Journal of Environmental Biology **September 2008,** 29(5) 793-798 (2008)

Impact of sewage irrigation on speciation of nickel in soils and its accumulation in crops of industrial towns of Punjab

M.P.S. Khurana* and R.L. Bansal

Department of Soils, Punjab Agricultural University, Ludhiana - 141 004, India

(Received: March 14, 2006; Revised received: March 03, 2007; Accepted: March 28, 2007)

Abstract: *Analysis of soil samples collected from sewage and tube well irrigated soils of Ludhiana, Amritsar, Jalandhar and Mandi Gobindgarh, revealed that Diethylene triamine pentaacetic acid extractable nickel (DTPA-Ni) was found to be higher in sewage fed soils. Sewage irrigation increased soil DTPA-Ni content by 3.04 times over the tube well irrigated soils. The content of DTPA –Ni showed decreasing trend with depth. Hydrogen concentration (pH) was negatively and significantly correlated with DTPA-Ni nickel whereas, organic carbon and total Ni show positive and significant correlation. Sequential fractionation was carried out to partition Ni in to fractions namely exchangeable and water soluble, organic bound, carbonate bound, Mn oxides bound, amorphous Fe oxides, crystalline Fe oxides bound and residual. Plant availability of these fractions is believed to decrease in the above order. Sequential fractionation indicated that every extracted fraction exhibited increase in Ni content with sewage irrigation with most prominent increases occurring in the organic and oxide fractions. The lowest amount of Ni in exchangeable and water soluble and the highest in residual pools testify that plants grown on these soils may not suffer from Ni toxicity. Though all the crops irrigated with sewage water had appreciably higher concentration of Ni as compared to the crops raised with tube-well water, yet raya (Brassica juncea) and toria (Brassica campestris) accumulated higher content of heavy metals as compared to other crops, with higher content in roots than shoots. Transport index suggested that major part of taken up Ni is translocated to top parts of plant. Based on values of transport indices, different crops may be arranged as toria > raya = maize> bajra >lady finger. As the plants take up nickel readily and there is danger of its excessive accumulation in plant organs and devaluation of the plant products. This is topical issue particularly in crops used for direct consumption.*

Key words: *Nickel, Sewage irrigated soils, Tubewell irrigated soils*
PDF of full length paper is available with author ***(*khuranamps1@rediffmail.com)***

Introduction

Industrial and agricultural activities in urban areas of Punjab (Saxena *et al.,* 2007) have led to a considerable increase in heavy metal levels in different environmental compartments, especially in soils over the course of recent decade. There are some reports which indicate that heavy metals pollution including Ni in soils arises as a result of various anthropogenic activities such as continuous use of sewage water (Brar *et al.,* 2002; Kumari *et al.,* 2006; Krishnan *et al.,* 2007), sewage sludge (Singh and Sakal, 2001) and fertilizers (Tiller, 1992; Indra and Sivaji, 2006). In Punjab, 93 towns produce about 113.4 millon litres of wastewater per day from domestic and industrial activities. Because of the high cost involved in the installation of treatment plants, these industries as such discharge their industrial effluents into sewer or nearby drain or water body. The scarcity and high nutrient potential of these waters allure the farmers to use such water for irrigation to their crops. The built up of increasing levels of Ni in agricultural soils from this mode of disposal may have an adverse effect on food chain. Nickel is hazardous highly carcinogenic metal and its target organs in human beings are mainly lungs and nasal sinuses. Recent studies have indicated large amount of Ni in the effluents of industries like electroplating, tanneries, steel and alloys varying from 0.85 to 3.00 mg l^{-1}. Trace element including Ni are present in different chemical forms because they are associated to diverse organic and inorganic components of the soils such as soluble, exchangeable, bound to carbonate, Fe and Mn oxides, organic matter and residual (Bell *et al.,* 1991). Nickel present in water soluble and exchangeable forms is generally considered bio-available. There fore partitioning of Ni is very important to evaluate its possible adverse effect. Further, the extent of metal accumulation also varies with plants and even with in plant parts. With the exception of Zn in plant tissues harvested from compost and sludge treated soils, root tissue of cabbage for both compost and sludge treated treatments appeared to accumulate more metals in the roots than the aerial parts (Chu and Wong, 1987). Transport indices which computes the translocation of Ni from roots to shoots is a good indicator of comparing the accumulation pattern of Ni among various crops. The present investigation evaluated the effects of irrigation with contaminated sewage water on the speciation of Ni, (most prevalent and dominant cation in waste water) in soils and its accumulation in crops grown in areas irrigated with such water in four major industrial towns of Punjab namely Jalandhar, Ludhiana, Amritsar and Mandi Gobindgarh and compared the transport indices of Ni of various crops grown on these soils.

Materials and Methods

Study area: In order to demarcate Ni polluted soils, four major industrial towns of Punjab namely Jalandhar, Ludhiana, Amritsar and Mandi Gobindgarh were selected which have high pollution potential. The description of the sites chosen for soil and plant sampling are described individually for each town. Jalandhar is one of the important industrial cities of Punjab where different types of industries such as, electroplating, hand tools, pipe fittings, rubber and leather are located. The polluted water released from these industries without any treatment, together with waste water of domestic origin find its way into respective drains located in the proximity alongside Garah, Kapurthala and Hoshiarpur bye pass road. Ludhiana is a big town and is commonly known as industrial hub of Punjab where machine tools, electroplating, bicycles, woolen and hosiery manufacturing units discharge their industrial effluents directly or through sewer into water tributary (Buddha Nallah). Amritsar is an other industrial city of Punjab where electroplating, fertilizer and woollen industries are dominant. These industrial units discharge their effluents in open drains namely "Gumtala Drain" lying in the exterior of Amritsar towards Ajnata side and "Gandha Nallah" passing through the interior of town along the Grand Trunk Road. Mandi Gobindgarh is known for its iron, steel and other related industries. These industrial units also discharge their effluents into open drain passing through the interior of the town along the Amloh road.

Methodology: In order to determine the pollution potential, surface (0-15 cm) and sub surface (15-30 cm) soil samples numbering 92 were collected from sewage irrigated soils of Ludhiana, Jalandhar Amrutsar and Mandi Gobindgarh. Forty three soil samples were collected from these towns where tubewell water is used for irrigation. The soils of these fields are classified as typic ustochrepts and ustipsament (Sehgal and Sys, 1970) with texture ranging from sandy to loamy sand. Available Ni in the samples was determined by DTPA method (Lindsay and Norvell, 1978). Surface soil samples were analysed for total Ni content after digesting them with HF and $HClO_4$ in platinum crucibles. The amount of Ni in each sample was estimated by atomic absorption spectrophotometer (Varian Spectraa-20). Since the soils of Ludhiana supposed to have potential hazards of Ni, they were partitioned into various fractions : exchangeable + water soluble (EX+WS), carbonate (CARB), Mn oxides bound (MnOX), organic matter complexed (OM), occluded in amorphous (A Fe OX) and crystalline (C Fe OX) Fe oxides and residual (RES) so as to evaluate the retention of Ni as per sequential procedure of Singh *et al.* (1988).

Shoots and roots of plant species such as maize (*Zea mays*), toria (*Brassica campestris*), raya (*Brassica juncea*), bajra (*Pennisetum typhoides*) and lady's finger (*Abelmoschus esculentus*) at grand growth stage (where maximum vegetative growth is expected) were sampled from both sewage and tubewell irrigated soils of Jalandhar whereas only shoots (above ground parts) of plant species namely sponge guard (*Luffa cyclindrica*), bottle guard (*Lagenaria sicenaria*), brinjal (*Solanum melongena*), green chilies (*Capscicum annuum*), spinach (*Spinacia oleracea*) were collected from Amritsar. The plant samples of brinjal and green chillies were collected only from sewage fed soils as these are not found growing in Tubewell irrigated soils. All the plant samples were collected from three sites both for tube well and sewage irrigated soils. The plants were washed with running tap water for a sufficient period of time to remove the soil and dust particles. The samples were then washed successively with 0.01 N HCl, distilled water and deionized water respectively. They were dried in hot air oven at 65°C and then ground (pulverized) in stainless steel grinder. The plant samples were analysed for total Ni, using di-acid mixture and determined with the help of atomic absorption spectrophotometer. The free oxides of iron and manganese in soils were extracted with sodium-dithionite, sodium-citrate and sodium-bicarbnonate (CBD) reagents, following the method described by Mehra and Jackson (1960). The extract was analysed for Fe and Mn using atomic absorption sepectrophotometer (AAS). Transport index [(concentration of metal in shoot/ concentration of metal in root) *100] was also computed for assessing the translocation of Ni from root to shoots for comparing relative of Ni accumulation of various crops. Transport Index on shoot to root metal concentration. Hyper accumulators are those plants where shoot to root metal concentration ration is > 1(Transport Index > 100 percent), where as non hyper accumulator plants generally have higher metal concentration in roots than shoots or where shoot to root metal concentration ratio is < 1 (Transport Index < 100%).

Results and Discussion

DTPA extractable Ni: Diethylene triamine pentaacetic acid (DTPA) and more precisely 0.005M DTPA + 0.01M $CaCl_2$ + 0.1M tri ethanol amine (pH 7.3) has been used to measure available form of Ni. Elevated concentration of DTPA extractable Ni was found in sewage fed soils in all the industrial towns of Punjab as compared to tube well irrigated soils. The data in Table 1 revealed that content of DTPA extractable Ni in surface (0-15 cm layer) varied from 0.72 to 7.2 with the mean value of 3.58 mg kg^{-1} soil, indicating high accumulation in surface soils of Ludhiana receiving sewage wastewater. The respective mean values of Ni for the sewage fed surface soils of Mandi Gobindgarh, Jalandhar and Amritsar were 1.37, 1.31 and 0.99 mg kg^{-1} soil (Table 1). These results indicated that among the four towns, the surface sewage irrigated soils of Ludhiana had highest accumulation DTPA extractable Ni followed by the soils of Mandi Gobindgarh, Jalandhar and Amritsar. This is because waste water loaded with Ni released from industries like electroplating, machine tools, stainless steel, bicycle and motor cycles manufacturing, which are dominant in Ludhiana, where Ni is used to impart corrosion resistance led to the enrichment of the soils with this metal.

The respective mean values of DTPA extractable Ni in surface layer of tube well irrigated soils were 0.78, 0.74, 0.62 and 0.26 mg kg^{-1} soil respectively in Ludhiana, Mandi Gobindgarh, Jalandhar and Amritsar respectively (Table 2). Thus the mean DTPA extractable Ni in 0-15 cm layer in sewage irrigated soils of, Ludhiana, Mandi Gobindgarh, Amritsar and Jalandhar was 4.59, 1.85, 2.11 and 3.81 times their respective values in the tube well irrigated soils. Mean values of DTPA extractable Ni in 15-30 cm layer in the tube well irrigated soils of Ludhiana, Mandi Gobindgarh, Jalandhar and Amritsar were found to be 23.9, 46.5, 41.2 and 47.1 percent of sewage irrigated soils (Table 1, 2). When all the towns were considered together, the mean content of DTPA-Ni in sewage irrigated soils in 0-15 cm and 15-30 cm layer was 3.02 and 2.93 times the mean content of DTPA-Ni in Tubewell irrigated soils. Azad *et al.* (1986) also observed that accumulation of Cd, Ni and Co was higher in soils irrigated with sewage water as compared to soils irrigated with tube well water. Brar *et al*. (2002) found that average concentration of Ni was greater in soils when irrigated with sewage water than with ground water by 2 times. Further, the increase in the contents of DTPA extractable Cd, Cu, Cr, Fe, Mn, Ni and Pb with increasing the number of irrigation with polluted water have been reported by Singh *et al.* (1991). Similar observation of higher accumulation of heavy metals in effluent treated soils were made by Patel *et al.* (2004).

The content of DTPA extractable Ni declined with depth in all the towns both in sewage and tubewell irrigated soils (Table 1, 2).The

Table - 1: DTPA-Ni (mg kg^{-1} soil) in sewage irrigated soils of major industrial towns of Punjab

	Ludhiana (n=24)		Jalandhar (n=23)		Mandi Gobindgarh (n=20)		Amritsar (n=25)	
Depth (cm)	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
Minimum	0.72	0.53	0.12	0.12	0.36	0.48	0.52	0.24
Maximum	7.20	6.95	3.72	2.40	6.69	5.40	2.85	1.94
Mean	3.58	2.96	1.31	0.91	1.37	1.14	0.99	0.51
SD±	2.19	1.85	1.06	0.68	1.08	1.06	0.54	0.44

n= number of soil samples

Table- 2: DTPA-Ni (mg kg^{-1} soil) in tube well irrigated soils of major industrial towns of Punjab

	Ludhiana (n=10)		Jalandhar (n=11)		Mandi Gobindgarh (n=12)		Amritsar (n=10)	
Depth (cm)	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
Minimum	0.24	0.14	0.09	0.09	0.18	0.16	0.15	0.12
Maximum	1.65	1.10	1.46	0.60	1.52	0.98	0.62	0.48
Mean	0.78	0.71	0.62	0.42	0.74	0.52	0.24	0.24
SD±	0.53	0.32	0.44	0.12	0.51	0.27	0.14	0.14

n = number of soil samples

Table - 3: Total-Ni (mg kg^{-1} soil) in sewage irrigated soils (0-15 cm) of major industrial towns

	Ludhiana (n=24)	Jalandhar (n=23)	Mandi Gobindgarh (n=20)	Amritsar (n=25)
Minimum	30.2	24.5	26.3	20.4
Maximum	66.8	56.4	60.7	50.8
Mean	48.1	35.5	40.2	29.1
SD±	11.7	9.0	9.3	8.7

n = number of soil samples

Table - 4: Total-Ni (mg kg^{-1} soil) in tube well irrigated soils of major industrial towns

	Ludhiana (n=10)	Jalandhar (n=11)	Mandi Gobindgarh (n=12)	Amritsar (n=10)
Minimum	16.4	13.9	15.2	12.8
Maximum	29.8	25.0	26.8	27.6
Mean	23.6	20.1	21.5	19.7
SD±	4.6	3.2	2.9	4.8

n = number of soil samples

mean values of 2.96, 1.14, 0.91 and 0.51 mg kg^{-1} of DTPA extractable Ni in 15-30 cm layer of sewage irrigated soils of Ludhiana, Mandi Gobindgarh, Jalandhar and Amritsar were comparatively lower compared to their respective value in 0-15 cm layer. Many metals including Ni accumulate in high concentration in surface layer of soils treated with sewage sludge. Their movement is very restricted and they are quite immobile in soils and usually stay at tillage depth (Dowdy *et al.,* 1991).

Total Ni content: In general, high concentration of total Ni was observed in the sewage irrigated soils of all the industrial towns in both the layers. As expected the sewage irrigated soils of Ludhiana had maximum mean concentration of total Ni (48.1mg kg^{-1}soil) followed by Mandi Gobindgarh (40.2 mg kg^{-1}soil), Jalandhar (35.5 mg kg^{-1} soil) and Amritsar (29.1 mg kg^{-1} soil). The average total Ni content in 0-15 cm layer in the soil receiving tube well water was 23.6, 21.5, 20.1 and 19.7 mg kg^{-1} soil in Ludhiana, Mandi Gobindgarh, Jalandhar and Amritsar respectively. The overall mean content of total Ni in sewage irrigated soils irrespective of the towns was 38.2 mg kg^{-1}soil as against 21 mg kg^{-1}soil in tubewell irrigated soils, there by registering an over all increase of 44.2 percent. The increase in total Ni content with sewage irrigation was dependent upon the rate of loading and chemical composition of sewage water as well as *in situ* properties of soils for categorizing the soils as polluted, critical concentration based on total Ni are generally considered. The threshold level of 100 mg, Ni kg^{-1} soi is taken as related to phyto-toxicity (Kitagishi and Yamane 1981; Kabata Pendias and Pendias, 1986). In the present study, no soil sample reached this threshold value. Therefore, the soils of Punjab had not yet crossed the threshold value but there is the possibility that these soils might approach this critical limit in a few years if same level of irrigation with sewage water continued.

Table - 5: Correlation coefficient (r) of DTPA-Ni of polluted soils (0-15 cm) of major industrial towns of Punjab with some selected soil properties and total Ni

Name of the town	Soil properties				
	pH	EC	OC	$CaCO_3$	Total Ni
Mandi Gobindgarh (n=20)	-0.51*	0.13	0.53*	-0.23	0.57*
Ludhiana (n = 24)	-0.59*	0.24	0.44*	-0.18	0.41*
Jalandhar (n=23)	-0.58*	0.22	0.46*	-0.37	0.53*
Amritsar (n = 25)	-0.56*	0.31	0.69*	0.03	0.63

*Significant at 5% level; n = number of soil samples

Table - 6: Forms of Ni (mg kg^{-1} soil) in sewage and tube well irrigated soils (0-15 cm)

	EX + WS	CARB	Mn OX	OM	AFe OX	CFe OX	RES
				Sewage irrigated soil			
Min.	0.16	0.80	1.81	1.34	6.42	1.21	13.40
Max.	0.64	2.02	5.42	2.64	16.96	5.24	38.42
Mean	0.31	1.23	3.32	1.82	10.98	2.61	27.14
SD±	0.12	0.35	0.96	0.37	2.91	1.14	7.20
				Tube well irrigated soil			
Min.	0.07	0.52	0.52	0.16	4.5	0.72	8.5
Max.	0.18	0.98	1.80	0.54	8.5	1.95	19.8
Mean	0.65	0.67	0.98	0.37	5.71	1.12	14.2
SD±	0.03	0.13	0.44	0.13	1.08	0.40	4.0

Table - 7: Mean amount of nickel (μg g^{-1}) in roots and shoots of various crops

	Root		Shoot	
	SW	TW	SW	TW
		Jalandhar		
Plant species				
Maize	1.97	1.50	1.67	1.20
Toria	7.0	4.0	6.40	1.52
Bajra	1.68	1.0	1.40	1.0
Lady finger	2.48	2.0	1.90	0.70
Raya	9.80	4.6	8.30	1.70
		Amritsar		
Sponge gourd	——	——	5.5	3.0
Bottle gourd	——	——	2.75	2.25
Brinzal	——	——	2.0	1.5
Green chilies	——	——	1.2	——
Spinach	——	——	3.53	——

SW = Sewage water , TW = Tube water

Relationship of DTPA- Ni with some soil properties and total Ni: It is pertinent to mention here that the properties of the soils such as pH, electrical conductivity (EC), organic carbon (OC) and calcium carbonate ($CaCO_3$) has been reported (Khurana *et al.,* 2003). However the pH, EC, OC and $CaCO_3$ of the investigated soils ranged from as low as 7.25 to as high as 8.50, 0.26 to 1.12 dSm^{-1}, 0.26 to 1.85 percent and nil to 2.20 percent respectively regard less of the towns. Coefficients of correlation were worked out for the polluted soils only between DTPA extractable Ni with soil properties and total Ni (Table 5). There was significant and negative correlation of DTPA extractable Ni with soil pH in the surface soils of all the towns of Punjab. The increase in soil pH increased the negative charge density on soil colloids which enhanced the adsorption and reduced the extractability of Ni in soils (Harter, 1983). King (1988) observed that soil pH was the most important factor affecting sorbed Ni and non exchangeable Ni in all soil horizons. DTPA extractable Ni were positively but non significantly correlated with the electrical conductivity in polluted soils in all the four towns of Punjab. The positive correlation might be due to the added effect of soluble salts present in sewage water but it was positively and significantly correlated with the organic carbon in sewage irrigated soils under both the layers in all the towns of Punjab. But showed no relation with calcium carbonate. Significant correlation in polluted soils might be due to simultaneous loading of soil with organic matter and Ni content. Canet *et al.* (1997) found substantial amounts of organically bound Cu and Ni in soils (0-20 cm) with the use of sludge and compost after 7 years during of their application. Organic matter has been shown to chelate Ni, thereby rendering it less available to plants (Cunningham *et al.,* 1975). There was highly significant and positive correlation between DTPA-Ni and total-Ni in sewage irrigated soils of all the towns. This suggested DTPA–Ni was dependent on total Ni which in turn depends on the amount of metal loading and in situ properties of the soils such as nature and concentration of Ni parent material and weathering processes. Alloway (1990) found that total Cd was the deciding factor in the multiple regression equations derived to describe the accumulation of DTPA extractable cadmium.

Sequential fractionation Ni of surface soils: In order to determine the various solid phases responsible for controlling the availability of Ni surface samples both from sewage and tube -well irrigated soils of Ludhiana having high amount of DTPA - Ni were subjected to sequential fractionation.

Exchangeable and water soluble nickel (EX + WS-Ni): This fraction ranged from 0.42 to 1.9 mg Ni kg^{-1} soil with a mean value of 0.83 mg mg Ni kg^{-1} soil (Table 6) In sewage irrigated soils this form was low (0.7 percent of the total Ni) as compared to other forms. Ramos *et al.* (1994) reported that small amounts of trace metals were extracted with $MgCl_2$ (exchangeable) and it ranged between non detected limit to 6.5 mg kg^{-1} soil for Cd in the soils with pH ranging from 7.42 to 8.85 and texture from sand to clay. Onianwa (2001) observed that about 3 percent of total Ni was associated with this fraction. This is good for food chain as this fraction is considered to be highly plant available.

Carbonate bound nickel (CARB-Ni): Nickel concentration in this pool varied from 0.80 to 2.02 mg kg^{-1} with mean value of 1.23 mg kg^{-1} soil in sewage irrigated soils. This form counted for 2.6 percent of total cadmium. The mean value for tubewell irrigated soils was 0.67 mgkg^{-1} soil which indicated that sewage irrigation did not influence this fraction appreciably

Organic bound nickel (OM-Ni): The average value of organically bound Ni in sewage irrigated soils was found to be 1.82 mg kg^{-1} soil as against average value of 0.37 mg kg^{-1} soil in tubewell irrigated soils. This could be ascribed to higher organic matter content of the sewage irrigated soils as compared to soil receiving tubewell irrigation. Cunningham *et al.* (1975) indicated that since Ni appears to be organo-philic, therefore, its chemical association was more favourable for the formation of strong complexes. This lent support to considerable amount of 4.92 percent in this pool.

Metal associated with oxides: The amount of Nickel in manganese oxides (MnOX), amorphous Fe oxides (A Fe OX) and crystalline Fe-oxides (C Fe OX) were in the range of 1.81 to 5.42 , 6.42 to 16.96 and 1.21 to 5.24 mg kg^{-1} soil respectively with a mean values of 3.32, 10.98 and 2.61 mg kg^{-1} soil respectively (Table 6) which were 3.37, 1.92 2.36 and 1.91 times the amount in tubewell irrigated soils. These forms constituted about 7.0, 23.2 and 5.6 percent respectively of the total Ni. The relative higher value of oxides fractions in sewage irrigated soils as compared to the values in tubewell irrigated soils was most likely due to predominance of free Fe and Mn oxide having a mean value of 0.79 percent and 176 mg kg^{-1} soil with ranges (0.350-1.21 percent) and (98-221 mg kg^{-1} soil) respectively in sewage irrigated soils. Bruemmer *et al.* (1986) described the importance of Fe oxides especially at neutral to alkaline pH values in lowering the activity of heavy metals in soil solutions. The adsorption of heavy metals was accomplished by the formation of hydroxyl species on oxide surfaces. On the other hand, more prevalent cations like Ca and Mg in soil. Did not exhibit such behaviour.

Residual nickel (Resi-Ni): This fraction which constituted 57.20 percent of the total was the most abundant pool of Ni in these soils. The higher proportion of Ni in this form might be due to the fact that as a result of irrigation with sewage water for many years, conditions would have become conducive for the diffusion of these metals into silicate minerals and other resistant materials. Narwal and Singh (1998), observed that Ni and Zn were mostly associated with residual fraction.

Results revealed that in sewage irrigated soil, every extracted fraction exhibited increase in Ni content as compared to tube-well irrigated soils with most prominent increases occurring in the organic and oxide fractions. It can be concluded that overall flux among different fractions was the combined result of readjustment of metal to the changing conditions as a result of long term waste water irrigation in these soils.

Total content in plants: Different crops showed wide variations in their Ni content both in sewage and tube-well irrigated soils. Nickel accumulation in plants in all the parts sampled was higher in sewage fed soils compared to their respective values in tube well irrigated soils in both the towns. Perusal of data in Table 7 revealed that almost roots of all the crops accumulated higher amounts of Ni as compared to their values in shoots These findings corroborate with those of Petterson (1976) who indicated that heavy metal usually accumulate more in roots than in aerial parts. In sewage irrigated soils of Jalandhar, Ni content varied from as low as 1.40 µg g^{-1} dry matter in the roots of bajra to as high as 9.80 µg g^{-1} dry matter in the roots of raya. It is to be noted that the percent increase in Ni content (µg g^{-1} dry matter) with waste water irrigation was 133, 22 and 83 in shoots of spinach, bottle guard and sponge guard respectively in soils of Amritsar. Adhikari *et al.* (1998) reported that the comparatively higher concentration of the micronutrients in vegetables in comparison to normal soils has resulted from the addition of these elements through the continuous application of sewage water in the outskirts of city of Calcutta.

The accumulated amount of Ni in various plants ranged below the critical toxicity limit. According to different authors the margin of toxicity is 25-50 µg g^{-1} dry matter (Allaway, 1968; Davis *et al.*, 1978; Magnicol and Beckett, 1985) in almost all the crops in spite of long term use of contaminated irrigation water. No symptoms of Ni toxicity were observed and all the crops showed good stand. These findings also find support to our earlier observation that sewage irrigation has resulted in ineffectual increase in exchangeable and water soluble fraction. Further result indicated that raya and toria belonging to family cruciferae appear to have higher extraction capacity and therefore accumulated higher amount of Ni compared to other crops indicating the involvement of plant factors. So there might be specific uptake mechanism in different plants for heavy metal tolerance. This also supported the view of Kuboi *et al.* (1986) that tolerance limit was dependent upon family characteristics rather than other factors of the soil.

Transport index: [(concentration of metal in shoot/ concentration of metal in root) *100]. This was calculated for assessing the translocation of Ni from root to shoot. Values of transport indices of Ni were 84.7, 91, 83.8, 76.6 and 84.7 for maize, toria, bajra, lady finger and raya respectively. Although the values of transport indices for all the plant species are below 100, these could not be regarded as hyper-accumulators (Hooda, 2007; Baker, 1981) yet the results suggested that by and large the major part of taken up Ni is translocated to the top parts of plants. As the plant take up nickel readily and there is danger of its excessive accumulation in plant organs and devaluation of the plant products. This is topical issue particularly in crops used for direct consumption.

References

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

Allaway, W.H.: Agronomic controls over the environmental cycling of trace elements. *Adv. Agron.*, **20**, 235-274 (1968).

Alloway, B.J.: Heavy metals in soils. Blackie London Wiley, New York. pp. 29-30 (1990).

Azad, A.S., G.S. Sekhon and B.R. Arora: Distribution of cadmium, nickel and cobalt in sewage water irrigated soils. *J. Ind. Soc. Soil Sci.*, **34**, 619-622 (1986).

Baker, A.J.M.: Accumulators and excluders strategies in response of plants to heavy metals. *J. Plant Nutr.*, **3**, 643-54 (1981).

Bell, P.F., R.J. Bruce and R.L.Chaney: Heavy metal extractability in long-term sewage sludge and metal salt -amended soils. *J. Environ. Qual.*, **20**, 481-86 (1991).

Brar, M.S., M.P.S. Khurana and B.D. Kansal: Effect of irrigation by untreated sewage effluents on the micro and potentially toxic elements in soils and plants. *In*: Proc 17th World Congress of Soil Science held at Bangkok,Thailand from August 14-21, 2002, Volume IV, Symposium no 24. p. 198 (2002).

Bruemmer, G.W., J. Gerth and U. Herms: Heavy metal species, mobility and availability in soils. *Z. Pfanzenernaeh Bodenk.*, **149**, 382-98 (1986).

Canet, R., F. Pomares and F. Tarazora: Chemical extractability and availability of heavy metals after seven years of application of organic wastes to a citrus soil. *Soil Use Manage.,* **13**, 117-21 (1997).

Chu, L.M. and M.H. Wong: Heavy metal contents of vegetable crops treated with refuse compost and sewage sludge. *Plant and Soil,* **103**,191-97 (1987).

Cunningham, J.D., D.R. Keeney and J.A. Rayan: Phytotoxity and uptake of metals added to soils as inorganic salts or in sewage sludge. *J. Environ. Qual.*, **4**, 460-462 (1975).

Davis, R.D., D.H.T. Beckett and E. Wollan: Critical levels of 20 potentially toxic elements in young barley. *Plant Soil.*, **49**, 395-404 (1978).

Dowdy, R.H., J.J. Lattreell., T.D. Hinesly., R.B. Grassman and D.L. Sullivan: Trace metal movement in an aeric ochraqualf following 14 years of annual sludge application. *J. Environ. Qual.,* **20**, 119-23 (1991).

Harter, R.D.: Effect of soil pH on adsorption of lead, copper, zinc and nickel. *Soil Sci. Soc. Am. J.*, **47**, 47-51 (1983).

Hooda, Vinita: Phytoremediation of toxic metals from soil and waste water. *J. Environ. Biol.,* **28**, 367-376 (2007).

Indra, V. and S. Sivaji: Metals and organic components of sewage and sludges. *J. Environ. Biol.*, **27**, 723-725 (2006).

Kabata, Pendias. A. and H. Pendias: Trace elements in soil and plants. CRC Press Inc Boca Raton, Florida, USA (1986).

Khurana, M.P.S., V.K. Nayyar, R.L. Bansal and M.V. Singh: Heavy metal pollution in soils and plants through untreated sewage water. *In*: Ground water pollution (*Eds.*: V.P. Singh and R.N. Yadav). Proc. International Conference on Water and Environment. Allied Publisher Pvt. Ltd. New Delhi. pp. 487-495 (2003).

King, D.L.: Retention of metals by several soils of the southeastern United States. *J. Environ. Qual.,* **17**, 239-288 (1988).

Kitagishi, K. and I. Yamane: Heavy metal pollution in soils of Japan. Japan Scientific Societies Press, Tokyo. p. 302 (1981).

Krishnan, Radha R., K. Dharmaraj and B.D. Ranjitha Kumari: A comparative study on the physicochemical and bacterial analysis of drinking, borewell and sewage water in the three different places of Sivakasi. *J. Environ. Biol.*, **28**, 105-108 (2007).

Kuboi, T., A. Noguchi and J. Yazaki: Family dependent cadmium accumulation characteristics in higher plants. *Plant Soil,* **92**, 405-415 (1986).

Kumari, Binu S., A. Kavitha Kirubavathy and Rajammal Thirumalnesan: Suitability and water quality criteria of an open drainage municipal sewage water at Coimbatore, used for irrigation. *J. Environ. Biol.*, **27**, 709-712 (2006).

Lindsay, W.L. and W.A. Norvell**:** Development of DTPA soil test for zinc, iron manganese and copper. *Soil Sci. Soc. Amer. J.,* **42**, 421-28 (1978).

Magnicol, R.D. and P.H.T. Beckett: Critical tissue concentration of potentially toxic elements. *Plant and Soil,* **85**, 107-129 (1985).

Mehra, O.P. and M.L. Jackson: Iron oxide removal from soils and clays by a dithionite-citrate system buffered with sodium bicarbonate. *Clay Miner.*, **7**, 317-27 (1960).

Narwal, R.P. and B.R. Singh: Effect of organic materials on partitioning, extractability and plant uptake of metals in an alum shale soil. *Water Air Soil Pollut.,* **103**, 405-21 (1998).

Onianwa, P.C.: Road side top soil concentration of lead and other heavy metals in Ibadan, Nigeria. *Soil Sed. Contam.,* **10**, 577-591 (2001).

Patel, K.P., R.P. Pandya, G.L. Maliwal, K.C. Patel, V.P. Ramani and V. George: Heavy metal content of different effluents and their relative availability in soils irrigated with effluents waters around major industrial cities of Gujrat. *J. Indian Soc Soil Sci.,* **52**, 89-94 (2004).

Patterson, O.: Heavy metal ion uptake by plants from nutrient solutions with metal ion, plant species and growth period variations. *Plant and Soil,* **45**, 445-459 (1976).

Ramos, I., L.M. Hernandezi and M.J. Gonzaliz: Sequential fractionation of copper, lead, cadmium and zinc in soils near Donana national park. *J. Environ. Qual.,* **23**, 50-57(1994).

Saxena, Shalini, D.K. Upreti and Neeta Sharma: Heavy metal accumulation in lichens growing in north side Lucknow city. *J. Environ. Biol.*, **28**, 49-51 (2007).

Sehgal, J.L. and C. Sys: The soils of Punjab, India. III. Classification and geographical distribution. *Pedologie*, **20**, 357-80 (1970).

Singh, A.P. and R. Sakal: Sewage sludge treated soils-Distribution and translocation of micronutrient cations in different plant species. *Sustainable use of Chemicals in Agriculture,* **2**, 22-32 (2001).

Singh, J.P., S.P.S. Karwasra and M. Singh: Distribution and forms of copper, iron, manganese and zinc in calcareous soils of India. *Soil Sci.*, **146**, 359-66 (1988).

Singh, R.R., V. Singh and A.K. Shukla: Yield and heavy metal content of berseem as influenced by sewage water and refinery effluent. *J. Ind. Soc. Soil Sci.,* **39**, 402-404 (1991).

Tiller, K.G.: Urban soil contamination in Australia. *Aust. J. Soil Res.,* **30**, 937-57 (1992).