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Markers of Environmental Health: Nickel and Chromium Levels in Soil and Vegetation around a Steel Recycling Facility in Southwest Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author OOA designed the study. Author OOS carried out the experiment, wrote the first draft of the manuscript and managed the analyses of the study. Author OKO managed the literature searches. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Aims: To mark the environmental health status in the vicinity of a steel recycling facility in southwestern Nigeria using Nickel and Chromium levels in the top soil and leaves of *Chromolaena odorata*.
Methodology: Conventional methods were used to determine some soil parameters (pH and electrical conductivity in 1:1 soil: deionized water; percentage organic carbon using chromic acid oxidation method and particle size analysis using hydrometer method). The metal content in the soil and plant samples were analysed using the Atomic Absorption Spectrophotometer after digestion and extraction.
Results: The results of the soil within the factory showed pH values of 7.50 – 8.80 and reduced organic matter content indicating alkaline conditions. Electrical conductivity values were comparatively higher for soils within the factory (423 – 1550 µs/m) than soils outside the factory (146 – 226 µs/m) showing presence of some soluble salts in the soil. The levels of Ni and Cr in the soil were higher within the factory than outside of the factory. Nickel concentrations of the soil increased with increasing distance from the factory up to 200 m. Similar trends occurred for Cr in the eastern side of the factory where the detectable concentrations (2.29±0.05 – 33.26±0.02 mgkg $^{-1}$) was observed. The Ni

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content in the soil around the factory ranged from: North (0.76±0.01 – 1.46±0.06 mgkg $^{-1}$); East (0.19±0.05 – 2.68±0.04 mgkg $^{-1}$); West (0.21 ± 0.01 – 1.46±0.07 mgkg $^{-1}$) and South (0.22±0.02 – 1.89±0.01 mgkg $^{-1}$). Within the factory however, the scrap yard contained high concentration of Cr 24.15±0.04 mgkg $^{-1}$ while the soils from the dumpsite for sorted wastes contained elevated concentrations of Ni (73.17±0.02 mgkg $^{-1}$). Nickel and chromium content in the plant leaves in this study ranged from 1.40 – 3.60 mgkg $^{-1}$ and 0.40 – 1.5 mgkg $^{-1}$.

Conclusion: Further increase in the Cr and Ni levels in the soil and plants of the study site poses a potential health hazard to animals that graze the area and man through consumption of forage and agronomic crops cultivated around the factory by peasant farmers.

Keywords: Environmental health; nickel; chromium; steel recycling.

1. INTRODUCTION

Nickel is a member of the elements of group 10 (previously group VIII) of the periodic table with density of 8.90 g/cm^3. Compounds of nickel are utilized as dyes in the manufacture of glass and ceramic, and in batteries containing nickel–cadmium compounds. About 68 % of nickel is also used as an alloy of several tools used in medicine, food technology or as kitchen equipment [1]. Therefore, nickel is a serious pollutant that is released in the fumes and solid wastes from metal recycling plants. The Ni distribution in soil profiles is related to the organic content of soil and clay fractions [2], depending on the soil type. The safe limit for Ni by the European Union in agricultural soil is 75 mg/kg [3]. However, there is no evidence of an essential role of Ni in plant metabolism and studies of the uptake and chemical behavior of Ni in plants are related mainly to its toxicity having possible implications with respect to animals and human. Gray-green leaves and restricted growths of plants caused by an excess of Ni were observed to be effects of Ni toxicity in some cereals [4]. The tolerable limit of Ni for most agronomic crops according to Kabata – Pendias, 2011 [4] is 10 mg/kg.

Chromium is a trace metal belonging to group 6 (formerly group VIb) of the periodic table with density of 7.19 g/cm^3. The main industrial use of Cr is in the metallurgical, refractory and chemical industries. Cr is used primarily in the manufacture of green tints for paints, varnishes, glazes, inks; in leather tanning, chromate plating, in metal finishing, and as wood preservatives [5]. Therefore, many municipal and industrial wastes from various sources may contain elevated amounts of Cr and lack of appropriate disposal facilities can lead to serious groundwater and soil pollution [6]. Although many different oxidation states of chromium exist in the environment, only the trivalent (III) and hexavalent (VI) forms are considered to be of biological importance. Soils surrounding a Cr smelter in Albania contained Cr at average of 3117 mg/kg, whereas its highest concentration, up to 20,300 mg/kg was reported in soils close to the slags [7]. The most available to plants is Cr^{6+}, which is the very unstable form under normal soil conditions [8] and its availability depends on soil properties, and especially on soil texture and pH. Cr^{3+} is rather benign to most plants and binds strongly to soil solids. The safe limit of Cr in soil by the European Union is 150 mg/kg [3] while that of agronomic crop is 2 mg/kg [4].There is no report of an essential role of Cr in plant metabolism. The forms and transformation of Cr in soils have great environmental and health implications. Therefore, most remediation treatments of Cr-contaminated soils is the conversion of easily mobile Cr^{6+} to Cr^{3+} and thus mitigates effects of Cr toxicity in plants [9]. Although Cr^{3+} is considered an essential food nutrient, very large doses had been reported

to be harmful [10]. Occupational exposure to Cr^{6+} containing compounds is also known to damage the kidney and liver [10] and also increase the incidence of respiratory-system cancers [11].

Trace metals distribution in the soil and vegetation around industries is a very good way of assessing the environmental effect of metals in relation to public health. The metals could accumulate in the soil and consumption of crops grown on such soil could affect human health. In Nigeria, several workers have investigated trace metals in soils and vegetation around lead smelter facility [12] and around a scrap dumpsite [18] but no report from the vicinity of a steel recycling facility. The study area is located in Ife Central Local Government Area of Osun State, Southwest Nigeria along Ife-Ibadan expressway (Fig. 1) and about 5 km from the Obafemi Awolowo University main campus gate. The main aim of this study was to assess, using the concentrations of Ni and Cr, the environmental health status of the steel recycling facility with no other apparent source of industrial pollution in the area. The specific focus is on the distribution and concentration of the two associated metals in soil and leaves of *Chromolaena odorata* around the factory.

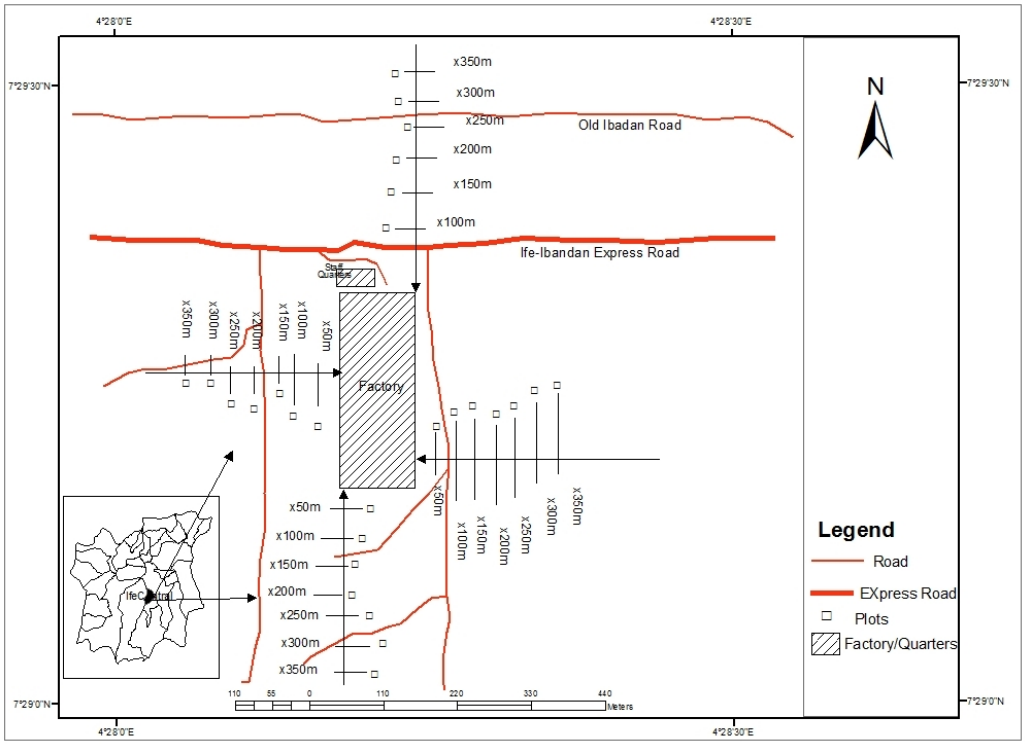


Fig. 1. Map of the study area showing the sampling location outside the factory

2. MATERIALS AND METHODS

2.1 Sample Collection

Sixty four soil samples were collected randomly using Dutch soil auger from the upper 15 cm within and around the factory. Fifty four samples in duplicates were collected from each of

the twenty seven 10 x 10 m^2 sampling plots covering a distance of 350 m at 50 m interval from the walls of the recycling factory site in the four cardinal directions. Eight samples were collected from four selected sites within the factory. A duplicate composite sample was collected at 2,000 m away in the western side of the factory to serve as control (location E). The four selected sites within the factory include location A (the scrap yard), location B (the slag area), location C (dumpsite for sorted wastes) and location D (the soil around the furnace area). The samples were collected before the raining season of the year 2012 due to the fact that research has shown that the concentrations of these metals in soil are higher in the dry season than in the rainy season [13]. This could be due to the absence of surface run-off and leaching.

2.2 Soil Analysis

The soils were air-dried for 6 days at room temperature, ground using agate mortar and sieved with a 2 mm mesh size. Air-dried soil samples (10 g each) were accurately weighed into series of 250 ml conical flasks and 100 ml of 0.1 N HCl was added into each of the flasks containing the soil samples. These were shaken properly for 30 minutes. The contents were filtered through Whatman's No.42 filter paper. The metals were analyzed with PG 990 series model of Flame Atomic Absorption Spectrophotometer. A reagent blank sample was taken through the method, analyzed and subtracted from the samples to correct for reagent impurities and other sources of errors. The particle size analysis was determined by the hydrometer method using sodium hexametaphosphate as the dispersing agent [14]. The pH and electrical conductivity was determined in 1:1 soil:deionized water by electrometric method. Percentage organic carbon was determined using the chromic acid oxidation method [15].

2.3 Plant Sampling and Analysis

Leaves of *Chromolaena odorata* (Linn.) R. King & H. Robinson, family Asteraceae (commonly called Siam weed), were collected only around the factory, because no plants grew on top of the slag piles and on the other wastes sites within the factory. *C. odorata* is a diffuse, scrambling shrub of about 3 – 7 m in height growing as an open weed of plantations and pastures of western Africa. It forms a ticket in almost all the sampling plots and the leaves have been reported to have medicinal, anti-microbial and wound healing properties [16]. The leaves were rinsed once with tap water and twice with deionized water, and dried in the oven at 70ºC for 48 hours. Two gram of the dried samples ground using a stainless steel hammer mill was weighed into a 50 ml Pyrex volumetric flask and 2 ml concentrated H_2SO_4 acid was added and heated on a hot plate at a temperature of 450ºC. Drops of hydrogen peroxide were added from time to time as the oxidizing agent until the sample became clear and was left to cool and made up to volume with distilled water. The concentrate was analyzed for Cr and Ni using the Atomic Absorption Spectrophotometer.

2.4 Data Analysis

The data from soil and plants tissue analyses of the sampled plots were subjected to descriptive and one-way analyses of variance using SAS 9.3 package at P = 0.05 level of significance.

3. RESULTS AND DISCUSSION

3.1 Soil Parameters

All the soil samples from the four cardinal directions of the factory were moderately and slightly acidic (Table 1) which is typical of most African soils [19]. The pH of the soils from the sites within the factory however, ranged from slightly alkaline (7.50 – 7.80) to strongly alkaline (8.80). High soil pH has also been reported in heavy metal contaminated soils [17-20]. The alkaline condition of the soils within the factory may be due to the crumbs of some carbonate materials used in the production processes and the basic slag which are high in pH and often used as liming materials in agricultural soils. At high pH values, the availability of phosphorus and most micronutrients as well as anaerobic conditions of soil tend to decrease. Except in the northern side of the factory where the soil was sandy clay loam, similar textural composition of the soils observed within and around the factory was sandy loam. However, there was a significant variation in the organic carbon content of the soils within the factory (Table 2). Low organic carbon content at the slag area and soils around the furnace could be attributed to the removal of topsoil and vegetation within the factory. This may cause a reduction in the population and activities of soil microorganisms as reported in heavy metal contaminated sites with low organic matter content [6]. Results of the electrical conductivity were very high within the factory (Table 2) with values ranging from 423 – 1550 µs/m. These values were higher than those reported by Akpoveta et al. [18]. This may be due to the presence of some soluble salts in the top soil within the factory. However, these conductivity values were comparatively lower than those around the factory which ranged from 146 – 226 µs/m in the soil samples.

3.2 Ni and Cr Content in the Soil around the Factory

The results from this study showed that Ni and Cr concentrations in the soils of the study area were generally low. Except in the northern side of the factory, the same trend occurred in all the sides of the factory where Ni concentrations first increased up to 150 m and 200 m and then decreased as the distance from the factory further increased. These confirmed the observations of Cartwright et al. [21] and Al-Khashman and Shawabkeh [22] that the soils closest to the factory contained elevated concentrations of the element than distances further away from the factory. The Cr concentration (2.29 ± 0.05 – 33.26 ± 0.02) of the eastern side of the factory (Table 3) followed similar trends with that of Ni except that the concentration in the soil increased up to 250 m before decreasing as the distance from the factory fence further increased. The Ni content in the soil around the factory (Table 4) ranged from 0.76 ± 0.01 to 1.46 ± 0.06 mgkg $^{-1}$ in the north; 0.19 ± 0.05 to 2.68 ± 0.04 mgkg $^{-1}$ in the east, 0.21 ± 0.01 to 1.46 ± 0.07 mgkg $^{-1}$ in the west and 0.22 ± 0.02 to 1.89 ± 0.01 mgkg $^{-1}$ in the southern side of the factory. Although the Ni values were within the normal soil concentration of 15 mgkg $^{-1}$ [23], the levels were higher than those recorded in the control site proving that the presence and activities of the factory influenced the content of the soils around the factory.

Table 1. Soil properties of the study sites from the four cardinal directions of the factory

Soil property	North	East	West	South	Non-polluted soil
pH (H_2O)	5.57 ± 0.39	6.46 ± 0.72	5.89 ± 0.38	6.16 ± 0.34	6.20 ± 0.21
Organic Carbon (%)	2.53 ± 0.46	2.72 ± 0.02	1.75 ± 1.17	1.75 ± 0.21	2.81 ± 0.12
Electrical conductivity (µs/m)	221 ± 1.01	226 ± 0.93	170 ± 0.54	146 ± 0.35	115 ± 0.28
Sand (%)	55.07 ± 0.29	67.86 ± 0.27	70.14 ± 0.25	70.00 ± 0.00	67.00 ± 0.05
Silt (%)	18.10 ± 0.39	14.86 ± 0.37	14.43 ± 0.36	16.14 ± 0.22	16.00 ± 0.11
Clay (%)	26.83 ± 0.09	17.28 ± 1.23	15.43 ± 0.13	13.86 ± 0.26	17.00 ± 0.06
Textural Class	Sandy clay loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam

Table 2. Soil properties from the study sites within the metal recycling factory

Soil property	A	B	C	D	E
pH (H_2O)	7.60 ± 0.45	7.50 ± 0.33	7.80 ± 0.27	8.80 ± 0.13	6.20 ± 0.21
Organic Carbon (%)	2.18 ± 0.26	0.94 ± 0.30	1.76 ± 0.29	0.43 ± 0.26	2.81 ± 0.12
Electrical conductivity (µs/m)	1335 ± 1.12	423 ± 0.44	1550 ± 0.34	877 ± 0.68	115 ± 0.28
Sand (%)	70 ± 1.20	75 ± 2.13	73 ± 0.00	59 ± 0.39	67 ± 0.05
Silt (%)	10 ± 0.41	16 ± 0.17	14 ± 0.26	36 ± 0.31	16 ± 0.11
Clay (%)	20 ± 0.11	9 ± 0.34	13 ± 0.07	5 ± 0.15	17 ± 0.06
Textural Class	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam

A – Scrap yard; B – Slag area; C – Dumpsite for sorted wastes; D – Soil around the furnaces; E – Non-polluted soil.

Conversely, the Cr concentrations in the soils were below detectable limits in the northern, western and southern side of the factory (Table 3) probably because of wind direction which was majorly southwesterly. These metals originating from the untreated fumes from the factory's furnaces are distributed in the air and deposited on the soil within some distances from the recycling factory depending on the size of particles. The concentration of these metals in soil can vary according to the strength and direction of wind, type of soil, and pH. The low and non-detection of chromium in some sites could be attributed to the fact that most of the paints in the scraps have peeled off before they were brought to the factory for recycling. It may also be due to possible conversion to the non available form (Cr^{6+}) due to the presence of organic matter content in the study site.

Table 3. Chromium concentrations (mgkg $^{-1}$) from the soil samples around the factory

Distances (m)	North	East	West	South
50	nd	nd	nd	nd
100	nd	2.29 ± 0.05	nd	nd
150	nd	21.97 ± 0.00	nd	nd
200	nd	22.48 ± 0.03	nd	nd
250	nd	33.26 ± 0.02	nd	nd
300	nd	15.57 ± 0.03	nd	nd
350	nd	nd	nd	nd
Non-polluted soil	0.53±0.03	0.53 ± 0.03	0.53 ± 0.03	0.53 ± 0.03

nd = not detected.

Table 4. Nickel concentrations (mgkg $^{-1}$) from the soil samples around the factory

Distances (m)	North	East	West	South
50	nd	0.19±0.05	0.21±0.01	0.22±0.02
100	0.76±0.01	0.58±0.02	0.46±0.06	1.24±0.04
150	1.36±0.02	0.87±0.02	0.78±0.03	1.89±0.01
200	1.18±0.03	2.68±0.04	1.46±0.07	1.02±0.02
250	1.02±0.02	nd	0.87±0.10	0.77±0.02
300	1.16±0.00	0.74±0.01	0.85±0.97	0.77±0.56
350	1.46±0.06	0.69±0.01	0.30±0.50	0.76±0.50
Non-polluted soil	0.17±0.02	0.17±0.02	0.17±0.02	0.17±0.02

nd = not detected.

3.3 Ni and Cr Content in the Soil within the Factory

The concentrations of the metals in the soils of the selected sites within the factory are presented in Table 5. The scrap yard contained high concentration of Cr 24.15 ± 0.04 mgkg $^{-1}$ followed by the site where the sorted wastes were dumped 19.75 ± 0.03 mgkg $^{-1}$. These values were within the Maximum Allowable Concentration of 50 -200 mgkg $^{-1}$ [4]. The metal levels in the soil of the scrap yard of this study were higher than those reported by Akpoveta et al. [18] in soils around a metal scrap dump, but lower than those of the soils around an iron smelter in brazil [24] and in the soils around chromium-containing slag heap of steel alloy factory [6]. The soils from the dumpsite for sorted wastes contained elevated concentrations of Ni (73.17 ± 0.02 mgkg $^{-1}$) which was above the Maximum Allowable Concentration of 20 – 60 mgkg $^{-1}$ in agricultural soil [4]. Except at location B (soil of the slag area), the Ni concentrations were significantly higher than those of Cr in all the locations within the factory. This is expected because Ni (as an alloy element) is contained in most of the scrap used. Continuous dumping of these wastes on exposed soil surface will lead to contamination of the soil and underground water sources.

Table 5. Concentrations of Nickel and Chromium (mgkg $^{-1}$) from the soil samples within the factory

Location	A	B	C	D	E
Ni	31.55±0.02	11.80±0.05	73.17±0.02	14.64±0.03	0.17±0.02
Cr	24.15±0.04	18.30±0.02	19.75±0.03	5.53±0.02	0.53±0.03

A – Scrap yard; B – Slag area; C – Dumpsite for sorted wastes; D – Soil around the furnaces; E – Non-polluted soil.

3.4 Ni and Cr Content in the Plant around the Factory

In Figs. 2 and 3, the Cr and Ni levels in the leaves of *Chromolaena odorata* in the four directions around the factory showed similar trends as elevated concentrations were recorded between 200 m and 250 m away from the factory. Nickel content in the plant tissue in this study ranged from 1.40 – 3.60 mgkg^{-1} while chromium content ranged from 0.40 – 1.5 mgkg^{-1} similar to those reported by Fagbote [25] in the same species around Agbabu Bitumen Deposit Area, Nigeria. The Ni values in the plant leaves were within normal range of 0.10 – 5.0 mgkg^{-1} and tolerable levels of 1.0 – 10.0 mgkg^{-1} for agronomic crops [4]. The Cr concentrations however exceeded the normal range of 0.10 – 0.50 mgkg $^{-1}$ suggested by the same author but were within the tolerable limit (2 mgkg^{-1}) for agronomic plants. Wilting and chlorosis of the young leaves and root injury are reported symptoms of Cr toxicity in plants [4]. Further increase in the Cr and Ni levels in the soil and plants of the study site poses a potential health hazard to nomadic animals and man through the consumption of forage and agronomic crops grown around the factory by some junior staffs and peasant farmers.

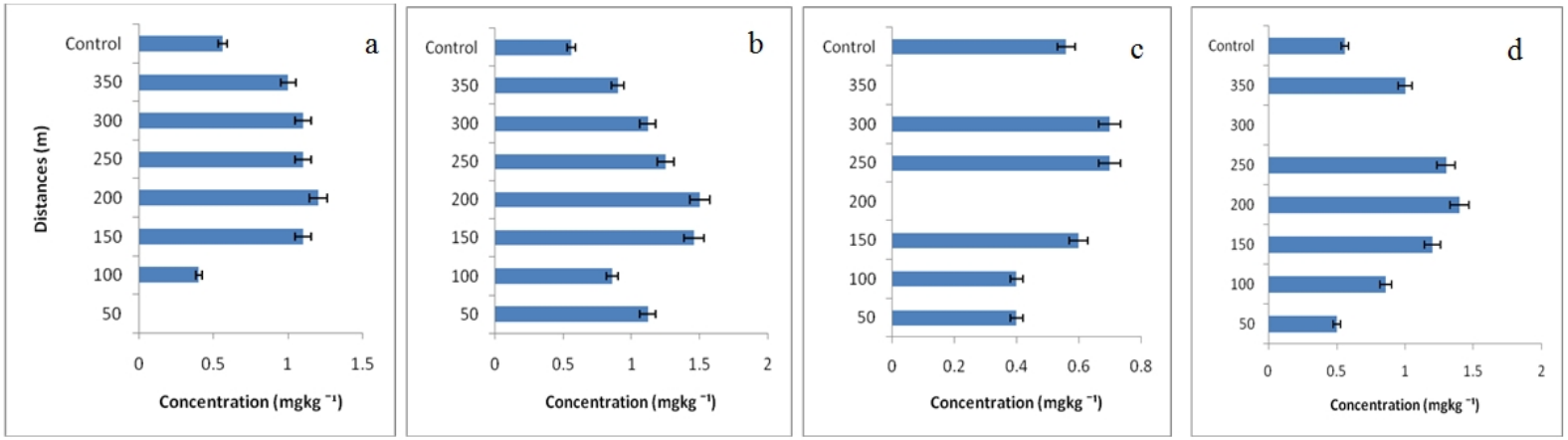


Fig. 2. Chromium accumulation (mgkg $^{-1}$) in leaves of *Chromolaena odorata* from four cardinal sides (a) North (b) East (c) West (d) South of the factory

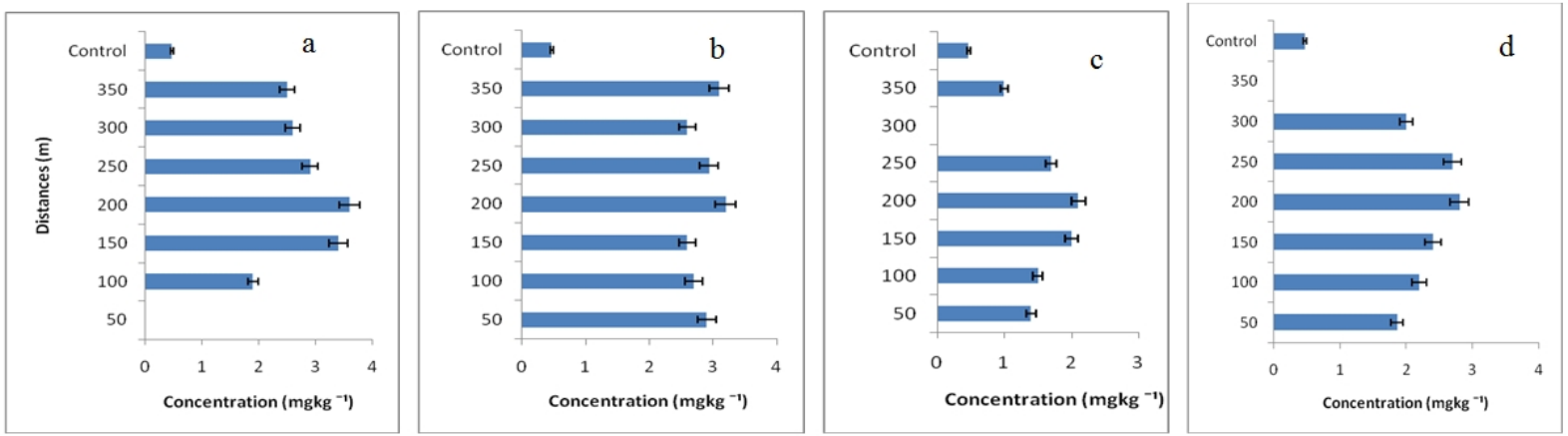


Fig. 3. Nickel accumulation (mgkg $^{-1}$) in leaves of *Chromolaena odorata* from the four cardinal sides (a) North (b) East (c) West (d) South of the factory

4. CONCLUSION

The result obtained from this study showed elevated levels of the metals in the soil and leaves of *Chromolaena odorata* collected from sites within and in the immediate surrounding of a steel recycling facility compared to an undisturbed site 2 km from the factory. Sites within the factory contained higher concentrations of the metals than those outside of the factory where some concentrations were below detectable levels. Although the values obtained at various points were within tolerable limits, further indiscriminate dumping of wastes and activities of the factory should be checked to prevent further deterioration of living systems in the factory's immediate environment.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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