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LEVELS OF HEAVY METALS IN NAKURU TOWN, KENYA AND THE SURROUNDING FARMLAND SOILS

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Abstract

Purpose: The purpose of the study was to investigate the concentration levels of total and extractable selected heavy metals such as Cadmium (Cd), Chromium (Cr), Copper (Cu), Nickel (Ni), Lead (Pb), and Zinc (Zn) in soils of Nakuru town and the surrounding farmlands. In addition, soil chemical properties such as pH, % organic carbon and cation exchange capacity were also determined.

Methodology: The study area was divided into two sampling sections, the town area being within 2 Km from the town center and the surrounding farmlands being those beyond 2 Km from the town center. From each section eight (8) sampling sites were established based on their activities and the samples collected in triplicate. The samples were air-dried, crushed, sieved, and stored at ambient temperature before analysis. The soil suspension was used to measure pH (potentiometric method) and the cation exchange capacity (ammonium acetate method), and the organic carbon was determined using oxidation-titration method. The potentially extractable heavy metals were extracted using EDTA method and total heavy metals extracted using digestion method and the concentration estimated using an atomic absorption spectrophotometer. The data obtained from the experimental analysis were subjected to descriptive statistics to get the mean concentration levels.

Results: The results obtained for total content in town soils were, 0.44-1.03 mg/Kg Cd, 0.88-2.24 mg/Kg Cr, 1.61-2.73 mg/Kg Cu, 0.92-2.00 mg/Kg Ni, 0.61-1.49 mg/Kg Pb and 0.21-0.46 mg/Kg Zn while the total content in the surrounding farmland were, 0.26-1.39 mg/kg Cd, 0.59-1.65 mg/Kg Cr, 0.91-4.39 mg/Kg Cu, 0.58-0.83 mg/Kg Ni, 0.50-0.83mg/Kg Pb and 0.11-0.31 mg/Kg Zn indicating higher content in town soils. Extractable heavy metal content levels in town soils were 0.12-0.74 mg/Kg Cd, 0.06-1.10 mg/Kg Cr, 0.76-1.55 mg/Kg Cu, 0.25-0.83 mg/Kg Ni, 0.17-0.11 mg/Kg Pb and 0.07-0.18 mg/Kg Zn, and those from the surrounding farmland soils were, 0.07-0.59 mg/Kg Cd, 0.30-0.59 mg/Kg Cr, 0.61-1.55 mg/Kg Cu, 0.25-0.42 mg/Kg Ni, 0.17-0.33 mg/Kg Pb and 0.04-0.12 mg/Kg Zn indicating the same trend as for the total content. The chemical properties such as pH, % organic carbon and cation exchange capacity in town soils were 6.02-6.92, 0.84-2.3 and 8.13-26 respectively while in surrounding farmland, 5.3-6.65, 0.81-2.3 and 3.9-14 respectively.

Unique contribution to theory, practice and policy: There is need for environmental quality assessment of heavy metal-contaminated soils to disclose the effects of human activities on the environment which will provide the critical information for sustainable development of the limited soil resource. There is need for geochemical studies to create an extensive database of heavy metal background values that can be used for the evaluation of environmental quality.

Keywords: *Total heavy metals; Extractable heavy metals; Chemical properties; Accumulation; Pollution*

1.0 INTRODUCTION

Urbanization in many cities across the developing world can be viewed as a typical phenomenon of economic growth and industrial advancement (Chen *et al*., 2014). In this manner, the increasing rate of urbanization continues to be a concern due to the impact of anthropogenic activities on urban and suburban soil (Wei & Yang, 2010). Urbanization and industrialization have changed the urban and suburban ecosystems and the soil is an important component of these systems (Jackson & Kulecho, 2008). The original structure and properties of soil have been deeply modified, and new soils with particular characteristics have been created (Rosenbaum *et al*., 2003). In the recent past much research has been done on urban and suburban soils including: (1) the studies on the distribution of heavy metals and their functional roles along industrialization gradients within single cities; (2) the possible different sources for the enrichment of heavy metals in soils; and (3) the bioavailability and toxicity of heavy metal in soil, in food chains via plant uptake, and the human health risks and control measures of soil heavy metal pollution (Wuana, & Okieimen, 2011). However, these studies have focused mainly on limited locations, particularly in urban and suburban areas or major pollution sources ((Wei & Yang, 2010). In contrast, there are few extensive surveys on heavy metal distributions in soils along an urban-suburban gradient, especially in agricultural soils (Kapungwe, 2013).

Excessive accumulation of heavy metals in soils, especially in urban and suburban soils may not only result in environmental contamination, but elevated heavy metal uptake by crops thus affecting food quality and safety (Singh *et al*., 2010). Owing to rapid economic development, heavy metal contamination of urban and suburban soils has also become increasingly serious in Kenya (Ngure *et al*., 2013; Mungai *et al*., 2016). Since substantial amount of food that is consumed in the cities is to a great extend contributed by urban and suburban soils, the potential risk indicates that there is an urgent need to conduct further studies into heavy metal contamination of urban and suburban soils. Most of soil heavy metals come from industrial or agricultural sources. The study was aimed at investigating the levels of heavy metals, Cadmium (Cd), Chromium (Cr), Copper (Cu), Nickel (Ni), Lead (Pb), and Zinc (Zn) in the urban–suburban soils of Nakuru town in Kenya.

2.0 MATERIALS AND METHODS

2.1. Study sites

The study area (0.30310S 36.08000 E) is within a closed drainage system of 1800 Km^2. Lake Nakuru national park lies in the depression of this catchment basin acting as a buffer zone between human activities and the Lake. The geology of the study area is made up of igneous rocks (volcanic) and the soil having high porosity, permeability and loose structure (Mavura, & Wangila, 2003). The study area occupies 290 Km^2, 70% being dominated by housing, 18% industry and commerce and the rest is intensive farming (Raini, 2009).

2.2. Sampling and test methods

The study area was divided into two sampling sections, the town area being within 2 Km from the town center and the surrounding farmlands being those beyond 2 Km from the town center. From each section eight (8) sampling sites were established based on their activities. Soil samples of approximately 10, 10, 15 cm (length, breadth, and depth values respectively) in triplicate were collected using a stainless steel soil auger. The samples were then air-dried, crushed, passed through a 2-mm-mesh sieve, and stored at ambient temperature before analysis in the laboratory. A soil suspension of 1:5 soil to water ratio was used to measure pH (potentiometric method and the cation exchange capacity (ammonium acetate method) (Sharama *et al*., 2007; Hendershot *et al*., 1993).). The organic carbon was determined using oxidation-titration (Walkley and Black) method (Page *et al*., 1982; Yeomans, & Bremner, 1988). The potentially available heavy metal was extracted using EDTA method and total heavy metals extracted using digestion (aqua regia) method and concentration estimated using an atomic absorption spectrophotometer (Khalkhaliani *et a*l., 2006; Güven, & Akinci, 2011). The data from the experimental analysis were subjected to descriptive statistics to get the mean concentration levels (SAS Version 9.1).

3.0 RESULTS AND DISCUSSION

3.1 Chemical properties levels

The mean levels of soil chemical properties in Nakuru town and the surrounding farmland soils were calculated statistically and are shown in Table 1.

Table 1: Mean levels of Chemical Properties in Nakuru Town and the surrounding Farmland soils

Site		Town			Farmland		
		pH	OC	CEC	pH	OC	CEC
1	Mean	6.87	1.42	12.02	5.41	2.07	8.02
	SD	0.02	0.01	0.04	0.02	0.07	0.03
2	Mean	6.92	1.26	22.08	5.32	2.13	12.02
	SD	0.05	0.02	0.04	0.03	0.02	0.04
3	Mean	6.56	1.85	26.02	5.41	2.32	12.0
	SD	0.02	0.02	0.03	0.03	0.03	0.02
4	Mean	6.50	2.27	18.03	5.73	1.27	9.96
	SD	0.02	0.02	0.02	0.02	0.02	0.02
5	Mean	6.21	2.26	8.13	5.77	0.99	3.94
	SD	0.02	0.02	0.02	0.02	0.03	0.06
6	Mean	6.72	0.84	14.65	6.02	0.82	14.02
	SD	0.04	0.02	0.02	0.04	0.03	0.04
7	Mean	6.02	2.32	12.05	5.64	1.59	5.97
	SD	0.04	0.03	0.015	0.02	0.02	0.02
8	Mean	6.53	2.017	13.02	6.65	0.96	8.01
	SD	0.04	0.04	0.04	0.02	0.01	0.03

SD- standard deviation.

Soils of Nakuru town ranged from 6.02 to 6.92 or slightly acidic (6.1-6.5), to neutral (6.6-7.3) based on grading (Charman,., & Murphy, 1993). This condition might have risen from increasing human modification of soils whereby the soils become more compacted and less acidic due to the liming effect of concrete, which is more prevalent here as in heavily developed town soils (Hagan *et al*., 2012). The mean soil pH in the farmland soils ranged from 5.32 to 6.65, a moderately acidic condition. The use of acidified fertilizers in soil has been known to raise the relative amounts of H^+ ions on the surface charges of the soils hence making the soils acidic which could be the case.

The mean percentage organic carbon (% OC) level in town soil ranged from 0.84% to 2.32% and the source could be waste disposal that input organic matter in soil. Studies have shown that the amount of organic carbon content in soil is influenced mostly by the amount of organic matter (Rattan, *et al*., 2005). The mean percentage organic carbon (% O.C) content of the farmland soils ranged from 0.82% to 2.32%. These results suggest that organic carbon content may be due to agricultural activities, including addition of compost manure into the soil (Hagan *et al*., 2012). The mean cation exchange capacity (CEC) levels for the soils in the town ranged from 8.13 to 26.02 (cmol/ Kg). CEC in the soil is dependent on the amount of organic matter and soil pH. (Gascó, &

Lobo, 2007).). The mean cation exchange capacity (CEC) values in the farmland soils ranged from 3.94 to 14.02 (cmol/ Kg). This also dependent on the amount of organic matter and soil pH.

3.2. Heavy metal levels

3.2.1 Total heavy metal content

In table 2 the mean concentration levels of the total heavy metal content in the town and the surrounding farmland soils are presented. Cadmium mean concentration levels in Nakuru town soils ranged from 0.4390 to 1.033 mg/kg. The observed results from the study area in relation to other research work were above the expected naturally occurring levels of (0.1-0.3 mg/kg) and the distribution is in agreement with observations from other urban areas in the world that range from 0.06 to 1.1 mg/kg (ATSDR, 2005). In addition to soil make up and the parent rock material of a particular area, paint peels and pigments from many buildings, and atmospheric deposition from industrial activities can contribute to total Cd content (Campbell *et al.*, 2006; Environment Agency, 2002). Anthropogenic activities, including vihecular emissions and burning of garbage from Nakuru town cannot be ignored (Nguta, & Guma, 2004; Jackson & Kulecho, 2008).The mean concentration of total Cadmium content in the farmland soils ranged from 0.2553 to 1.3940 mg/kg which is slightly above the background range (0.06-1.1 mg/kg) found in most uncontaminated soils of the world (ATSDR, 2012). The amounts of Cd in soils from farmlands are due to use of phosphatic fertilizers, pesticides and other farming activities that are a source of Cd input in the soil (Environment Agency, 2002; ATSDR, 2005).

Chromium in town soils ranged from 0.8823 to 2.2350 mg/kg as compared to 0.5880 to 1.6470 mg/kg found in the surrounding farmland soils. Both of these values lie well below the world average of (37.0 mg/kg) Cr in soils (ATSDR, 2012). It is attributed to natural causes with evidence of anthropogenic activities explaining the higher town values and are in agreement with a study of Nakuru soils carried out by Jackson & Kulecho, 2008.

Copper ranged from 1.6060 to 2.7270 mg/kg in town sites while in farmland soils ranged from 0.9090 to 4.3940 mg/kg. Both results indicate that copper in town soils was below the world average range of (20-50 mg/kg) for urban area soils and below the range (20-30 mg/kg) found in uncontaminated soils (ATSDR, 2012). The mean values were below the maximum permissible levels or limits of 100.00 mg/kg and it suggests that apart from the naturally occurring levels, activities that contribute to Cu input such as dumping or accumulation of solid waste in town soil are minimal compared to other urban areas of the world (Environment Agency, 2002; Wei & Yang, 2010). Copper in farmland soils was low compared to levels from other parts of the world meaning its natural distribution is low in this area and that the inputs of Cu here are minimal (Kapungwe, 2013).

Nickel mean concentration levels in town soils ranged from 0.8333 to 2.0000 mg/kg. The average nickel content in soils is 20 mg/kg especially in soils derived from igneous rocks and therefore the results are within the observed range (Oladele *et al*., 2011.). Apart from Ni coming from the parent rock material, domestic cleaning products that contain Ni as part of their composition e.g. soaps and powdered detergents are known to add Ni in town soils as observed from the results (Kabata-Pendias, 2000). The total nickel content in the farmland soils ranged from 0.5833 to 0.8333 mg/kg. Though the total content of nickel as observed from the study is within the average of uncontaminated soil (20 mg/kg), its presence in the soil is influenced by the underlying geology and soil forming processes (Kabata-Pendias, & Mukherjee, 2007).

The lead concentration levels in town soils ranged from 0.6113 to 1.4867 mg/kg, while that from farmland soils ranged from 0.4960 to 0.8313 mg/kg. Both these values were below the range of uncontaminated soils of 13 to 20 mg/kg as observed by Kabata-Pendias, & Mukherjee, (2007). The results are indicative of low natural levels from parent rock materials in comparison with levels from other parts of the world where the use of lead formulated paints and automobile emissions are a major source of Pb into soil (Environment Agency, 2002).

Zinc in town soils ranged from 0.2093 to 0.4640 mg/kg as compared to that from farmland soils which ranged from 0.1060 to 0.3107 mg/kg. Naturally occurring Zn on average is 64 mg/kg and the results obtained in this work indicate that the content of zinc is very low in this area (Emsley, 2011). The slight variation from town to the farms soils indicated zinc was due to anthropogenic activities unlike in most developed countries, where the observed Zn levels are high due to its industrial use (Cheng, 2003).

3.2.2 Extractable heavy metal content

Table 3 below shows the mean concentration levels of extractable (easily available) heavy metal contents in town and the surrounding farmland soils. It was observed that extractable cadmium in town sites ranged from 0.1167 to 0.7390 mg/kg while in the farmland ranged from a value of 0.0667 to 0.5947 mg/kg. The observed amounts of Cd in both places were low and below the 0.06 to 1.1 mg/kg range found in uncontaminated soils (ATSDR, 2012). Extractable chromium content in town soils ranged from 0.0590 to 1.0980 mg/kg while that from the farmland soils ranged from 0.3010 to 0.5880 mg/kg. These results supported previous data finding that chromium is not very mobile in soil, especially in the trivalent oxidation state (Sahuquillo *et al*., 2003).

Extractable copper ranged from 0.7573 to 1.5457 mg/kg in town while that from the farmland soils ranged from 0.6057 to 1.5453 mg/kg. The observed results were low in comparison to those of uncontaminated soil (20-50 mg/kg) and above maximum permissible levels (0.2 mg/kg) in city soil solution (Environment Agency, 2002; ATSDR, 2005). Though the source of Cu is diverse, the variation observed could also be due to partitioning between the soil solution and the soil solid phase (Cornu *et al*., 2007). Extractable nickel in the town soils ranged from 0.2500 to 0.8333 mg/kg compared to a range of 0.2500 to 0.4167 mg/kg in the farmland and were above the maximum permissible levels in soil solution (0.2 mg/kg) (Environment Agency, 2002; ATSDR, 2005). As indicated by many studies, the type of the soil and amount of organic matter affects Ni solubility (Kabata-Pendias, & Mukherjee, 2007; Wuana & Okieimen, 2011).

Extractable lead in the town soils ranged from 0.1663 to 0.6113 mg/kg while that from farmland soils ranged from a mean value of 0.1660 to 0.3330 mg/kg. The observed results were low in comparison to maximum permissible levels of 5.0 mg/kg in soil solution (Environment Agency, 2002; ATSDR, 2005). Studies have shown that chemical properties have an effect on availability as it is held by the soil colloids (Cornu *et al*., 2007). Extractable zinc in the town soils ranged from 0.0693 to 0.1757 mg/kg and from 0.0417to 0.1177 mg/kg in farmland soils. Observation from many research work have shown that zinc is one of the most abundant metals in everyday use as

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well as in urban waste but from these results there is a suggestion that Zinc is bound tightly and very little goes into the soil solution (Mule, & Nguta, 2009).

Table 2: Mean Concentration levels of Total Heavy Metal in Nakuru town and the surrounding Farmland soils

		Town						Farmland					
Site		**Cd**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**	**Cd**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**
1	Mean	0.70	2.24	2.70	2.00	1.49	0.27	0.42	0.61	1.64	0.67	0.61	0.18
	SD	0.06	0.06	0.19	0.25	0.02	0.01	0.03	0.09	0.09	0.14	0.10	0.02
2	Mean	1.03	1.06	1.61	1.50	0.61	0.32	0.58	1.00	2.42	0.83	0.56	0.31
	SD	0.06	0.06	0.14	0.25	0.10	0.00	0.02	0.06	0.19	0.14	0.10	0.00
3	Mean	0.72	1.59	1.79	1.75	0.72	0.27	0.73	0.84	1.73	0.58	0.61	0.15
	SD	0.06	0.06	0.22	0.25	0.10	0.01	0.03	0.07	0.09	0.14	0.10	0.00
4	Mean	0.76	1.06	1.73	0.92	0.89	0.23	0.92	1.08	1.67	0.58	0.56	0.13
	SD	0.05	0.06	0.09	0.14	0.10	0.01	0.02	0.03	0.11	0.14	0.10	0.01
5	Mean	0.72	0.88	1.61	1.17	1.17	0.26	0.84	0.88	0.91	0.58	0.83	0.17
	SD	0.04	0.06	0.11	0.14	0.00	0.02	0.03	0.06	0.09	0.14	0.00	0.01
6	Mean	0.48	1.65	2.73	1.08	1.00	0.46	0.91	1.65	2.58	0.75	0.50	0.12
	SD	0.03	0.06	0.18	0.14	0.17	0.01	0.03	0.06	0.10	0.25	0.01	0.00
7	Mean	0.44	1.73	1.73	0.83	0.72	0.21	1.39	0.59	2.61	0.67	0.50	0.11
	SD	0.03	0.12	0.09	0.14	0.10	0.01	0.04	0.06	0.05	0.14	0.00	0.01
8	Mean	0.63	1.12	2.52	1.08	1.11	0.32	0.26	1.10	4.39	0.83	0.67	0.16
	SD	0.11	0.06	0.19	0.14	0.11	0.01	0.02	0.09	0.11	0.14	0.00	0.01

SD- standard deviation.

Table 3: Mean Concentration levels of Extractable Metal in Town and the surrounding Farmland soils

Site		Town						Farmland					
		Cd	Cr	Cu	Ni	Pb	Zn	Cd	Cr	Cu	Ni	Pb	Zn
1	Mean	0.20	1.10	0.76	0.42	0.61	0.07	0.24	0.30	0.79	0.25	0.17	0.07
	SD	0.02	0.09	0.05	0.14	0.10	0.01	0.03	0.01	0.05	0.00	0.00	0.00
2	Mean	0.74	0.75	1.55	0.83	0.17	0.09	0.17	0.45	0.88	0.33	0.33	0.09
	SD	0.03	0.03	0.64	0.14	0.00	0.00	0.02	0.03	0.11	0.14	0.00	0.00
3	Mean	0.22	0.65	0.88	0.50	0.39	0.07	0.34	0.59	0.73	0.25	0.17	0.12
	SD	0.02	0.06	0.14	0.25	0.10	0.00	0.02	0.06	0.09	0.00	0.00	0.00
4	Mean	0.33	0.51	0.82	0.42	0.39	0.13	0.40	0.59	0.73	0.25	0.17	0.05
	SD	0.02	0.03	0.09	0.14	0.10	0.00	0.02	0.06	0.09	0.00	0.00	0.00
5	Mean	0.30	0.4	0.82	0.58	0.49	0.15	0.42	0.47	0.61	0.25	0.33	0.05
	SD	0.02	0.06	0.09	0.14	0.02	0.01	0.03	0.06	0.05	0.00	0.00	0.00
6	Mean	0.22	0.06	0.76	0.58	0.49	0.18	0.43	0.57	1.55	0.25	0.17	0.04
	SD	0.02	0.00	0.05	0.14	0.01	0.00	0.12	0.07	0.09	0.00	0.00	0.00
7	Mean	0.12	0.47	0.91	0.42	0.17	0.08	0.59	0.37	1.00	0.25	0.33	0.08
	SD	0.02	0.06	0.09	0.14	0.00	0.01	0.03	0.03	0.09	0.00	0.00	0.01
8	Mean	0.26	0.59	1.36	0.25	0.33	0.13	0.07	0.59	1.36	0.42	0.17	0.06
	SD	0.03	0.06	0.09	0.00	0.00	0.00	0.02	0.06	0.09	0.14	0.00	0.01

SD-Standard deviation

4.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

4.1 Summary

In summary the pH values, amounts of organic carbon contents and cation exchange capacity of town soils were generally higher than those of farmland soils. The complex nature of town soils is known to affect its chemical properties making it significantly different from farmland soils (Sekwakwa, & Dikinya, 2012). The wearing of concrete surfaces, use of cement, peeling of paints and many other factors is known to lime the soils thus affecting the organic matter content (Hagan *et al*., 2012). The results obtained from this study suggest that heavy metals can accumulate in town soils over time thus resulting in soil pollution. In the farmland soils, the chemical properties suggest that heavy metals can easily go into soil solution which is an immediate hazard unlike in town soils (Violante *et al*., 2010).

The results observed indicated the presence of heavy metals in the soils (Cheng, 2003; Nguta and Guma, 2004). The levels were low suggesting natural content that originate from the parent rock material, but it is also possible that anthropogenic activities both in town and the farmland such as industrial and automobile emissions, peeling of paints and building debris, and the use of phosphatic fertilizers, pesticides, herbicides and other soil ameliorants could be an attributing factor to the total content levels observed (He *et al*., 2005; Kabata-Pendias and Mukherjee, 2007). Easily extractable heavy metals in soil solution were observed though in small quantities and therefore much of it is held tightly by the soil colloids. Though the observed amounts were low, they can be hazardous when taken up by plants, washed away easily by runoff water into rivers hence endangering the aquatic life or leaching into aquifers thus contaminating drinking water (Nabulo, 2006).

4.2 Conclusion

Heavy metals were detected in both town and farmland soils. The metal contents levels whether in total form or easily extractable form could be the naturally occurring content coming from the parent rock material though anthropogenic activities could not be ruled out as a source loading the heavy metals in the soils. The mean concentration levels as observed were low both in town and the surrounding farmland soils as compared to maximum permissible levels and therefore they were not significant. Though there was a slight variation in chemical properties from town to the surrounding farmland, the levels were average and therefore they could favor the accumulation of heavy metals over time which could lead to soil pollution (Violante *et al*., 2010; Hagan *et al*., 2012).

4.3 Recommendations

Environmental quality assessment of heavy metal-contaminated soils to disclose the effects of human activities on the environment which will provide the critical information for sustainable development of the limited soil resource. Geochemical studies to create an extensive database of heavy metal background values that can be used for the evaluation of environmental quality. Establish appropriate geochemical backgrounds based on the soil and site specific criteria and soil quality standards to guide assessment and remediation of soil environment. Establish ecological risk assessment.

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