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Heavy metals profile and heavy metals pollution indices in surface water of Kolo Creek, Ogbia, Bayelsa State, Nigeria

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Abstract
This study investigated the concentrations of some heavy metals in surface water of the Kolo Creek, Ogbia axis, Bayelsa State, Nigeria. The study was carried out by collecting samples from four different stations within the creek. The heavy metals concentrations were analyzed using atomic absorption spectrophotometers (AAS) after necessary laboratory processes has been carried out. The concentrations of heavy metals obtained after examination were in the range 0.278±0.10 to 2.461±0.15mg/L for Pb, not detected to1.427±0.13mg/L for Cd, 1.589±0.12 to 4.856±1.01mg/L for Ni, 1.682±0.17 to 4.581±0.56mg/L for Cr, 2.468±0.50 to 6.306±1.23mg/L for Cu, 4.503±1.02 to 7.116±1.53mg/L for Zn, not detected to 1.141±0.57mg/L for As, not detected to 0.472±0.21mg/L for Co and 2.138±0.16 to 6.814±1.20mg/L for Fe. The mean concentrations of heavy metals in the creek were in the order Zn > Cu > Fe > Ni > Cr >Pb > Cd > As > Co. The concentrations of the studied heavy metals in water samples were above WHO maximum permissible limits for potable water. The pollution indices used in measuring the extent of contamination of the surface water by heavy metals indicated different levels of contamination or pollution. The study has shown that the surface water of Kolo Creek has reached an alarming stage due to the high occurrence of heavy metals and therefore urgent steps must be taken to forestall any impending danger that could pose severe threat to the aquatic ecosystem.

Keywords: contamination factor, kolo creek, heavy metals, pollution indices, surface water

Introduction
Environmental pollution due to anthropogenic activities is at an alarming stage, and it is of great concern to humans especially those that dwell along the coastal environments. These resultant effects of aquatic pollution had widely influenced the general ecosystem of the aquatic environment and also humans that dwell within the area where such pollution occurs (Neff, 2002; Tornero & d'Alcala, 2014; Edori & Edori, 2021) [30, 40, 10]. Large volume of organic and inorganic contaminants in the aquatic environment enter the creek or any other water body through runoffs from adjoining farmlands, illegal refining sites, direct discharge of contaminants, biogenic inputs and aerial deposition (Uzoekwe & Achudume, 2011; Edori & Iyama; 2020) [42, 13].
Heavy metals gain entrance into surrounding water bodies through runoffs or erosion, while their concentrations increase through disposal of high metal waste and domestic sewage discharge. The incidence of heavy metals in water bodies and water organisms largely forecast the presence of natural and anthropogenic sources of heavy metals in the ecosystem (Mahipal *et al*., 2016) [24]. Heavy metals are one of the major sources of pollution in the aquatic environment. Contamination of surface water is detrimental to humans, animals and plants, it produces severe disorder to the environment if not properly managed or controlled (Mishra & Patel, 2015) [28].
The increase in the quantity of heavy metals is in most cases are from industrial and agricultural activities (Williams and Benson, 2010; Edori and Kpee, 2018) [43, 14]. Aquatic environments like rivers lakes, creeks, seas, rainwater become polluted due to human activities. Such human activities includes gas flaring, effluents discharged from homes, public places and industries. Wastes are also dumped directly into the creeks, rivers and streams resulting in the increase in the levels of contaminants of the aquatic environments (Uzoekwe and Achudume, 2011; Edori and Iyama; 2020) [42, 13]. These waste in the surface water of the creek pose severe environmental consequences.
As population increases there is a resultant increase in the discharge into the water environments. These wastes that enter the creek come through illegal bunkering activities, pesticides and fertilizer application, transportation using outboard engines and through direct dumping of agricultural wastes (Ghosh and Singh, 2005) [20]. Natural ways through which heavy metals and other pollutants enter into the water environments are soil weathering and leachates from the soil (Nadaska *et al*., 2010; Mesias *et al*., 2013) [29, 27].
This study investigates the concentrations of some heavy metals in surface water of Kolo Creek, Ogbia Local Government Area, Bayelsa State, Nigeria.

Materials and Methods

Study area

Kolo Creek is situated in the central Niger Delta area of Nigeria (A1agoa, 1999). The creek lies between latitude 4º23 and 4º36 N and longitude 6º14 and 6º16 E. Kolo Creek is a tributary of Orashi River and it begins at Okarki Town in Engenni, Ahoada West,Rivers State. The creek is a fresh water body which flow north south and terminate at Ekole Creek close to Dorgu Ama Okoroma Tereke in Nembe Local Government Area of Bayelsa State by a mangrove swamp forest. A larger part of Kolo Creek is within Ogbia Local Government Area of Bayelsa State. The study was carried out using four different locations namely; Oruma (1), Imiringi (2), Kolo 1 (3) and Akoloma (4). The occupation of the inhabitants that dwell along the coast of the Kolo Creek are majorly fishermen and Farmers. The area also host the Oloibiri and Kolo oil fields.

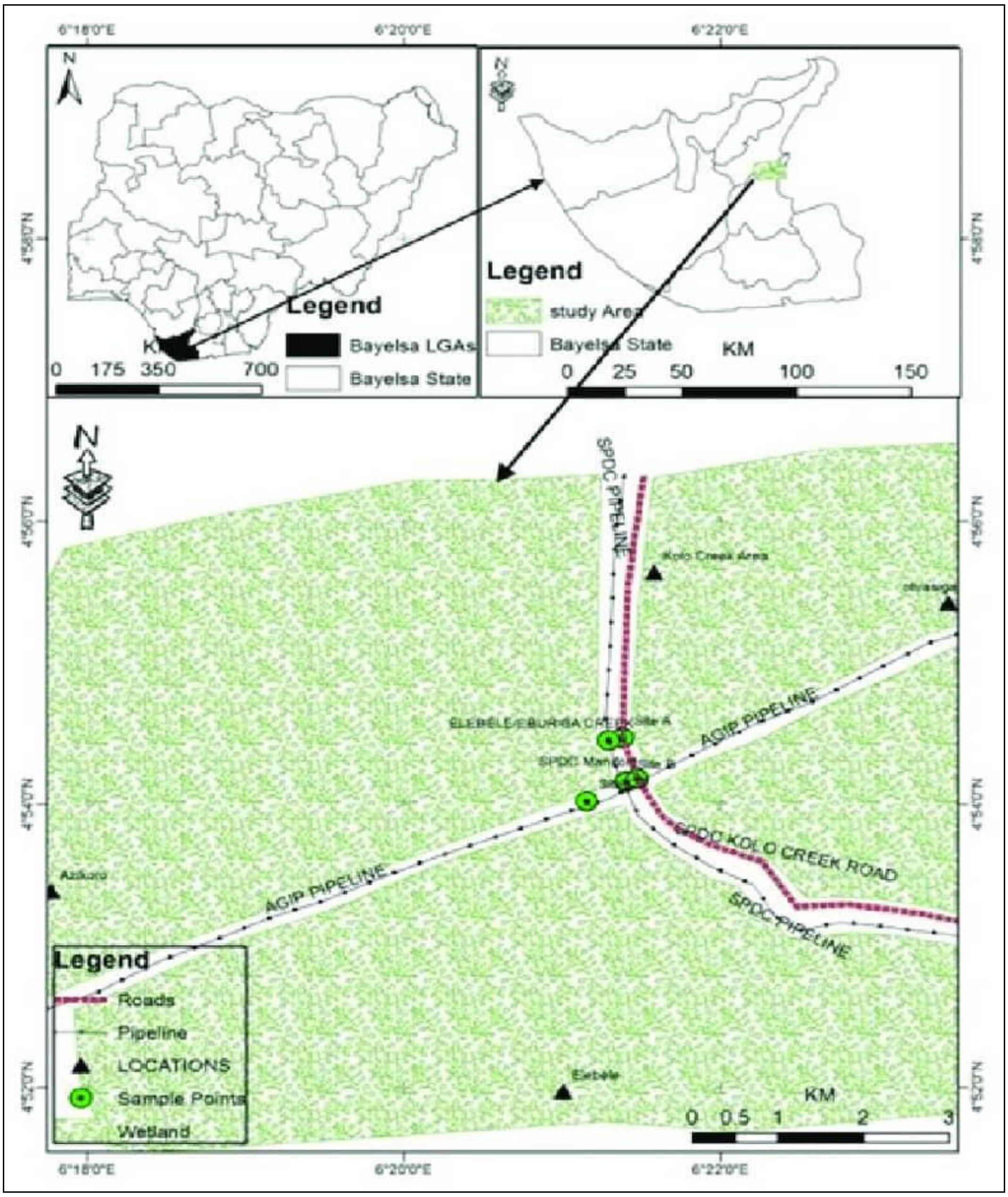

Fig 1: Map of kolo creek showing sampling location

Collection of water samples

Water samples were collected at a depth of 50cm from four different stations. The water was sampled with different containers. Plastic bottles which were previously washed were used for the collection of samples for heavy metals analysis and was immediately sealed with cork under the water. The samples were collected at four different point within a location and then mixed together to form a composite sample. Trioxonitrate (v) acid was used in the preservation of the collected water samples and then taken to the laboratory for preparation and analysis. The samples were stored in a refrigerator at a temperature of 4ºC to keep the natural state of the water till analysis is over.

Heavy metal digestion methods

About of $50cm^3$ of water sample was digested bath together with concentrated acids (H_2SO_4, HNO_3 and HCl) in a proportion of 5:3:2. The digestion was completed the moment at which the sample turned clear or colorless. Deionized water was added to the digested samples to make up to the initial 50 cm^3 (Benson *et al*., 2016) [43]. The filtered digest was then analyzed for heavy metals contents using Atomic Absorption Spectrophotometer (AAS). A blank sample analysis was carried out for each batch of all the samples collected. Each sample was analyzed three times for a particular heavy metals and the results obtained and recorded.

Determination of heavy metals

The filtered digest was used for the analysis of the studied heavy metals. Thermo Elemental Atomic Absorption Spectrophotometer (model SE-71906) was used in the determination of the concentrations of heavy metals in the samples. The characteristic wavelengths used for the determination of the metals were set differently depending on hollow cathode lamp used. The digested samples were directly aspirated into air-acetylene flame. The calibration of the instrument was done by the analysis of known concentration of heavy metals (Sehgal *et al*., 2012) [37]. The heavy metals determined in the surface water from the four different stations were Pb, Cd, Ni, Cr, Cu, Zn, As, Co, and Fe.

In order to reduce error during the analysis, a blank solution was run after every 10 samples have been examined. This was done in order to check the performance and effectiveness of the instrument. Each metal was determined thrice for a given sample and the results obtained was expressed as mean ± standard deviation (Sehgal *et al*., 2012) [37].

Pollution Assessment Indices

Some pollution evaluation indices which are useful instruments in indicating the degree of contamination/pollution of water and the intensity of its consequences on the water body were used in this study. The evaluation indices used this study were contamination factor (CF), pollution load index (PLI), contamination degree (CD), modified contamination degree (mCD).

Contamination Factor (CF)

The contamination factor was estimated by using the mathematical expression of Lacatusu (2000) [23]. The mathematical formula for the estimation of contamination is expressed as:

$$CF = Cn/Bn,$$

Where, Cn is the concentration of the studied metal and Bn is background concentration of the metal allowed in water by WHO (2015). The category of interpretation for contamination index of the heavy metal as used in the work of Hakanson (1980) and also applied in the work of El-Sherbiny *et al*. (2019), were CF < 1 = low level of contamination, 1< CF < 3 = moderate level of contamination, 3 < CF < 6 = considerable level of contamination and CF > 6 = high level of contamination.

Pollution Load Index (PLI)

The PLI index assesses in general the level of contamination of all the heavy metals studied in the environment**.** The PLI assessment index was at first mathematically expressed in the work of Tomilson *et al*. (1980) [39] and was adopted in this work. The mathematical expression given by Tomilson *et al*. (1980) [39] and was adopted in this research is:

$$PLI = [CF1 \times CF2 \times CF3 \times \ldots\ldots\ldots\ldots \times CFn]^{-n}$$

Where, CF = accumulation factor and n = number of metals studied. The interval of interpretation for pollution load index given by Tomilson *et al*. (1980) [39] are; > 0 PLI ≤ 1, not polluted to moderately polluted, >1 PLI ≤ 2, moderately polluted, > 2 ≤ 3, between moderately polluted to highly polluted, > 3 ≤ 4, polluted at high level and ≤ 5, extremely polluted.

Degree of Contamination (CD)

The mathematical formulation adopted by Hakanson (1980) [22] was used in this work. The formula is given mathematically as;

$$CD = \sum_{i=1}^{n} CF$$

Where, CD = contamination degree, CF = contamination factor and n = number of the studied heavy metals. This index is assesses all the contamination factors of the heavy metals studied in the environment under investigation**.** The interval of classification used in interpreting contamination degree are CD < 8; low contamination, 8 ≤ CD ≤ 16; moderate contamination, 16 ≤ CD ≤ 32; considerable contamination and Cd > 32; very high contamination.

Modified Contamination Degree (mCD)

The mCD evaluates the entire level of contamination of all the studied heavy metals within the environment under investigation that has brought about contamination or pollution. This was fisrt initiated by Hakanson (1980) [22]. The equation for computing mCD is expressed as:

$$\text{mCD} = \frac{1}{N}\sum_{i=1}^{N} CFI$$

Where, CF = contamination factor, n = number of heavy metals studied and I = the ith metal.

The categories of classification for the interpretation of modified contamination degree (mCD) given by Hakanson (1980) [22] and applied in this work were < 1.5; significantly low contamination, ≤ 1.5 mCD < 2; low contamination, ≤ 2 mCD < 4; moderate contamination, ≤ 4 mCD < 8; high contamination, ≤ 8 mCD < 16, very high contamination, ≤ 16 mCD < 32 extremely high degree of contamination and ≥ 32, ultrahigh contamination.

Results and Discussion

Heavy metals concentrations

The concentrations of heavy metals in surface water sample collected from four different stations of Kolo Creek are provided in Table 1, while the mean concentrations of heavy metals in surface water samples collected from four different stations of Kolo Creek during the time of study is illustrated in Figure 1. The mean concentrations of the studied heavy metals were in the order; Zn > Cu > Fe > Ni > Cr >Pb > Cd > As > Co.

Table 1: Heavy metals concentrations in surface water sample collected from four different stations of Kolo Creek.

Heavy metals (mg/kg)	Stations				
	Ebelebiri	**Oruma**	**Kolo1**	**Akoloman**	**WHO 2015**
Pb	2.461±0.15	1.597±0.10	0.466±0.08	0.278±0.10	0.05
Cd	1.427±0.13	0.892±0.09	ND	0.032±0.00	0.005
Ni	3.972±0.14	4.856±1.01	1.589±0.12	2.641±0.09	0.02
Cr	4.581±0.56	3.728±0.65	2.159±0.23	1.682±0.17	0.05
Cu	6.306±1.23	4.921±1.30	2.468±0.50	3.728±0.76	2.0
Zn	7.116±1.53	5.872±1.44	4.917±1.07	4.503±1.02	5.0
As	0.532±0.04	1.141±0.57	0.072±0.00	ND	0.01
Co	0.311±0.03	0.472±0.21	ND	0.062±0.00	0.05
Fe	6.814±1.20	4.376±1.07	2.138±0.16	3.895±0.87	0.3

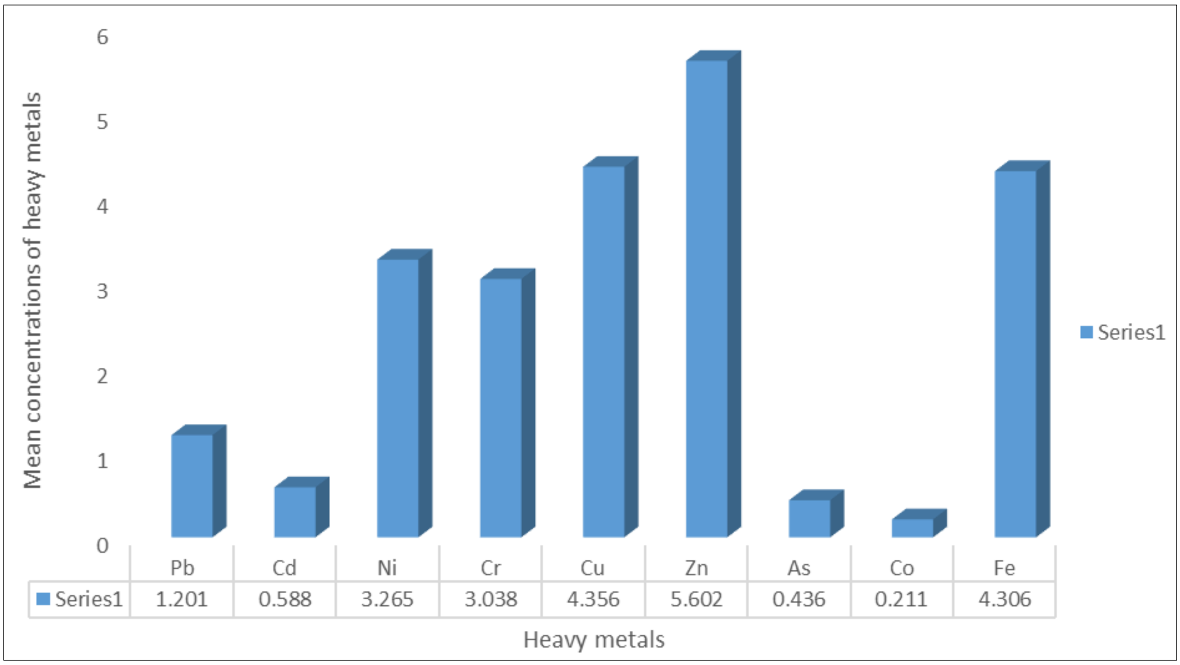

Fig 2: Mean concentrations of heavy metals in surface water samples collected from four different stations of Kolo Creek during the time of study

Lead (Pb)

The values of lead in the surface water of the creek varied from 0.278±0.10 to 2.461±0.15mg/L with an average value of 1.201±0.11mg/L within the stations used in the study. The average concentration of Cd in the creek was higher than that recommended by WHO (2015) [44] which is 0.05mg/L for potable water. The concentrations of

Pb obtained in this study were within the same range obtained in the Iko River in Akwa Ibom state (Benson & Etesin, 2008) [7] and that which was obtained by Nwineewii and Edem (2014) [31]. The presence of lead in the creek might probably be connected to paints that fall off from boats which have been abandoned over the years (Turner, 2014; Rees *et al.*, 2014) [35, 41, 35] and paints used in painting the materials used in the oil bunkering works the is common along the coasts of the creek. Consequences of Pb on water organisms are loss of sodium, reduction in ability, difficulties in development and alteration in algae growth (Freda 1991) [19]. Early signs observed due to lead toxicity in adults are not usually specific and includes pain in the abdomen, depression, diarrhea, loss of appetite, nausea and constipation (Merrill *et al*., 2007) [26].

Cadmium (Cd)

The values of cadmium in the surface water of the creek varied from not detected to 1.427±0.13mg/L with an average value of 0.588±0.06mg/L within the stations used in the study. The average concentration of Cd in the creek was higher than that recommended by WHO (2015) [44] which is 0.005mg/L for potable water. The values of Cd obtained in water samples in this present work were higher than the values observed by Nwineewii and Edem, (2014) [31] and those of Wu *et al*. (2014) [45] in two Plateau reservoirs in China. High level of cadmium concentration found in creek might have arisen or gained entrance into the creek water through waste disposal, combustion and burning of fossil fuels in the flow stations along the creek. Cadmium is relatively water soluble and long term exposure through water can result in cancer and severe organ damage such as in the respiratory, urinary, reproductive and skeletal systems (Edori *et al*, 2021) [11]. Other ways through which cadmium could easily gain entrance into our environment is in its application in industries such as a corrosive reagent, through discharge of petroleum discharge and by oil spillage. Individual workers in rigs, filling stations and other petrochemical establishments can easily contact cadmium. Low level exposure to cadmium could even pose severe damages to kidney, liver and cardiovascular system, as well as cause hearing and sight defects (Amini *et al*, 2015) [5].

Nickel (Ni)

The observed concentrations of Nickel (Ni) found across all four station in Kolo Creek indicated a range of 1.589±0.12 to 4.856±1.01 mg/L for water with an average value of 3.265±0.34mg/L in the stations used in the study. The average concentration of Cd in the creek was higher than that recommended by WHO (2015) [44] which is 0.02mg/L for potable water. The observed Ni values in this present work was higher than the concentrations obtained in the work of Nwineewii *et al*. (2019) [32] in New Calabar River and also those of Edori and Iyama (2018) [13] in Edagberi Creek, Engenni, Rivers State, Nigeria. Compounds of Ni are useful by products for the manufacturing of battery in industries, catalyst in various chemical processes and ceramic productions companies used them as colourants (Edori *et al*, 2020) [12]. High level absorption of Ni poses severe physiological damaged on laboratory test animals and may result in deadly lung infection if not properly checked, and decreasing intake and exchange of gases in and out of the lungs is most likely to cause death (Ekpete *et al*., 2019) [16].

Employees of metallurgical industries are predisposed to Ni infection due to Ni dust originating from the production process, especially for individuals who had worked for over 10 years. Ni dust and its compounds are tagged carcinogenic (Edet & Ukpong, 2014) [9]. Hence human exposures to Ni must be controlled not to exceed 0.05mg/cm^3 in Ni equivalents within a stipulated time frame of 40 hour per week (Edori *et al*., 2020) [12].

Chromium (Cr)

The variations in the concentrations of chromium (Cr) in the four different stations in Kolo Creek fall between the ranges of 1.682±0.17 to 4.581±0.56mg/L with an average value of 3.038±0.40mg/L in the stations used in the study. The average concentration of Cd in the creek was higher than that recommended by WHO (2015) [44] which is 0.05mg/L for potable water. The observed variations of Cr in all the stations were higher than WHO (2015) [44] maximum permissible limits of 0.05mg/L in domestic water usage. The value recorded in this work were higher than that reported by Nwineewii and Edem (2014) [31]. The deficiencies of chromium include the reduction in serum hemoglobin, erythrocytes count and thrombocytes, glycogen, proteins and sterols (Edori *et al*, 2020) [12]. Chromium (Cr) is a micronutrient element required by both plants and animals, but at an elevated concentration poses severe health challenges to various organisms (Edori & Kpee, 2018) [14]. The occurrence of chromium (Cr) in the environment is largely is due to extraction activities where deposits of chromium are found and also as a result of effluents discharged by manufacturing firms (Edori *et al*., 2020) [12]. At high concentrations in water chromium affects the physiology and behaviour of fish, although it might not cause death of fishes at all times (Yusuf *et al*., 2009) [46].

Copper (Cu)

The variations in the concentrations of copper (Cu) in the four different stations in Kolo Creek fall between the ranges of 2.468±0.50 to 6.306±1.23mg/L with an average value of 3.038±0.40mg/L in the stations used in the study. The average concentration of Cd in the creek was higher than that recommended by WHO (2015) [44] which is 0.05mg/L for potable water. The observed variations of Cu in all the stations were higher than WHO (2015) [44] maximum permissible limits of 0.05mg/L in domestic water usage. The values of Cu obtained in this study were within the same range with that reported by Aigberua *et al*. (2017) [2] in the Middleton River, Bayelsa

State but was higher than the values observed by Marcus and Edori (2016) [25] in Bomu and Oginigba Rivers in Rivers State, Nigeria. The level of Cu in the creek was primarily due to the oil bunkering business common along the coast of the creek while that observed by Marcus and Edori (2016) [25] was basically due to exhaust from heavy duty trucks and power generating plants, oil bunkering and other associated businesses in the area. Although copper is vital and is for the breakdown and build-up of cells, at high concentrations poses severe nervous system disorders, necrosis renal cells disorders (Singh *et al*, 2016) [38]. The effective maintenance metabolic processes in animals and human body systems is enabled by Cu and its occurrence in human tissues at high levels results in various ailment that could disrupt DNA functions, cause heart muscle injury and spinal cord myelination, spots in skin colour, destruction of bones and excessive tissues replication (Akporido, 2008) [4]. Copper deficiency in animals pose severe consequences on the central nervous system (CNS), renal nerves, tissues enzymes, hepatocytes and blood receptacles. However, excessive intake and retention of Cu in human tissues can prevent enzymes activities, causes anaemia and dilution of blood. Enzymes that could be affected by excess copper in human system include, aldolases, aminoacyl RNA, pepsin, alkaline phosphodiesterase and lipase adenosine triphosphate (Edori & Iyama, 2018) [13].

Zinc (Zn)

The variations in the concentrations of zinc (Zn) in the four different stations in Kolo Creek fall between the ranges of 4.503±1.02 to 7.116±1.53mg/L with an average value of 5.602±1.27mg/L in the stations used in the study. The average concentration of Cd in the creek was slightly higher than that recommended by WHO (2015) [44] which is 5.0mg/L for potable water. The value of Zn obtained in this study was above that recorded by Aghoghovwia *et al*. (2015) [1] in the water column of Warri River and that obtained by Akankali and Davies (2018) [3], in Choba axis of the New Calabar River. Sources of Zn in the creek could be as a result of runoffs from drainages, farm lands and effluents from industries and homes. Zinc in human system help in the healing of wounds and it is also vital for sense of taste and smell (Damodharan & Vikram, 2013) [8]. The presence of excess Zn could likely lead to intestinal itching, despondency, impotence, diarrhea and cough, which however, are temporal. Although there have not been any scientific or experimental evidence of physiological impairment when Zn is consumed at a higher concentration beyond 5mg/L. the presence of Zn at a critical level could pose severe health challenges such as diarrhea and increased alkaline pH in domestic water (Nwineewii *et al*., 2018) [33].

Arsenic (As)

The observed concentration of arsenic (As) found across all four different stations in Kolo Creek showed that arsenic (As) concentrations ranged from not detected to 1.141±0.57 mg/L for water with an average value of 0.436±0.15mg/L in the stations used in the study. The average concentration of Cd in the creek was higher than that recommended by WHO (2015) [44] which is 0.01mg/L for potable water. Regardless of the fact that As is a natural component of the earth's crust and is distributed widely all over the air, land and water, it is highly toxic in its organic form (Edori & Kpee, 2016) [14]. Exposure to arsenic over a long period especially through drinking of water and food can result into cancer lesion of the skin. Arsenic has also been associated with cardiovascular ailment and diabetes (Edori *et al*, 2020) [13]. Early childhood exposure to arsenic can have to negative effects on cognitive development and increased deaths rate in young adults (Saha & Hossain, 2011) [36]. Hence, preventive measures should be taken against further exposure to arsenic by provision of a safe water supply.

Cobalt (Co) Co

The observed variations in all four different stations of Kolo Creek indicated that the concentrations of cobalt (Co) varied from not detected to 0.472±0.21 mg/L with an average value of 0.211±0.06 mg/L in the stations used in the study. The average concentration of Cd in the creek was higher than that recommended by WHO (2015) [44] which is 0.05mg/L for potable water. The study therefore revealed that the concentration of Cobalt (Co) in all the four stations were higher than WHO standard for potable or drinking water. Cobalt is a vital micronutrient element that can be accumulated by plants in very small amount. Co ions can be accumulated in the plant parts such as fruit, grains and seeds (Saha & Hossain, 2011) [36]. It is vital to every animal and microorganisms. Co is emitted to the atmosphere in small proportion through the burning of coal and mining processes containing ores, and also through the production and use of chemicals and fertilizer containing Co salts. Higher concentrations of Co inhibit active transport in plants (Gimeno-Garcia *et al*., 2018) [21]. Excess cobalt has detrimental effects on plant growth and metabolic functions, including leaf necrosis, inhibition of cellular mitosis and chromosomal damage. Cobalt is also known to inhibit seed germination, root and hypocotyl elongation (Enuneku *et al*, 2017) [18].

Iron (Fe)

The observed variations in the four different stations of Kolo Creek showed that the values of Iron (Fe) ranged from 2.138±0.16 to 6.814±1.20 mg/Lin water with an average value of 4.306±0.83mg/L within the stations used in the study. The average concentration of Cd in the creek was far higher than that recommended by WHO (2015) [44] which is 0.3mg/L for potable water. Despite the fact that iron (Fe) enable several enzyme functions in animals and plants, it is on the other hand poisonous to human when present at a higher value in organs and tissues (Asonye *et al*, 2007) [6]. Fe if found as Fe^{3+} oxide in water damages the gills of fish and also reduce the amount of oxygen intake, which therefore perturbs the regular respiratory processes of fish. It also act in the biomolecules which are very useful in facilitating the different functions of blood (Ogaga *et al*., 2018) [34].

Pollution indices

Contamination factor

The results obtained for the contamination factors analysis of the heavy metals studied in the surface water of the creek are shown in Table 2. The results indicated that the contamination factor ranged from 5.56 to 49.22 for Pb, 0.20 to 285.40 for Cd, 79.45 to 242.80 for Ni, 33.64 to 91.62 for Cr, 1.23 to 3.15 for Cu, 0.90 to 1.42 for Zn, 0.10 to 114.10 for As, 0.02 to 9.44 for Co and 7.127 to 22.71 for Fe. The contamination factor data obtained from the four different stations in Kolo Creek were expressed on the basis of intervals of pollution, as proposed by Lacatusu (2000) [23]. The results indicated that creek was severely polluted with Pb, Ni, Cr, and Fe in all the stations, severely polluted with Cd in Stations 1, 2 and 4, severely polluted with Co in stations 1 and 2, moderately polluted with Cu in stations1 and 2, slightly polluted with Cu in stations3 and 4 and Co with station4, very severely contaminated with Zn in stations 3 and 4 and slightly contaminated with Cd in station 3, and Co in station 3.

The contamination of the creek in varying degrees by the different heavy metals was as a result of the various anthropogenic activities such as illegal oil bunkering, transportation activities, gas flaring and improper waste disposal along the creek which is a common practice among the inhabitant of the area.

Table 2: Contamination factor analysis of heavy metals concentrations in water sample collected from four different stations of Kolo Creek

Heavy Metals	Stations			
	1	2	3	4
Pb	49.22	31.94	9.32	5.56
Cd	285.40	178.40	0.20	6.40
Ni	198.60	242.80	79.45	132.05
Cr	91.62	74.56	43.18	33.64
Cu	3.15	2.46	1.23	1.86
Zn	1.42	1.17	0.98	0.90
As	53.20	114.10	7.20	0.10
Co	6.22	9.44	0.02	1.24
Fe	22.71	14.59	7.127	12.98

Pollution index, contamination degree, and modified contamination degree

Pollution index, contamination degree and modified contamination degree of water samples collected from the four different stations of Kolo Creek are shown in Table 3.

The results obtained for pollution index were 1.270, 1.187, 1.259 and 1.960 for stations 1, 2, 3 and 4 respectively. The pollution index values gotten from the four stations when analyzed at intervals of pollution index measurement as proposed by Zhang *et al*, (2011) showed that all four different stations in Kolo Creek were within the category of 1.1-2.0 which is under slight pollution. This therefore indicated that the creek was slightly polluted by the heavy metals.

The results obtained for contamination degree in the four stations of Kolo Creek were 711.546, 669.465, 148.714 and 194.735 for stations 1, 2, 3 and 4 respectively. The application of the interval of interpretation as initially given by Hakanson (1980) [22] showed that all the results fell within the category $CD > 32$ which is for very high contamination degree.

The results obtained for modified contamination degree in the four stations of Kolo Creek were 79.061, 74.385, 16.526 and 21.637 for stations 1, 2, 3 and 4 respectively. The application of the interval of interpretation as initially given by Hakanson (1980) [22] showed that stations 1 and 2 fell into the category $mCd \leq 32$ which is for ultra-high degree of contamination while stations 3 and 4 fell into the category $16 \leq CD < 32$ which is considerable contamination degree. The results obtained indicated that the creek has been grossly contaminated with the heavy metals investigated.

Table 3: Pollution index, contamination degree, and modified contamination degree of water samples from four different stations in Kolo Creek

Contamination Indices	Stations			
	1	2	3	4
PI	1.270	1.187	1.259	1.960
CD	711.546	669.465	148.714	194.735
mCD	79.061	74.385	16.526	21.637

Conclusion

The study has shown that the Kolo Creek is contaminated with heavy metals. The occurrence of heavy metals at the high concentration observed in the study was connected with the illegal oil bunkering activities taken place along the coasts of the creek and other uncontrolled human activities such as improper waste disposal, gas flaring, and effluents discharged or through leakages from storage tanks. Such hazardous condition could result into severe environmental degradation and ecological imbalance thereby having resultant health consequences among people living within the area. The inhabitants should be enlightened or educated on possible health challenges posed by discharging wastes and petroleum products directly into the creek. Furthermore, there should be urgent need for the implementation of policies that could help in restoring the creek to its original nature.

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