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Heavy Metals Pollution in Surface Soils in the Vicinity of Abundant Railway Servicing Workshop in Kumasi, Ghana

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ABSTRACT: Heavy metals in soils are of great environmental concern, in order to determine heavy metal content in the surface soil from the vicinity of an abundant railway servicing workshop and evaluate the contamination levels, 40 surface soil samples were collected and analyzed for Cu, Zn, Cd, Pb, Fe and Ni contents using atomic absorption spectroscopy. Soil texture, conductivity, pH, total organic content and cation exchange capacity were also measured. Heavy metals concentrations were determined after digestion of samples with aqua regia. In the investigated soils, the mean recorded concentrations of the heavy metals were 7.21 mg/kg f ff or Cu, 0.033 mg/kg for Ni, 0.087 mg/kg for Cd, 48.52 mg/kg for Fe, 7.33 mg/kg for Zn and 26.66 mg/kg for Pb. The reported results indicate that the enrichment factors of the measured heavy metals were 2.26, >0.1, 0.39 and 3.47 for copper, nickel, zinc and lead respectively. I-geo (geoaccumulation index) values of the metals in the soils under study indicate that they are uncontaminated to slightly contaminate with nickel and iron but highly contaminated with copper and lead.

Key words: Contamination, Enrichment Factor, Geo-accumulation Index, Heavy Metals, Surface Soil

INTRODUCTION

There is increasing awareness that heavy metals present in soil may have negative consequences on human health and on the environment (Abrahams, 2002; Schroeder *et al.*, 2003; 2004; Mielke *et al.*, 2005; Selinus *et al.*, 2005). From the environmental point of view, all heavy metals are important because they can not be biodegraded and are largely immobile in the soil system, so they tend to accumulate and persist in urban soils for a long time. This results in levels that are harmful to humans upon both acute and chronic exposure (Thornton, 1991; Brinkmann, 1994; Sheppard, 1998). The most frequently reported heavy metals with regards to potential hazards and the occurrence in contaminated soils are Cd, Cr, Pb, Zn, Fe and Cu (Alloway, 1995). The concentration of these toxic elements in soils may be derived from various sources, including anthropogenic pollution, weathering of natural high background rocks and metal deposits (Senesi *et al.*, 1999). lthough heavy metals distribution in soils is well documented for many cities of developed countries, comparatively little is studied in less developed countries (Thuy *et al.*, 2000). However, in recent years, a few of these countries have achieved significant strides in their quest for rapid economic growth through industrialization. Thus, a number of factories, usually sited haphazardly, have developed. Population explosion and the increased use of automobiles have become very common in urban areas. The impact of pollution in the vicinity of overcrowded cities and from industrial effluents and automobile exhausts has reached a disturbing magnitude and is arousing public awareness. At present, relatively little data are available on the extent of environmental pollution because there are few agencies with inadequate capacity charged with the routine monitoring and protection of the environment Olade, 1987).

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The study area covers the vicinity of the abundant railway servicing workshop of the Ghana railway cooperation in Kumasi the second largest city in Ghana. Therefore, high levels of contaminants, such as heavy metals, might have been released into the soil. Most of the land in this area is intensively used for different purposes including residence and agriculture. Thus, it is necessary to carry out an investigation of heavy metals in soils of this urban area. This study of heavy metal content in urban soils provides baseline information on the anthropogenic impact of environmental pollution in Kumasi. This study is important because it can be used as basis for planning management strategy to achieve better environment quality and substantial development of this city. This paper forms part of a larger investigation aimed to identify the point and non-point sources of soil pollutants in the city of Kumasi and also to study the geochemical behavior of heavy metals in different soils.

MATERIALS & METHODS

The sampling sites were selected in order to cover the entire vicinity of the Servicing Workshop. To provide a satisfactory geographical representation of the site, the vicinity was divided into four zones; zone S_1 was to the north, S_2 south, S_3 east and S_4 west of the workshop. Sampling sites were distributed among these zones with the aim of ensuring that each zone had equal number of sites. A bulk sample was prepared by collecting about 1 kg of surface soil (0–20 cm) by hand digging at 5 sampling sites within a maximum area of 20 m^2. Ten composite samples were collected from each zone. The control (background) samples were obtained from a remote location within the Botanical garden of the Kwame Nkrumah University of Science and Technology also in Kumasi. Samples were collected with a stainless steel spatula and kept in labeled plastic bags for laboratory analysis. After air drying, samples were passed through a 2 mm sieve and stored in plastic bags until they were analyzed. The sampling was carried out in January 2007. Texture was investigated by using the pipette method (ISO, 2001a). A weight sample was oven dried at 105 °C for twelve hours and cooled in desiccators. The weight loss was used for calculating the soil water content. Organic matter contents were determined by soil ignition at a temperature of 450 ^{o}C (Allen et al., 1974). Electrical conductivity (EC) and pH were measured in a soil deionized water suspension (soil: water, 1:2.5 by volume) by a calibrated pH meter and conductivity meter respectively (ISO, 2002a). Soil samples were analyzed for CEC, using the ammonium acetate method at pH 7 (Chapman, 1965)**.**

The samples were digested using aqua regia (ISO, 2002b). The solutions of the digested samples were analyzed using air/acetylene atomic absorption spectroscopy (UNICAM 929 model) with the use of prepared standards for Fe, Cu, Ni, Cd, Zn and Pb. Analytical grade of nitrate salt of lead, analytical granules of copper and zinc and iron and general purpose reagent cadmium nitrate of maximum purity of 99% were used in the preparation of standard solutions. Calibration curves were used to calculate the concentration of the metals. A reagent blank was used to zero the instrument. This was followed by aspiration of standard solution and finally the soil sample extract were aspirated.

RESULTS & DISCUSSION

The results of the physicochemical analysis of the study area are given in Table 1. The relative percentage of clay, silt and sand in the soils were in the range (2.6-6.67 %) for clay, (12-20 %) for silt and (73.34-79.24 %) for sand. The soils were classified as loamy sand. The values of pH ranged in a narrow interval from 6.33 to 7.61 which suggest slightly acidic to neutral conditions for all the top soils in the entire study area. The cation exchange capacity (CEC) of the soil samples ranged between 17.32 and 26.67 meq/100g with a mean value of 22.59 meq/100g. As shown in Table 1 the soil samples collected from the north displayed the highest mean CEC value, those from the east had the least value. The total organic matter content (TOM) in the samples ranges between 21.59% and 12.69%, with an average of 15.26% (Table 1). There was a significant difference in the TOM distribution in the entire study area. The relatively high content of TOM in samples from the vicinity of the workshop may probably be due to the high organic content of used lubricants that were discharged at the site. Furthermore, the plant and animal remains in various stages of decomposition and substances from plant roots and soil microbes are considered as an additional source**.** Again medium and heavyloamy textured soils generally have higher organic matter due to their ability to support vegetation compared to light textured soils (Brady and Weil, 1999). Soil organic matter is important because it improves both the physical and the chemical properties of soil. It decreases soil erosion by stabilizing soil particles. It also enhances aeration, increases water holding capacity and restores and supplies nutrients for the growth of plants and soil micro-organisms.

Concentrations of Pb, Zn, Cu, Cd, Ni and Fe in the soil samples from the vicinity of the railway servicing workshop in Kumasi are listed in (Table 2) together with mean values, standard deviations and variance. Iron had the highest mean value (48.52 mg/kg), followed by Pb (26.66 mg/kg). Compared to average concentrations in urban soils in the world, the mean values of the Pb in the analyzed soils are much lower than those reported from samples from large and industrialized cities such as Palermo (Sisily) 202 mg/kg (Manta *et al.*, 2002), Central London 647 mg/kg (Rundle and Duggan, 1980), and Rome 330.8 mg/kg (Angelone et al. (1995). Cadmium and Ni concentrations were generally low, close to those reported for the unpolluted soils. Moreover, these metals display quite homogeneous distributions across the sampling area and therefore had lower standard deviations, thus suggesting a major natural (i.e. indigenous lithologic) source. However there were significant differences in the distribution of Pb and Cu. Lead recorded the highest mean value of 40.64 mg/kg in the samples from the west and a least 13.35 mg/kg from the south. Copper is both an essential and potentially toxic element (Merian, 1991). In this study, Cu had the maximum mean concentration value of 9.67 mg/kg in the samples from the north and a minimum value of 5.93 mg/kg in the south. Zinc plays an important role as an essential element in all living systems, in this work the concentration if Zn was found ranging from an average of 6.38 mg/kg to 8.73 mg/kg in the south and west samples respectively.

Table 1. Values of texture class, pH, TOM, Conductivity, CEC, Moisture content and their mean and standard deviation

	S1	S2	S3	S4	mean	St. D
Texture class	Loamy sand	Loamy sand	Loamy sand	Loamy sand		
Sand %	73.34	79.24	77.24	77.24	76.77	2.47
Clay %	6.67	2.67	6.76	10.76	6.72	3.30
Silt %	20	18	16	12	16.5	3.42
pH	7.61	7.36	6.42	6.33	6.93	0.65
Moisture content %	3.20	1.14	2.63	7.69	3.67	2.82
Organic content %	14.84	21.59	12.69	20.80	17.48	4.39
Conductivity (mS)	0.20	0.19	0.11	0.29	0.197	0.07
CEC (meq/100g)	26.67	23.98	17.32	22.40	22.59	9.23

Table 2. Statistical parameters of Extracted Heavy Metals at different zones

Element	S_1	S_2	S_3	S_4	Mean	St. D
Cu (mg/kg)	9.67	5.93	6.72	6.52	7.21	1.67
Ni (mg/kg)	0.03	0.03	0.03	0.04	0.033	0.005
Cd (mg/kg)	0.03	0.07	0.06	0.15	0.078	0.05
Fe (mg/kg)	48.84	48.64	48.10	48.52	48.52	0.31
Zn (mg/kg)	7.47	6.38	6.75	8.73	7.33	1.04
Pd (mg/kg)	32.36	13.53	20.11	40.64	26.66	12.15

In this study enrichment factor was used to assess the level of contamination and the possible anthropogenic impact in soils from the vicinity of the abundant railway servicing workshop. To identify anomalous metal concentration, geochemical normalization of the heavy metals data to a conservative element, such as Al, Fe, and Si were employed. Several authors have successfully used iron to normalize heavy metals contaminants (Baptista Neto *et al.*, 2000; Mucha *et al.*, 2003). In this study iron was also used as a conservative tracer to differentiate natural from anthropogenic components. According to Ergin *et al.*, (1991) and Rubio *et al.*, (2000) the metal enrichment factor (EF) is defined as follows:

$$EF = \frac{\left(\frac{M}{Fe}\right)_{sample}}{\left(\frac{M}{Fe}\right)_{background}}$$

Where EF is the enrichment factor, $(M/Fe)_{sample}$ is the ratio of metal and Fe concentration of the sample and $(M/Fe)_{background}$ is the ratio of metals and Fe concentration of a background. The background concentrations of metals were taken from soils from an undisturbed area. Table 3 shows EF values and I_{geo} of Cd, Zn, Fe, Ni, Pd and Cu in soils along with the background concentrations of these metals. According to Zhang and Liu (2002), EF values between 0.5 and 1.5 indicate the metal is entirely from crust materials or natural processes, whereas EF values greater than 1.5 suggest that the sources are more likely to be anthropogenic. The results of the present study show that Pb and Cu were significantly enriched in the soils from the vicinity of the workshop since EF values of these two metals are greater than 1.5 (Table 3). The highest average EF is seen for Pb with a value of 3.47. Copper has the second highest EF with an average value of 2.26. This suggests that Pb and Cu are from anthropogenic and the soils have been contaminated by these two metals in the recent years. The difference in EF values may be due to the difference in the magnitude of input for each metal in the sediment and/or the difference in the removal rate of each metal from the soil. The EFs of Zn, Cd and Ni were less than 0.5 which suggest a natural source of these metals in the study area.The geoaccumulation index (I_{geo}) introduced by Muller (1969) was also used to assess metal pollution in soils. It is express as:

$$Igeo = Log_2\left(\frac{Cn}{1.5Bn}\right)$$

Where C_n is the measured concentration of the examined metal in the soil and B_n is the geochemical background concentration of the same metal. Factor 1.5 is the background matrix correction factor due to lithogenic effect. The index of geoaccumulation includes seven grades (0-6) ranging from unpolluted to very highly polluted. The pollution levels of these metals in the environment expressed in terms of geoaccumulation indices indicate that the environment is highly to very highly polluted with Pb and Cu. The level of pollution with Zn was moderate. The results reveal that the samples are uncontaminated to slightly contaminated with respect to Ni and Fe.

Table 3. Enrichment Factor, geo-accumulation index and background concentration of heavy metals in the soils of the vicinity of the railway workshop

Element	Enrichment Factor (EF)	Geo-accumulation Index (I_{geo})	Background conc. (mg/kg)
Cu	2.26	7.04	0.27
Ni	> 0.1	0.13	0.25
Cd	< 0	< 0	N.D
Fe	N.D	0.91	4.1
Zn	0.397	1.4	1.37
Pb	3.47	4.16	0.76

§ N.D = not detectable

CONCLUSION

This survey has allowed us to determine total metals levels (Cu, Fe, Ni, Pb, Cd and Zn) in surface soils from the vicinity of a railway workshop. Soil pollution in the present study was assessed using enrichment factor and geoaccumulation index values. The calculation of the enrichment values showed that Pb and Cu are enriched with 3.47 and 2.26 respectively. The results of geoaccumulation index based on Muller's classification allows us to conclude that, for analyzed metals, the concentrations of Cd and Ni can be generally considered as background levels moderately polluted with Zn and highly to very highly polluted with Pb and Cu. Some of the elevated concentration of Pb, Cu and Zn are due to anthropogenic sources. The soils from the vicinity can be described as moderately to very highly polluted since all the samples collected showed a moderately high levels of contamination in at least one metal.

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