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The Evaluation of Anthropogenic Impacts on The Community Structure of Benthic Macroinvertebrates in Lagos Lagoon, Nigeria

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Abstract:
Introduction: Contaminants generated from different human activities combine to pose stress on the benthic macroinvertebrates and alter their community structure.
Aim: To evaluate the impacts of human activities on the Lagos lagoon, by examining changes in abundance and diversity of benthic macroinvertebrates.
Materials and Methods: Eight sampling points with varying human impacts along the edges of the Lagos lagoon were investigated monthly between September 2020 and February 2021, for the effects of human-induced stress on the abundance and diversity of benthic macroinvertebrates in the study area. Water and benthic macroinvertebrates were collected monthly using Hydrobios Water Sampler and Van-Veen grab respectively, and analysed in the laboratory using standard methods.
Results: The hydrochemistry of the stations differed significantly ($P<0.05$), with the exception of temperature. A total of 1390 individuals, comprising twelve species, eleven genera, six orders, four classes and three phyla were recorded. The benthic macroinvertebrates assemblage was dominated by relatively pollution-sensitive and tolerant species such as *Tympanotonus fuscatus* and *Nereis diversicolor*. There was a generally low abundance and diversity of benthic macroinvertebrates in the study area, and this may be attributed to the combined impact of different anthropogenic activities in the study area. The low abundance and diversity of benthic macroinvertebrates indicate an overall decline in water quality and ecosystem health.
Conclusion: This highlights the need for better management of anthropogenic activities in the area, to maintain a healthy aquatic environment.
Keywords: Anthropogenic influence; Water chemistry; Benthic macroinvertebrates; Lagos lagoon

1. INTRODUCTION

Coastal environments, for some obvious reasons, are convenient choices for localisation of industries, high human population concentration, developmental projects, and agricultural and farming activities. The combination of all these anthropogenic activities generates variant pollutants that are directly or indirectly released into the nearby coastal waters as the last sink. Coastal lagoons are among the most productive ecosystems in the world [1], sustaining important environmental services such as fisheries [2]. Their importance for biodiversity conservation has been recognized extensively [3]. Despite the undeniable relevance for conservation coastal lagoons possess, they are yet seriously threatened by eutrophication, pollution, urbanization, and diverse forms of modification in their watersheds, caused by human activity in the coastal zones of all continents.

There is indiscriminate construction of buildings along the coast as well as dredging and sediment mining. Kennish *et al*. [4] identified 12 major anthropogenic stressors on coastal ecosystems. These include eutrophication, sewage and organic wastes, habitat loss and alteration, shoreline hardening, and erosion, chemical contaminants, human-induced sediment/particulate inputs, overfishing, intensive aquaculture, introduced/invasive species, human-altered hydrological regimes, climate change, coastal subsidence, and floatables/debris. The combined effects of these pollutants could have devastating effects on both the flora and fauna of the waterbody and the benthic macroinvertebrates are the worst hit, mostly because of their sedentary and sessile lifestyle.

Benthic macroinvertebrates are animals without backbone living at the bottom of an aquatic environment and are large enough to be seen with an unaided eye. These organisms which have special adaptations that allow them to live at the bottom of water bodies, are extremely important in the coastal ecosystem as they are involved in ecological processes such as energy transfer between detritus, consumers, and organic matter recycling [5]. They are used as biological indicators or environmental monitors because they are in contact with both the water column and the sediment covering the ocean and are sensitive to toxic compounds in both and could respond to a variety of environmental variables such as sediment quality, water quality, hydrological conditions, shading and biological factors [5, 6, 7]. Their limited mobility makes them very susceptible to the impacts of these pollutants [8, 9].

According to Wallace and Webser [10], benthic fauna performs a variety of roles that are essential for the proper functioning and health of the aquatic ecosystem. Secondary production by benthic macroinvertebrates serves as natural food source to pelagic and bentho-pelagic community. They accelerate detrital decomposition [10] thereby making food available for the detrital and deposit feeders. The benthic fauna also releases bound nutrients into solution by feeding activities, excretion and burrowing into the sediment [11]. Benthic faunae play a key role in the cycling of nutrients and controlling nutrient outflows from the ecosystems by transforming organic detritus from sedimentary storage into dissolved nutrients [12, 13].

This study operationally integrates the two approaches to environmental monitoring which are: the stressor-based monitoring approach, centred on the physicochemical characteristics of some pollution hotspots in the western part of the Lagos Lagoon; and the response-based monitoring approach, focused on community structure of the benthic macroinvertebrates to assess the various anthropogenic effects of pollutants on the Lagos lagoon.

2. MATERIAL AND METHODS

2.1 Description of Study Area and Stations

The Lagos lagoon (Figure 1) is located between Longitudes 3º 23' and 3° 40' E, and Latitudes 6º 26' and 6º 38' N. The lagoon which is the largest lagoon system in the West African coast, covers an area of about 208 km^2, and opens into the Atlantic Ocean via Lagos Harbour. Lagos lagoon is one of the nine lagoons in south western Nigeria with a depository of last resort for over 70% of surface runoffs, containing both solid and liquid wastes generated around the coast. The lagoon is ecologically very important because it provides nursery, breeding, spawning, and feeding ground for an array of diverse forms of aquatic habitats [14]. The continuous growth in human population in and around the Lagos metropolis has resulted to such tremendous increase in generated wastes of unprecedented quantities and variants. Industries of various types and nature have been birthed and in addition, recreational and tourist centres have been built. A total of eight sampling locations (Table 1) were selected for this study based on the apparent sources of pollution of the areas. A motorized survey boat and Global Positioning System (GPS) was used to ascertain station coordinates and sampling points.

Table 1: Sampling Stations and their Coordinates

Station No.	Stations	Latitude Coordinates	Longitude Coordinates
1.	Carter Bridge	6º28'10.404''N	3º23'40.280"E

2.	Makoko	6º29'43.223"N	3º24'13.853"E
3.	Abule Agege	6º30'25.083"N	3º24'40.513"E
4.	Lagoon Front	6º31'14.067"N	3º24'24.714"E
5.	Ogudu	6º33'24.409"N	3º24'42.488"E
6.	Agboyi	6º33'44.158"N	3º26'35.056"E
7.	Majidun	6º34'54.266"N	3º27'17.516"E
8.	Ogolonto	6º35'19.939"N	3º28'17.749"E

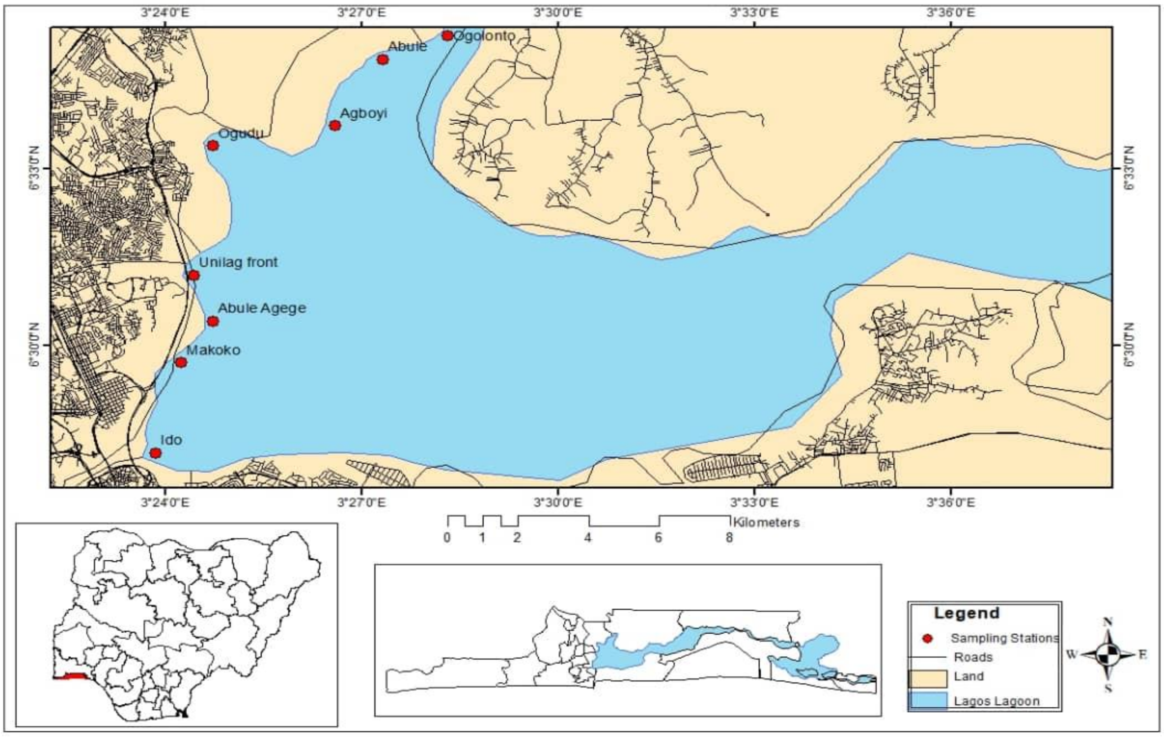

Figure 1: Lagos Lagoon Showing Sampling Stations

2.2. Collection and analysis of samples

2.2.1. Collection and analysis of water samples

Water samples were collected monthly at each study station for six months. Water temperature, dissolved oxygen (DO), and total dissolved solids (TDS) were measured *in-situ* at every sampling station with mercury-in-glass thermometer, hand-held LaMotte DO Meter (DO 6 PLUS) and LaMotte TDS Meter (TDS 6 PLUS) respectively. Surface water samples were collected at stations using an hydrobios water sampler, following the methods described in APHA [15]. The samples were stored in a large, airtight plastic ice chest at 4^0C to prevent sample deterioration. The samples were analysed using standard laboratory methods [15]. Salinity and pH were measured at the laboratory with a water quality checker (Horiba-U10). Nitrate, phosphate and sulphate were measured by colorimetric analysis, and spectroscopy with a LaMotte Smart-Spectrophotometer. Water samples were collected at each station in a 250 ml dissolved oxygen bottles and incubated in the dark for five days, for biochemical oxygen demand (BOD_5) determination as described in [15].

2.2.2. Collection and analysis of benthic samples

Benthic samples were collected with a 0.25 m^2 Van-Veen grab (weight - 25kg, height - 20cm) at each station from an anchored boat, and sieved through a 0.55 mm mesh size sieve. The materials retained on the sieve were stored in labeled plastic containers and preserved with 10% formalin for sorting, grouping, classification, and further analysis of the benthic macroinvertebrates, according to standard procedures.

2.2.3. Statistical analysis

The descriptive and inferential statistical analyses of the physicochemical parameters of water were carried out using *Statistical Package for the Social Sciences 21* (SPSS 21) Windows version. The diversity indices such as Margalef's and Shannon–Wiener's indices were computed using the Paleontological statistical (PAST) program [16]. Principal Component Analysis was used to identify the interrelations between the PCPs and study stations using Originlab software. The Canonical Correspondence analysis was used to estimate the relationship between the physicochemical parameters and the macroinvertebrate fauna across the study area using PAST.

3. RESULTS AND DISCUSSION

The P-statistics and F-distribution results of the physical and chemical parameters of the water samples measured (Table 2) shows that they are significantly different (*P*<0.05) except for water temperature. The water temperature of the study indicated relative uniform distribution. The hydrogen ion concentration (pH) of the samples ranged between 5.6 and 6.9 during the period of study, hence, it indicates that the water is slightly acidic. Very low dissolved oxygen level (<4 mg/L) was recorded in stations with high biodegradable wastes. The mean level of suspended solids in the water ranged between 21.0±1.4 and 96.9±3.3 mg/L, which is relatively high and corresponds with high turbidity values (24.8±4.5 - 58.6±6.2) recorded in the water. The biochemical oxygen demand recorded relatively high values across study stations, with the highest value (36.5±2.2 mg/L) recorded at the Ogudu sampling station. The nutrients in water, especially Nitrates, recorded relatively high concentration across the sampling stations, with the least (2.9±0.4 mg/L) recorded at Carter Bridge, and the highest (9.9±0.6) recorded at the Agboyi sampling station.
Figure 2 highlights the results of the PCA based on the correlation matrix of the water physicochemical parameters.

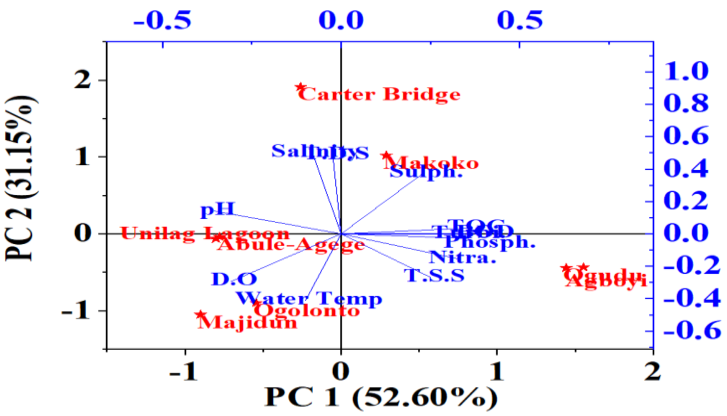

Figure 2: Principal Component Analysis biplot across the sample stations

The PCA was used to analyze data sets, including 12 variables obtained from water samples, and was expressed as two components (PC 1 and PC 2). The first principal component (PC 1), which accounted for 52.60% of the overall variation, is mostly comprised of weak loadings (<0.50). It shows that parameters including TOC, turbidity, nitrate, phosphate, BOD, TSS were loaded in the Agboyi and Ogudu study stations. These parameters in PC 1 indicates that contamination in the study stations is of anthropogenic sources. On the other hand, PC 2 showed 31.15% of the total variation, and salinity, TDS, pH, sulphate are loaded in the Makoko and Carter Bridge sampling stations.

Benthic macroinvertebrates sampled in the area recorded a total of 1390 individuals. They comprise of 12 Species, 11 Genera, 6 order, 4 Classes and 3 Phyla (Table 3). The month of February recorded the highest number of individuals (674), while the least (108) was recorded in the month of October (Figure 3). The higher number of individuals during the dry season could be as a decrease in water volume, which limits mobility and migration of organisms to other habitats. The more sensitive Crustacea, *Clibanarius africanus,* recorded the least number (13) of individuals collected during the period of study, constituting less than 1% of the total number of individuals sampled during the period (Figure 4). The pollution sensitive *Tympanotonus* sp. [19] dominated the benthic macroinvertebrates assemblage of the study area, constituting about 72% of sampled individuals (Figure 5). Study stations like Ogudu and Makoko with profound diverse pollution inputs, recorded the least number of individuals (Figure 6). The overall species diversity and richness in these two stations in particular, and in all the stations in the study area in general, were very low (Figure 7). This could be as a result of the combined effects of different pollutants on the water and benthic macroinvertebrates in the study area.

Table 2: The Mean ± SD and inferential statistics of the Physico-chemical Parameters of the Water Samples in the Study Area for the Period of Study

	Water Temp (^{o}C)	pH	Salinity (PPT)	D.O (Mg/L)	T.S.S (Mg/L)	T.D.S (g/L)	BOD (Mg/L)	TOC (Mg/L)	Turbidity (Mg/L)	Nitrate (Mg/L)	Phosphate (Mg/L)	Sulphate (Mg/L)
Carter Bridge	29.7±1.0	6.7±0.1	10.7±1.4	4.4±0.3	39.3±2.4	18.3±.2	17.3±2.1	4.4±0.2	35.4±4.3	2.9±0.4	0.7±0.1	453±2
Makoko	29.5±1.0	6.7±0.1	9.3±1.3	4.4±0.1	63.7±3.2	9.2±0.5	19.7±1.8	7.0±0.6	37.4±4.7	3.3±0.3	2.0±0.8	349±3
Abule-Agege	29.9±1.0	6.6±0.1	5.7±0.8	5.4±0.2	21.0±1.4	4.9±0.5	8.3±2.7	3.9±0.8	35.2±3.9	4.7±0.3	0.8±0.2	281±5
Unilag Lagoon	29.9±0.9	6.7±0.1	5.6±0.4	5.1±0.1	39.2±2.4	4.6±0.2	6.9±1.6	3.5±0.2	31.4±3.8	5.4±0.3	0.6±0.3	274±6
Ogudu	29.9±1.2	6.2±0.6	2.8±2.1	4.5± 0.2	96.9±3.3	3.4±0.3	36.5±2.2	8.4±0.4	43.1±10.4	9.5±0.2	2.3±0.4	355±5
Agboyi	30.2±0.8	6.0±0.3	2.5±1.8	4.4±0.2	85.7±2.8	4.7±0.2	34.9±1.3	6.8±1.1	58.6±6.2	9.9±0.6	1.9±0.4	387±1
Majidun	30.7±1.0	6.7±0.1	2.1±1.4	5.3± 0.3	78.6±2.7	3.2±0.2	10.0±3.6	3.6±0.4	24.8±4.5	3.1±0.6	0.7±0.2	249±2
Ogolonto	30.8±0.7	6.7±0.1	3.0±2.2	5.2±0.2	80.1±1.6	3.4±0.4	11.5±1.9	4.2±0.4	35.8±2.2	3.0±0.5	1.1±0.2	283±2
F-Value	1.440	6.758	27.139	26.931	704.726	1359.6	159.257	63.598	19.321	257.088	19.566	51.912
P-Stat.	$P>0.05$	$P<0.05$	$P<0.05$	$P<0.05$	$P<0.05$	$P<0.05$	$P<0.05$	$P<0.05$	$P<0.05$	$P<0.05$	$P<0.05$	$P<0.05$

Table 3: Classification of Benthic Macroinvertebrates sampled from the selected sample station in Lagos lagoon

Phylum: Mollusca Class: Gastropoda Order: Mesogastropoda Family: Melaniidae Genus: *Pachymelania* Species: *Pachymelania aurita* Family Potamididae Genus *Tympanotonus* Species *Tympanotonus fuscatus* Species *Tympanotonus fuscatus* var *radula* Order: Archeogasropoda Family: Neritidae Genus: *Neritina* Species: *Neritina glabrata* Class: Bivalvia Order: Veneroida Family: Donacidae Genus: *Iphigenia* Species: *Iphigenia truncate* Family: Tellinidae Genus: *Macoma* Species: *Macoma cumana* Order: Ostreoida Family: Ostreidae	Genus: *Crassostrea* Species: *Crassostrea gasar* Family: Aloididae Genus: *Aloides* Species: *Aloides trigona* Phylum: Arthropoda Class: Malacostraca Order: Decapoda Family: Diogenidae Genus: *Clibanarius* Species: *Clibanarius africanus* Family: Portunidae Genus: *Callinectes* Species: *Callinectes* sp. Phylum: Annelida Class: Polychaeta Order: Aciculata Family: Nereididae Genus: *Nereis* Species: *Nereis* sp. Family: Capitellidae Genus: *Capitella* Species: *Capitella capitata*

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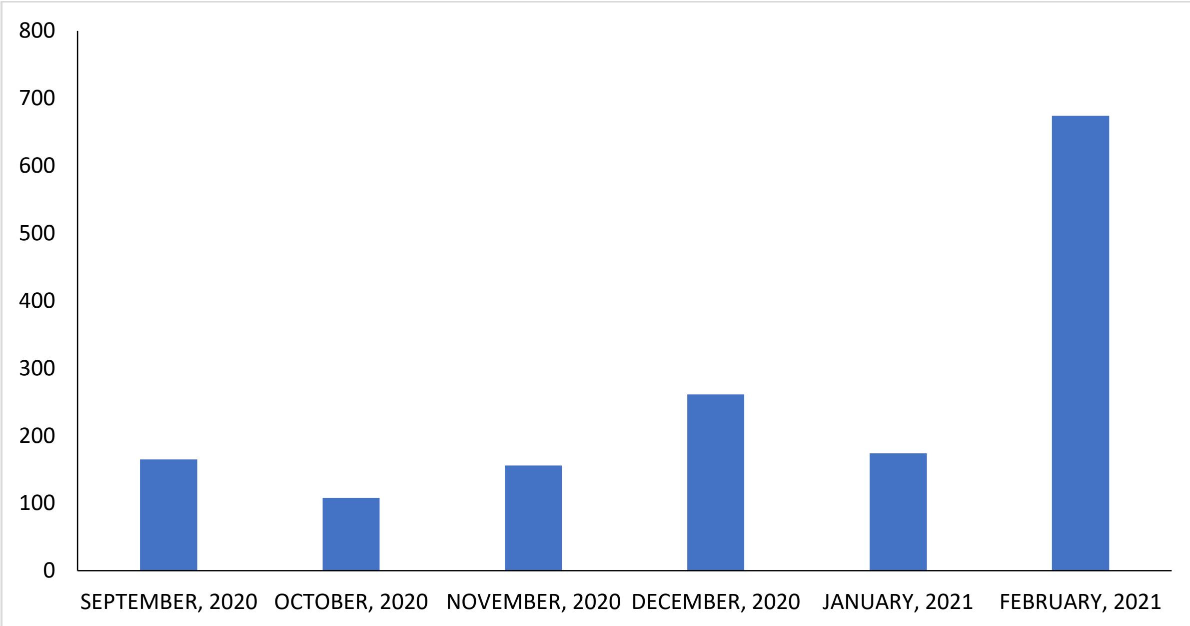


Figure 3: Mean Monthly Variation in the Abundance of Benthic Macroinvertebrates in the Study Area

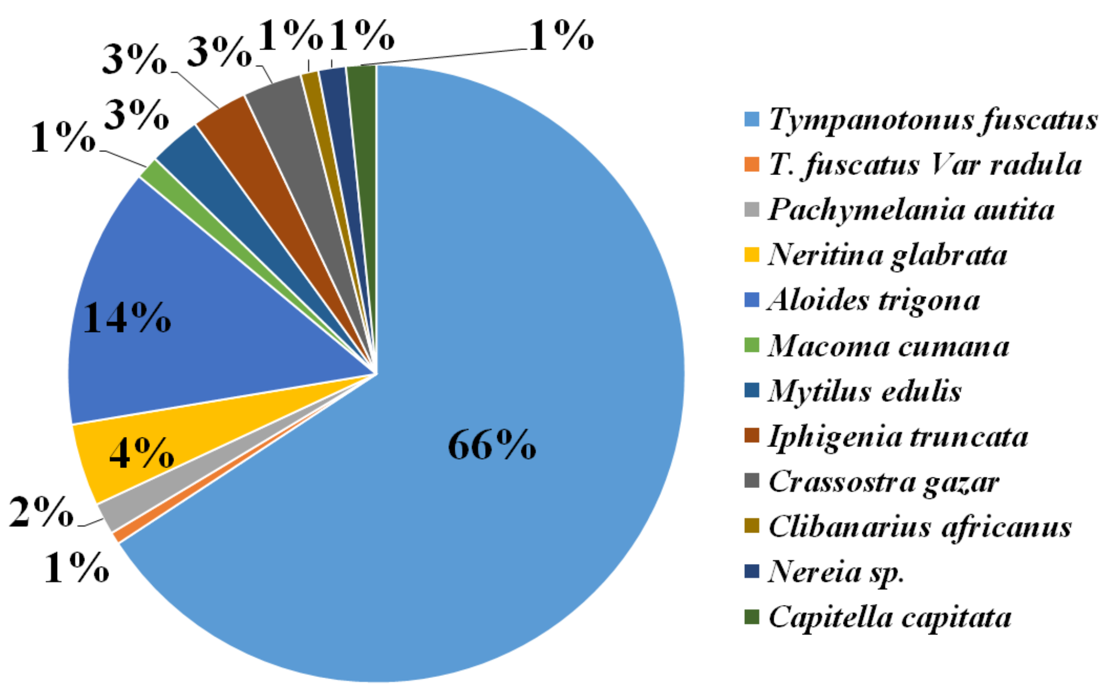


Figure 4: Percentage Taxa Contribution of Benthic Macroinvertebrates for the Period of Study

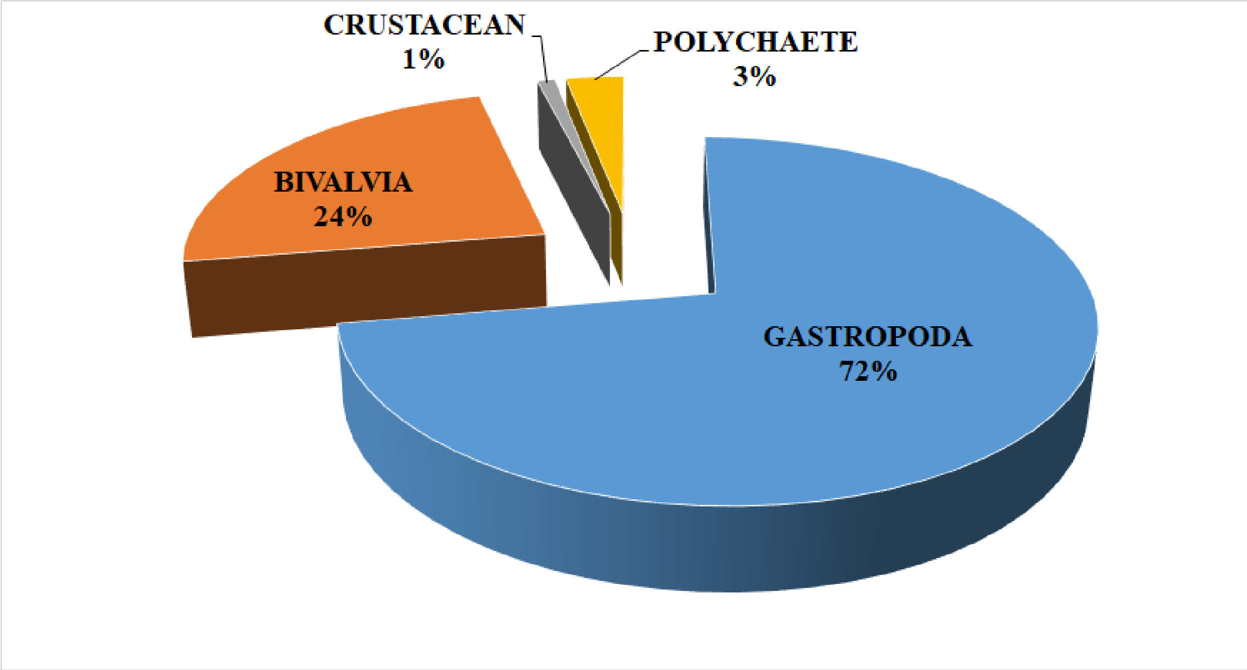


Figure 5: Percentage Contribution by Class of the Benthic Macroinvertebrates during the Period of Study

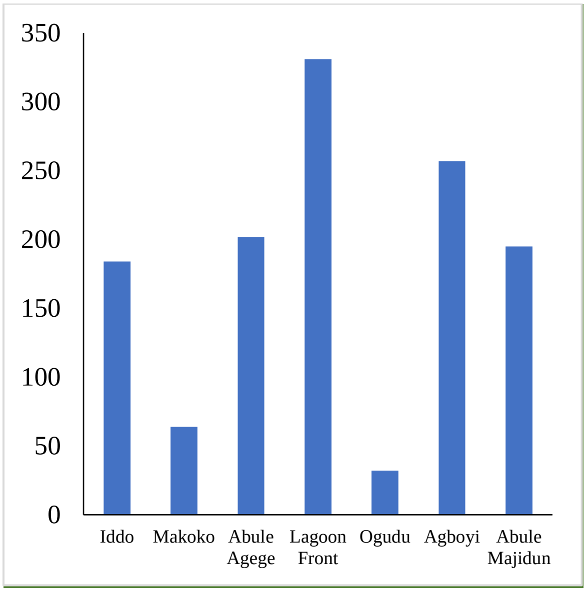


Figure 6: Mean Spatial Variation in Abundance of Benthic Macroinvertebrates

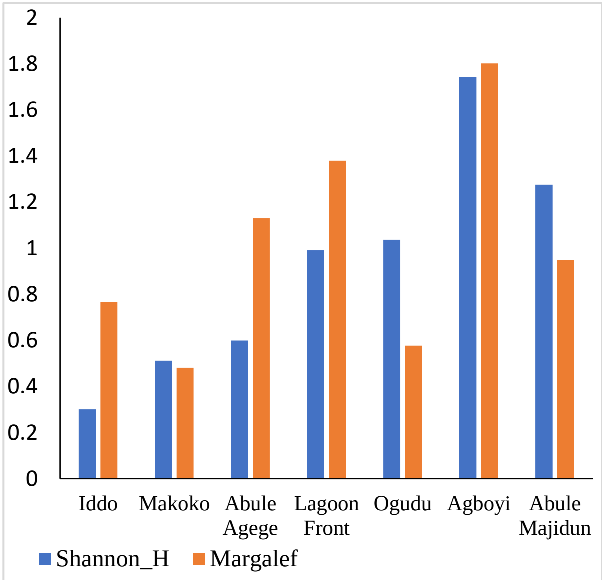
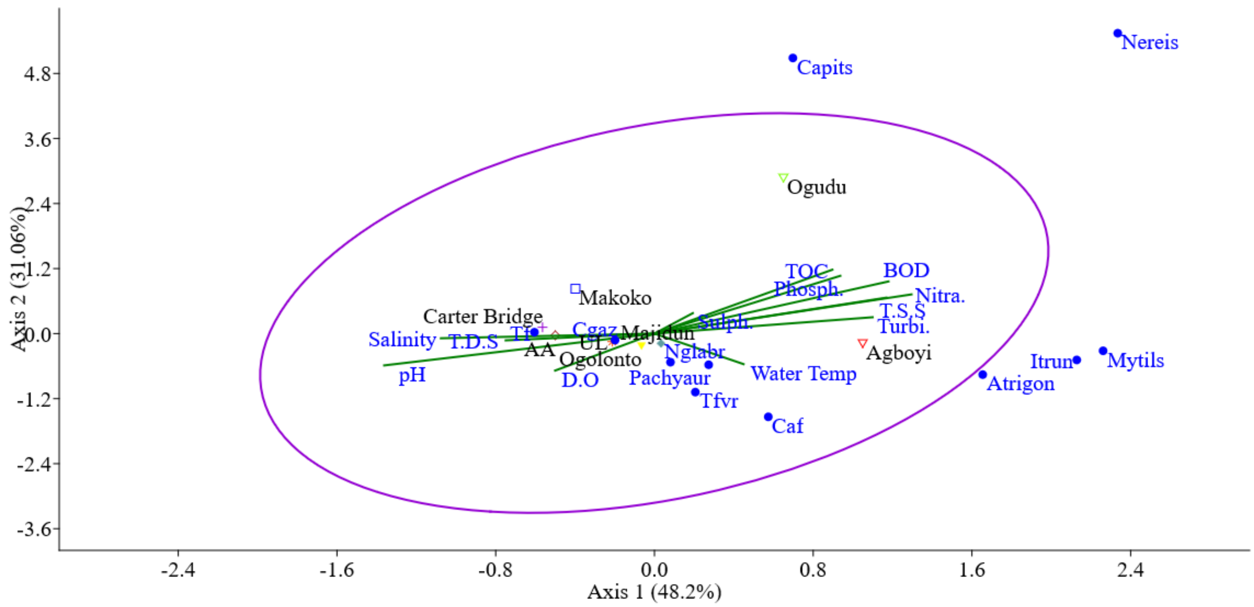


Figure 7: Spatial Variation in Diversity and Richness Indices

Canonical Correspondence Analysis (CCA) result presented in Figure 8 shows relations between the macroinvertebrates assemblage the physicochemical parameters of water obtained in this study area.



Key: UL: Unilag Lagoon; AA: Abule Agege; Tf: *Tympanotonus fuscatus*; Tfvr: *T. fuscatus* var *radula:* Nglabr: *Neritina glabrata*; Itrun: *Iphigenia truncate*; Atrigon: *Aloides trigona*; Cgaz: *Crassostra gazar*; Caf: *Clibanarius africanus*; Mytils: *Mytilus edulis*; Nereis: *Nereis* sp.; Capits: *Capitella capitata*; Pachyaur: *Pachymelania aurita*

Figure 8: Canonical Correspondence Analysis triplot across the sample stations

The main environmental gradient (Axis 1) explained 48.2% of the total variation in macroinvertebrates community assemblage pattern, while CCA axis 2 explained 31.06% of total variation. Agboyi study station was positively associated with the main CCA axis (axis 1). The macroinvertebrates which were related to Agboyi station include the sensitive *Aloides trigona, Mytilus edulis,* and *Iphigenia truncate* linked to TSS, BOD, turbidity and nitrate concentrations. However, the sensitive *Tympanotonus fuscatus* were negatively loaded in CCA axis 1, while the tolerant *Capitella capitata* and *Nereis* sp. in CCA axis 2 were associated with TOC, phosphate and sulphate, and linked to the Ogudu and Makoko study stations.

The assessment of water quality in coastal water ecosystems has conventionally been done through the measurement of physicochemical variables [17]. The water quality could reflect the status of pollution or otherwise, of the water body. In recent years, the anthropogenic influences such as urban, industrial and agricultural activities have increased, and these have negative impacts on the water bodies. Table 2 indicates relatively uniform values in the water temperature of the study area. This result agrees with the studies of Nkwoji *et al* [18] and Onyena et al [19], that surface water temperature in the tropics is conservative and could only vary significantly with seasons. The slight variation in the values of water temperature could be linked with the differences in the time of sampling in each station. The mean hydrogen ion index (pH) values across the study stations showed very little or no variation. It ranged between 5.6 and 6.9 during the period of study, indicating slightly acidic water samples. Changes in pH can drastically affect the structure and function of the ecosystem both directly and indirectly, as it could result from increasing concentration of heavy metals in water, through increased leaching from sediments [20].

The study area has a considerably high level of biodegradable wastes, resulting in depleted dissolved oxygen. The observed relative increase in dissolved oxygen during the rainy seasons in the study period could be attributed to increased aeration because of rainfall. Ayoade *et al.* [21] reported that DO concentration at Asejire Lake reached its peak at the height of the rainy season, and Onyema *et al* [22] attributed the presence of high levels of dissolved oxygen to the perturbation of water which was prevalent in the wet season. A higher level of dissolved oxygen recorded could also be linked to floodwater dilution and reduced resident time of the polluted water, as this study was carried out during the wet season (September- October).

A relatively high level of suspended particles could be attributed to the land-based sources of industrial and domestic wastes from drainages that flow into the lagoon. This observation is in agreement with earlier works on the Lagos lagoon [8, 23]. Relatively high TSS could also be attributed to siltation from adjourning drainage systems and dredging activities in some parts of the study area. The values of total dissolved solids which ranged between 18555 mg/L and 3015 mg/L could be considered high. The high values were mostly observed at the Carter Bridge study station and this could be attributed to the fact that the station is heavily impacted by several anthropogenic stressors, ranging from illegal oil bunkering which results in spillage of oils.

The results of high BOD values are similar to those associated with low dissolved oxygen and include physiological stress of aquatic organisms, their suffocation, and death [15]. High BOD values imply an increase in concentration of aerobic microbes, which act on biodegradable wastes and consequently, depletes the ambient dissolved oxygen. The relatively high levels of BOD in the study area is associated with an increased influx of biodegradable wastes introduced from land as a result of high run-offs occasioned by the rains. According to Naveen *et al* [24], the aerobic decomposition of the biodegradable wastes is the primary factor that affects the BOD levels in both wastewater and surface waters. Biochemical oxygen demand showed significant differences ($P < 0.05$) amongst the sampling stations. This variation could be attributed to the presence of the diverse pollutants prevalent at specific sampling stations.

Higher concentrations of Nitrate-Nitrogen were recorded at study stations with high anthropogenic influence. This is in consonance with Nkwoji and Edokpayi [8], and previous works on the Lagos lagoon [25; 26]. This high concentration could be attributed to the prevalent domestic and industrial wastes from drainage channels that flow into the Lagoon through the station. Surface run-off could be a contributing factor to the increasing higher levels of concentration observed as the study progressed. Ajao and Fagade [25], as well as Chukwu and Nwankwo [27] attributed higher levels of PO_4-P and NO_3-N in the wet season to the effect of direct discharges, nutrient enrichment, and surface run-offs prevalent during the season.

Representative samples of the benthic macroinvertebrates of the Lagos lagoon for the period of study are presented in Table 3. The benthic macroinvertebrates assemblage was dominated by the species, *Tympanotonus fuscatus*, belonging to the class Gastropoda (Figure 3). The pollution sensitive nature of this gastropod molluscan species has been documented [12, 25]. On the other hand, the Gastropod *Pachymelania aurita*, a less-sensitive species [26] recorded a very low amount, and at very few stations. This is in consonance with Nkwoji *et al.* [26] who identified the species as being sensitive.

The sedentary nature of the benthic macroinvertebrates makes them very vulnerable to the impacts of the pollution [9, 19]. However, some of the species have some adaptive features, both physiological and morphological, to hypoxia and these have given them some advantages and resulted to their relative abundance, as in the case of *Tympanotonus fuscatus.* The presence of polychaetes: *Capitella capitata* and *Nereis* sp. shown in CCA axis 2 which were correlated with TOC, phosphate and sulphate and observed in stations Ogudu and Makoko is indicative of an organically polluted ecosystem.

Generally, the benthic macroinvertebrates diversity and abundance reported in this study are low compared to earlier works on the lagoon [8, 27, 29, 30], which could largely be due to poor water and sediment quality. These conditions could have a negative impact on habitat suitability for the macroinvertebrates, thereby reducing their numerical abundance. Exposure to high concentrations of contaminants from various human activities can directly disrupt macroinvertebrate assemblages, leading to reduced abundance. According to Edokpayi and Nkwoji [31], and Nkwoji *et al*. [26], most parts of the Lagos lagoon and its adjacent creeks are under stress resulting from both industrial and anthropogenic pollution sources.

4. CONCLUSION

Anthropogenic influence have had significant negative impacts on the water chemistry of the Lagos lagoon, and hence, reduced the diversity and abundance of its benthic macroinvertebrates community. The sedentary nature of this group of organisms is the major reason they are most impacted by these pollutants. A combined system for water quality monitoring that integrates both physicochemical analysis and biological assessment of the resident biota will be more effective for the evaluation of the pollution in coastal waters.

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COMPETING INTERESTS

There are no competing interests, among the authors, with the publishing of this article. All of the authors put their own effort into this study and no grants were given for it.

AUTHORS' CONTRIBUTIONS

Joseph A. Nkwoji: Conceptualization and Supervision; Joy J. Abodunde: Field work; Joseph A. Nkwoji, Joy; J. Abodunde and Amarachi P. Onyena: Writing, review and editing; All authors: Reading and approving the final manuscript.

CONSENT

Not Applicable

ETHICAL APPROVAL

Not Applicable

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