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RESEARCH ARTICLE

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Health Exposure and Ecological Risk Assessment of Cadmium and Lead in Agricultural Soil in Uasin Gishu, Kenya

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Abstract

Increased industrialization, agrochemicals, polluted irrigation water and atmospheric deposition are foremost sources of toxic metals accumulation in proximate agricultural soil. In Kenya, prolonged mono-cropping and farm amendments enhance cadmium and lead accretion in the environment. Hence, understanding anthropogenic activities in the study areas is crucial as human exposure to any level of Lead and Cadmium is unsafe. To evaluate potential impacts of these metals, soil samples were randomly collected from farms in the study areas and analyzed for contamination and ecological health risk using standard procedures. The levels of Cd:Pb in the soil were 0.12:24.84, 0.06:16.46, 0.13:33.29, and 0.13:35.89 for Kaprobu, Kosyin, Moiben, Naiberi and Ziwa, respectively. Cadmium and Lead concentrations exceeded World Health Organization allowable limits of 0.003 mg/kg and 0.1 mg/kg in agricultural soil, but were within limits of United States Environmental Protection Agency, 0.48 mg/kg and 200 mg/kg respectively. The computed Hakanson's potential ecological risk index (E_{ri}) indicates low to moderate risk of Lead. This is possibly due to intense agricultural activities in the areas and atmospheric deposition. It is concluded that excess use of fertilizer and pesticide aggravates toxic metals in agricultural soils. Recommendation is made to lower agrichemical inputs and regularly monitor soil health to reduce human exposure and health risks.

Keywords: Toxic Metals, Contamination, Ecological Hazard, Toxicity, Human Health

INTRODUCTION

Heavy (Toxic) metals pollution in urban and agricultural soils has presented thoughtful environmental concerns over the years in many areas (L. Zhang et al., 2018). There are several indices-single and complex, toxic metals pollution assessment tools in different environmental matrices-water, air, sediment, and soil. Widely use indices include Geo-accumulation index (Igeo), enrichment factor CEF), risk index (RI) and contamination security index (CSI) that give detailed insight of toxic metals pollution (Kowalska et al., 2018).

Excessive toxic metals pollution in agricultural soils potentially affects quality farm food production. Long use of metal laden inorganic fertilizers and pesticides increase heavy metal concentrations in farmlands that are subsequently transfer into food crops (Kelepertzis, 2014). Also, dumpsite, sewage, and industrial wastes are often loaded with high levels of toxic metals that spread to the environment through irrigation, erosion and flooding (Opaluwa et al., 2012). High amounts of toxic metals such as Cadmium (Cd), Lead (Pb), Mercury (Hg) and Arsenic (As) present health risk to exposed human and plants populations through soil, air, water and sediment within the ecosystem. Toxic metals exposure prompts neurotoxicity impairments and morphological deformation in bodily parts development in children (Rahman et al., 2019). Soil microbial community is also significantly impacted by toxic metals pollution. Increased toxic metals contamination affects soil microbial diversity, population and bioactivity (Xie et al., 2016).

Lead is one of the toxic metals that naturally occurs in the earth crust that causes harm to human, especially children who are exposed. Although , it is found in the environment naturally but mechanized farming, uncontrolled industrial effluents, and atmospheric deposition from CO_2 emissions are primary anthropogenic sources that have increased Pb concentration levels in soil and dust within the ecosystem (Chaney et al., 1996). Also, exposure to lead-based décor paints and leaded fuels is weighty source of lead in the environment. Lead-based paint dust together with soil lead are common causes of increased lead blood levels and lead poisoning in children as well as the environment (Mielke et al., 1998). Increased Pb levels in the environment poses health threats to human being and other organisms as results of gradual accumulation into bodily tissues and organs from food chain. Thus, efforts are being made to minimize human exposure through various remediation technologies to reduce future pollution of the metal (Li et al., 2019).

Cadmium, on the other the hand, is a naturally occurring toxic metals found in soils, rocks and marine shales. It is carcinogenic and mostly less abundant compared to other toxic metals in the environment. In many cases, it accumulates gradually into the environment and agricultural soils from anthropogenic sources smelting, agrochemicals, sewage slurry, from whence it subsequently gets into the food chain (Thornton, 1992). Other sources of cadmium pollution in the environment include wastes disposal, volcano emissions, steel and zinc production (Hutton, 1983). Elevation of Cd levels in environment can also affect groundwater sources for human consumption. It is easily mobilized and can formed complexes transportable in aquatic environment (Kubier et al., 2019).

MATERIALS AND METHODS

Study Area

Soil samples were collected from selected farms in Kaprobu, Kosyin, Moiben, Naiberi and Ziwa, Uasin Gishu County, Kenya. Soil samples were randomly taken from four locations in each farm at the depth of 30 cm below the surface and subsampled. Uasin Gishu County is located in high plateau, about 1500 to 2700 meters above sea level; relatively cool with annual mean temperature below 21^0C. The area receives about 1000 to 1250 millimeter of rainfall per annum (MoALF, 2017). Its area is found within the productive highlands of Western Kenya, predominantly inhabited by farmers (Lomurut, 2014). The county is one of the highest producer of milk in Kenya, producing about 70%, 20% and 10% for subsistence, semi-marketable and marketable farmers, respectively (Kembe et al., 2016).

To evaluate the ecological risk and assess human health threats associated with toxic metal levels in soil samples from the study areas, Hakanson's ecological risk index was used (Hakanson, 1980). The pollution index (equation) was originally used to evaluate toxic metals physiognomies and environmental patterns in sediments. The quantitative method assesses possible contamination effects of toxic metals in ecosystem. It catalogues and isolates single and multiple contaminants effects on given environment from different probable hazards (Wang et al., 2013).

1. $C_{f=} {C_n}/{B_n}$ ---------------Equation 1

2. $Eri = \sum E(i) = \sum Ti\, x \frac{Ci}{Coi}$, where $\frac{Ci}{Coi}$ is Cf, hence $ERI = \sum Ti\, x\, Cf$---- -Equation 2

From the above equations, Cf =Contaminator Factor of the individual element; RI is the Ecological Risk Index, C_n is metal concentration in the soil at sampling sites; B_n is metal concentrations in background (preindustrial) soil; and T_i is the toxic response factor of toxic metals in the soil. There are several other indices use to measure toxic metals ecological and environmental health risks and exposure from different media. Commonly use indices include Contamination Factor, Contamination Degree, Geo-Accumulation Factor, Ecological Risk Index amongst others (Weissmannová et al., 2017).

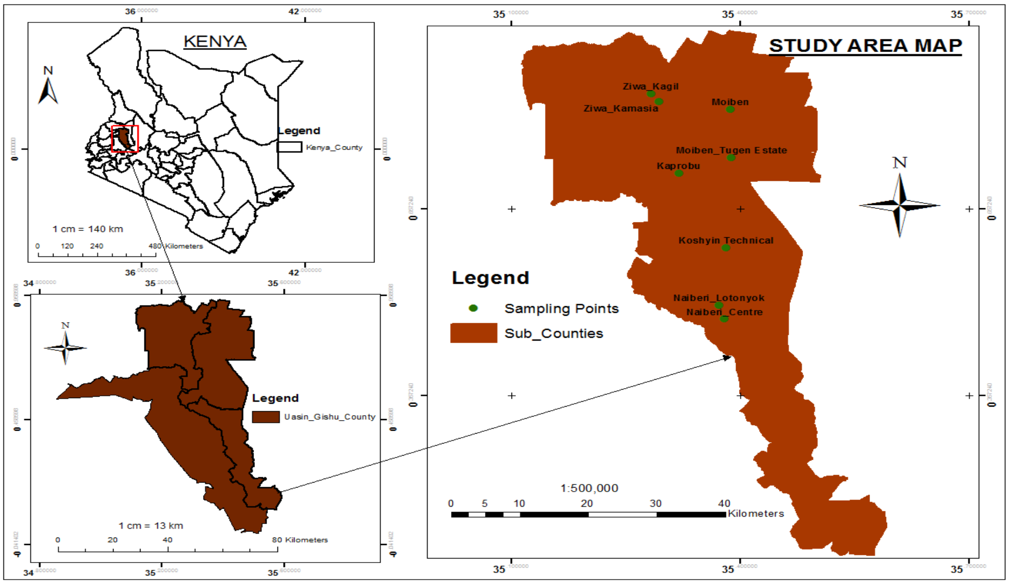

Figure 1: Study area showing sampling dotted in green colors.

Samples Preparation and Analysis

The samples were air-dried, crushed and filtered through a 250-um sieve. The samples (per farm) were homogenized and subsampled for analysis. To determine total toxic Metals-Cd and Pb concentrations, about 0.5 g of pulverized soil sample each was digested by gradually adding 9 mL, 1mL and 4mL of concentrated HNO_3, HCl, and $HClO_4$, respectively to the soil sample and transferred into ultra clean and dry inert polymeric reaction vessel under a fume hood. The mixture is left under the hood for a while to allow complete reaction of the solution before sealing the vessels. The vessels are placed on the rotor into a microwave assisted digester. Upon complete digestion, the samples are cooled, transferred into 250 mL volumetric flask filled to the mark using deionized water and the samples are ready and taken for analysis by means of ICPMS (Agilent 7900).

RESULTS

Physicochemical Analysis of Soil Samples

The physicochemical properties of the sampled agricultural soils include electrical conductivity, pH, total organic matter (TOC), cation exchange capacity, and texture class were determined using conventional methods (Figure 2). The soil pH recorded ranges from 4.04 to 5.43 with a mean of 5.20 indicating soil acidosis. Mean TOC, 2.57% established presence of organic matters and existence of microbial activities in the soil. The pH and TOC play pivotal role of metals and nutrients availability, distribution and uptake by plants in soils (Solis et al., 2005).

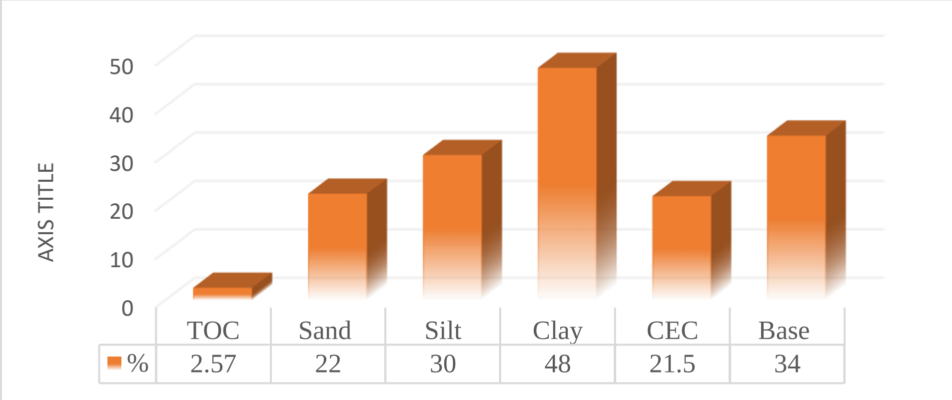

Figure 2: Physicochemical parameters of the Soil.

Heavy Metals in Soil Samples

The finding in Table 1, showed toxic metals –Cd and Pb concentrations (mg/kg) in soils from the study areas are within range of a review study on potentially toxic elements (PTEs) monitoring in East Africa agroecosystems. The elements reviewed focused on Hg, Cu, Cd, Zn, Pb, and Cr that are most probably sourced from use of agrochemicals (Munishi et al., 2021). A similar study of Cd, Pb, Zn, Cu, Cr, As, Hg, and Ni in agricultural soils Kenya also reported comparable concentrations of metals (Mungai et al., 2016).

Table 1: Concentrations of pH, Cd (mg/kg) and Pb (mg/kg) in Soil Samples

Site	**pH**	**Cd (mg/kg)[a,b]**	**Pb (mg/kg)[a,b]**
Kaprobu	4.86 ± 0.56	0.12 ± 0.02	24.84 ± 1.13a
Kosyin	4.20±0.00	0.06 ± 0.00	16.46 ± 0.00a
Moiben	4.62 ± 0.01	0.13 ± 0.06	33.29 ± 8.45a
Naiberi	4.41 ± 0.23	0.08 ± 0.02	29.55 ± 3.64a
Ziwa	4.68 ± 0.12	0.12 ±0.13	35.89 ± 2.71
tmean	4.54 ± 0.31	0.10 ± 0.03	28.72 ± 7.59

a Toxic metals (Cd & Pb) exceeding WHO allowable limits in agro soil
b Toxic metals (Cd & Pb) within USEPA allowable limits in agro soil

A general description of the data (Table 2) and analysis of variance (ANOVA) gave summary of the dataset. It was found that at minimum pH 4.04, the concentrations of Cd, 0.05 and Pb, 16.46 were lower, whereas at higher pH 5.43, the concentration for Cd and Pb were higher, 0.19 and 43.32, respectively. Thus, it is widely accepted that low pH enhances increased heavy metals concentrations. But this finding is supported by other previous studies that concluded heavy metals concentration and availability in soils are greatly influence by soil pH (Khaledian et al., 2017; Mao et al., 2019) that From Table 2, it was found that there is no significant different among the pH, Cd, and Pb of the 40 soil samples collected from 10 farms within the study areas.

Table 2: Combined ANOVA and Descriptive Statistics Table

	min	**max**	**mean**	**Std**	**Sum of Squares**	**df**	**Total Square**	**F**	**Sig**
$Site_n$=10	1	5	3.20	1.48	---	---	---	---	----
pH	4.04	5.43	4.58	.39	1.37	9	0.29	0.56	.70
Cd	0.05	0.19	0.11	0.04	0.02	9	0.01	0.88	0.54
Pb	16.46	43.32	29.32	8.56	6558.85	9	147.95	1.21	0.41

Potential Ecological Risk Index

Calculated Potential Ecological Risk Indices for the study area are summarized and presented in Tables 3 and 4 below**.** The Hakanson's indexing method follows equations 1 and 2 above calculating procedures and are interpreted as indicated in Table 3. Though the selection of reference soil values differs significantly, with some studies considering means of toxic metals contain in sediments and shale, whereas other studies adopt recognized national soil standard and environmental screening (Wang et al., 2013; Weissmannová et al., 2017). However, the Hakanson followed preindustrial levels of toxic metals in soil and was adopted in this study.

Table 3: Single Element Contamination Factor with Corresponding Potential Ecological Risk Indices

Value Index	Contamination Factor	Value Index	Risk Status
$C_f < 1$	Low C_f	$E_{ri} < 40$	Low E_{ri}
$1 < C_f < 3$	Moderate C_f	$40 \leq E_{ri} < 80$	Moderate E_{ri}
$3 < C_f < 6$	Considerable C_f	$80 \leq E_{ri} < 160$	Considerable E_{ri}
$6 \geq C_f$	Very High C_f	$160 \leq E_{ri} < 320$	High E_{ri}
		$E_{ri} \geq 320$	Very High E_{ri}

Toxic metals, Cd and Pb concentration levels (Table 2) showed that both elements concentration levels exceeded WHO allowable limits in agricultural soil. The single factor contamination of element ranged from 2.35 to 12.66 and 0.06 to 0.26 for Pb and Cd, respectively in the study areas; and with mean of 0.21 and 8.37 indicating considerable contamination with respect to Pb>Cd. For the site, the potential ecological risk index: 70.80, 58.80, 53.35, 42.35 and 13.55 with mean of 47.77 representing **NAIBERI>ZIWA>MOIBEN>KAPROBU>KOSYIN**, respectively.

Table 4: Ecological Risk Index of the Study Areas

SITE	Cf			ERI		
	Cadmium	**Lead**	**$tERI_{site}$**	**Cd**	**Pb**	**tERIsite**
Kaprobu	0.23	7.09	7.32	6.90	35.45	42.35
Kosyin	0.06	2.35	2.41	1.80	11.75	13.55
Moiben	0.26	9.51	9.77	7.80	47.55	53.35
Naiberi	0.25	12.66	70.62	7.50	63.30	70.80
Ziwa	0.25	10.26	10.51	7.50	51.30	58.80
$tERI_{element}$	1.05	41.87	42.92	31.50	209.35	240.85

DISCUSSION

Soil health is crucial to sustainable agriculture, ecosystem services and human health. It enhances soil nutrient, microorganism, carbon and structure management, improves high productivity and supports food security (Chu et al., 2019; Kibblewhite et al., 2008). On the other hand, persistent toxic metals including Cadmium, Lead and Arsenic contaminate agricultural soils, synergistically and antagonistically reduce macro and micro nutrients bioavailability to different crops and vegetables (Khan et al., 2019). Several toxic metal remediation techniques are being developed to minimize human health exposure and improve soil quality for agricultural purpose, for example, phytoremediation, soil washing, soil excavation, electrokinetics, and metals binding (Awa et al., 2020).

Though the levels of the metals in the study areas were in range of some previous findings and standards as shown in Table 2. Correspondingly, the concentrations of Cd and Pb at all sampling areas were above the World Health Organization (WHO) allowable limits of 0.003 mg/kg and 0.1 mg/kg (Chiroma et al., 2014). Increased levels of toxic metals in agricultural soils poses threat of toxic metals translocation and bioaccumulation in food crops (Chen et al., 2016). This is typically common for Cd and Pb in cereal crops such as maize, rice and wheat grown in toxic metal contaminated agricultural soils (Feng et al., 2021; Zhang et al., 2018). Hence, chronic exposure through ingestion (water, food and vegetables) and inhalation (dust and air) to high levels of toxic metals, especially Cadmium and Lead in children can lead to serious health consequences such as cancer, malformation and retarded growth (Pruvot et al., 2006).

Also, Potential ecological risk per sites computed values (Table 4) agrees similarly with the single factor results (Table 3) of low to considerable toxic metal contamination in the areas (Pan et al., 2016). This is so for many agricultural-induced soil pollutions compared to industrial, smelting and mining induced soil pollutions, though both contamination categories are anthropogenic in nature (Wang et al., 2013). Therefore, this level of toxic metals pollution calls for timely hazards control, monitoring and management measures to avoid further Pb contamination of the soil and lower the likely potential harm of the toxic metals (Abuduwaili et al., 2015).

CONCLUSION

Toxic metal concentrations of the elements, Cadmium and Lead were evaluated using conventional methods from digestion to analysis. The Hakanson's single and multi-factor contamination indices were used to assess the potential ecological risk of the metals in the sampled soils from Kaprobu, Kosyin, Moiben, Naiberi and Ziwa, Uasin Gishu County, Kenya.

The concentration of Cd and Pb exceeded WHO allowable limit in agricultural soil used for growing food crops and gardening. However, the concentrations for Cd and Pb at the same areas were within limit of the USEPA allowable standards for garden and agriculture soils.

The Hankason's potential ecological risk indices showed that the overall contamination of the areas ranked from moderate to considerable risk, that is, from the mean to the highest value computed. At Naiberi, Ziwa, Moiben, Kaprobu, and Kosyin there is need for immediate intervention measures in order to revert additional toxic metals aggregation in soils.

Therefore, the study recommends minimum use of toxic metals source in agricultural inputs such as inorganic fertilizers and pesticides; and continuous monitoring of the soil. Also, conduct of similar assessment for other toxic metals such as Cobalt (Co), Mercury (Hg), Arsenic Iron (Fe) (As), Copper (Cu), Zinc (Zn), Nickel (Ni), Chromium (Cr), this will provide a more general understanding of the extend of toxic metals pollution in the areas.

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Conflict of Interest

"The authors declare no conflict of interest"

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