academicJournals

Vol. 7(9), pp. 917-924, September, 2013
DOI: 10.5897/AJEST2013.1543
ISSN 1996-0786 © 2013 Academic Journals
http://www.academicjournals.org/AJEST

African Journal of Environmental Science and Technology

Full Length Research Paper

Heavy metal levels in soil samples from highly industrialized Lagos environment

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Accepted 5 September, 2013

The effect of heavy metals on the environment is of serious concern and threatens life in all forms. Environmental contamination is correlated with the degree of industrialization and intensities of chemical usage. The aim of this study was to determine to what extent, human and industrial activities have affected the quality of soil due to contamination of soil with heavy metals and the consequent effects on the health status of the inhabitants. Twenty five sites representing 25 soil samples were collected from various manufacturing companies which include: Mattress manufacturing companies, artificial hair manufacturing companies, farm lands, soft drinks bottling companies, electrical/ electronics companies and pharmaceutical companies. Soil samples from these sites were air-dried and digested with nitric acid. Digested samples were analyzed using Atomic Absorptive Spectophotometry (AAS) with a lamp current set at 5-8 mA, reslope limits of 75-125%. The levels of cadmium, arsenic, lead, chromium, iron and copper in mg/kg ranged from 0.56-4.2, ND, 2.10-12.50, 0.24-2.20, 1111-2216 and 2.20-5.58 in all of the samples, respectively. These results show that the soil samples from dump yards, mattress manufacturing companies and soft drinks bottling companies had the highest concentration of heavy metals in them. Cadmium and iron levels exceeded that of the European Regulatory Standards (ERS).

Key words: Heavy metals, environment, contamination, industrialization.

INTRODUCTION

Contamination of the environment by heavy metals due to certain industrial activities has been on the rise in recent times. Toxicity of these compounds has been reported extensively (Dupler, 2001; Momodu and Anyakora, 2010; Anyakora et al., 2011). They accumulate over time in soils which act as a sink from which these toxicants are released to the groundwater and plants, and end up through the food chain in man thereby causing various toxicological manifestations. Occupationally exposed individuals to lead poisoning tend to have high blood pressure (Pocock et al., 1984; Harlan et al., 1985; Landis and Flegal, 1988), and are at an increased risk for cardiovascular disease, myocardial infarction and stroke (Momodu and Anyakora, 2010), acute and chronic nephropathy (Goyer, 1988) and others are gastrointestinal disturbances-abdominal pain, cramps, constipation, anorexia and weight loss, immune suppression, and slight liver impairment (ATSDR, 1993; US EPA, 1986). Toxicity of chromium is associated with allergic dermatitis in humans; arsenic is associated with skin damage, increased risk of cancer and problems with circulatory system while mercury is associated with kidney damage (Scragg, 2006). Aluminum toxicity has been shown to produce excessive headaches, abnormal heart rhythm, depression, numbness of the hands and feet and blurred vision (Kilburn and Warshaw, 1993).

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Other effects of aluminum include: impairment in choice reaction time, long-term memory, psychomotor speed (Willis and Savory, 1985).

Heavy metals occur in the environment naturally and are released during anthropogenic activities. Soil contamination with heavy metals results from human-related activities such as mining (Navarro et al., 2008), smelting procedures (Brumelis et al., 1999) and agriculture (Vaalgamaa and Conley, 2008) as well as earth-related activities. Chemical and metallurgical industries are the most important sources of heavy metals in the environment (Cortes, 2003), sewage-treated sludge, known as biosolids and used as fertilizers on the soil can contribute to heavy metal levels in the soil (Snyder, 2005). Khan et al. (2008) and Zhang (2010) opined that major sources of contamination are by the accumulation of heavy metals and metalloids through emissions from the rapidly expanding industrial areas, mine tailings, disposal of high metal wastes, leaded gasoline and paints, land application of fertilizers, animal manures, sewage sludge, pesticides, wastewater irrigation, coal combustion residues, spillage of petrochemicals and atmospheric deposition. Particularly, zinc and cadmium may also be added to soils adjacent to roads, the sources being car tyres and lubricant oils (USEPA report, 1996).

Each contamination source has peculiar damaging effects on plants and animals and consequently on human health, but sources that add heavy metals to soils and waters are of serious concern due to their persistence in the environment and carcinogenic tendencies to humans. They cannot be destroyed biologically but are only transformed from one oxidation state or organic complex to another (Garbisu and Alkorta, 2001; Gisbert et al., 2003). Therefore, heavy metal pollution poses a great potential threat to the environment and human health.

In most countries (developed and developing alike), despite overwhelming literature on the toxicity of these metals, avoidable contaminations are on the rise. Recent studies on some New Zealand soils treated with biosolids have shown increased concentrations of cadmium, nickel and zinc in drainage leachates (Keller, 2002; Mclaren et al., 2004). In the United States, an estimated 70% of heavy metals in landfills come from discarded electronics, further buttressing the potential toxicity tendencies on the residents. Soil pollution is also a serious challenge in China, where one-sixth of total arable land has been polluted by heavy metals, and more than 40% has been degraded to varying degree due to erosion and desertification. In Western Europe, over a million sites were affected by heavy metals (McGrath et al., 2001), of which, over 300 000 were contaminated, and the estimated total number in Europe could be much larger, as a result of the contribution from the Central and Eastern European countries (Gade, 2000). In Nigeria in 2010, there was a report of over 300 deaths in Zamfara state due to lead contamination. On the whole, all countries have been affected with soil heavy metals contamination through one source or the other, though at varying rates and intensities.

Monitoring the endangerment of soil with heavy metals is of interest due to their influence on groundwater and surface water (Weiting, 1988; Boukhalfa, 2007), on plants (Stimpfl et al., 2006; Stobrawa and Lorenc-Plucińska, 2008) on animals and humans (Lagisz and Laskowski, 2008; De Vries et al., 2007; Korashy and El-Kadi, 2008) and on any entity that has life. The aim of this study was to determine to what extent, human and industrial activities have affected the quality of soil due to contamination of soil with heavy metals and the consequent effects on the health status of the inhabitants.

MATERIALS AND METHODS

Studied area

Twenty five sampling sites were chosen based on their proximity to manufacturing companies that could contribute to a higher level of heavy metals contamination. These include: two pharmaceutical manufacturing companies, four mattress manufacturing companies, four electrical/electronics manufacturing companies, four soft drinks bottling companies, three artificial hair manufacturing companies, four farmlands and four dump yards. All the samples were taken from Ikeja Industrial Estate in Lagos Nigeria. Table 1 shows the sampling details.

Sampling

For the manufacturing sites, a suitable spot nearest to the production area of site was located. The top soil layer was scrapped off using a shovel, and a portion of soil was scooped inclining the shovel beneath the earth. A hole with an area of 40 × 50 cm was dug. Soil samples were taken from depths of 5, 15 and 25 cm. The soil samples were put in polyethylene containers pre-treated with a molar solution of hydrochloric acid and rinsed with distilled water (Hanns, 1984). Triplicate collections were made from spots other than the first to ensure uniformity of soil samples from a site. Collection procedure for the dump sites was similar to that of the manufacturing sites except that the spots for collection were soils beneath overturned debris. The farmlands each had triplicate samples collected from the areas were fertilizer and manure are frequently used. In all cases, the collections per sample site were mixed together in pre-treated containers and labeled appropriately.

Analysis of the samples

The samples were air dried until they were moisture-free. They were then crushed and sieved. One gram of each sample was weighed and transferred into pre-washed and oven dried beakers, digested and labeled.

Digestion of samples

Each soil sample was transferred into a 50 mL beaker and 20 mL of concentrated nitric acid was added. The mix was allowed to stand for 2 h prior to heating on a hot plate. Heating was carried out at 150°C for 6 h until the organic soil material is completely dissolved resulting in an almost clear solution and steam. The solution was allowed to cool at room temperature, filtered into a 25 mL volumetric flask and made up to volume with distilled water. This solution

Table 1. Sample information.

Site code	Site
Site A	Mattress Manufacturing Industry I
Site B	Mattress Manufacturing Industry II
Site C	Mattress Manufacturing Industry III
Site D	Mattress Manufacturing Industry IV
Site E	Electrical, Electronics and Cable Manufacturing Company I
Site F	Electrical, Electronics and Cable Manufacturing Company II
Site G	Electrical, Electronics and Cable Manufacturing Company III
Site H	Electrical, Electronics and Cable Manufacturing Company IV
Site I	Soft drinks and bottle manufacturing company I
Site J	Soft drinks and bottle manufacturing company II
Site K	Soft drinks and bottle manufacturing company III.
Site L	Soft drinks and bottle manufacturing company IV
Site M	Dump Yard I
Site N	Dump Yard II
Site O	Dump Yard III
Site P	Dump Yard IV
Site Q	Farm Land I
Site R	Farm Land II
Site S	Farm Land III
Site T	Farm Land IV
Site U	Artificial hair manufacturing industry I
Site V	Artificial hair manufacturing industry II
Site W	Artificial hair manufacturing industry III
Site X	Pharmaceutical Company Manufacturing Multivitamins
Site Y	Pharmaceutical Company Manufacturing Prescription medicines.

was aspirated into a Varian AAS 200 spectrophotometer to determine the metals.

AAS configuration

A four lamp turret Varian 200 flame AA spectrometer was optimized for the determination of cadmium (Cd), lead (Pb), chromium (Cr), copper (Cu), iron (Fe) and arsenic (As). The concentrations were measured in parts per million (ppm). The instrument mode was absorbance. The sampling mode of the instrument was manual, set at the prompt measurement mode. The photomultiplier voltage was set at 330 V. Precision of the standard, sample and expansion factor was 1%. A background correction factor was not used in the determination of any of the metals. The reslope was carried out after every 12 samples and the reslope standard was 2.0. The reslope lower limit was 75% and upper limit 125%. The lamp current for all the metals were set between 5-8 mA.

RESULTS AND DISCUSSION

The standard calibration curves for all six metal ions were obtained using a series of varying concentration. All calibration curves were linear with correlation coefficients close to unity. Table 2 gives the summary of the results obtained in this study. The progression of metal accumulation in soil samples does not only indicate the level of current contamination but can portray a history of activities over a long period of time since soil is a sink for these contaminants. All the metal ions analyzed were present in varying concentrations except for arsenic that was not detected. Various agencies including World Health Organization (WHO), United States Environmental Protection Agency (US-EPA) and European Regulatory Standards (EURS) have set different maximum contaminant limits for heavy metals. The maximum recommended by EURS for soil samples are: cadmium 3 mg/kg; chromium 100 mg/kg; copper 30 mg/kg and lead 150 mg/kg. Figures 1 to 4 show the graphical representation of the levels of cadmium, lead, chromium and copper, respectively, in comparison with the EURS recommended minimum standards.

Table 2. Summary of result.

Sample	Cd (mg/kg)	As (mg/kg)	Pb (mg/kg)	Cr (mg/kg)	Fe (mg/kg)	Cu (mg/kg)
Site A	1.25	ND	5.40	0.46	1111	4.40
Site B	3.40	ND	10.40	0.56	2190	4.36
Site C	3.60	ND	8.40	1.75	1234	3.80
Site D	4.10	ND	9.30	2.20	1256	3.20
Site E	0.80	ND	4.40	0.88	1189	3.11
Site F	0.90	ND	3.60	0.96	1134	4.40
Site G	1.20	ND	3.70	0.70	1178	3.60
Site H	1.50	ND	3.20	0.80	1189	4.56
Site I	4.20	ND	9.20	1.86	1145	2.24
Site J	0.56	ND	4.40	0.55	1267	3.36
Site K	2.58	ND	12.50	1.86	2167	4.46
Site L	2.20	ND	9.54	1.96	1267	5.58
Site M	2.10	ND	9.56	2.20	2214	3.42
Site N	2.20	ND	8.80	1.76	2216	2.20
Site O	1.00	ND	3.40	0.88	1786	2.56
Site P	1.03	ND	3.56	0.82	1343	2.58
Site Q	1.10	ND	3.80	0.83	1876	2.40
Site R	0.90	ND	2.54	0.84	1945	3.40
Site S	0.80	ND	2.20	0.90	1120	2.90
Site T	2.40	ND	2.10	0.99	1140	2.45
Site U	2.50	ND	2.22	0.75	1138	3.30
Site V	2.10	ND	3.20	0.24	1156	2.20
Site W	1.80	ND	2.40	0.75	1134	2.67
Site X	1.10	ND	2.20	0.66	1128	2.67
Site Y	2.24	ND	7.80	1.36	1134	6.60

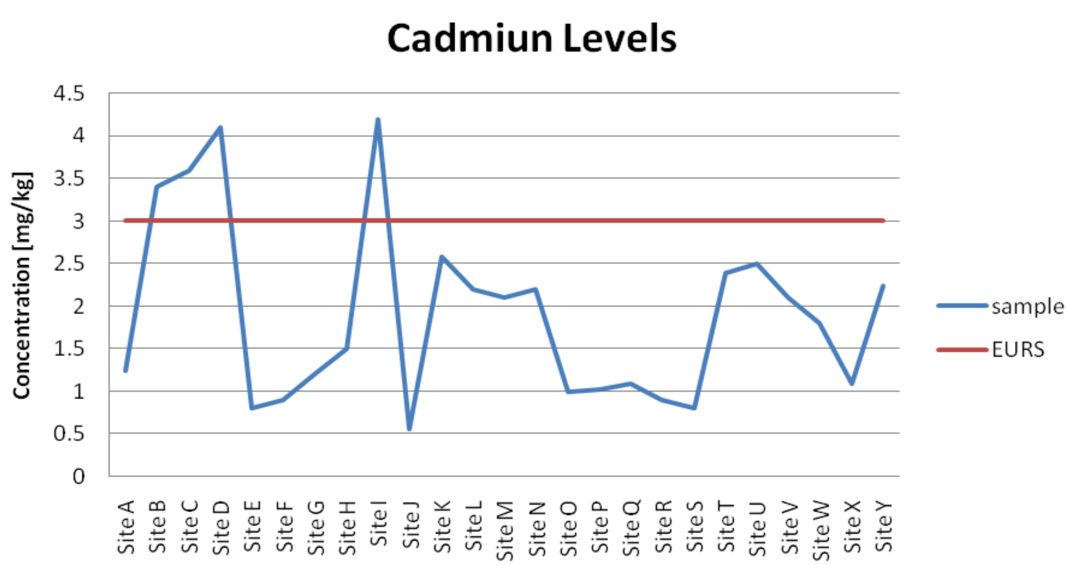

Figure 1. A graphical illustration of cadmium concentrations in the soil samples relative to EURS permissible limits.

In Figure 1, site I (soft drink bottling company) had the highest concentration of cadmium with a concentration of 4.20 mg/kg. 16% of the sites had values of cadmium higher than the EURS maximum concentration limit (MCL) of 3 mg/kg. Heavy metals are dangerous because they tend to bioaccumulate. Even low exposure levels

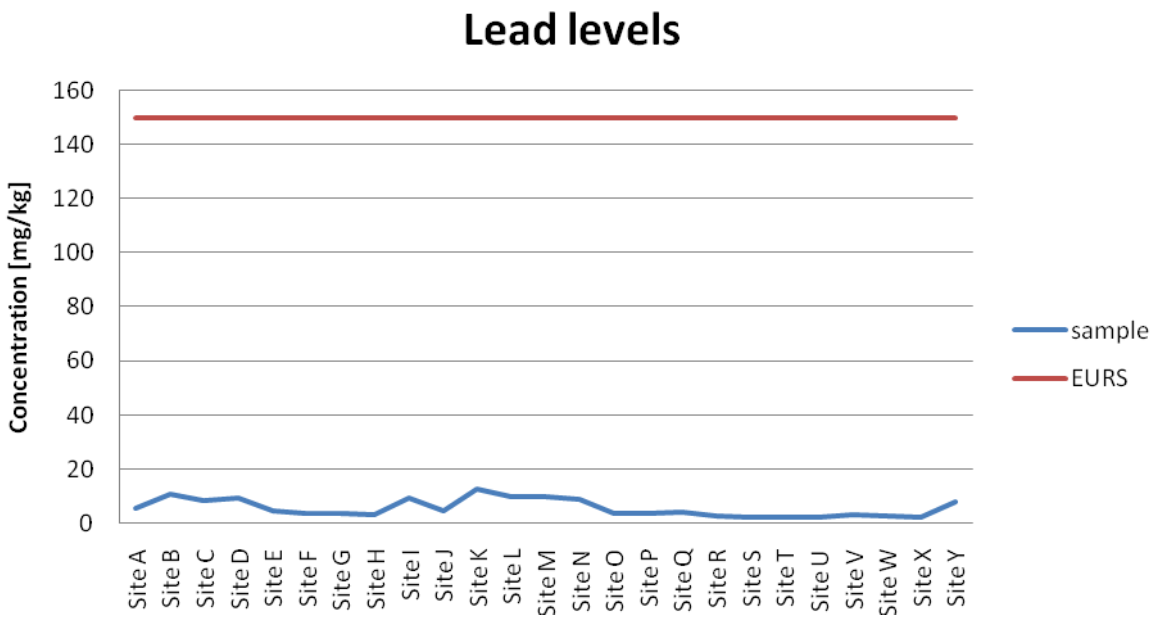

Figure 2. A graphical illustration of lead concentrations in the soil samples relative to EURS permissible limits.

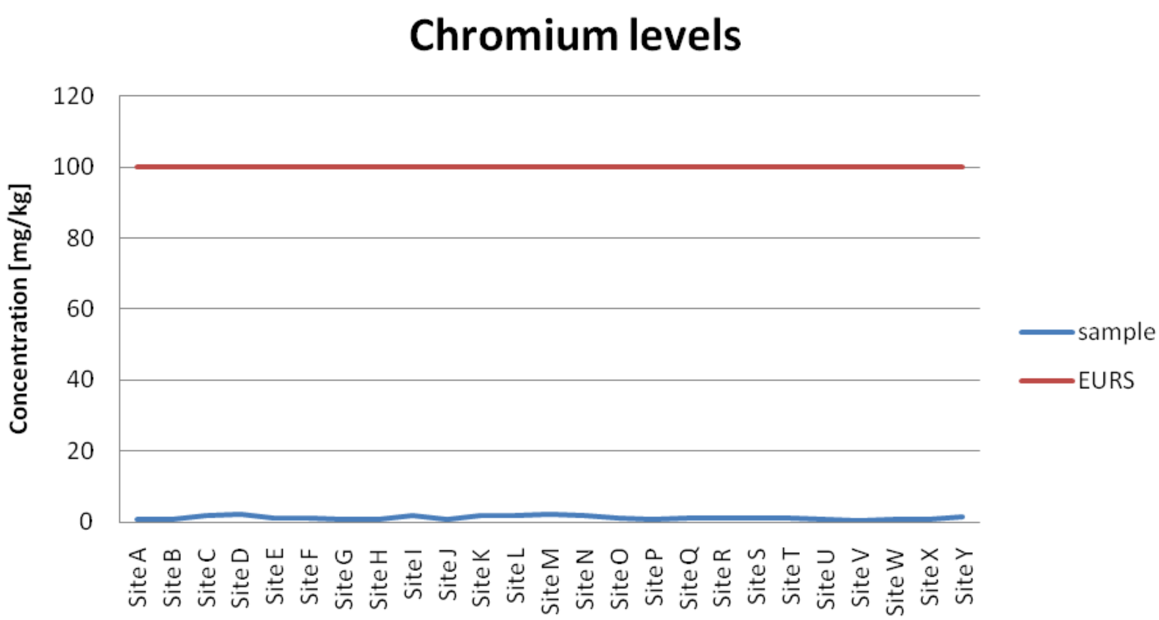

Figure 3. A graphical illustration of chromium concentrations in the soil samples relative to EURS permissible limits.

may, in time, cause accumulation, especially in the kidneys. Both the kidneys and liver act as cadmium stores (together storing 50 to 85% of the body burden), with 30 to 60% being stored in the kidneys; cadmium stored in the liver is gradually released to the kidneys (Anyakora et al., 2011). Though there has been paucity of information on reported carcinogenicity by oral route, most classifications are based on occupational exposure to cadmium with inhalation as the primary route of exposure. A study also reported an association between environmental exposure to cadmium and cancer via inhalation exposure (Nawrot et al., 2006). These authors also compared cancer incidence in an area contaminated with cadmium (geometric mean cadmium soil concentration 7.97 mg/kg) with incidence in an area with low exposure to cadmium (geometric mean cadmium soil concentration 0.81 mg/kg). Nawrot et al. (2006) also found a significant relationship between cadmium concentration in the soil, or residence in a high-exposure area, and lung cancer even after adjustment for age, sex, smoking and exclusion

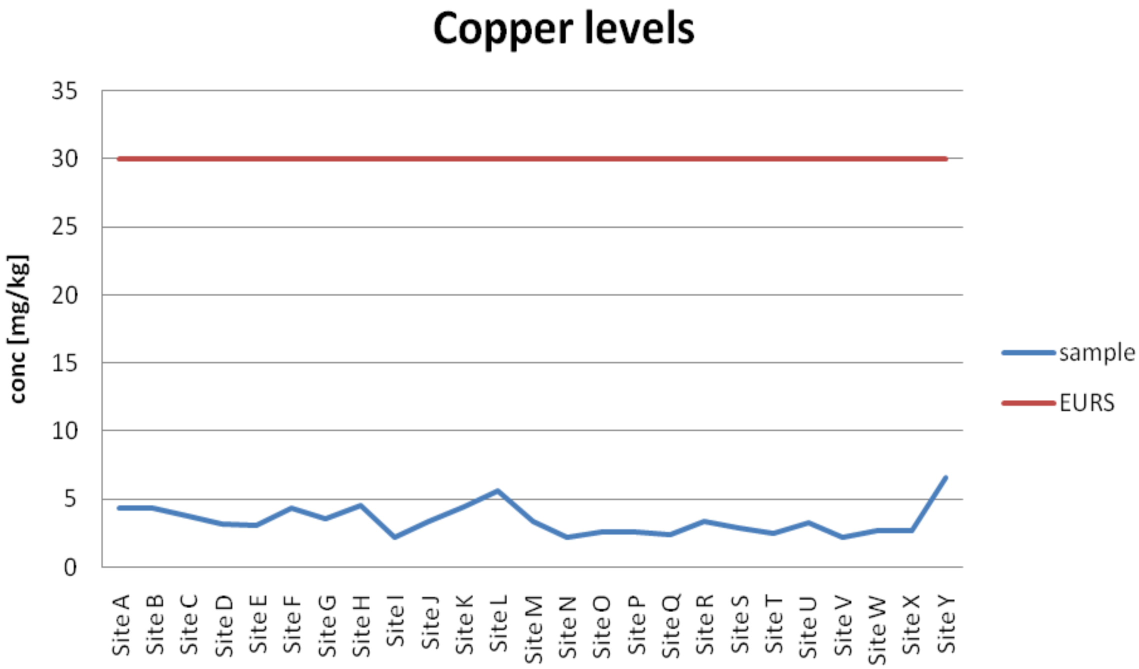

Figure 4. A graphical illustration of copper concentrations in the soil samples relative to EURS permissible limits.

of cadmium-exposed workers.

Of the 25 sites analysed, lead concentration was found to be high in eight sites: two mattress manufacturing companies, three bottling companies, one dump site and one pharmaceutical company. The site with the highest concentration level of lead was site K (12.50 mg/kg)- a bottling company, followed by site B (10.40 mg/kg)- a mattress manufacturing company. Soil is contaminated by lead from various sources (American Academy of Pediatrics, 1987). Lead particles are deposited in the soil from flaking lead paint, incinerators (and similar sources), and motor vehicles that use leaded gasoline. Waste disposal is also a factor. Urban environments in general have received higher depositions of lead from vehicular emissions than rural areas (Xintaras, 1992). Lagos being an urban town is typified by large anthropogenic activities of varying forms. Some individuals may be exposed to lead from occupational or hobby sources or from other less-common sources, such as the use of lead-glazed pottery, stained glassworking, and target practice in poorly ventilated indoor firing ranges.

Table 2 and Figure 2 depicts the concentration levels of chromium with sites D and M having the highest concentration levels of 2.20 mg/kg each. These two sites represent the mattress and dump site, respectively. Other sites with relative high values for chromium were three bottling companies and one dump site. A suite of Industrial activities has led to widespread of chromium contamination within soils and natural waters. Although, chromium is an essential element for humans, the hexavalent form is toxic, mutagenic and carcinogenic (National Research Council, 1974). On this premise, the widespread presence of chromium in the environment poses a serious threat to human and animal life. It has also been shown that Cr(VI), which typically exists as the oxyanion chromate (CrO_4^{2-}), has a high solubility in soils and ground waters resulting in increased mobility in the environment. In contrast, the reduced form of chromium, Cr(III), has a limited hydroxide solubility and forms strong complexes with soil minerals (Sass and Rai, 1987). Accordingly, reduction of Cr(VI) to Cr(III) is an important means by which the deleterious effects of this heavy metal are mitigated. This general procedure forms the fundamental basis of a large number of technologies currently being tested for remediation of chromium-contaminated soils (Collen, 2003).

The result also showed site N (a dump site) to have the highest iron concentration (2216 mg/kg) followed by site M (another dump site) with a concentration of 2214 mg/kg. These values suggest that the dump sites in Lagos are not only reservoirs for most heavy metals but also have a high propensity for iron overload and possible toxicity in the soil samples, therefore placing dump-sites as a good candidate for remediation. Our study reveals that seven out of the study sites, had iron concentrations higher than the EURS MCL limits of 1500 mg/kg.

Copper is both an essential element and a contaminant. Our analysis shows that the soil samples from a pharmaceutical company (site Y) had the highest concentration of copper (6.60 mg/kg). This was followed by site L (a soft drink bottling company) with a concentration of 5.58 mg/kg. Though some studies have shown copper to be carcinogenic in tests with mice and dogs (WHO, 1998), the US-EPA (1991) has not classified copper with regards to its carcinogenicity on the basis that there is no human data, inadequate animal data from assays of copper compounds, and equivocal mutagenicity data.

An overview of the heavy metal analysis showed farmlands, electrical manufacturing companies and artificial hair manufacturing companies to have low concentrations of heavy metals leached into the soil samples. The reverse is seen with the dump sites, mattress manufacturing companies, soft drinks bottling companies and only one of the pharmaceutical companies. We establish that through the various activities carried out by the residents and workers in these work sites, heavy metals are been introduced into the soil in various forms and ways. The progression of metal accumulation in soil samples does not only indicate the level of current contamination but can portray a history of activities over a long period of time since soil is a sink for these contaminants.

The elemental analysis of all soil samples shows that cadmium and iron exceeded the maximum concentration level in the sites used. Our results confirmed the correlation between a densely populated area and heavy-metal contaminations. The highest cadmium value of 4.20 mg/kg can be seen in sample site I which represents the soft drinks bottling companies. 16% of sample sites had a high concentration of cadmium. Site N, a dump yard, had the highest concentration of iron of all samples investigated. 28% of the sites exceeded the maximum concentration level of iron in soil. Hence dump yards, mattress manufacturing companies and soft drinks bottling manufacturing companies were implicated in the heavy metals contamination.

Precautionary measures should thus be taken to avoid chronic toxicity in humans resulting from planting food crops on soils in high-exposure areas and other human activities which can cause ingestion of edibles contaminated with these metals. Even though the farmlands did not show a significant level of contamination, Giller et al. (1998) reported that there was a detrimental effect to soil microbial diversity and microbial activities (indexes of microbial metabolism and of soil fertility) in metal-polluted environments. Previous studies done on this environment on ground water revealed high level of heavy metal load (Anyakora et al., 2011). This indicates a possibility of leaching of heavy metals from the soil into the groundwater and surrounding water bodies. Bioremediation of this environment is highly recommended to reverse a possible adverse health effect to the population.

Until now, methods used for remediation of heavy metals in communities or sites that are heavy metal prone include acid leaching and electro reclamation, excavation and land fill, thermal treatment, which are not suitable for practical applications, due to high cost, low efficiency, large destruction of soil structure and fertility and high dependence on the contaminants of concern, soil properties, site conditions. The advent of phytoremediation strategies for heavy metals contaminated soils has offered better solution (Cheng et al., 2002; Lasat, 2002). However, the ideal plant for phytoextraction or phytoremediation should grow rapidly, produce a high amount of biomass, and be able to tolerate and accumulate high concentrations of metals in shoots. Most of the commonly known heavy metal accumulators belong to the Brassicaceae family (Kumar et al., 1995). Although, hyperaccumulator plants have exceptionally high metal accumulating capacity, most of these have a slow growth rate and often produce limited amounts of biomass when the concentration of available metal in the contaminated soil is very high.

An alternative is to use species with a lower metal accumulating capacity but higher growth rates, such as Indian mustard (*Brassica juncea*); another alternative is to provide them with an associated plant growth-promoting rhizobacteria, which also is considered to be an important component of phytoremediation technology (Wenzel et al., 1999; Glick, 2003). Also, through the use of microbially generated redox potentials, heavy metals could be rendered immobile such that they do not leach into water bodies. This way, the various sites that are heavily contaminated would be mopped up of the injurious metals.

Conclusion

This study indicates the presence of lead, chromium, copper and cadmiun in the study area. Cadmium was found in concentrations above European Regulatory Standards maximum allowable concentration indicating a threat to the population. Even though the levels for chromium, lead and copper are below the European Regulatory Standards maximum concentration limits, they still pose a threat since these toxicants are known to be bioaccumulative. The study also concludes that there is a correlation between industrialization and level of heavy metal contamination.

REFERENCES

Anyakora C, Nwaeze K, Awodele O, Nwadike C, Arbabi M, Coker H (2011) Concentrations of Heavy Metals in some Pharmaceutical Effluents in Lagos, Nigeria. J. Environ. Chem. Ecotoxicol. 3(2): 25-31.

Boukhalfa C (2007). Heavy metals in the water and sediments of Oued Es-Souk, Algeria, a river receiving acid effluents from an abandoned mine. Afr. J. Aquat. Sci. 2(3):245–249.

Brumelis G, Brown DH, Nikodemus O, Tjarve D (1999). The monitoring and risk assessment of Zn deposition around a metal smelter in Latvia. Environ. Monit. Assess. 58 (2):201–212.

Cheng S, Grosse W, Karrenbrock F, Thoennessen M (2002). Efficiency of constructed wetlands in decontamination of water polluted by heavy metals. Ecol. Eng. 18(3):317–325.

De Vries W, Romkens PF, Schutze G (2007). Critical soil concentrations of cadmium, lead, and mercury in view of health effects on humans and animals. Rev. Environ. Contam. Toxicol, 191:91–130.

Dupler D (2001). Heavy metal poisoning. Gale Encyclopedia of Alternative Medicine. Farmington Hills, MI: Gale Group.

Gade LH (2000). Highly polar metal – Metal bonds in “early-late” heterodimetallic complexes. Angewandte Chemie-International Edition. 39(15):2658–2678.

Garbisu C, Alkorta I (2001). Phytoextraction: A cost effective plant-based technology for the removal of metals from the environment. Bioresour. Technol. 77(3):229–236.

Giller KE, Witter E, McGrath SP (1998). Toxicity of heavy metals to microorganisms and microbial processes in agricultural soils. Soil Biol. Biochem. 30 (10-11):1389–1414.

Gisbert C, Ros R, de Haro A, Walker DJ, Pilar Bernal M, Serrano R, Avino JN (2003) A plant genetically modified that accumulates Pb is especially promising for phytoremediation. Biochem. Biophys. Res. Commun. 303(2):440–445.

Glick BR (2003). Phytoremediation: synergistic use of plants and bacteria to clean up the environment. Biotechnol. Adv. 21(5):383–393.

Goyer RA (1988). Lead. In: Handbook on Toxicity of Inorganic Compounds. H.G. Seiler and H. Sigel, eds. Marcel Dekker, Inc.: New York. pp. 359-382.

Hanns Wedepohl K (1995). The composition of the continental crust. Geochimica et cosmochimica Acta 59 (7): 1217-1232

Keller C, McGrath SP, Dunham SJ (2002) Trace metal leaching through a soil-grassland system after sewage sludge application. J. Environ. Qual. 31(5):1550–1560.

Khan S, Cao Q, Zheng YM, Huang YZ, Zhu YG (2008) Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. Environ. Pollut. 152(3): 686–692.

Kilburn KH, Warshaw RH (1993). Neurobehavioral testing of subjects exposed residually to groundwater contaminated from an aluminum die-casting plant and local referents. J. Toxicol. Environ. Health 39: 483-496.

Korashy HM, El-Kadi AOS (2008). Modulation of TCDD-mediated induction of cytochrome P450 1A1 by mercury, lead, and copper in human HepG2 cell line. Toxicology *in vitro* 22(1):154–158.

Kumar PBA, Dushenkov V, Motto H, Raskin I (1995). Phytoextraction: the use of plants to remove heavy metals from soils. Environ. Sci. Technol. 29(5):1232–1238.

Lagisz M, Laskowski R (2008). Evidence for between-generation effects in carabids exposed to heavy metals pollution. Ecotoxicology 17(1):59–66.

Lasat HA (2002). Phytoextraction of toxic metals: a review of biological mechanisms. J. Environ. Qual. 31(1):109–120.

McGrath SP, Zhao FJ, Lombi E (2001). Plant and rhizosphere process involved in phytoremediation of metal-contaminated soils. Plant Soil. 232 (1/2):207–214.

McLaren RG, Clucas LM, Taylor MD, Hendry T (2004). Leaching of macronutrients and metals from undisturbed soils treated with metal-spiked sewage sludge. 2. Leaching of metals. Austr. J. Soil Res. 42(4): 459–471.

Momodu M, Anyakora C (2010). Heavy metal contamination of groundwater: the Surulere case study. Res. J. Environ. Earth Sci. 2(1):29-43.

Navarro MC, Pérez-Sirvent C, Martínez-Sánchez MJ, Vidal J, Tovar PJ, Bech J (2008). Abandoned mine sites as a source of contamination by heavy metals: A case study in a semi-arid zone. J. Geo. Expl. 96(2–3):183–193.

Nawrot T, Plusquin M, Hogervorst J, Roels H, Cells H, Thijs L, Vangronsveld J, Van Hecke E, Staessen JA (2006). Environmental exposure to cadmium and risk of cancer: a prospective population-based study. Lancet Oncology 7: 119–126.

Pocock SJ, Shaper AG, Ashby D, Delves T, Whitehead TP (1984). Blood lead concentration, blood pressure, and renal function. Br. Med. J. 289:872-874.

Sass BM, Rai D (1987). Solubility of amorphous chromium (III)-iron(III) hydroxide solid solutions. Inorg. Chem. 26:2228-2232.

Scragg A (2006). Environmental Biotechnology, Oxford University Press, Oxford, UK, 2nd edition.

Snyder C (2005). The dirty work of promoting "recycling" of America's sewage sludge. Int. J. Occup. Environ. Health 11(4): 415–27.

Stimpfl E, Aichner M, Cassar A, Thaler C, Andreaus O, Matteazzi A (2006). The state of fruit orchard soils in South Tyrol (Italy). Laimburg J. 3(1):74–134.

Stobrawa K, Lorenc-Plucińska G (2008). Thresholds of heavy-metal toxicity in cuttings of European black poplar (*Populus nigra* L.) determined according to antioxidant status of fine roots and morphometrical disorders. Sci. Total Environ. 390(1):86–96.

USEPA, Report: recent Developments for In Situ Treatment of Metals contaminated Soils, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, 1996.

Vaalgamaa S, Conley DJ (2008). Detecting environmental change in estuaries: Nutrient and heavy metal distributions in sediment cores in estuaries from the Gulf of Finland, Baltic Sea. Estuar. Coast Shelf Sci. 76 (1):45–56.

Wenzel WW, Lombi E, Adriano DC (1999). Biochemical Processes in the Rhizosphere: Role in Phytoremediation of Metal-Polluted Soils. In: Prasad MNV, Hagemeyer J, editors. Heavy Metal Stress in Plants: from Molecules to Ecosystems. Berlin: Springer. pp. 273–303.

WHO (1998). Environmental Health Criteria 200: Copper. International Programme on Chemical Safety, World Health Organization: Geneva.

Wieting J (1988). Effects of air-pollutants on groundwater quality in the Federal Republic of Germany. Wasser Boden. 40 (4):183–186.

Willis MR, Savory J (1985). Water content of aluminum, dialysis dementia, and osteomalacia. Environ. Health Perspect. 63: 141-147.

Zhang MK, Liu ZY, Wang H (2010). Use of single extraction methods to predict bioavailability of heavy metals in polluted soils to rice. Commun. Soil Sci. Plant Anal. 41(7) 820–831.