CHAPTER SEVEN

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GENERAL DISCUSSION

7.1 Introduction

Soils are serving as long-term sinks for accumulated heavy metals. To estimate the potential and residual risk of heavy metal contaminants in the soil environment it is important to focus on the fate of metals and the factors that influence it. The fate of heavy metals in the environment is a function of their mass loading, chemical speciation, bioavailability and the length of time that soil is exposed to specific metal contaminants. There are many soil processes that largely affect the accommodation and release of heavy metals in the soil therefore, control the speciation and bioavailability of such pollutants in the soil environment. Hence, the trend of this chapter is to discuss the fate and environmental significance of cadmium, lead, nickel and zinc disposed in the soil environment as influenced by the above-mentioned factors, to illustrate the contaminants-soil-plant-human exposure pathway and to model the risk which arise from heavy metals in the soil environment

7.2 Distribution of cadmium, lead, nickel and zinc in soil phases as affected by the amendment level, soil type and residence time

One of the fundamental processes controlling the fate of heavy metals pollutants in soil environments is their partitioning between the dissolved and sorbed state. It is believed that the amount of a metal in the soil solution provides a good measure of its bioavaiable component. On the other hand the solid phase proportion represents the potential source of metals released into the soil environment (Viets, 1982 and Brady and Weil 1999). The main mechanism of heavy metals retention in soils is the adsorption onto soil solids (Brian, 1980). This part focuses on the portioning of the added heavy metals between the solution and solid phases of the experimental soils and discusses the effect of amendment level, soil type and residence time on metal distribution.

7.2.1 The effect of amendment level

Although heavy metal cations may be absorbed at low concentrations, increasing their mass loading in a soil may result in high concentrations of these metal ions in soil solution and solid phases. Such information is critical to understanding the limit of heavy metals adsorption and desorption in soil subjected to different levels of contamination. The following discussion cover the results presented in Tables 4.1 to 4.4 and Figures 4.1, 4.4, 4.7 and 4.10. In different soil types the Cd and Pb adsorption by the solid phase was found to increase with the level of their amendment. The total adsorption value of Cd, Pb, Ni and Zn onto soil particles in the three soils showed some increment with each increase in their amendment level and this situation is clearly demonstrated in sandy clay loam (soil III). This is consistent with previously published data by Frost and Griffin, (1977); Hickey and Kittrick, (1984;) Linda and Chang, (1992); Andreu *et al*., (1996); McBride *et al*., (1997a); Krishnamurti *et al*., 1997 and Percival (1999).

In addition the slight increase of Cd, Pb, Ni and Zn with the intensification of their amendment level can be explained by the decreasing storage of solid compounds onto the soil surface correspondingly a decreasing soil adsorption capacity for such metals. On the other hand the solution concentration of Ni and Zn is approximately double for each increase in their amendment level, this situation is clearly demonstrated in sandy loam soils (soil I and II). The increase in solution concentration of metals with the intensification of their amendment level is due to that soils reach their maximum soil adsorptive capacity and virtually most of the added amendment will remain in the soluble phase.

7.2.2 The effect of soil type

The soil adsorption capacity for heavy metals varies greatly with soil type and with in the studied metals. The three soils adsorbed the added metals to different extents. This can be illustrated by comparing results presented in Tables 4.1 to 4.4 and Figures 4.2, 4.5, 4.8 and 4.10. In general soil type had a significant effect on metal adsorption; generally metals were more adsorbed by the sandy clay loam (Soil III) than the sandy loam soils (soil I and 1I). There are several possible reasons for this. The first is due to the pH. This is because pH is controlling the variables in adsorption and solubility of heavy metals in soils (Gerritse and Driel 1984; Hahne and Kroonje, (1973) and Basta et al., 1993). As it was shown in Table 3.1 among the studied soil, soil III has the higher soil pH Gerritse and Driel 1984Basta et al., 1993); David et al., (1995); Krishnamurti et al., (1997); Fischer et al., (1991); McBride et al., (1997a) and Scheidegger et al., (1997) proved the significance of soil pH on heavy metal adsorption.

Second, many heavy metal adsorption studies confirmed the significance of CEC in the metal adsorption capacity of soils (Frost and Griffin, 1977; Jette et al., 1996; Bolton and Evans 1996). Soil I and soil II are sandy loams containing small amounts of clay minerals, which therefore play a minor role on the adsorption of the added metal onto the soil. Soil III on the other hand adsorbed high amounts of the added metals and showed lower solution concentration of the studied metals (Bolton and Evans 1996; Merrington and Alloway 1997). Thus, the fraction of Cd, Pb, Ni and Zn in the soluble phase in soil III is substantially lower than in the other two soils. This can be illustrated by comparing Figures 4.2, 4.5, 4.8 and 4.10 for Cd, Pb, Ni and Zn adsorption in the three soils. This is supported by the fact that the maximum sorption capacity of a soil is a function of many factors such as clay content and CEC. However, the two parameters exert a large influence on the number of exchange sites available to metal ions the higher the values of these parameters, the greater the number of sites. Soil III contains 32.6%

clay while the clay content of the other two soils is 12.2 and 18.2. Consequently the sorption capacity of soil III is higher due to the higher CEC and the clay content. (Hahne and Kroonje, (1973); Hickey and Kittric 1984, McBride, 1989 and Sillanpa, 1972).

Third, metals in soil can form relatively stable organo-metal complexes or chelates with the organic matter in soil (Lopes and Cox 1977). Furthermore, the adsorption of some metals (Ni and Pb) by Fe and Al oxide could possibly contribute to the increase in the amount of such metals adsorbed by soils (Frost and Griffin, (1977); Jenne, 1968; Duke 1980; Gerritse and Driel (1984); Papadopoulus and Rowell 1988; Eilliott et al., 1986; Borrow et al., 1989 and Zachara et al., 1992; Wenzel et al., 1992 and Merrington and Madden 2000). Soil III has both the higher organic matter, Fe and Al content compared to that of other two soils (Table 3.1).

7.2.3 **The effect of residence time**

As defined earlier the residence time is the average amount of time a particular element will remain in a given reservoir. The residence time of pollutants in the soil is a critical factor in estimating their environmental risk (Stigliani, 1988 and Daniel and Donald 1999). It is important to gain an understanding of the processes that govern the fate of contaminant over timescales (McBride 1994;Verburg and Baveye 1994; Backes et al., 1995). Hence, the timescales is important to human concerns it can be viewed as the ultimate distribution of heavy metals and their availability throughout their residence time in the soil environment. This part discusses the results presented in Figure 4.3, 4.6, 4.9 and 4.12.

In general, metals concentration in the soil solution showed steady elevation as the residence time of metal amendment increases/ On the other hand there was a steady decrease of Cd, Pb and Ni adsorption in the three soils with the increase in residence time. These results are in a good agreement with short termed studies of the above-mentioned metals carried out separately (Bibak *et al*., 1995; Schultz *et al*., 1987; McLaren *et al*., 1986) which can be explained by looking into the processes that govern the balance between accumulation and solubilization of heavy metals in soils through time. Soil particles contain negative sites at their surfaces, which can attract and absorb metal cations. The number of sites available for a given volume of soil depends on soil type and CEC. As long as negatively charged sites on a soil particle are available for adsorption by metal cations the soil will serve as a sink for the heavy metal. When all the sites are exhausted through additional inputs of metal cations over time and the soil is said to be saturated.

As noted above, the time scale is one of the factors affecting the sorping capacity, accommodation and release of heavy metals in the soil environment (Brady and Weil 1999 and Daniel and Spark 1999). However, at an early stage of incubation time most of the amendments remain in the adsorbed phase, as incubation continues, soils reach their maximum soil sorption capacity and virtually most of the added amendment will remain in the soluble phase.

7.3 Speciation of cadmium, lead, nickel and zinc in soil phases as affected by the soil type and residence time

The determination of the total content of contaminants in the soil is clearly important. However, the quantification of the chemical species of the contaminants present in the soil environmental is equally if not more important. (Soon and Bates, 1982; Hirner, 1992; Sager and Stoeppler, 1992; Legret; 1993; Mench *et al*.,., 1993; and Winistorfer, 1995). The knowledge of chemical speciation of heavy metals in soils is proved to be essential in understanding their chemical and biological interactions in the soil environment (Viets 1962; Soon and Bates, 1982 Sager and Stoeppler 1992; Hirner, 1992; and Legret 1993). This section discusses the quantitative distribution data of the added cadmium, lead, nickel and zinc between their different chemical forms in the soil environment.

7.3.1 Effect of soil type

The chemical speciation of heavy metal in the soil environment is largely determined by the soil properties (Brian, 1980; Salomons and Stigliani, 1995 and Brady and Weil 1999). The fractionation of the added heavy metals into their different chemical forms varies greatly with soil type. The following discussion covers results presented in Tables 5.1 to 5.4. Generally greatest percentages of the added Zn, Ni and Cd were in the exchangeable proportion while Pb is mostly associated with the acid soluble phase and did not display a great availability in exchangeable fraction (Legret 1993).

Exchangeable extracted Cd, Pb Ni, and Zn from soil I and II was generally higher than that in soil III. This can be justified by the effect of soil pH based on the findings of Cavallaro and McBride (1979); Eilliott (1983); Kuo _et al_., (1983); Boekhold _et al_., (1993); Merrington, and Alloway (1994); Basta _et al_., (1993) and McBride _et al_., (1997) who reported positive correlation between soil pH and heavy metals in solution form. The result is in agreement with results obtained for sand loam and sandy clay loam soils (Soon and Bates, 1982). In the three soils the order of exchangeable pool was Zn> Cd > Ni >Pb.

Soil III showed the greatest percentage of complexed metal, that is due to the higher clay, CEC and Fe and Al content of soil III (Table3.1) compared to the other two soils (Jenne 1968; Papadopoulus and Rowell 1988; Borrow _et al_., 1989; Fischer _et al_., 1992; Wenzel _et al_., (1992). Furthermore among the studied soils, soil III has the higher soil pH and according to Gerritse and Driel (1984) Basta _et al_., (1993); David _et al_., (1995); Krishnamurti _et al_., (1997); Fischer et al., (1991); McBride et al., (1997a) and Scheidegger et al., (1997) there a significance effect of soil pH on heavy metal adsorption and precipitation. The order of the complexed pool was varied from soil to soil; in soil I it was Cd > Ni > Zn > Pb, in soil II Cd > Ni > Pb > Zn, while in soil III it was Pb > Cd > Zn > Ni.

The percentage of acid soluble fractions of Cd, Ni and Zn is higher in soil III, which is illustrated by the strong adsorption capacity of soil III and its ability to form strong bound complexations with metal cations (Jenne, 1968; Cavallaro and McBride 1979; Kuo et al., 1983; Eilliott 1983; Eilliott et al., 1986; McBride, 1989; Winistorfer, 1995; and Zachara et al., 1992). Acid soluble fraction percentage in soil I was in this order Pb > Ni > Cd > Zn, in soil II Pb > Ni > Zn > Cd and in soil III Ni > Zn > Pb > Cd. This is supported by the findings of Andreu et al., (1996) and Krishnamurti et al., (1997).

7.3.2 Effect of residence time

The distribution of the added heavy metals among their different chemical forms is greatly influenced by the residence time. Generally, the exchangeable fraction showed a steady elevation as the incubation time proceeds, both the complexed and precipitated pools were higher in the first months of incubation and gradually decrease as the incubation time proceeded. This can be justified by understanding changing in soil properties and processes that govern the balance between accumulation and solubilization of metals in soils through time (Schultz et al., 1987 and Bibak et al., 1995).

The CEC is one of the processes that control the balance between the accumulation and solubilization of heavy metals in soils through time (Bardy and Weil, 1999), as long as the negatively charged sites on a soil particle are available for the adsorption of metal cations the soil will accumulate the heavy metal (complexed and acid soluble forms). When the entire negative charge in the soil surface is occupied by metal cations, soil reaches its maximum sorption capacity and virtually most of the added amendment will remain in the soluble and exchangeable phase. Moreover, the influence of residence time on metals distribution into their different chemical forms in the soil environment can be demonstrated the influence of some other soil properties which are subjected to alteration through time like the soil pH, redox potential and organic complexes (Salomons, 1993 and Bardy and Weil, 1999).

7.4 Plant uptake of cadmium, lead, nickel and zinc in soil phases as affected by the amendment level and residence time

Human consumption of fruits and vegetables grown in heavy metal contaminated soils is identified as the major route for metal contaminants to the human body (USEPA, 1992). Biomonitoring is an ecotoxicological concept for contaminated soils, which was developed throughout the recent years, consisting of the direct investigation of soil contamination risk with plant uptake data (Ali 1993; Turcsanyi, 1992 and Brown *et al.*, 1995).

To estimate the bioavailability and potential risk of cadmium, lead, nickel and zinc added to soils, lettuce (*Lactuce sativa)* is used as a bio-monitor in this study based on its ability to adsorb and tolerate heavy metals, metals (Mench *et al.*, 1998; Kastori 1992 and Kulli *et al.*, 1999). The plant uptake of heavy metal is a function of the mass loading, chemical speciation and the length of time that the soil has been exposed to specific heavy metal contaminants This part discusses the plant uptake of the studied heavy metals as influenced by the metal amendment level, chemical speciation and residence time.

7.4.1 The effect of amendment level

The plant uptake of Cd, Pb, Ni and Zn by lettuce showed a significant relationship with the metal amendments level (Tables 6.1 to 6.4). Simple regression analysis of the plant uptake data of Cd, Pb, Ni and Zn revealed positive correlations between plant concentration of Cd, Pb, Ni and Zn and the total soil content of metals (R^2= 0.928, 0.968, 0.948 and 0.960). The possible reason for this is the increase of metals in soil solution, which is immediately available in the environment. As discussed in 7.1.1 the metal amendment level exerts a positive significant effect on the solution concentration of the studies metals. Results are consistent with t with the findings of Murthy, (1982); Sterrett et al., (1996); Qian et al., (1996); Solan et al., (1997; Arnesen and Singh (1998); Ma and Uren (1996); Singh et al., (1995); Robert et al., (1995, and Rooney et al., 1999).)

The relative bioavailability of the applied heavy metals is in this order Zn > Ni> Pb>Cd. That is due to the less mobility of Cd (Adriano, 1986: Chang et al., (1984); Dowdy et al., (1991) and Williams et al., (1987). Pb also have little mobility within plants and tend to accumulate in the roots while Zn, Ni and Cd, are easily transported up to the edible parts (Kabata and Pendias 1992). Phillips and Chapple (1995) showed that the potential mobility and biological availability of the Zn in greater than Cd and Pb.

As in the findings reported by Phillips and Chapple (1995); Misra et al., (1994); Merrington and Alloway. (1994); Misra et al., (1994); Nemeth et al., (1993); Moreno et al., (1997); Chang et al.,, (1984); Dowdy et al., (1991) and Williams et al., (1987among the metals studied, Zn and Ni showed the highest bioavailability index in terms of the metals concentrations in the harvested lettuce.

7.4.2 The effect of metal speciation

It is generally recognized that the particular behavior of trace metals in the environment is determined by their specific physicochemical forms rather than by their total concentrations (Soon, and Bates, 1982; Stoeppler, 1992; Legret; 1993; Mench *et al.*, 1993; and Winistorfer, 1995. Simple regression analysis of the Cd, Pb, Ni and Zn uptake data revealed positive correlations with the percentage of exchangeable chemical pool (R^2= 0.879, 0.966, .919 and 0.936) respectively. The results are supported by the fact that soluble and exchangeable chemical pool is the most immediate source for metal cations, thus it is a significant indicator for harmful effect of heavy metals in soils (Viets, 1962; Lindsay, 1979 and Soon, and Bates, 1982; Tu and Tu (1996) and Narwal *et al.*, (1999). Results are in agreement with the findings of Jinadasa *et al.*, (1997); Murthy, (1982); Roca and Pomares (1991); Heinz, (1996): Sterrett *et al.*, (1996); Qian *et al.*, (1996); Sloan *et al.*, (1997); Miner *et al.*, (1997); Lorenz *et al.*, (1997; Singh *et al.*, (1997); Arnesen and Singh (1998) and Rooney *et al.*, 1999).

The plant uptake of Cd, Pb and Ni decreases as the percentages of complexed pool increases (R^2=0.885, 0.773 and 0.989) respectively. The possible reason for that is the Cd, Pb and Ni are being strongly absorbed soil clay minerals and hydrous oxides and are therefore, largely unavailable to plants (Viets, 1962; Soon, and Bates, 1982; Rooney *et al.*, 1999 and). The results are supported by the findings of Soon, and Bates, (1982); Rooney *et al.*, (1999). In contrast to that there a positive correlation of the bioavaiable Zn and the complexed fraction (0.924), which is supported by the fact, due to it's large size, the complexed metal pool is the important significant source for plant uptake of metal cations through the reversible equilibrium between this pool and the exchangeable chemical pool (Soon and Bates 1982 and Viets 1962).

The co-precipitated (acid soluble fraction) is found to not an important immediate source of plant available metals because the equilibrium between this pool and the exchangeable pool is normally established only very slowly (Viets, 1962 and Soon, and Bates, 1982). The plant uptake of Cd, Ni and Zn decreases as the percentages of acid soluble Cd, Ni and Zn increases (R^2= 0.773, 0.989 and 0.876) respectively. Similar conclusion was stated by Soon, and Bates, (1982); Arnesen and Singh (1998) and Rooney et al., (1999).

7.4.3 The effect of residence time

There are significant enhancements in plant concentrations of Cd, Pb, Ni and Zn of lettuce grown on the amended soils as the residence time increases. This part of the discussion will cover results presented in Tables 6.1 to 6.4 and Figures 6.7 and 6.8. The plant uptake of the of Cd, Pb, Ni and Zn is significantly influenced by the residence time (R^2 = 0.974, 0.964, 0.977 and 0.891, This may be attributed to processes that govern the balance between accumulation and solubilization of metals in soil that allow more metals to be released in the soil solution through time (McLaren et al., 1986; Schultz *et al*., 1987; Stigliani, (1988) and Ainsworth et al., 1994). It can also be justified by the significant positive relationship between the metals concentration in the soil solution and the residence time.

The present results are in agreement with the findings of Ylaranta, (1996; Brallier et al., 1996; Logan et al., (1997); Canet et al., (1998); Smit et al., (1998); Chaney et al., 1998); Narwal et al., (1999 and Merrington and Madden (2000), who reported significant correlation between plant concentrations of Cd, Pb, Ni and Zn and residence time that vary from 2 to 16 years. In contrast to the present result Singh et al., (1995), reported that the lettuce uptake of Cd, Ni and Zn decreased with increasing the length of incubation time (3 years), Brallier et al., (1996) stated that the relative plant uptake of Cd, Ni and were reduced after 16 years experiment and Singh *et al.*, (1995) reported decreasing uptake of Ni after three years of application

7.5 Contaminant soil-plant-human exposure pathway

Contaminated soils are the pre-eminent sources of most biologically active toxic metals, that can reach man through food chain (Oliver, 1997). From soils the usual mode of entry of metals into the human body is by the route of food chain: soil-plant-man or soil-plant-animal-man. The consumption of vegetables and fruits grown in contaminated soils is identified as the major exposure pathway to contaminants (Hawley, (1985); USEPA, 1990b; Paterson and Mackay, 1991 and USEPA, 1992). The concentration of such metals are either magnified or reduced when going up the food chain depending on soil and metal properties (Wallace and Wallace, 1994). To address this pathway with guidance there are several methods introduced for evaluating soil screening levels for heavy metals soil-plant-human exposure (USEPA, 1992; McFarlance, 1995 and Trapp and McFarlance, 1995). In this part we implement the simple equation recommended by US Environmental Protection Agency (1992) to calculate soil-screening levels for the soil-plant-human exposure pathway.

The screening level equation for the soil-plant-human exposure pathway is given by:

$$\textit{Screening level (mg/kg)} = C_{Plant}/Br \ldots\ldots\ldots\ldots(1)$$

C_{Plan} is the acceptable concentration of metal contaminant in plant tissue (mg/kg Dry weight), which is backcalculated using the following equation:

$$C_{Plant} = Ix\ BW/(FxCR) \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Parameter Definition (units)	**Default**	
I = Acceptable daily intake (mg/kg)	see Appendix D	
BW= Body weight (kg)	70	
F= Fraction of vegetable consumed	0.4 (see Appendix D)	
CR= Consumption rate (kg Plant per day)	0.0197 (aboveground)	0.0024(below ground)

Br is the plant- soil bioconcentration factor, which can be estimated by the following formula:

$$Br = (\text{mg contaminant}/\text{kg plant tissue})(\text{mg contaminant}/\text{kg soil})^{-1} \ldots\ldots\ldots(3)$$

For more elaboration in the above-mentioned factors, and methods involved in their estimation please refer to Appendix D. The previously published data for the acceptable concentration of metal contaminant in plant tissue vary greatly among metals (Asami, 1981). The plant- soil bioconcentration factor varies with plant type because certain types of plants are resistant to some metals, while the same metals may be highly toxic to other plant species. Lettuce was proven to tolerate relatively high concentrations of the studied metals (Mench *et al*.,, 1998 and Kulli *et al*., 1999).

The empirical data on plant uptake for, Cd, Pb, Ni and Zn (Tables 6.1-6.2) is used to calculate the plant- soil bioconcentration applying equation (3). Table 7.1 presents values of the estimated plant- soil bioconcentration factor (Br_{cal}) for Cd, Pb, Ni and Zn, in lettuce grown in sandy clay loam soil with pH 7.3 (soil III), treated with the above mentioned metals for incubation time varied from 3 to 15 months. Table 7.2 presents the previously published data for plant- soil bioconcentration factor ((Br_{pub}), and the Acceptable daily intake of metals (I)

Table 7.1: Summary of mean empirical plant- soil bioconcentration factor (Br) of cadmium, lead, nickel and zinc

Heavy metal	Plant- soil bioconcentration factor ((Br)				
	Incubation time (months)				
	3	6	9	12	15
Cadmium	0.0040	0.0040	0.0041	0.0041	0.0042
Lead	0.0147	0.0152	0.0153	0.0154	0.0155
Nickel	0.0150	0.0150	0.0150	0.0160	0.0150
Zinc	0.0607	0.0612	0.0617	0.0625	0.0625

Table 7.2: Summary of the published bioconcentration factors and the maximum acceptable daily intakes of cadmium, lead, nickel and zinc (mg/kg)

Heavy metal	Published Br		Acceptable daily intake (mg/kg/day)
	Range	Mean	
Cadmium	0.002-14.20[1]	[1]0.364	[2]6 x 10^{-2}
Lead	0.002-0.076[1]	[1]0.016	[3]7.5 x 10^{-2}
Nickel	0.002-30.00[1]	[1]0.032	[1]1.43
Zinc	0.012-4.488[1]	[1]0.250	[4]12.0

[1]USEPA, (1992), [2]UNEP/FAO/WHO, (1992), Schumacher et al., (1991) and [4]Robson, (1993)

The variation between the estimated and the mean of previously published values of plant- soil bioconcentration factor for the studied metals is due the soil type effect. The published data for daily intake is used in Equation 2 to estimate the acceptable metal contaminant concentration in plant tissue (**C_{Plant}**). The calculated soil-plant bioconcentration factor is used along with the acceptable metal contaminant concentration in plant to estimate soil-screening level for soil – plant-human exposure pathway of the studied metal. To demonstrate how the method described above may used to calculate the soil screening level for the soil-plant-human pathway of metals, a sample calculation provide below for cadmium in lettuce grown in 10mmol/kg treated soils. Equations (1) and (2) are combined to calculate the ingestion of lettuce.

$$\text{Screening level (mg/kg)} = \text{Ix BW} \ / \ (\text{Fx} \sum \ (\text{CRxBr})) \text{………….(4)}$$

The input parameters of Equation (4) correspond to input parameters in Equations (1) and (2) with a contaminated fraction (F) of 0.4 and consumption rate (Crag) because lettuce is belong to the aboveground group. Solving Equation (4) for cadmium using default parameters in Equations (2) for R and Crag results in:

$$\text{Screening level (mg/kg)} = \text{Ix BW} \ / \ 0.4 \text{ x } (0.0197\text{x } 0.004$$

$$\text{Screening level (mg/kg)} = 6.0 \text{ x } 10^{-2} \text{ x } 70/0.4/0.0197\text{x}0.004$$

$$\text{Screening level (mg/kg)} = 53.299$$

Following the same procedure, the soil screening level for the soil-plant-human pathway of Cd, Pb, Ni and Zn in lettuce. Table 7.3 present s SSL values of Cd, Pb, Ni and Zn in lettuce grown in soils treated with these metals in a 10mmol/kg for incubation time varied from 3 to 15 month

Table 7.3: Comparison of the estimated SSL for soil-plant-human pathway with published SSL

Metal	Estimated SSL mg/kg)					Mean SSL (mg/kg)	Published* SSL (mg/kg)
	Length of residence time (months)						
	3	6	9	12	15		
Cadmium	53.299	53.299	51.999	51.999	50.761	52.271	24.00[1]
Lead	181.290	175.320	174.180	173.050	171.930	175.154	-
Nickel	270.761	270.761	270.760	253.830	270.761	267.375	5400.00[1]
Zinc	1826.407	1811.486	1796.806	1773.807	1773.807	1796.463	10000.00[1]

[1] *USEPA, (1992)*

* *SSL for sewage Sludge mended soils*

The mean SSL soil-plant-human pathway for Cd, Pb, Ni and Zn are comparable to published values obtained from The USEPA, (1992). The *SSL* for soil-plant-human pathway alteration in response to residence time is varied among the studied metals; except for Cd the SSL is undergoing gradual elimination over time From this we may conclude that there is a potential health risk form the soil-plant-human transfer of the four studied metals.

7.6 Modeling the risk of cadmium, lead, nickel and zinc disposed in the soil environment

Soil is a crucial component of the environment and the contamination of the soil with heavy metals poses a continuing and increasing threat to human health. Cadmium, lead, nickel and zinc are among the twenty metals, which are known to be highly toxic at relatively low concentrations and can accumulate in body tissues over long periods of time. In the environment, heavy metals often persist for long periods bound to soils or sediment. The dynamics of heavy metal contaminants in the soil environment is subjected to short and long term fluctuation and undergoing gradual alteration in response to management and environmental factors. These factors need to be considered in decisions on the use of soils for the disposal of waste material containing high levels of heavy metals.

However, changes in weather, in the pH of the soil or in other combinations of environmental factors can mobilize bound metals and greatly increase their toxicity. Consequently, there is a need for detailed studies of the deposition and availability of pollutants and to develop pollutant transfer models including interactions between soil and pollutants, their impact on biota and their residual accumulation in soils (Hawley, 1985 and Selim, 1999). This part intended to create risk assessment models for cadmium dumped in soils using the correlations between contaminant concentrations in the edible plant with in amendment level and residence time (Tables 6.1-6.4).

7.6.1 Risk estimation Model

The empirical data on plant uptake for cadmium as influenced by the amendment level and residence time along with plant- soil bioconcentration factor and residence time correlation model. Linear equation was obtained from the simple regression correlation between the concentration of Cd in lettuce (Cp) (µg/g) and Cd amendment level (L)(g/kg)

$$Cp = 3.6 \text{x} \ 10^{3} L - 0.398 \ldots\ldots\ldots\ldots\ldots \ (5)$$

Polynomial equation was obtained from regression between concentration of Cd in lettuce (Cp) and residence time (T):

$$Cp = -1.47 \text{x} \ (10T)^{2} + 0.3661 \text{x} T + 7.241 \ldots\ldots\ldots (6)$$

Under assumption that the entire metal concentration in the plant may enter the human food, we consider the Cp as the amount of contaminant available for human intake. Thus Equation (5) may be applied to calculate the amount of Cd available for human intake in soils with an identified level of contamination and Equation (6) to estimate the change in human intake in response to the contaminant residence time. Another alternative model is generated from the regression analysis of plant- soil bioconcentration factor (Br) against contaminant residence time (T) after converting the time unit to years as follows:

$$Br = 12 \text{x} 10^{-4} \ T^{2} + 33 \text{x} 10^{-5} + 0.004 \ldots\ldots\ldots (7)$$

To estimate the amount available for human intake from specific level of soil contamination over specific length of contaminant residence time we propose the following two steps:

1 Using Equation (7) we may estimate the Br over any length of contaminant residence time

2 By substituting the Br value obtained for a specific time length in Equation (3) we can determine the concentration of contaminant in plant tissue, which we previously assume to represent the contaminant level available for human intake

Br= ***(mg contaminant /kg plant tissue)(mg contaminant /kg soil)***$^{-1}$……….(3)

To demonstrate the proposed model the following is a calculation of Cd level available for human intake in a soil with 4000 mg/kg Cd contamination level after 10 years of the contaminant residence time:

1 Calculate Br after 10 years using Equation (7)

$$Br= 12x10^{-4} x100 +33x10^{-5}+ 0.004$$

$$Br= 0.1243$$

2 Substitute Br value and the contaminant level in Equation (3)

Br= ***(mg contaminant /kg plant tissue)(mg contaminant /kg soil)***$^{-1}$

Contaminant level available for human intake = ***Brx mg contaminant /kg soil***

$$0.1243x4000=497 \text{ mg/kg plant tissue}$$

Table 7.4 summarize the risk estimation equations resulted from the correlation between of plant concentration of Pb, Ni and Zn, amendment level (L) and residence time (T) along with the equations obtained from the correlation between Pb, Ni and Zn plant- soil bioconcentration factor (Br) against contaminant residence time.

Table 7.4: Summary of risk estimation equations of Pb, Ni and Zn

Metal	Risk estimation Equation		
	Level	Residence time	Bioconcentration factor
Lead	$Cp = 4.707 L + 4.326$	$Cp=6T^2x10^{-3}+0.2158x+ 44.157$	$Br = 6L^2-x10^{-6}$
Nickel	$Cp = 4.044x + 16.819$	$Cp=1.5T^2x10^{-3}+ 0.153x +50.674$	ns
Zinc	$Cp=4.0229L+ 38.39$	$Cp=5.4 T^2x10^{-3}+ 0.122x + 71.924$	$Br =2Lx10^{-4} + 0.0603$

ns= *for nickel there is no significant relationship between Br and residence time*