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(Research Article)

Health risk assessment of polycyclic aromatic hydrocarbons and heavy metals in surface water from Bakana river in southern Nigeria

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Abstract

The level of polycyclic aromatic hydrocarbons (PAHs) and heavy metals (HMs) in surface water from Bakana River located within the hydrocarbon pollution-prone Niger Delta Region of Nigeria was assessed to evaluate possible human health hazards and other associated risk to seafood. Surface water samples were analyzed for various physicochemical parameters using standard analytical methods. The level of sixteen (16) USEPA-recognized PAH compounds and selected HMs (Zn, Cu, Ni, Pb, Cr and Cd) were investigated. PAHs and HMs were determined using gas chromatography-flame ionization detector (GC-FID) and atomic absorption spectrophotometer (AAS). Analytical results revealed deterioration of surface water from the study location, with significantly ($P \leq 0.05$) high turbidity (30.00 ± 0.63 NTU), BOD (8.06 ± 0.66mg/l), total hardness (1079.05 ± 10.11mg/l) and nitrite (4.98 ± 0.16mg/l). For HMs, Cd and Pb showed values above WHO permissible limits, recording 0.014±0.001mg/l and 0.132±0.001mg/l respectively. Varying levels of PAH compounds were found to be present in the surface water samples. Naphthalene, acenaphthylene acenaphthene, phenanthrene, fluoranthene and pyrene showed significance presence when values were compared with results for control surface water samples. Health risk evaluation was performed using Estimated Daily Intake (EDI), Target Hazard Quotient (THQ) and Carcinogenic Risk (CR) assessment, and indicated that surface water from Bakana River has potential health risk cancer risk for Cd, Pb, Cr and Ni in adult and children populations. These findings demonstrate that residents of Bakana Community and its environs are exposed to contaminated surface water and the health risks associated with consumption of toxic contaminants in water.

Keywords: Polycyclic Aromatic Hydrocarbon; Heavy metals; Risk assessment; Surface water

1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) are predominant pollutants of major environmental concern. PAHs are organic compounds made up of two or more benzene rings, produced by incomplete combustion and pyrolysis of organic matters such as cigarette smoke, bush fire, automobile emissions and forest fire, among other sources [1, 2]. Of the several possible sources of PAHs in the environment, anthropogenic activities are considered major causes of PAHs release into the environment. Among the anthropogenic sources, petrogenic and pyrolytic sources are known to be the most important. Sixteen (16) PAH compound were classified by United States Environmental Protection Agency (USEPA) as priority pollutants because of their toxicity [3]. Generally, PAHs have been reported to cause serious threats to human health depending on the level of exposure [4].

Heavy metal poisoning of aquatic ecosystems has been reported to be a global hazard due to its associated toxic ecological and public health effects [5, 6]. Heavy metal pollution in surface water and sediments can come from sources such as industrial and agricultural discharges, improper disposal of industrial wastes, dumping of domestic and municipal wastes, and inadequate drainage systems [7–9]. Several environmental pollution studies have noted that the

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concentration of heavy metals in surface water can be relatively high due to considerable anthropogenic metal loadings carried by tributary rivers [10]. Surficial sediments may act as metal puddle, releasing metals into the overlying water and potentially harming riverine ecosystems [11–13]. Varying amounts of the heavy metals are released into water bodies and surface water from sources such as industrial and consumer wastes, crude oil contaminated among others [14, 15].

Access to safe drinking water is an essential component of public health, playing a pivotal role in the overall well-being of communities. With rapid urbanization and industrial activities, the level of contaminants in surface water has increased significantly and needs urgent attention due to the reported effects on human life [16]. Similarly, oil spills contaminate soil, vegetation and water sources and contribute to reduction in the portability of drinking water through the introduction of total petroleum hydrocarbon (TPH) [17-20]. Water contamination is getting worse around the world due to pollution of water sources as a result of interaction by various contaminants within the atmosphere, biosphere, lithosphere, and hydrosphere [21]. Increased levels of harmful compounds such as heavy metals and polycyclic aromatic hydrocarbons (PAHs) in surface water have negative impacts on biodiversity and pose a threat to human health [22–26]. It is therefore pertinent to ensure that sources of drinking water are free from various contaminants such as PAHs, heavy metals, microorganisms, and other hazardous compounds that can pose a serious threat to human health [27].

The current study investigated the physicochemical properties, and the levels of PAHs and heavy metals in surface water from Bakana River in Southern Nigeria, in order to assess possible human health risks and other associated exposure risks to seafood in the study location.

2. Material and methods

2.1. Study Location

Bakana River is located within the coastal region of Southern Nigeria, and situated in Degema Local Government Area of Rivers State. Bakana River is within the Niger Delta basin which spans 20,000 km2 and includes all of the territories between latitudes 4º 14'N and 5º 35'N and longitudes 5º 26'E and 7º 37'E. The location is characterized by silt and mud deposits, swampy areas, and mangrove plants. Bakana Community is known for fishing and serve as an important source of seafood supplies.

Bakana River is prone to contamination by hydrocarbon pollutants, organic waste and toxic chemicals. The area lies in the Niger Delta wet equatorial climatic which experience extensive-rainy season from March to November, with mean annual rainfall range from 1500 mm around the northern fringe to 4500 mm around the coastal margin [28, 29].

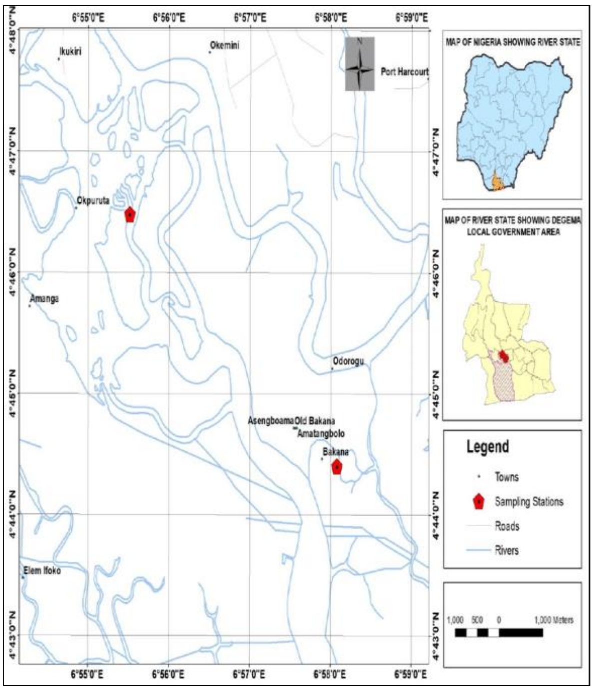

Figure 1 Map of the study area

2.2. Water Sample Collection

Water sample was collected from the Bakana River in plastic vials at a depth of 25 cm under water at different points and the vials immediately capped. Sampling was done in triplicates at each sampling point and was done between the months of June and August, 2024. The samples were placed in ice-cold chest packs and transported to the laboratory, where they were stored at 4°C temperature. Additional surface water samples (control) were collected from a different location located 500 km distance, south of Bakana River and without any known history of hydrocarbon pollution.

2.3. Determination of Physicochemical and Microbial Parameters

Parameters such as pH, conductivity, turbidity, temperature and TDS were determined in-situ using the water checker electrometric instrument (model: Hanna H19828). Other physicochemical (TSS, COD, DO, BOD, Total Alkalinity, Total Hardness, Chloride, Fluoride, Phosphate Nitrate and Nitrite) in the surface water samples were determined using standard methods applicable to them. Microbial parameters in water samples were analyzed according to APHA standard methods [30].

2.4. PAHs and Heavy metal determination

Sixteen (16) priority PAHs listed by the USEPA were analyzed [31, 32]. Sample analysis followed the method described by Odesa and Olannye [33]. Water samples were examined using Gas Chromatography Flame Ionization Detector (GC model: Agilent 6890N) and Atomic Absorption Spectrophotometry (AAS model: SP-AA4530). The congeners were detected via flame ionization detection. Heavy metal levels in water samples were determined using an atomic absorption spectrophotometer (ASTM-E594-96).

2.5. Health Risk Assessment for PAHs and Heavy metals

Health risk evaluation was performed for children and adult population using Estimated Daily Intake (EDI), Target Hazard Quotient (THQ) and Carcinogenic Risk (CR) assessment.

2.6. Estimated Daily Intake (EDI)

Since water samples were obtained from the Bakana River, it was necessary to determine the approximate daily consumption of the water samples using the formula below, taking into account the levels of PAHs and heavy metals in the water samples.

$$\text{EDI} = \frac{Cm \ x \ IR}{BW x 10-3} \quad \text{………………..(1)}$$

where BW is the average adult and child body weight exposed to the water samples, IR is the ingestion rate of heavy metals and PAHs in kg/day, and Cm is the saturation of metals and PAHs in the water sample in mg/kg.

2.7. Target Hazard Quotient (THQ)

The target hazard quotient (HQ), which is the ratios of the computed chronic intake (CDI) to the ingestion reference dose (RfD) of the chosen heavy metals, is typically used to highlight the degree of non-carcinogenic concerns [33]. USEPA [34] provides the formula, which is displayed in equation 2. If HQ > 1, it suggests that the exposed population is more likely to experience bad health impacts. Conversely, if HQ < 1 then there is no possibility of negative health effects with the ingestion reference dose for heavy metals to be that set by the WHO 2017, with PAHs having the ingested reference dose to be Acy 6.0 x 10^{-2}, Acp 6.0- x 10^{-2}, Flr 4.0 x 10^{-2}, Ant 3.0 x 10^{-1}, Phe3.0 x 10^{-2}, Flt 4.0 x 10^{-2} and Pyr 3.0 x 10^{-1} [35].

$$\text{HQ} = \frac{CDI}{RfD} \quad \text{………………..(2)}$$

The ratio of estimated daily intake (EDI) to RfD was used to compute the health risks associated with exposure to the water samples. Equation 5 was used to determine the EDI (Ding et al. 2012).

$$\text{THQ} = \frac{EDI \ X \ EF \ X \ ED}{AT \ X \ RFD} \text{x10-3} \text{……………(3)}$$

$$RFD_{derm} = RFD_{oral} \text{ x ABSgi ………(4)}$$

The ABSgi value is the gastrointestinal absorption factor. It has no unit of its own, Cr (0.25), Pb, (0.1), Cd (0.08), Cu (0.3) and Zinc (0.61) with Ni not assigned and is 0.89 for PAHs [36].

2.8. Carcinogenic Risk Assessment

The malignant growth slant factor (SF) was duplicated by the CDI or EDI to gauge the HQs for cancer-causing risk from ingestion/dermal openness to surface water, as indicated in equation (5). The Incremental Lifetime Cancer Risk (ILCR) is calculated using potential cancer risk when the ratios are larger than 1.

$$ILCR = CDI \times CSF \text{ (for water samples)} \ldots\ldots(5)$$

According to the toxicological assessments and risk system created by the USEPA, WHO, and International Agency for Research on Cancer (IARC), the following heavy metals have carcinogenic slopes coefficients of 0.38, 0.84, and 0.5 that indicate they are recognized human carcinogens: Cd, Ni, Cr, and Pb. and 8.5×10^{-3} (mg L^{-1} day^{-1}) [34] while verified cancer slope factor for PAHs is 11.5 mg/kg/day [37].

2.9. Statistical analysis

Statistical analysis of data All values were expressed as mean ± SD and then subjected to analysis of variance (ANOVA) using the Statistical Package for Social Sciences (SPSS) version 17.0 (SPSS Inc. Chicago Illinois). Statistical significance was considered at P=0.05.

3. Results and discussion

Results for physicochemical and selected microbial parameters are presented in Table 1. Results for turbidity (30.00 ± 0.63 NTU), Dissolved Oxygen (5.70 ± 0.78mg/l), Biochemical Oxygen Demand (8.06 ± 0.66mg/l), Total Hardness (1079.05 ± 10.11mg/l), Chloride (298.51 ± 3.24 mg/l), Phosphate (23.17 ± 9.11 mg/l) and Nitrite (4.98 ± 0.16 mg/l) were all above both the WHO permissible values, and values recorded for control water samples. Similarly, an assessment of microbiological characteristics of the surface water samples showed that the total coliform (12.62± 1.73CFU/ml) was higher than standard recommended values of 0 CFU/ml. However, other physicochemical results were within acceptable limits.

Table 1 Physiochemical and microbial parameters in surface water samples

PARAMETER	BAKANA RIVER WATER SAMPLE	CONTROL WATER SAMPLE	PERMISSIBLE LIMITS: WHO [39]
pH	7.50 ± 0.53^{ab}	6.75 ± 0.03^{ab}	6.5-8.5
Temperature (^{o}C)	24.90 ± 1.12^{ab}	24.00 ± 0.67^{ab}	25
Turbidity (NTU)	30.00 ± 0.63^{a}	9.05 ± 0.36^{b}	5
EC (mS/cm)	46.77 ± 1.92^{a}	21.15 ± 0.65^{b}	1000
TDS (mg/l)	47.81 ± 1.65^{a}	27.87 ± 0.36^{b}	500
TSS (mg/l)	4.87 ± 0.04^{a}	1.98 ± 0.14^{b}	25
COD (mg/l)	17.00 ± 1.00^{a}	6.85 ± 1.05^{b}	100
DO (mg/l)	5.70 ± 0.78^{a}	8.35 ± 0.03^{b}	5.0
BOD (mg/l)	8.06 ± 0.66^{a}	5.75 ± 0.17^{b}	4
Total Alkalinity (mg/l)	128.00 ± 5.33^{a}	45.08 ± 2.32^{b}	500
Total Hardness (mg/l)	1079.05 ± 10.11^{a}	329.43 ± 11.52^{b}	150
Chloride (mg/l)	298.51 ± 3.24^{a}	111.87 ± 10.00^{b}	250
Fluoride (mg/l)	1.08 ± 0.56^{a}	0.28 ± 0.51^{b}	1.5
Phosphate (mg/l)	23.17 ± 9.11^{a}	0.98 ± 0.16^{b}	5
Nitrate (mg/l)	8.54 ± 1.16^{a}	4.27 ± 0.78^{b}	50

Nitrite (mg/l)	4.98 ± 0.16[a]	1.70 ± 0.16[b]	0.2
Total Coliform (CFU/ml)	12.62 ± 1.73[a]	1.01 ± 0.00[b]	0

Values are Mean ± Standard Deviation. Data with the same alphabets (a,b) as superscript indicate non-significant differences (p≥0.05), while that with different alphabets as superscript indicate significant differences (p≤0.05).

The concentration of cadmium and lead in all analyzed water samples was found to be higher than the permissible limits for both heavy metals in water. However, other heavy metals investigated (Chromium, Zinc, Nickel and Copper) showed no exceedances as compared with WHO permissible limits.

Table 4 shows the results for PAHs level in surface water samples. Sixteen (16) PAH compounds recognized PAHs by USEPA [38] (acenaphthene, acenaphthylene, anthracene, fluoranthene, fluorene, naphthalene, phenanthrene, pyrene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[ghi]perylene, benzo[a]pyrene, chrysene, dibenz[a,h]anthracene, and indeno[1,2,3-cd]pyrene) were investigated in the surface samples under study. GCMS analysis detected seven (7) different PAH compounds in the water samples analyzed. Fluorene, Anthracene, benz[a]anthracene, benzo[b]fluoranthene, Benzo (k) fluoranthene, Benzo (a) pyrene, indeno[1,2,3-cd]pyrene, Dibenz (a,h) anthracene and Benzo (g,h,i) perylene were below detectable levels in the analyzed surface water samples.

Table 2 Mineral composition of surface water samples

MINERAL	BAKANA RIVER WATER SAMPLE	CONTROL WATER SAMPLE	PERMISSIBLE LIMITS: WHO [39]
Fe (mg/100g)	0.02±0.07ab	0.003±0.00ab	0.3
Na (mg/100g)	30.00±0.33a	23.6±0.12b	200
Ca (mg/100g)	30.94 ±0.24ab	31.06 ±0.17ab	20
Mg (mg/100g)	11.70±1.21a	10.00±0.33b	50
K (mg/100g)	0.24 ± 0.08ab	0.31 ± 0.12ab	<20
P (mg/100g)	0.18 ± 0.03ab	0.17 ± 0.11ab	NS

Values are Mean ± Standard Deviation. Data with the same alphabets (a,b) as superscript indicate non-significant differences (p≥0.05), while that with different alphabets as superscript indicate significant differences (p≤0.05).

Table 3 Heavy metal levels in surface water samples

Heavy metals	Bakana river Water sample	Control water Sample	Permissible limits: Who [39]
Cadmium (Cd) (mg/l)	0.014±0.001a	0.0005±0.001b	0.001
Lead (Pb) (mg/l)	0.132±0.001a	0.002±0.000b	0.10
Chromium (Cr) (mg/l)	0.001±0.000ab	0.001±0.000ab	0.10
Zinc (Zn) (mg/l)	0.012±0.001a	0.002±0.000b	3
Nickel (Ni) (mg/l)	0.283±0.001a	0.003±0.001b	NS
Copper (Cu) (mg/l)	0.002±0.000a	0.001±0.000a	2

Values are Mean ± Standard Deviation. Data with the same alphabets (a,b) as superscript shows non-significant differences (p≥0.05), while that with different alphabets as superscript shows significant differences (p≤0.05).

Table 4 PAHs level in surface water samples

Pah compound (mg/l)	Bakana river Water sample	Control water Sample
Naphthalene	11.11 ± 0.050	BDL
Acenaphthylene	22.432 ± 0.087	BDL
Acenaphthene	14.847 ± 0.028	0.001 ± 0.000
Fluorene	BDL	BDL
Phenanthrene	8.135 ± 0.009	0.001 ± 0.000
Anthracene	BDL	BDL
Fluoranthene	17.175 ± 0.009	0.001 ± 0.000
Pyrene	21.573 ± 0.005	0.002 ± 0.000
Benz (a) anthracene	BDL	BDL
Chrysene	10.125 ± 0.001	0.001 ± 0.000
Benzo (b) fluorathene	BDL	BDL
Benzo (k) fluorathene	BDL	BDL
Benzo (a) pyrene	BDL	BDL
Indeno (1,2,-cd) pyrene	BDL	BDL
Dibenz (a,h) anthracene	BDL	BDL
Benzo (g,h,i) perylene	BDL	BDL

Table 5 Estimated Dietary Intake for PAHs in surface water samples

Pah compound	Bakana river water Sample		Control water Sample	
	Adults	Children	Adults	Children
Naphthalene	3.17E-04	4.63E-04	0.00E+00	0.00E+00
Acenaphthylene	6.41E-04	9.35E-04	0.00E+00	0.00E+00
Acenaphthene	4.24E-04	6.19E-04	2.86E-08	4.17E-08
Fluorene	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Phenanthrene	2.32E-04	3.39E-04	2.86E-08	4.17E-08
Anthracene	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Fluoranthene	4.91E-04	7.16E-04	2.86E-08	4.17E-08
Pyrene	6.16E-04	8.99E-04	5.71E-08	8.33E-08
Benz (a) anthracene	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Chrysene	2.89E-03	4.22E-03	2.86E-07	4.17E-07
Benzo (b) fluoranthene	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Benzo (k) fluoranthene	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Benzo (a) pyrene	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Indeno (1,2,3-cd) pyrene	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dibenz (a,h) anthracene	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Benzo (g,h,i) perylene	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 6 THQ for PAHs in surface water samples

Pah compound	**Bakana river water Sample**		**Control water Sample**		**Usepa [40]**
	Adults	**Children**	**Adults**	**Children**	
Naphthalene	1.59E-02	2.31E-02	0.00E+00	0.00E+00	1
Acenaphthylene	-	-	-	-	1
Acenaphthene	7.07E-03	1.03E-02	4.76E-07	6.94E-07	1
Fluorene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1
Phenanthrene	-	-	-	-	1
Anthracene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1
Fluoranthene	1.23E-02	1.79E-02	7.14E-07	1.04E-06	1
Pyrene	2.05E-02	3.00E-02	1.90E-06	2.78E-06	1
Benz (a) anthracene	-	-	-	-	1
Chrysene	-	-	-	-	1
Benzo (b) fluoranthene	-	-	-	-	1
Benzo (k) Fluoranthene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1
Benzo (a) pyrene	-	-	-	-	1
Indeno (1,2,3-cd) Pyrene	-	-	-	-	1
Dibenz (a,h) Anthracene	-	-	-	-	1
Benzo (g,h,i) Perylene	-	-	-	-	1
THI	5.58E-02	8.13E-02	3.09E-06	4.51E-06	1

Table 7 THQ for Heavy metals in surface water samples

Heavy Metal	**Bakana river water Sample**		**Control water Sample**		**Usepa [40]**
	Adults	**Children**	**Adults**	**Children**	
Cd (mg/kg)	3.64E-09	4.38E-08	8.32E-02	5.26E-07	1
Pb (mg/kg)	2.75E-07	3.30E-06	8.32E-02	3.97E-05	1
Cr (mg/kg)	7.80E-07	9.38E-06	8.32E-02	1.13E-04	1
Zn (mg/kg)	1.87E-06	2.25E-05	8.32E-02	2.70E-04	1
Ni (mg/kg)	2.94E-06	3.54E-05	8.32E-02	4.25E-04	1
Cu (mg/kg)	4.16E-08	5.00E-07	8.32E-02	6.01E-06	1
THI	5.92E-06	7.11E-05	4.99E-01	8.54E-04	1

Table 8 Lifetime Carcinogenic risk assessment for PAHs in surface water samples

PAH Compound	Bakana river water Sample		Control water Sample		USEPA [40]
	Adults	Children	Adults	Children	
Naphthalene	4.22E-05	1.76E-05	0.00E+00	0.00E+00	10E-6 – 10E-4
Acenaphthylene	8.52E-05	3.55E-05	0.00E+00	0.00E+00	10E-6 – 10E-4
Acenaphthene	5.64E-05	2.35E-05	3.80E-09	1.58E-09	10E-6 – 10E-4
Fluorene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	10E-6 – 10E-4
phenanthrene	3.09E-05	1.29E-05	3.80E-09	1.58E-09	10E-6 – 10E-4
Anthracene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	10E-6 – 10E-4
Fluoranthene	6.52E-05	2.72E-05	3.80E-09	1.58E-09	10E-6 – 10E-4
Pyrene	8.19E-05	3.41E-05	7.59E-09	3.16E-09	10E-6 – 10E-4
Benz (a) anthracene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	10E-6 – 10E-4
Chrysene	3.84E-04	1.60E-04	3.80E-08	1.58E-08	10E-6 – 10E-4
Benzo (b) fluoranthene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	10E-6 – 10E-4
Benzo (k) fluoranthene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	10E-6 – 10E-4
Benzo (a) pyrene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	10E-6 – 10E-4
Indeno (1,2,3-cd) Pyrene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	10E-6 – 10E-4
Dibenz (a,h) Anthracene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	10E-6 – 10E-4
Benzo (g,h,i) perylene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	10E-6 – 10E-4

Table 9 Lifetime Carcinogenic risk assessment for heavy metals in surface water samples

Heavy Metal	BAKANA RIVER WATER SAMPLE		CONTROL WATER SAMPLE		USEPA [40]
	Adults	Children	Adults	Children	
Cd (mg/kg)	2.77E-06	3.33E-05	9.88E-08	1.19E-06	1E-6 – 1E-4
Pb (mg/kg)	5.83E-07	7.01E-06	8.84E-09	1.06E-07	1E-6 – 1E-4
Cr (mg/kg)	2.60E-07	3.13E-06	2.60E-07	3.13E-06	1E-6 – 1E-4
Zn (mg/kg)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1E-6 – 1E-4
Ni (mg/kg)	2.50E-04	3.01E-03	2.65E-06	3.19E-05	1E-6 – 1E-4
Cu (mg/kg)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1E-6 – 1E-4
THI	2.54E-04	3.05E-03	3.02E-06	3.63E-05	1E-6 – 1E-4

Humans, plants and aquatic organisms need water for survival. Access to good quality water remains one of the major requirements of a healthy society. Analytical results for physicochemical parameters reveal the underlying properties of water and gives insight into the safety or otherwise of water both for humans and aquatic life. Values obtained for Turbidity, Dissolved Oxygen, Biochemical Oxygen Demand (BOD), Total Hardness, Chloride, Phosphate and Nitrite were found to be higher than both WHO recommended values, and results for control water samples. This finding is corroborated by research findings of Ugwoha et al. [41] and Braide et al. [42] who both reported elevated temperatures in surface water samples that were investigated. High BOD is due to the presence of microorganisms (high bacteria count) which is an indication of water contamination [43]. Turbidity is an indication of suspended solids of different sizes present in water thereby resulting in cloudiness which could be as a result of colloidal particles, sewage wastes and industrial waste in water [44].

Elevated Cd and Pb levels were observed in the surface water samples. There is documented evidence that following oral exposure, the kidneys and the bone are primary and susceptible targets of Cd poisoning. In addition, Cd is proven to be a cancer-causing substance in humans. Other toxic effects of Cd include reproductive toxicity, hepatic, haematological, and immunological effects in both animals and human [45, 46]. The kidneys and liver absorb most of the Cd that enters the human body, and this metal can persist within these organs for several years. Only a small amount of Cd is excreted slowly through the urine and faeces. Also, more Cd is absorbed from food by the body when there is insufficient iron and other nutrients in the diet [45].

GCMS analysis detected seven (7) different PAH compounds in the water samples analyzed namely naphthalene, acenaphthylene, acenaphthene, phenanthrene, fluoranthene, pyrene and chrysene. PAHs known for their carcinogenic, mutagenic and teratogenic properties are benzo(a)anthracene, chrysene, benzo (b) fluoranthene, benzo (j) fluoranthene, benzo (k) fluoranthene, benzo (a) pyrene, benzo (g,h,i) perlyene, dibenzo (a,h) anthracene and ideno (1,2,3 – d) pyrene [47]. Regulatory guidelines designate benzo[a]pyrene as a marker for occurrence of carcinogenic PAHs [48]. Interestingly, benzo[a]pyrene level in the surface water samples analyzed was found to be lower than the recommended regulatory limit.

Tables 8 and 9 show Lifetime Carcinogenic Risk Assessment for PAHs and heavy metals in surface water samples respectively. Cancer risks greater than 1.00E-4 for heavy metals are considered high and values below 1.00E-6 are considered not to pose any cancer risk to humans [49]. The lifetime carcinogenic risk assessment of PAH compounds and heavy metals in the investigated surface water samples were observed to show mean values within the regulatory threshold of 10E-6 – 10E-4. However, high cancer risk was observed for Cd, Pb, Cr and Ni in both adult and children populations. It is a fact that heavy metals make up a large host of high chemical exposure risk to humans that can pose health concerns to them and as such, the calculated values show that adults and children are at risk of surface water-based exposure to heavy metals

4. Conclusion

The present study has provided insight into contamination levels in surface water within the study area. Findings reveal that physicochemical and microbiological water quality indicators for surface water from Bakana River are not in full compliance with permissible regulatory values; this is an indication of surface water contamination. The study also demonstrated that there is cancer risk for Cd, Pb, Cr and Ni in both adult and children populations, following consumption of water from this source. Although the level of PAHs in the water samples investigated is relatively low, it is of great concern that the particular PAH compounds detected in the water sample are poisonous even at low concentrations. These findings demonstrate that residents of Bakana Community and its environs are exposed to contaminated surface water and health risks associated with consumption of toxic contaminants in water.

Compliance with ethical standards

Disclosure of conflict of interest

Authors have declared that no competing interests exist.

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