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Assessment of Heavy Metal Concentrations in Parts of Meme River Distributaries Lokoja, North Central Nigeria

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ABSTRACT

The level and mobility of heavy and trace metals in sediments within parts of Meme River tributaries, Northwest of Lokoja. Heavy metal concentrations were delineated in fifteen (15) downstream sediment samples domicile within the study area, using Atomic Absorption Spectrometry (AAS). Mean value results showed that the degree of heavy metals decreased in order of Mo>As>Co>Hg>Mn>Pb>Cr>Cd>Cu>Fe. However, Cd, As, and Hg debut as metals with the highest concentration in sediments, when compared with the World Health Organization (WHO), World Surface Rock Average (WSRA) and other standards. The mapped area is not located within mining of Cd-bearing ore minerals, which suggests that anthropogenic sources of elemental enrichment of Cd, Pb, and Hg are more likely than bedrock geochemical dissolution (weathering). Each sample elemental concentrations were subjected to environmental indices evaluation using different equations. Cadmium (Cd) fall within the high degree of contamination in all the sample analyzed. Index of geo-accumulation (Igeo) was determined and the results indicate that elements such as Pb, As, Cr, Cu, Hg, Mo, Fe and Mn are unpolluted. Nonetheless, Cd shows enrichment that range between the class of moderately polluted to strongly polluted. The ecological risk factors revealed that only Cd shows very high ecological risk. The correlation analysis shows several significant relationships among the elements, suggesting potential co-occurrence patterns or shared sources in the sampled locations. Lead (Pb) has a strong positive correlation with cadmium (Cd) and mercury (Hg), which may indicate a common origin or similar environmental factors affecting their concentrations. This trend is echoed with Cd, which also correlates positively with Hg, further strengthening the hypothesis of a shared source for these elements, possibly from anthropogenic activities. The factor analysis reveals three main components explaining about 69.5% of the total variance in the heavy metal concentrations across the sampled locations. The first factor accounts for 34.5% of the variance, indicating a significant underlying influence common to multiple elements. This factor likely represents metals that co-occur due to similar environmental or anthropogenic sources, as suggested by the high communalities for lead (Pb: 0.854), cadmium (Cd: 0.753), mercury (Hg: 0.800), and iron (Fe: 0.796). This call for immediate attention by the environmental protection agencies in the study area for urgent remediation exercise.

Keywords: Geochemistry, Stream Sediment, Environmental Indices, Multivariate Analysis, Lokoja

INTRODUCTION

According to Hudson-Edward (2007), stream sediments are significant sinks and possible future sources of environmentally hazardous substances. As fluvial systems, streams collect materials from a variety of sources, including geological and human-caused inputs, both nearby and far upstream (Amadi *et al.,* 2017). Both clastic and hydromorphic materials contribute to stream loads through weathering, erosion, and final disintegration. Through

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runoff from many locations, human activities such as industrial, municipal, and agricultural operations significantly contribute extraneous elements to fluvial systems. Because they get inputs from many sources within the catchment, streams that drain into or are situated in urban areas are especially vulnerable to contamination with potential toxic elements (PTEs) and other harmful compounds (Shuaibu *et al.,* 2023).

Municipal areas release a variety of discharges into streams, which alter the chemical composition of the water and bottom sediments as well as their overall quality. One of the main sources of harmful metals that find their way into streams that drain an urban area is road deposited sediments (RDS) (Murana *et al.,* 2019). According to Abrahim and Parker (2008), numerous researches have demonstrated that the presence of hazardous heavy metals can result in a variety of health issues.

Depending on their life stages, aquatic biota prefers particular sediment quality and quantity, which is why sediments are crucial to aquatic ecosystems and have a significant impact on their services and functions (Shuaibu *et al.,* 2023). As a sink for pollutants, sediments can re-suspend pollutants, including heavy metals, under specific environmental conditions, which can lead to secondary pollution in the water column (Liang *et al.,* 2015; Pejman *et al.,* 2015). According to Odekina *et al.* (2021) and Davies *et al.* (2022), heavy metals are among the most dangerous contaminants found in aquatic environments.

Their detrimental characteristics, persistence, and capacity for accumulation are drawing attention from all over the world (Guan *et al.,* 2014; Pandiyan *et al.,* 2021; Anyanwu *et al.,* 2022a). Because heavy metals have a lengthy residence period and are not as biodegradable as other organic chemicals, the risks associated with their contamination in aquatic ecosystems may last for a long time (Kumar *et al.,* 2020).

The amount of contamination and toxicity of heavy metals in the environment cannot be adequately determined by evaluating their concentration (Wei *et al.,* 2019; Kumar *et al.,* 2020). The two most dangerous aspects of environmental heavy metal pollution are bioavailability and eco-toxicity (Jacob *et al.,* 2018). Consequently, despite certain inherent difficulties, pollution indices are employed to evaluate the toxicity and environmental contamination of metals (Masindi and Muedi, 2018; Davies *et al.,* 2022; Ahirvar *et al.,* 2023).

Various assessment indices, such as contamination factor, contamination degree, ecological risk factor, potential ecological risk index, pollution load index, geo-accumulation index, degree of contamination, enrichment factor, and contamination quantification, have been used by researchers to assess heavy metal contamination in sediments (Ogbeibu *et al.,* 2014; Shirani *et al.,* 2020; Amin *et al.,* 2021; Malvandi, 2021; Moldovan *et al.,* 2022).

Geological processes and human activity are the two main ways that heavy metals enter waterbodies (Pandiyan *et al.,* 2021). After entering, the majority of the metals are deposited in the sediment, which raises their concentration there relative to the water column (Liu *et al.,* 2018; Shyleshchandran *et al.,* 2018). Since heavy metal pollution is increasingly contributing to environmental concerns in aquatic ecosystems worldwide, evaluating it in sediments is crucial for the ecological conservation of waterbodies (Li *et al.,* 2022). (Mohajane *et al.,* 2022).

The geochemistry of sediments in the Minna region and other portions of central Nigeria has been the subject of numerous studies. Although it included certain environmental elements, Lapworth *et al.* (2012)'s study on the geochemistry of stream sediments in west-

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central Nigeria was a more regional endeavor. Key *et al.* (2012) conducted a follow-up study in this field with the goal of elucidating the elevated zirconium contents in sediments.

Using statistical techniques and pollution indices, Obaje *et al.* (2014) examined the environmental geochemistry of River Gora (Chanchaga River) sediments in Minna and suggested additional research to look into the potential for additional pollution hazards in the region. The ecological danger of potentially poisonous element (PTE) contamination of local stream sediments was not, however, assessed in the earlier investigations.

This research work is aim at to identify the natural and anthropogenic sources of sediment contamination in distributaries, to evaluate the level and mobility of heavy and trace metals in stream sediments, via geochemical and geological assessment within the parts of NW Lokoja Environs. It has the objective of acquiring stream sediment samples along distributary channels of the research area; to determine the concentration of trace and heavy metals in stream sediment samples within the Study area and to evaluate the geochemistry of the stream sediment samples in the study area via metal contamination, accumulation and concentration factors and indices.

The Study Area

The Study Area is located NW Lokoja town, and it spans across Latitude **7º48¹N** to **7º 47¹N** and Longitude **06º 32¹E** to **06º 38¹E** within sheet number 247 Lokoja N.W. Sampling location encompasses localities like Kabawa, Mount Patti, Ayoola Ajao Avenue, GRA and back of new Stadium in Lokoja. It is easily located and accessible via state and federal highways. Most of the sampled area are located adjacent to large flowing water body (In NW-SE, Busil W.) emanating from River Niger (Fig. 1) and the widespread of Mount Patti, both of them influence the settlement pattern encountered in the study area, which is observed to be linear.

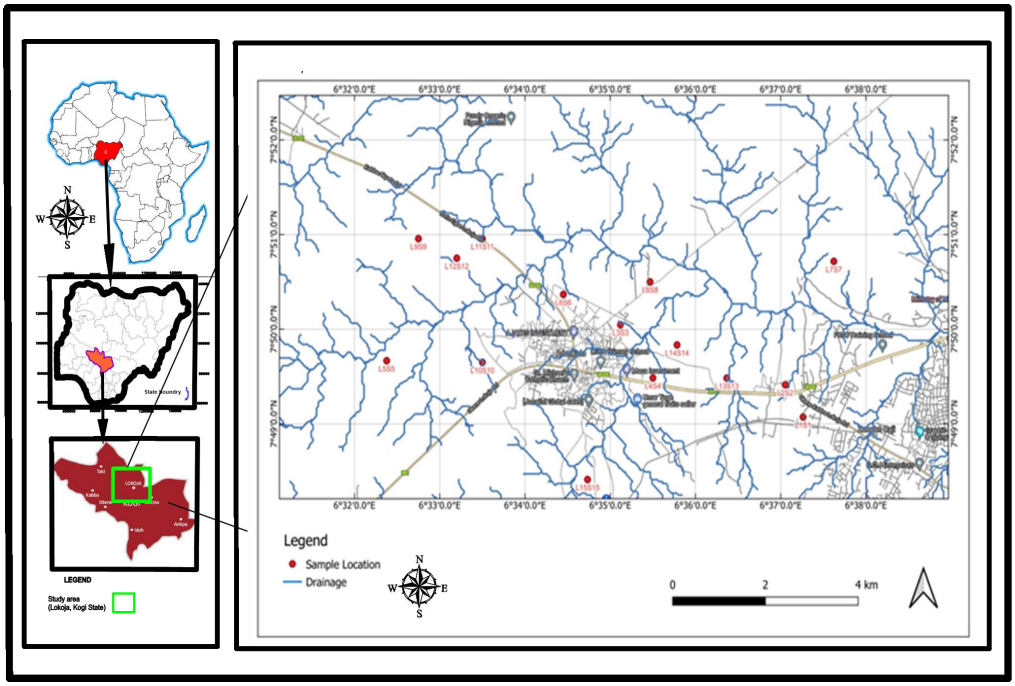

Figure 1: Drainage Pattern of the Study Area with the Sample location

DOI: 10.56892/bima.v8i4.1153

MATERIALS AND METHODS

The materials used during this fieldwork are: Digitalized base Map, Hard cover book, Polythene bags, Sample Bag, sterilized scooping Plate, GPS, Measuring tape, Ethanol for sterilization.

The Sample acquisition involved two stages. Stage one was the fieldwork phase which was carried out and it involved systematic stream sediment sampling of the distributaries adjacent to the Meme River sources where distributaries emanated from (Figure 1). Samples were taken from fifteen (15) different exposures at Lokoja town covering environs opposite Cemetery, Robinson Street at Kabawa, Mount Patti, Ayoola Ajao Avenue GRA, and back of the new stadium in Lokoja, Kogi State.

A total of fifteen (15) stream sediment samples were collected at a depth of 3-4cm and at interval of 500-700m along the distributaries. In order to avoid contamination, the collection was done with a sterilized scooping plate and afterward put in a pre-labeled polythene bag. At each sample location, observations such as the direction of flow of the river, the surrounding lithology were made and the coordinates were taken.

Laboratory Analysis

The second stage of the research methodology was the laboratory stage. This stage involved sample preparation and analysis. In the laboratory, the collected samples were prepared for geochemical analysis by first air-drying them for two weeks at room temperature. The dried samples were then disaggregated using porcelain mortar and pestles and later sieved to minus 80 (<177 microns) mesh size using nylon sieve. Thereafter, 200g of each of the selected sieved stream sediment samples were then sent to the Docchy Analytical laboratories, Akwa, Anambra State. Heavy metal analysis was conducted using Varian AA240 Atomic Absorption Spectrophometer according to the method of APHA 1995 (American Public Health Association).

Assessment of Sediment / Soil Contamination

It is possible for sediments and soils to document the past and show the level of contamination. In order to determine the level of pollution for a particular heavy metal, the concentration of the pollutant metal must be compared to an unpolluted reference material (geochemical background). It was decided to use the reference material because Nigerian academic systems did not include background values for metal concentrations. The reference material serves as a standard by which the levels of metals in the contaminated samples are evaluated and contrasted. The average shale values or the average crustal abundance statistics have been utilized as reference baselines by numerous authors. Pb = 20, Zn = 95, Cu = 45, Cr = 90, Ni = 68, Mn = 850, and Fe = 47200 are the average shale values that were used as reference material for background values in this work.

To determine the degree of contamination or pollution, the following environmental pollution models were employed.

Contamination Factor (Cf)

The contamination factor (Cf) can be used to express the degree of metal contamination. According to Martin and Meybeck (1979), Cf is the ratio of the metal content in the sediment to the metal's background value. It is a useful instrument for tracking pollution over time and is computed as follows:

$Cf = C_i$ heavy metal $/C_b$ metal background value (1)

DOI: 10.56892/bima.v8i4.1153

Hakanson (1980) defined low contamination as CF < 1, moderate contamination as 1 < CF < 3, significant contamination as 3 < CF < 6, and very high contamination as CF > 6.

Contamination Degree (Cd)

Hakanson (1980) developed a diagnostic tool called "degree of contamination" (Cd) to aid in pollution control. It is calculated as the total of the CF for every sample:

$$Cd = \Sigma Cf \quad (2)$$

The purpose of the Cd is to quantify the level of general contamination in the surface layers of a certain core or sampling location. The degree of contamination (Cd) in sediments was classified by Hakanson (1980) as follows: Cd < 6 (low degree of contamination), 6 < 12 (moderate degree of contamination), 12 < 24 (substantial degree of contamination), and Cd > 24 (high degree of contamination).

Ecological Risk Factor

Using the equitation proposed by Hakanson (1969), the ecological risk factor (Er) is quantitatively computed to express the possible ecological risk.

$$Er = Ti * Cf \quad (3)$$

where Cf is the contamination factor and Ti is the toxic-response factor for a substance. Table 1 lists the heavy metals' Ti values as determined by Hakanson (1980).

Table 1: Toxic- Response Factor (Hakanson, 1980)

Pb	Mn	Hg	Cu	Cd	Cr	As	Co
5	1	10	5	30	2	10	5

The ecological risk factor was described using the subsequent criteria: 40 ≤ Er < 80, moderate; 80 ≤ Er < 160, significant; 160 ≤ Er < 320, high; and Er ≥ 320, extremely high. Initially employed as a diagnostic tool for water pollution control, the risk factor has also been successfully applied to evaluate the level of heavy metal contamination of environmental soils.

Hakanson (1980) and Yang et al. (2011) proposed that the potential ecological risk index (RI) is a measure of the toxicity of heavy metals and the environment's reaction to the five risk factors (Pb, Cd, Cu, Zn, and Cr as total Cr) in surface soils. The RI is defined as the sum of the risk factors (Equation (5)).

$$RI = \Sigma Er \quad (4)$$

To describe the RI, the following criteria were used: RI < 150, low risk; 150 ≤ RI < 300, moderate; 300 ≤ RI < 600, considerable; RI ≥ 600, very high.

Geo-accumulation

By comparing present concentrations with pre-industrial levels, Muller (1983) developed an index of geo-accumulation (Igeo) to identify and quantify metal pollution in soils. It is possible to calculate using equation (6):

$$Igeo = Log2[\frac{Ci}{Cr} * 1.5] \quad (5)$$

where Cr is the geochemical background concentration, or reference value, and Ci is the observed concentration of the metal under study in the sediment. Due to extremely slight anthropogenic influences and potential differences in background values for a particular metal in the environment, factor 1.5 is utilized. According to Müller, the geo-accumulation index (Igeo) has seven classes: Igeo ≤ 0, class 0, unpolluted; 2 < Igeo ≤ 3, class 3, from moderately to strongly polluted; 3 < Igeo ≤ 4, class 4, from strongly to extremely polluted; 4 < Igeo ≤ 5, class 5, from strongly to extremely polluted; and Igeo > 5, class 6, extremely polluted.

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Multivariate Statistical Analysis

For factor analyses, the data gathered from laboratory analyses served as variable inputs. With the SPSS software, a factor analysis was carried out as detailed by Nie et al. (1975). Prior to the study, all variables were given a normal distribution by standardizing the data (Davis, 1973). In order to extract initial factor solutions using the principal component analysis approach, a correlation matrix of the data was then prepared. According to Kaiser (1958), factor extraction was carried out with a minimum acceptable eigenvalue of 1.

Kaiser's varimax technique (Kaiser, 1958) was used to rotate these beginning factors orthogonally to terminal factor solutions table 4.3. This approach modifies the factors to be either+1, -1, or zero in order to maximize the variance of the loadings on the factors. Each sample's factor score is calculated by multiplying the factor score coefficient by the standardized data in a matrix. It should be mentioned that a factor score > +1 implies strong process influence. Each factor score's value reflects how important a particular factor is at the sample location. A score of zero indicates locations where the process has only a mild impact, whereas highly negative values (< -1) indicate areas that are essentially untouched.

RESULTS AND DISCUSSION

The results of the geochemical assessment of the fifteen (15) samples of the studied stream sediment are presented in Table 2. The concentrations of heavy metal and trace elements analyzed fall within the world health organization (WHO) standard and world rock average (WSRA) except cadmium (Cd) that has concentrations higher than the permissible limit, though the sample locations with extreme concentration of it are: 5, 6, 7, 8, 9 10, 11 and 12 (Table 2). This enrichment could be primarily sourced from smelter waste, commercial fertilizes derived from phosphate ore or sewage sludge and municipal waste which are anthropogenic in nature.

Table 2: General Geochemical Assay of Stream Sediment.

Sampled Locations	Pb	Cd	As	Cr	Cu	Hg	Fe	Mo	Co	Mn
S1L1	1.4	2.8	0.2	1.675	20.6	1.675	112.4	1.125	1.625	6.075
S2L2	1.85	3.6	0.3	1.975	17.9	1.5	107.1	0	0.85	4.8
S3L3	2.375	2.525	0.425	1.7	15.7	2.125	91.9	0	0.7	3.3
S4L4	2.15	3.05	0.7	1.875	18.4	1.8	129.7	0.125	0.475	2.625
S5L5	7.225	10.225	0.375	7.675	11.1	2.975	173.5	0.05	0.875	3.575
S6L6	5.075	12.325	0.675	6.675	1.63	3.625	107.3	0.325	o.019	5.125
S7L7	5.7	9.675	0.7	8.875	17.4	4.725	137.4	0.25	0.7	3.85
S8L8	6.625	8.05	0.25	9.85	2.1	4.85	89.7	0.125	0.925	3.6
S9L9	4.875	12.3	0.85	7.375	23.6	2.625	112.4	0.075	0.75	3
S10L10	3.675	11.925	0.4	8.2	14.1	3.3	187.4	0.25	2.25	5.1
S11L11	8.625	12.575	1.125	0	1.3	4.1	109.9	0.4	1.1	4.725
S12L12	8.05	12.775	0.675	7.05	9.23	4.875	143.4	0.25	2.15	3.475
S13L13	4.85	6.95	0.675	3.6	11.1	3.325	101	0.25	0.75	7.225
S14L14	5.85	8.05	1.4	12.08	7.23	3.5	126.2	0	1.4	7.55
S15L15	4.975	5.85	1	4.8	11.1	3.25	101	0.05	0.7	3.3
World Surface Rock Average (WSRA)	16	0.3	10	71	32	200	300	1.5	13	750
World Health Organization (WHO)	100	3	20	100	100	722	5000	-	-	2000

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The dataset collected from multiple locations reveals notable variability across metal concentrations, with particular emphasis on heavy metals such as lead (Pb), cadmium (Cd), and chromium (Cr). Descriptive statistics (Table 3) show that Pb concentrations range from 1.4 to 8.625, with a mean of 4.89 (±2.25), indicating that Pb is moderately distributed across sampled areas. Cd has a higher mean concentration of 8.18 (±3.88) and a wider spread, which may point to specific regions of contamination. Indicating contamination as the average concentration is higher than its permissible crustal abundance (Table 3).

This is ultimately from waste discharge in to the stream from commercial activities within the Lokoja metropolis. Cr exhibits the highest variability, ranging from non-detectable levels to a peak of 12.08, with an average of 5.56 (±3.60), suggesting significant local concentration fluctuations potentially influenced by natural or anthropogenic factors.

Essential trace elements such as iron (Fe) have a notably high mean concentration of 121.99 (±28.41), with values ranging from 89.7 to 187.35, showing Fe is widely present across locations. Molybdenum (Mo), on the other hand, has low mean levels at 0.22 (±0.28), suggesting its sporadic occurrence. The section for correlation and factor analysis will provide deeper insights into underlying patterns or groupings of these elements, potentially linking certain metals due to common sources or environmental conditions, such as proximity to industrial activities or natural mineral deposits.

Further, the variability in arsenic (As) and mercury (Hg) levels, with Hg having a mean of 3.22 (±1.12), warrants attention for health and environmental monitoring. The concentration of other elements analyzed fall below their average crustal abundance as presented in Tables 2 and 3. Based on the average concentration of analyzed parameters, Fe > Cu > Cd > Cr > Pb > Mn > Hg > Co > As > Mo.

Table 3: Statistical Summary of the Geochemical Assay.

Parameters	Minimum	Maximum	Mean	Std. Deviation
Pb	1.40	8.63	4.89	2.25
Cd	2.52	12.78	8.18	3.87
As	.20	1.40	.650	.34
Cr	.00	12.08	5.56	3.60
Cu	1.30	23.63	12.16	6.98
Hg	1.50	4.88	3.22	1.12
Fe	89.70	187.35	121.99	28.41
Mo	.00	1.13	.22	.28
Co	.02	2.25	1.02	.60
Mn	2.63	7.55	4.49	1.51

The upper continental crust's maximum permissible limit and the mean concentration of the 10 elements examined in the study area were compared (Table 4). Cadmium (Cd), arsenic (As), and mercury (Hg) concentrations are high, according to Wedepohl's (1995) and

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Taylor and McLennan's (1995) categorization, but other elemental compositions including Pb, Cr, Cu, Fe, Mo, Co, and Mn are classified as having low limit status (Table 4).

The mapped area is not located within mining of Cd-bearing ore minerals, which suggests that anthropogenic sources of elemental enrichment of Cd, Pb, and Hg are more significant than bedrock geochemical dissolution (weathering). The result indicated that Cd is highly polluted in the stream sediment of Lokoja tributaries. Cadmium is extremely toxic, and the primary use of soil high in Cd in the form of manure for the cultivation of vegetations and other food crops could have negative health effects on consumers, such as cancer and renal disease (Gorenc *et al.,* 2004).

Table 4: Comparing the average metal content in the soils surrounding Madaka mining sites to their average crustal abundance (Wedepohl, 1995; Taylor and Mclenna, 1995).

Parameters	Mean conc. (ppm)	Wedepohl ,(1995)	Status	Taylor and Mclenna (1995)	Status
Pb	4.89	17 ppm	Low	20ppm	Low
Cd	8.18	0.102 ppm	High	0.098	High
As	0.65	0.055ppm	High	0.05	High
Cr	5.56	10ppm	Low	7.5ppm	Low
Cu	12.16	14.3ppm	Low	25ppm	Low
Hg	3.22	0.056ppm	High	0.040ppm	High
Fe	121.99	30890ppm	Low	7.07wt%	Low
Mo	0.22				
Co	1.02	11.6 ppm	Low	10ppm	Low
Mn	4.49	527 ppm	Low	600ppm	Low

Environmental Indices Evaluation

Each sample elemental concentrations were subjected to contamination level evaluation using equation 1 and 2. Only cadmium (Cd) fall within the high degree of contamination in all the sample analyzed. Whereas, other elements fall within the zero-contamination level (Table 5).

Table 5: Contamination Factor/Degree of Contamination

Sampled Locations	Pb	Cd	As	Cr	Cu	Hg	Fe	Mo	Co	Mn
L1	0.09	9.33	0.02	0.02	0.64	0.01	0.37	0.75	0.13	0.01
L2	0.12	12	0.03	0.03	0.56	0.01	0.36	0	0.07	0.01
L3	0.15	8.42	0.04	0.02	0.49	0.01	0.31	0	0.05	0
L4	0.13	10.17	0.07	0.03	0.57	0.01	0.43	0.08	0.04	0
L5	0.45	34.08	0.04	0.11	0.35	0.01	0.58	0.03	0.07	0
L6	0.32	41.08	0.07	0.09	0.05	0.02	0.36	0.22	0	0.01
L7	0.36	32.25	0.07	0.13	0.54	0.02	0.46	0.17	0.05	0.01
L8	0.41	26.83	0.03	0.14	0.07	0.02	0.29	0.08	0.07	0.01
L9	0.3	41	0.09	0.1	0.74	0.01	0.37	0.05	0.06	0
L10	0.23	39.75	0.04	0.12	0.44	0.01	0.62	0.17	0.17	0.01
L11	0.54	41.92	0.11	0	0.04	0.02	0.37	0.27	0.08	0.01
L12	0.5	42.58	0.07	0.09	0.29	0.02	0.48	0.17	0.17	0

DOI: 10.56892/bima.v8i4.1153

L13	0.3	23.17	0.07	0.05	0.35	0.02	0.34	0.17	0.06	0.01
L14	0.37	26.83	0.14	0.17	0.23	0.02	0.42	0	0.11	0.01
L15	0.31	19.5	0.1	0.07	0.35	0.02	0.34	0.03	0.05	0
Contamination Degree	4.58	408.91	0.99	1.17	5.71	0.229	6.1	2.19	1.18	0.09

Index of geo-accumulation (Igeo) was determined using equation (6). The results indicate that elements such as Pb, As, Cr, Cu, Hg, Mo, Fe and Mn are unpolluted. Nonetheless, Cd shows enrichment that range between the class of moderately polluted to strongly polluted (Table 6).

Table 6: Geo-Accumulation Indices of the Analyzed Parameters.

Sampled Locations	Pb	Cd	As	Cr	Cu	Hg	Fe	Mo	Co	Mn
L1	-2.89	3.81	-5.06	-5.06	-0.06	-6.06	-0.83	0.17	-2.36	-6.06
L2	-2.47	4.17	-4.47	-4.47	-0.25	-6.05	-0.89	0	-3.25	-6.06
L3	-2.15	3.65	-4.06	-5.06	-0.44	-6.05	-1.14	0	-3.73	0
L4	-2.36	3.93	-3.25	-4.48	-0.23	-6.21	-0.63	-3.05	-4.06	0
L5	-0.57	5.68	-4.05	-2.59	-0.93	-6.05	-0.20	-4.47	-3.25	0
L6	-1.06	5.95	-3.25	-2.89	-3.74	-5.05	-0.89	-1.59	0	-6.06
L7	-0.89	5.59	-3.25	-2.36	-0.30	-5.05	-0.54	-1.97	-3.73	-6.06
L8	-0.70	5.33	-4.47	-2.25	-3.25	-5.06	-1.20	-3.06	-3.25	-6.06
L9	-1.15	5.94	-2.88	-2.74	0.15	-6.05	-0.84	-3.73	-3.47	0
L10	-1.54	5.89	-4.05	-2.47	-0.59	-6.06	-0.10	-1.97	-1.97	-6.06
L11	-0.30	5.97	-2.59	0	-4.06	-5.06	-0.85	-1.30	-3.05	-6.05
L12	-0.42	5.99	-3.25	-2.89	-1.20	-5.06	-0.47	-1.97	-1.97	0
L13	-1.15	5.12	-3.25	-3.74	-0.92	-5.06	-0.97	-1.97	-3.47	-6.06
L14	-0.85	5.33	-2.25	-1.97	-1.53	-5.06	-0.67	0	-2.59	-6.05
L15	-1.10	4.87	-2.74	-3.25	-0.92	-5.06	-0.97	-4.47	-3.73	0

The ecological risk factors using equation 4 and 5 was calculated, the results revealed that only Cd shows very high ecological risk. Whereas, other elements fall within the low ecological risk as presented in Table 7.

Table 7: Ecological Risk Factor and Potential Ecological Risk Index (RI) of the Analyzed Parameters.

Sample Locations	Pb	Cd	As	Cr	Cu	Hg	Mo	Co	Mn
L1	0.45	279.9	0.2	0.04	3.2	0.4	3.75	0.65	0.01
L2	0.6	360	0.3	0.06	2.8	0.4	0	0.35	0.01
L3	0.75	252.6	0.4	0.04	2.45	0.4	0	0.25	0
L4	0.65	305.1	0.7	0.06	2.85	0.36	0.4	0.2	0
L5	2.25	1022.4	0.4	0.22	1.75	0.4	0.15	0.35	0
L6	1.6	1232.4	0.7	0.18	0.25	0.8	1.1	0	0.01
L7	1.8	967.5	0.7	0.26	2.7	0.8	0.85	0.25	0.01
L8	2.05	804.9	0.3	0.28	0.35	0.8	0.4	0.35	0.01
L9	1.5	1230	0.9	0.2	3.7	0.4	0.25	0.3	0
L10	1.15	1192.5	0.4	0.24	2.2	0.4	0.85	0.85	0.01
L11	2.7	1257.6	1.1	0	0.2	0.8	1.35	0.4	0.01
L12	2.5	1277.4	0.7	0.18	1.45	0.8	0.85	0.85	0

DOI: 10.56892/bima.v8i4.1153

L13	1.5	695.1	0.7	0.1	1.75	0.8	0.85	0.3	0.01
L14	1.85	804.9	1.4	0.34	1.15	0.8	0	0.55	0.01
L15	1.55	585	1	0.14	1.75	0.8	0.15	0.25	0
RI	22.9	12267.3	9.9	2.34	28.55	9.16	10.95	5.9	0.09

Multivariate Statistical Analysis of the Analyzed Geochemical Parameters

The correlation analysis (Table 8) shows several significant relationships among the elements, suggesting potential co-occurrence patterns or shared sources in the sampled locations. Lead (Pb) has a strong positive correlation with cadmium (Cd) ($r = .767$, $p < 0.01$) and mercury (Hg) ($r = .835$, $p < 0.01$), which may indicate a common origin or similar environmental factors affecting their concentrations. This trend is echoed with Cd, which also correlates positively with Hg ($r = .689$, $p < 0.01$), further strengthening the hypothesis of a shared source for these elements, possibly from industrial or anthropogenic activities.

Chromium (Cr) and Hg show a moderate positive correlation ($r = .562$, $p < 0.05$), which, while not as strong as other relationships, could reflect periodic co-contamination in certain areas. Copper (Cu), on the other hand, displays negative correlations with Pb ($r = -.670$, $p < 0.01$) and Hg ($r = -.644$, $p < 0.01$), suggesting that areas high in Cu might be low in these elements, potentially due to differing environmental processes or sources. Iron (Fe) shows a moderate positive correlation with cobalt (Co) ($r = .531$, $p < 0.05$), implying that Fe-rich areas may also have elevated levels of Co, which could reflect underlying geological factors like mineral composition. Overall, these relationships highlight specific elemental pairs that may require further examination for environmental or geological impact assessments.

Table 8: Correlation Matrix of the Analyzed Parameters.

Parameters	Pb	Cd	As	Cr	Cu	Hg	Fe	Mo	Co	Mn
Pb	1									
Cd	.767**	1								
As	0.44	0.32	1							
Cr	0.41	0.48	0.19	1						
Cu	-.670**	-0.43	-0.28	-0.22	1					
Hg	.835**	.689**	0.28	.56*	-.644**	1				
Fe	0.17	0.42	-0.09	0.37	0.14	0.11	1			
Mo	-0.19	-0.08	-0.28	-0.32	0.01	-0.09	-0.022	1		
Co	0.13	0.22	-0.09	0.19	0.06	0.18	.531*	0.299	1	
Mn	-0.06	-0.03	0.21	0.11	-0.22	-0.02	-0.043	0.328	0.229	1

**. Correlation is significant at the 0.01 level (2-tailed).

The analyzed parameters were subjected to factor analysis in order to determine the predominant or influencing geochemical parameters. Three factors were extracted as presented in Table 10 while the total variance explained by each factor are presented in Table 9. The factor analysis reveals three main components explaining about 69.5% of the total variance in the heavy metal concentrations across the sampled locations. The first factor accounts for 34.5% of the variance, indicating a significant underlying influence common to multiple elements. This factor likely represents metals that co-occur due to similar environmental or anthropogenic sources, as suggested by the high communalities for lead (Pb: 0.854), cadmium (Cd: 0.753), mercury (Hg: 0.800), and iron (Fe:

DOI: 10.56892/bima.v8i4.1153

0.796). These metals' high communalities show they strongly contribute to shared variance across factors.

The second factor explains an additional 19.8% of the variance and could indicate a secondary source or process influencing metals like copper (Cu: 0.727) and cobalt (Co: 0.746). The third factor adds 15.3% of the variance, potentially highlighting another distinct grouping or geochemical behavior affecting elements such as manganese (Mn: 0.658). Together, these components suggest a structured pattern of heavy metal distribution, where certain metals are linked due to environmental clustering, possibly from industrial emissions or natural geochemical processes. This factor breakdown provides a foundation for further spatial or source-specific analyses, which can help identify specific contamination sources or natural deposits in the sampled locations.

Table 9: Total Variance Explain

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.679	36.794	36.794	3.679	36.794	36.794	3.446	34.461	34.461
2	1.824	18.239	55.033	1.824	18.239	55.033	1.980	19.795	54.256
3	1.451	14.506	69.539	1.451	14.506	69.539	1.528	15.283	69.539
4	1.000	9.996	79.534						
5	.706	7.065	86.599						
6	.467	4.667	91.266						
7	.435	4.351	95.617						
8	.205	2.050	97.668						
9	.137	1.367	99.035						
10	.096	.965	100.000						

Extraction Method: Principal Component Analysis.

Table 10: Factor Analysis of the Analyzed Geochemical Parameters.

Parameters	Factor 1	Factor 2	Factor 3
Pb	0.914	-0.132	0.027
Cd	0.848	0.159	-0.093
As	0.473	-0.376	0.194
Cr	0.66	0.171	-0.258
Cu	-0.676	0.327	-0.405
Hg	0.89	-0.052	0.065
Fe	0.313	0.726	-0.414
Mo	-0.242	0.492	0.622
Co	0.234	0.825	0.107
Mn	0.073	0.229	0.775

Extraction Method: Principal Component Analysis.

The analysis of heavy metal concentrations across sampled locations reveals three main components that explain the majority of the variance, suggesting distinct sources or processes influencing metal distribution. Lead (Pb), cadmium (Cd), and mercury (Hg) show strong correlations and cluster in Component 1, indicating likely anthropogenic sources, such as industrial emissions. Iron (Fe) and cobalt (Co) load heavily on Component 2, pointing to a probable geogenic origin related to soil composition. Molybdenum (Mo) and

DOI: 10.56892/bima.v8i4.1153

manganese (Mn) are strongly associated in Component 3, hinting at unique localized factors, possibly agricultural activities or soil amendments. These results highlight complex interactions between natural and human-influenced sources affecting metal levels in the environment and provide a foundation for targeted environmental monitoring and management strategies.

CONCLUSION

The research assesses heavy and trace metal concentrations in sediments from the Meme River distributaries in Lokoja, North Central Nigeria, using geochemical and statistical methods. The findings indicate significant anthropogenic influence on metal pollution, particularly with cadmium (Cd), arsenic (As), and mercury (Hg), which surpass permissible limits according to WHO and World Surface Rock Average (WSRA) standards. These metals exhibit high contamination and ecological risk indices, underscoring their potential adverse impacts on environmental and public health.

The dominance of Cd, Pb, and Hg contamination suggests industrial, agricultural, and urban sources rather than natural geochemical processes. Cadmium (Cd) emerges as the most concerning element, with high ecological risk, significant contamination, and widespread presence across sample locations. Most metals, except Cd, fall within the "unpolluted" to "moderately polluted" categories. Cd exhibits moderate to strong pollution levels, necessitating urgent mitigation efforts.

Correlation and factor analyses reveal clustering patterns among metals, such as a strong relationship between Cd, Pb, and Hg, pointing to common sources or co-occurrence mechanisms likely linked to human activities.

The study highlights the need for intervention by environmental protection agencies. Remediation of the affected sediments and stricter regulations on pollutant discharge are crucial to mitigate ecological risks.

This research serves as a critical baseline for understanding sediment contamination in the study area and calls for comprehensive environmental management strategies to address identified risks.

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