



## Chemical Partitioning of Iron, Cadmium, Nickel and Chromium in Contaminated Soils of South-Eastern Nigeria

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### Abstract

*Selected heavy metals Fe, Cd, Ni, and Cr were studied in contaminated soil samples collected from South – Eastern Nigeria, for their geochemical differentiation into different chemical fractions, using Ma and Rao six steps sequential chemical extraction procedure in order to assess the potential mobility and bioavailability of the heavy metals in the soil profiles. It is evident from the study that the residual fraction was the most important phase for the four heavy metals under study with the following average percentage values 74.43 for Fe, 37.69 for Cd, 70.11 for Ni and 62.47 for Cr. The carbonate fraction contained an appreciable portion of Fe, Cd and Ni with the average percentage values of 16.29, 14.86 and 10.47 respectively, while organic fraction was of next importance for Cr with an average percentage value of 27.14. Fe – Mn oxide fraction also contained 15.86% of Cd. Relatively low amount of the metals were associated with water soluble and exchangeable fractions. The mobility factors for the metals in all the sites ranged from 8.55 to 40.04 for Fe, 8.66 to 56.58 for Cd, 12.74 to 30.19 for Ni and 0.82 to 7.22 for Cr. The generally low values of mobility factors coupled with significantly high level of association of the metals with the residual fraction, indicate that the metals do not pose any environmental risk or hazard.*

**Keywords:** Sequential extraction, geochemical fractions, heavy metals, soil contamination, South Eastern Nigeria.

### Introduction

The management of our environment and the control of discharge of waste products from anthropogenic activities is of high interest to researchers, regulatory bodies, environmental advisory agencies and policy makers all over the world. Rapid urbanization and population growth have been the major causes of stress on the environment leading to problems like human health problems, eutrophication and fish death, coral reef destruction, biodiversity loss, ozone layer depletion and climatic changes<sup>1-3</sup>.

Urbanization gives rise to a lot of industrial, commercial and agricultural activities. Wastes emanating from these activities are co-deposited on every available space indiscriminately. These waste dumps consist of leaves, plastics, discarded cans, tins, pails, motor and machine parts at various stages of corrosion, rags and textile, dry cell batteries, paper cardboards, woods and plants, etc. There is no doubt that these dumps contribute significant amounts of heavy metals migrating to the soil. Surface run offs from such sites end up in the ground water or in the surface water, thereby increasing the metal burden of the aquatic ecosystem. Soils contaminated with heavy metals are not only a problem with respect to plant nutrition and food chain, they may constitute a direct health hazard as well. Since protection of both terrestrial and aquatic ecosystem from contamination as a result of anthropogenic activities is a global concern, monitoring the concentration, phase association and mobility of metals in the environment that has significant

anthropogenic activities, is therefore necessary. Like other urban centers, where the demand for suitable land for development exceeds the availability, such contaminated sites may be used in the future for residential, industrial, recreational or educational purposes. If these sites are cleared for redevelopment project without any form of assessment, people using such lands may be faced with environmental hazards. Monitoring the concentrations of heavy metals in the soil and sediment is important since knowledge of the heavy metal levels in soil and sediments give vital information regarding their sources, distribution and degree of pollution<sup>4</sup>.

Heavy metals are associated with various soil components in different ways and these associations determine their mobility and availability<sup>5</sup>. As a result, studies on the speciation or chemical forms of heavy metals in polluted soils using sequential extraction techniques have increased because they provide knowledge on metal affinity to soil components and the strength with which they are bound to the soil matrix<sup>6</sup>. By knowing those heavy metal bearing phases and their solubility in aqueous fluids, one can infer the potential mobility and bioavailability (lability) of toxic metals<sup>7,8</sup>. Numerous selective sequential extraction procedures for studying metal mobility and availability in soils and sediments have been described in literature<sup>9-16</sup>.

Many studies have been carried out on speciation of heavy metals in soils in different parts of this country. Although there are a few reports in literature on heavy metal concentration in soils of this area<sup>17,18,19,20</sup>. There is relatively little or no

information regarding the speciation of these metals in soils in this part of the country.

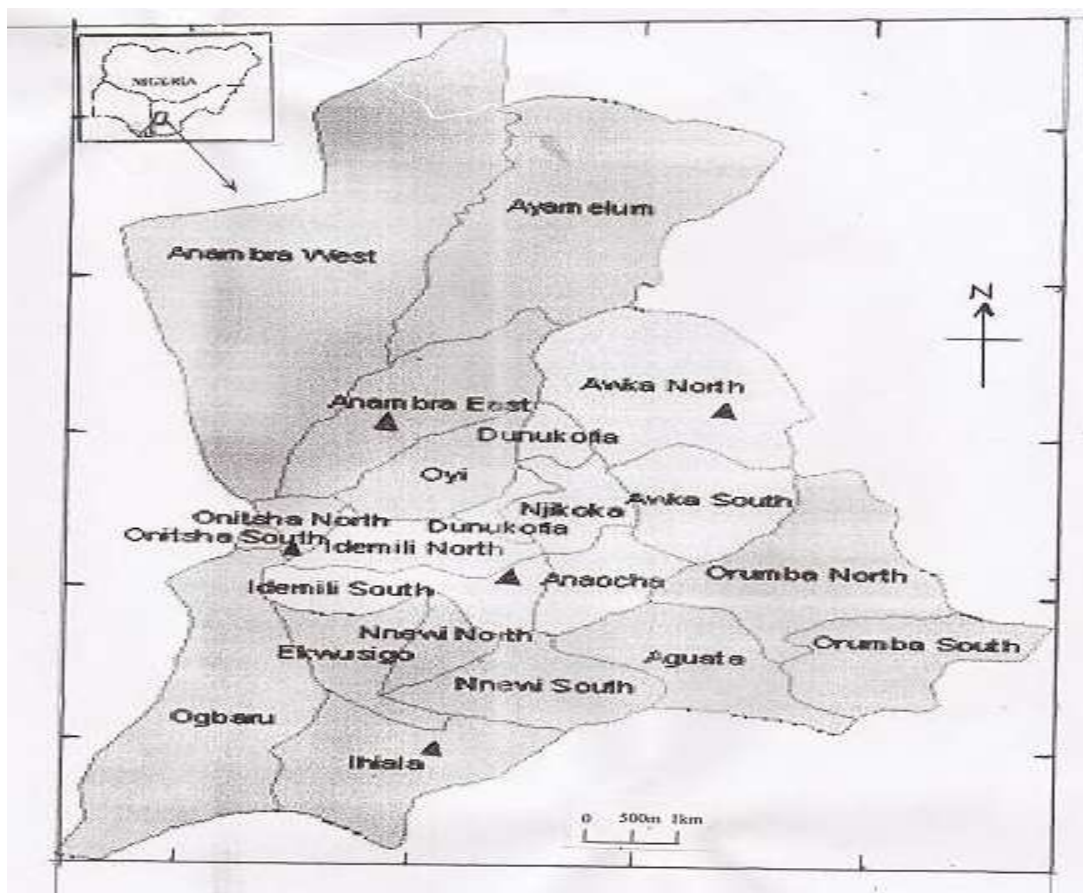
The objective of the present study was to determine the speciation or different forms of heavy metals in the contaminated soils in South-Eastern Nigeria. This study will reveal the chemical behaviour of heavy metals in the soil environment which is the basis of risk assessment, decontamination and remediation of soils contaminated with heavy metals as a result of anthropogenic activities. Since no speciation studies on heavy metals in soils in this part of the country has been reported, it is expected that the results from this study would form a baseline data for future heavy metal pollutional status of soils in the area under study.

### Material and Methods

**Study Area:** The study area lies approximately between longitude  $7^{\circ} 16^1$  N to  $7^{\circ}.00^1$  E and latitude  $6^{\circ} 20^1$  N to  $7^{\circ}.00^1$ E. Its topography is basically plain with the exception of little

sloppy terrain. The area is located within the broad vegetation of tropical rain forest. The vegetation is however affected by activities like agriculture, construction and urbanization. The area lacks functional drainage system and as a result whenever it rains heavily, some areas are flooded while others are scarved by erosion. Due to poor disposal of solid waste, the areas are faced with the problem of indiscriminate dumping of waste on any available space.

**Sampling and Analysis:** Soil samples were collected from waste dumpsites from five different towns. In each town, samples were collected from five different dumpsites at the depths of 0-15cm, 15-30cm and 30-45cm representing topsoil, subsoil and bottom soil respectively. The soil samples collected at the same depth in each town were bulked and representative samples were taken using coning and quartering method. The composite or representative samples got from each of the towns are designated as samples from one site. All the samples were air dried and ground to pass through a 2mm sieve.



Key: ▲ Sampling locations

Figure – 1  
Map of study area showing sampling locations

The procedure of Ma and Rao<sup>15</sup>, which is a modified version of a method described by an earlier researcher<sup>10</sup>, was used to separate the heavy metals into six operational defined geochemical fractions (F<sub>1</sub> to F<sub>6</sub>). Two grams of the soil were placed in a 50ml polypropylene centrifuge tube and subjected to the following extraction processes:

Water-soluble fraction (F<sub>1</sub>): Soil extracted with 20ml of deionized water for 2 hours.

Exchangeable fraction (F<sub>2</sub>): Residue from F<sub>1</sub> extracted with 20ml of 1molL<sup>-1</sup> MgCl<sub>2</sub>, pH 7 for 1 hour.

Carbonate-bound fraction (F<sub>3</sub>): Residue from F<sub>2</sub> extracted with 20ml 1molL<sup>-1</sup> NH<sub>4</sub>OC<sub>2</sub> pH 5 for 5 hours.

Fe-Mn oxide-bound fraction (F<sub>4</sub>): Residue from F<sub>3</sub> extracted with 20ml 0.04molL<sup>-1</sup> NH<sub>2</sub>OH.HCl in 25% (v/v) HOAc at 90°C with occasional agitation.

Organic-bound fraction (F<sub>5</sub>): from F<sub>4</sub> residue extracted with 15ml 30% H<sub>2</sub>O<sub>2</sub> at pH 2 (adjusted with HNO<sub>3</sub>) for 5.5 hours (waterbath, 85°C). After cooling, 5ml of 3.2molL<sup>-1</sup> NH<sub>4</sub>OA<sub>2</sub> in 20% HNO<sub>3</sub> was added and shaken for 30 minutes before final dilution to 20ml with deionized water.

Residual fraction (F<sub>6</sub>): Residue from F<sub>5</sub> digested using a HF-HCl/HNO<sub>3</sub> (hydrofluoric/aqua regia) digestion procedure.

All the solid phases from F<sub>1</sub> to F<sub>6</sub> were washed with 10ml of deionized water before further extraction. The washes were collected with supernatant from the previous fraction. After each extraction, the supernatant was separated by centrifugation at 10,000rpm for 30 minutes.

To verify the sum of metal recovered in the sequential extraction steps a separate total concentration of Fe, Cd, Ni and Cr was determined on the sample after HF/aqua regia digestion using Atomic Absorption Spectrophotometer (Perkin Elmer Model Analyst 2002).

## Results and Discussion

The speciation patterns of the heavy metals in the soils based on their geochemical fractions are presented on table-1 and expressed as percentage on table-2.

**Iron:** The residual fraction with iron content varying from 62.70% to 86.71% and an average of 74.43%, formed the predominant species of iron in all the sites. This result is consistent with numerous studies indicating that iron is insoluble in these types of soils<sup>21-26</sup>. The metals in the residual forms are not available to the biota as it is considered to be held within the mineral matrix<sup>27</sup>. It has been suggested that metal concentrations in the residual fraction of soils or sediments may be indicative of background metal levels<sup>10</sup>. Heavy metals in the residual (HF-soluble) fraction are in all likelihood, associated with silicate minerals<sup>28</sup>.

The next important fraction for iron is the carbonate fraction. The concentration of iron found in the carbonate fraction ranged from 8.71% to 27.20% with an average of 16.29%. The iron concentration obtained in this study is in agreement with earlier results reported<sup>24,29</sup>. The carbonate fraction is relatively stable (slowly labile, poorly leachable), hence the high percentage of metals in this fraction is an indication that metals will not be readily available for uptake by aquatic organisms or plants<sup>30</sup>. The percentage of iron in organic fraction ranged from 2.89 to 6.73 with an average of 5.63. This result corroborates the report from previous study where an average of 6.44% of iron in organic fraction was observed<sup>31</sup>. A very low percentage of iron (1.09%) in this fraction was reported in a similar study<sup>23</sup>. The average percentage of iron in the remaining fraction was 3.06, 1.51 and 0.08 for Fe-Mn oxide, exchangeable and water soluble fractions respectively. The low amount of iron found in the exchangeable and water soluble fractions is probably due to the fact that iron is easily absorbed and utilized by plants and other organisms in the soil environment. The distribution of iron in various fractions was in the order residual > carbonate > organic > exchangeable > water soluble.

**Cadmium:** Cadmium was found to be mostly associated with the residual fraction with the percentage ranging from 16.67 to 76.94 and average of 37.69%. Similar results have been reported by many investigators<sup>15,23,31,32</sup>. The percentage of cadmium in this fraction suggests that a relatively high percentage of cadmium in these soils is of lithogeneous origin and can not be mobilized. The Fe-Mn oxide having the percentage ranging from 3.93 to 21.51 with an average of 15.86% was the next important fraction for this element. The percentage of cadmium observed in this fraction is similar to that reported in some other similar studies<sup>23,33,34</sup>. This fraction could be considered relatively stable but could change with variations in redox condition<sup>23</sup>. It has been proposed that hydrous oxides of manganese and iron furnish the principal control on the fixation of cadmium, nickel, copper and zinc in soils and freshwater sediments<sup>35</sup>.

An appreciable amount of cadmium was found in water soluble fraction (11.57%). This suggests that cadmium is potentially available to some extent in these soils because metals in this fraction are usually thought to be readily available for plants uptake<sup>36</sup>. This result is in agreement with the observation of several researchers<sup>15,37,38,39,40</sup>. It has been suggested that mobility and bioavailability of the metals decrease approximately in the order of the extraction sequence<sup>37</sup>. The operationally defined extraction sequence follows the order of decreasing solubility of the geochemical forms of the metals, hence the exchangeable fraction may indicate which metals are most available for plant uptake<sup>41</sup>. By these criteria, cadmium must be considered quite mobile and biologically available in the soil samples. The organically complexed cadmium was relatively low. Low level of cadmium in the organic fraction has been reported<sup>28</sup>.

**Table - 1**  
**Iron, Cadmium, Nickel and Chromium Concentrations in each of the Operationally Defined Geochemical Fractions of the Soils (mgkg<sup>-1</sup>)**

Sampl es Sites	Depth (cm) Fractions	Fe			Cd			Ni			Cr		
		0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45
A.													
	Water soluble F <sub>1</sub>	ND	2.14	2.14	0.40	0.40	ND	0.06	ND	ND	0.04	0.04	0.03
	Exchangeable F <sub>2</sub>	12.52	16.11	17.10	0.46	0.26	0.28	0.57	0.29	0.13	0.02	0.02	0.01
	Carbonate F <sub>3</sub>	147.80	533.20	787.60	0.39	0.30	0.29	0.59	0.51	0.52	0.08	0.01	ND
	Fe-Mn oxide F <sub>4</sub>	67.50	62.90	61.54	0.71	0.62	0.43	0.17	0.15	0.13	0.70	0.52	0.59
	Organic F <sub>5</sub>	83.60	95.30	124.10	0.21	0.22	0.25	0.22	0.21	0.21	1.22	1.34	1.32
	Residual F <sub>6</sub>	1346.30	1016.10	1022.60	1.06	1.06	1.06	3.15	2.72	2.69	3.60	2.79	2.90
B.													
	Water soluble F <sub>1</sub>	1.28	1.31	1.32	0.33	ND	ND	0.05	0.05	ND	0.05	0.04	0.02
	Exchangeable F <sub>2</sub>	44.87	40.16	38.46	0.11	0.14	ND	0.63	0.31	0.18	0.02	0.01	ND
	Carbonate F <sub>3</sub>	141.30	399.70	563.60	0.11	0.11	ND	0.47	0.44	0.36	0.06	0.07	0.03
	Fe-Mn oxide F <sub>4</sub>	70.50	67.30	19.20	0.14	0.10	ND	0.29	0.19	0.19	0.63	0.29	0.18
	Organic F <sub>5</sub>	107.10	103.70	115.40	0.32	0.11	ND	0.28	0.23	0.23	1.36	1.22	1.06
	Residual F <sub>6</sub>	993.60	1021.30	1114.70	2.80	1.26	0.58	3.64	3.28	3.28	3.75	2.46	2.22
C.													
	Water soluble F <sub>1</sub>	1.28	1.27	1.30	0.62	0.64	ND	0.13	0.10	0.10	0.13	0.06	0.02
	Exchangeable F <sub>2</sub>	20.08	30.11	32.05	0.32	0.26	ND	0.83	0.17	0.17	0.03	0.02	0.02
	Carbonate F <sub>3</sub>	217.50	259.10	276.30	0.50	0.39	0.39	0.64	0.60	0.51	0.13	0.16	0.03
	Fe-Mn oxide F <sub>4</sub>	98.40	97.40	97.40	0.60	0.31	0.22	0.22	0.21	0.20	0.84	0.40	0.03
	Organic F <sub>5</sub>	136.50	127.10	92.60	0.25	0.12	0.12	0.16	0.06	ND	1.54	1.28	1.11
	Residual F <sub>6</sub>	1462.70	1296.30	1334.60	0.80	0.56	0.53	4.63	4.18	4.11	5.16	4.18	2.33
D.													
	Water soluble F <sub>1</sub>	1.28	1.28	1.31	0.46	ND	ND	0.09	0.08	ND	0.09	0.03	0.03
	Exchangeable F <sub>2</sub>	12.82	42.11	43.16	0.18	0.11	ND	0.54	0.53	0.39	0.03	ND	ND
	Carbonate F <sub>3</sub>	133.80	162.20	187.30	0.75	0.11	0.11	0.39	0.28	0.16	0.28	0.11	ND
	Fe-Mn oxide F <sub>4</sub>	60.20	51.60	16.70	0.46	0.38	0.33	0.19	0.10	0.10	0.37	0.22	0.16
	Organic F <sub>5</sub>	140.30	110.90	89.70	0.36	0.32	0.32	0.13	0.13	ND	1.31	1.14	1.00
	Residual F <sub>6</sub>	1381.90	1362.10	1426.10	0.53	0.51	0.51	3.94	2.63	2.11	3.46	3.39	1.44
E.													
	Water soluble F <sub>1</sub>	1.27	1.28	1.31	0.41	0.36	ND	0.03	0.03	ND	0.04	0.03	0.03
	Exchangeable F <sub>2</sub>	9.36	15.16	15.28	0.22	0.18	0.10	0.38	0.16	0.16	0.01	ND	ND
	Carbonate F <sub>3</sub>	128.21	133.96	158.20	0.48	0.39	0.22	0.40	0.28	0.16	0.03	0.03	ND
	Fe-Mn oxide F <sub>4</sub>	15.40	12.30	10.30	0.29	0.25	0.25	0.26	0.18	0.18	0.17	0.11	0.11
	Organic F <sub>5</sub>	58.70	40.60	40.40	0.38	0.31	0.31	0.28	0.16	ND	1.23	1.10	1.00
	Residual F <sub>6</sub>	1362.90	1361.30	1462.90	0.33	0.32	0.18	1.84	1.02	1.00	2.28	1.92	1.52

**Table-2**  
**Percentage concentrations of iron, cadmium, nickel and chromium in each of the operationally defined geochemical fractions**

Sites	A	B	C	D	E	AVERAGE
<b>Metal fraction</b>						
<b>Fe</b>						
F1 Water Solution	0.08	0.08	0.07	0.07	0.08	0.08
F2 Exchangeable	0.85	2.55	1.47	1.88	0.82	1.51
F3 Carbonate	27.20	22.80	13.49	9.25	8.71	16.29
F4 Fe-Mn oxide	3.35	3.24	5.25	2.46	0.79	3.06
F5 Organic	5.61	6.73	6.38	6.52	2.89	5.63
F6 Residual	62.70	64.60	78.33	79.81	89.71	74.43
<b>Cd</b>						
F1 Water Soluble	9.52	5.40	19.00	8.46	15.46	11.57
F2 Exchangeable	11.90	4.09	8.75	5.33	10.04	8.02
F3 Carbonate	11.67	3.60	19.31	17.83	21.89	14.86
F4 Fe-Mn oxide	20.95	3.93	17.04	21.51	15.86	15.86
F5 Organic	8.10	7.04	7.39	18.38	20.08	12.20
F6 Residual	37.86	76.94	28.51	28.49	16.67	37.69
<b>Ni</b>						
F1 Water Soluble	0.49	0.71	1.94	1.44	0.92	1.10
F2 Exchangeable	8.04	7.94	6.87	12.38	10.74	9.19
F3 Carbonate	13.15	9.01	10.87	7.04	12.88	10.47
F4 Fe-Mn oxide	3.65	4.75	3.70	3.31	9.51	4.98
F5 Organic	5.19	5.25	1.29	2.21	6.75	4.14
F6 Residual	69.48	72.34	75.91	73.62	59.20	70.11
<b>Cr</b>						
F1 Water Soluble	0.72	0.82	1.18	1.15	1.04	0.98
F2 Exchangeable	0.33	0.22	0.39	0.23	0.10	0.25
F3 Carbonate	0.59	1.88	1.80	2.99	0.62	1.58
F4 Fe-Mn oxide	11.88	8.17	8.68	5.74	4.06	7.71
F5 Organic	25.48	27.02	22.15	26.42	34.65	27.14
F6 Residual	61.00	62.58	65.78	63.48	59.52	62.47

**Nickel:** The residual fraction was by far the most important fraction for nickel. The values ranged from 59.20% to 75.91% with an average of 70.11%. This result is consistent with the results of many researchers who found the greatest percentage of nickel in the residual fraction<sup>10,21,26,27,28,31,34,41,42</sup>. A majority of nickel in soils and sediments is distributed in nature<sup>10,21,23</sup>. It has been indicated that nickel is commonly occluded by silicate during soil weathering<sup>42</sup>. The next important fraction for nickel is the carbonate fraction having the percentage range from 7.04% to 13.15 with average of 10.47%. This result is consistent with previous reports<sup>23,26</sup>. Low levels of nickel bound to carbonate has been reported<sup>10,28</sup>. Significant percentage of nickel associated with carbonate phase has been reported elsewhere<sup>24</sup>. The total percentage of nickel in the exchangeable and water fractions indicates that some little amount of nickel is potentially available for plants uptake in these soils. Low levels of nickel were associated with the Fe-Mn oxide and organic fractions (4.98% and 4.14% respectively). Low levels of nickel

in these fractions have been reported<sup>31,32</sup>. A significant level of nickel in organic fraction and a relatively low level in the Fe-Mn oxide fraction has been reported<sup>31</sup>. It has been suggested that the levels of nickel in Fe-Mn oxide fraction depends on how much Mn oxide is absorbed in soil because Ni<sup>2+</sup> can substitute for surface manganese in mixed valence Mn oxides<sup>35,43</sup>. The amount of nickel associated with different phases follow the trend residual>carbonate>exchangeable>Fe-Mn organic>water soluble

**Chromium:** Like other metals considered in this study, the predominant species of chromium in all the sites was residual fraction. The amount ranged from 59.52% to 65.78% with an average of 62.47%. This is consistent with numerous studies<sup>31,32,34,44,45,46,49</sup>. The results suggest that chromium is not available for plants uptake or biota in soils studied. The low solubility of chromium in these soils may be attributed to the poorly soluble hydroxo complexes where Cr (iv) forms

oxyanion such as  $\text{CrO}_4^{2-}$  and  $\text{Cr}_2\text{O}_7^{2-}$  and are adsorbed minimally to negatively charged soil particles<sup>34</sup>. The next important fraction for chromium was organic fraction with a range from 22.15% to 34.65% and an average of 27.4%. In a similar study 35% to 42% organic associated chromium was reported<sup>31</sup>. Another researcher reported a substantial proportion of chromium bound to organic fraction in River Nile sediment, Egypt<sup>47</sup>.

A similar association of chromium with organic fraction has been observed in sandy soils where chromium had a strong affinity for organic matter<sup>48</sup>. It has been suggested that the existence of chromium in the organic bound fraction results from the existing physicochemical conditions<sup>32</sup>. An average of 7.71% of chromium was associated with Fe-Mn oxide fraction. Similar result has been reported in soils around oil installation in Assam, India<sup>32</sup>. The total amount of chromium associated with carbonate bound, exchangeable and water soluble fraction was 2.81%. This is consistent with some other findings<sup>31,32</sup>. The present finding of relatively low levels of chromium in the exchangeable phases corroborated with the finding of another researcher who reported relatively low levels of chromium associated with the easily exchangeable/adsorbed and carbonate phases in Cox sediments<sup>49</sup>.

For the purpose of the evaluation of the accuracy of the sequential extraction procedure, the total concentrations of the

metals on each of the soil samples were compared with the sum of the metal fractions extracted into six fractions (table -3). The values are in close agreement which indicate some degree of accuracy in the procedure used.

**Mobility Factors of the Metals in the Soil Profile:** In any sequential extraction procedure the early fractions capture the most mobile and bioavailable fractions. Consequently, the mobility factor value determines the relative mobility and biological availability of the metal in the soil. On this basis high mobility factor (MF) values have been reported or interpreted as evidence of relatively high reactivity, high lability and high biological availability of heavy metals in soil<sup>15, 50, 51</sup>.

The mobility of the metals in the soil may be evaluated on the basis of absolute and relative contents of fractions weakly bound to soil components<sup>51</sup>. The relative index of metal mobility has been calculated as a mobility factor using six step extraction scheme<sup>6, 51, 52</sup>. In this study the mobility factor was calculated on the basis of the equation

$$\frac{E_1 + E_2 + E_3}{F_{\text{Total}}} \times 100$$

The mobility factors (MF) of the metals in all the sites and soil depths are presented on table - 4.

**Table – 3**  
**Total concentrations of Fe, Cd, Ni and Cr and the sum of fractions obtained by sequential extraction procedures**

Metal total concentrations (mgkg <sup>-1</sup> )						Sum of the fractions F1 to F6 (mgmg <sup>-1</sup> )			
Sites	Soil Depth (cm)	Fe	Cd	Ni	Cr	Fe	Cd	Ni	Cr
A	0-15	1657.81	3.30	4.78	5.69	1657.72	3.23	4.76	5.66
	15-30	1725.79	2.90	3.90	4.75	1725.75	2.86	3.88	4.72
	30-45	2015.12	2.34	3.72	4.86	2015.08	2.31	3.68	4.85
B	0-15	1358.68	3.88	5.36	5.90	1358.65	3.81	5.36	5.87
	15-30	1633.55	1.78	4.51	4.11	1633.47	1.72	4.50	4.09
	30-45	1852.72	0.61	4.27	3.52	1852.68	0.58	4.24	3.54
C	0-15	1936.48	3.12	6.66	7.85	1936.46	3.09	6.61	7.83
	15-30	1811.30	2.88	5.36	6.20	1811.28	2.28	5.32	6.10
	30-45	1834.26	1.30	5.13	3.85	1834.25	1.26	5.09	3.81
D	0-15	1730.30	2.77	1.28	5.58	1730.30	2.74	1.27	5.54
	15-30	1730.43	1.48	5.35	4.92	1730.39	1.43	5.28	4.89
	30-45	1764.28	1.31	3.80	2.64	1764.27	1.27	3.75	2.63
E	0-15	1575.84	2.15	3.23	3.79	1575.84	2.11	3.19	3.76
	15-30	1564.64	1.80	1.84	3.24	1564.60	1.81	1.83	3.19
	30-45	1688.43	1.11	1.55	2.74	1688.86	1.06	1.50	2.66

**Table – 4**  
**Mobility factors of the heavy metal in the soil profile**

Sites	Soil Depth (cm)	Fe	Cd	Ni	Cr
A.	0-15	9.67	38.70	25.63	2.14
	15-30	31.95	33.57	20.62	1.48
	30-45	40.04	40.04	17.66	0.82
B.	0-15	13.80	14.40	21.46	2.21
	15-30	27.00	14.33	17.78	2.93
	3-45	32.57	-	12.74	1.42
C.	0-15	12.33	46.60	24.21	3.70
	15-30	16.04	56.58	16.35	3.93
	30-45	16.88	30.95	15.32	1.84
D.	0-15	8.55	50.73	19.32	7.22
	15-30	11.88	15.38	27.73	2.86
	30-45	13.14	8.66	19.93	1.14
E.	0-15	8.81	52.61	30.19	2.13
	15-30	9.61	51.38	25.39	1.88
	30-45	10.35	30.19	25.68	1.13

The values recorded in this study are almost in the same range with the values reported in similar studies<sup>31, 52, 54</sup>. The mobility factor observed for iron increases with depth in all the sites. This implies that the mobility and biological availability of Fe increases with soil depth. However, there is no regular trend for other metals. The mobility factors were observed to be in the order Cd > Fe > Ni > Cr

### Conclusion

Although the sequential extraction procedure employed in this study cannot identify the actual forms of a given metal in the soil, it appears to be very useful in categorizing the metals within several general geochemical fractions.

The residual fraction proved to be the most important for the soils examined in this study, and contained significantly high levels of Fe, Cd, Ni and Cr. The carbonate fraction contained an appreciable portion of Fe, Cd, and Ni while organic fraction was of next importance for Cr.

The present study indicates that the metals under study do not pose environmental risk considering their generally relatively low mobility factor values and the geochemical fractions they are associated with.

The levels of heavy metals obtained in this study when compared with recommended standard concentrations of various pollutants in soils, shows that the areas can be reclaimed and effectively utilized for agricultural, residential, commercial, industrial or educational purposes. It is however recommended that the sites be continuously monitored because of the deleterious health effects of exposure to heavy metal pollution in the events of reclaim.

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