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Assessment of Heavy Metals Pollution in Urban Soils and the Implications to Consumers Health

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Abstract
Elevated levels of metals due to anthropogenic activities are a cause of environmental concern because of their effects on human health. Eldoret Municipality, in Kenya, is one of the fastest growing municipalities with both industrial and agricultural developments. The study aimed at determining the concentration of five elements namely zinc (Zn), lead (Pd), copper (Cu), chromium (Cr) and cadmium (Cd) in five sample sites within the municipality and established the possible health risks in the residents. Measured concentrations of Zn, Pb, Cr, Cu and Cd in surface horizon soils were used to estimate the geochemical load indices and their spatial distribution. Four soil samples were collected monthly from each sample site on the same farms totaling 200 soil samples. The samples were dried, ground and sieved for metal digestion using varied acids in the laboratory and analysis was done against metal standards using Atomic Absorption Spectrometry (AAS). Only Cd concentration (0.0286mg/kg) in all sites was above the recommended unpolluted soils. Epidemiological data were obtained from the residents and hospitals to establish associated health risks. Determination of metals' combined effects using multivariate Principal Component Analysis showed that varying concentrations of Zn and Pb tended to increase incidences of cancer, hypertension and stroke. Metals Zn, Pb and Cu concentrations correlated with development of cardiovascular diseases. Awareness rising to residents of Eldoret Municipality on high Cd concentration in the soil and use of alternative forms of fertilizers and related chemicals with low Cd content is recommended.
Keywords: Elements, Human Health, Spatial Distribution, Urban Soils

1.Introduction

Urbanization and industrialization are a consequence of human population growth. In the process, there is a tendency for poor disposal and accumulation of heavy metals in the environment. The gravity of these environmental concerns has been exposed by several studies (Adamo et al., 2002; Adamo et al., 2005). Nonetheless, it has aggravated in recent years as a result of increased anthropogenic activities associated with urbanization and agricultural development (ATSDR, 2006), resulting in negative effects on the environment with affiliated disruption of the normal environmental stability (Adamo et al., 2005). The consequences, especially on human health are slow and take longer to be realized.

Metals released into the environment under natural and anthropogenic pathways accumulate in soils, water and food crops eventually finding their way into humans and other animals along the food chain. As such, soils and water are good indicators of the levels of metals in an environment. For most individuals, however, food and water are the main sources of contamination (Fordyce, 2000). In the human body, the metals are deposited in various organs such as lungs, kidneys and bones resulting in serious ill health consequences. However, metal pollution still remains significant owing to less attention it has received from environmental lobby groups in relations to other forms of environmental pollutions.

Majority of heavy metals and their compounds have been established to possess pronounced properties of toxicants, which can be phytotoxic at even low concentrations (Fordyce, 2000, Fordyce and Johnson, 2002). For instance, severe Zn deficiency in humans causes growth retardation, enzyme and skin disorders, and a delay in sexual and skeletal maturation. However, Zn toxicity manifests as nausea, vomiting, diarrhea, fever and lethargy especially after ingestion of 4-8 g of Zn (Ngure et al., 2011). Human exposure to Pb can result in a wide range of biological effects depending on the level and duration of exposure. Low Cu intake in the diet has been associated with neutropenia and osteoporosis but severe intramuscular hemolysis, jaundice, hepatic necrosis, haemoglobinuria and proteinuria accompany Cu toxicity (Ngure et al., 2011). However, the entry of Cd into the food chain is known to cause kidney disorders, anemia and bone marrow disorders. Chromium has been reported to be carcinogenic depending on the species and mode of exposure. Additionally, Cd derives its toxicological properties from its chemical similarity to Zn. Cadmium is bio-persistent and once absorbed by an organism, it remains resident for many years (Ngure et al., 2011).

In addition to the biological roles, heavy metals are physically significant because of their ability to move too rapidly in a particular environment. Thus, they can pollute ground water supplies, especially in areas with high water tables. Hence to control the above negative effects on humans and environment, knowledge of heavy metal pathways in the ecosystems is important. Soil being a long-term sink for heavy metals can influence the concentrations of heavy metals in both the water column and humans if they are absorbed or become available to living organisms. Although these metals have different mobility and bioavailability in soils, leaching losses and plant uptake are usually relatively small compared to the total quantities entering the soil from different sources (Nicholson et al., 2006). Consequently, metals slowly accumulate in topsoil, with long-term implications for agricultural soil quality and could easily find their way to the human body, with detrimental effects. Studies of metals in their accumulation pathways into the humans are rare and sporadic.

Growing towns and cities, generally, have industrial activities which have high potential to immensely contribute to metal pollution. Industries generate solids, gases and effluent wastes containing metals that are released to the environment. Furthermore, increased usage of chemicals in agriculture, adds metals in the soils. In this study we measured the concentrations of Zn, Pb, Cu, Cr and Cd in soils and related the metals' concentrations to human chronic diseases in Eldoret Municipality.

2. Materials and Methods

2.1. Study area

This study was conducted in Eldoret Municipality, in Uasin Gishu County, Kenya (Figure 1). Eldoret town is one of the fastest growing towns in Kenya due to its rich agricultural hinterland and strategic location on the main Mombasa-Kampala highway. The municipality has over years expanded its size from 25 km^2 in 1959 to 59 km^2 and 147.9 km^2, respectively, by 1974 and 1988. The population has also increased from 200,830 in 1999 to 500,000 by 2009 (CBS 2010) with population growth rate estimated at 4.12%. The county is one of the leading wheat and maize producer in the country producing between 300,000 and 350,000 tonnes of wheat per year apart from other food and cash crops including horticulture. As an upcoming industrialized town, some of the industries and factories include: wood processing Rai Ply and Highland Paper mills, textile factories (Rivertex, Raymond and Kennit), Coca cola factory, cooking oil producing factory (Arkay Industries), Milk processing plant (KCC), tannin factory for leather, and maize and wheat storage facility (National Cereals and Produce Board) among others. These anthropogenic activities produce hazardous wastes which find their way into the soil, crops, rivers and eventually into human bodies through ingestion.

2.2. Selection of sampling sites

Five zones in the Eldoret Municipality namely EATEC, Yamumbi, Kimumu, Hawaii, Kahoya, Huruma and Jua Kali were selected for sampling in this study (Figure. 1). The zones were located out of the main town centre ranging between 8 km and 13 km. These zones were selected based on anthropogenic activities undertaken in the zones (Table 1). River Sosiani which is heavily depended on by some areas that lack piped water runs through town where lots of garages are located. It also passes through heavily farmed areas.

2.3. Soil sampling and laboratory analysis for metals

A total of 200 soil samples were collected for a period of 18 months comprising of two samples the 10 farms in each of the five sites purposely selected collected during the wet and dry seasons. Two composite near surface (10-30 below A_o) soil samples were collected from each zone. Using the assembled sectional auger 4 holes were made at the corners of the grid of 20m^2 in accordance with IGCP

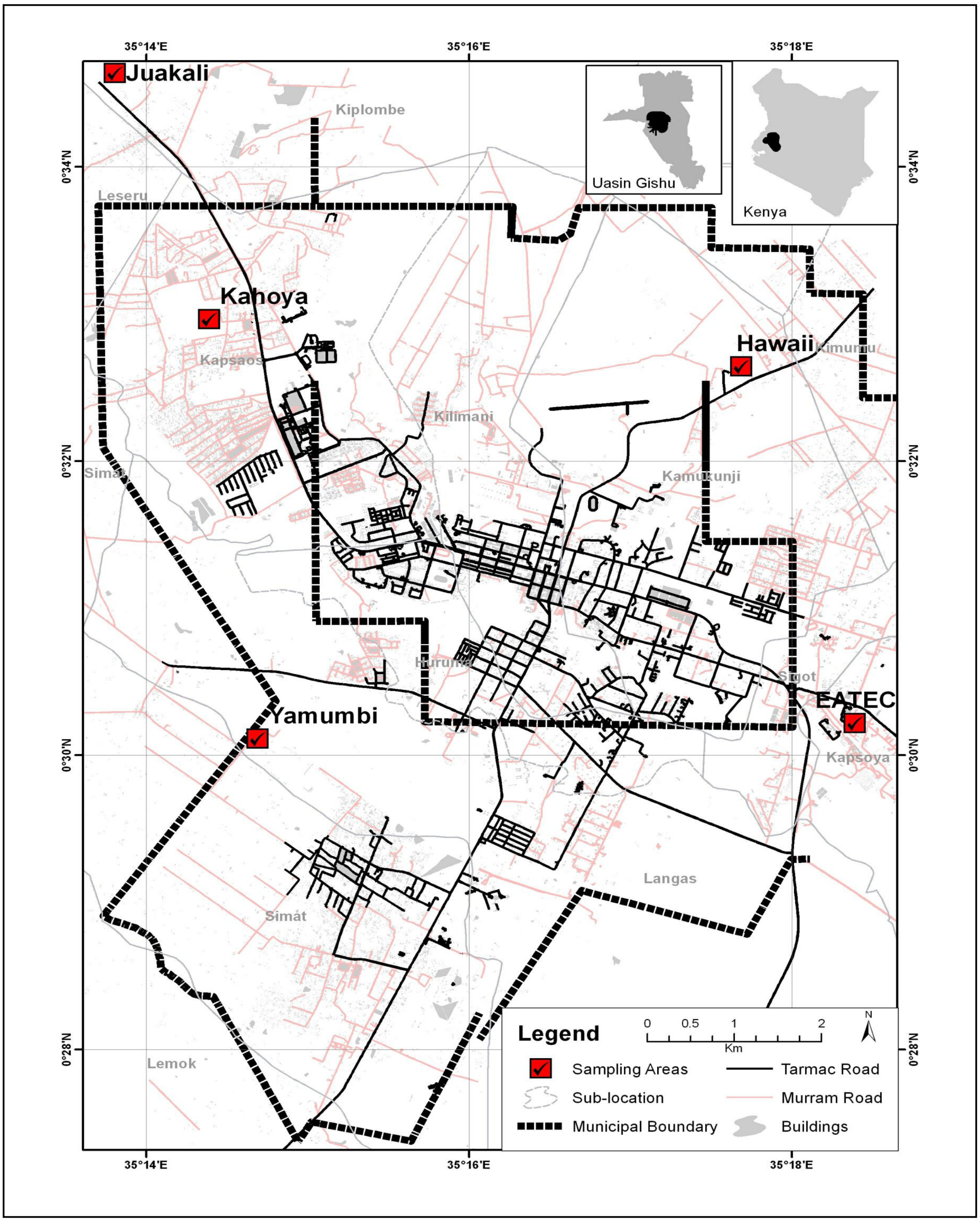

Figure 1: Map showing the position of sampling areas in Eldoret Municipality

259 recommendations (Fordyce et al., 2000), from whence soil was collected using a scoop and homogenized on a plastic sheet. The mixed soil samples were emptied into air tight plastic containers to retain the moisture content (Fordyce et al., 2000) and taken to the laboratory for metal analyses.

The wet season soil samples were oven dried at 32-35^{o}C to constant weight for 6-12 hours to avoid loss of metals through volatilization while the dry season samples were air dried. A sample of 1.250g ground soil, sieved through 0.002mm plastic sieve, was transferred to a digestion tube and 50 ml of deionised water added followed by a mixture of 50 ml conc. HNO_3 and HCl in the ratio of 1:3. The detailed procedure is described in Ngure et al. (2011).

Table 1. Anthropogenic activities in the sampling zones within the study area

Zone	Anthropogenic activities
Juakali (Control)	Out of the Municipality with wattle trees and cultivation and no piped water and use water from Sosiani River, springs and boreholes. It is 13 km from town centre.
EATEC	Wattle trees and the tannin factory for processing and has piped water.
Yamumbi	Oldest settlements with small farms and lacks piped water
Kahoya	Heavy human settlements with lots of garages and little farms. It has both piped and borehole water.
Hawaii	Oldest human settlement with medium farms including horticulture. It lacks piped water

2.4. Epidemiological survey

Epidemiological surveys were conducted concurrently during the sampling of residents (Ngure et al., 2011). Epidemiological research ethics were observed including ensuring confidentiality of the information obtained, recording data under coded system and avoiding names of individuals. The study targeted only male adults aged between 35 and 55 years and who had lived in the areas for more than five years to provide data on their disease history. Women were not considered because of chemical treatment to their hair and are unwilling in most cases to participate in search studies. Hence, only 68 respondents on the 10 farms qualified to be interviewed. The respondents wrote down any health complications they experience. The responses were then used to correlate with heavy metal concentrations in the respective sampling site focusing on only four diseases namely cancer, hypertension, stroke and cardio-vascular diseases. Through expert judgments from various hospitals, the responses were categorized and any heavy metal related illness inferred. Secondary medical data were also obtained from hospitals and health centres within the study area including; Huruma Sub District Hospital, Langas Health Centres, Eldoret District Hospital and Moi Teaching and Referral Hospital in order to compare the prevalence of the diseases.

2.5. Data analysis

The data collected were analyzed using STATISTICA 12.0 and GenStat 4.24. statistical softwares. Before analysis, a apriori test was undertaken to determine the homoscedasticity of the data (Michael and Douglas, 2004). Secondly, normality of data distribution was checked using skewness and Kurtosis for analysis of variance tests. Heavy metal concetration in soils were calculated as means (± S.E) first in general and then for each sampling site. Mean differences in the heavy metals between sites were analyzed using a one-way ANOVA while spatial variation was analyzed using a two-way ANOVA. However, where significant differences in ANOVA tests occurred, Duncans Multiples Range Test (DMRT) was used to discriminate between the different means (Michael and Douglas, 2004). The relationships between disease occurrence and prevalence and concentration of heavy metals were analyzed using Spearman Rank Correlations. A combination of heavy metals acting simultaneously to determine the occurrence of various heavy metals related diseases were clustered using multivariate Principal Component Analysis (PCA) employing the Eigen value factor extraction method. Factors extracted with Eigen values greater than 1 accounted for the observed variations in the observed disease conditions within the population of the study areas.

3. Results

3.1. Concentration of heavy metals in Eldoret Municipality soils

The concentrations of heavy metals in the soil from Eldoret Municipality varied (Table 2). Zinc concentration was the highest of followed by Pb. However, Cd recorded the lowest concentration. Of the five metals, only Cd concetration was above the recommended level.

Table 2. Relative concentrations of heavy metals (mean ± SE) in the five zones in the soils within Eldoret Municipality with recommended levels

Metals	Metal concentration (mg/kg)	Recommended metal levels (mg/kg)	Source
Zinc	2.3700± 0.3014	3.0mg/kg	Frink, 1996
Lead	0.6810 ± 0.0260	1.0mg/kg	Frink, 1996
Copper	0.3492 ± 0.0091	0.6 mg/kg	Frink, 1996
Chromium	0.7188 ± 0.0904	1.0mg/kg	Frink, 1996
Cadmium	0.0385 ± 0.0026*	0.01mg/kg	Frink, 1996

*Mean (± SEM) values higher than recommended concentration

The concentrations of Zn, Pb, Cu and Cr in each of the five sites namely Juakali, EATEC, Yamumbi, Kahoya and Hawaii were below the recommended concentrations. However, Cd concentration was higher than the recommended levels in all the five sites with Yamumbi having the highest and Kahoya the lowest (Table 3). Zinc concentration was highest in Kahoya followed by EATEC while Yamumbi had the lowest concentration (Table 2). Lead concentration was highest in Yamumbi followed by EATEC while Kahoya had the lowest concentration. Yamumbi recorded highest concentrations of copper and cadmium with chromium concentration being highest in Juakali. However, lower concentrations were recorded in EATEC, Hawai and Kahoya for Cu, r and Cd, respectively.

3.2. Relationship between heavy metals and disease disorders

In order to determine the combinations of heavy metals that are responsible for the causality of the observed diseases associated with heavy metals prevalence and cause association (PCA) methods were employed (Figure 2). According to extraction of the combination of metals that caused each of the most prevalent metal-associated diseases, Zinc was factor 1, Pb factor 2 and Cu factor 3 (Figure 2). Chromium and Cd factor values were below 1 and did not account for observed disease conditions as shown by the factor extraction (Figure 2) and Eigen values (Table 4). Zn, Pb and Cu were significant ($\propto = 0.05$). Metals were associated with diseases in the study area namely cancer, stroke, hypertension and cardio-vascular diseases. Zinc accounted for highest (49.83%) of the variance followed by Pb (27.01%) in cancer cases (Table 4). Cadmium was the lowest with less than 1%. For hypertension conditions, Zn accounted for 38.47% followed by Pb with 29.80%, Cadmium was the lowest with 3.53%. Equally, Zn accounted for 45.54% for stroke followed by lead with 34.73% for stroke and Cd being the lowest (1.93%). In cardiovascular diseases, Zn accounted for 46.02% followed by Pb with 28.12% and Cd being the lowest (1.41%).

3.3 Cases of various disease conditions relative to sampling site

Out of the 250 respondents, 68 cases of various disease conditions related to the environment were reported namely cancer, hypertension, stroke and cardio-vascular diseases (Table 3). Juakali reported the highest (29.4%) incidences followed by Kahoya (27.9%), then EATEC (22.1%), Yamumbi (11.8%) and Hawai (8.8%), respectively.

Cardio-vascular related diseases and hypertension recorded the highest incidences of 32.4% each followed by cancer (23.5%) and lastly stroke (11.8%). Disease incidences also varied within each sample site (Table 5). In Juakali, incidences of cardio-vascular disease were higher (60%) followed by hypertension (20%) and cancer (15%) and stroke (5%) respectively. However, in EATEC, hypertension was the highest with 40% followed by cancer (33.3%), stroke (20%) and cardio-vascular diseases (6%), respectively. There were higher incidences (50%) of cancer in Yamumbi followed by hypertension (25%). Stroke and cardio-vascular diseases had the lowest incidences with 12.5% each. Kahoya recorded the highest (47.4%) incidences of hypertension followed by cardio-vascular diseases with 31.6%. Cancer and stroke had the lowest incidences of 15.8% and 5%, respectively.

Table 3. Relative concentration of heavy metals (mean ± SE) by each sampling zone in the soils within Eldoret Municipality compared with recommended levels

	Sampling site	**Metal concentration (mg/kg)**	**Recommended levels**
Zinc (Zn)	Juakali	1.6806 ± 0.0643	3.0mg/kg each site was below the observed level in unpolluted soils
	EATEC	1.7390 ± 0.0526	
	Yamumbi	1.5165 ± 0.1169	
	Kahoya	2.3700 ± 0.3014	
	Hawaii	1.6364 ± 0.0367	
Lead (Pb)	Juakali	0.6020 ± 0.0259	
	EATEC	0.6060 ± 0.0305	
	Yamumbi	0.6810 ± 0.0260	1.0mg/kg each site was below the observed level in unpolluted soils
	Kahoya	0.5600 ± 0.0228	
	Hawaii	0.6620 ± 0.0122	
Copper (Cu)	Juakali	0.2878 ± 0.0145	0.6 mg/kg each site was below the observed level in unpolluted soils
	EATEC	0.2540 ± 0.0192	
	Yamumbi	0.3492 ± 0.0091	
	Kahoya	0.2870 ± 0.0173	
	Hawaii	0.2758 ± 0.0150	
Chromium (Cr)	Juakali	0.7188 ± 0.0904	1.0mg/kg each site was below the observed level in unpolluted soils
	EATEC	0.4126 ± 0.0406	
	Yamumbi	0.5543 ± 0.0294	
	Kahoya	0.4232 ± 0.0129	
	Hawaii	0.2780 ± 0.0312[a]	
Cadmium (Cd)	Juakali	0.0298 ± 0.0011[a]	0.01mg/kg each site was above the observed level in unpolluted soils
	EATEC	0.0272 ± 0.0017[a]	
	Yamumbi	0.0385 ± 0.0026[c]	
	Kahoya	0.0196 ± 0.0011[a]	
	Hawaii	0.0298 ± 0.0014[a]	

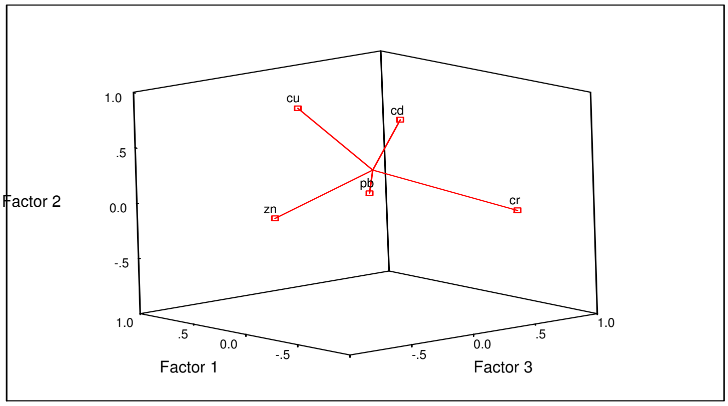

Figure 2. Factor extraction of metals accounting for observed causality for most diseases in Eldoret Municipality

Table 4. Total variance explained by the extracted factor loadings of metals causing observed diseases in Eldoret Municipality

Chronic Diseases	Metal	Eigen values (factor statistica) Extraction: Principal Components		
		Eigen Values	% total Variance	Cumulative %
	Zn	2.49*	49.83	49.83
	Pb	1.35*	27.01	76.83
Cancer	Cu	0.77	15.49	92.26
	Cr	0.34	6.82	99.08
	Cd	0.04	0.91	100
	Zn	1.92*	38.47	38.47
	Pb	1.49*	29.80	68.27
Hypertension	Cu	0.91	18.37	86.65
	Cr	0.49	9.811	96.46
	Cd	0.17	3.533	100
	Zn	2.27*	45.54	45.54
	Pb	1.73*	34.73	80.27
Stroke	Cu	0.70	14.06	94.34
	Cr	0.18	3.72	98.07
	Cd	0.09	1.93	100
	Zn	2.30*	46.02	46.02
	Pb	1.40*	28.12	74.13
Cardio-vascular	Cu	1.03*	20.60	94.74
diseases	Cr	0.19	3.84	98.59
	Cd	0.07	1.41	100

Total Eigen values marked with asterisk superscript (*) are significant at $\propto = 0.05$

Table 5. Cancer, hypertension, stroke and cardiovascular diseases associated with metals in Eldoret Municipality

Sampling zones	Diseases	Frequency (n=68)	Percentage
Juakali (n=20)	Cancer	3	4.3
	Hypertension	4	5.7
	Stroke	1	1.4
	Cardio-vascular diseases	12	17.1
EATEC (n=15)	Cancer	5	7.1
	Hypertension	6	8.6
	Stroke	3	4.3
	Cardio-vascular diseases	1	1.4
Yamumbi (n=8)	Cancer	4	5.7
	Hypertension	2	2.9
	Stroke	1	1.4
	Cardio-vascular diseases	1	
Kahoya (n=19)	Cancer	3	4.3
	Hypertension	9	12.9
	Stroke	1	1.4
	Cardio-vascular diseases	6	8.6
Hawaii (n=6)	Cancer	1	1.4
	Hypertension	1	1.4
	Stroke	2	2.9
	Cardio-vascular diseases	2	2.9

Finally, in Hawai, stroke and cardio-vascular diseases were prevalent with 33.3% each while cancer and hypertension had 16.7% each, respectively.

4. Discussion

4.1. Spatial and temporal variations of metals in the soils

Concentration of Zn in soils was significantly higher in Kahoya than other sampling sites possibly because of Raiply Kenya Ltd in close vicinity providing conditions necessary for the deposition of Zn containing compounds to the surrounding soils. Further, there are numerous non-point sources of pollutants including cattle dips, livestock and abattoirs, which can enhance increased levels of Zn into the soil. Moreover, the nearby River Sosiani may load Zn onto the soils when the banks spill over. According to Hsu and Lo (2001), river systems that have higher metallic loads are likely to increase the amount of heavy metals in their points of deposit. Generally, Pb exhibited low levels, which probably could be attributed to the parental rock type. However, significantly higher concentrations of Pb were recorded in Yamumbi and Hawaii as compared to other sampling zones. However, in comparison with other levels in the world, Pb were not very high (Nabulo, 2008), in the wetlands of Lake Victoria basin in Uganda, Katanga (51.2mg/kg), Butabika (30.7mg/kg), and did not exceed Pb concentration in unpolluted soils (Frink, 1996, Table 2). Besides the input from natural and anthropogenic sources, Pb distribution in soils could also be affected by several factors such as sediment chemical composition and diagenesis (Salmonns and Forstner, 1984).

The concentration of Cu in soils varied significantly among the sampled sites (Table 3). The elevated Cu concentration in Yamumbi could be as a result of pesticides and herbicides used in the farming activities. However, this elevated soil Cu concentration did not exceed the levels established in unpolluted soils (Frink, 1996, Table 2). Concentration of Cr in soils was high in Juakali followed by Yamumbi., but the concentration was below the recommended concentrations (Frink, 1996, Table 2). The concentration of Cd was significantly different between the sample sites. In this zone there is Rivatex factory whose mode of waste deposition could have contributed to the release of Cd into the environment from its effluents. Further, the use of fertilizers, batteries, fungicides, incineration of car tyres, rubber, iron roofs and motor oil, which contain Cd, could elevate the heavy metal in the soils causing soil Cd in all zones to exceed the recommended concentration (Frink, 1996).

4.2.Interrelationships among metals in soils

Correlations that could be linked to a common causal factor was not evident from the statistical analysis of the heavy metals in soils. According to the study findings, the presence of metals within Eldoret Municipality could account for the health risk to the residents. There is a clear relationship between the levels of metals and the occurrence of environmental related diseases. Juakali and EATEC reported high Pb and low Zn. Lowered Zn levels and high Pb have been reported (Goyer, 2004) to create conditions favourable for the development of cardiovascular and hypertension conditions. EATEC reported more case of high blood pressure followed by cancer and stroke (Table 5). These results are in line with Popko *et al*., (2003), findings indicating relationship between Pb, Zn concentration in relation to blood related disorders. Yamumbi reported high Cr and low Zn but reported higher cancer cases and hypertension. Kilic et al., (2004) reported low levels of Zn and Cr in patients with breast cancer in areas where the two were low.

Kahoya reported low Pb and high Zn in soils and reported more high blood pressure cases followed by cardiovascular diseases. Similar results were reported by Goyer (2004) that correlated elevated levels of Cd to hypertension condition. Hawaii with slightly high Pb and high Zn concentration in soils may explain the more cases of cardiovascular diseases and strokes. It has been shown that individuals who die from hypertension complications generally have greater concentration of Cd or higher ratios of Cd to Zn in their kidneys compared to those individuals who die from other diseases (Stoecker, 1999). Further, studies in North Wales and Cheshire, showed a positive relationship between the concentration of Zn, Co, and Cr and stomach cancer as reported by Stoecker, (1999). These findings agree with Ouyang and Li (2000), who noted that geochemical metals especially Cd and Pb could lead to increased environmental related diseases such as cardio-vascular diseases and cancer.

According to the PCA results, Zn, Pb, Cu, Cr and Cd concentrations in Eldoret Municipality determine presence of chronic diseases such as cancer, hypertension, strokes and cardiovascular diseases. Zn, Pb and Cu were associated with the diseases in the study area namely cancer, strokes, hypertension and cardio-vascular diseases. The Zn and Pb ratio is important in the body as it results in development of either cancer or hypertension or strokes. As such continued monitoring of Zn and Pb in the environment is important to reduce human exposure to minimize development of the chronic disease.

5. Conclusion

There exist spatial variations in concentrations of heavy metal in the soils within Eldoret Municipality. This could be attributed to the increasing human activities within and outside the municipality as well as the nature of the parent rock. However, the contribution of anthropogenic pollution from both the industrial activities and farming practices could not be established. The anthropogenic effect of metals in the environment is minimal with the exception of Cd in soils which were slightly higher than the accepted levels recommended by WHO and by other studies. Soils in agricultural areas contain high Cd and recommended is the use of alternative forms of fertilizers and fungicides. Residents within the municipality have greater health risks arising from elevated levels of heavy metals. Education and awareness is imperative to sensitize the residents about the dangers of ingesting heavy metals.

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