

Research Article

Trace Metal Contamination and Associated Ecological and Human Health Risk Assessment in Before Sediments of the Koko Watershed (Korhogo, Côte D'Ivoire)

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Abstract

The contamination of aquatic environments can be caused by several types of pollutants, notably heavy metals. Heavy metals present in ecosystems have become a significant environmental risk. Thus, sediments, which are the major sinks of these contaminants, may represent a significant environmental concern to human well-being, aquatic plants, and various benthic organisms. The objective of this study was to assess sediment quality in order to examine the potential ecological and health risks associated with heavy metal concentrations in sediments. Sediment samples streams and the river of the Koko watershed were collected and analyzed for the presence of Pb, As, Zn, Cu, Ni and Cr using atomic absorption spectrophotometry (AAS). The heavy metal concentrations obtained from the analysis revealed that highest average concentrations for Pb, Zn, Cu, Ni, and Cr were recorded during the dry season, with 35.60, 101.26, 23.36, 26.80, and 80.12 mg kg⁻¹, respectively, whereas As reached its highest average concentration during the rainy season (1.51 mg kg⁻¹). The results generally indicate that the accumulation of trace metals varies according to both the sampling site and the season. Comparison of our data with Upper Continental Crust (UCC) values indicates that the studied sediments are contaminated with Pb, As, Zn, Cu, Ni, and Cr in the dry season. This result is supported by the geo-accumulation index (I_{geo}), which generally indicates moderate contamination of sediments 1, 2, 3, and 5 by Pb, As, Zn, Cu, Ni, and Cr. The quality of the sediments indicates a potential toxic risk to benthic organisms at sediment 3 (PERI: 393.72) during the rainy season and in the dry season (PERI: 342.34). In the rainy season, the m-ERM-Q indicates a moderate-to-low probability of ecosystem hazard, although Ni poses a high-risk level in all sediments. But in the dry season, Ni has a moderate-to-high ecological impact on biota in all sediments.

Keywords

Heavy Metals, Sediment Quality Indices, Potential Ecological Risk, Potential Human Health Risk

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1. Introduction

Rapid urbanization, population growth, and expanding agriculture have significantly increased the release of contaminants into aquatic environments worldwide [1]. Among these, trace elements (TMEs) are of particular concern due to their persistence, toxicity, and potential for bioaccumulation in aquatic ecosystems [2]. Sediments play a crucial role in the geochemical cycling of TMEs, acting both as sinks that accumulate contaminants [3] and as potential secondary sources that may release them under changing environmental conditions [4, 5]. Consequently, assessing TMEs concentrations in sediments is essential for evaluating ecological risks and potential impacts on aquatic organisms [6] and human health [2].

In Côte d'Ivoire, anthropogenic discharges continue to pose significant environmental and public health challenges [7, 8]. The Koko Dam, located in Korhogo, is a major source of drinking water for the local population. Its tributaries flow through areas of intensive agricultural activity, including vegetable and rice cultivation, as well as artisanal activities such as scrap metal processing and brick production. Runoff and waste from these activities can introduce TMEs into the aquatic environment, leading to their accumulation in sediments [9].

Although previous studies have examined the physico-chemical characteristics of water in this watershed [10], sediment contamination by trace metals remains poorly studied. This study therefore aims to evaluate the contamination of sediments by Pb, Cr, Cd, As, Hg, Zn, Cu, and Ni in the waterways feeding the Koko Dam. The specific objectives are to: (i) determine metal concentrations in sediments, (ii) compare

these levels with established sediment quality guidelines [11] and (iii) assess the potential ecological and human health risks associated with metal contamination [12, 13].

We hypothesize that sediments from the Koko Dam tributaries are significantly contaminated with trace metals due to surrounding agricultural and artisanal activities. These elevated concentrations are expected to pose ecological risks to benthic organisms and potential human health risks through bioaccumulation and exposure. We further anticipate spatial variability in contamination along the watershed, reflecting differences in land use intensity, and that certain metals (e.g., Pb, Cd, Hg) may exceed international sediment quality guidelines [11].

2. Materials and Methods

2.1. Study Area and Sediment Sampling

Two sampling campaigns were conducted in the Koko Basin at five sites along the study area during two periods: the rainy season (30 September 2023) and the dry season (20 May 2023), as shown in Figure 1. The coordinates of the sampling points were recorded using a Garmin GPS of the sampling points in Figure 1 and Table 1. A total of 10 samples were collected, including 5 samples in the rainy season and 5 samples during the dry season. The collected sediments were placed in pre-labeled plastic bags and stored in a cooler at 4 °C before being transported to the laboratory for analysis.

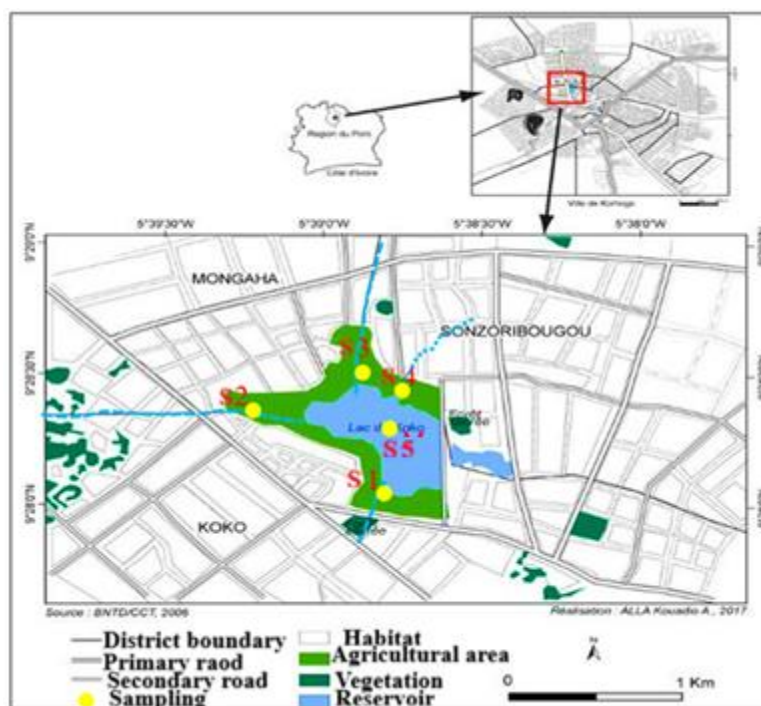


Figure 1. Location of the study area ([3], modified by [4]).

Table 1. Geographical coordinates of the sample collection points.

Tributary an river	Sediment	X	Y
Tributary 1	S1	30 P 0209281	1047317
Tributary 2	S2	31 P 0208769	1047848
Tributary 3	S3	30 P 0209231	1048197
Tributary 4	S4	30 P 0209598	1047910
River	S5	30 P 0209432	1047899

2.2. Chemical Treatment of the Fine Fraction

The sediments were dried in an oven at 105 °C for 5 hours. They were then ground in a porcelain mortar, and then sieved through a 63 µm mesh. The fine fraction (< 63 µm) was retained as it has a higher affinity for trace metals [14]. A 0.5 g aliquot of the sediment was used for the analyses. The digestion of the elements in this fine fraction was performed at high temperature by a mixture of 4 mL of aqua regia (hydrochloric acid (37%), nitric acid (65%). Three milliliters of hydrofluoric acid were added to Teflon vials (numbers <10 are spelled out in formal writing; capitalization of “Teflon”) to dissolve all silicates. After a resting period at ambient temperature, the residue was collected in a boric acid solution (2.7 g in 20 mL of double-distilled water). Bi-distilled water was then added to bring the final volume to 50 mL. The mineralized solution, i.e., the supernatant liquid obtained after decantation, was then analyzed using an atomic absorption spectrophotometer (AAS). The trace metals (Pb, As, Zn, Cu, Ni and Cr) were quantified by Atomic Absorption Spectrophotometry (AAS). To ensure the accuracy of the analytical results, blanks and a certified reference sediment (BCR-320) were treated. The whites correspond to acid attacks and bi-distilled water without sediments. allowing verification of the absence of contamination from the equipment. The certified sediment was subjected to the same treatment as the sediment samples, enabling evaluation of the precision of the measurements. The metal concentration was determined using a specific formula (1).

$$C = ((A - B)/m) * 50 \quad (1)$$

C = Concentration of the metal (mg/kg)
 A = brut concentration of the metal (mg/L)
 B = brut concentration of the white (mg/L)
 m = mass (g) of the sample
 50 = final volume after mineralization

2.3. Data Processing

2.3.1. Geoaccumulation Index

The geoaccumulation index (Igeo) can be used to assess the degree of metal pollution in sediments [15]. It is based on the

comparison between the concentration of a metal in the analyzed sediment and the local geochemical background value, using the following formula (2):

$$I_{geo} = \log_2 (C_n/1.5FGx) \quad (2)$$

In this formula, C represents the concentration of a metal in the sediment, and FG represents the local geochemical background concentration of that same metal. The factor 1.5 accounts for the natural fluctuations in the concentration of a given metal in the sediment. The values of Igeo are used to classify pollution intensity ranging from class 0 (no pollution) to class 6 (extremely polluted). The assessment of metal contamination based on the Igeo is presented in Table 2.

Table 2. Assessment of metal contamination based on the Igeo [15].

Class	Value	Pollution intensity
0	$I_{geo} \leq 0$	unpolluted
1	$0 < I_{geo} < 1$	unpolluted to moderately polluted
2	$1 < I_{geo} < 2$	moderately polluted
3	$2 < I_{geo} < 3$	Moderately to strongly polluted
4	$3 < I_{geo} < 4$	Strongly polluted
5	$4 < I_{geo} < 5$	Strongly to extremely polluted
6	$5 < I_{geo}$	Extremely polluted

2.3.2. Evaluation of Potential Ecological Risk

The Potential Ecological Risk Index (PERI), introduced by [16], provides a framework for evaluating ecological risk in aquatic environments. The potential ecological risk factor for an individual heavy metal (Er) in Table 3 and the comprehensive potential ecological risk index (PERI) in Table 4, were calculated using the following equations (3) [16]:

$$ER_i = T_r^i \times C_f^i \quad (3)$$

Where

T_r^i : Toxicity factor of element i [16] The Tri values are 5, 10, 1, 5, 5, and 2 for Pb, As, Zn, Ni, Cu, and Cr, respectively.

C_f^i : contamination factor of element i, defined by (4):

$$C_f^i = \frac{C_i}{C_n^i} \quad (4)$$

Where:

C_i is the measured concentration of element i in the sediment (or soil);

C_n^i is the background concentration (reference value or natural geochemical value) of element i. The following terminology is used to describe the ecological risk factor (Er) [16]:

Table 3. Risk grades potential ecological risks of heavy metal pollution.

Values of ER_i	Level of ecological risk
$ER_i < 40$	Low potential ecological risk
$40 < ER_i < 80$	Moderate potential ecological risk
$80 < ER_i < 160$	Considerable potential ecological risk
$160 < ER_i < 320$	High potential ecological risk
$ER_i > 320$	Very high ecological risk

Analogous to the previous calculation of the potential ecological risk factor (Er) [17] defines the potential ecological risk index (PERI) as the sum of the individual risk factors, as shown in equation (5):

$$PERI = \sum_{i=1}^n ER_i \quad (5)$$

The following terminology is used to describe the potential ecological risk index (PERI) [17]:

Table 4. Risk grades potential ecological risk index of heavy metal pollution.

Values of PERI	Level of ecological risk
$PERI < 150$	Low ecological risk
$150 < PERI < 300$	Moderate ecological risk
$300 < PERI < 600$	Considerable ecological risk

Table 5. Interpretation of m-ERM-Q and PEL-Q scores [18].

Values of m-ERM-Q	Probability of toxic biological effects	Values de m-PEL-Q	Probability of toxic biological effects
$m-ERM-Q > 1.5$	high	> 2.3	high
$1.5 > m-ERM-Q > 0.51$	moderate to high	$2.3 > m-PEL-Q > 1.51$	moderate to high
$0.5 > m-ERM-Q > 0.11$	Low to moderate	$1.5 > m-PEL-Q > 0.11$	Low to moderate
$m-ERM-Q < 0.1$	Low	$m-PEL-Q < 0.1$	Low

2.3.4. Human Health Risk Assessment

Human health risk assessment (HHRA) of sediments is commonly used to assess both carcinogenic and non-carcinogenic risks to people exposed to heavy metal. The HHRA technique was based on the US Environmental Protection Agency's guidelines and exposure factors handbook [12, 13].

Values of PERI	Level of ecological risk
$PERI > 600$	Very high ecological risk

2.3.3. Mean ERM Quotient (m-ERM-Q) and Mean PEL Quotient (m-PEL-Q)

To evaluate the potential biological effects of combined toxicants based on sediment quality guidelines (SQGs), we calculated these mean quotients are associated with the probability of toxicity and two factors were calculated using the following equations [18]:

$$m-ERM-Quotient = \frac{\sum_{i=1}^n \left(\frac{C_i}{ERM_i}\right)}{n} \quad (6)$$

$$m-PEL-Quotient = \frac{\sum_{i=1}^n \left(\frac{C_i}{PEL_i}\right)}{n} \quad (7)$$

In this context, C_i represents the concentration of the contaminant (TMEs) in the sediment, while PEL_i and ERM_i denote the respective screening levels based on the sediment quality guidelines (SQGs). The variable 'n' signifies the number of contaminants under consideration in the study area. The evaluation of the potential ecological impact of TMEs has led to the characterization of four relative priority levels of contamination, as delineated in previous studies in Table 5 [19, 20]. The values of l'EMR (Effects-Range Median) are (Long, 1995): Cu (270 $\mu\text{g/g}$), Ni (51,6 $\mu\text{g/g}$), Zn (410 $\mu\text{g/g}$), Cd (9,6 $\mu\text{g/g}$) et Pb (218 $\mu\text{g/g}$). The values of PEL (Probable Effect Level) are (Long, 1995): Cu (270 mg/kg), Ni (36 mg/kg), Zn (315 mg/kg), Cd (3,53 mg/kg) et Pb (91, 3 mg/kg).

The average daily doses (ADD) (mg/kgday) of through ingestion (ADD_{ing}), inhalation (ADD_{inh}), and dermal contact (ADD_{der}) for both children and adults were calculated by using Equations as follows (8), (9), (10):

$$ADD_{der} = \frac{C \times SA \times AF \times FE \times ABS \times EF \times ED \times CF}{BW \times AT} \quad (8)$$

$$ADD_{ing} = \frac{C \times IngR \times EF \times ED \times CF}{BW \times AT} \quad (9)$$

$$ADD_{inh} = \frac{C \times InhR \times EF \times ED}{PEF \times BW \times AT} \quad (10)$$

Where all the abbreviations are given and explained in Table 1. According to Tables 6 and 7, the factors that were used to estimate the human health risks were chosen according to the literature [21-24] due to the unavailability of relevant data for our study area. To determine the non-carcinogenic risk, the hazard quotient (HQ) and the hazard index (HI) are calculated (11) and (12):

$$HI = \sum HDi = \sum \left(\frac{ADD_i}{RfDi} \right) \quad (11)$$

$$Total\ Life\ Cancer\ Risk = LCR_{ingest} + LCR_{dermal} + LCR_{inhale} \quad (14)$$

where ADD is the average daily dose (mg/kg/day), k is each exposure route and SF (mg/kg/day) is the cancer slope factor. Risks $> 1 \times 10^{-4}$ are viewed as unacceptable, risks $< 1 \times 10^{-6}$ are not considered to pose significant health effects, and risks ranging between 1×10^{-4} and 1×10^{-6} are generally considered acceptable, depending on the exposure circumstances [25, 26].

3. Results and Discussion

3.1. Concentration of Heavy Metals in Sediments

The Figure 2 shows the variation in metal concentration levels based on climatic seasons and their distribution in the koko basin. We observe that Pb, Zn, and Cr concentration levels are higher in the dry season than in the rainy season in all sediments. In contrast, Ni and Cu concentrations are low in the dry season in sediment S2 (Ni) and in sediment S4 (Cu), respectively. Finally, As shows high concentrations in sediments S2, S3, S4, and S5 in the rainy season, except in sediment S1, its concentration is higher in the dry season. Analysis of Table 8 indicates the average concentration of as is lower

$$HI = \sum HQi = HQ_{ingestion} + HQ_{Dermal} \quad (12)$$

than the recommended limit value [11] in the sediments. Moreover, in both the rainy and dry seasons, the average concentration of Cu exceeds the accepted sediment for sediments (14 mg/kg). As for Pb, Zn, Ni, and Cr, their average concentrations in the dry season are nearly twice the recommended sediment limit values in the sediments [11]. We observed that trace metal concentrations in sediments are higher in the dry season than in the rainy season. In the rainy season, sediments are resuspended, promotes the mobility of trace metals, which are either in particulate form or dissolved in the water column [27]. However, in the dry season, low water flow allows these metallic elements to interact with suspended particulate matter present in the water and settle to the bottom [28]. Also, these low concentrations in the rainy season can likely be attributed to dilution caused by the influx of less contaminated or uncontaminated sediments [29]. By contrast, during the dry season, suspended particles settle, and trace metals are sequestered in the sediments [30]. The results from this study indicate that the average concentrations of Ni, Cu, and As are lower than those reported by [31] at the Nangbáo Hydroelectric Dam. However, the average concentrations of Pb and Zn are higher than those reported by [32] at the Koudiet Medouar Dam (Togo) [31].

$$Life\ Cancer\ Risk = ADD_k \times SF_k \quad (13)$$

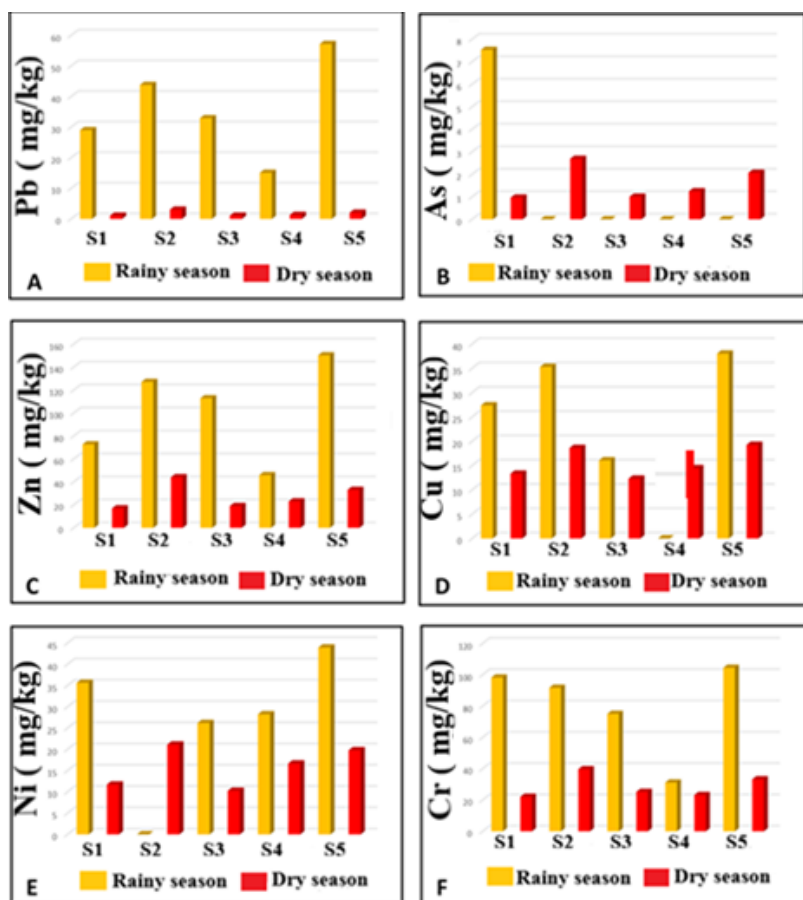
Table 6. Recommended standard values for dusts health risk assessment.

Parameters	Pb (mg/kg/day)	As (mg/kg/day)	Zn (mg/kg/day)	Cu (mg/kg/day)	Ni (mg/kg/day)	Cr (mg/kg/day)
RFDing	0.0035	3.00E-04	0,3	0,0371	0,02	0.003
RFDinh	3.50E-02	1.00E-03	-	-	-	0.0001
RFDdermal	5.25E-04	1.00E-05	0,009	0,0012	$8,0 \times 10^{-4}$	0.00006
CSFing	0.0085	1.5	-	-	-	0.5
CSFinh	4.20E-02	1.50E+01	-	-	0,84	4.10E-01
CSFdermal	-	1.5	-	-	-	2.0E+1

Table 7. Values of parameters used for non-carcinogenic risk assessment.

Parameters	Symbol	ADULT	CHILD
Ingestion rate	IngR	100 mg	200 mg
Exposure duration	ED	24 years	6 years
Exposure frequency	EF	350 days	350 days
Average body weight	BW	70	15 kg
Averaging time (AT)	ATnon-carcinogenic	ED × 365 days	ED × 365 days
	ATcarcinogenic	70 × 365 days	70 × 365 days
Conversion factor	CF	1 × 10 ⁻⁶ kg/mg	1 × 10 ⁻⁶ kg/mg
Surface area of skin	SA children	5800 cm ²	2800 cm ²
Skin adherence factor	AF _{dust}	0.07 mg/cm ² /day	0.2 mg/cm ² /day
Dermal absorption factor	ABS non-carcinogenic	0.001 mg/cm ²	0.001 mg/cm ²
	ABS carcinogenic	0.03 mg/cm ²	0.03 mg/cm ²
Inhalation rate	InhR	20	10 m ³ /day
Particle emission factor	PEF	1.36 × 10 ⁹ m ³ /kg	1.36 × 10 ⁹ m ³ /kg
Dermal exposure ratio	FE	0.61	0.61

3.2. Geo-accumulation Index (Igeo)

**Figure 2.** Temporal distributions of heavy metal concentrations in sediments.

The results of the calculated Igeo in Figure 3 show that Pb, As, Zn, Cu, Ni, and Cr indicate no pollution during the rainy season. In the dry season, moderate pollution is indicated in the sediments S1, S2, S3 and S5. However, we observed no pollution during the dry season in sediment S4. It is well known that various anthropogenic activities can alter the dynamics of a watercourse and introduce a variety of heavy metals into the sediments [33, 34]. Pb contamination may result from fertilizers and biocides (pesticides, preservatives) used in agricultural activities carried out around the Koko watershed.

Canadian research has shown that various fertilizer formulations can contain up to 3.54 mg/kg Pb and 6.29 mg/kg Cd [35]. Biocides contain As, Hg, Pb, Cu, Sn, Zn and Mn while fuels contain Ni, Hg, Cu, Fe, Mn, Pb and Cd [36].

3.3. Evaluation of the Potential Ecological Risk Index (PERI)

Potential ecological factor results highlight the significant impact of TMs on the watershed biota in Figures 4 and 5. In

the rainy season, Pb and Ni indicated a considerable potential with a value of 85.77 and 83.08 respectively in the sediment S3. Furthermore, As, Zn, Cu and Cr confirmed a moderate potential ecological risk with respectively 46,46 (sediment S4); 44, 13 (sediment S2); 58, 14 (sediment S3); 65, 97 (sediment S3) and 79, 91 (sediment S3). following the studies area in rainy season, sediment S3 can be assigned with considerable ecological risk (PERI: 393.72 During the dry season, Pb, Cu, Ni, and Cr exhibited moderate potential ecological risk, with values of 43.81 (sediment S2), 41.96, 69.81, and 53.45 (sediment S3), respectively.

But Pb, Zn and Cr indicated a moderate potential ecological risk with respectively 96,41; 80,41 (sediment S3) and 91,7 (sediment S2). A high potential ecological risk manifested by Zn with 127.06 in sediment S2. Based on the overall assessment in dry season, sediment S2 can be assigned with moderate ecological risk (PERI: 393.72) and sediment S3 showed considerable ecological risk (PERI: 342.34). The low toxicity values of certain heavy metals in sampling areas may mask chronic accumulation that could induce long-term effects on benthic organisms [37].

Table 8. Concentrations (in mg/kg) of trace metals in the sediments of the KOKO watershed.

ETM	Rainy season			Dry season			Value UCC
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	
Pb	1,09	3,06	1,73	15,07	57,18	35,60	17
As	0,97	2,69	1,60	0,00	7,53	1,51	2
Zn	17,01	44,13	27,27	45,90	150,22	101,76	52
Cu	12,30	19,26	15,59	0,00	38,03	23,36	14
Ni	10,25	21,12	15,90	0,00	43,94	26,80	19
Cr	22,10	39,70	28,70	31,17	104,46	80,12	35

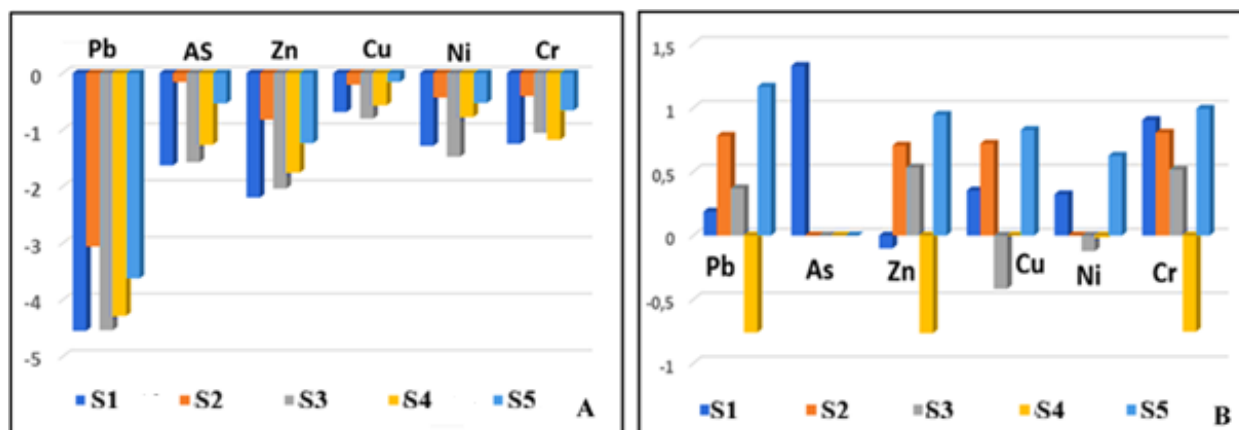


Figure 3. Geo-accumulation indices of metals in the sediments of the Koko watershed: A (rainy season) and B (dry season).

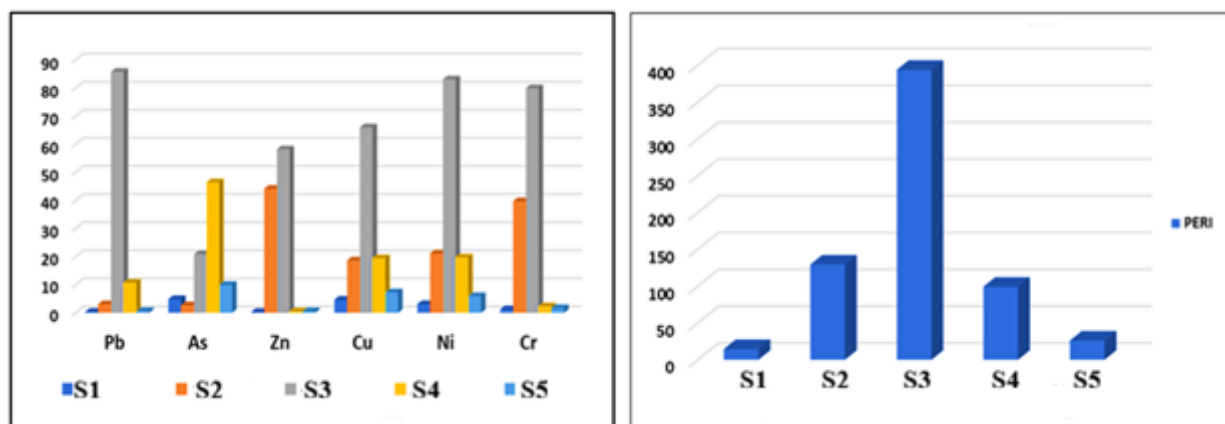


Figure 4. Variation in the potential ecological risk (Er; PERI) in surficial sediment in the rainy season.

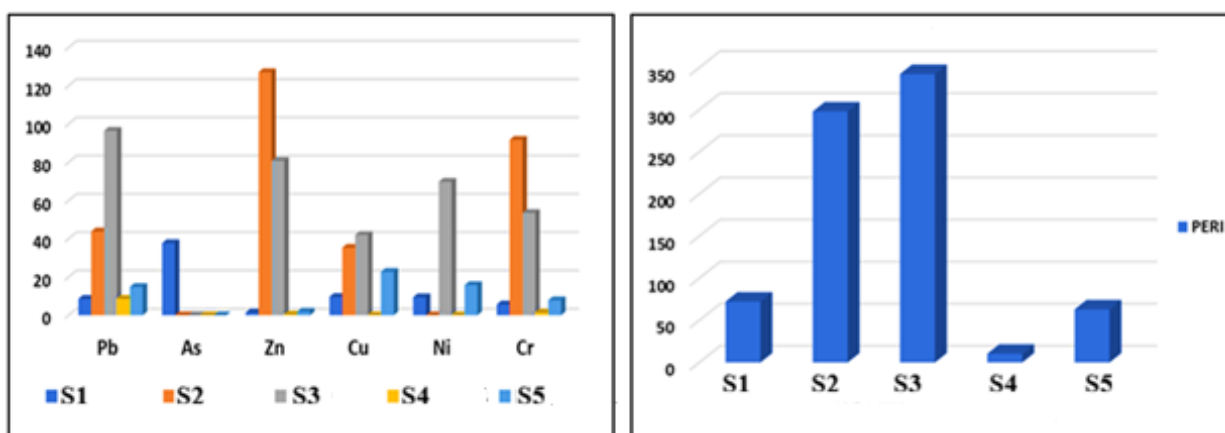


Figure 5. Variation in the potential ecological risk (Er; PERI) in surficial sediment in the dry season.

3.4. Determination of Sediment Quality

The findings of the mean ERM and PEL quotients are depicted in the Figures 6 and 7 below. In the rainy season, the m-ERM-Q indicates a Low probability of ecosystem hazard, corresponding to a Low-risk level for Pb, As Cu and Cr in all the sediments. For Zn, the m-ERM-Q similarly indicates a low probability of ecological risk in sediments S1, S3, and S4. However, benthic organisms living in sediments S1 and S5 are exposed to a medium-low toxic risk, corresponding to a high-risk level for Zn. The m-ERM-Q indicates a moderate-low probability of ecosystem hazard, corresponding to a high-risk level for Ni for all sediments. In conclusion, the probability for these sediments to be toxic to benthic organisms is 40% (Figure 6).

Values of m-PEL-Q less than 0.1 constitute the first category of toxic risk. Heavy metals (Pb, As, Cu), whose values are in this interval, occur at the level of sediments S1, S2, S3, S4 and S5. In contrast, Zn values are lower than 0.1 in sediments 1, 3, 4, and 5. Benthic organisms are not exposed to toxic risk. In the second category, the values of toxic risk range between 0.11 and 0.15. The sediments concerned are

found in the tributaries and the main river for Ni and Cr. Sediments of tributary 2 are also included. The poor quality of the sediments exposes benthic organisms to a low to moderate toxic risk. In conclusion, the probability that these sediments are toxic to benthic organisms is 100% in Figure 6. In the dry season, the m-ERM-Q indicates a Low probability of ecosystem hazard, corresponding to a Low-risk level for As and Cu all sediments. For Cr, the m-ERM-Q indicates a medium low probability of ecosystem hazard in all sediments. However, the m-ERM-Q indicates a Medium low probability of ecosystem hazard for Pb and Zn respectively in sediments 1, 2, 3 and 4. The Ni emerge as the heavy metals exerting the medium high substantial ecological impact on the biota in all sediments. The m-ERM-Q indicates a moderate- high probability of ecosystem hazard, corresponding to a high-risk level for Pb and Zn for le sediment 5. In conclusion, the probability for the sediments exhibiting a low a moderate to low risk is 80%, compared to 20% for a moderate to high toxic risk for benthic organisms (Figure 7). The heavy metals As, Cu, and Ni have m-PEL-Q values lower than 0.1. Values in this range are found in sediments S2, S3, S4, and S5 for As; S3 and S4 for Cu; and finally, S2 for Ni. The benthic organisms in these areas are not exposed to a toxic risk. In the category of toxic risk values

ranging from 0.11 to 1.5. it includes all sediments contaminated Pb, Zn, and Cr. Similarly, sediments from tributary 1 (As, Cu), tributary 2, and the river (Cu) are also concerned. These sediments may be toxic to benthic organisms. In conclusion, the probability that these sediments are toxic to benthic organisms is 100% in Figure 7.

3.5. Human Health Risk Assessment

Different contact routes for heavy metal exposure to individuals were studied. The results for the Hazard Quotient and carcinogenic risk for the three exposure pathways (namely: ingestion, Dermal and Inhalation) is as shown in Table 9 and Table 10. the Hazard index and Total life cancer risk (TLCR) are shown in Table 11 and Table 12.

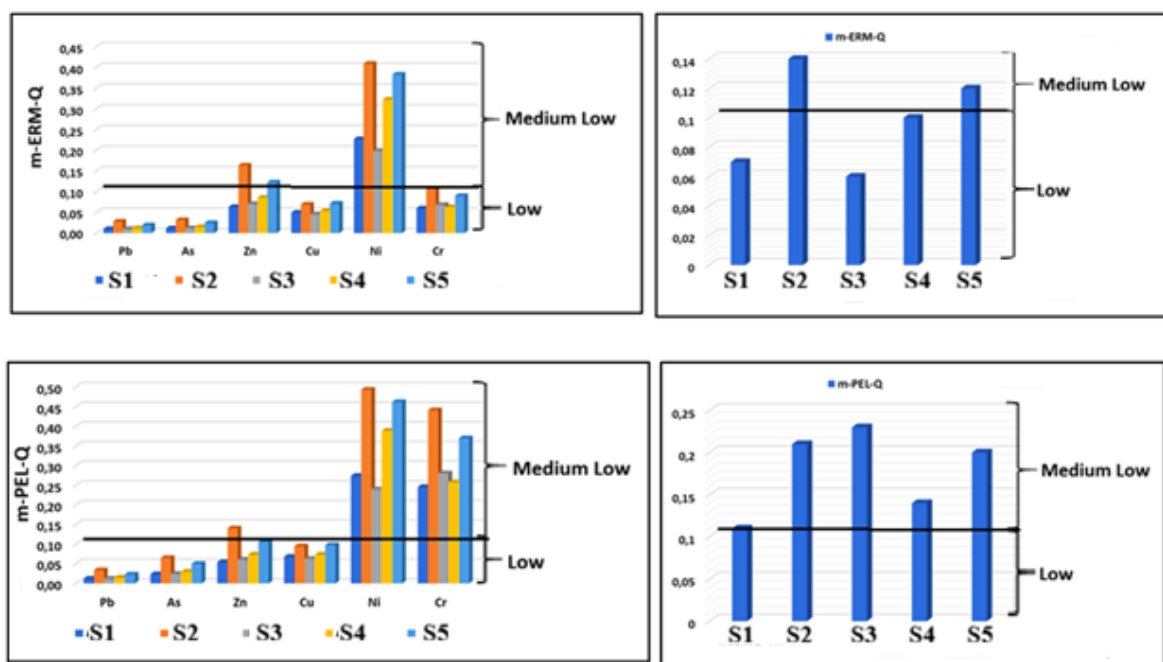


Figure 6. Variation in the mean ERM Quotient ($m\text{-ERM-Q}$) and mean PEL Quotient ($m\text{-PEL-Q}$) in the rainy season.

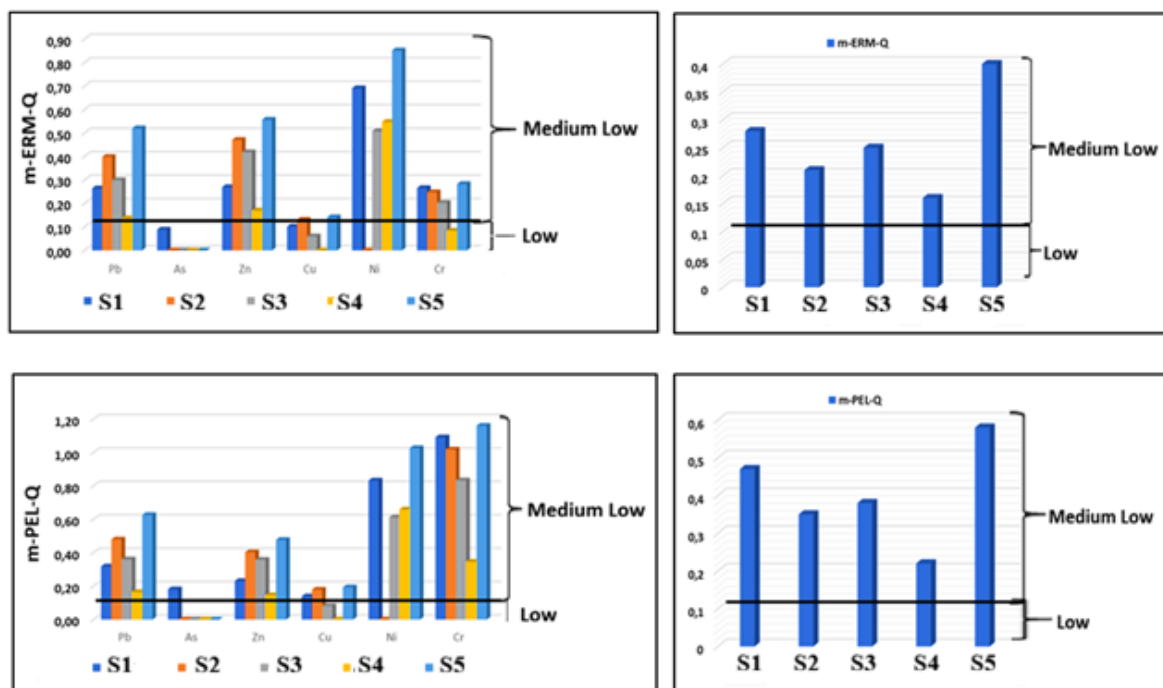


Figure 7. Variation in the mean ERM Quotient ($m\text{-ERM-Q}$) and mean PEL Quotient ($m\text{-PEL-Q}$) in the dry season.

3.5.1. Quantification of Non-carcinogenic Effects in Dry Season

According to Table 9, the HQ for ingestion were below the reference doses (RFD) as recommended by USEPA. HQ ingestion has a range from 1.46×10^{-4} to 4.11×10^{-4} ; 1.52×10^{-3} to 4.21×10^{-3} ; 2.66×10^{-5} to 6.91×10^{-5} ; 1.56×10^{-4} to 2.44×10^{-4} ; 2.75×10^{-4} to 4.96×10^{-4} ; 3.46×10^{-3} to 6.22×10^{-3} for Pb, As, Zn, Cu, Ni, and Cr ingestion respectively in adults whereas. That of children ranged from 1.59×10^{-3} to 4.47×10^{-3} ; 1.65×10^{-2} to 4.59×10^{-2} ; 2.90×10^{-4} to 7.52×10^{-4} ; 21.70×10^{-3} to 2.65×10^{-3} ; 2.62×10^{-3} to 5.40×10^{-3} ; 3.77×10^{-3} to 6.77×10^{-3} for Pb, As, Zn, Cu, Ni, and Cr, respectively for ingestion. The maximum levels were seen at sediment S2, for Pb, As, Zn, Ni, and Cr whereas the sediment S5, has the maximum level for Cu. The average Hazard Quotients (HQ) for dermal contact in adults ranged as follows from 2.37×10^{-6} to 4.51×10^{-6} ; 9.24×10^{-6} to 2.56×10^{-5} ; 2.16×10^{-6} to 5.61×10^{-6} ; 1.38×10^{-5} to 1.83×10^{-5} , for Pb, As, Zn, and Cu for adult Population and 1.30×10^{-5} to 5.17×10^{-5} ; 5.24×10^{-5} to 2.01×10^{-4} ; 1.32×10^{-5} to 4.71×10^{-5} ; 6.38×10^{-5} to 2.77×10^{-5} , for Pb, As, Zn, and Cu for children. The maximum levels were seen in adults at the sediment S2 for Zn and Cr, and at the river for Pd and Cu. In contrast, in children, the sediment S1 has the maximum level for all. The average Hazard Quotients (HQ) for inhalation in adults ranged as follows from 2.15×10^{-9} to 6.04×10^{-9} ; 6.70×10^{-8} to 3.78×10^{-11} and 1.53×10^{-5} to 2.74×10^{-5} for Pb, As, and Cr respectively for adult and 5.91×10^{-9} to 1.64×10^{-8} ; 1.90×10^{-7} to 5.06×10^{-7} and 4.36×10^{-5} to 8.31×10^{-5} for Pb, As, and Cr respectively for children. The maximum levels of exposure for adults were observed at sediment S2 for Pb and Cr, and at the river for As. In contrast, for children, the highest levels were recorded at sediment S2 for Pb and As, and at tributary 1 for Cr. The Hazard Index (HI) values for the respective heavy metals across the sampled waters for adults followed the order:

Pb: S2 > S5 > S4 > S3 > S1

As: S2 > S5 > S4 > S3 > S1

Zn: S2 > S5 > S4 > S3 > S1

Cu: S5 > S2 > S4 > S1 > S3

Ni: S2 > S5 > S4 > S1 > S3

Cr: S2 > S5 > S4 > S3 > S1

For children

Pb: S2 > S5 > S4 > S3 > S1

As: S2 > S5 > S4 > S3 > S1

Zn: S2 > S5 > S4 > S1 = S3

Cu: S5 > S2 > S4 > S1 > S3

Ni: S2 > S5 > S4 > S1 > S3

Cr: S2 > S5 > S3 > S4 > S1

The HI values obtained from this study were less than one as set by USEPA, [38] for both adult and children. This however indicates that the region may be relatively free from non-carcinogenic risks due to ingestion, inhalation and dermal contact. However, it was observed that the sediments S2 and

S5 They may present long-term effects non carcinogenic risks for population.

3.5.2. Quantification of Non-carcinogenic Effects in Rainy Reason

According to Table 10, the Hazard Quotients (HQ) for ingestion were all below the reference doses (RFD) as recommended by USEPA. HQ ingestion has a range from 2.02×10^{-3} to 7.67×10^{-3} ; 0 to 1.8×10^{-2} ; 1.14×10^{-4} to 7.19×10^{-5} ; 2.03×10^{-4} to 4.81×10^{-4} ; 6.15×10^{-4} to 1.03×10^{-3} ; 4.88×10^{-3} to 1.64×10^{-3} for Pb, As, Zn, Cu, Ni, and Cr ingestion respectively in adults whereas. That of children ranged from 12.20×10^{-2} to 8.36×10^{-2} ; 0 to 1.28×10^{-1} ; 7.82×10^{-4} to 2.56×10^{-3} ; 0 to 5.24×10^{-3} ; 0 to 9.11×10^{-3} ; 5.31×10^{-2} to 1.78×10^{-1} for Pb, As, Zn, Cu, Ni, and Cr, respectively for ingestion. The maximum levels were seen in adults at sediment S1 for As, sediment S4 for Zn and at the sediment S5 for Pb Cu, Ni and Cr. In contrast in children, the maximum levels were seen at sediment S1 for As and Ni, and at the sediment S5 for Pb, Zn, Cu and Cr.

The average dermal Hazard Quotients (HQ) for adults ranged from 3.28×10^{-5} to 1.25×10^{-4} ; 0 to 7.17×10^{-5} ; 5.83×10^{-6} to 1.91×10^{-5} ; 0 to 3.62×10^{-5} , for Pb, As, Zn, and Cu for adult and 1.79×10^{-4} to 1.38×10^{-3} ; 0 to 1.56×10^{-3} ; 3.17×10^{-5} to 2.01×10^{-4} ; 0 to 5.68×10^{-4} for Pb, As, Zn, and Cu for children. The maximum levels were seen in adults at sediment S1 for As and at the sediment S5 for Pb, Zn and Cu. In contrast, in children, the sediment S1 has the maximum level for all. The average inhalation Hazard Quotients (HQ) for adults ranged from 2.97×10^{-8} to 1.13×10^{-7} ; 0 to 5.20×10^{-7} and 2.15×10^{-5} to 7.21×10^{-5} for Pb, As, and Cr respectively for adult Population and 8.10×10^{-8} to 3.12×10^{-7} ; 0 to 2.83×10^{-6} and 5.86×10^{-5} to 3.69×10^{-4} for Pb, As, and Cr respectively for children. The maximum levels were seen in adults sediment S1 for As and at the sediment S5 for Pb and Cr. In contrast, in children, the sediment S1 has the maximum level for all.

The values of HI followed the following order for the respective heavy metals across the sampled sediments:

for adults

Pb: S5 > S2 > S3 > S1 > S4

As: S1

Zn: S5 > S2 > S3 > S1 > S4

Cu: S5 > S2 > S1 > S3

Ni: S5 > S1 > S4 > S3

Cr: S5 > S1 > S2 > S3 > S4

For children

Pb: S5 > S2 > S3 > S1 > S4

As: S1

Zn: S5 > S2 > S3 > S1 > S4

Cu: S5 > S2 > S1 > S3

Ni: S5 > S1 > S4 > S3

Cr: S5 > S1 > S2 > S3 > S4

Smoother phrasing: “The Hazard Index (HI) values obtained in this study were all below 1, as recommended by USEPA [32] for both adult and children. This however indicates that the region may be relatively free from non-carcinogenic risks due to ingestion, inhalation and dermal contact. However, it was observed that the sediments S2, S1 and S5 may present potential long-term non-carcinogenic effects.

3.5.3. Carcinogenic Risk Exposure Ria Sediments in Dry Season

The Table 11 shows Carcinogenic risk exposure via the sediments in dry season. LCR ingestion has a range from $7,24 \times 10^{-5}$ to $1,69 \times 10^{-4}$; $3,04 \times 10^{-7}$ to $8,42 \times 10^{-7}$; $2,08 \times 10^{-5}$ to $3,73 \times 10^{-5}$; for Pb, As, and Cr ingestion respectively in adults whereas. That of children ranged from $6,56 \times 10^{-4}$ to $1,84 \times 10^{-3}$; $3,31 \times 10^{-6}$ to $9,17 \times 10^{-6}$; $2,26 \times 10^{-4}$ to $4,06 \times 10^{-4}$ for Pb, As, and Cr, respectively for ingestion. The maximum levels were seen in adults at sediment S1 and S5 for Pb. In contrast in children, the maximum levels were seen at all sediments for Pb and Cr. LCR dermal has a range from $7,39 \times 10^{-10}$ to $12,05 \times 10^{-9}$; $1,26 \times 10^{-9}$ to $2,27 \times 10^{-9}$ for As and Cr skin respectively in adults whereas. That of children ranged from $4,19 \times 10^{-9}$ to $1,61 \times 10^{-8}$; $7,22 \times 10^{-9}$ to $1,03 \times 10^{-8}$ for As and Cr respectively for skin. All these values are significantly less than 1×10^{-6} . Average the LCR inhalation ranged from $1,81 \times 10^{-9}$ to $5,03 \times 10^{-9}$; $4,47 \times 10^{-12}$ to $1,24 \times 10^{-11}$; $8,43 \times 10^{-10}$ to $1,37 \times 10^{-9}$ and $3,72 \times 10^{-9}$ to $6,69 \times 10^{-9}$ for Pb, As, Ni and Cr respectively for adult and $4,92 \times 10^{-9}$ to $1,37 \times 10^{-8}$; $1,27 \times 10^{-11}$ to $3,37 \times 10^{-11}$; $2,29 \times 10^{-9}$ to $5,25 \times 10^{-9}$ and $1,06 \times 10^{-8}$ to $2,03 \times 10^{-8}$ for Pb, As, Ni and Cr respectively for children. All these values are significantly less than 1×10^{-6} . In the case of Cancer Risk (CR), Pb and Cr are metal the most dangerous concerning the ingestion in Table 11. Carcinogenic risks that exceed the Total life cancer risk (TLCR) acceptable values (10^{-4}) [38] were found in children exposed to Pb and Cr in all the sediments. However, in adults, the carcinogenicity risks exceed this acceptable value (10^{-4}) [38] for Pb in all sediments S4 and S5. Adults were seen to have Σ TLCR for Pb (sediments S1, S2, and S3) and Cr (all sediments) within the threshold range (10^{-6} to 10^{-4}). This entails that the adults are less exposed to the risk of cancer associated with exposure to sediments containing these heavy metals (Pb, Cr). The cancer risk associated with HMs (As, Ni) in surface sediment samples considered negligible, with Total life cancer risk (TLCR) values below

the recommended limit As, and Ni for children and adults (according to [39]). This finding confirms the absence of any significant lifetime cancer risk for these elements in Table 11.

3.5.4. Carcinogenic Risk Exposure via the Sediments in Rainy Season

The Table 12 shows Carcinogenic risk exposure via the sediments in dry season. LCR ingestion has a range from $8,33 \times 10^{-4}$ to $3,16 \times 10^{-3}$; 0 to $2,36 \times 10^{-6}$; 2, $2,93 \times 10^{-5}$ to $39,81 \times 10^{-5}$; for Pb, As, and Cr ingestion respectively in adults whereas. That of children ranged from $9,07 \times 10^{-3}$ to $3,44 \times 10^{-2}$; 0 to $2,57 \times 10^{-5}$; $7,67 \times 10^{-4}$ to $1,07 \times 10^{-3}$ for Pb, As, and Cr, respectively for ingestion. The maximum levels were seen in adults all the sediments for Pb. In contrast in children, the maximum levels were seen at all the sediments for Pb and Cr. LCR dermal has a range from 0 to $5,74 \times 10^{-9}$; $1,78 \times 10^{-9}$ to $5,97 \times 10^{-9}$ for As and Cr skin respectively in adults whereas. That of children ranged from 0 to $1,25 \times 10^{-7}$; $9,7 \times 10^{-9}$ to $1,22 \times 10^{-7}$ for As and Cr respectively for skin. All these values are significantly less than 1×10^{-6} . Average the LCR inhalation ranged from $2,48 \times 10^{-8}$ to $9,40 \times 10^{-8}$; 0 to $3,47 \times 10^{-11}$; $2,15 \times 10^{-9}$ to $3,61 \times 10^{-9}$ and $5,25 \times 10^{-9}$ to $1,76 \times 10^{-8}$ for Pb, As, Ni and Cr respectively for adult Population and $6,75 \times 10^{-8}$ to $2,60 \times 10^{-7}$; 0 to $1,89 \times 10^{-10}$; $9,84 \times 10^{-9}$ to $1,60 \times 10^{-8}$ and $1,43 \times 10^{-8}$ to $9,01 \times 10^{-8}$ for Pb, As, Ni and Cr respectively for children. All these values are significantly less than 1×10^{-6} . Same as in the rainy season, Pb and Cr are metal the most dangerous concerning the ingestion in Table 12. (Table 4). In adults, the total cancer risk (TCR) exceeds this acceptable value (10^{-4}) [38] for Pb in all sediments. Moreover, the average total cancer risk (TLCR) values for Cr in adults range from 10^{-6} to 10^{-4} , meaning that residents are very unlikely to be prone to cancer. Considering the carcinogenic risk on cumulative effect of the heavy metals assayed, it was observed that children in contact with these sediments, are exposed to carcinogenic risks as the Σ TLCR was seen to be above the range of threshold values (10^{-6} to 10^{-4}) above which environmental and regulatory agencies consider the risk unacceptable. The cancer risk associated with heavy metals (As, Ni) in sediment samples is negligible in adults and children. Total lifetime cancer risk (TLCR) values below the recommended limit confirm the absence of a significant cancer risk for these elements in Table 12.

Table 9. Mean values of Hazard Quotient for each exposure route for dry season.

Adults		Pb	As	Zn	Cu	Ni	Cr
S1	HQing	3,90E-03	1,18E-02	1,14E-04	3,47E-04	8,37E-04	1,54E-02
	HQder	6,32E-05	7,17E-05	9,24E-06	2,61E-05	-	-

Adults							
Sample		Pb	As	Zn	Cu	Ni	Cr
S2	HQInh	5,73E-08	5,20E-07	-	-	-	6,79E-05
	HI	3,96E-03	1,19E-02	1,23E-04	3,73E-04	8,37E-04	1,54E-02
	HQing	5,88E-03	-	1,99E-04	4,47E-04	-	1,44E-02
	HQder	9,54E-05	-	1,61E-05	3,36E-05	-	-
	HQInh	8,65E-08	-	-	-	-	6,33E-05
	HI	5,97E-03	-	2,15E-04	4,81E-04	-	1,44E-02
S3	HQing	4,42E-03	-	1,77E-04	2,03E-04	6,15E-04	1,17E-02
	HQder	7,17E-05	-	1,43E-05	1,53E-05	-	-
	HQInh	6,50E-08	-	-	-	-	5,18E-05
	HI	4,49E-03	-	1,91E-04	2,19E-04	6,15E-04	1,18E-02
S4	HQing	2,02E-03	-	7,19E-05	-	6,63E-04	4,88E-03
	HQder	3,28E-05	-	5,83E-06	-	-	-
	HQInh	2,97E-08	-	-	-	-	2,15E-05
	HI	2,06E-03	-	7,77E-05	-	6,63E-04	4,90E-03
S5	HQing	7,67E-03	-	2,35E-04	4,81E-04	1,03E-03	1,64E-02
	HQder	1,25E-04	-	1,91E-05	3,62E-05	-	-
	HQInh	1,13E-07	-	-	-	-	7,21E-05
	HI	7,80E-03	-	2,54E-04	5,18E-04	1,03E-03	1,64E-02
Children							
Sample		Pb	As	Zn	Cu	Ni	Cr
S1	HQing	4,24E-02	1,28E-01	1,24E-03	3,77E-03	9,11E-03	1,67E-01
	HQder	1,38E-03	1,56E-03	2,01E-04	5,68E-04	-	-
	HQInh	3,12E-07	2,83E-06	-	-	-	3,69E-04
	HI	4,38E-02	1,30E-01	1,44E-03	4,34E-03	9,11E-03	1,68E-01
S2	HQing	6,40E-02	-	2,17E-03	4,87E-03	-	1,56E-01
	HQder	5,19E-04	-	8,79E-05	1,83E-04	-	-
	HQInh	2,35E-07	-	-	-	-	1,72E-04
	HI	6,45E-02	-	2,25E-03	5,05E-03	-	1,56E-01
S3	HQing	4,81E-02	-	1,92E-03	2,22E-03	6,70E-03	1,28E-01
	HQder	3,90E-04	-	7,81E-05	8,33E-05	-	-
	HQInh	1,77E-07	-	-	-	-	1,41E-04
	HI	4,85E-02	-	2,00E-03	2,30E-03	6,70E-03	1,28E-01
S4	HQing	2,20E-02	-	7,82E-04	-	7,22E-03	5,31E-02
	HQder	1,79E-04	-	3,17E-05	-	-	-
	HQInh	8,10E-08	-	-	-	-	5,86E-05

Children							
Sample		Pb	As	Zn	Cu	Ni	Cr
S5	HI	2,22E-02	-	8,14E-04	-	7,22E-03	5,32E-02
	HQing	8,36E-02	-	2,56E-03	5,24E-03	1,12E-02	1,78E-01
	HQder	6,78E-04	-	1,04E-04	1,97E-04	-	-
	HQInh	3,07E-07	-	-	-	-	1,96E-04
	HI	8,42E-02	-	2,66E-03	5,44E-03	1,12E-02	1,78E-01

Table 10. Mean values of Hazard Quotient for each exposure route for rainy season.

Adults							
Sample		Pb	As	Zn	Cu	Ni	Cr
S1	HQing	1,46E-04	1,52E-03	2,66E-05	1,69E-04	2,75E-04	3,46E-03
	HQder	2,37E-06	9,24E-06	2,16E-06	1,27E-05	-	-
	HQInh	2,15E-09	6,70E-08	-	-	-	1,53E-05
	HI	1,49E-04	1,53E-03	2,88E-05	1,81E-04	2,75E-04	3,48E-03
S2	HQing	4,11E-04	4,21E-03	6,91E-05	2,36E-04	4,96E-04	6,22E-03
	HQder	6,66E-06	2,56E-05	5,61E-06	1,77E-05	-	-
	HQInh	6,04E-09	1,86E-07	-	-	-	2,74E-05
	HI	4,17E-04	4,24E-03	7,47E-05	2,53E-04	4,96E-04	6,24E-03
S3	HQing	1,48E-04	1,58E-03	2,98E-05	1,56E-04	2,41E-04	3,95E-03
	HQder	2,40E-06	9,62E-06	2,42E-06	1,17E-05	-	-
	HQInh	2,17E-09	6,98E-08	-	-	-	1,74E-05
	HI	1,50E-04	1,59E-03	3,22E-05	1,67E-04	2,41E-04	3,97E-03
S4	HQing	1,76E-04	1,96E-03	3,61E-05	1,83E-04	3,91E-04	3,63E-03
	HQder	2,85E-06	1,19E-05	2,93E-06	1,38E-05	-	-
	HQInh	2,59E-09	8,63E-08	-	-	-	1,60E-05
	HI	1,79E-04	1,97E-03	3,91E-05	1,97E-04	3,91E-04	3,65E-03
S5	HQing	2,78E-04	3,24E-03	5,18E-05	2,44E-04	4,64E-04	5,21E-03
	HQder	4,51E-06	1,97E-05	4,20E-06	1,83E-05	-	-
	HQInh	4,08E-09	1,43E-07	-	-	-	2,30E-05
	HI	2,82E-04	3,26E-03	5,60E-05	2,62E-04	4,64E-04	5,23E-03

Children							
Sample		Pb	As	Zn	Cu	Ni	Cr
S1	HQing	1,59E-03	1,65E-02	2,90E-04	1,84E-03	3,00E-03	3,77E-02
	HQder	5,17E-05	2,01E-04	4,71E-05	2,77E-04	-	-

Children							
Sample		Pb	As	Zn	Cu	Ni	Cr
S2	HQInh	1,17E-08	3,65E-07	-	-	-	8,31E-05
	HI	1,64E-03	1,67E-02	3,37E-04	2,11E-03	3,00E-03	3,78E-02
	HQing	4,47E-03	4,59E-02	7,52E-04	2,57E-03	5,40E-03	6,77E-02
	HQder	3,63E-05	1,40E-04	3,05E-05	9,65E-05	-	-
	HQInh	1,64E-08	5,06E-07	-	-	-	7,46E-05
	HI	4,51E-03	4,60E-02	7,83E-04	2,66E-03	5,40E-03	6,78E-02
S3	HQing	1,61E-03	1,72E-02	3,24E-04	1,70E-03	2,62E-03	4,30E-02
	HQder	1,30E-05	5,24E-05	1,32E-05	6,38E-05	-	-
	HQInh	5,91E-09	1,90E-07	-	-	-	4,74E-05
	HI	1,62E-03	1,73E-02	3,37E-04	1,76E-03	2,62E-03	4,31E-02
S4	HQing	1,91E-03	2,13E-02	3,94E-04	1,99E-03	4,26E-03	3,95E-02
	HQder	1,55E-05	6,48E-05	1,60E-05	7,50E-05	-	-
	HQInh	7,04E-09	2,35E-07	-	-	-	4,36E-05
	HI	1,93E-03	2,14E-02	4,10E-04	2,07E-03	4,26E-03	3,96E-02
S5	HQing	3,02E-03	3,53E-02	5,64E-04	2,65E-03	5,06E-03	5,67E-02
	HQder	2,45E-05	1,07E-04	2,29E-05	9,99E-05	-	-
	HQInh	1,11E-08	3,89E-07	-	-	-	6,25E-05
	HI	3,05E-03	3,54E-02	5,87E-04	2,75E-03	5,06E-03	5,68E-02

Table 11. Total life cancer risk in dry season.

Adults						
Sample		Pb	As	Ni	Cr	
S1	LCRing	1,60E-03	2,36E-06	-	-	9,23E-05
	LCRdermal	-	5,74E-09	-	-	5,62E-09
	LCRinh	4,77E-08	3,47E-11	2,93E-09	-	1,65E-08
	TLCR	1,60E-03	2,36E-06	2,93E-09	-	9,23E-05
S2	LCRing	2,42E-03	-	-	-	8,61E-05
	LCRdermal	-	-	-	-	5,24E-09
	LCRinh	7,20E-08	-	-	-	1,54E-08
	TLCR	2,42E-03	-	-	-	8,62E-05
S3	LCRing	1,82E-03	-	-	-	7,05E-05
	LCRdermal	-	-	-	-	4,29E-09
	LCRinh	5,42E-08	-	2,15E-09	-	1,26E-08
	TLCR	1,82E-03	-	2,15E-09	-	7,05E-05
S4	LCRing	8,33E-04	-	-	-	2,93E-05

Adults					
Sample		Pb	As	Ni	Cr
	LCRdermal	-	-	-	1,78E-09
	LCRinh	2,48E-08	-	2,32E-09	5,25E-09
	TLCR	8,33E-04	-	2,32E-09	2,93E-05
	LCRring	3,16E-03	-	-	9,81E-05
S5	LCRdermal	-	-	-	5,97E-09
	LCRinh	9,40E-08	-	3,61E-09	1,76E-08
	TLCR	3,16E-03	-	3,61E-09	9,81E-05
Children					
Sample		Pb	As	Ni	Cr
S1	LCRring	1,75E-02	2,57E-05	-	1,00E-03
	LCRdermal	-	1,25E-07	-	1,22E-07
	LCRinh	2,60E-07	1,89E-10	1,60E-08	9,01E-08
	TLCR	1,75E-02	2,58E-05	1,60E-08	1,01E-03
S2	LCRring	2,64E-02	-	-	9,38E-04
	LCRdermal	-	-	-	2,85E-08
	LCRinh	1,96E-07	-	-	4,21E-08
	TLCR	2,64E-02	-	-	9,38E-04
S3	LCRring	1,98E-02	-	-	7,67E-04
	LCRdermal	-	-	-	2,33E-08
	LCRinh	1,47E-07	-	5,86E-09	3,44E-08
	TLCR	1,98E-02	-	5,86E-09	7,67E-04
S4	LCRring	9,07E-03	-	-	3,19E-04
	LCRdermal	-	-	-	9,70E-09
	LCRinh	6,75E-08	-	6,32E-09	1,43E-08
	TLCR	9,07E-03	-	6,32E-09	3,19E-04
S5	LCRring	3,44E-02	-	-	1,07E-03
	LCRdermal	-	-	-	3,25E-08
	LCRinh	2,56E-07	-	9,84E-09	4,79E-08
	TLCR	3,44E-02	-	9,84E-09	1,07E-03

Table 12. Total life cancer risk in rainy season.

Adults					
Sample		Pb	As	Ni	Cr
S1	LCRing	6,02E-05	3,04E-07	-	2,08E-05
	LCRdermal	-	7,39E-10	-	1,26E-09
	LCRinh	1,79E-09	4,47E-12	9,64E-10	3,72E-09
	TLCR	6,02E-05	3,04E-07	9,64E-10	2,08E-05
S2	LCRing	1,69E-04	8,42E-07	-	3,73E-05
	LCRdermal	-	2,05E-09	-	2,27E-09
	LCRinh	5,03E-09	1,24E-11	1,74E-09	6,69E-09
	TLCR	1,69E-04	8,44E-07	1,74E-09	3,73E-05
S3	LCRing	6,08E-05	3,16E-07	-	2,37E-05
	LCRdermal	-	7,70E-10	-	1,44E-09
	LCRinh	1,81E-09	4,65E-12	8,43E-10	4,25E-09
	TLCR	6,08E-05	3,17E-07	8,43E-10	2,37E-05
S4	LCRing	7,24E-05	3,91E-07	-	2,18E-05
	LCRdermal	-	9,53E-10	-	1,33E-09
	LCRinh	2,15E-09	5,76E-12	1,37E-09	3,91E-09
	TLCR	7,24E-05	3,92E-07	1,37E-09	2,18E-05
S5	LCRing	1,14E-04	6,48E-07	-	3,12E-05
	LCRdermal	-	1,58E-09	-	1,90E-09
	LCRinh	3,40E-09	9,53E-12	1,63E-09	5,60E-09
	TLCR	1,14E-04	6,50E-07	1,63E-09	3,12E-05
Children					
Sample		Pb	As	Ni	Cr
S1	LCRing	6,56E-04	3,31E-06	-	2,26E-04
	LCRdermal	-	1,61E-08	-	2,75E-08
	LCRinh	9,76E-09	2,43E-11	5,25E-09	2,03E-08
	TLCR	6,56E-04	3,32E-06	5,25E-09	2,26E-04
S2	LCRing	1,84E-03	9,17E-06	-	4,06E-04
	LCRdermal	-	1,12E-08	-	1,24E-08
	LCRinh	1,37E-08	3,37E-11	4,73E-09	1,82E-08
	TLCR	1,84E-03	9,18E-06	4,73E-09	4,06E-04
S3	LCRing	6,62E-04	3,44E-06	-	2,58E-04
	LCRdermal	-	4,19E-09	-	7,85E-09
	LCRinh	4,92E-09	1,27E-11	2,29E-09	1,16E-08
	TLCR	6,62E-04	3,45E-06	2,29E-09	2,58E-04

Children					
Sample		Pb	As	Ni	Cr
S4	LCRing	7,88E-04	4,26E-06	-	2,37E-04
	LCRdermal	-	5,19E-09	-	7,22E-09
	LCRinh	5,86E-09	1,57E-11	3,73E-09	1,06E-08
	TLCR	7,88E-04	4,27E-06	3,73E-09	2,37E-04
S5	LCRing	1,25E-03	7,06E-06	-	3,40E-04
	LCRdermal	-	8,59E-09	-	1,03E-08
	LCRinh	9,27E-09	2,59E-11	4,43E-09	1,53E-08
	TLCR	1,25E-03	7,07E-06	4,43E-09	3,40E-04

4. Conclusions

This study evaluated trace metal contamination in sediments of the Koko watershed, highlighting seasonal variations. In the rainy season, Tributary 2 exhibited the highest concentrations of Pb, As, Zn, Cu, Ni, and Cr, primarily due to rainwater runoff from agricultural and urban discharges. In the dry season, Pb, Zn, Cu, and Cr concentrations peaked in the same tributary, with the geoaccumulation index indicating moderate pollution.

Non-carcinogenic risk assessments revealed no immediate threat to human health, whereas carcinogenic risks were observed in children exposed to Pb and Cr. The findings underscore the importance of monitoring sediment contamination, as heavy metals can bioaccumulate in aquatic organisms and enter the food chain. Contamination indices provide essential guidance for targeted environmental management and risk mitigation strategies.

Abbreviations

TMEs	Trace Metals Elements
S	Sediment
UCC	Upper Confidence Limit of the Mean Concentration
USEPA	United States Environmental Protection Agency
TLCR	Total Life Cancer Risk
PERI	The Potential Ecological Risk Index
m-ERM-Q	Mean ERM Quotient
m-PEL-Q	Mean PEL Quotient
ADD	Average Daily Doses
HI	Hazard Quotient (HQ) and the Hazard Index
HM	Concentration the Contaminant
LCR	Lifetime Cancer Risk

Author Contributions

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Conflicts of Interest

The authors declare no conflicts of interest.

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