EFFECTS OF POLYCYCLIC AROMATIC HYDROCARBONS (PAHS) ON AQUATIC BIOTA OF JABI LAKE

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ABSTRACT
Aquatic ecosystems are critical components of the global environment and essential contributors to biodiversity and ecological productivity. Lakes are among the most biodiverse places on Earth, and a plethora of water pollutants jeopardises their quality. The presence of PAHs in aquatic environments can have serious consequences for the health and biodiversity of aquatic biota, as well as the overall function of the aquatic ecosystem. The primary objective of this research is to investigate the impact of various environmental factors on the aquatic biota of Jabi Lake and its tributaries and to provide information that can inform the management and optimal utilisation of its aquatic resources.

The effects of PAHs on the aquatic biota of Jabi Lake and its tributaries were investigated using a combination of in situ and laboratory equipment to determine the strata of poisonous substances and to provide information that may aid in the management and optimal utilisation of the lake's aquatic resources. Seven stations were chosen: tributaries (3 stations), confluence, and within the lake (3 stations) to determine hydrocarbons and biological characteristics based on activities at the various stations using standard procedures.

Data collected over the course of the study from both surface water and sediment were subjected to means and ANOVA for significant differences in the parameters of PAHs (benzene,toluene,ethylbenzene, and xylene (BTEX)) (ppb) within the stations. The highest value, 32.4±0.07 ppb of benzene (ppb) upstream (tributaries), was recorded at surface water, and 162±0.01 ppb from the sediment (downstream, the lake). Toluene fluctuated between 0.07±0.0 and 20.9±0.00 ppb for surface water sampled, while it was within 0.10±0.00 and 0.10±0.01 ppb for sediment.

The fauna recorded (both pelagic and benthic macrofauna) in this study indicated a composition and abundance of 4 phyla (Chordata, Mollusca, Arthropoda and Annelida). High concentrations of benzene in both surface water and sediment analysed raised serious concerns about consumer health. Jabi Lake desired a systematic approach to lake management in order to ensure its sustainability.

Keywords: Anthropogenic, PAHs, Aquatic biota, Tributaries, Benzene, Lake

1. Introduction

According to Ginebreda, Kuzmanovic, and Guasch (2014), human activities such as deforestation, channelisation, filling, canal, levee, dam, road, and bridge construction, agricultural, industrial, and domestic activities, exotic species introduction, and overexploitation of plant and animal species all disrupt the hydrological regime, sediment characteristics, and several biotic components. Upstream activities bring pollutants into mangrove swamps and estuaries. Hydrocarbons, heavy metals and organic compounds can be accumulated in aquatic biota (USEPA, 2007). Bioaccumulation measurements of poison chemicals are very important because of their deleterious effect on aquatic animals and other inhabitants of the area, as reported by Makpo*et al.* (2019).According to Ezemonye*et al.* (2011), excessive pollution causes significant damage to human and animal health, plants, including tropical rainforests, and the environment as a whole.

Rivers, lakes, and wetlands are among the most biodiverse places on earth. They cover less than 1% of the planet's total surface, yet they're home to almost a quarter of all vertebrate species – including over half of the entire world's fish species. According to Barnosky *et al.* (2013), freshwater fishes are the most threatened large taxon in the world, with 18,075 – or 51% – living there, and more are being discovered all the time. As a result, our own long-term future will be jeopardised unless we recognise the high intrinsic and commercial value of fish and their supporting ecosystems and take the necessary precautions, as stated by Baillie *et al.* (2010) and Barnosky *et al.* (2012). According to Ginebred*et al.* (2014), organisms in aquatic environments are typically exposed to a complex mixture of chemicals, resulting in multiple damage at the organism, population, and ecosystem levels, as well as organ function. The purpose of this study was to determine the concentration of PAHs in both water samples and sediment from Jabi Lake and its tributaries.

1.1 Statement of the Problem

Several researchers, Mustapha (2008); Rajesh and Yadav (2011); Amarachi and Ako (2012); and Gambhir *et al.* (2012), have reported that the impact of human activities in and around water bodies is reflected in their environmental variables, which are the physical and chemical properties of water and the survival of organisms that inhabit the water. Human activities have been blamed on several factors, such as agricultural activities by farmers and discharges of industrial waste (effluents) to the water body directly or by runoffs, coupled with environmental factors such as weather and climate, etc. Obviously, indiscriminate waste (liquid and solid) dumping has been illegal in Nigeria since 1987, when the Nigerian government promulgated the Harmful Wastes Decree, which provides the legal framework for the effective control of the disposal of toxic and hazardous waste into any environment within the confines of Nigeria. This was immediately followed by the establishment of the Federal Environmental Protection Agency (FEPA) in 1988. However, this research was carried out to determine the influence of environmental variables on the water quality and fish of Jabi Lake and its tributaries.

1.2 Justification

The choice of Jabi Lake as the study area for this scientific investigation stems from the diversity of human activities in and around the lake due to its location within the Abuja metropolis. The gradual influx of people into Abuja City within the Federal Capital Territory from various states across the country, as well as from abroad, is primarily due to the city's sociopolitical and economic significance, as it houses the three arms of Nigeria's federal government. As a result, the growing population in Abuja leads to increased social, sporting, recreational, religious, economic, and educational activities in the city. The lake's location is acceptable in terms of pollution, roadside petroleum spills, and mechanical garages. There is little or no data on the lake's pollution status.

2. Materials and Methods

2.1 Study Area

Jabi Lake is located between the Jabi and Kado Districts of Abuja, within the Federal Capital Territory of Nigeria. It is located within Latitude 9°4'38"N and Longitude 7°25'18"E. The lake is a man-made lake which, daily, witnesses a variety of human activities such as fishing, swimming, bathing, and washing, as well as sporting and recreational activities. Its breathtaking sites, combined with its lush vegetation, make the natural environment ideal for relaxation and other social activities. The lake is a multidirectional water body with shrubs and shady trees, which provides canopy-like cover for other organisms in some parts of the lake. The vegetation consists of fringing, floating, submerged, and emergent plants. There are also water hyacinths (invasive weeds) in some areas of the lake.

The lake originated from three different streams, which form the tributaries. The first stream started from Nicon Hotel Junction, while the second stream began from Gwarinpa Estate, and the third stream started from Katampe extension. The tributaries joined together at Kado Gishiri (Confluence). At the meeting point, the Gwarinpa stream is very clean, while others are very muddy, but the streams mix to produce turbid and coloured water, which clears before reaching the lake, which is about one and a half kilometres away from the confluence. The topography shows that the tributaries, which are far apart from each other, are at the upstream and midstream (confluence) at Kado Gishiri, while Jabi Lake, as the receiving end, is downstream. Any effluents or chemicals deliberately or accidentally discharged into the upstream will affect all the aquatic organisms.

2.2 Coordinates of Sampling Stations

The coordinates of the various sampling stations were taken using a Geographical Positioning System (GPS) device (GPS 45 XL), as shown in Table 1 below. The hand-held device was switched on at each station, and the latitude and longitude of each station were displayed on the device screen and recorded. Station 1 (Nicon Hotel Junction stream, tributary) has a latitude of 9.096598 and a longitude of 7.473435. Station 2 (Katampe stream, tributary) has a latitude of 9.118115 and a longitude of 7.436540. Station 3 (Gwarinpa extension stream, tributary) has a latitude of 9.098758 and a longitude of 7.428326. Station 4 (KadoGishiri, confluence) has a latitude of 9.089126 and a longitude of 7.429520. Station 5 (recreational area of Jabi Lake) has a latitude of 9.073763 and a longitude of 7.418126. Station 6 (Carnival ground of Jabi Lake) has a latitude of 9.076248 and a longitude of 7.420038, while station 7 (Fruit Garden area of Jabi Lake) also has a latitude of 9.077503 and a longitude of 7.418150.

2.3 Sampling Stations and Sampling Techniques

Samples were collected monthly between January 2022 and December 2023 in seven (7) different sampling locations: four locations from the tributaries, including the confluence, and the remaining three stations within the Jabi Lake Area of Abuja, in the Federal Capital Territory of Nigeria. The period of sampling spanned twenty-four (24) months, two (2) years, covering two (2) wet seasons (rainy seasons) and two dry seasons. The samples were collected in the morning between 7.00 am and 9.30 am. The seven (7) sampling points are referred to as sampling stations 1, 2, 3, 4, 5, 6 and 7. Figure 2 shows sampling stations, Jabi Lake, and the tributaries.

Table 1: Sampling stations and their coordinates of Jabi Lake and its Tributaries

Station	Location	Coordinates	
		Latitude	Longitude
1.	Nicon Hotel Junction tributary	9.096598	7.473435
2.	Katampe tributary	9.118115	7.426540
3.	Gwarinpa Ex. Tributary	9.098758	7.428326
4.	KadoGishiri confluent	9.089126	7.429520
5.	Recreational Area Jabi Lake	9.073763	7.418126
6.	Carnival Ground Jabi Lake	9.076248	7.420039
7.	Fruit Garden Jabi Lake	9.077503	7.418150

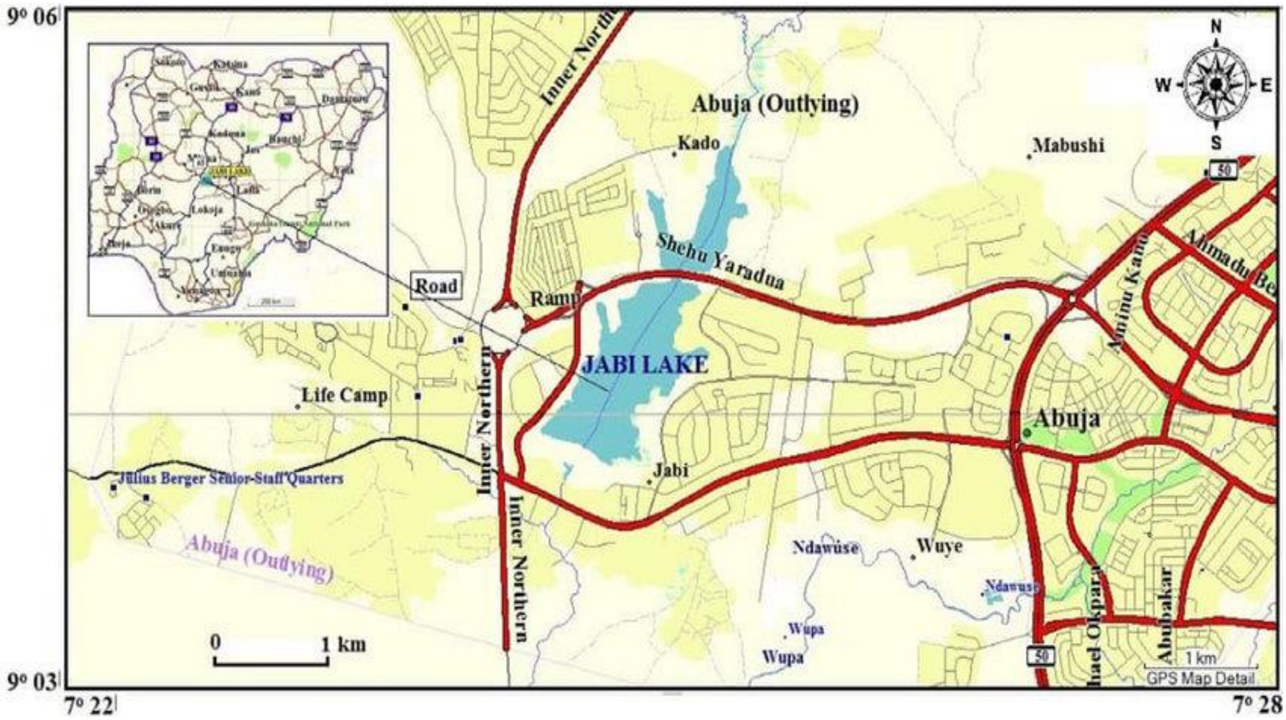

Figure 1: Google Map of Nigeria showing FCT Abuja and Jabi Lake in blue colour

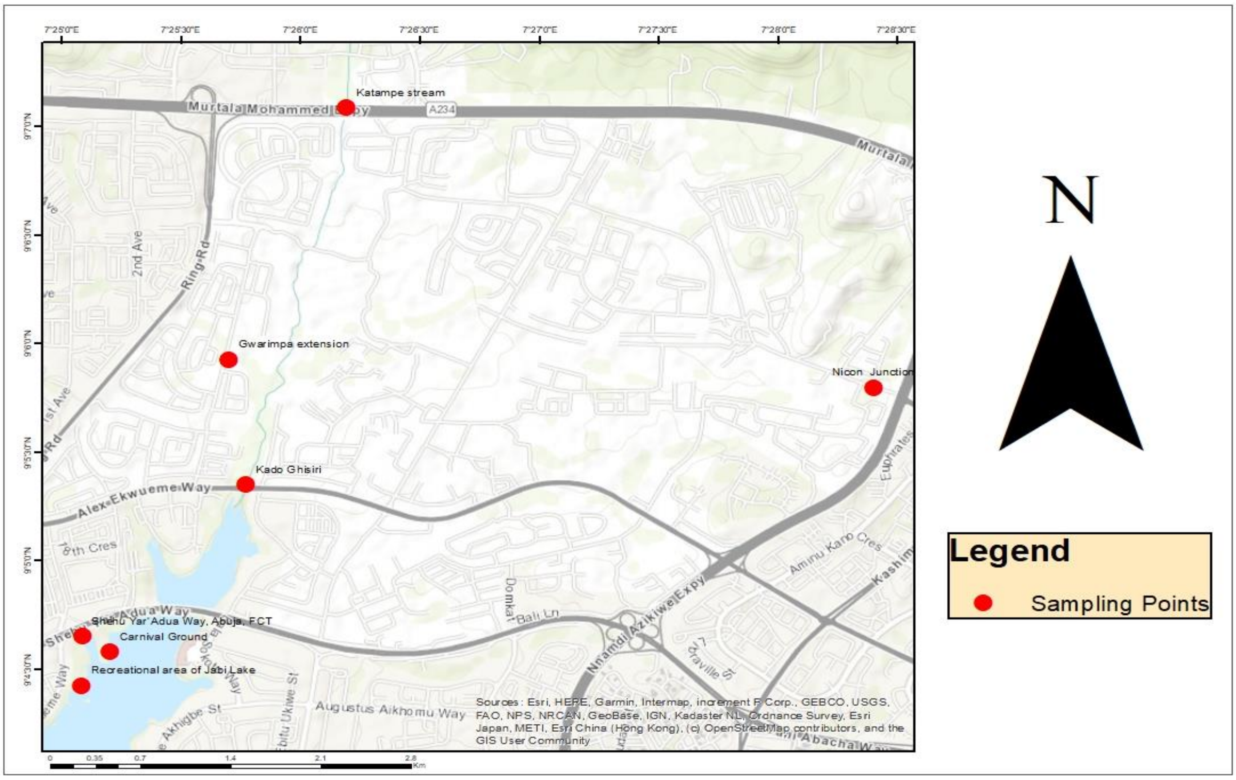

Figure 2: Google Map of Jabi Lake and the Tributaries showing the sampling station.

2.4 Materials Used

Material used includes a sampling container (bottle and plastic), distilled water, a conical flask, a paper table, preservation, an ice chest, a cooler, and aluminium fuel.

2.5 Sample collection and pre-treatment

Water samples for Polycyclic Aromatic Hydrocarbons (PAHs) were collected from each station into amber bottles and preserved with H_2SO_4 in order to maintain the integrity of the sample, then transported to Fisas Laboratory at Lugbe, Airport Road, Abuja, where modern SRI gas chromatograph analytic techniques were used. According to the United States Environmental Protection Agency (US EPA, 2009), semi-volatile organic compounds (PAHs) must be extracted from water samples within 7 days for proper analysis; thus, the analysis was completed within 48 hours of collection. The obtained results are expressed as parts per billion (ppb).

2.6 Sampling of Biota

Fishes were observed and counted by fishermen; an artisanal fishery survey was conducted at the lake on every sampling day. Fish were bought from an artisan and preserved with 70% alcohol, transported to the Nasarawa State University, Keffi (NSUK) for identification and recorded.

Sediment samples were collected from each sampling station using a fabricated grab sampler for shallow sediments, a combination of the Travelling-Kick-and-Sweep-Transect method, and near-shore lake sampling methods known as Sampling Reaches, as described by Jones, Somers, Craig, and Reynoldson (2007) for shoreline substrate. Sediments were collected into a polyethene bag with labels, preserved, and stored in an ice chest at -4°C and transferred to the Zoology Laboratory of Nasarawa State University, Keffi (NSUK), for further examination. In the laboratory, sediment samples were washed with tap water and filtered through seven (7) standard-sized sieves in descending order (6 mm, 4 mm, 2 mm, 1 mm, 0.5 mm, and 0.25 mm mesh size with the bottom receiver), after which the sieved samples (specimens) were preserved in 70% ethanol. Macroorganisms were further sorted and identified to the lowest possible taxonomic level, as described by Mezquita (1996) and Meisch (2000), using the identification guide below: Methods Protocol: Benthic Macroinvertebrate Assessment, Field guide to freshwater Invertebrates of North America, Taxonomic key to Benthic Macroinvertebrates, Field guide to Nigerian freshwater fishes (Olaosebikan and Raji, 2004). Freshwater Benthos by Carl (1978) and Understanding Lake Ecology by Horne and Goldman (1994).

2.7 Statistical Analysis

The mean and standard deviation were determined. Analysis of Variance (ANOVA) was used for inter-station comparisons to test for significant differences in the conditions of the parameters using parametric ANOVA.

The Pearson correlation coefficient was used to analyse the relationship between parameters and macrofauna. The data were tested at a 95% level of significance (0.05). Statistical analyses for fauna were based on the Shannon-Wiener and Simpson diversity indexes, which are commonly used to characterise species diversity in a community, as well as the Jaccard Index, which calculates index values between species and seasons. It explains both the abundance and evenness of the species that exist.

3. Results

Mean Value of Hydrocarbons (Benzene, Toluene, Ethylbenzene, and Xylene) (ppb) in Jabi Lake and Tributaries

The results of hydrocarbons – benzene, toluene, ethylbenzene, and xylene (BTEX) – are shown in Table 2. Point A, the upstream representing the tributaries, had the highest mean value of 32.4±0.01 ppm for benzene, followed by C (downstream – representing Jabi Lake – 16.1±0.01 ppm), and the midstream representing the confluence had the lowest mean value of 0.07±0.00 ppm. The highest mean value of toluene was recorded at downstream (20.9±0.00 ppm), followed by upstream (0.07±0.01 ppm and midstream 0.07±0.00 ppm. Ethylbenzene ranged within the mean value of 0.11±0.01 ppm for both upstream and midstream and downstream with a mean value of 0.11±0.00 ppm. O-Xylene had a higher mean value at midstream (3.49±0.00 ppm), followed by a 2.92±0.01 ppm mean value downstream, while the least mean value of 0.05±0.01 ppm was recorded at midstream. The values with the same superscript along the row are not significantly different.

Table 2: Mean Values of Hydrocarbons (BTEX) in surface water for Jabi Lake and its Tributaries

Parameters	Concentrations at Sampling Points				
	A	B	C	Mean	P-value
Benzene (ppb)	32.4±0.07^{a}	0.07±0.00^{c}	16.1±0.01^{b}	3.1±0.00^{b}	<0.01
Toluene (ppb)	0.07±0.01^{a}	0.07±0.00^{b}	20.9±0.00^{b}	7.0±0.00^{b}	<0.01
Ethylbenzene (ppb)	0.11±0.01^{c}	0.11±0.01^{b}	0.11±0.00^{a}	0.1±0.00^{b}	<0.001
o-Xylene (ppb)	0.05±0.01^{a}	3.49±0.00^{b}	2.92±0.01^{c}	2.15±0.00^{b}	<0.001
m-Xylene (ppb)	0.05±0.01^{a}	0.05±0.00^{b}	0.05±0.01^{b}	0.05±0.00^{b}	<0.001
p-Xylene (ppb)	0.11±0.01^{c}	0.11±0.01^{b}	0.11±0.01^{a}	0.11±0.01^{a}	<0.001

The values with the same superscript along the row are not significantly different.
*A=Upstream, *B=Midstream, *C=Downstream, ±=Standard error of the means, ppb=part per billion,

Table 3 also presents the results of BTEX for the sediment of both Jabi Lake and the tributaries, showing higher concentrations of BTEX in sediment compared to surface water. A higher mean value of 162.0±0.01 ppm was recorded for benzene downstream of the Jabi Lake environment, followed by a mean value of 115.01±0.01 ppm recorded upstream. The confluence had the least value of 89.9±0.01 ppm. Toluene recorded throughout the sampling stations is within 0.10±0.01 ppm (for both upstream and midstream) and 0.01±0.00 ppm (for downstream). Ethylbenzene fell within the same range of mean value as toluene, while xylene – o-xylene fluctuated with a mean value of 5.21±0.00 (midstream), followed by downstream with a mean value of 5.17±0.01 ppm and the least mean value of 4.92±0.01 ppm recorded upstream.

Table 3: Mean Values of Hydrocarbons (BTEX) in Sediments for Jabi Lake and its Tributaries

Parameters	Concentrations at Sampling Points A	B	C	Mean	P-value
Benzene (ppb)	115 ± 0.07^{b}	89.9 ± 0.00^{c}	162 ± 0.01^{a}	122.3 ± 0.00^{b}	<0.01
Toluene (ppb)	0.10 ± 0.01^{a}	0.10 ± 0.00^{b}	0.10 ± 0.00^{b}	0.10 ± 0.00^{b}	<0.01
Ethylbenzene (ppb)	0.10 ± 0.01^{c}	0.10 ± 0.01^{b}	0.10 ± 0.00^{a}	0.1 ± 0.00^{b}	<0.001
o-Xylene (ppb)	4.91 ± 0.01^{a}	5.21 ± 0.00^{b}	5.17 ± 0.01^{c}	5.10 ± 0.00^{b}	<0.001
m-Xylene (ppb)	0.10 ± 0.01^{a}	0.10 ± 0.00^{b}	0.10 ± 0.01^{b}	0.10 ± 0.00^{b}	<0.001
p-Xylene (ppb)	0.10 ± 0.01^{c}	0.10 ± 0.01^{b}	0.10 ± 0.01^{a}	0.10 ± 0.01^{a}	<0.001

The values with the same superscript along the row are not significantly different.

*A=Upstream, *B=Midstream, *C=Downstream, ±=Standard error of the means, ppb=part per billion,

Distribution and Composition of Macrofauna at Jabi Lake and Its Tributaries

The result of the fauna recorded (both pelagic and benthic macrofauna) in this study indicated a composition and abundance (figs. 2 & 3, respectively) of 4 phyla (Chordata, Mollusca, Arthropoda, and Annelida). 10 classes, 26 families, and 44 species. The total number of individual species encountered was 3,422. Class Gastropoda has 6 families, followed by Hirudinea with 4 families. The most abundant family in terms of species was Naididae, which had 4 species. Unionoidae and Chironomidae had 3 species each. The majority of the families sampled had 2 species. The familyBithyniidae, *Ganiobasislivescens,* were abundantly present during the dry season but gradually drifted away at the onset of the rainy season. Station 5, being a recreational area with plenty of nutrients compared to other stations, had the highest individual number of 998 spp. Followed by Station 6 with 761 and Station 7 with 362. Representatives of species encountered were presented in the plates below.

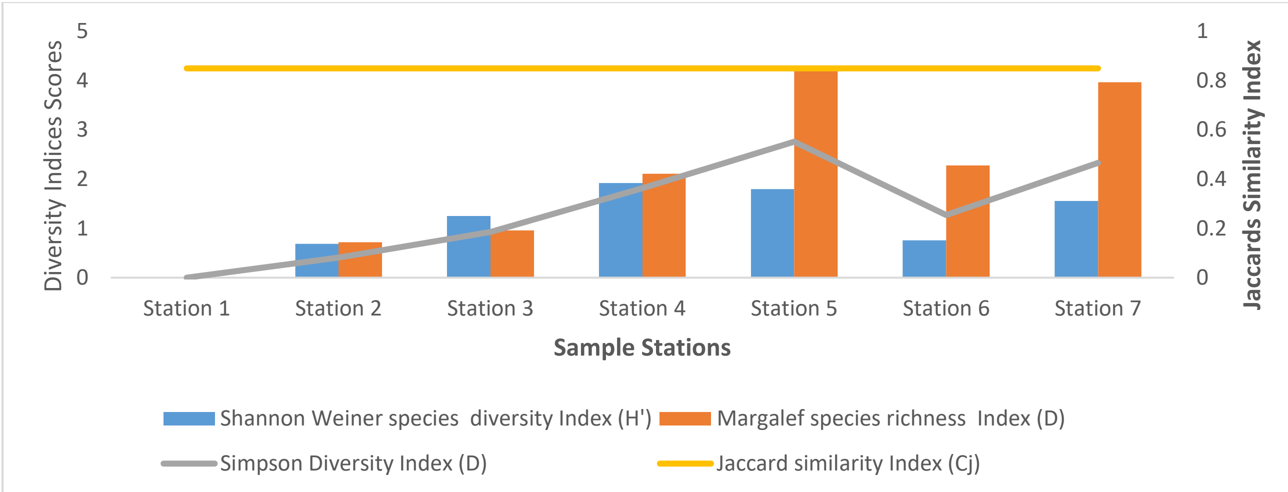

Fig 2: Diversity of Species in Jabi Lake and Tributaries

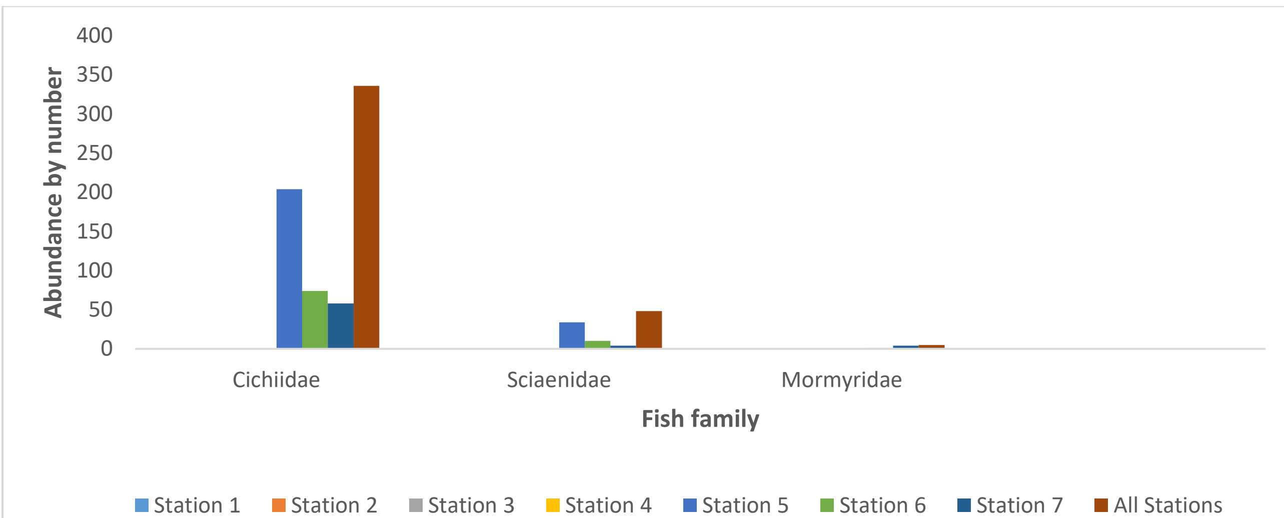

Fig 3: Species Abundance in Jabi Lake and Tributaries

Plates 1, 2, 3 & 4: *Oreochromis niloticus* (Tilapia), *Clarias gariepinus*(Catfish), *Pseudotolithus senegalensis* (Croaker) and *Gnathonemuspetersii*(Elephant fish) found in Jabi Lake

Plates 5, 6, 7, 8 & 9: Ganiobasislivescens (Bithyniidae), *Viviparous sp.* (Viviparidae), *Dreissenabugensis* (Bivalvia), *Chironomus sp*. (Chironmidae), and Dolomedes *sp*. (Pisaurudae) found in Jabi Lake.

A Jaccard Similarity Index score of 0.85 (Table 4) indicates that 85 percent of the species can be found around all stations, suggesting a wide spread of species across sampled stations.

Table 4: Species Diversity Indices for The Seven (7) Sampling Stations of Jabi Lake and its Tributaries

	Shannon Weiner species diversity Index (H')	**Margalef species richness Index (D)**	**Simpson Diversity Index (D)**	**Jaccard similarity Index (Cj)**
Station 1	0.00	0.00	0.00	
Station 2	0.69	0.72	0.41	
Station 3	1.25	0.96	0.93	
Station 4	1.92	2.11	1.82	
				0.85
Station 5	1.80	4.25	2.76	
Station 6	0.76	2.28	1.27	
Station 7	1.56	3.97	2.33	
All stations	**1.14**	**2.04**	**1.80**	**0.85**

4.1 Discussion

The BTEX results for both surface and sediment (upstream – 115±0.07 ppb, middle stream – 89.9±0.00 ppb, and downstream – 122.3±0.00 ppb) were within the regulatory limits. The regulatory permissible limit of benzene is 0.3 mg/L in the aquatic environment; then, toluene and xylene are 1 mg/L. The National Institute for Occupational Safety and Health (NIOSH, 2012) stated that the major effects of benzene are manifested through chronic exposure through the blood.

Benzene damages the bone marrow, causing a decrease in red blood cells, leading to anaemia. It can also cause excessive bleeding, depress the immune system, and increase the risk of infection. It is associated with blood cancers and pre-cancer of the blood. ATSDR (2012) and Environmental Health News (2010) stated that benzene targets the liver, kidney, lung, heart, and brain and can break DNA strands.

Some studies observed lethal effects in fish when exposing fish to hydrocarbons: spent oil/crankcase oil. Makpo (2021) reported a very significant ($P < 0.05$) elevation in the concentration level of spent oil in the muscle at the highest toxicant concentration of 140 mg/L, with the value at 256 ± 0.441, while the same value in the control was as low as 13.35 ± 75.90 in the gills of the fish, which also agreed with the report of Vasanth *et al. (2012)*. Therefore, accumulation of hydrocarbons within the surface water and sediment will have greater effects on aquatic organisms.

Aromatics are the most acutely toxic components of petroleum products, and they have also been linked to chronic and carcinogenic effects, according to Rochaddi, Atmodjo, Satriadi, Suryono, Irwani*et al.*, 2019. According to Short, Rice, Heintz, Carls, and Moles (2003), lighter monocyclic aromatic hydrocarbons, primarily BTEX, are assumed to account for the majority of the toxicity and are the most abundant aromatic hydrocarbons in most crankcase oils, but they are the least persistent due to their relatively high vapour pressures.

Fish Distribution at Jabi Lake and its Tributaries

The result of the fish recorded in this study shows the composition and abundance of four (4) families (Cichlidae, Clariidae, Sciaenidae, and Mormyridae). Environmental factors have long been known to explain variation in the distribution pattern of macrofauna and thus community structure in the global dependent taxa. An increase in temperature will probably further decrease breeding in the hot months but increase breeding in the rainy season months of major aquatic organisms, according to Brook, Sodhi, and Bradshaw (2008). NARESCON (1992) reported that the freshwater fishery resources in Nigeria comprised over 200 species from inland waters, with Kainji having about 100 species of fish, while Lake Chad had 87 species. Ita (1993) reported 101 species of fish in Lake Kainji and 52 species in Jebba. Balogun, Auta, Balarebe, and Bako (2000) recorded eighteen (18) species belonging to nine families. Balogun and Auta (2001) reported 34 species of fish in Ikere Gorge; 32 species were reported in Erinle Lake (Komolafe and Arawomo, 2011); 16 species were reported in Ikwori Lake (Offem, Oyetunde, Ikpi, Ochang, and Ada, 2011); and 27 species were reported at Asejire Lake (Ipinmoroti, 2013).

Other works with comparable results are the Doma reservoir with eleven (11) species of fish belonging to six (6) families (Banyigyi, Auta, Oniye, Balogun, and Umaru, 2016), which is almost the same as the present finding of four (4) species belonging to four (4) families. Dan-Kishiya, Olatunde, and Balogun (2013) reported low diversity of fish species in Lower Usuma Dam, Bwari, Abuja. Eleven (11) species of fish were recorded in Tagwai Lake, Minna, while eight (8) species of fish were recorded in Egbe Reservoir (Edward, 2013).

Distribution of Benthos Organisms in Jabi Lake and Its Tributaries

The result of the benthos recorded in this study shows the composition and abundance of three (3) phyla (Mollusca, Arthropoda, and Annelida). The overall composition and abundance of benthos in Jabi Lake and tributaries varied both spatially and temporally in response to physical and chemical (BTEX) factors of the aquatic environment. A total of 3,098 individuals distributed among 4 taxa were observed among the stations within the lake and its tributaries. The present finding corresponds with Aina and Oyebamiji (2011) but shows a substantial reduction compared to the number observed by Tyokumbur, Okorie, and Ugwumba, A.O. (2002).

The dominant influence of parameters on the distribution and abundance of macroinvertebrate fauna can explain the significantly higher species counts observed at all stations during the sampling period. However, this does not explain the high density observed during the hot dry season for the families Bithyniidae and Lymnaeidae. The abundance of Gastropoda in Jabi Lake could be attributed to the types of aquatic macrophytes found in and around the lake. It is also possible that gastropod abundance is due to differences in predator protection and avoidance strategies. Aina and Oyebamiji (2002) suggested that the presence of gastropods can be traced to their tolerance to some levels of pollution. According to Emere and Nasiru (2007), the presence of Chironomus species in almost all stations is considered normal because they are typically found in water bodies with less pollution. Victor and Onomivbori (1996); Trichkova, Tyufekchieva, Kenderov, Vidinova, Botev, *et al.* (2013); and other studies documented some species asopportunistic fauna with high reproductive rates, short life spans, high dispersibility, and reduced long-term competitive abilities occupying disturbed habitats. This phenomenon was also observed in other water bodies in Ethiopia, including the wetlands of Lake Tana (Gezie*et al.,* 2017). This was especially true for the Tubifera and Culex species, which were found at a few stations. Studies by Oben (2000) and Tyokumbur*et al.* (2002). It is possible that the species was transported by a water current from the source. Arthropoda and Annelida were evenly distributed throughout the stations, which may be due to their ability to adapt in and on sediment.

4.2 Conclusion and Recommendations

There were monthly and seasonal variations in some parameters in the lake and its tributaries. This observation could be attributed to changes in climatic conditions and human activities near sampling points, such as weather, flooding from catchment areas, agricultural activities, runoff, municipal waste, an oil spill from a nearby garage, and so on.

There were monthly and seasonal variations in the macrofauna composition of Jabi Lake and its tributaries, implying that the two climatic regimes (seasons) interact with anthropogenic activities to influence their distribution and abundance. The species composition and abundance of the biological communities studied may be related to the prevailing abiotic factors in the aquatic ecosystem.

The degradation of aquatic ecosystems is largely due to human activities. Increased urbanisation and industrialisation contribute significantly to water pollution. Human contribution to water pollution is enormous, such as the dumping of solid wastes, industrial wastes, and domestic wastes. Water pollution is a major concern for the world. Environmental education is very important to reduce the pollution of aquatic ecosystems.

Hydrocarbons constitute a very serious problem due to their high molecular weight and density; thus, they accumulate in the living tissues of organisms and cause serious problems across the food chain. As a result, biodiversity is declining, and serious chronic diseases in humans are becoming more prevalent, making the immune system vulnerable to further disease. To protect ourselves and ensure high biodiversity, we must reduce and eliminate pollution agents by implementing legislation, improving environmentally friendly pollutant treatment methods, and achieving a zero-waste strategy.

In conclusion, the limnological features strongly suggest that Jabi Lake is maintaining eutrophic status and is not really polluted nor adversely affected by environmental variables.

4.3 Recommendations

In this context, water pollution is a global problem; therefore, the international regulations demand water quality compliance with the quality standards both in surface water and groundwater and in biota (WFW Directive, 2000). Jabi Lake desired a systematic approach to lake management for the sustainability of its fishery resources and environs.

With considerable information on environmental factors obtained from this research work, the following measures are recommended:

- To protect and enhance fishery resources, aquatic scientists should actively review and establish government, industry, and private sector policies on chemical manufacturing, control, and use.
- Aquatic scientists should learn about hazard assessment programmes for new and expanded-use chemicals. Competent researchers should develop and apply meaningful aquatic hazard evaluation programmes to chemicals as part of the evolving remanufacturing notification and review processes governed by federal, state, and local regulations.
- Future review studies should continue focusing on the trends of water pollutants such as nutrients, metals and metalloids, sediments, pharmaceuticals, pesticides, herbicides, persistent organic compounds, polycyclic hydrocarbons, microplastics, engineered nanoparticles, and endocrine-disrupting chemicals.
- To prevent future pollution, the Recreation and Park Department should establish monitoring and control mechanisms for the lake's physico-chemical parameters.
- There is a need to monitor human activities, especially from upstream (tributaries) and fishing intensity on the lake, in order not to destroy the fishing diversity.

- To prevent overfishing, potential fishermen should be educated on the importance of sustaining the lake's fishery resources. The number of fishermen operating on the lake should also be regulated and registered by the relevant authorities.
- More research should be directed towards the study of species composition of the biotic communities in relation to their specific habitats in the lake.
- Efforts should also be directed towards the study of benthic biota in the lake. In doing so, a picture of the dynamics of the lakes' components will provide a broader understanding of the lake.
- It is also advisable that more research be carried out by including more climatic variables like atmospheric air pressure, solar radiation, etc., to further understand the effect of climate change on the lake.
- Proper awareness should be provided to the public about the harmful effects of heavy metals and PAH toxicity in our environment.
- Cost-effective methods are needed to predict the concentration of a chemical substance that will have no chronic effects on exposed aquatic species in receiving waters.
- Everyone should agree that it must be a priority to keep a clean environment for everyone to enjoy and to ensure the protection of our unique aquatic biota. It is the responsibility of each individual to protect our environment and its ecosystem.

4.4 Contribution to Knowledge

Environmental variables such as Polycyclic Aromatic Hydrocarbons (PAHs) present in the freshwater aquatic environment pose a danger to aquatic biota and human consumers of fish. Jabi Lake is very rich and productive; therefore, it requires a systematic approach towards management and development for the sustainability of the fishery.

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