0.015	-	-	-
	Mn						
	Bittergourd	52.2-90.4	76.9	17.53	5.10-11.20	8.25	2.64
	Okra	49.4-145.4	96.8	42.50	5.10-12.30	7.70	3.22
	Spinach	72.4-162.4	102.2	54.66	-	-	-
Site II	**Cd**						
	Spinach	0.061-0.068	0.065	0.005	-	-	-
	Mint	0.052-0.058	0.055	0.004	-	-	-
	Co						
	Spinach	0.038-0.055	0.047	0.012	-	-	-
	Mint	0.049-0.054	0.052	0.004			
	Mn						
	Spinach	122.1-135.7	128.9	9.62	-	-	-
	Mint	42.1-48.4	45.25	4.45			

*Means are average of 4 observations for Site I and 2 for Site II.

Manganese

Manganese in different parts of plants varied from 5.10-162.40 mg kg^{-1} (Table 5). Maximum value of Mn was found in spinach leaves (115.77 mg kg^{-1}). On overall means basis, Mn in the leaves was in the ascending order mint<bittergourd<okra<spinach, and in fruits, it was as bettergourd<okra. Similar results were found by Adhikari *et al.* (1998). Almost in all samples of fruits and leaves, Mn was found above permissible limit of 6.61 mg kg^{-1} as suggested by WHO (1996). The Mn concentration was lower in fruits than leaves, perhaps through genetic control of the plant regarding its translocation from leaves to fruits.

CONCLUSIONS

Effluent samples collected from drains at site I and site II in the Municipal limit of Faisalabad, Pakistan during 1998 and 1999 were unfit for irrigation. Concentration of Cd and Co remained below safe limits while Mn was present in toxic amount. The pH_s, EC_e and SAR were generally higher at the surface (0.00-0.20 m depth) than the sub soil layers. In plants, generally concentration of Cd, Co and Mn was higher in leaves than in their fruits, although in both the plant parts metal concentration was above permissible limits inspite these metals were within permissible safe limits in soils. Manganese concentration was much higher than that of Cd and Co. It is concluded that indiscriminate use of untreated sewer waters for irrigation will not only make the soils unproductive but will also aaccentuate pollution problem. Ingestion of the metal-contaminated vegetables can induce severe health effects in human beings. Thus either the effluent must be treated at source to reduce the metal load and/or some soil treatment (e.g. gypsum, green manuring etc.) should be tested to decrease the plant availability of these metals.

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REFERENCES

Adhikari, S., A, Mitra, S.K. Gupta and S.K. Banerjee. 1998. Pollution metal contents of vegetables irrigated with sewage water. J. Indian Soc. Soil Sci. 46: 153-155.

Ahmad, N., M. Ibrahim and A. Khan. 1994. Sewage effluent for raising vegetables. p.593-597. In: Proceedings, 4th National Congress of Soil Science, 24-26 May 1992, Islamabad.

AOAC. 1990. Official methods of analysis of the Association of Official Analytical Chemists. AOAC Inc., Virginia, USA.

Ayers, R.S. and D.W. Westcot. 1985. Water Quality for Agriculture. FAO Irrigation and Drainage Paper 29 (Rev. 1), FAO, Rome, Italy.

Azad, A.S., G.S. Sekhon and B.R. Arora. 1986. Distribution of Cd, Ni and Co in sewage water irrigated soils. J. Indian Soc. Soil Sci. 34: 619-621.

Boon, D.Y. and P.N. Soltanpour. 1992. Lead, cadmium and zinc contamination of Aspen Garden soils and vegetation. J. Environ. Qual. 21: 82-86.

Bouwer, H., P. Fox, P. Westerhoff and J. Drewes. 1999. Integrating water management and re-use: Causes for concern?. Water Qual. Internat. 1999: 19-22.

Bouyoucos, G.J. 1962. Hydrometer method improved for making particle-size analyses of soils. Agron. J. 54: 464-465.

Farid, S. 1998. Metal ion concentration in vegetables and soils irrigated with city effluent. M.Sc. Thesis, Dept. Soil Sci., Univ. Agric., Faisalabad.

Hernandez, T., J.I. Moreno and F. Costa. 1991. Influence of sewage sludge application on crop yields and heavy metal availability. Soil Sci. Plant Nutr. 37: 201-210.

Ibrahim, M. and S. Salmon. 1992a. Chemical composition of Faisalabad city sewage effluent. I. Nitrogen, phosphorus and potassium contents. J. Agric. Res. 30: 381-390.

Ibrahim, M. and S. Salmon. 1992b. Chemical composition of Faisalabad city sewàge effluent. II. Irrigation quality. J. Agric. Res. 3: 391-401.

Khan, A., M. Ibrahim, N. Ahmad and S.A. Anwar. 1994. Accumulation of heavy metals in soil receiving sewage effluent. J. Agric. Res. 32: 525-533.

Kirkham, M.B. 1983. Study on accumulation of heavy metals in soils receiving sewage water. Agri. Ecosystem and Environ. 9: 251-255.

Kuhad, M.S., R.S. Malik, R. Singh and A. Singh. 1989. Studies on mobility and accumulation of heavy metals in agricultural soils receiving sewer water irrigation. J. Indian Soc.Soil Sci. 37: 290-294.

MacLean, K.S., A.R. Robinson and H.M. MacConnell. 1987. The effect of sewage-sludge on the heavy metal content of soils and plant tissue. Commun. Soil Sci. Plant Anal. 18: 1303-1316.

Qadir, M., A. Ghafoor, S.I. Hussain, G. Murtaza and T. Mahmood. 1998. Metal ion contamination in vegetables and soils irrigated with city effluent. p. 89-92. Proceedings NSMTCC 97 on "Environmental Pollution" Third National Symposium on Modern Trends in Contemporary Chemistry. February 24-26, 1997, Islamabad, Pakistan.

Qadir, M., A. Ghafoor and G. Murtaza. 1999. Irrigation with city effluent for growing vegetables: A silent epidemic of metal poisoning. Proc. Pakistan Acad. Sci. 36: 217-222.

Qadir, M., and A. Ghafoor. 1997. Metal ion toxicities in soils and vegetables irrigated with city effluent. Project Research Report. Dept. Soil Sci., Univ. Agric., Faisalabad, Pakistan.

Sandhu, G.R. and R.H. Qureshi. 1986. Salt-affected soils of Pakistan and their utilization. Recl. Reveget. Res. 5: 105-113.

Soltanpour, P.N. 1985. Use of ammonium bicarbonate DTPA soil test to evaluate elemental availability and toxicity. Commun. Soil Sci. Plant Anal. 16: 323-338.

U.S. Salinity Lab. Staff. 1954. Diagnosis and improvement of saline and alkali soils. USDA Agric.Handb. 60. United States Goverment Printing Office, Washington, DC., USA.

Walkley, A. 1947. A critical examination of a rapid method for determining organic carbon in soils-effects of variations in digestion conditions and of inorganic soil constituents. Soil Sci. 63: 251-264.

WHO (World Health Organization). 1996. Guidelines for drinking water quality. Health criteria and other supporting information. 94/9960-Mastercom/Wiener Verlag-800, Australia.