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Physicochemical properties, total hydrocarbon content, and trace metals of water and sediments from major River Estuaries within the Niger Delta Region of Nigeria

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Abstract

Water and sediment samples from Cross River, Imo River, and Qua Iboe River Estuaries were collected and treated using standard analytical procedures. The samples were analyzed for their physicochemical properties, total hydrocarbon content (THC), and trace metals. Results obtained revealed that, the mean levels of total suspended solids (TSS), total dissolved solids (TDS), turbidity, colour, biochemical oxygen demand (BOD), THC, cadmium (Cd), iron (Fe), nickel (Ni), lead (Pb), and zinc (Zn) in water were higher than their acceptable limits in Nigeria. Whereas, the mean levels water pH, electrical conductivity (EC), dissolved oxygen (DO), nitrate, sulphate, phosphate, and copper (Cu) were within their acceptable limits. The results obtained also revealed that, the mean levels of nitrate, THC, and Fe in sediments were higher than their recommended limits. While the levels of pH, EC, sulphate, phosphate, Cd, Cu, Ni, Pb, and Zn in sediments were within their recommended limits. This study indicated that the anthropogenic activities by oil and oil-related companies within the Niger Delta Region of Nigeria may have contributed significantly to the high level of toxic substances in the water channels within the zone. The results obtained revealed that, the direct or indirect exposure to untreated water from the studied water channels may result in serious health challenges. Hence, the environment should be closely monitored to forestall a devastating situation in the region.

Keywords: Water pollution; Trace Metals; Physicochemical Properties; Niger Delta Region; Estuary; Nigeria

1. Introduction

Water is one of the major six (6) classes of food needed by all biological systems including human. However, when human beings are exposed to a highly contaminated water either directly or indirectly it becomes harmful. The oil exploration and exploitation activities within the Niger Delta Area of Nigeria has contributed significantly to the accumulation of toxic substances in the aquatic ecosystem within the region. Studies have revealed the high levels of toxic substances in water bodies within the Niger Delta Region of Nigeria [1, 2,3,4,5]. Nwidu *et al.* [6] has also revealed that, the health status of people in a community depends significantly on the quality of water within the community. Studies have shown that most deaths within the developing nations of the world are caused by water related diseases [7, 8]. According to Shyamala *et al.* [9] contaminated water bodies are channels for transmitting disease causing organisms and deadly chemicals into the human system. Some metals are essential for human but all metals are potentially harmful to most living things including human at levels higher their recommended limits [10]. It has been reported that about 3.4 million deaths every year mostly children are attributed to water-related diseases [11]. The consumption of aquatic foods obtained from a contaminated aquatic ecosystem is a death trap for the consumers [12]. The interaction between the studied rivers and the Atlantic Ocean at the estuary might also elevate the contaminants in these water channels.

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Sediments in water bodies within the Niger Delta Region also accumulate high levels of contaminants and discharge them later into the water channels [13]. The contamination and subsequent pollution of sediments is a serious environmental problem since aquatic organisms may bioaccumulate these pollutants and transfer them into human body through food chain [14, 15, 16]. It has also been established that, exposure to water and aquatic organisms from a contaminated water body could be very harmful to human health [17, 18]. Consequently, monitoring of aquatic water channels within the Niger Delta Region should be done regularly. This study was undertaken to ascertain the safety or otherwise of these water bodies and sea foods harvested from them. The activities of crude oil and related companies has made it a necessity for the regular monitoring of the water quality within the Niger Delta area of Nigeria.

2. Material and methods

2.1. Study Area

Cross River Estuary lies between latitudes of 4°12! and 5°14! N and longitudes 8°10' and 8° 42! E. The Cross River originates from the Cameroun mountains and moves southwards into Nigeria where it empties into the Atlantic Ocean at the Gulf of Guinea. Qua Iboe River Estuary lies within latitudes 4°30' to 4°45' N and longitudes 7°30' to 8°00' E on the south eastern Nigerian shoreline. It originated from Umuahia Hills in Abia State and traverses through sedimentary terrains before emptying into the Atlantic Ocean. The Imo River Estuary is within latitudes 4°.35' to 4° 46' and longitudes 7° 21' to 7°43'. The river originated from Okigwe in Imo State, Nigeria and moves southwards into the Atlantic Ocean at the Bight of Bonny. These river estuaries are brackish water which have been impacted negatively by the oil exploration and exploitation activities within the Niger Delta Region of Nigeria. They are also used for water transportation and fishing activities. The study area has two separate seasons (dry and wet), the dry season lasts from the last week of November or early December to early March. The wet seasons has a longer period from mid-March to the end of November [19].

2.2. Sample Collection, Treatment, and Analysis

Water and sediment samples were obtained at Cross River, Imo River, and Qua Iboe River Estuaries between October and December, 2000. At each of the estuaries, samples were collected at three (3) designated points and mixed together to from a composite sample for that location. The collection and treatment of water samples were done following the procedures of APHA [20, 21].

The surface sediment samples were also collected at the same locations where water samples were collected using Grab Sampler using the methods of USEPA [22].

Sediment samples were air dried for three (3) days, ground and sieved with a 2mm mesh (USEPA, 2001). One gram (1g) each of the dried sediment was digested with Aqua-regia on a hot plate following the procedures of USEPA [23].

The pH of the samples was determined using pH meter following the procedures of APHA [20], while the turbidity, colour, and electrical conductivity were analyzed for using nephelometer, photometer, and conductivity meter, respectively [21]. The total suspended solids (TSS) and total dissolved solids (TDS) were determined by the filtration method following the methods of USEPA [24]. Water samples for DO, BOD, and nitrate analyses were collected and treated according to the procedures of APHA [21, 25, 26]. The nutrients (anions) in the water samples were determined by spectrophotometric methods as described by APHA [20]. The total hydrocarbon content (THC) in samples were obtained spectrophotometrically using the methods of ASTM [27]. The total concentrations of all the trace metals analyzed for in water and sediments was determined using an Agilent 710 inductively coupled plasma optical emission spectrometer (ICP-OES) following the methods of USEPA [28].

3. Results and discussion

3.1. Physicochemical Properties of Water from the studied River Estuaries.

The results for the physicochemical properties, nutrients, total hydrocarbon content, and trace metals in water samples from the studied river estuaries are indicated in Table 1.

As shown in Table 1, the pH of the studied water channels range of 6.84 to 7.14 with a mean value of 6.95±0.13. This range is higher than 4.70 -6.50 reported by Akpan [29] in water body within the studied area. The pH range obtained in this study is favourable for optimal aquatic life [30]. The reported range is also within the acceptable limit of 6.5 – 8.5 by NESREA [31]. Consequently, the human activities within the studied rivers may not have affected the pH levels of these water channels. Hence, the pH of these water bodies may not affect neither the aquatic nor human beings exposed to these water bodies.

The total suspended solids (TSS) of the studied river estuaries varied between 17.72 and 23.25 mg/l with a level of 20.67±2.27 mg/l. This range is lower than 12.55 - 49.57 mg/l reported by Anhwange *et al*. [32]. However, the mean TSS value is higher than 0.75 mg/l recommended by NESREA [31] for an unpolluted water. Thus, the TSS contents of the studied water channels may have a negative effect on the aquatic life of the studied water channels. Similarly, the activities within these water bodies may have elevated their TSS contents.

The levels of total dissolved solids (TDS) in the studied river estuaries indicates a range of 558.53 - 654.10 mg/l with a mean value of 611.70±38.75 mg/l. The obtained range is higher than 120.00 – 143.7mg/l reported by Ukpong and Peter [33]. The mean value of TDS obtained is also higher than 500.0 mg/l recommended for unpolluted water by NESREA [31]. Hence, human and activities within these water bodies may have elevated their TDS levels. Consequently, human beings exposed to these water channels may experience cancer, arteriosclerotic heart disease, and cardiovascular disease [34].

The values recorded for turbidity in this study varied from 74.80 to 110.36 mg/l with a mean concentration of 94.16±14.69 NTU. The reported range is higher than 76.00 – 96.70 NTU obtained by Ebigwai *et al*. [35]. The mean value obtained is also higher than 5.0 NTU stipulated by NESREA [31] for an unpolluted water. Consequently, the anthropogenic activities in the study area may have attributed to the high levels of turbidity reported. The high turbidity of these water bodies is harmful to those exposed to these water bodies because according to Reza and Singh [36] high turbidity in water is directly related to high disease-causing microorganisms.

The studied river estuaries exhibited colour intensity between 39.04 and 48.62 Hu. This

obtained range is lower than 4.00 – 402.20 Hu reported by Anhwange *et al*. [32]. However, the mean value obtained (44.52±4.03 Hu) is higher than 15.0 Hu recommended for potable water by NESREA (2011). The levels of colour recorded in the studied river estuaries could be attributed to the high TDS and turbidity contents of the water channels [37]. As a consequence of this, these water bodies may not be suitable for domestic use based on their high levels of contaminants.

Electrical conductivity (EC) of the studied river estuary ranged from 443.35 to 574.13 μS/cm. This range is higher than 16.40 – 64.40 μS/cm obtained by Ugbaja and Ephraim [38]. Nevertheless, the mean value of EC obtained in this research (526.18±58.81 μS/cm) is lower than the 1000.0 μS/cm limit recommended for water by NESREA [31]. Hence, the values of EC in the studied water channels may not affect the ecosystem negatively.

The dissolved oxygen (DO) which indicates the healthy nature of a water body with respect to organic wastes varied between 3.64 and 3.82 mg/l. This range is lower than 4.0 – 5.4 mg/l reported by Simeon *et al*. [39]. The mean value of DO obtained in the studied river estuaries (3.74± 0.08 mg/l) is lower than 4.0 mg/l recommended for a healthy water system by NESREA [31]. Consequently, the river estuaries may have been highly contaminated by biodegradable wastes due to anthropogenic activities in the area and the interactions of these rivers with the Atlantic Ocean at the estuary. This low level of DO may have impact on the survival of fishes, photosynthetic process, nutrients availability and growth of microorganisms [40, 41].

Biochemical Oxygen Demand (BOD) of a water channel indicates the level of oxygen required by microorganisms to decompose organic waste under aerobic conditions. The BOD of the studied river estuaries ranged from 6.42 to 6.76 mg/l with a mean value of 6.59±0.14 mg/l. The range of BOD reported is higher than 2.75 – 3.74mg/l obtained by Etesin *et al.* [42]. However, the mean value is higher than 6.0 mg/l recommended for an unpolluted water by NESREA [31]. This is an indication of high level of biodegradable wastes and nutrients in these water channels thus, these water bodies are unsuitable for human consumption [43]. The high BOD values reported may be attributed to the natural and anthropogenic activities at the estuaries.

3.2. Distribution of Nutrients in the studied River Estuaries.

The level of nitrate in the studied water channels ranged from 28.44 to 41.27 mg/l (Table 1). This range is higher than 4.2 – 5.7 mg/l reported by Simeon *et al*. [39]. The mean value of nitrate obtained (36.77±5.90 mg/l) is lower than the recommended limit of 40.0 mg/l for unpolluted water by NESREA [31]. However, the mean values of nitrate obtained for Imo and Qua Iboe River Estuaries were higher than the recommended limit. The high values of nitrate reported may be attributed to anthropogenic activities with the studied locations. Studies have shown that, high levels of nitrate in water may lead to blue-eye syndrome in children and pregnant women [44]. Thus, untreated water from the studied channels may not be fit for human consumption.

Sulphate concentrations in the studied river estuaries varied from 68.82 to 100.95 mg/l. These values are higher than 0.05 – 23.19mg/l reported by Ebigwai *et al*. [35]. However, the mean value of sulphate (86.40±13.29 mg/l) obtained is lower 500.0 mg/l recommended for unpolluted water by NESREA [31]. Subsequently, the levels of sulphate in the studied water channels may not be harmful to both human health and aquatic life.

The levels of phosphate in the studied river estuaries varied between 1.37 and 3.11 mg/l. The reported range is lower than 2.144 to 9.741mg/l by Isiuku and Enyoh [45]. The mean value of phosphate recorded (2.45±0.77 mg/l) is also lower than the limit recommended for unpolluted water (3.5 mg/l) by NESREA [31]. This is an indication that, the natural and anthropogenic activities within the studied estuaries may not have affected the phosphate content significantly. Hence, the phosphate content of the studied water channels may not have serious impact on both human and aquatic animals exposed to these aquatic ecosystems.

3.3. Total Hydrocarbon Content of Water from the studied River Estuaries.

The total hydrocarbon content (THC) of the studied river estuaries varied from 6.89 to 13.08 mg/l with a mean value of 10.07±2.53 mg/l. These values are lower than 15.6 – 23.4 mg/l of THC in surface water reported by Wokoma [46]. The mean value obtained is higher than 10.0 mg/l recommended for an unpolluted water channel by NESREA [31]. Consequently, the THC of the studied water channels may have been affected negatively by the crude oil activities within the area. However, the mean level of THC Cross River Estuary (6.89 mg/l) is within the acceptable limit. THC of a water channel has direct impact on the availability of oxygen for aquatic organisms hence, the values reported may reduce the growth of aquatic plants and animals significantly [47].

3.4. Distribution of Trace Metals in Water from the studied River Estuaries.

The results in Table 1 show a range and a mean concentration for cadmium (Cd) as 0.12 – 0.16 mg/l and 0.14±0.02 mg/l, respectively. The obtained range is higher than 0.01 – 0.02 mg/l reported by Ebigwai *et al*. [35]. The mean is also higher than 0.01 mg/l recommended limit for Cd in unpolluted water by NESREA [31]. Consequently, the anthropogenic activities within the studied river estuaries may have elevated the levels of Cd in the water channels. Cd is a toxic metal even at a very low concentration to both higher and the lower animal [48]. Consequently, human beings exposed to untreated water from these channels may be at risk of liver, kidneys, pancreas and spleen problems [49].

The results for copper (Cu) concentrations in the studied river estuaries ranged from 0.87 to 1.69 mg/l. This range is higher than 0.0011 – 0.0630 mg/l reported in surface water by Nwineewii and Edem [50]. The mean value concentration obtained (1.23±0.34 mg/l) is lower than 2.0 mg/l recommended for unpolluted water by WHO [11]. Accordingly, the studied water channels may not pose any serious risk associated with Cu toxicity to the aquatic environment and human exposed to the water.

Iron (Fe) concentrations in the studied river estuaries ranged from 5.06 to 13.25 mg/l. The range reported is lower than 0.025 – 122.10mg/l recorded by Jonah *et al*. [51]. The mean Fe concentration obtained (9.90±3.50 mg/l) is higher than 0.5 mg/l stipulated for unpolluted water by NESREA [31]. Thus, the anthropogenic activities within the studied estuaries may have resulted in elevating the levels of Fe in these water channels. Consequently, this may result in risk associated with pathogenic organisms; since the organisms' requirement Fe for their optimal growth [52].

The results in Table 1 indicate a range and mean value of nickel (Ni) as 0.74 – 1.02 mg/l and 0.90±0.12, respectively. The range of Ni reported in this study is higher than 0.19 - 0.29 mg/l obtained by Elemile *et al*. [53]. The mean value of Ni obtained is also higher than 0.10 mg/l limit recommended for unpolluted water by NESREA [31]. Therefore, the human activities around these estuaries may have resulted in the elevated Ni levels reported. Hence, human beings exposed to unpolluted water from the studied locations over time may could be at a risk of suffering cancer [54].

Lead (Pb) in the studied water channels ranged between 1.02 and 1.63 mg/l with a mean value of 1.40±0.27 mg/l. This range is higher than 0.01-0.61mg/l reported by Oribhabor and Ogbeibu [55] in surface water. The mean value of Pb obtained in this study is higher than 0.1 mg/l recommended for unpolluted water by NESREA [31]. The high levels of Pb obtained could be attributed to the anthropogenic activities within the studied water channels. According to Cleveland *et al*. [56] human exposure to untreated water from these channels may results in depression, nausea, and abdominal pain, loss of coordination, vomiting, diarrhea, and anemia.

The concentrations of zinc (Zn) in the studied water channels varied from 2.13 to 3.41 mg/l. The obtained range is consistent with the range reported by Ebong and Etuk [8] but higher than 0.0197 - 0.2140 mg/l obtained by Nwineewii and Edem [50]. The mean concentration of Zn reported (3.31±0.11) is higher than the safe limit of 3.0 mg/l by NESREA [31]. Hence, the human beings exposed to untreated water from these estuaries may be at risk of Zn toxicity and its attendants' health implications [57]. The high levels of Zn reported in the studied areas may also have negative impact on the growth of aquatic plants and animals [58, 59].

Table 1 Physicochemical properties and Trace metals in water from Cross River, Imo, and Qua Iboe River Estuaries

S/N	Parameter	Cross River Estuary	Imo River Estuary	Qua Iboe River Estuary	Min	Max	Mean	SD	Acceptable Standard
1	pH	6.87	6.84	7.14	6.84	7.14	6.95	0.13	6.5 – 8.5
2	TSS	17.72	21.05	23.25	17.72	23.25	20.67	2.27	0.75
3	TDS	558.53	654.10	622.48	558.53	654.10	611.70	38.75	500.0
4	Turbidity	74.80	110.36	97.31	74.80	110.36	94.16	14.69	5.0
5	Colour	39.04	48.62	45.90	39.04	48.62	44.52	4.03	15.0
6	EC	443.35	561.06	574.13	443.35	574.13	526.18	58.81	1000.0
7	DO	3.77	3.82	3.64	3.64	3.82	3.74	0.08	4.0
8	BOD	6.58	6.76	6.42	6.42	6.76	6.59	0.14	6.0
9	THC	6.89	10.24	13.08	6.89	13.08	10.07	2.53	10.0
10	Nitrate	28.44	41.27	40.61	28.44	41.27	36.77	5.90	40.0
11	Sulphate	68.82	100.95	89.43	68.82	100.95	86.40	13.29	500.0
12	Phosphate	1.37	3.11	2.87	1.37	3.11	2.45	0.77	3.5
13	Cadmium	0.12	0.16	0.14	0.12	0.16	0.14	0.02	0.01
14	Copper	0.87	1.13	1.69	0.87	1.69	1.23	0.34	2.0
15	Iron	5.06	11.38	13.25	5.06	13.25	9.90	3.50	0.5
16	Nickel	0.74	0.95	1.02	0.74	1.02	0.90	0.12	0.1
17	Lead	1.02	1.54	1.63	1.02	1.63	1.40	0.27	0.1
18	Zinc	3.16	3.37	3.41	3.16	3.41	3.31	0.11	3.0

TSS = Total suspended solids; TDS = Total dissolved solids; EC = Electrical conductivity; DO = Dissolved oxygen; BOD = Biochemical oxygen demand; THC = Total hydrocarbon content; Min = Minimum; Max = Maximum; SD = Standard deviation

3.5. Physicochemical Properties in Sediments from the studied River Estuaries

Results for the physicochemical properties, nutrients, total hydrocarbon content and trace metals in sediments from the studied river estuaries are shown in Table 2.

The pH of sediments from the studied river estuaries varied between 6.58 to 6.69. This range is lower than 7.18 – 7.28 reported in sediments by Simeon *et al*. [39]. The obtained range of pH is also within the acceptable range of 6.5 – 8.5 by WHO [60]. Thus, the pH levels of sediments from the studied river estuaries may not have adverse effect on the chemistry of the river channels.

The electrical conductivity (EC) of sediments from the studied river channels ranged from 554.74 to 573.62 µS/cm. This EC range is consistent with that reported by Adesuyi *et al*. [61] but lower than 40.0 - 1940.0 uS/cm obtained by Ezekiel *et al*. [62]. The mean EC value obtained (565.49±7.93 µS/cm) is within the safe limit of 1500.0 µS/cm by WHO [60]. The low level of EC values in the studied sediments may be attributed to the levels of ions within the studied water channels.

3.6. Distribution of Nutrients in Sediments from the studied River Estuaries.

Nitrate levels in the studied sediments varied from 57.54 to 68.28 $mgkg^{-1}$ with a mean value of 63.78±4.56 $mgkg^{-1}$. This range is lower than 1.34 – 4.0 $mgkg^{-1}$reported in sediments by Wokoma and Friday [63]. The mean value reported is also higher than 40.0 $mgkg^{-1}$recommended limit for nitrate by WHO [60] in unpolluted water. The high levels of nitrate reported in sediments from the studied estuaries could be attributed to the anthropogenic activities within the study area. Hence, exposure to these water channels may results in blue-eye syndrome in children and pregnant women [44]. The high nitrate content of these water channels may also cause eutrophication [64].

The sulphate content of the studied sediments varied between 83.72 and 89.56 $mgkg^{-1}$. The range reported is higher than 1.06 – 3.81 $mgkg^{-1}$ obtained by Seiyaboh *et al*. [65]. The mean value of sulphate obtained (86.92±2.42 $mgkg^{-1}$) is also lower than 240.0 $mgkg^{-1}$recommended limit for unpolluted sediment by WHO [60]. Hence, the studied sediments may not have been polluted by the sulphate content.

Phosphate content of sediments from the studied river estuaries ranged from 2.71 to 3.54 $mgkg^{-1}$ with a mean value of 3.18±0.35 $mgkg^{-1}$. The reported range is lower than 5.6 – 16.89 $mgkg^{-1}$ obtained in sediments by Adesuyi *et al*. [61]. Nevertheless, the mean value recorded is within the safe limit of 5.0 $mgkg^{-1}$ by WHO [60]. Thus, the water channel may not have been polluted by phosphate and may not experience eutrophication.

3.7. Total Hydrocarbon Content in Sediments from the studied River Estuaries.

The total hydrocarbon content (THC) of sediments from the studied river estuaries indicated a range and a mean value of 32.04 - 61.85 $mgkg^{-1}$ and 45.46±12.35 $mgkg^{-1}$, respectively. The reported range is lower than 16.01 – 136.04 $mgkg^{-1}$ obtained in sediments by Dumka and Kingdom [66]. The mean THC obtained in the studied sediments is higher than 30.0 $mgkg^{-1}$ recommended for unpolluted sediment by WHO [60]. The high levels of THC in the studied sediments could be attributed to the activities by oil and oil related companies operating within the area. Consequently, the oxygen level of the studied river estuaries may be drastically reduced and this may be harmful to the aquatic life [67].

3.8. Distribution of Trace Metals in sediments from the studied River Estuaries.

Cadmium (Cd) in sediments from the studied river estuaries ranged from 0.70 to 2.11 $mgkg^{-1}$. This range is higher than 0.04-0.65 $mgkg^{-1}$ reported in sediments from the Niger Delta Region of Nigeria by Moses *et al*. [68]. The mean value of Cd obtained (1.56±0.61 $mgkg^{-1}$) is lower than 3.0 $mgkg^{-1}$ recommended limit for sediment by WHO [60]. Thus, Cd may not be regarded as a pollutant in sediments from the studied aquatic environments.

Copper (Cu) concentrations in the studied river estuaries varied from 6.75 to 8.06 $mgkg^{-1}$. The obtained range is lower than 1.20 – 13.56 mg/kg reported by Alinnor and Alagoa [69]. Although, the mean obtained (7.52±0.56 $mgkg^{-1}$) is lower than 25.0 $mgkg^{-1}$ recommended limit for Cu in unpolluted sediment by WHO [60].

Nickel (Ni) in sediments from the studied rivers varied between 7.63 and 9.21 $mgkg^{-1}$ with a mean value of 8.63±0.71 $mgkg^{-1}$. The obtained range is higher than 0.4 – 2.3 $mgkg^{-1}$ reported in the region by Vincent-Akpu [70]. However, the mean value obtained is lower than 20.0 $mgkg^{-1}$ recommended for unpolluted sediment by WHO [60].

Iron (Fe) concentrations in sediments from the studied rivers ranged from 65.91 – 83.52 $mgkg^{-1}$ with a mean value of 83.52±8.13 $mgkg^{-1}$. The obtained range is lower than 6914.0 – 7543.0 μg/g reported in sediments by Howard and Olulu [71]. The mean obtained is higher than 30.0 $mgkg^{-1}$recommended for Fe in unpolluted sediment by WHO [60]. Consequently, Fe may pose serious risk in the studied aquatic ecosystem as high levels of the metal could be released into these water channels. This high levels of Fe in the studied locations could be attributed to both natural and anthropogenic influence as the metal is naturally available in the study area (Onyedika [72].

Lead (Pb) in sediments from the studied rivers ranged between 2.34 and 6.33 $mgkg^{-1}$. This is lower than 12.43 – 36.65 μg/g obtained in sediments from the Niger Delta Area of Nigeria by Ebong and Etuk [73]. The mean obtained (4.61±1.68 $mgkg^{-1}$) is also lower than 10.0 $mgkg^{-1}$ recommended limit for Pb in unpolluted sediment by WHO [60]. Correspondingly, Pb in the studied sediments may not be regarded as a pollutant but, should be monitored since the metal is highly toxic.

The levels of zinc (Zn) in sediments from the studied river estuaries varied from 23.46 to 67.36 $mgkg^{-1}$. This is higher than 5.00 – 39.00 ppm obtained in sediments by Diayi and Gbadebo [74]. Nevertheless, mean value of Zn obtained (52.0±20.24 $mgkg^{-1}$) is lower than 123.0 $mgkg^{-1}$ recommended limit by WHO [60]. for unpolluted sediment. Thus, Zn as one of the macro elements may not pose any serious risk to lives exposed to sediments from the studied sources.

Table 2 Physicochemical properties and Trace metals in surface sediments from Cross River, Imo, and Qua Iboe River Estuaries

S/N	Parameter	Cross River Estuary	Imo River Estuary	Qua Iboe River Estuary	Min	Max	Mean	SD	Acceptable Standard
1	pH	6.81	6.67	6.58	6.58	6.81	6.69	0.10	6.5 – 8.5
2	EC	568.10	554.74	573.62	554.74	573.62	565.49	7.93	1500.0
3	Nitrate	57.54	65.53	68.28	57.54	68.28	63.78	4.56	40.0
4	Sulphate	83.72	87.48	89.56	83.72	89.56	86.92	2.42	240.0
5	Phosphate	2.71	3.29	3.54	2.71	3.54	3.18	0.35	5.0
6	THC	17.04	42.48	61.85	17.04	61.85	40.46	18.35	30.0
7	Cadmium	0.70	1.86	2.11	0.70	2.11	1.56	0.61	3.0
8	Copper	6.75	8.06	7.74	6.75	8.06	7.52	0.56	25.0
9	Iron	65.91	82.76	83.52	65.91	83.52	77.40	8.13	30.0
10	Nickel	7.63	9.21	9.04	7.63	9.21	8.63	0.71	20.0
11	Lead	2.34	5.17	6.33	2.34	6.33	4.61	1.68	10.0
12	Zinc	23.46	65.38	67.36	23.46	67.36	52.07	20.24	123.0

EC = Electrical conductivity; THC = Total hydrocarbon content; Min = Minimum; Max = Maximum; SD = Standard deviation

4. Conclusion

This research has shown the variations in the physicochemical properties, nutrients, total hydrocarbon content, and trace metals in water and sediments from Cross River, Imo River, and Qua Iboe River Estuary. The health and environmental implications of the parameters determined in water and sediments from the studied estuaries have been highlighted. This study revealed that, the levels of TSS, TDS, turbidity, colour, BOD, THC, Cd, Fe, Ni, Pb, and Zn in water were higher than their recommended limits. While the levels of nitrate, THC, and Fe were also higher than their acceptable limits in sediments from the studied estuaries. The study has also indicated the negative impact of crude oil and oil related activities on the quality of the studied aquatic ecosystems. Consequently, the water quality of the studied locations should be closely monitored to forestall unpleasant situation since majority of the inhabitants of the Niger Delta Region depend mainly on these water bodies for their water supply and aquatic animals.

Compliance with ethical standards

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We want to state clearly that, there is no conflict of interest regarding this research and this article.

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