



Geospatial Assessment of Selected Heavy Metal Concentrations in and around Chetambe Hills, Kenya

Mukanda Kere Wanyama¹, Michael Nakitare Waswa¹, Felix Wanjala Omonya²

¹Department of Science, Technology & Engineering, Kibabii University, Bungoma, Kenya

²IAEA, Vienna, Austria

Email: kerewanyama2018@gmail.com

How to cite this paper: Wanyama, M.K., Waswa, M.N. and Omonya, F.W. (2026) Geospatial Assessment of Selected Heavy Metal Concentrations in and around Chetambe Hills, Kenya. *Open Access Library Journal*, **13**: e15226. <https://doi.org/10.4236/oalib.1115226>

Received: March 23, 2026

Accepted: May 3, 2026

Published: May 6, 2026

Copyright © 2026 by author(s) and Open Access Library Inc.

This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

A geospatial assessment of selected heavy metal concentration and associated human exposure risks in and around Chetambe Hills has been done in this study in soils at different depths using the Energy Dispersive X-ray Fluorescence (EDXF). 16 soil samples were collected at different depths and analyzed for elemental concentrations using the AXIL software. The heavy metals analyzed were Ni, Cu, Zn, Pb and As. Ni concentrations ranged from 289 ± 12.3 ppm to 478.4 ± 2.3 ppm with an average of 409.1 ± 26.3 ppm which was higher than the permissible limit of 100ppm given by WHO. Cu heavy metal concentrations varied from a minimum of 33.6 ± 8.19 ppm to 383.1 ± 23.0 ppm with an average of 319.4 ± 17 ppm. Zn concentrations varied from 39.93 ± 0.8 ppm to 619.5 ± 34.8 ppm with an average of 125.8 ± 11.4 ppm. The heavy metal concentrations of Pb ranged from a minimum of 24.7 ± 1.5 ppm to a maximum of 159.2 ± 23 ppm with a mean of 60.4 ± 9.32 ppm, As concentrations ranged from 0.4 ppm to 7.1 ppm with an average of 0.7 ppm. The metal pollution indices were also computed to assess the level of contamination for the five selected heavy metals. Geo-accumulation assessment (Gaa) values ranged from 0.12 (As) to 2.89 (Cu), corresponding to contamination levels from unpolluted to moderately polluted up to moderately to seriously polluted. From the study Cu and Ni showed the highest accumulation. Potential Ecological Risk (PER) values varied from 0.59 for As to 71.94 for Cu. Cu showed a moderate ecological risk, while Ni, Zn, Pb, and As posed low risks. Synthesized Potential Ecological Risk (SPER), was determined as 117.81, suggesting a moderate risk. This SPER value is an indication that while the ecosystem is not severely at risk, there is moderate risk, mainly from Cu and Ni concentrations since overall, the indices show that the study area is moderately polluted with Cu and Ni as the primary pollution risk contributors, while Zn, Pb, and As remain within safe

limits.

Subject Areas

Geology

Keywords

Geoaccumulation Assessment, EDXRF, Potential Ecological Risk

1. Introduction

Heavy metals are elements that have metallic properties, their atomic number is greater than 20 and density above 5 g/cm³ [1]. Increase in some heavy metal concentrations in soils and water has been enhanced by industrialization, increase in population and human activities [2]. Over 10 million sites all over the world have been reported with soil pollution of heavy metals [3]. Anthropogenic activities especially agricultural activities have been linked to the highest percentage of environmental elemental pollution [4]. Natural processes like natural radioactivity have also been found as a basis for sources of heavy metals [2]. The most common contaminants of heavy metals are Ni, Zn, Pb, Cu, and As [5]. The presence of heavy metals in soils can also be associated with parent materials like those derived from metal-enriched serpentine and black shale [6]. Soil polluted with heavy metals results in human health risks, groundwater pollution and plant phytotoxicity [7]. In recent times, research on heavy metals in water and soils has been a matter of great concern to scientists. This is because they are non-biodegradable; at certain concentrations they are toxic and can find their way to human beings via the food chain [8]. Once consumed, the heavy metals get accumulated by the human body causing discomfort in the digestive system [9].

According to [10], human exposure to heavy metals can cause stunted growth, kidney damage, cancer and eventually loss of life in cases of prolonged exposure. Despite some of the heavy metals helping in body metabolism, higher concentrations can hinder the latter [11]. Excess levels of Pb in humans can lead to high rates of miscarriage, still births, infertility, permanent damage to the central nervous system, kidneys, cancer and even death among others in worst situations [12]. Long-term consumption of zinc beyond permissible levels can result in reduced iron stores [13]. High doses of copper cause anemia, liver damage, intestinal irritation, neurological complications, and thyroid damage [14]. Continuous and prolonged exposure to heavy metals through the various pathways can result in accumulation in the body organs hence disrupting biochemical processes [15].

Therefore, this study was done to assess the elemental concentrations of the selected heavy metals in soils at different depths in and around Chetambe Hills, Kenya. The assessment of levels of the selected heavy metals in soils was important to ascertain the levels of concentration in the study area and hence bring attention to the general population on the importance of environmental conservation. The

study also intended to inform the various stakeholders in environmental management authorities on the level of heavy metal pollution in the study area hence providing a reference for remediation programs that can enhance environmental sustainability.

2. Materials and Methods

2.1. Study Area

Chetambe Hill is located in Mihuu location, Bungoma East Sub-County, Bungoma County. Bungoma County has a population of 1670540 persons with 552 persons per Km² and an average household of 4.6 persons. Bungoma East Sub-County where the study area is located has a population of 114, 548 persons [16]. Bungoma County has an estimated size of 2207 km² of which Chetambe Hills covers approximately 58 km² [17]. The Hills are part of the Nandi escarpment extending from Mount Elgon southwards to Muhoroni Sub-County [18]. The Hills rise steeply to a height of 1685 m above sea level. Chetambe Hills area was previously called the Broderick Falls area bounded by latitudes 0°30'N and 1°00'N and by longitudes 34°30'E and 35°00'E [19]. There are various activities that are undertaken at the study that can be a cause for the high levels of heavy metals: pan paper mills (currently RAI paper), agricultural activities, Jua kali industries (welding, motor garage), Airstrip, quarrying among others. (See **Figure 1**)

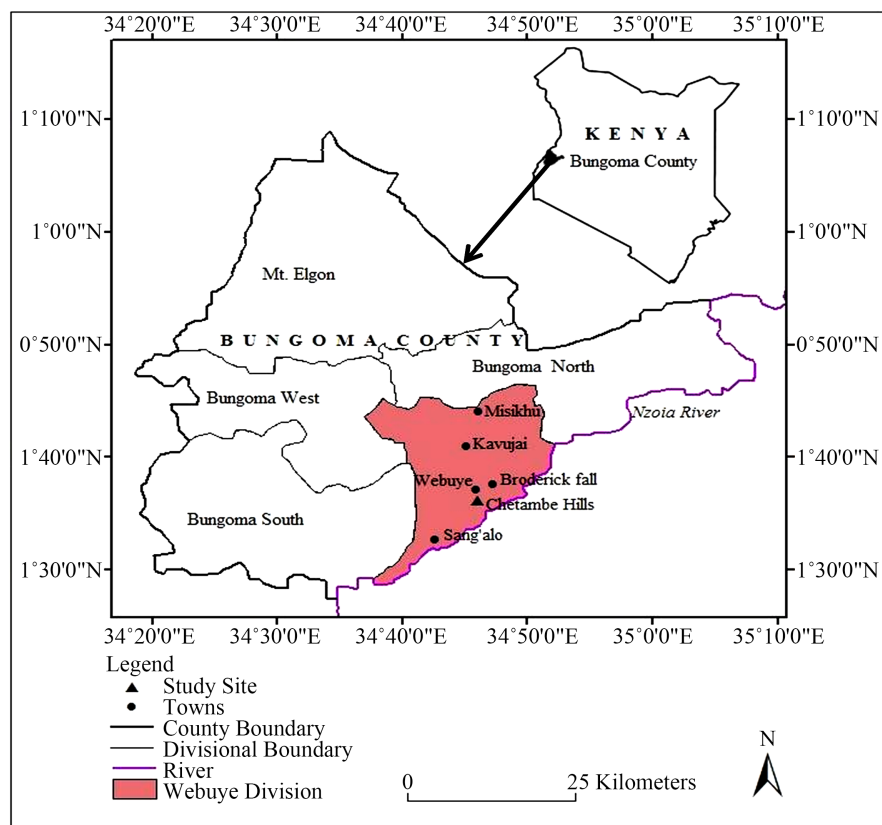


Figure 1. Location of study area (source: Survey of Kenya, 1969).

2.2. Soil Sample Collection and Preparation for Selected Heavy Metal Concentrations

A total of 16 soil samples of about 500 g each at different depths were collected at different locations of the study area. The sampling points were recorded using a handheld Global Positioning System (GPS) model. The depth of soil sampling was 0 - 9 cm, 10 - 19 cm and 20 - 30 cm. Pebbles, grass and roots were removed from the soil sample then dried, ground to a fine powder, and sieved through a 2.00 mm sieve. A small amount of 0.4 g was weighed using the electronic weighing balance. The soil sample was homogenized using the mixer and made into a pellet using the pellet dice with a pressure of 100,000 Pa from a hydraulic press machine. The pellet formed (2.5 cm) in diameter was then analyzed using EDXRF spectrometer and Amptek XRF kit.

3. Experimental Procedures

3.1. Energy Dispersive X-Ray Fluorescence Spectrometer (EDXRF)

When elements are subjected to sufficient amount of external energy, they emit radiation on impact with fast-moving particles like electrons, protons and neutrons [20]. The EDXRF consists of a gamma ray detector, pre-amplifier, linear amplifier, MCA, personal computer and printer. Energy Dispersive X-ray Fluorescence spectrometer works by bombarding a sample with high-energy X-rays, which causes the sample's atoms to emit characteristic X-rays of lower energy. These emitted X-rays are detected and analyzed to determine the elemental composition of the sample. The X-ray tube generates primary X-rays that bombard the sample. The generated primary X-rays interact with the atoms in the sample, thereby ejecting inner-shell electrons creating vacancies in the inner electron shells, and electrons from higher energy levels quickly fill these vacancies. As electrons move to lower energy levels, they release energy in the form of characteristic X-rays, which are unique to each element; an X-ray fluorescence phenomenon [21]. An energy-dispersive detector measures the energy and intensity of the emitted X-rays by sorting them by energy, and a Multi-Channel Analyzer (MCA) counts the number of X-rays at each energy level, creating an X-ray spectrum. The energy of each peak in the spectrum corresponds to a specific element, while the intensity corresponds to the concentration of that element in the sample [22]. The characteristic x-rays are unique for each element, thus representing a particular element. The EDXRF consists of ^{219}Cd that was used for excitation of the sample to produce particular X-rays, while Silicon Lithium detector was used to detect X-rays with energy resolution between 170 electron volts and 200 electron volts at 5.9 kilovolts.

3.2. Calibration of EDXRF Spectrometer

Calibration of the EDXRF spectrometer was done by using IAEA reference material soil 7 [23]. The elemental concentrations of the radionuclides were determined using EDXRF analytical technique [24].

3.2.1. Determination of Elemental Concentrations in the Soil Samples

The elemental concentrations in the soil samples were determined using AXIL software. Spectral acquisition of each pellet was done followed by spectral analysis by fitting the spectrum both with and without target where elemental concentration and identification of individual elements were done. Finally, quantitative analysis was done to quantify the individual elements using the emission transmission method. The quantification was done for all the pellets then an average was taken. The elemental concentrations of selected heavy metals were then used in determining metal pollution indices to ascertain the level of contamination of the soils.

Metal Pollution Indices.

Geo-accumulation assessment (Gaa), Potential Ecological Risk (PER) and Synthesized Potential Ecological Risk (SPER) metal pollution risks were calculated in selected heavy metals (Ni, Cu, Zn, As and Pb).

Geo-accumulation assessment (Gaa)

The Gaa calculated was used to evaluate metal pollution levels for Ni, Cu, Zn and Pb in the soil samples by measuring the enrichment of the heavy metals above the background levels. The Geo-accumulation assessment was determined using Equation (1) [25].

$$Gaa = \log 2 \left(\frac{C_i}{1.5B_i} \right) \quad (1)$$

where C_i is the measured metal concentration i and B_i is the concentration of the background value of element i , the coefficient 1.5 is the background matrix correction. The metal pollution levels were classified according to [25].

Potential Ecological Risk (PER)

The potential ecological risk was assessed to show the level of contamination risk for each of the selected heavy metals (Pb, Cu, Ni, As and Zn) to the environment following Equation (2) [26].

$$PER = \sum_{i=1}^n T_i \times \frac{C_i}{B_i} \quad (2)$$

where C_i is the measured metal concentration i and B_i is the concentration of the background value of element i , T_i is the biological toxic factor for metal i . The biological toxic factors for Ni, Cu, Zn, Pb and As are 5, 5, 15 and 1 respectively.

3.2.2. Synthesized Potential Ecological Risk (SPER)

The synthesized potential ecological risk was determined to reveal the overall environmental hazard of selected heavy metals. It was the summation of the potential ecological risks. SPER was computed using Equation (3) [25].

$$SPER = \sum_i^n PER \quad (3)$$

The determination of elemental concentrations of selected heavy metals in selected soil samples was done using AXIL software by spectral acquisition, spec-

trum analysis (individual elemental concentration identification of elements) and finally quantification. The elemental concentrations are represented in **Table 1**.

Table 1. Elemental concentrations of selected heavy metals in selected soil samples in this study.

S/p	S/NO	Depth (cm)	Activity	Long (E)	Lat (N)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Pb (ppm)	As (ppm)
A	S ₁	0 - 9	Air strip	34°46.17'	0°43.22'	416 ± 22.38	347 ± 7.5	64 ± 6.0	29 ± 4.9	7 ± 0.0
C	S ₇	0 - 9	Water spring	34°37.29'	0°36.18'	441 ± 28.7	359 ± 23.8	79 ± 9.1	34.5 ± 7.0	1 ± 0.7
D	S ₁₀	0 - 9	Hospital/ school	34°45.31'	0°36.20'	371.9 ± 19.0	321.0 ± 16.0	72.5 ± 3.27	30.3 ± 4.49	2.1 ± 1.60
E	S ₁₃	0 - 9	Webuye town	34°44.32'	0°35.21'	389.6 ± 23.6	355.1 ± 19.0	394.2 ± 23.2	101.2 ± 8.3	0.8 ± 0.01
E	S ₁₄	10 - 19	Webuye town	34°44.32'	0°35.21'	371.1 ± 23.6	348.6 ± 21.6	619.5 ± 34.5	81.0 ± 3.47	1.5 ± 0.32
I	S ₂₅	0 - 9	Ppm ponds (kales)	34°45.38'	0°31.32'	478.4 ± 21.3	366.7 ± 7.28	82.4 ± 4.62	74.5 ± 6.89	1.6 ± 0.96
J	S ₂₇	20 - 30	Ppm ponds (kales)	34°45.38'	0°31.32'	466.1 ± 30.0	108.3 ± 10.6	53.9 ± 2.73	153.7 ± 17.0	-
J	S ₂₈	0 - 9	Ponds (nappier grass)	34°45.39'	0°31.35'	442.7 ± 28.3	381.8 ± 19.2	72.8 ± 2.40	36.4 ± 1.46	4.2 ± 0.63
J	S ₂₉	10 - 19	Ponds (nappier grass)	34°45.39'	0°31.35'	420.5 ± 26.3	383.1 ± 23.0	81.0 ± 6.84	28.7 ± 5.24	7.1 ± 4.00
K	S ₃₀	20 - 30	Ponds (nappier grass)	34°45.39'	0°31.35'	289.6 ± 12.3	249.87 ± 14	39.93 ± 0.8	24.7 ± 1.5	-
L	S ₃₅	10 - 19	Cowpeas	34°49.39'	0°34.36'	395.5 ± 56.1	136.7 ± 16.6	59.3 ± 10.36	159.2 ± 23	1.8 ± 0.3
M	S ₃₈	10 - 19	Nabuyole primary. s	34°48.42'	0°35.37'	409.6 ± 26.8	33.6 ± 8.19	78.4 ± 1.43	45.2 ± 6.62	0.4 ± 0.00
N	S ₄₁	0 - 9	Nabuyole quarry	34°46.41'	0°36.38'	382.6 ± 3.06	339.5 ± 11.0	64.8 ± 5.5	46.0 ± 5.78	0.9 ± 0.00
N	S ₄₂	20 - 30	Nabuyole quarry	34°46.41'	0°36.38'	435.3 ± 14.4	373.9 ± 22.6	113.7 ± 10.0	50.8 ± 4.53	0.4 ± 0.00
P	S ₄₆	0 - 9	Chetambe hill	34°46.41'	0°34.38'	414.4 ± 27.0	345.7 ± 22.5	74.6 ± 7.56	33.5 ± 6.04	4.9 ± 5.27
P	S ₄₈	20 - 30	Chetambe hill	34°46.41'	0°34.38'	420.9 ± 26.3	360.6 ± 17.4	62.5 ± 6.31	37.6 ± 5.33	2.3 ± 0.47
AVE						409.1 ± 26.3	319.4 ± 17	125.8 ± 11.4	60.4 ± 9.32	2.7 ± 0.14

From **Table 1**, Ni concentrations ranged from 289 ± 12.3 ppm (S30) to 478.4 ± 2.3 ppm (S25) with an average of 409.1 ± 26.3 ppm which was higher than the permissible limit of 100 ppm given by [27] which is indicative of widespread contamination. The Ni concentrations at all the sampling points and depths exceeded the world permissible limit. The relatively high and consistently higher levels of nickel in the study area could be attributed to geogenic baseline. For the samples from the ponds, the high Ni levels can be attributed to the industrial waste from the pulp and paper (RAI) factory and urban waste from Webuye town. The industrial waste from the factory is treated at the ponds before being let into river Nzoia while urban waste from Webuye town including wastes from jua kali sec-

tors (garages and welding) and households, is carried by surface run off to the pond area enriching the site with nickel.

Cu heavy metal concentrations varied from a minimum of 33.6 ± 8.19 ppm to 383.1 ± 23.0 ppm with an average of 319.4 ± 17 ppm. All the samples had higher values of Cu concentrations except S₃₈, which was below the recommended 100ppm by [28]. The higher levels of Cu across the sampling points could be a reflection of fertilizer or pesticide application, geological setup of the study area and waste from engines.

Zn concentrations varied from 39.93 ± 0.8 ppm to 619.5 ± 34.8 ppm with an average of 125.8 ± 11.4 ppm, which was below the world limit of 300 ppm [27]. However, the very high values in S13 (394.2 ± 23.2 ppm) and S14 (619.5 ± 34.8) may suggest high Zn contamination from anthropogenic input (garage).

The heavy metal concentrations of Pb ranged from a minimum of 24.7 ± 1.5 ppm to a maximum of 159.2 ± 23 ppm with a mean of 60.4 ± 9.32 ppm, which was within the international limit of 100 ppm [29]. Four samples were above the permissible limit: S13, S14, S27 and S35, which could be attributed to fuels (S13, S14), battery depositions and paints (S35).

As concentrations ranged from 0.4 ppm to 7.1 ppm with an average of 0.7 ppm. All samples recorded low values except for S1 (7.0 ppm) at the airstrip and S29 (7.1 ppm) at the ponds with some samples recording no concentration S27 and S30. It's also worth noting that the As concentrations did not depend on depth since there was no specific trend in the concentrations with depth.

From the above discussions on the results of selected heavy metal concentrations, it can be deduced that the concentrations do not assume a specific trend and therefore exhibit a spatial distribution at different depths at the different sampling points.

For a comprehensive discussion of the selected heavy metals, correlation graphs for Ni/Cu and Zn/Pb were also drawn; **Figure 2** and **Figure 3** respectively.

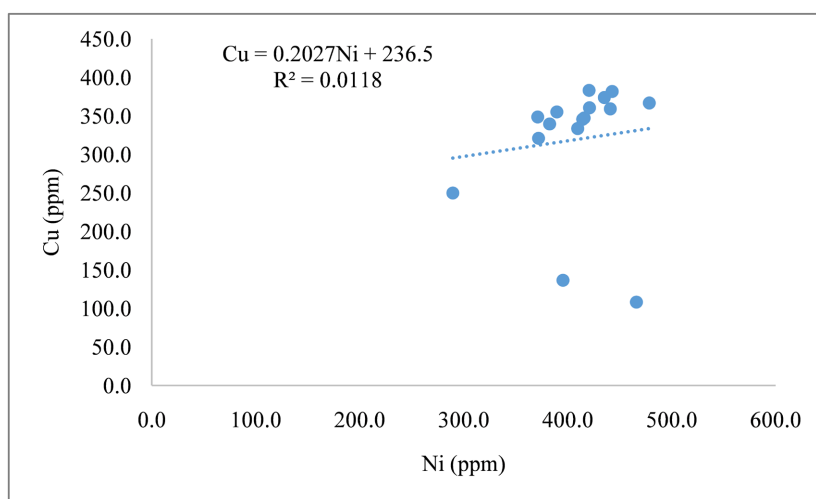


Figure 2. Correlation graph of Cu (ppm) and Ni (ppm) of selected soil samples in this work.

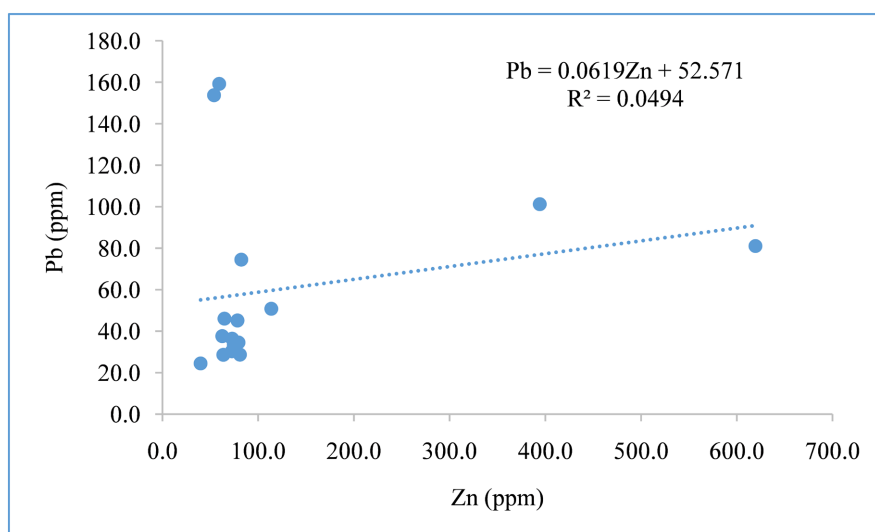


Figure 3. Correlation graph of Pb (ppm) and Zn (ppm) of selected soil samples.

From **Figure 2** and **Figure 3**, $R^2 = 0.0118$ and $R^2 = 0.0494$, it is clear that the relationship between Ni/Cu and Zn/Pb is very weak.

The Geoaccumulation assessment (Gaa), Potential Ecological Risk (PER), and Synthesized Potential Ecological Risk (SPER) were evaluated for heavy metals Ni, Cu, Zn, Pb and As pollution in soil samples using Equations (1), (2) and (3) respectively. The results obtained were classified according to **Table 2** and **Table 3** after being tabulated in **Table 4**.

Table 2. Metal pollution level classification for Gaa [25].

	Level	Classification
1	<0	Unpolluted
2	0 - 1	Unpolluted to moderately polluted
3	1 - 2	Moderately polluted
4	2 - 3	Moderately to seriously polluted
5	3 - 4	Seriously polluted
6	4 - 5	Seriously to extremely polluted
7	>5	Extremely polluted

Table 3. Classification of PER and SPER risk indices [30].

Sn	PER levels	Classification (PER)	SPER levels	Classification (SPER levels)
1	<40	Low risk	<150	Low risk
2	40 - 80	Moderate risk	150 - 300,	Moderate risk
3	80 - 160	High risk	300 - 600	High risk
4	160 - 320	Serious risk	600 - 1200	Serious risk
5	>320	Severe risk	>1200	Severe risk

Table 4. Metal pollution indices Gaa, PER and SPER [25] [30].

Metal	(Ci)	(Bi)	(Ti)	Gaa	Pollution classification (Gaa)	PER	Potential ecological risk (SPER)
Ni	409.1	56.97	5	1.44	Moderately polluted	35.90	Low risk
Cu	319.4	22.20	5	2.89	Moderately to seriously polluted	71.94	moderate risk
Zn	125.8	47.42	1	0.53	Unpolluted to moderately polluted	2.65	Low risk
Pb	60.4	44.87	5	0.27	Unpolluted to moderately polluted	6.73	Low risk
As	2.7	4.6	1	0.12	Unpolluted to moderately polluted	0.59	Low risk
Average				1.05	Moderately polluted	$\Sigma^n \text{PER} =$ $n = 1$ $=$ 117.81	Moderate risk

From **Table 4**, Gaa values ranged from 0.12 (As) to 2.89 (Cu), corresponding to contamination levels from unpolluted to moderately polluted up to moderately to seriously polluted. With reference to the classification in **Table 2**, the mean Gaa value of 1.05 is an indication that the study area is overall moderately polluted. From the study, Cu (2.89) and Ni (1.44) showed the highest accumulation, which can be attributed to the anthropogenic inputs such as industrial emissions (from collapsed Pan Paper mills), vehicular activities and runoff from agricultural fields [31]. On the other hand, As, Zn and Pb had Gaa values less than 1, which may mainly be from natural sources [32].

PER values varied from 0.59 for As to 71.94 for Cu. From the classification in **Table 3**, Cu showed a moderate ecological risk, while Ni, Zn, Pb, and As posed low risks. The relatively high PER for Cu could be due to its greater environmental mobility and bioavailability, in addition to its common use in industrial and agricultural processes [31].

SPER, was determined as 117.81, suggesting a moderate risk. This SPER value is an indication that while the ecosystem is not severely at risk, there is moderate risk, mainly from Cu and Ni concentrations since overall, the indices show that the study area is moderately polluted with Cu and Ni as the primary pollution risk contributors, while Zn, Pb, and As remain within safe limits. There is a need for continuous monitoring to prevent further accumulation and to alleviate potential long-term ecological risks [26] [33].

4. Conclusions and Recommendations

Ni concentrations ranged from 289 ± 12.3 ppm to 478.4 ± 2.3 ppm with an average of 409.1 ± 26.3 ppm which was higher than the permissible limit of 100 ppm which is indicative of widespread contamination. The Ni concentrations at all the sampling points and depths exceeded the world permissible limit. Cu heavy metal

concentrations varied from a minimum of 33.6 ± 8.19 ppm to 383.1 ± 23.0 ppm with an average of 319.4 ± 17 ppm. All the samples had higher values of Cu concentrations except S₃₈, which was below the recommended 100 ppm. Zn concentrations varied from 39.93 ± 0.8 ppm to 619.5 ± 34.8 ppm with an average of 125.8 ± 11.4 ppm, which was below the world limit of 300 ppm. The heavy metal concentrations of Pb ranged from a minimum of 24.7 ± 1.5 ppm to a maximum of 159.2 ± 23 ppm with a mean of 60.4 ± 9.32 ppm, which was within the international limit of 100 ppm. As concentrations ranged from 0.4 ppm to 7.1 ppm with an average of 0.7 ppm. All samples recorded low values except for S1 (7.0 ppm) at the airstrip and S29 (7.1 ppm) at the ponds with some samples recording no concentration S27 and S30. It's also worth noting that the As concentrations did not depend on depth since there was no specific trend in the concentrations with depth. The selected heavy metal concentrations suggested that mostly anthropogenic pollution from industrial waste and agrochemicals had affected the soils in the study area.

Gaa values ranged from 0.12 (As) to 2.89 (Cu), corresponding to contamination levels from unpolluted to moderately polluted up to moderately to seriously polluted. With reference to the classification in **Table 2**, the mean Gaa value of 1.05 is an indication that the study area is overall moderately polluted. On the other hand, As, Zn and Pb had Gaa values less than 1, which may mainly be from natural sources.

PER values varied from 0.59 for As to 71.94 for Cu. From the classification in **Table 3**, Cu showed a moderate ecological risk, while Ni, Zn, Pb, and As posed low risks. SPER, was determined as 117.81, suggesting a moderate risk. This SPER value is an indication that while the ecosystem is not severely at risk, there is moderate risk, mainly from Cu and Ni concentrations since overall, the indices show that the study area is moderately polluted with Cu and Ni as the primary pollution risk contributors, while Zn, Pb, and As remain within safe limits.

The study recommends continuous monitoring of heavy metals in soils especially Ni and Cu, in the study area to prevent further accumulation and to alleviate potential long-term ecological risk. The study further recommends phytoremediation programs in the study area to enhance environmental sustainability.

Acknowledgments

The authors thank the Institute of Nuclear Science and Technology at the University of Nairobi for assisting in the analysis of the samples.

Conflicts of Interest

The authors declare no conflict of interest.

References

- [1] Chowdhury, S., Mazumder, M.A.J., Al-Attas, O. and Husain, T. (2016) Heavy Metals in Drinking Water: Occurrences, Implications, and Future Needs in Developing Coun-

- tries. *Science of The Total Environment*, **569**, 476-488.
<https://doi.org/10.1016/j.scitotenv.2016.06.166>
- [2] Shentu, J., Fang, Y., Wang, Y., Cui, Y. and Zhu, M. (2023) Bioaccessibility and Reliable Human Health Risk Assessment of Heavy Metals in Typical Abandoned Industrial Sites of Southeastern China. *Ecotoxicology and Environmental Safety*, **256**, Article 114870. <https://doi.org/10.1016/j.ecoenv.2023.114870>
- [3] Martin, S. and Griswold, W. (2009) Human Health Effects of Heavy Metals. *Environmental Science and Technology Briefs for Citizens*, **15**.
- [4] Nyairo, W.N., Owuor, P.O. and Kengara, F.O. (2015) Effect of Anthropogenic Activities on the Water Quality of Amala and Nyangores Tributaries of River Mara in Kenya. *Environmental Monitoring and Assessment*, **187**, Article No. 691.
<https://doi.org/10.1007/s10661-015-4913-8>
- [5] Nagajyoti, P.C., Lee, K.D. and Sreekanth, T.V.M. (2010) Heavy Metals, Occurrence and Toxicity for Plants: A Review. *Environmental Chemistry Letters*, **8**, 199-216.
<https://doi.org/10.1007/s10311-010-0297-8>
- [6] He, Z.L., Yang, X.E. and Stoffella, P.J. (2005) Trace Elements in Agroecosystems and Impacts on the Environment. *Journal of Trace Elements in Medicine and Biology*, **19**, 125-140. <https://doi.org/10.1016/j.jtemb.2005.02.010>
- [7] Nyiramigisha, P., Komariah, and Sajidan, (2021) Harmful Impacts of Heavy Metal Contamination in the Soil and Crops Grown around Dumpsites. *Reviews in Agricultural Science*, **9**, 271-282. https://doi.org/10.7831/ras.9.0_271
- [8] Opaluwa, O.D., Aremu, M.O., Ogbo, L.O., Abiola, K.A., Odiba, I.E., Abubakar, M.M. and Nweze, N.O. (2012) Heavy Metal Concentrations in Soils, Plant Leaves and Crops Grown around Dump Sites in Lafia Meropolis, Nasarawa State, Nigeria. *Advances in Applied Science Research*, **3**, 780-784.
- [9] Kunwar, A. (2009) Base Line Health Survey and Prevalence of Intestinal Parasities Among the Children in Kanti Children's Hospital, Maharajgunj, Kathmandu Nepal. Doctoral Dissertation, Department of Zoology.
- [10] Aderinola, O.J., Clarke, E.O., Olarinmoye, O.M., Kusemiju, V. and Anatekhai, M.A. (2009) Heavy Metals in Surface Water, Sediments, Fish and Periwinkles of Lagos Lagoon. *American-Eurasian Journal of Agricultural & Environmental Sciences*, **5**, 609-617.
- [11] Song, Y., Choi, M.S., Lee, J.Y. and Jang, D.J. (2014) Regional Background Concentrations of Heavy Metals (Cr, Co, Ni, Cu, Zn, Pb) in Coastal Sediments of the South Sea of Korea. *Science of The Total Environment*, **482**, 80-91.
<https://doi.org/10.1016/j.scitotenv.2014.02.068>
- [12] Momodu, M.A. and Anyakora, C.A. (2010) Heavy Metal Contamination of Ground Water: The Surulere Case Study. *Research Journal of Environmental and Earth Sciences*, **2**, 39-43.
- [13] Hughes, S. and Samman, S. (2006) The Effect of Zinc Supplementation in Humans on Plasma Lipids, Antioxidant Status and Thrombogenesis. *Journal of the American College of Nutrition*, **25**, 285-291. <https://doi.org/10.1080/07315724.2006.10719537>
- [14] Lenntech (2012) Chemical Properties of Cobalt, Health Effects of Cobalt and Environmental Effects of Cobalt. <https://www.lenntech.com/>
- [15] Msc, J.M.N. and Njagi, M. (2013) Assessment of Heavy Metal Concentration in the Environment and Perceived Health Risks by the Community around Kadhodeki Dumpsite, Nairobi County. Doctoral Dissertation, Kenyatta University.
- [16] Kenya National Bureau of Statistics (2019) Kenya Population and Housing Census

Volume I: Population by County and Sub-County. Vol. I.

- [17] Muchuma, K.F., Obando, J. and Kweyu, R. (2021) Land Use/Land Cover Change Detection Using Geospatial Techniques and Field Survey on Chetambe Hills in Bungoma County, Kenya. *Middle East Journal of Applied Science & Technology*, **4**, 80-93.
- [18] Kipseba, E., Ogora, M., Kotut, J., Kurgat, H., Borura, G. and Maina, G. (2008) Land-Slide Prone Areas along Part of the Nandi Escarpment. Unpublished Internal Report.
- [19] Gibson, A.B. (1954) Geology of the Broderick Falls Area: Degree Sheet 33, NE Quadrant (No. 26). Government Printer.
- [20] Omonya, W.F. (2021) Human Exposure and Associated Risks due to Natural Radioactivity and Heavy Metals in Ortum, West Pokot County, Kenya. Doctoral Dissertation, Kenyatta University.
- [21] Jenkins, D. (1998) The Effect of Reformulation of Household Powder Laundry Detergents on Their Contribution to Heavy Metals Levels in Wastewater. *Water Environment Research*, **70**, 980-983. <https://doi.org/10.2175/106143098x123309>
- [22] Beckhoff, B., Kanngießer, B., Langhoff, N., Wedell, R. and Wolff, H. (2007) Handbook of Practical X-Ray Fluorescence Analysis. Springer Science & Business Media.
- [23] IAEA (1987) IAEA-Soil-7, Report IAEA/RL/112.
- [24] IAEA (1997) Sampling, Storage and Sample Preparation Procedures for X Ray Fluorescence Analysis of Environmental Materials. Technical Reports Series No. 486, 10-11.
- [25] Wu, J., Long, J., Liu, L., Li, J., Liao, H., Zhang, M., *et al.* (2018) Risk Assessment and Source Identification of Toxic Metals in the Agricultural Soil around a Pb/Zn Mining and Smelting Area in Southwest China. *International Journal of Environmental Research and Public Health*, **15**, Article 1838. <https://doi.org/10.3390/ijerph15091838>
- [26] Hakanson, L. (1980) An Ecological Risk Index for Aquatic Pollution Control. A Sedimentological Approach. *Water Research*, **14**, 975-1001. [https://doi.org/10.1016/0043-1354\(80\)90143-8](https://doi.org/10.1016/0043-1354(80)90143-8)
- [27] Järup, L. (2003) Hazards of Heavy Metal Contamination. *British Medical Bulletin*, **68**, 167-182. <https://doi.org/10.1093/bmb/ldg032>
- [28] Codex Alimentarius Commission (2015) General Standards for Contaminants and Toxins in Food and Feed. 2015 Amendment (CODEX STAN 193-1995). International Food Standards. FAO/WHO, 59.
- [29] Wang, L.K., Chen, J.P., Hung, Y.T. and Shammas, N.K. (2009) Heavy Metals in the Environment. CRC Press.
- [30] Ojekunle, O.Z., Ojekunle, O.V., Adeyemi, A.A., Taiwo, A.G., Sangowusi, O.R., Taiwo, A.M., *et al.* (2016) Evaluation of Surface Water Quality Indices and Ecological Risk Assessment for Heavy Metals in Scrap Yard Neighbourhood. *SpringerPlus*, **5**, Article No. 560. <https://doi.org/10.1186/s40064-016-2158-9>
- [31] Wang, X., Zhang, L., Zhao, Z. and Cai, Y. (2018) Heavy Metal Pollution in Reservoirs in the Hilly Area of Southern China: Distribution, Source Apportionment and Health Risk Assessment. *Science of The Total Environment*, **634**, 158-169. <https://doi.org/10.1016/j.scitotenv.2018.03.340>
- [32] Zhao, H., Xia, B., Fan, C., Zhao, P. and Shen, S. (2012) Human Health Risk from Soil Heavy Metal Contamination under Different Land Uses Near Dabaoshan Mine, Southern China. *Science of The Total Environment*, **417**, 45-54. <https://doi.org/10.1016/j.scitotenv.2011.12.047>
- [33] Kowalska, J.B., Mazurek, R., Gąsiorek, M. and Zaleski, T. (2018) Pollution Indices as

Useful Tools for the Comprehensive Evaluation of the Degree of Soil Contamination–
a Review. *Environmental Geochemistry and Health*, **40**, 2395-2420.
<https://doi.org/10.1007/s10653-018-0106-z>