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Research Article

HEAVY METALS CONCENTRATIONS AND ASSESSMENT OF STREAM SEDIMENTS CONTAMINATION IN JEBBA AREA, SOUTHWESTERN NIGERIA

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ABSTRACT
The study presents an investigation into the concentrations of heavy metals and an assessment of stream sediments contamination in the Jebba area of Southwestern Nigeria. Heavy metal contamination in aquatic ecosystems is a growing concern due to its potential ecological and human health implications. The Jebba area, located in the southwestern region of Nigeria, is characterized by significant anthropogenic activities, including agriculture, mining, and industrial operations, which have the potential to introduce heavy metals into the local environment.
A total of 138 stream sediment samples were collected from multiple sites within the Jebba area and analyzed for the presence and concentration of heavy metals, including lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), zinc (Zn) and other elements. The Inductively Coupled Plasma-Mass Spectrophotometry (ICP-MS) analyses was employed to determine the heavy metal concentrations in the sediments.
The order of abundance of these heavy metals analyzed in the stream sediments followed this pattern Mn>Ba>Sr>Zr>Zn>Cu. The values of Th is higher than the background values indicating that anthropogenic activities had influence in the study area. The results of the study revealed low to medium concentrations of several heavy metals in the stream sediments, notably As, Cd, Th, and Zr, but all below the permissible levels set by environmental quality standards. The contamination levels were found to be associated with anthropogenic activities, including agricultural runoff, mining operations, and industrial discharge, which release heavy metals into the local streams and water bodies.
Furthermore, an ecological risk assessment was conducted to evaluate the potential impact of heavy metal contamination on the aquatic ecosystem. The assessment considered factors such as metal bioavailability, sediment toxicity, and the potential for bioaccumulation in aquatic biota. The findings indicated a low to moderate ecological risk in certain areas of the Jebba stream system, suggesting the need for remediation and mitigation measures to protect the local environment and safeguard public health.
In conclusion, the study highlights the significance of monitoring and assessing heavy metal concentrations in stream sediments, particularly in regions like Jebba with a history of diverse anthropogenic activities. The results underscore the importance of implementing effective environmental management strategies to reduce heavy metal contamination and mitigate its adverse effects on both the ecosystem and human populations in the area.

Keywords*: Heavy Metals, Stream Sediments, Contamination, Southwestern Nigeria, Ecological Risk Assessment, Environmental Management*

INTRODUCTION
Assessing the concentrations of heavy metals in stream sediments is crucial for understanding environmental contamination and potential risks to ecosystems and human health. Sediments act as sinks for heavy metals, accumulating over time and reflecting the historical input of pollutants into water bodies. Sediments are said to represent the ultimate sinks for heavy metals in the environment (Gibbs *et al.*, 1977). Stream sediments are

mixtures of sediments, soils and rock fragments from the drainage basin upstream of the collection site (Mikoshiba *et al.,* 2006). An understanding of the geology of the area, the processes of rock weathering and sediment formation requires not only a sound knowledge of the geochemical behaviour of elements during weathering, but also of sediment redistribution processes. It is well established that factors such as geological setting and mineralogy have strong influence over the chemistry of stream sediments and on natural waters, which in turn influence metal distribution (Liaghati, 2004, Oyebamiji *et al.,* 2018). However, the extent to which these factors interact within active sedimentation processes has received only limited attention.

Elements may be mobilized as a result of natural processes (e.g. weathering and erosion of geological formations) as well as by anthropogenic activities (e.g. land use practices). Only 30% of the lithosphere is dry land of which the upper surface is affected by some degree of chemical decomposition or physical weathering (Carroll, 1970). The natural processes are dominant in sub-Saharan regions through the water-rock-sediment interactions starts and moves forward during chemical weathering towards equilibrium by dissolving or leaching bedrock minerals in to the solution which are eventually settled in sediments.

The mixing of major and trace elements within the environment due to their solubility rate warrants the determination and examination of stream sediments. Heavy metal pollution has become a serious environmental problem in recent times as its occurrence has entailed a great increase in discharge of pollutants to receiving water bodies, which eventually settle in bottom sediments (Oguzie, 2002). The danger of heavy metals has been aggravated due to their relative high toxicity and persistent nature in the environment (Aboud and Nandini, 2009). Sediments act as a major reservoir of metals and as a source of contaminants in aquatic environments under favourable conditions (Aboud and Nandini, 2009). In summary, assessing heavy metal concentrations in stream sediments involves a comprehensive approach that combines field sampling, laboratory analysis, data interpretation, and consideration of potential environmental impacts. The goal is to inform decision-makers, regulators, and stakeholders about the state of sediment contamination and facilitate appropriate actions to protect both the environment and human health. This research attempts to observe the exposed lithologic units, as well as understanding the geochemical characteristics of the rock units in relation to quality of water bodies around Jebba and its environment, by analyzing stream sediment of the study area.

MATERIALS AND METHODS

Study area description

The study area falls between longitude 4°30’00” and 4°50’30” and latitude 9°03’-9°10’ (Fig. 1). Notable towns located close to the study area include Gbajibo, Kalema, Bukah and Mokwa which are traversed by the River Niger. Jebba is a town in Kwara State, western Nigeria. It lies on the south bank and at the natural head of navigation of the Niger River, 550 miles (885 km) from the sea. It is populated by the predominantly Muslim Nupe people.

The relief of the area is undulant and uniform at some spots. The vegetation covers most of the area is typically southern Guinea Savannah woodland physiognomy, and floristic conformation is replicated in soil/water relations and effective soil depth. The project area belongs to the marginal areas of southwest Nigeria climatic zone characterized by an average annual temperature of 29°C. The rainy season spans form April/May to October/November. This is usually followed by a period of the dry season from November to April. The stream within the area is dendritic and seasonal.

The geology of the study area is underlain by granite gneiss, quartzo-feldspathic gneiss, quartz mica schist, quartzite and metagraywacke intruded by the Neoproterozoic (Pan-African) granitic rocks of fine to coarse grained granite texture. Four lithostratigraphic units have been identified in the study area (Fig. 2). In the western and eastern segment of the area, quartzite occur as pebbles, while quartz-mica schists outcropped in the extreme west. These metamorphic rocks have been intruded by largely undeformed granitic rocks alternating between porphyritic to medium-grained rocks. The eastern flank is exhibited by a North-South trending belt of quartzo-feldspathic gneiss with local quartzo-feldspathic veins which contains a thick, intercalated quartzite. This gneiss is bounded on the western side by a North-South trending belt of granitic gneiss. Towards the western part is the occurrence of metagreywacke unit with intercalated amphibolites bands.

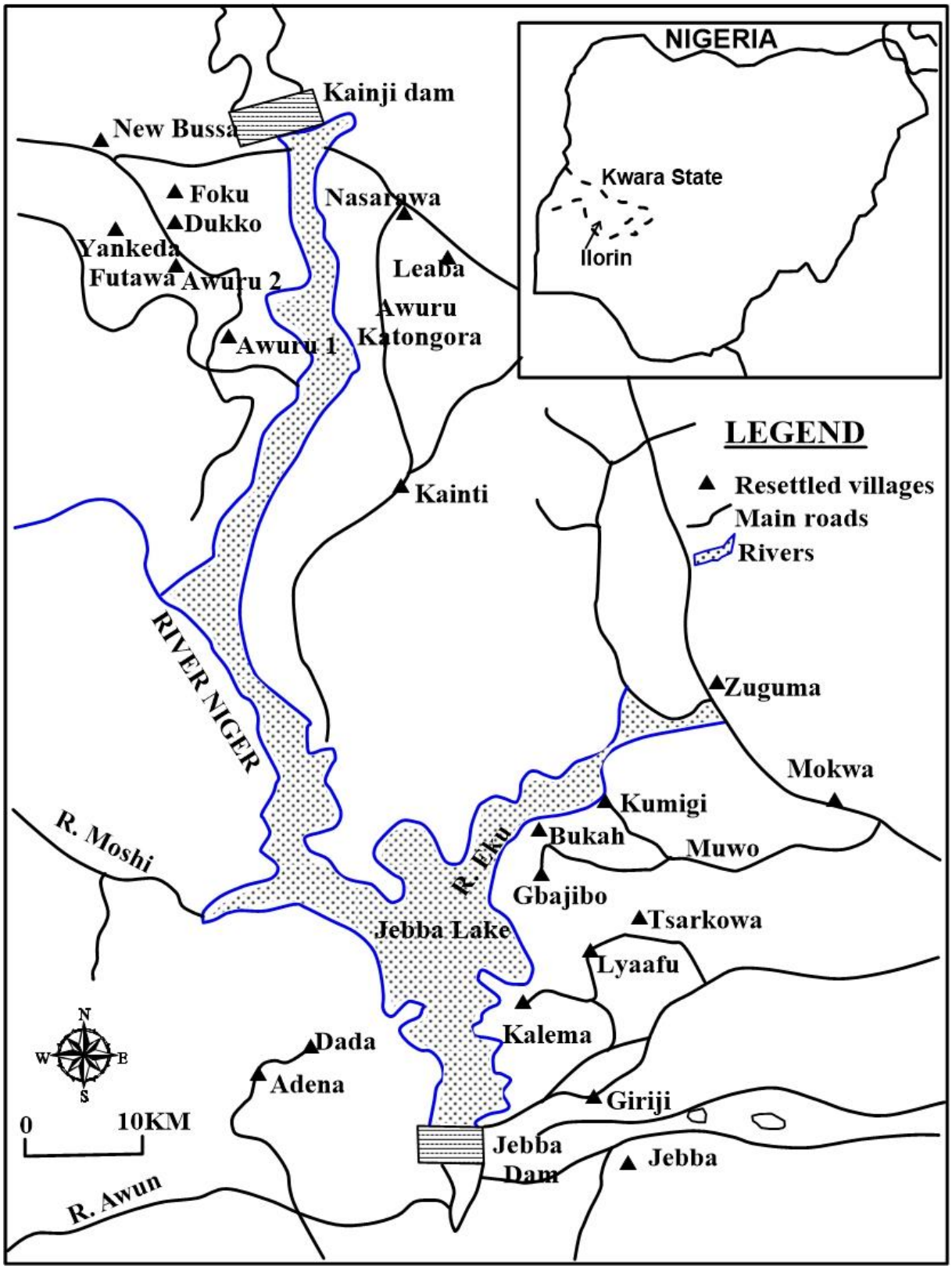

Figure 1: Location map of the study area.

Sampling collection and preparation

The stream sediment samples were carefully collected at a depth of 20-25cm, bagged and labeled appropriately. Sediment samples were prepared for analysis by air drying for five days to remove moisture. Organic debris and other unwanted large particles were handpicked from each sample. The air-dried samples were then ground into a homogenous mixture using a porcelain mortar and pestle and sieved through 2mm mesh screen to remove the coarse materials. The samples were placed in Ziploc bags and transported to the laboratory for the determination of major elements and heavy metal concentrations. The concentrations were determined using the Inductively Coupled Plasma-Mass Spectrophotometry (ICP-MS) analyses.

Sample analysis procedure and accuracy

The air-dried fine-grained stream sediment particles were digested in aqua regia using a mixture of 25% HNO_3 and 75% HCl. Afterwards a near total absorption by hydrofluoric-perchloric acid, the major and trace elements were analyzed by means of the Inductively Coupled Plasma-Mass Spectrophotometry (ICP-MS) in a certified commercial laboratory. The accuracy of the analytical methods was checked by the repetitive analysis of a standard reference material completed together with a batch of samples. These data provide acceptable results, with precision values within ±1-10% for various elements.

Pollution indices

Contamination factor (CF)

CF is a numerical calculation of the level of pollution and sources of contamination. The contamination factor makes use of conventional elements as the reference element. CF is expressed as follows:

$$C_f^i = C_i/C_{ri} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(i)}$$

Where C_i is the content of metal *i* instead of mean content from at least five sample sites; C_{ri} is the reference value, baseline level of metal *i.* The degree of heavy metal pollution of CF is divided into four classes.

Geoaccumulation index (Igeo)

Igeo index as shown by the equation below is used to categorize identification of ecological influences by anthropogenic activities, also used to compute the extent of heavy metal contamination associated with stream sediments. Igeo is expressed as follows:

$$I_{geo} = log_2 \frac{Cn}{1.5*Bn} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(ii)}$$

Where *Cn* is the measured concentration of metal n, *Bn* is the geochemical background value and constant 1.5 is used to denote the natural variations and negligible anthropogenic influences. The Igeo was distinguished into seven classes.

Contamination degree (CD)

This is expressed by the summation of the whole contamination factors for each metal in the sequence. CD is expressed as follows:

$$\text{CD}=\sum_{i=1}^{n} Cf \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(iii)}$$

Where *n* is the number of metals, *i* is the baseline level of the metal and *Cf* is the contamination factor. The CD is divided into four classes.

Pollution load index (PLI)

PLI is used to determine the magnitude of heavy metal contamination in soils. It is a effective tool in heavy metal pollution evaluation (Tomlinson et al., 1980). The pollution load indexes are calculated for all the metals. PLI is expressed as follows:

$$\text{PLI}= (Cf_1 \times Cf_2 \times Cf_3 \ldots\ldots \times Cf_n)^{1/n} \ldots\ldots\ldots \text{(iv)}$$

Where Cf_1 is the contamination factor, *n* is the number of metals. The degree of heavy metal risk assessed by PLI is mainly divided into three classes (Chakravarty and Patgiri, 2009).

Ecological risk index (ERI)

The ecological risk index is used to evaluate heavy metal pollution in soil and stream sediments to associate ecological and environmental effects with their toxicology and the toxic-response factor (T_{ri}) of Cu, Zn, Cd, Cr, Ni, and Pb is 5, 1, 30, 2, 5, and 5 (µg/g) respectively (Hakanson, 1980). ERI is stated as follows:

$$E_r^i = T_r^i \times Cf_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(v)}$$

Where T_r^i is the toxic-response factor for a given substance, and Cf_i is the contamination factor. The degree of heavy metal risk assessed by ERI is mainly divided into five classes.

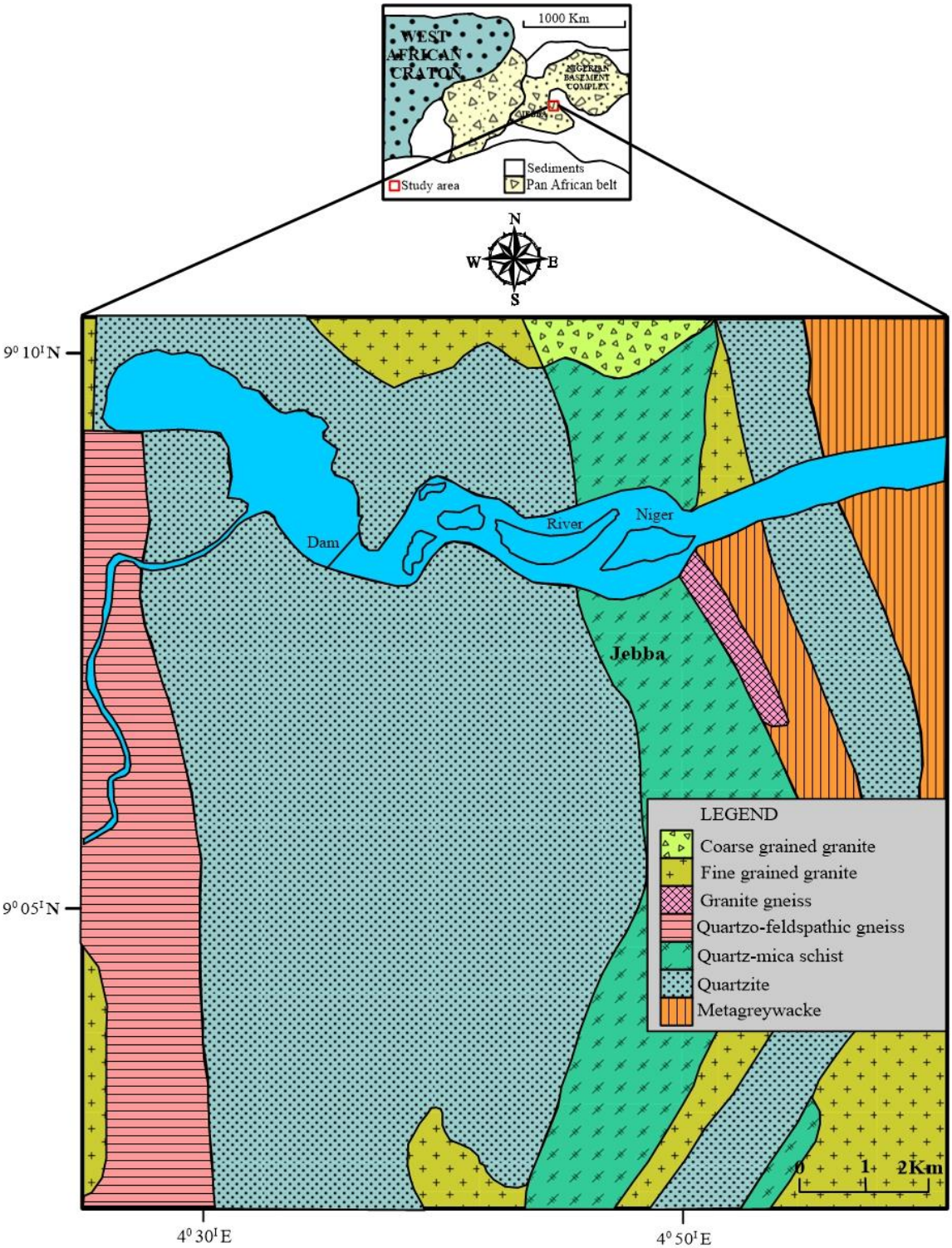

Figure 2: Geological map of the study area.

RESULTS AND DISCUSSION

Heavy metals concentration in stream sediments

The statistics of heavy metals are presented in Table 1. Concentrations of Ag, As, Ba, Cd, Co, Cu, Fe, Mn, Pb, Sr, Th, Zn, Zr in the stream sediments, as well as the background values of heavy and trace metals are presented. The concentrations of Ag, As, Ba, Cd, Co, and Cu varied between 0.005-0.009, 0.05-3.8, 5-394, 0.05-0.05, 0.6-20.6, and 1.5-37.7ppm respectively with average concentrations of 0.016, 0.574, 84.78, 0.017, 5.082 and 6.282 ppm respectively. The order of abundance of these heavy metals analysed in the stream sediments followed this pattern Mn>Ba>Sr>Zr>Zn>Cu. The values of Th is higher than the background values indicating that mining activities had influence in the study area. The concentrations of As, Ba, Co, Cu, Mn, Ba, Zn and Zr varied greatly across the study area. Mn is relatively low and slightly homogenous in all the stream sediments samples analysed. The coefficient of variation (CV) which is a measure of relative variability and used to compare the degree of variation from one data series to another. Pb has the lowest Cv of 38.68% followed by Ba, Cd, Fe, Mn, Co, Th, Zr, Cu and Zn having CVs of 66.02, 58.82, 57.64, 73.43, 80.87, 84.08, 84.76, 85.48, 86.01% respectively. As, Ag and Sr have CV more than 90% (113.24, 93.95 and 90.57 % respectively). This indicates that the (CV<90%) values of heavy metals are dominated by anthropogenic sources are generally high compared to (CV >90 %) dominated by geogenic sources. Several other factors could be responsible for the large coefficient variation across the study area and these may include the following; sampling methods, sample preparation methods and analytical techniques. However, these variations can be further separated into direct and indirect contributions to the total variation with the use of principal component analysis. Therefore, As, Ag and Sr concentrations in the stream sediments samples tend to be high and introduced by anthropogenic activities while Ba, Cd , Fe, Mn, Co, Th, Zr, Cu and Zn are associated with natural sources. The high concentration of Ag, As and Sr in the stream sediments posed a serious threat to vegetation and animal rearing and ultimately affecting the overall quality of human health through consumption. Moderately high concentrations of Ba, Cd, and Fe indicate evidence of leaching of mine waste under acidic conditions. In general, different sample points showed varied stream sediments heavy metal concentrations, indicating influence of human activities from mineral exploitation and processing indicate evidence of leaching of mine waste under acidic conditions. In over-all, different sample points showed varied stream sediments heavy metal concentrations, indicating influence of human activities from mineral exploitation and processing.

Table 1: The summary of chemical parameters of the stream sediment samples of the study area.

Elements	Minimum	Maximum	Mean	Standard deviation	Coefficients of variation (%)	Background value*
Ag	0.005	0.09	0.016	0.015	93.95	0.07
As	0.05	3.8	0.574	0.65	113.24	13
Ba	5.0	394.0	84.78	55.97	66.02	580
Cd	0.05	0.05	0.017	0.01	58.82	0.3
Co	0.6	20.6	5.082	4.11	80.87	19
Cu	1.5	37.7	6.282	5.37	85.48	45
Fe	0.51	4.37	1.388	0.80	57.64	4.72
Mn	65.0	2102.0	364.73	267.82	73.43	900
Pb	4.4	33.2	10.11	3.91	38.68	20
Sr	0.9	83.1	20.25	18.34	90.57	170
Th	4.4	141.7	27.08	22.77	84.08	12
Zn	2.0	65.0	13.87	11.93	86.01	95
Zr	1.3	35.2	7.48	6.34	84.76	160

Number of samples= 138
***Background values are from the compositions of average shale values (Turekian and Wedepohl, 1961).*

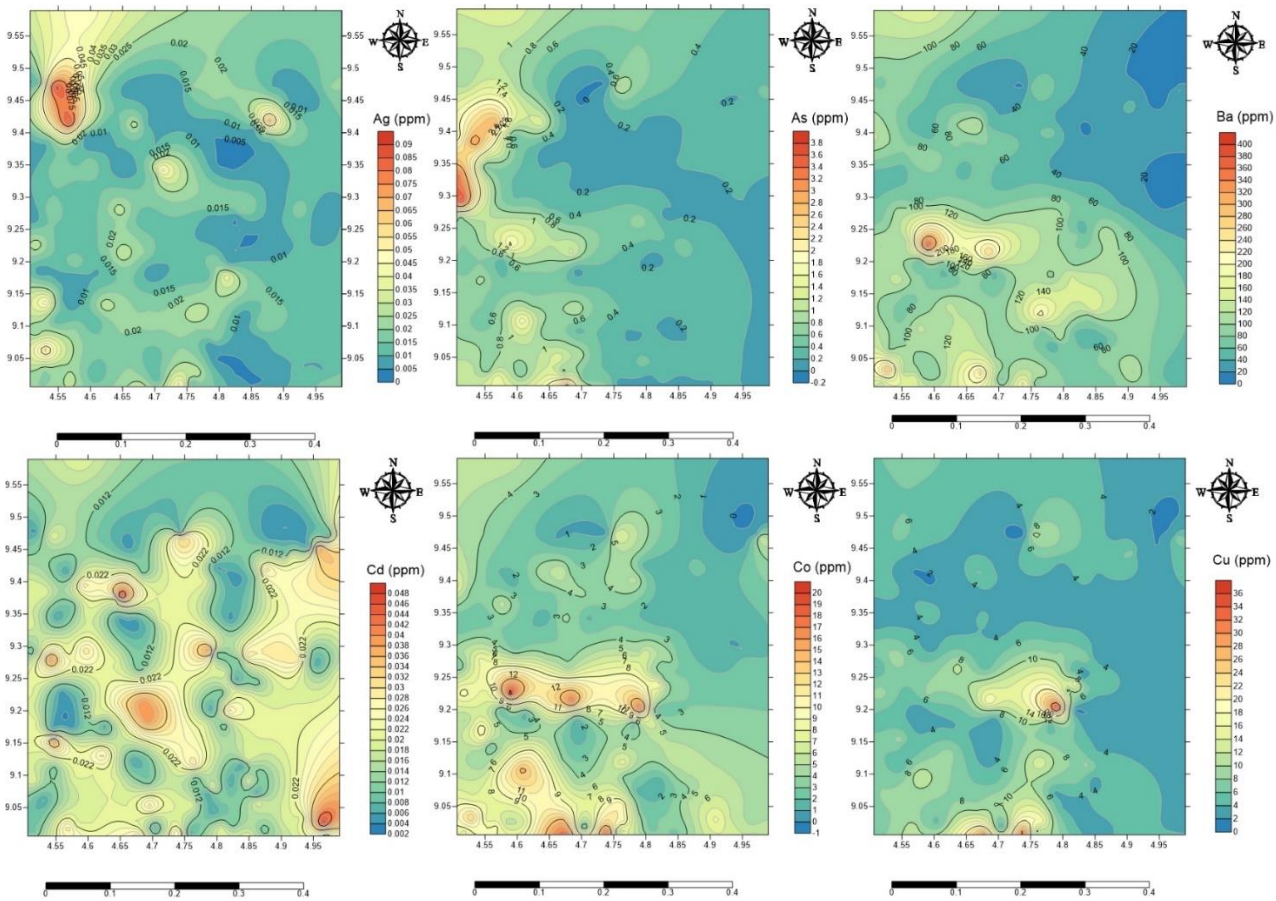

Figure 3a: Spatial distribution maps of As, Ag, Ba, Cd, Co and Cu in study area.

Spatial distribution of heavy metals

The spatial distribution of heavy metals refers to how these elements are dispersed or spread across a geographical area, such as a region, ecosystem, or landscape. Heavy metals are naturally occurring elements with high atomic weights and densities. They include metals like lead (Pb), mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), and others. Human activities, such as industrial processes, mining, agriculture, and improper waste disposal, have led to increased concentrations of heavy metals in various environments, often resulting in environmental contamination and potential health risks. The spatial distribution of heavy metals concentrations is an absolute tool used to decipher the potential sources of enrichment and identify likely hotspot regions with elevated metal concentration. The spatial distribution maps of the study area are presented in Fig. 3a and 3b. For this study, the concentration variability maps of Ag, As, Ba, Cd, Co, Cu, Fe, Mn, Pb, Sr, Th and Zn were made with the method of kriging interpolation using the Surfer software package. The distribution patterns of Ag, As, Ba, Cu, Mn, Pb, Sr and Zn displayed core concentrations in a zoned region while the distribution patterns of Cd, Co, Fe and Th showed varied pattern.

The spatial dispersal of Ag, As and Sr vary slightly from other metals. They peaked at two points located in the northwestern part of the study area, associated with amplified farming activities and heavy transportation density. The spatial distribution of Cd is relatively diverse from other heavy metals, the distribution pattern is even. The mean concentration is comparable to the background value, suggesting that Cd concentrations in the stream sediments have not been altered by anthropogenic activities. The spatial distribution of Ba, Mn and Pb showed relatively low spatial variability across the study area. A single hotspot is shown at the extreme northwest section indicating the presence of intense agricultural activities.

Furthermore, the spatial distribution of Zn concentrations revealed very high spatial variability with two distinct peaks around the agricultural land space. The mean concentrations of Sr are lower compared with the background values, suggesting that Sr concentrations in the samples of the study area have not been affected by anthropogenic activities.

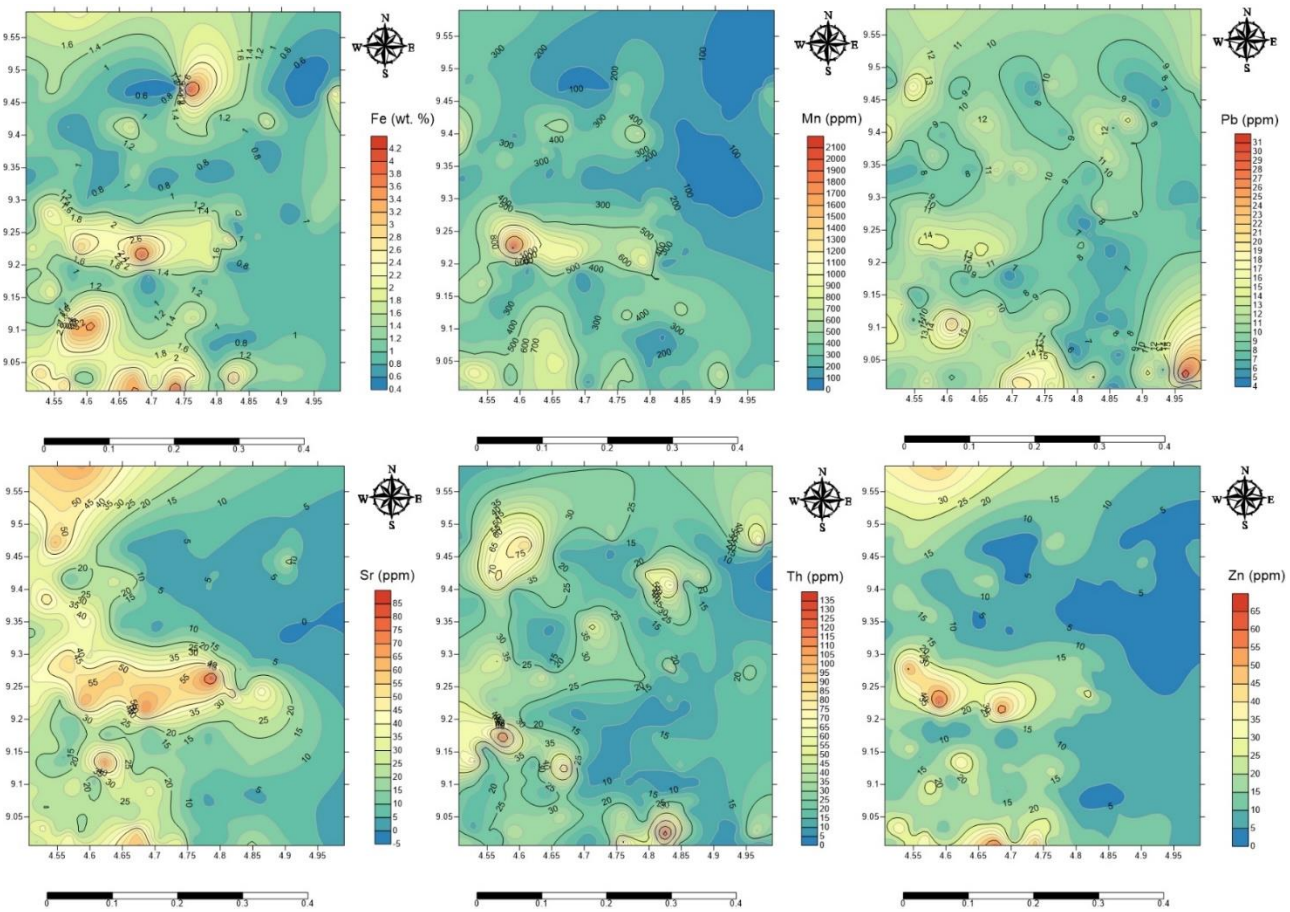

Figure 3b: Spatial distribution maps of Fe, Mn, Pb, Sr, Th and Zn in study area.

Indices of contamination and environmental effect

The environmental effects of heavy metal pollution in the study area were assessed through a quantitative analysis of monitoring data of soil quality. The contamination factor (Tables 2) relative to the background values, were used in the evaluation.

The concentration of a metal in soil can be affected by a number of factors, including the geology of the area, the type of soil, and the presence of anthropogenic sources of pollution.

The background concentrations for the metals are all 100. This means that the CF values are relative to this background concentration.

The CF is a method used to assess the level of contamination of a metal in an environment. It is calculated using the following formula:

CF = Cn / Bn

where:

Cn is the measured concentration of the metal in the sample, Bn is the background concentration of the metal in the environment.

The CF is classified into four grades, or classes, from uncontaminated (CF < 1) to very high contamination (CF > 6).
In the Table 2, the background concentrations for the metals are all 100. This means that a value of CF < 1 indicates that the metal concentration in the sample is below the background concentration and is therefore uncontaminated.
The following metals are classified as uncontaminated: Ag, As, Ba, Cd, Co, Cu, Fe, Mn, Pb, Sr, Th, Zn and Zr. No metals are classified as having high or very high contamination.
From the Table 2, all of the metals except Th is classified as low contamination. This means that the concentrations of these metals in the samples are below the background concentration and are therefore not significantly elevated. Th is classified as moderate to considerable contamination, which means that the concentration of Th in the sample is slightly above the background concentration.
Overall, the results of the CF analysis indicate that the metals in the samples are not significantly contaminated. However, it is important to note that the CF is a relative measure of contamination and that the results should be interpreted in conjunction with other information, such as the sampling method and the analytical method.
The Igeo is a method used to assess the level of heavy metal pollution in an environment. It is calculated using the following formula:
Igeo = $\log_2$(Cn / (1.5 * Bn))
where:
Cn is the measured concentration of the metal in the sample, Bn is the background concentration of the metal in the environment, and 1.5 is a factor that is used to account for natural variations in the background concentration of the metal.
From Table 3, the following metals are classified as uncontaminated (Igeo less 0): Ag, As, Ba, Cd, Co, Cu, Fe, Mn, Pb, Sr, Zn and Zr. except for Th which indicates uncontaminated to moderately contaminated(0 < Igeo < 1) of the Class 1 order . Based on the average values, the samples of the study area are mostly uncontaminated by almost all elements.
Table 4 shows the classification of the contamination degree (CD) for different heavy metals. The CD is calculated by summing the contamination factors (CF) for each metal. The CF is calculated by dividing the metal concentration in the sample by the background concentration. The background concentration is the natural concentration of the metal in the environment.
The overall level of heavy metal contamination in the samples, as measured by the sum of contamination factors for each metal, ranges from moderate to very high. As, Cd, and Zr are moderately contaminated in all samples with Ba, Cu, Sr, and Zn considerably contaminated, and Th>Pb>Mn>Fe>Co>Ag in decreasing order indicating alarming anthropogenic impacts as a result of mining and agricultural activities having a significant impact on the environment.
The PLI is a method used to assess the overall level of pollution in an environment. It is calculated using the following formula:

$$PLI = (Cf_1 \times Cf_2 \times Cf_{3\ldots\ldots} \times Cf_n)^{\frac{1}{n}}$$

where:
$Cf_1 \times Cf_2 \times Cf_{3\ldots\ldots} \times Cf_n$..., CFn are the contamination factors for the individual metals.
The PLI provides a simple, comparative means to determine the magnitude of heavy metals in a site. A value of PLI=0 indicates perfection, PLI=1 indicates only baseline levels of pollutants, while PLI>1 indicates progressive deterioration of site (Chakravarty and Patgiri, 2009).
The values of the pollution load index (PLI) in Table 5 were found to be generally equals to zero (PLI=0) in most of the sampled points except for the PLI of 9.94 indicating that the sample is significantly polluted.
The ERI was presented to control the semi-quantitative assessment of regional pollution level, according to the toxicity of heavy metals and the response of the environment. Based on the standardized heavy metal toxic factor expressed by Hakanson (1980), the toxic response factor (Tri) of Pb, Zn, Cu, Cd, Ni, and Cr is 5, 1, 5, 30, 5 and 2 (μg/g), respectively. The ecological risk indices of Pb (1.1-8.3), Zn (0.02-0.68), Cu (0.2-

4.2), Cd (0.5-5), Ni (0.14-2.79) and Cr (0.64-3.96) with an average of 2.53, 0.15, 0.70, 1.70, 0.60, and 1.25, respectively, in all the sampling locations show low risk (Eri < 30).

Table 2: Percentage (%) of Contamination factors for heavy metals in stream sediment of the study area (n=138).

Indices	Equation	Classification	Ag	As	Ba	Cd	Co	Cu	Fe	Mn	Pb	Sr	Th	Zn	Zr
Contamination factor (Cf)	$Cf = \frac{C_n}{B_n}$	Cf < 1 (low Cf)	97.83	100	100	100	99.28	100	100	97.83	97.83	100	21.74	100	100
		1 ≤ Cf < 3 (moderate Cf)	2.17	0.00	0.00	0.00	0.72	0.00	0.00	2.17	2.17	0.00	57.97	0.00	0.00
		3 ≤ Cf < 6 (considerable Cf)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.31	0.00	0.00
		Cf ≥ 6 (very high Cf)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.07	0.00	0.00

Table 3: Percentage (%) of Geoaccumulation Index (Igeo) for metals in stream sediment of the study area.

Indices	Equation	Classification	Ag	As	Ba	Cd	Co	Cu	Fe	Mn	Pb	Sr	Th	Zn	Zr
Geo-accumulation Index (Igeo)	$Igeo = log_2 \frac{Cn}{1.5*Bn}$	Igeo < 0 Class 0 (uncontaminated)	100	100	100	100	100	100	100	100	99.28	100	51.44	100	100
		0 < Igeo < 1 Class 1 (uncontaminated to moderately contaminated)	0	0	0	0	0	0	0	0	0.72	0	48.55	0.00	0
		1 < Igeo < 2 Class 2 (moderately contaminated)	0	0	0	0	0	0	0	0	0	0	0	0	0
		2 < Igeo < 3 Class 3 (moderately to heavily contaminated)	0	0	0	0	0	0	0	0	0	0	0	0	0
		3 < Igeo < 4 Class 4 (heavily contaminated)	0	0	0	0	0	0	0	0	0	0	0	0	0
		4 < Igeo < 5 Class 5 (heavily to extremely contaminated)	0	0	0	0	0	0	0	0	0	0	0	0	0
		Igeo ≥ 5 Class 6 (extremely contaminated)	0	0	0	0	0	0	0	0	0	0	0	0	0

Multivariate statistical analysis

Pearson's correlation analysis

Correlations between different elements are often adopted as a basis to determine whether the considered elements have a common source, and it is generally considered that elements with a significant positive correlation may exhibit similar sources. Correlation coefficients between 0.9 and 1 are deemed very high, Correlation coefficients between 0.7 and 0.9 are considered high, between 0.5 and 0.7 are moderate, 0.3–0.5 low correlation, and < 0.3 low correlation (Rollinson, 1993). Correlation coefficients that are high indicate the occurrence of similar geochemical processes, factors, and reactions, which influence metal distribution. Inter elemental relationship in the stream sediments suggests different geochemical pathways are responsible for the metal content in the media. In the stream sediment samples, a strong positive correlation exists between Co-Ba (0.810), Ba-Mn (0.852), Ba-Zn (0.775), Co-Cu (0.799), Co-Fe (0.825), Co-Mn (0.846), Co-Zn (0.790), Fe-Zn (0.762) and Sr-Zn (0.751) indicating that these elements may have had the same source (Table 6). In addition, a significantly moderate positive correlation was also observed between Ba-Cu (0.511), Ba-Fe (0.667), Ba-Sr (0.626) and Co-Sr (0.531) suggesting that these elements may have come from the same source.

Table 4: Contamination degree of heavy metals in stream sediments of the study area.

Indices	Equation	Classification	Ag	As	Ba	Cd	Co	Cu	Fe	Mn	Pb	Sr	Th	Zn	Zr
Contamination degree (CD)	$CD = \sum_{i=1}^{n} Cf$	CD < 6 (low CD)													
		6 ≤ CD < 12 (moderate CD)		6.05		7.78									6.41
		12 ≤ CD < 24 (considerable CD)			20.03			19.13				16.32		20.00	
		CD ≥ 24 (very high CD) indicating alarming anthropogenic contamination metals	31.79				36.65		40.30	55.52	69.24		309.13		

Table 5: Pollution Load Index of heavy metals in stream sediments of the study area.

Indices	Equation	Classifications.	Ag	As	Ba	Cd	Co	Cu	Fe	Mn	Pb	Th	Sr	Zn	Zr
Pollution Load Index (PLI)	$PLI = (Cf_1 \times Cf_2 \times Cf_{3\ldots} \times Cf_n)^{1/n}$	PLI = 0 (perfection)	0	0	0	0	0	0	0	0	0		0	0	0
		PLI = 1 (baseline levels of pollutants present)													
		PLI > 1 (progressive deterioration of site)										9.94			

Table 6: Pearson correlation matrix for the elements in the stream sediments.

	Ag	As	Ba	Cd	Co	Cu	Fe	Mn	Pb	Sr	Th	Zn	Zr
Ag	1												
As	0.278*	1											
Ba	0.206*	0.365*	1										
Cd	0.111	0.079	0.162	1									
Co	0.225*	0.370*	0.810*	0.177*	1								
Cu	0.277*	0.235*	0.511*	0.139	0.799*	1							
Fe	0.273*	0.364*	0.667*	0.217*	0.825*	0.693*	1						
Mn	0.162	0.357*	0.852*	0.070	0.846*	0.496*	0.645*	1					
Pb	0.332*	0.165	0.271*	0.185*	0.379*	0.238*	0.454*	0.336*	1				
Sr	0.195*	0.468*	0.626*	0.217*	0.531*	0.414*	0.492*	0.499*	0.102	1			
Th	0.197*	0.089	-0.047	-0.180*	-0.042	-0.081	0.073	0.059	0.343*	-0.038	1		
Zn	0.298*	0.484*	0.775*	0.255*	0.790*	0.647*	0.762*	0.685*	0.300*	0.751*	0.004	1	
Zr	0.012	-0.269*	-0.282*	0.018	-0.205*	-0.117	-0.036	-0.191*	0.245*	-0.289*	0.389*	-0.264*	1

** The correlation is significant at the 0.05 level (two-tailed).*

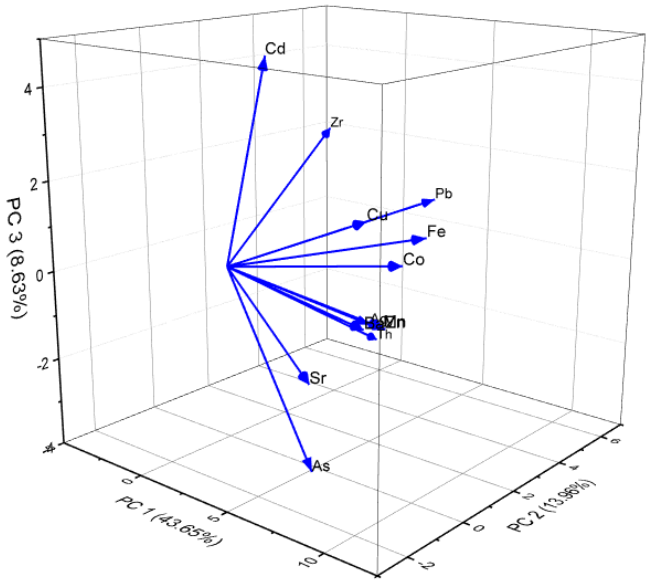

Figure 4: Three-dimensional principal component loading plot of the PCA results for stream sediments.

Source identification of elements-Principal component analysis

The principal component analysis for stream sediments revealed a three-component model as presented in Table 7. The component factor one consisted of the following metals: As, Ba, Co, Cu, Fe, Mn, Sr, Zn. It accounted for 43.65% of the variance. Co, Zn and Fe are siderophilic (having a strong affinity for metallic phase and usually depleted in the silicate portion of the earth) and were well correlated with one another. The component factor two consists of the following metals Ag, Pb, Th, Zr and accounted for 13.96% of the total variance. Pb and Th showed weak correlation with the other elements, so it can be inferred that they were anthropogenic influenced. In factor three, Cd accounted for 8.63% variance and Cd was poorly correlated with other elements. It may have been formed by adsorption of the metal by its oxide in the media. Although the statistical analysis may group them, they were anthropogenically introduced into the soil. This may be a result of weathering and erosion of rocks into the mining environment.

Table 7: The result of principal component analysis for stream sediments in the study area.

	Coefficients of PC1	Coefficients of PC2	Coefficients of PC3
Ag	0.152	0.284	-0.202
As	0.223	-0.043	-0.491
Ba	0.365	-0.096	-0.022
Cd	0.107	-0.014	0.599
Co	0.391	-0.010	0.125
Cu	0.312	0.001	0.214
Fe	0.359	0.130	0.153
Mn	0.349	-0.004	-0.052
Pb	0.178	0.497	0.128
Sr	0.302	-0.171	-0.164
Th	0.006	0.562	-0.390
Zn	0.384	-0.055	-0.026
Zr	-0.106	0.544	0.275
Eigenvalue	5.675	1.815	1.122
Percentage of Variance	43.65%	13.96%	8.63%
Cumulative	43.65%	57.61%	66.25%

Hierarchical Cluster Analysis

Hierarchical Cluster Analysis (HCA) is commonly used to analyse the sources of contamination or the sources of associated elements. The results of HCA can reveal the relationships among the analysed elements, between and within groups. Elements from different sources are clustered according to the maximum and minimum levels of clustering similarity. HCA can often be used as an auxiliary method to validate the results of PCA analysis and facilitate the classification of variables. The results of HCA for the stream sediments studied are shown in Figure 5. These elements can be classified into three groups: (1) As-Ba-Mn-Co-Fe-Zn-Cu-Sr-Cd; (2) Ag-Pb; and (3) Th-Zr. The results of the correlation coefficient and the PCA agreed well with the cluster analysis and hence helped to interpret the data. The linkage and clustering

pattern of the trace elements in the media indicated three clusters. This was generally consistent with the PCA results.

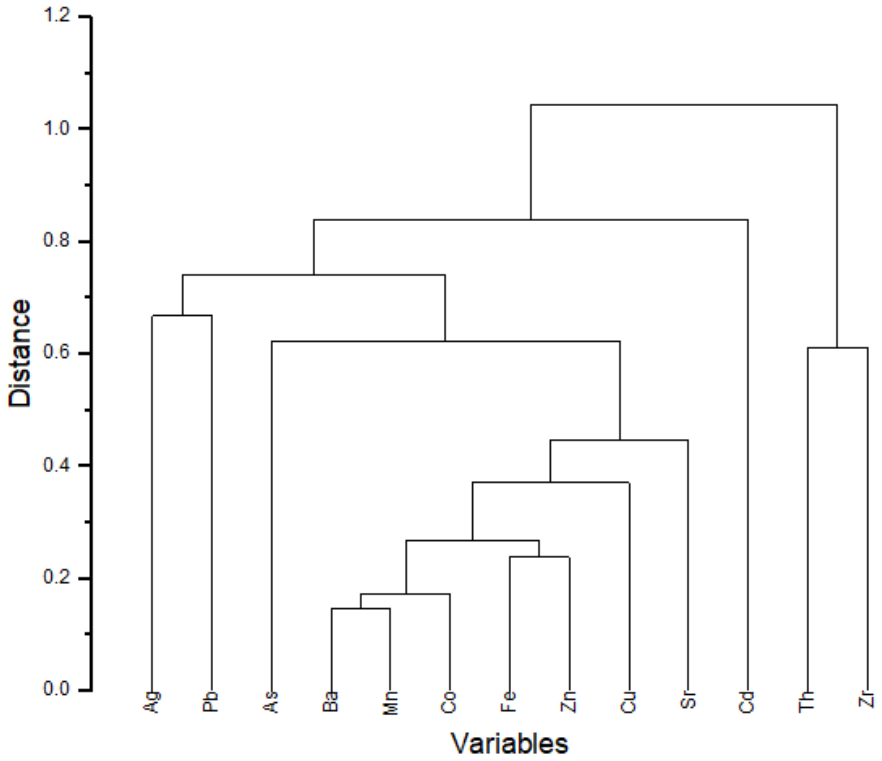

Figure 5: Dendrogram of HCA of the concentration of elements in the stream sediments.

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the study sheds light on the concerning issue of heavy metal contamination in this region. The findings of this research have significant implications for both the environment and public health.

a. Elevated Heavy Metal Concentrations: The analysis of stream sediments in the Jebba area revealed low to moderate concentrations of heavy metals, particularly Ag, Co, Fe, Mn, Pb, and Th. These concentrations exceeded acceptable environmental quality standards, indicating a clear problem of contamination.

b. Anthropogenic Sources: The contamination of stream sediments was predominantly linked to anthropogenic activities in the region. Agricultural runoff, mining operations, and industrial discharges were identified as significant sources of heavy metal pollutants. These activities contribute to the ongoing degradation of the local environment.

c. Ecological Risk Assessment: The study also conducted an ecological risk assessment, which demonstrated a low to moderate ecological risk in specific areas of the Jebba stream system. This suggests that the contamination poses a threat to the aquatic ecosystem, potentially affecting aquatic organisms and the broader food web.

d. Need for Remediation and Mitigation: The findings underscore the urgent need for remediation and mitigation measures in the Jebba area. These measures should include the development and implementation of stricter regulations and best practices for industries, agriculture, and mining to reduce the release of heavy metals into the environment.

e. Public Health Concerns: Furthermore, heavy metal contamination in water bodies can have significant public health implications, as these pollutants can find their way into drinking water sources and

local food chains. Thus, there is a need for public health interventions, such as monitoring the safety of drinking water sources and educating the local population about potential risks.

f. Environmental Management: Overall, effective environmental management strategies are essential to address the issue of heavy metal contamination in the Jebba area. These strategies should focus on reducing the sources of contamination, implementing sustainable land-use practices, and rehabilitating affected areas to restore the health of the ecosystem.

g. Future Research: Future research in this area should include continuous monitoring of heavy metal concentrations, tracking changes in contamination levels over time, and conducting in-depth studies on the specific impacts of heavy metal contamination on both the environment and human health in the Jebba area. Overwhelmingly, the findings of this study highlight the pressing need for action to mitigate heavy metal contamination in the Jebba area of Southwestern Nigeria. Addressing this issue is crucial not only for preserving the local ecosystem but also for safeguarding the health and well-being of the community that depends on the affected water bodies and land for their livelihoods.

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