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Analysis of Hydrocarbon and Heavy Metal Load in Fishes and Waters in Coastal Islands

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Abstract

This study gives an explicit analysis of physico-chemical properties, heavy metals, and total hydrocarbon content (THC) for water samples obtained from the mangrove environment, as well as determining the levels of heavy metals in fishes (*Clarias Gariepinus and E.fimbriata*) collected from Iko, Emeroke, and Okoroette Rivers. The physical variables investigated in the course of this study were: Temperature, Electrical Conductivity and Turbidity while the chemical variables were: pH, alkalinity, dissolved oxygen, total dissolved solid, total suspended solid, total hardness, biochemical oxygen demand, total hardness, iron, sulphate, zinc, nitrate, potassium, magnesium, sodium, calcium, cobalt, in addition to Total hydrocarbon content (THC). In a bid to understand the status of petroleum contamination in the mangrove ecosystem, total petroleum content was determined from water samples using standard scientific procedures. Six heavy metals: cadmium, chromium, copper, arsenic, lead, and mercury were taken into concentration. Seasonal variations of the various variables were taken into cognizance to ascertain whether changes in seasons affect chemical concentration in the aquatic system. As compared with the World Health Organisation standard, out of 29 tested parameters, including THC, the results of water samples for both dry and wet seasons, 14 parameters were above permissible limits, while 15 were below. Specifically, the value of hydrocarbon (THC) was above permissible limits in all the water samples. Meanwhile, the values for heavy metals in fish were above the permissible limit except for copper, whose value was slightly below the permissible limit for both seasons in the three sampled locations. The result so far obtained calls for urgent attention to save the lives of fish and surface water in oil-producing areas of Akwa Ibom State.

Keywords

Hydrocarbon; Heavy metal load; Fishes; Waters; Coastal islands

1. Introduction

Heavy metal contamination in coastal islands has been a serious concern throughout the world for many decades, as it has caused devastating effects on the ecological balance of the recipient environment and aquatic organisms generally. “Heavy metals” is a collective term that applies to the group of metals and metalloids with an atomic density greater than 4 g/cm^3 or 5 times or more greater than water. Heavy metals include lead (Pb), cadmium (Cd), zinc (Zn), mercury (Hg), arsenic (As), silver (Ag), chromium (Cr), copper (cu), iron (Fe), and the platinum group elements [1].

They are considered to be grouped into the category of persistent bioaccumulative chemicals, and some of them are endocrine-disrupting and carcinogenic. These metals are highly toxic to plankton, invertebrates, and various larvae at high concentrations [1].

Heavy metals penetrate the coastal islands of Akwa Ibom State and the Niger Delta through various pathways, including

solid mineral extraction, toxic waste disposal, dredging, farming, and oil spills from the petroleum industry. From a book written by Jimmy and Osogi entitled "Emerging issues on blue economic investment in Niger Delta Regions", it was brought to the fore that oil companies have seriously polluted coastal waters in the Niger Delta, particularly those earliest communities where oil and gas exploration began, particularly Ogoni and Eastern Obolo respectively [2]. A certain study maintains that in the past 50 years, at least 9-13 million barrels have been spilled by 11 oil companies managing 159 oil fields and 1,481 wells in the Niger Delta in Nigeria [3]. His study seemed to contradict earlier works in the number of oil fields, oil wells, and oil spills. A study in Nigeria identified about 606 oil fields with 355 situated onshore; 251 situated offshore with 5,284 drilled oil wells and 7,000 km of oil and gas pipelines [4]. With this data, by considering the number of oil fields operational in the Niger Delta, one can easily deduce that there is a high level of pollution in the mangrove ecosystem.

Petroleum-impacted heavy metal accumulation in the aquatic food chain is no longer a Nigerian-based ecological disaster but permeates the Gulf of Mexico, the Thar-Jath oilfield of South Sudan, and the Shoreline of Saudi Arabia [5]. Succinctly, some of the oil fields found near mangrove ecosystems are seriously posing a threat to biota and human health by extension [6].

By way of following International Best Practices on pollution control in oil fields, oil and gas operators are expected to cut down spillage during and after production, likewise seal wells at the end of production, yet most multinationals care little about post-management of oil production sites, thus causing the release of pollutants into soils and groundwater, particularly mangrove, where aquatic organisms breed. Recently, the United States Environmental Protection Agency has documented over 120,000 orphaned and abandoned oil wells across the USA, and the potential risk to the ecosystem has been quantified [7, 8].

While the developed economy is affected by orphaned wells leakages, though little effort of ecosystem restoration is ongoing, developing nations, including Nigeria, are completely disadvantaged due to a lack of funds and expertise on ecosystem recovery from petroleum-related ecological hazards. Some years back, about 32 officially recognized oil fields with numerous orphaned wells had been documented in Nigeria, though with no recovery plan, including many found within Eastern Obolo LGA and other parts of coastal Akwa Ibom State [9]. The indigenous people of Eastern Obolo have agitated for intervention since 1996, when Shell BP abandoned some wells in the area. Since then, the glamour for restoration of soil and water, floristic, faunatic habitats has been raised.

According to Enemugwem [9], oil was discovered in Eastern Obolo in 1957 by the Shell D' Archy Petroleum Development Company, but commercial production began in 1976, and after 30 years of exploitation and ecological damage, the operation was shut down. Since then, extensive literature has been built up on the consequences of oil and gas production in the air, land, mangrove, and water environment of Eastern Obolo [10-13].

Study revealed that the abandoned oil fields in Utapete and the Iko oil field (OML 13), as well as Okorofield (OML 112), have had enormous effects on livelihood and socio-economic development [11]. One of the earliest reports on the contamination of water and mangrove environment was released by Enemugwem in 2009, who had conducted extensive research on the fate of petroleum pollution in Eastern Obolo from 1957 to 2007. He outlined the processes in drilling operations capable of discharging contaminants into the environment, such as drill ships and jack-up rigs, drilling mud, pipeline installation, flaring, and drilling waste. He identified about seventy-six (76) sites, including rivers, creeks, and fish breeding grounds, affected by oil pollution in the entire Eastern Obolo. Contemporary scholars had carefully studied the fate of oil Exploration in Eastern Obolo water and coastal island disruption from 1996 to 2021 and noted that numerous resources in the coastal islands with surface water being contaminated [12-15].

Nevertheless, pollution from petroleum affects not only the land and water environment, but it also causes corrosion of the roof, food contamination, and bio-accumulation in flora and fauna. Given the Level of metal exposure on coastal islands, especially within orphaned and abandoned oil well zones, where research has shown the capability of accidental chemical leakages, numerous studies have been made in this direction [16-20]. While these studies have investigated the content of heavy metals and THC and their associated effect on fish and water, little or no interest has been directed toward laboratory analysis of heavy metals in fish and water within coastal islands with a specific focus on oil-producing areas in Eastern Obolo. This work considers seasonal variation of physico-chemical properties, the concentration of heavy metals in water and fish, and the level of hydrocarbons in the sampled waters.

2. Materials and Methods

2.1 Study area

This research was carried out in the three most prominent oil communities in Akwa Ibom State. These locations are blessed

with sufficient oil and gas deposits: Okoroette, Emeroke, and Iko in Eastern Obolo. Eastern Obolo LGA is one of the earliest and largest oil-producing areas in Nigeria, with almost all the villages, including Elek-Okpoon, Otunene, Ikonta, and Obianga, Iko, Emeroke, Okoroette, endowed with sufficient reserves of oil and gas. This study focused only on areas within Iko, Emeroke, and Okoroette oil-producing communities. The coastal islands in Eastern Obolo are blessed with offshore and onshore petroleum operations and host the largest oil fields in Nigeria. Over six decades of oil production in the islands have totally polluted surface water and the fish that live therein.

The most popular island in the region is Iko Town. Iko town is a community in Eastern Obolo and was selected as the first sampling point. It is one of the busiest settlements in the area. The Iko oil field has been in operation since 1973 by Shell Petroleum Development Company Nigeria Limited, in what was referred to as the Utapete Operational Zone with 32 oil wells, shut down and later leased to Sterling Oil some years ago [21].

Iko River takes its rise from the Qua Iboe River catchment and drains directly into the Atlantic Ocean at the Bight of Bonny. Iko Town is located in the Eastern part of the Niger Delta between latitude "4º 30" N and "4º 45" N and longitudes "7º 35"E and "7º 40" E. The river has a shadow depth ranging from 1.0 metre to 7.0 metres at flood and ebb tide and an average width of 16 meters [22]. The Iko River has many adjoining tributaries and creeks, and part of it also drains into the Imo River estuary. The shoreline of the Iko River is characterized by soft-dark mud flats, usually exposed during low tide, mangrove swamps with mangrove trees, shoals, and sand bars.

Additionally, Okoroette, being the second sampled location, is a community in Eastern Obolo where an oil well was first discovered by Shell BP in the 1950s, after Oloibiri oil field, the genesis of oil and gas operation in Nigeria. Okoro oil field is found offshore in the Atlantic Ocean, and it is situated in Okoroette community, the local government headquarters of Eastern Obolo.

This is one of the most widely known oil-producing communities in Eastern Obolo. Lastly, Emeroke is a kingdom comprising 5 oil-producing villages, though suffering from serious petroleum-related hazards, including oil spills, mangrove contamination, and water pollution. The communities are economically backward with poor water supply, little or no electricity supply, poverty, hunger, land pollution, which affects agricultural activities, and high cost of living due to inaccessibility. The communities within this kingdom do not have a large population of indigene due to the plight they have suffered, and this forces the indigene to migrate out in search of greener pastures. Some migrants from Rivers State have dominated the kingdom, especially the Ijaws and Andonis, who have settled for many years in the fishing business. The population of people within the estuarine environment is not much compared to the outskirts of Iko Town, which is one of the busiest settlements. Numerous fruit gardens and mangrove forests are found by the edge of the estuaries, and these are the raw materials for fishers, traders, and traditional medicine practitioners.

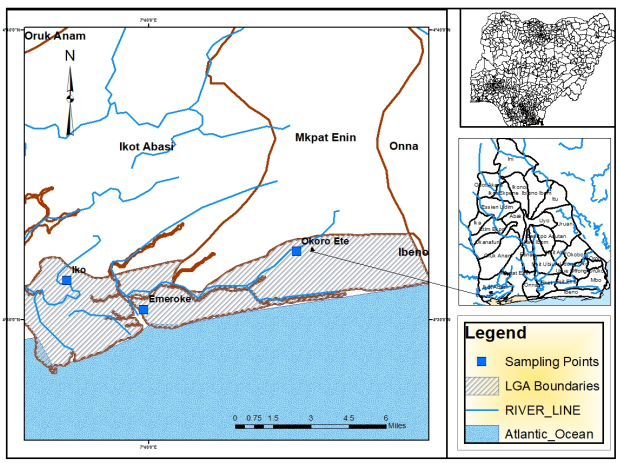

Figure 1. Map of Eastern Obolo showing the Study Area.

2.2 Methods

Samples were collected from oil-producing communities in Eastern Obolo. Samples were collected monthly for six months from September 2022 to March 2023. A total of 18 water samples were collected at 30cm below the surface water at several points within designated sampling locations. The samples were taken once a month. All samples were taken in the early hours of the day.

Two species of fish (Clarias Gariepinus and E.fimbriata) were collected from the study area by fishermen. The collected fish samples were properly labelled, packaged, and transported to the laboratory for identification, preparation, and analysis. A total of 72 fish samples were subsequently collected for the wet and dry seasons. All captured fish were labeled accordingly and placed in an ice chest before being transported to the laboratory. The fish were also weighed and categorized based on the two species: C. Gariepinus and E.fimbriata. For fish preparation, the gills and kidneys were used in this study. Fish tissues were carefully dissected and dried in an oven at 110 ^{o}C to a constant weight. Heavy metal content of the fish was determined from the laboratory analysis [23]. Subsequently, all the glassware was thoroughly washed with distilled water, soaked in diluted nitric acid for 24 hours, and then rinsed with distilled water [23]. All the samples were taken to the State state-funded laboratory- Ministry of Science and Technology, Akwa Ibom State.

The collected water samples were subjected to the standard analytical procedure of the American Public Health Association to determine the physico-chemical properties, Total hydrocarbon content, and heavy metals, including Mercury, Lead, Cadmium, Chromium, Arsenic, and Copper, using standard scientific procedure [22, 24]. The level of changes in physico-chemical parameters, heavy metals, and petroleum content was illustrated using a chart and the ANOVA statistical technique.

3. Results and Discussions

Table 1. Mean value for seasonal variations of water's physico-chemical properties in a mangrove ecosystem

Parameters	Wet	Dry
Ph	6.54 ± 0.24	6.70 ± 0.21
Temp. (^{o}C)	26.82 ± 0.82	27.14 ± 0.29
Ec (uScm-1)	76.56 ± 13.68^{a}	96.22 ± 21.55^{b}
TDS	34.66 ± 4.86 ^{b}	40.28 ± 7.37 ^{b}
Total suspended solids	107.69 ± 6.77	106.99 ± 9.63
Turbidity	61.31 ± 8.86 ^{a}	49.04 ± 9.76 ^{b}
BOD (mg/L)	16.58 ± 2.40 ^{a}	17.86 ± 3.01 ^{b}
DO (mg/L)	6.97 ± 0.70	6.21 ± 1.02
Alkalinity (Mg/L)	20.54 ± 2.24 ^{a}	23.81 ± 2.51 ^{b}
Acidity	69.84 ± 7.34	69.44 ± 8.78
Total hardness	20.62 ± 1.54	25.56± 3.61
Cobalt (mg/L)	0.32 ± 0.15 ^{b}	0.45 ± 0.17 ^{b}
Potassium (mg/L)	2.32 ± 0.75	1.24 ± 0.35
Chloride	2.99 ± 0.67 ^{b}	3.75 ± 0.73 ^{b}
Sulphate (Mg/L)	15.18 ± 7.77	14.31 ± 6.85
Nitrate	2.73 ± 0.80 ^{a}	2.90 ± 0.68 ^{b}
Zinc (mg/l)	0.97 ± 0.25 ^{b}	0.96 ± 0.21 ^{b}
Sodium	1.94 ± 0.72	1.56 ± 0.50
Iron (mg/l)	2.55 ± 0.87 ^{a}	2.03 ± 0.76 ^{b}
Calcium (mg/l)	5.48 ± 1.10 ^{b}	5.54 ± 0.72 ^{a}
Magnesium (mg/l)	3.04 ± 0.52	1.90 ± 0.36
THC	182.49 ± 22.46	162.13 ± 31.47
COD (mg/l)	78.78 ± 7.14	78.78 ± 9.87

Note. Means with different superscripts along the same row are significantly different (Duncan's test) $p<0.05$. Source: Fieldwork, 2025.

Table 2. Variations in heavy metals in water based on study locations

Heavy Metals	Okoroette River	Iko River	Emeroke River
Mercury	1.02 ± 0.35[b]	1.58 ± 0.76[b]	2.90 ± 0.39[a]
Lead	0.37 ± 0.12	0.17 ± 0.09	0.18 ± 0.07
Cadmium	0.80 ± 0.28	1.22 ± 0.39	0.82 ± 0.23
Chromium	0.39 ± 0.20	0.44 ± 0.21	0.25 ± 0.08
Arsenic	0.48 ± 0.16	0.44 ± 0.15	0.41 ± 0.18
Copper	2.12 ± 0.56[a]	0.61 ± 0.23[b]	0.81 ± 0.30[b]

Note: Means with different superscripts along the same row are significantly different (Duncan's test) $p<0.05$. Source: Fieldwork, 2025

Table 3. Seasonal variation in heavy metals in water in the three mangrove communities

Heavy Metals	Wet	Dry
Mercury	1.98 ± 0.49	1.69 ± 0.52
Lead	0.19 ± 0.06	0.28 ± 0.09
Cadmium	0.91 ± 0.27	0.98 ± 0.17
Chromium	0.45 ± 0.07	0.27 ± 0.10
Arsenic	0.47 ± 0.12	0.41 ± 0.09
Copper	1.29 ± 0.22	1.06 ± 0.27

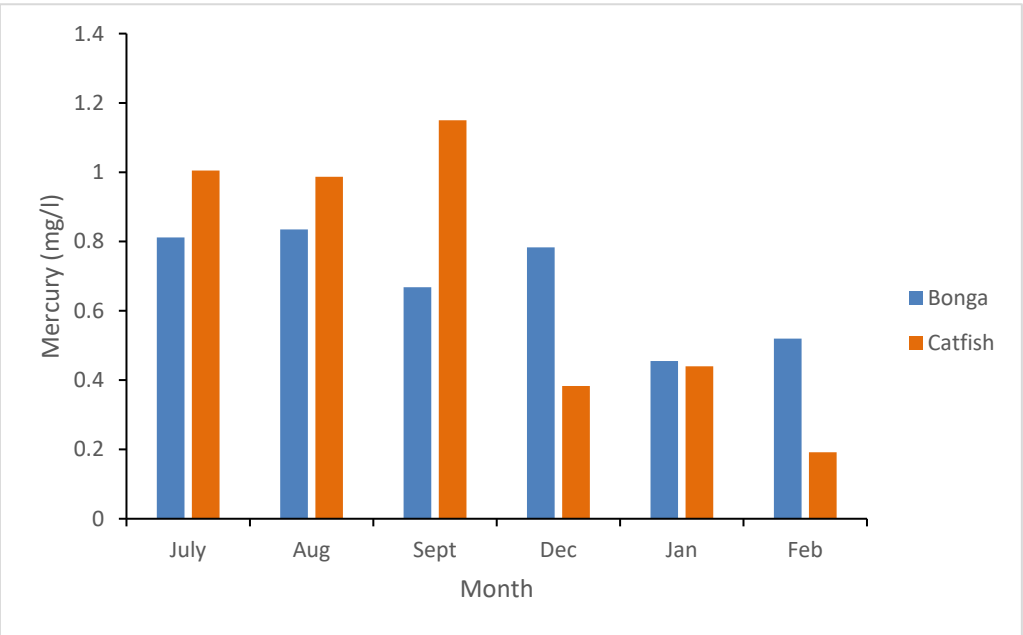

Figure 2. Variations in Mercury measured in Different Fish Species.

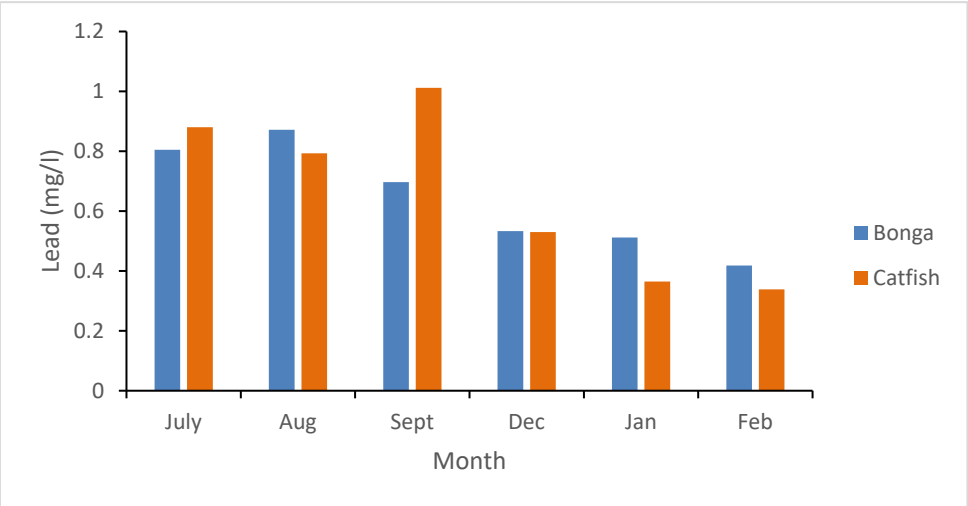

Figure 3. Variations in Lead measured in Different Fish Species.

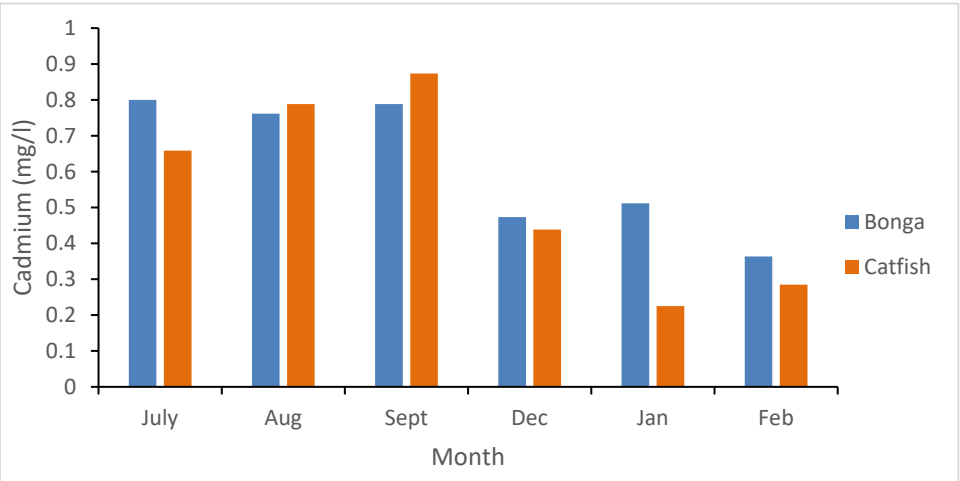

Figure 4. Variations in Cadmium measured in Different Fish Species.

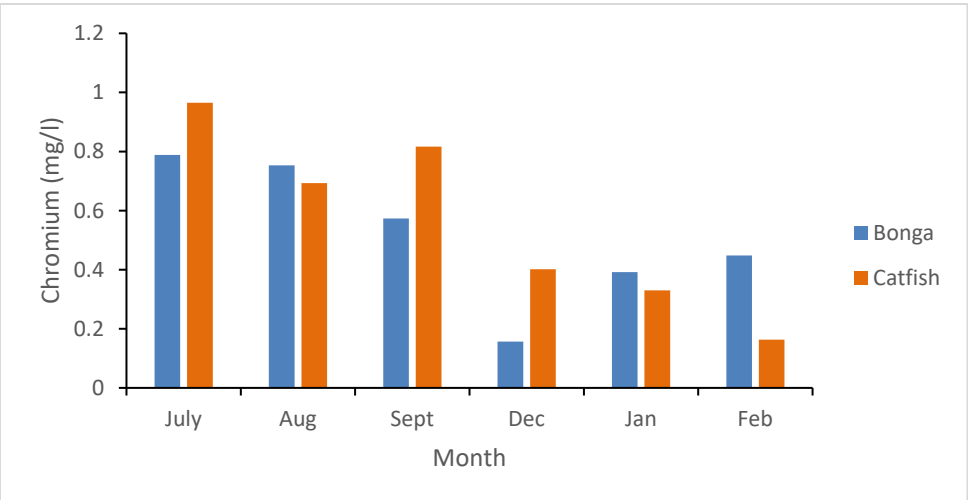

Figure 5. Variations in Chromium measured in Different Fish Species.

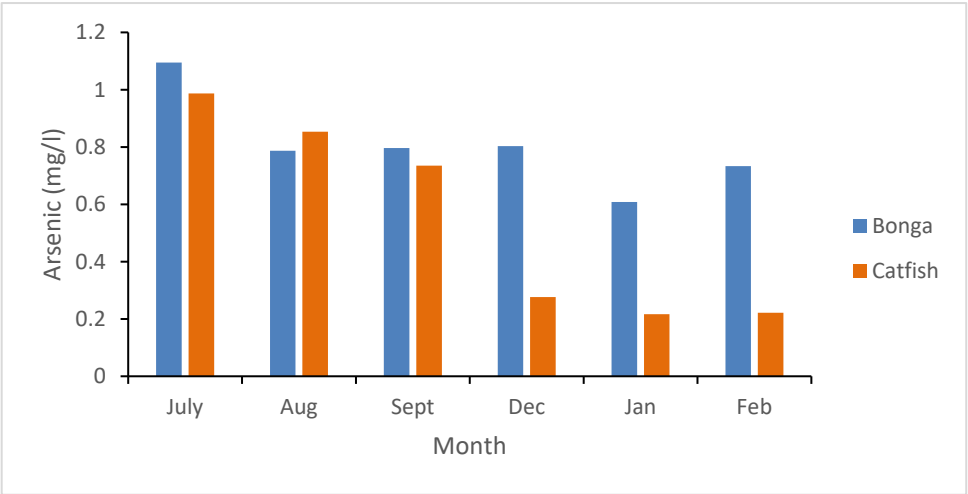

Figure 6. Variations in Arsenic measured in Different Fish Species.

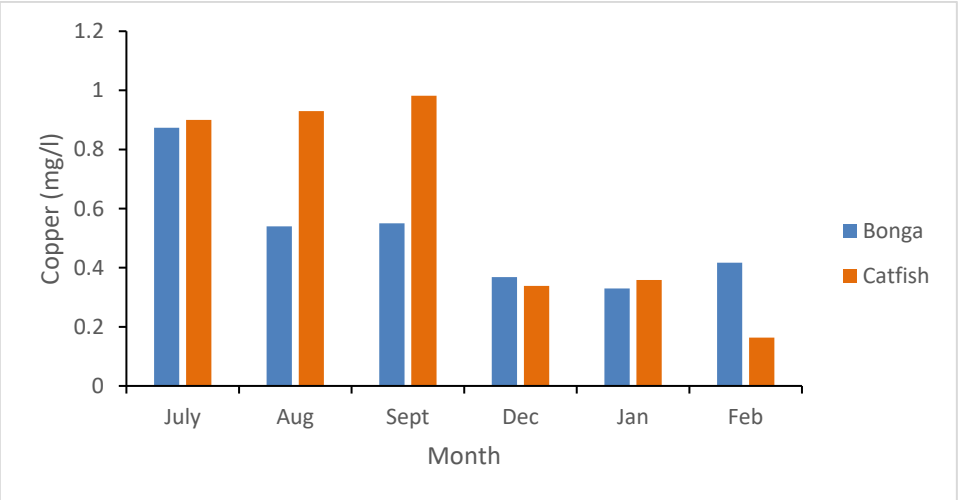

Figure 7. Variations in Copper measured in Different Fish Species.

4. Discussion of Findings

The physicochemical properties determine the overall health of any aquatic system. Anthropogenic activities influence the physicochemical properties of rivers due to the persistent discharge of contaminants.

The seasonal variation of physico-chemical properties of water in the study area shows that during the wet season, the mean value for pH was 6.54 ± 0.24 and 6.70 ± 0.21 for the dry season (see Table 1). It was observed from a study that low pH values of a river indicate poor buffering capacity of total alkalinity and may also be a result of organic matter decomposition [25].

A good knowledge of the pH of water is important. The result of the study was compared to studies carried out a decade ago on the water quality of the Otamiri River in Owerri along the Imo River [26]. They found out that the mean pH value of the dry season water samples (6.5) and rainy season (6.4) fell within the stipulated limits of 6.0-8.5 for drinking water.

The temperature of the water samples varied remarkably between the wet and dry seasons. The temperature for the wet season was 26.82 ± 0.82 and 27.14 ± 0.29 for the dry season. In terms of temperature, it was observed that temperature levels are higher in the dry season than in other seasons because of higher air temperature [26]. A similar study found that the temperature values of Otamiri along the Imo River ranged from 30.6-32.2ºC in the dry season and 27.0-28.6ºC in the wet season.

The variation in temperature values could be attributed to time of sampling, river gradient, rate of flow of the river, and weather conditions. However, temperature plays a vital role in controlling chemical reactions in water and metabolic

processes in fish [27, 28]. An increase in temperature leads to the growth of algae, which chokes aquatic organisms to death [29], whereas a decrease in temperature allows most substances to become insoluble in water. The result was comparable to studies done in Kenya on heavy metals in Naivasha Basin, whose temperature ranges between 22-24ºC with a dissolved oxygen between 6.9-20mg/l [30].

The electrical conductivity values determined between locations in wet and dry seasons were all lower than the WHO limit of 1400Scm-1. The level of conductivity values obtained in this study could be linked to ions containing drilling wastes dumped into the rivers. The little disparity in seasonal values may be due to the high volume of water and the dilution effect caused by heavy rainfall. The result was similar to that conducted in the Dzindi River, Limpopo, in South Africa [31]. According to their study, the mean value for EC was in the range of 30-133mS/cm while TDS was between 20-89mg/l. The value of EC was lower than that of some Nigerian rivers in the Eastern region [32], who observed electrical conductivity of 17.24-22.5 µs/cm in Chokocho, Edegelem, and Imeh rivers along Imo River. In his assessment of Nworie River, Owerri, it was revealed that conductivity values vary between 100.0-193.2 µs/cm [33].

Total dissolved solids provide information on the aesthetic value, turbidity status, and density of water. The contributors to the total dissolved solids in water are bicarbonate, sulphate, phosphate, nitrate, magnesium, calcium, sodium, heavy metals, and organic ions [34]. The value for TDS in the wet season was 34.66 ± 4.86 and 40.28 ± 7.37 for the dry season. Findings showed that total dissolved solids (TDS) in excess of 1200 were not likely to support good freshwater organisms [35].

As a result, TSS dropped from 107.69 ± 6.77 in the wet season to 106.99 ± 9.63in the dry season. In terms of turbidity, it measures the loss in transparency in water caused by the presence of suspended particles in water, such as phytoplankton and silt from run-off [36]. This is why high turbidity (>5 NTU) can stop light penetration. This can affect the photosynthetic process and the reduction of DO, thereby affecting aquatic life. In the study area, levels of turbidity were significantly lower during the dry season than during the wet season. This is because turbidity increases significantly after a heavy rain. The results recorded a higher mean turbidity value of 61.31 ± 8.86 in the wet season, compared to 49.04 ± 9.76 in the dry season. The higher concentrations of turbidity observed is an indication of heavy toxic load being discharged into the aquatic environment.

Feature 8. Sample river at Emeroke affected by Oil spill.

Feature 9. Land Contamination calls for concern.

Biochemical oxygen demand (BOD) is an empirical analysis that measures all the biodegradable materials present in water, and a high BOD value indicates the eutrophic status of a water body. High BOD concentration may induce excessive algal growth and provoke oxygen depletion in the aquatic system. BOD varies between 16.58 ± 2.40 in the wet season to 17.86 ± 3.01 in the dry season. Okeke and [37] in their findings on impacts of anthropogenic activities on water quality reported that BOD is a fair measure of the cleanliness of any water on the basis that values less than 2mg/L are clean, 3-5mg/L fairly clean, and 10mg/L definitely bad or polluted. Biochemical oxygen demand is the amount of dissolved oxygen needed by aerobic biological organisms to break down organic material present in a given water sample at a certain temperature over a specific time period. These values are, however, below the 28-30 mg/l World Health Organisation permissible levels of BOD.

For DO, there was a slight difference in the level of concentration, with 6.97 ± 0.70 recorded for wet season and 6.21 ± 1.02 for the dry season, respectively. Dissolved oxygen concentrations of 5.0mg/L and above are desirable for fish survival. Low dissolved oxygen concentrations are known to be one of the major problems of fauna and floral survival in the aquatic environment. This has been reported by [25] in their study of Black and Baltic Sea.

Seasonal variation in Alkalinity (Mg/L) was between 20.54 ± 2.24 to 23.81 ± 2.51 for both wet and dry season respectively [38] in his work stated that the low level of alkalinity of water samples indicate that the underlying rocks which is the main source of natural alkalinity, contain low carbonate, bicarbonate, and hydroxide. The seasonal variation of Acidity content was 69.84 ± 7.34 in the wet season and 69.44 ± 8.78 in the dry season. Total hardness was between 20.62 ± 1.54 for the wet season and 25.56 ± 3.61 in the dry season. The value for cobalt in the wet season was 0.32 ± 0.15 and 0.45 ± 0.17 in the dry season. Potassium varies between 2.32±0.75 in the wet season and 1.24 ± 0.35 in the dry season. There was a difference in chloride concentration between 2.99 ± 0.67 in the wet season and 3.75 ± 0.73 in the dry season. Sulphate (Mg/L) varies between 15.18 ± 7.77 in the wet season and 14.31 ± 6.85 in the dry season. The mean concentration of sulphate shows that the value ranges from 43.67 (mg/L) and 37.33 (mg/L).

Nitrate varies between 2.73 ± 0.80 in wet season and 2.90 ± 0.68 in dry season. Seasonal variation was noticeable in Zinc between 0.97 ± 0.25 in the wet season and 0.96 ± 0.21 in the dry season. Sodium concentration was 1.94±0.72 in the wet season and 1.56 ± 0.50 in the dry season, while the concentration of Iron was 2.55 ± 0.87 in the wet season and 2.03 ± 0.76 in the dry season. Differences in calcium concentration range between 5.48 ± 1.10 in the wet season and 5.54 ± 0.72 in the dry season. Magnesium concentration varies between 3.04 ± 0.52 in wet season and 1.90±0.36 in dry season. THC was between 182.49 ± 22.46 in the wet season and 162.13 ± 31.47 in the dry season. The value for COD varies from 78.78 ± 7.14 in wet season to 78.78 ± 9.87 in dry season.

From findings in the study, there was a significant difference between wet and dry season in the concentration of heavy metals in fish. Mercury concentration varies between 0.909444 ± 0.07 in wet season and 0.462222 ± 0.06 in dry season. In lead, the concentration was 0.843056 ± 0.05 in wet season and 0.449444 ± 0.06 in dry season. Moreover, the concentration of cadmium in wet season was 0.778333 ± 0.04 and 0.382778 ± 0.05 for dry season. Chromium concentration was between 0.765 ± 0.05 and 0.315278 ± 0.05. The value of arsenic varies from 0.875556 ± 0.08 to 0.476667 ± 0.10. The value of copper was between 0.795833 ± 0.05 to 0.329167 ± 0.06. In terms of hydrocarbon content, THC was between 182.49 ± 22.46 in wet season and 162.13 ± 31.47 for dry season above permissible limit showing that petroleum impact on mangrove ecosystem is nothing but a reality.

5. Conclusion and Recommendations

Sustainable management of water in coastal islands is a key to development and blue economy growth, especially in the contemporary era characterised by anthropogenic disturbance in the riverine communities. Human activities such as sand dredging, chemical-based fishing, abandoned oil wells, waste from petroleum exploitation, waste disposal from households and industries, as well as pesticides from farmland have been considered a threat to the breeding ground of fish where they are emptied into. The presence of metals is associated with pollutants capable of negatively impacting on fish population and humans who feed on aquatic organisms. However, it is imperative that the health of coastal islands be protected at all costs for ecosystem functionality and economic productivity.

Hence, there is need for periodic monitoring of the level of pollutant in biota. There is also need for the adoption of geospatial tools in coastal island management in the area of water quality changes detection, fishes disappearance and real time pollutant monitoring. Moreover, inventory and periodic monitoring of islands affected by petroleum can be useful in decision making. In addition, coastal ecosystem restoration can be a good strategy to mitigate ecological problems in the study area. Lastly, Oil companies operating in the region should adhere strictly to international best practices in oil exploration/exploitation, Island conservation, maintenance of equipment and safety of their infrastructure.

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