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Research Application Summary

Toxic Metals Pollution and Environmental Risk Assessment of Agricultural Soil in Uasin Gishu County, Kenya

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Abstract

Increased industrialization, typically mechanized farming, addition of agricultural inputs and urbanization are prime sources of metal toxicity in soil, sediment, and water in periurban areas. In Kenya, prolonged mono-cropping and use of agrochemicals trigger toxic (heavy) metals accumulation in environmental media. It is crucial to understand the link between anthropogenic activities and toxic metal concentration in soil in Kenya. Many farmers and residents that may be exposed to toxic metals are uninformed about the potential impacts of these metals on the ecosystem and human health. Soil samples were collected from Jema, Kaprobu, Moiben, Naiberi and Ziwa in Uasin Gishu County and analyzed for mineralogical and toxic metal compositions to assess the contamination and ecological risk indices. Algorithmic environmental risk assessment indices including Hakanson's ecological index, Muller's geo-accumulation index and potential ecological risk index were used to compute the likely health risk. Mean concentrations of toxic metals in soils from the study areas in an ascending order were: Mercury (Hg) < Cadmium (Cd) < Selenium (Se) < Arsenic (As) < Chromium (Cr) < Lead (Pb), that is ND, 0.10, 5.34, 27.75, 28.72, respectively. Lead concentration in studied soils was relatively high and its assessed contamination factor (Cf), Geo-Accumulation Index (Igeo), Contamination Degree (Cdeg), and Ecological Risk Index (Eri) showed varying degrees from moderate to very high Cf, moderate to strong Igeo, very high Cdeg and considerable potential Eri, respectively, in the study areas. The increase in Pb is attributable to anthropogenic farming activities in the studied areas.

Key words: Environment risk assessment, geoaccumulation, Kenya, soil pollution, toxic metal, Uasin Gishu

Résumé

L'industrialisation accrue, l'agriculture généralement mécanisée, l'ajout d'intrants agricoles et l'urbanisation sont les principales sources de toxicité des métaux dans le sol, les sédiments et l'eau dans les zones périurbaines. Au Kenya, la monoculture prolongée et l'utilisation de produits agrochimiques déclenchent l'accumulation de métaux toxiques (lourds) dans les milieux environnementaux. Il est crucial de comprendre le lien entre les activités anthropiques et la concentration de métaux toxiques dans le sol au Kenya. De nombreux agriculteurs et résidents susceptibles d'être exposés à des métaux toxiques ne sont pas informés des impacts potentiels de ces métaux sur l'écosystème et la santé humaine. Des échantillons de sol ont été prélevés à Jema, Kaprobu, Moiben, Naiberi et Ziwa dans le comté d'Uasin Gishu et analysés pour les compositions minéralogiques et métalliques toxiques afin d'évaluer la contamination et les indices de risque écologique. Des indices algorithmiques d'évaluation des risques environnementaux, notamment l'indice écologique de Hakanson, l'indice de géoaccumulation de Muller et l'indice de risque écologique potentiel, ont été utilisés pour calculer le risque probable sur la santé. Les concentrations moyennes de métaux toxiques dans les sols des zones d'étude par ordre croissant étaient : Mercure (Hg) < Cadmium (Cd) < Sélénium (Se) < Arsenic (As) < Chrome (Cr) < Plomb (Pb), c'est-à-dire ND, 0,10, 5,34, 27,75, 28,72, respectivement. La concentration de plomb dans les sols étudiés était relativement élevée et son facteur de contamination évalué (Cf), son indice de géo-accumulation (Igeo), son degré de contamination (Cdeg) et son indice de risque écologique (Eri) présentaient des degrés variables allant de modéré à très élevé Cf, modéré à Igeo fort, Cdeg très élevé et Eri potentiel considérable, respectivement, dans les zones d'étude. L'augmentation du Pb est attribuable aux activités agricoles anthropiques dans les zones étudiées.

Mots clés : Evaluation des risques environnementaux, géoaccumulation, Kenya, pollution des sols, métal toxique, Uasin Gishu

Introduction

Increasing levels of toxic metals in soil, plants and the atmosphere come from industries, combustion of fossil fuels in transportation, chemical wastes, inorganic fertilizers and pesticides use in agriculture (Falahi-Ardakani, 1984). A research conducted in some Chinese villages showed that dietary contamination of heavy metals through food chain transfer is a major route of exposure in humans (Liu *et al*., 2013). Heavy metals exposure causes serious health problems including carcinogenicity, mutagenicity and teratogenicity as well as endocrine disruption and behavior changes in children (Ali *et al*., 2013). Studies showed that agriculture is a major source of -Cd and Pb pollutions in the environment. Excess use of agrochemicals contributes considerably to heavy metals contamination in the environment and ultimately end up into the food chain (Wong *et al*., 2002). In Kenya, a study found high levels of trace elements-arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc in agricultural soils (Mungai *et al*., 2016). In addition, use of irrigated sewage is considered a significant source of heavy metals pollution in agriculture soils. Routine application of irrigated sewage sludge in horticultural crops pose serious health hazard to humans (Udom *et al*., 2004; Karanja *et al*., 2009).

Increased heavy metal concentrations in agricultural soil poses potential risk not only to human health but also lowers soil quality (Golui *et al*., 2019). Chronic exposure to heavy metals such Hg, Cd, and Pb may cause health consequences including carcinogenicity, mutagenicity and teratogenicity as well as endocrine disruption and behavior change in children (Ali *et al*., 2013). As such, environmental risk indices including Cf, Igeo, Cdeg and Eri are widely used to evaluate and monitor heavy metals pollution and toxicity in environmental matrices (Hakanson, 1980; Bahloul *et al*., 2018; Golui *et al*., 2019; Rostami *et al*., 2021). Therefore this study was undertaken to establish the level of metal contamination in an agricultural production area of Kenya.

Materials and Methods

Study area. The study was conducted in Uasin Gishu County, Kenya (Figure 1). This region is considered a part of Kenya's economic and agricultural zone. It is referred to as the breadbasket of Kenya and inhabitants are predominantly involved in livestock, wheat and maize farming (Youe, 1988). The digital soil map of the area showed varieties of soil types including Ferrasols, Nitisols, Gleysols, Luvisols, Cambisols, and regosols (Ngunjiri *et al*., 2019).

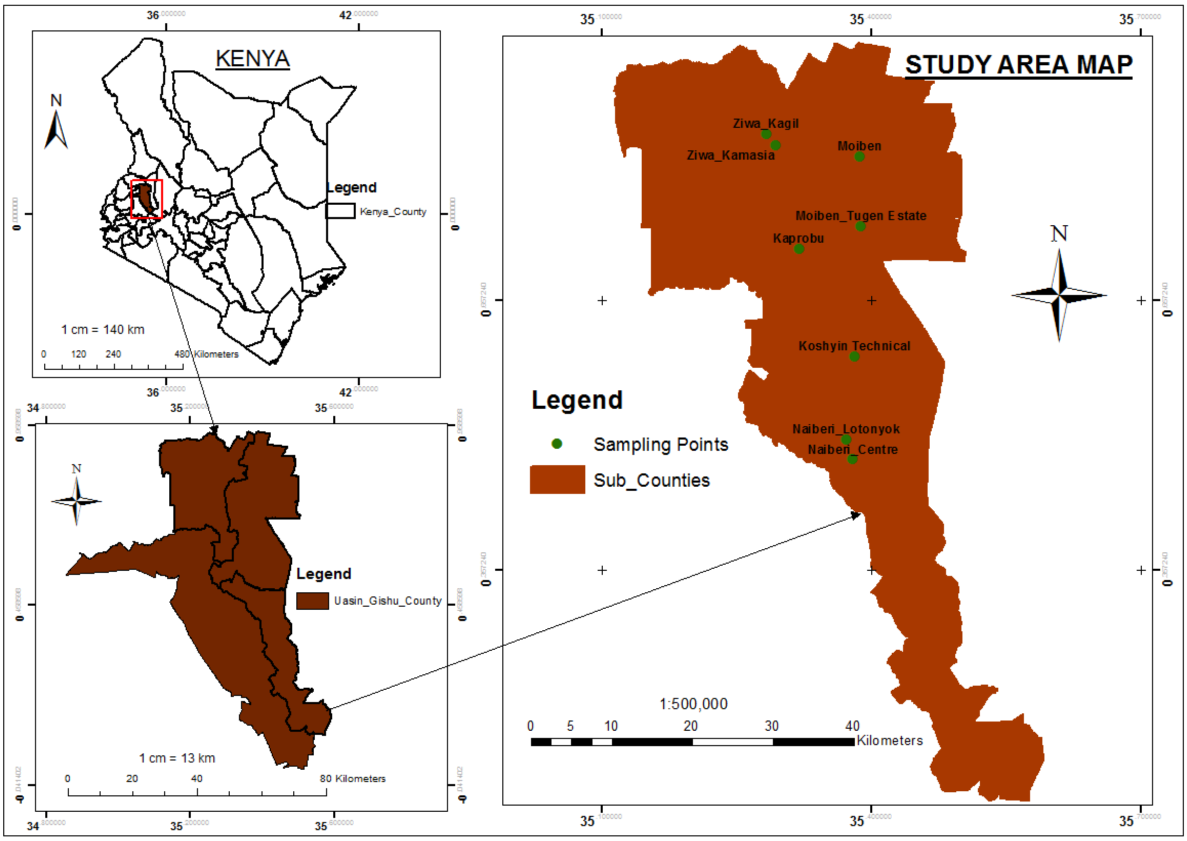

Figure 1. Location of the Study area in Uasin Gishu County, Kenya

A study on physicochemical parameters (Okalebo *et al*., 2002) indicated human interference with the soils (Mbene *et al*., 2017).

Sample collection and analysis. The soil samples were collected in duplicates from maize and wheat growing areas at Kaprobu, Koshyin Technical Institute, Moiben, Naiberi, and Ziwa, respectively (Figure 1). A total of 40 soil samples were collected using standard methods. The soil samples were air dried, ground in pestle and motor and sieved through a 250 µm mesh wire. Portions of the dried samples were accurately weight, treated and analyzed for electrical conductivity, pH, organic matter (OM) and cation exchange capacity respectively. In addition, the samples were digested and analyzed for toxic metals using high performance microwaves digestion system (Ethos up) and ICPMS (Agilent 7900), respectively (Kolawole *et al*., 2018). The soils were also analyzed for texture using Bouyoucos hydrometer method (Klute, 1986).

The soil risk assessment indices-Contamination Factor, Contamination Degree, Geo-accumulation Factor and Ecological Risk index were estimated using equations 1-4 adopted from (Turekian and Wedepohl, 1961; Hakanson, 1980; Ali *et al.*, 2013; Odukoya, 2015). The pollution indices equations were:

1. $C_{f=C_n/B_n}$ -----------------equation 1
2. $C_{Deg=\sum_{n=1}^{i} Cf}$ ------------equation 2
3. $I_{geo=log_2}\,(C_n/_{1.5xB_n})$----------equation 3
4. $RI = \sum E(i) = \sum Ti\ x\ C_f$ -------equation 4

Where Cf =Contaminator Factor of the individual element; C_{Deg} is the Contamination Degree; I_{geo} is the Geo-accumulation factor; RI is the Ecological Risk Index, C_n is metal concentration in the soil at sampling sites; B_n is metal concentration in background (preindustrial); and T_i is the toxic response factor of toxic metals in the soil.

Results and Discussions

The results showed increased acidity and organic matter. The toxic metals As, Cd, Cr, Hg, and Pb concentrations in studied soil are presented in Table 1. The mean Pb concentration (28.72±7.59 mgkg^{-1}) was relatively higher than the background (Hakanson preindustrial) values, while the other metals, As, Cd, Cr and Hg showed relatively lower concentrations, 15, 1, 90, and 0.03-0.8 mg kg^{-1} , respectively, compared to background concentration in soils considered uncontaminated.

Table 1. Heavy Metals concentrations (mg/kg) in soil collected from surface soil, Uasin Gishu, Kenya

Site	pH	As (mg/kg)	Cd(mg/kg)	Cr(mg/kg)	Pb(mg/kg)	Hg
Kaprobu	4.87 ± 0.79	5.68 ± 1.20	0.12 ± 0.02	26.76 ± 0.40	24.84 ±1.60	ND
Koshyin TI	4.20 ± 0.00	2.94 ±00	0.06 ±00	14.31 ±00	16.46 ±00	ND
Moiben	4.62 ± 0.02	6.39 ±1.33	0.13 ± 0.08	27.65 ±3.43	33.29 ±11.95	ND
Naiberi	4.41 ± 0.40	5.04 ± 1.78	0.08 ± 0.03	25.46 ± 12.73	29.55 ± 6.31	ND
Ziwa	4.68 ± 0.02	5.63 ± 0.00	0.12 ± 0.00	48.19 ± 0.59	35.89 ± 10.50	ND
tmean	4.54 ± 0.31	5.34 ± 1.08	0.10 ± 0.03	27.75 ± 4.29	28.72 ± 7.59	ND

ND = Not detectable

The high concentration of Pb is illustrated in Figure 2. Concerns about increasing toxic metals concentrations in agricultural soils have long been investigated in order to understand the potential risk of transfer from soil into food crops/chains (Holmgren *et al.,* 1993). The increased Pb concentrations in agricultural soil in the study area is mostly associated with application of commercial fertilizers. Though the Arsenic and Chromium bars (Figure 2) are higher than Pb in some areas indicating higher concentration levels of these metals, the levels are still below estimated moderate to high environmental risk exposure unlike for Lead (Table 2).

The computed C_F, C_{deg}, and E_{ri} in this study according to equations 1, 2, and 4, respectively; showed that of the toxic metals analyzed, only Pb presented high levels of contamination and ecological risk (Table 2), that is, mean C_F, C_{deg}, and E_{ri} were 4.19, 41.88, and 180.07, respectively. Similarly, the Geo-Accumulation Factor (Igeo), used to determine toxic metals contamination levels of soil/sediment was computed (Förstner and Müller, 1981). Using equation 3, the calculated result, mean 1.38, indicates same trend, slight Pb contamination in the study areas.

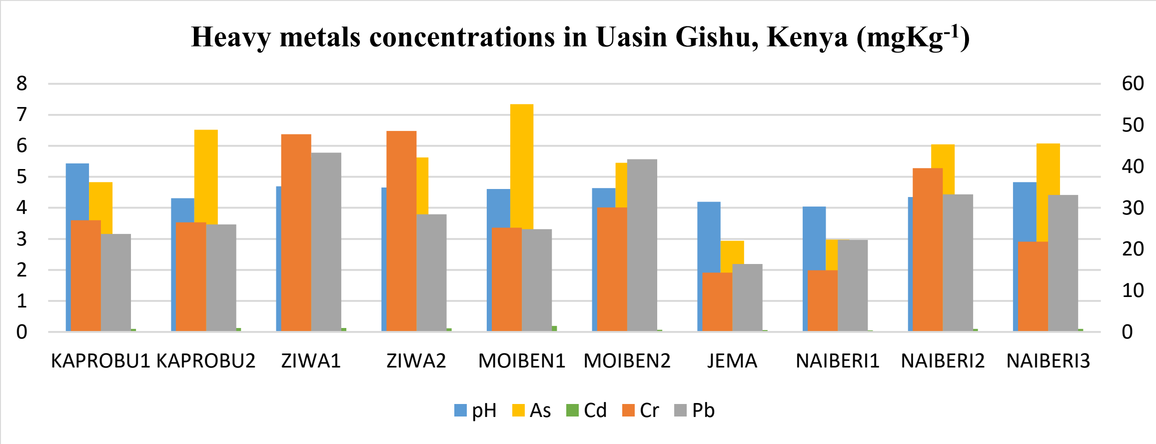

Figure 2. pH and Heavy Metals concentrations in soil (Cs, mg/kg) collected from surface soil in Uasin Gishu, Kenya

Table 2. Matrices of Contamination Factor (Cf), Contamination Degree (C_{deg}) and Ecological Risk Index (E_{ri})

Contamination Factor		**Contamination Degree (C_{deg})**		**Ecological Risk Index (E_{ri})**	
Value Index	Contamination	Value index	Contamination Status	Value Index	Risk Status
$C_f < 1$	Low C_f	$C_{deg} \leq 8$	Low C_{deg}	$E_{ri} < 40$	Low E_{ri}
$1 < C_f < 3$	Moderate C_f	$8 \leq C_{deg} < 16$	Moderate C_{deg}	$40 \leq E_{ri} < 80$	Moderate E_{ri}
$3 < C_f < 6$	Considerable C_f	$16 \leq C_{deg} < 32$	Considerable C_{deg}	$80 \leq E_{ri} < 160$	Considerable E_{ri}
$6 \geq C_f$	Very High C_f	$C_{deg} \geq 32$	Very high C_{deg}	$160 \leq E_{ri} < 320$	High E_{ri}
		---	---	$E_{ri} \geq 320$	Very High E_{ri}

Conclusion

The results showed higher levels of Lead (Pb) compared to As, Cd, and Cr in soils in the study area. Environmental risk assessment indices (Eri) indicate that there is Pb contamination and ecological risk. Similarly, the contamination factor (Cf) and degree of contamination (CDeg) computed showed moderate to very high contamination factor and very high degree of contamination. These levels are as result of human activities mainly combustion of leaded fuel and agriculture amendment (Figure 2). Therefore, regular soil testing and of standardized fertilizer (organic and inorganic) is needed to reduce agricultural soil heavy metal toxicity.

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References

Ali, Z., Malik, R. N., Shinwari, Z. K. and Qadir, A. 2013. Enrichment, risk assessment, and statistical apportionment of heavy metals in tannery-affected areas. *International Journal of Environmental Science and Technology* 12 (2): 537-550. doi:10.1007/s13762-013-0428-4

Bahloul, M., Baati, H., Amdouni, R. and Azri, C. 2018. Assessment of heavy metals contamination and their potential toxicity in the surface sediments of Sfax Solar Saltern, Tunisia. *Environmental Earth Sciences* 77 (1):1-22. doi:10.1007/s12665-018-7227-7

Falahi-Ardakani, A. 1984. Contamination of environment with heavy metals emitted from automotives. *Ecotoxicology and Environmental Safety* 8 (2): 152-161.

Förstner, U. and Müller, G. 1981. Concentrations of heavy metals and polycyclic aromatic hydrocarbons in river sediments: geochemical background, man's influence and environmental impact. *GeoJournal* 5 (5): 417-432.

Golui, D., Datta, S., Dwivedi, B., Meena, M., Varghese, E., Sanyal, S. and Trivedi, V. 2019. Assessing soil degradation in relation to metal pollution–A multivariate approach. *Soil and Sediment Contamination: An International Journal* 28 (7): 630-649.

Hakanson, L. 1980. An ecological risk index for aquatic pollution control. A sedimentological approach. *Water Research* 14 (8): 975-1001.

Holmgren, G.G.S., Meyer, M.W., Chaney, R.L. and Daniels, R.B. 1993. Cadmium, lead, zinc, copper, and nickel in agricultural soils of the United States of America (Vol. 22, No. 2, pp. 335-348). American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.

Karanja, N. N., Njenga, M., Prain, G., Kangâ, E., Kironchi, G., Githuku, C. and Mutua, G. 2009. Assessment of environmental and public health hazards in wastewater used for urban agriculture in Nairobi, Kenya. *Tropical and Subtropical Agroecosystems* 12 (1): 85-97.

Klute, A. (1986). Methods of soil analysis.

Kolawole, T. O., Olatunji, A. S., Jimoh, M. T. and Fajemila, O. T. 2018 . Heavy metal contamination and ecological risk assessment in soils and sediments of an industrial area in Southwestern Nigeria. *Journal of Health and Pollution* 8 (19): 1-16.

Liu, X., Song, Q., Tang, Y., Li, W., Xu, J., Wu, J. and Brookes, P. C. 2013. Human health risk assessment of heavy metals in soil–vegetable system: a multi-medium analysis. *Science of the Total Environment* 463: 530-540.

Mbene, K., Kome, G. K., Mvondo-zé, A. D., Tamungang, E. B. N. and Mofor, N. A. 2017. Assessment of physico-chemical and heavy metals properties of some agricultural soils of Awing-North West Cameroon. *Archives of Agriculture and Environmental Science* 2 (4): 277-286. doi:10.26832/24566632.2017.020405

Mungai, T. M., Owino, A. A., Makokha, V. A., Gao, Y., Yan, X. and Wang, J. 2016. Occurrences and toxicological risk assessment of eight heavy metals in agricultural soils from Kenya, Eastern Africa. *Environmental Science and Pollution Research* 23 (18): 18533-18541.

Ngunjiri, M. W., Libohova, Z., Minai, J. O., Serrem, C., Owens, P. R. and Schulze, D. G. 2019. Predicting soil types and soil properties with limited data in the Uasin Gishu Plateau, Kenya. *Geoderma Regional* 16: e00210.

Odukoya, A. M. 2015. Contamination assessment of toxic elements in the soil within and around two dumpsites in Lagos, Nigeria. *Ife Journal of Science* 17 (2): 351-361.

Okalebo, J. R., Gathua, K. W. and Woomer, P. L. 2002. Laboratory methods of soil and plant analysis: a working manual. Second edition. Sacred Africa, Nairobi.

Rostami, S., Kamani, H., Shahsavani, S. and Hoseini, M. 2021. Environmental monitoring and ecological risk assessment of heavy metals in farmland soils. *Human and Ecological Risk Assessment: An International Journal* 27 (2): 392-404.

Turekian, K. K. and Wedepohl, K. H. 1961. Distribution of the elements in some major units of the earth's crust. *Geological society of America Bulletin* 72 (2): 175-192.

Udom, B., Mbagwu, J., Adesodun, J. and Agbim, N. 2004. Distributions of zinc, copper, cadmium and lead in a tropical ultisol after long-term disposal of sewage sludge. *Environment International* 30 (4): 467-470.

Wong, S., Li, X., Zhang, G., Qi, S. and Min, Y. 2002. Heavy metals in agricultural soils of the Pearl River Delta, South China. *Environmental Pollution* 119 (1): 33-44.

Youe, C. P. 1988. Settler capital and the assault on the squatter peasantry in Kenya's Uasin Gishu District, 1942–63. *African Affairs* 87 (348): 393-418.