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Assessment of the Heavy Metal Contamination in the Coastal Sediments of Meme River in Lokoja, Nigeria Using Geoaccumulation Index

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Abstract

The Meme River in Lokoja is a tributary of the River Niger and a place where household discharge their domestic and industrial refuse. This however makes the river to be highly polluted due to these discharges. This necessitates the present study to assess the level of heavy metals contamination in the coastal sediment of Meme River in Lokoja using Flame Atomic Absorption Spectrometric technique. The various levels of contamination was analysed using the geo-accumulation index. Results of this study for water analysis indicates a concentration range of 0.04 – 0.06 ppm (Fe), 2.33 – 10.40 ppm (Cr), 0.30 – 0.72 ppm (Zn), 0 – 1.81 ppm (Ni), 0.01 – 0.70 ppm (Cu) and 0.03 – 0.10 ppm (Cd). The observed metal concentrations for sediments ranged from 3.50 – 5.60 mg/kg (Fe), 5.93 – 9.89 mg/kg (Cr), 0.65 – 1.04 mg/kg (Zn), 0.13 – 2.45 mg/kg (Ni), 0.10 – 0.20 mg/kg (Cu) and 0.070 – 0.61 mg/kg (Cd). Results of some measured metals like K, Mg and Na in the water ranged from 30.0 – 44.0 ppm, 9.30 – 9.80 ppm, and 5.40 – 5.70 ppm respectively, while the concentration observed in the sediment samples ranged from 49.0 – 78.0 mg/kg (K), 9.50 – 9.80 mg/kg (Mg) and 5.55 – 5.68 mg/kg (Na). The geo-accumulation index analysis showed that the sediment and water samples are not polluted with Cr, Zn, Cu and Cd. However, the water samples are highly polluted with Fe. The measured metals such as Mg and K indicated a moderately high concentration in the water and sediment samples. The results of this work generally indicate that the sediment and water samples are moderately polluted by Fe which possibly may be due to anthropogenic activities along the River bank.

Keywords: FAAS, Coastal Sediments, pollution, heavy metals, geo-accumulation index .

Introduction

Heavy metals are one of the more serious pollutants in our natural environment due to their toxicity, persistence and bioaccumulation problems. Trace metals in natural waters and their corresponding sediments have become a significant topic of concern for scientists and engineers in various fields associated with water quality, as well

as a concern of the general public [1]. Direct toxicity to man and aquatic life and indirect toxicity through accumulations of metals in the aquatic food chain are the focus of this concern.

The presence of trace metals in aquatic systems originates from the natural interactions between the water, sediments and atmosphere with which the water is in contact [2]. The concentrations fluctuate as a result of natural hydrodynamic chemical and biological forces. Man, through industrialisation and technology, has developed the capacity to alter these natural interactions to the extent that the very waters and the aquatic life therein have been threatened to a devastating point.

The activity of trace metals in aquatic systems and their impact on aquatic life vary depending upon the metal species. Of major importance in this regard is the ability of metals to associate with other dissolved and suspended components [3][4]. Most significant among these associations is the interaction between metals and organic compounds in water and sediment. These organic species, which may originate naturally from process such as vegetative decay or result from pollution through organic discharge from municipal and industrial sources, have a remarkable affinity and capacity to bind to metals. This phenomenon would naturally alter the reactivity of metals in the aquatic environment [5].

Many human activities (e.g.; mining, overuse of chemicals, industrial waste from ports and refineries) have a negative impact on several biological processes and there is no doubt that these will continue to affect the functioning of highly productive coastal ecosystems [6]. Contamination caused by trace metals affects both ocean waters, those of the continental shelf and the coastal zone where, besides having a longer residence time, metal concentrations are higher due to input and transport by river runoff and the proximity to industrial and urban zones [2]. Trace metals, including those defined as “heavy”, arising from industrial and mining activities are discharged into coastal waters and estuaries at many sites. The term heavy metal refers to any metallic chemical element that has a relatively high density and is toxic, highly toxic or poisonous at low concentrations. These anthropogenically derived inputs can accumulate in local sediments up to five orders of magnitude above the overlying water [1] and invertebrates living on it or in food, and the rate of accumulation caries widely between species and heavy metal concentration found in “clean” conditions. Less is known of the uptake of these metals by ingestion with food or from close contact with contaminated sediments [7].

The aim of this study was to assess heavy metal contamination in the coastal sediment of Meme River in Lokoja using geoaccumulation index technique.

Materials and Methods

Study area

The study area is Lokoja in Kogi State Central Nigeria. Lokoja is the capital of Kogi State which is a confluence town between the Rivers Niger and Benue Figures 1 and 2.

Equipment and reagents

Agate Mortar and Pestle, Hot Plate, Stainless Steel Mesh, Whatman filter paper (No. 10), Stirrer, Oven, Microprocessor flame photometer Model Li-1382 (Lasany), Buck Scientific Flame atomic absorption spectrometer, Water bath, Hydrochloric acid, Nitric Acid, Hydrogen peroxide, De-ionized water. All reagents used are of analytical grade.

Sample collection and digestion

Ten sampling sites were chosen for collection of sediments along Meme River and its water. Sediment samples were collected in October 2014 along the river bank at varying distances. The samples were placed in plastic containers and transported to the laboratory. The samples were dried in the laboratory at 104 ^{0}C for 48 hours, ground to a fine power and sieved through 106 µm stainless steel mesh wire [8].

Ten water samples were collected at different distance 0, 200, 400, 600, 800, 1000, 1200, 1400, 1600, 1800 meters apart, using 1 L plastic container and transported to the laboratory [8].

Digestion of sediments and water sample

One gramme (l.0 g) of each sample was digested with 30 cm^3 aqua regia (HCl: HNO_3 3:1) in a beaker on a thermostatically controlled hot plate with constant swirling. The digested sample was allowed to cool down to room temperature and 5.0 cm^3 of hydrogen peroxide was added to complete the digestion. The wall of the beaker was washed with 10 cm^3 of de-ionized water. The mixture was transferred into a 100 cm^3 standard flask and was made up to the mark with de-ionized water. This was then filtered using Whatman filter paper with 406 µm pore size and stored in special container prior to analysis.

Fifty millilitre (50 cm^3) for each water sample was measured using measurement cylinder into 100ml standard flask, and 7 cm^3 (HCI:HNO_3 5:2) was added, the mixture was shaken vigorous and was made up to the mark. The resulting mixture was placed in the water bath for 45 minutes to evaporate until it reached 20 cm^3 mark. The mixture was again made up to the mark with de-ionized water and was stored in a special container prior to analysis [8]

Sample analysis

Each of the 10 samples (sediment/water) in the special container was analyzed for K, Mg and Na using flame photometer while Fe, Cr, Zn, Ni, Cu and Cd were analysed using Flame Atomic Absorption Spectrometer (Buck scientific model VGP 210).

Geo-accumulation index

Enrichment of metal concentration above base line concentrations was evaluated using the method proposed by Salah [9] termed the Geo-accumulation index as expressed in the following equation

Geo-accumulation index (I_{geo}) = $log_2 \frac{C_n}{1.5B_n}$

Where B_n is the concentration of the metal in unpolluted sediments according to a list of regional backgrounds for the different gram sizes/medium

sand, fine sand or silt and clay, C_n is the concentration of the metal and the factor 1.5 introduces possible variation of the metal concentration [10]. There are seven classes of the Geo-accumulation index. These are given in the Table 2. The overall total geo-accumulation index (I_{tot}) is defined as the sum of I_{geo} for all trace elements obtained from the site. The number of toxic elements determined in a sediment sample and their respective I_{geo} values would influence the I_{tot} [11].

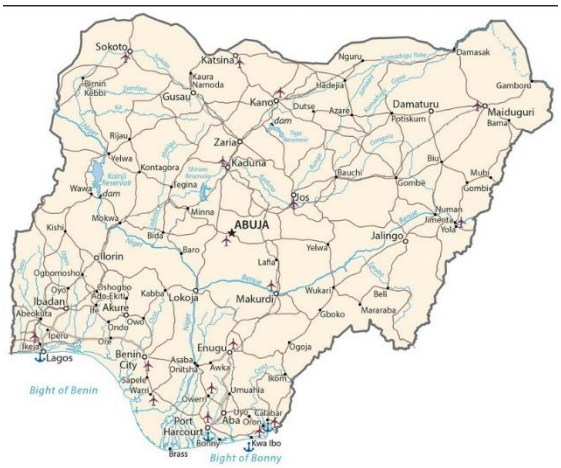

Figure 1. Map of Nigeria

Results

The results of the assessment of some major and heavy metal contaminants in the coastal sediment of Meme River and the water samples, in Lokoja Nigeria, are shown in Tables 3 and 4, while Tables 5 and 6 are the result of the geo-accumulation index of the metals in the sediments and water sample respectively.

Figure 2. Map of Lokoja.

Table 1: Location, description of activities and sediment type

Site	Distance (m)	Activities	Released to
Upstream bridge before army barracks Lokoja	0 - 200	2 – 3 Mega block industries	Sediment and water
Domestic sewage channelled through drainage system from phase 1 Lokoja	400 - 600	Domestic sewage	Sediment and water
Sewage dump site at Ganaja junction Lokoja	800 - 1000	Refuse dump	Sediment and water
Specialist hospital, Treasure and Halims hotel discharge.	1200 - 1400	Sewage discharge	Sediment and water
Car wash complex before old market Lokoja	1600 - 1800	Car wash	

Table 2: Classification for geo-accumulation index [11]

Igeo value	Class	Sediment quality
<0	0	Unpolluted
0 – 1	1	From unpolluted to moderately polluted
1 - 2	2	Moderately polluted
2 - 3	3	From moderately polluted to strongly polluted
3 - 4	4	Strongly polluted
4 - 5	5	From strongly polluted to extremely polluted

Table 3: Concentrations of some selected major and heavy metals obtained in sediment sample (mg/kg)

Distance (m)	k	Mg	Na	Fe	Cr	Zn	Ni	Cu	Cd
0	57	9.8	5.61	4.70	8.29	0.89	2.45	0.10	0.61
200	65	9.8	5.58	4.70	9.62	1.04	1.84	0.14	0.07
400	60	9.8	5.62	4.50	9.35	0.75	1.58	0.18	0.10
600	58	9.6	5.56	4.80	9.72	0.86	1.40	0.19	0.23
800	78	9.7	5.68	5.60	8.33	0.88	1.90	0.20	0.32
1000	46	9.5	5.68	5.20	8.59	0.87	2.26	0.19	0.35
1200	70	9.6	5.61	5.60	5.93	0.81	1.93	0.17	0.41
1400	52	9.6	5.57	4.40	7.71	0.65	2.10	0.19	0.49
1600	54	9.8	5.59	4.40	7.67	0.74	2.12	0.16	0.54
1800	49	9.6	5.55	3.50	9.89	0.73	1.13	0.14	0.07

Table 4: Concentrations of some selected major and heavy metals obtained in the water samples (ppm)

Distance (m)	K	Mg	Na	Fe	Cr	Zn	Ni	Cu	Cd
0	48	9.8	5.51	0.04	2.59	0.41	0.18	0.08	0.04
200	39	9.4	5.61	0.05	4.65	0.72	0.60	0.05	0.03
400	30	9.7	5.55	0.04	2.33	0.36	0.61	0.06	0.04
600	39	9.4	5.58	0.20	4.24	0.55	0.43	0.03	0.06
800	34	9.3	5.70	0.30	3.88	0.63	0.14	0.0 4	0.06
1000	55	9.6	5.62	0.50	8.60	0.48	0.45	0.12	0.04
1200	30	9.8	5.55	0.60	7.72	0.47	ND	0.70	0.04
1400	36	9.8	5.62	0.60	6.51	0.62	0.70	0.06	0.08
1600	44	9.8	5.48	0.60	6.24	0.47	0.73	0.04	0.10
1800	34	9.5	5.40	0.30	10.40	0.37	1.81	0.01	0.07

Table 5: Geo-accumulation index of metals in the sediment samples

Distances (m)	K	Fe	Mg	Na	Cr	Zn	Ni	Cu	Cd
0	0.40	-4.24	0.37	2.90	-4.46	-8.87	2.60	-9.43	-8.66
200	0.10	-3.92	0.31	2.91	-3.61	-8.05	4.33	-10.11	-9.08
400	-0.28	-0.91	0.36	2.99	-4.61	-9.05	4.33	-9.84	-8.66
600	0.10	-1.91	0.31	2.90	-3.74	-8.79	4.85	-10.85	-8.07
800	0.01	-1.33	0.39	2.94	-3.87	-8.24	2.22	-10.43	-8.07
1000	0.60	0.59	0.34	2.92	-2.72	-8.63	3.91	-8.84	-8.66
1200	0.28	-0.32	0.37	2.99	-2.96	-8.66	0	-6.29	-8.66
1400	-0.01	-0.32	0.37	2.92	-3.12	-8.26	4.55	-9.84	-7.66
1600	-0.28	-0.32	0.37	2.88	-3.18	-8.66	4.61	-10.43	-7.33
1800	0.01	-1.33	0.34	2.86	-2.44	-9.01	5.93	-12.44	-7.85

Table 6: Geo-accumulation index of metals in the water samples

Distances (m)	K	Fe	Mg	Na	Cr	Zn	Ni	Cu	Cd
0	0.65	2.66	0.37	2.91	-2.77	-7.74	6.37	-9.10	-4.72
200	0.84	2.66	0.37	2.90	-2.55	-7.51	5.95	-8.62	-7.82
400	0.73	1.76	0.37	2.92	-2.59	-7.91	5.73	-8.25	-7.33
600	0.68	2.69	0.34	2.99	-2.54	-7.79	5.56	-8.17	6.13
800	1.11	2.91	0.36	2.93	-2.76	-7.76	6.09	-8.19	-5.65
1000	0.34	2.80	0.33	2.93	-2.72	-7.77	6.25	-8.17	-5.52
1200	0.95	2.91	0.34	2.91	-3.33	-7.88	6.02	-8.34	-5.29
1400	0.52	2.44	0.34	2.90	-2.87	-8.19	6.14	-8.17	5.03
1600	0.57	2.44	0.37	2.91	-2.87	-8.01	6.16	8.42	-4.89
1800	0.43	0.11	0.34	2.99	-2.51	-8.03	5.25	-8.62	-7.85

Major metals in sediment

The result of the K determination along the river trajectory indicates a maximum concentration at 800 m from the point source (78 mg/kg) Table 3. There was a gradual decrease from 1000 m-1800 m with a cumulative range of 46 – 78 mg/kg. At 1600 m, the concentration increased to 9.8 mg/kg and decreased at 1800 m to 9.6 mg/kg. For Mg, the observed concentration ranged from 9.5 - 9.8 mg/kg. Na was detected in the range of 5.55 -5.68 mg/kg.

Heavy metals in sediment

The results of the heavy metals in the sediment samples are presented in Table 3. The result of the analysis of Fe in the water ranged from 3.50 - 5.6 mg/kg. Maximum concentration of Fe was detected at 800 m and 1200 m. However, least concentration was observed at a distance of 1800 m (3.50 mg/kg). Cr was observed in the range of 5.93 - 9.89 mg/kg. The observed concentration of Zn ranged from 0.65 - 1.04 mg/kg. This concentration range is not objectionable in comparison with maximum permissible limit for SQGs [12]. Ni concentration in the observed sediment trajectories indicated a range of 1.13 - 2.45 mg/kg. For Cu analysis, the observed concentration ranged from 0.10 - 0.20 mg/kg. Cd concentration observed in the analysis of water and sediment along Meme River ranged from 0.07 - 0.61 mg/kg.

Major metals in water samples

The result of major and heavy metals contamination in water sample in Meme River (Table 4) showed that K concentration ranged from 30 - 55 ppm. Maximum concentration of K was observed at 1000 meters. For Mg, the observed concentration ranged from 9.3 - 9.8 ppm. The concentration of sodium observed ranged from 5.40 - 5.70 ppm.

Heavy metals in water samples

The result of analysis of Iron (Fe) as shown on Table 4 indicated a range of 0.04 – 0.60 ppm. It was observed that the concentrations of Cr varied significantly at different distances with a range of 2.33 – 10.40 ppm. Zinc indicated a concentration range of 0.36 – 0.72 ppm with the highest concentration of 0.72 ppm detected at 200 m distance from the first point of collection. Nickel on the other hand showed a range of 0 – 1.81 ppm. The range for Cu concentration detected was 0.01 – 0.70 ppm. This is quite low in comparison to the metals mentioned previously. In analogy, the observed concentration of Cd occurred in the range of 0.03 – 0.10 ppm. This plausibly suggests that most of the discharges onto the river are non Cu and Cd bearing effluents.

Discussion

Sediment sample

The high concentration of K observed at 800 m distance (Table 3) from the point source may be ascribed to human activities due to deposition of domestic refuse and its accumulation over time. It is on record that Meme River is contaminated with waste from some household activities, this renders the water body highly polluted as a result of refuse discharge. Magnesium is highly mobile in the sediment. Therefore, the observation in terms of high concentration is not surprising. The Mg concentration observed similarly may be ascribed to influence of domestic activities around the river trajectory. Meme River is a river that passes through a densely populated area of Lokoja metropolis. Therefore, it serves as a discharge point for most domestic and industrial effluent. As stated earlier, it partly may be ascribed to the high increase in K and Mg observed in comparison with the statistics from sediment quality guidelines (SQGs). The SQGs limit for Mg is 0 - 0.50 mg/kg [13][14].

There was no significant difference between the observed Na concentrations at various distances (Table 3). This may be ascribed to natural Na matrix. The three (3) major metals (K, Mg, and Na) are beneficial to humans. Therefore, the limits observed so far, have exceeded the limit prescribed by Sediment Quality Guidelines (SQGs). The SQGs for K, Mg and Na are 25 mg/kg, 5 mg/kg and 0.5 mg/kg respectively. This can affect balance system in human [7].

Heavy metals

The decrease in the concentration Fe at 1800 m may be due to dilution as the water traverses its course. It is on record that the sediments continually moves as the water traverses it course and therefore, the rate of dilution increases downstream at 1800 m [15]. The geography of Meme River is in such a way that it empties into River Niger and therefore most discharges are pushed into the River Niger. Another factor that could be responsible is the presence of Fe species in the soil, the formation of iron (Fe) complex, non humus interaction, and leaching [16]. Iron is equally a trace metal that is responsible for oxygen transport in the human system, in the form of oxy-haemoglobin and therefore it is essential for human

system [6]. The SQGs for Fe is 0.5 mg/kg. However, excess Fe beyond the limit prescribed by SQGs may cause certain ailments like depressed respiration, convulsion, cardiac arrest, coma, rapid respiration [5].

The concentration of Cr may be ascribed to the fact that Cr has the tendency to occur in various oxidation states (Cr^{3+}) and (Cr^{4+}) [17]. The distribution of chromium in the sediments depends on the redox potential, pH, and presence of oxidizing and reducing compounds, kinetics of the redox reaction and formation of chromium complexes [18]. The maximum acceptable value as prescribed by SQGs for Cr is 37.30 mg/kg [13]. It was equally observed that there was a progressive increase in the concentration of Cr from the 600 m. There was a significant decrease in concentration at 800 m, 1000 m, 1200 m, 1400 m, and 1600 m but a tremendous decrease in concentration was observed at 1200 m. Because of the proximity of the river to the nearby residential areas, there is every tendency for Cr deposition and dissolution in the water. Therefore, it is important to ascertain the level of Cr and ensure it does not exceed the maximum permissible limit. Cr could be absorbed in plants matrix that may end up in humans, thereby having an adverse effect in human systems. Such adverse effects may include cancer [8].

For Zn in the sediments (Table 3), factors that may contribute to the concentration of Zn observed at 200 m may be connected with anthropogenic activities such as effluent discharge on the sediment as observed in the sample area [16][19]. Thus Zn might have impacted undesirable astringent taste in the water body [20]. Results of this study on Zn may be compared to the result obtained from recent studies [2]. The SQGs for Zn is 123 mg/kg.

The recorded Ni concentration may be ascribed to anthropogenic activities. It is observed that most electronic waste and some industrial waste are made up of Ni compounds. This Ni compounds when discharged into the water bodies has the tendency to increase the Ni load on the banks of the river. Previous studies have suggested that absorption of soluble Ni in human from drinking water may be higher than that of Ni from food [21]. The Ni from point source to 1800 m may be attributed to dilution of Ni species as the water traverses its course. At 1000 m from the point source the concentration of Ni increases to 2.26 mg/kg after which there was a decrease to 1.13 mg/kg at 1800 m. Factors such as complex formation, ion-ion interaction, chemical oxidation, leaching may play a role in this trend [22].

Copper is easily oxidizable and can go into solution at varying pH. Factors such as soil interaction and anthropogenic activities may be responsible for this spatial distribution of Cu species, as the distance of the sampling point increases from the point source [23]. There is no definite anomaly in terms of higher value of copper observed; therefore Cu existence at this concentration range may be from natural sources [24]. Cu (II) form complexes with both inorganic and organic compound such as ammonium and chloride ion etc. The SQGs limit for Cu is 35.70 mg/kg [8]. Thus the Cu concentration observed was

far below the SQGs limits and it is said to be free for humans. However, long exposure to Cu species may have adverse effect on human such as gastrointestinal disorder and in uncommon cases, liver toxicity in susceptible individuals with repeated exposure [20].

The trend observed in Cd is similar to the trend observed for Zn. The concentration of Cd reduces as the distance increases and subsequently increases gradually from 400-1600 m from the point source. Incidentally, the concentration of Cd at the source point is 6.61 mg/kg which is slightly above the maximum permissive limited for SQGs for Cd which is 10.60 mg/kg [24]. Cadmium has the tendency to accumulate in biological system such as plants and humans [8]. Previous studies have suggested that Cd compound are currently mainly used in rechargeable nickel-cadmium batteries, electronic components and nuclear reactions [16]. It is not surprising that presence of Cd as observed in the sediments may be due to the fact that most of the domestic and industrial discharges are composed chiefly of Cd compounds. Acute exposure of Cd may lead to necrosis of the intestinal and gastric mucosa, kidney damage, bone fracture and dystrophic changes of the liver, heart and kidney [25].

Water

For water analysis, the values observed for K and Mg are far above the maximum permissible limit. The presence of Mg at this concentration could be as a result of anthropogenic activities. The maximum permissible limit for Mg is 0.20 mg/L [25]. There was no significant difference between the observed sodium concentrations at various distances. The concentration of sodium in the water samples did not exceed the maximum permissible limits of 20 ppm [26]. Therefore, the river is contaminated with potassium and magnesium while the concentration of sodium is below the maximum permissible limit.

The concentration of Fe at 0 – 1000 m does not exceed the maximum permissible limit by World Health Organisation. It was observed that at 1200 – 1600 m (Table 4) the value exceeded the maximum permissible limit and at 1800 m the concentration decreased to 0.30 mg/kg. The maximum permissible limit of Fe is 0.30 mg/L [27]. The concentration of Cr in the water samples exceeded the maximum permissible limit. The maximum permissible limit is 0.50 ppm [28].

Conclusion

From the sediment and water data obtained after geochemical accumulation calculations, the followings were observed: the concentrations of Cr, Zn, Cu and Cd in the sediments and water samples as shown in the geo-accumulation index indicates that the water and sediment samples are unpolluted by these heavy metal species. Fe, Ni and Na are highly polluted in the sediment and water samples. Mg, K, Na, Ni, Fe and Cr are higher in water samples than in the sediments, hence the water is not safe for domestic purposes.

Conflicting Interest

The authors declare that no conflicting interest exist.

Authors Contributions

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