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Impacts of Anthropogenic Stressors on Hydrochemistry, Benthic Macroinvertebrates and Sediment Characteristics of the Lagos Lagoon, Nigeria

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ABSTRACT: The anthropogenic impact on the water, benthic macroinvertebrates and sediment grain size of Lagos lagoon was investigated between July and October, 2019. Ten sampling stations were selected based on their importance as likely sources of different forms of anthropogenic stressor to the lagoon. Water temperatures, pH and salinity were measured *in situ*. Water and benthic samples were collected monthly and analysed using standard methods. Nutrient levels were determined using a spectrophotometer. The hydrochemistry of the stations differed significantly ($p<0.05$) with the exception of temperature and pH. The sediment grains across the study stations consists basically of sand and mud, with sand dominating the grain type. A total of 502 individuals comprising 3 phyla, 4 classes, 10 families and 11 species was recorded. The phylum mollusca which contributed 92% to the total number of individuals was represented by two Classes; Gastropoda and Bivalvia, with the gastropod *Tympanotonus fuscatus* having the highest number of individuals (321). The phylum Annelida represented by one Class, Polychaeta and two Species *Nereis* sp. and *Capitella capitata* contributed 6% to the total number of individuals. The class Crustacea, representing the Phylum Arthropoda was the least sampled (7 individuals) constituting about 1.4% of the total population Result showed that different pollution sources have negatively impacted the water chemistry of the lagoon and reduced the diversity and abundance of its benthic macroinvertebrates community. The sedentary nature of this group of benthic fauna could be the major reason why they are most impacted.

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Lagoons serve as ecotones between freshwater, marine and terrestrial biotopes (Saki-Yao *et al*., 2017) and hence, are heavily impacted (Kennish, 2002). Heightened anthropogenic activities increase the influx of stressors into the lagoons (Christensen *et al.*, 2006, Halpern *et al.* 2007, Crain *et al.*, 2008) leading to declines in biodiversity and significant distortion of the ecosystems function (Bulling et al., 2010). Macroinvertebrates are impacted by pollutants primarily as a result of changes in primary production and in the chemistry of water column and sediment. These changes potentially lead to reduced diversity and abundance, shifts in community composition, physiological changes and mass mortality. Several authors have published quite a number of research articles on the Lagos lagoon due to its inexhaustible importance and location. Ajao and Fagade, (1991) studied of the sediments and communities in Lagos Lagoon. The study focused more on the role of sediment composition and type in the structure of the benthic communities. Nkwoji *et al.* (2010) worked on the benthic macroinvertebrates Bioindicators at the Lagos lagoon and emphasized on the importance of pollution sensitive macroinvertebrates on the health of the coastal lagoon. Edokpayi and Nkwoji (2007) also recorded a relatively high number of polychaete worms at the sewage dump site of the Lagos lagoon. Olapoju and Edokpayi (2018) carried out a study on the water quality and sediment quality of the Lagos Lagoon. The aim of this research is to determine the impacts of anthropogenic stressors on hydrochemistry, benthic macroinvertebrates and sediment characteristics of the Lagos Lagoon.

MATERIALS AND METHODS

Study area: The Lagos lagoon (Fig. 1) located between longitudes 3º 23' and 3° 40' E, and latitudes 6º 26' and 6º 38' N, is the largest lagoon system in the West African coast, covering 208 km^2. It has a total surface area of approximately 6,354.7km^2**.** Ten sampling stations were selected for this study based on their importance as sources of different forms of anthropogenic stressor to the Lagos lagoon. The Global Positioning System (GPS) was used to ascertain coordinates of the sampling points.

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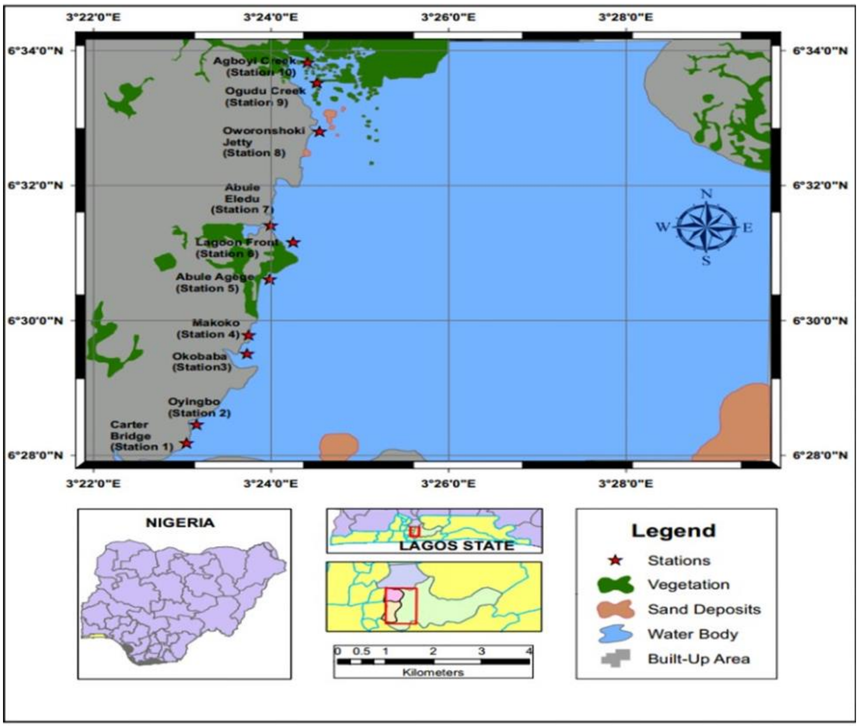

Fig 1: Map of the Lagos Lagoon Showing Sampling Stations

Collection and Analysis of Water samples: Water temperatures, pH and salinity were measured *in situ* at every sampling station with mercury in glass thermometer, Hach Picket pH Meter and Horiba water checker (Model U-10) respectively. Subsurface water samples were collected with 1dm^3 Hydrobios water sampler and stored in a pre-labelled plastic containers following the methods described by APHA (2002). The dissolved oxygen (DO) and biological oxygen demand (BOD) of the water samples were determined using Winkler's technique. The total suspended solids were determined using gravimetric methods while the total dissolved solids and conductivity were measured using a HACH conductivity/Salinity/TDS meter (Model, CO150), while nutrient levels were determined and using a spectrophotometer.

Collection and Analysis of Benthic Samples: Benthic samples were collected with the use of 0.1 m^2 Van-Veen grab. Part of the benthic samples were kept in a polyethene bag and preserved for further analysis on the sediment grain size. The remaining benthic samples were sieved through 0.5 mm mesh size sieve. The materials retained on the sieve were stored in labelled plastic container and preserved in 10% formalin for further analysis in the laboratory. Sorting of the benthic samples was done with the aid of a hand-held magnifying lens to obtain the clean samples of the benthic macro fauna.

Statistical Analysis: The statistical package for social sciences (SPSS) was used to calculate the Analysis of Variance (ANOVA) for all the physicochemical parameters while Microsoft Excel was employed for the descriptive statistics of the data. Data processing of the benthic macro invertebrates involved the calculation of biological indices such as Margalef's index for Species richness, Shannon-Wiener and Simpson's indices for species diversity, and the Equitability index for evenness of the community (Ogbeibu, 2005). Margalef's Species Richness Index (d): The Species richness index (d) was calculated using the Margalef's index and used to evaluate the community structure. The equation below was applied and results were recorded to two decimal places.

$$d = \frac{S-1}{lnN}$$

Where: d = Species richness index; S = Number of species in a population; N = Total number of individuals in S species.

Shannon and Wiener Diversity Index (H): Shannon and Weiner diversity index (H) is given by the equation:

$$H' = \sum_{i=1}^{S} (p_i)(\ln p_i)$$

Where: H' = Diversity Index; i = Counts denoting the ith species ranging from i–n; Pi = Proportion that the ith species represents in terms of numbers of individuals with respect to the total number of individuals in the sampling space as whole.

Species Equitability (j) or Evenness Index: Species evenness or equitability was used to calculate how evenly the species are distributed in a community. It was determined by the equation:

$$J = \frac{Hs}{log2S}$$

Where: J = Equitability index; Hs = Shannon and Weiner index; S = Number of species in a population

Simpson's Dominance Index (Ogbeibu, 2005)

$$C = \sum [\frac{ni}{N}]^2$$

Where: n = the total number of organisms of a particular species; N = the total number of organisms of all species.

RESULTS AND DISCUSSIONS

The low water temperatures across the months and sample stations may be due to the effect of high insulation and the dilution effects of flood waters. The slight variation in the values of water temperature (27.25- 27.88 ºC) may be linked to regular tidal motions, which ensured the complete mixing of the water. There was no significant difference in the water temperature ($p>0.05$) across the study stations in consonance with previous works which confirms that temperature is a conservative factor in most tropical waters. The values are within desirable limits for aquatic normal life. The mean hydrogen ion index (pH) values across the study stations showed very little variations. It ranged between 6.25 and 6.73 during the period of study, hence slightly acidic. There was no significant ($P<0.05$) difference in the pH values at the study stations as this was in harmony with earlier works of Nkwoji (2017). The wide salinity variation ($p<0.05$) recorded across the study stations reflects tidal influences on the salinity of the study stations on the premise of their closeness to the sea and introduction of freshwater through run-offs and precipitation causing a dilution effect on the Lagoon. The highest salinity value (14.43%) recorded at Carter Bridge could be as a result of their proximity to the Lagos Harbour. Analysis of Variance showed significant difference ($P<0.05$) in Dissolved Oxygen among the study stations. This observed increase in dissolved oxygen during the period of study could be as a result of increased aeration because of rainfall (Adeyemo *et al.*, 2008). Ayoade *et al.* (2006) reported that D.O concentration at Asejire Lake reached its peak at the height of rainy season. Onyema *et al* (2009) had attributed high level of dissolved oxygen to the perturbation of water and this was prevalent in the wet season. The highest TSS value recorded in Ogudu (92.95mg/L) could be attributed to the land-based sources of industrial and domestic wastes from drainages that flow into the lagoon through the adjourning creeks. This observation is in harmony with earlier works on the Lagos lagoon (Okoye *et al* 2010; Nkwoji and Edokpayi, 2013). This study recorded relatively high values of total dissolved solids across the stations. The TDS values ranged between 3830mg/L and 18,010mg/L. High values were observed in Carter Bridge (Station 1), Oyingbo (Station 2) and Okobaba (Station 3). Carter Bridge recorded the highest value of TDS. This could be as a result of wood wastes washed down this this study station. These stations are heavily impacted by several anthropogenic stressors ranging from illegal oil bunkering resulting in spillage of oils and washing of cement bags at Carter Bridge to wood-logging and wood exudates at Okobaba. These activities would have impacted on the water quality of the study area. The Analysis of the sediment of the study area revealed that the sediment grains consists basically of sand and mud. The mean spatial variation in sediment grain size is presented in Figure 2 and indicates the sediment from all stations was dominated by sand, except for Carter bridge (Station 1), Abule Eledu (Station 7) and Ogudu (Station 9) sampling stations. Carter Bridge (Station 1) recorded an equal percentage of mud and sand in its sediment composition during the period of study. The study stations that had higher percentage of sediment composition as mud are Ogudu (Station 9) and Abule Eledu (Station 7). These stations have intense dredging and sediment mining activities going on, which has made them relatively deeper than other stations. The subsequent siltation would lead to accumulation of mud. A total of 502 individuals comprising 3 phyla, 4 Classes, 10 Families and 11 Species was recorded. The Phylum Mollusca was represented by two Classes; Gastropoda and Bivalvia. Gastropoda, represented by 4 Families and 5 Species recorded the highest number of individuals (374) accounting for 74.5% of the total number of individuals sampled for the period of study while the Class Crustacea, representing the Phylum Arthropoda were the least sampled (7 individuals) constituting about 1.4% of the total population. Only one species *Clibanarius africanus* was recorded from this phylum throughout the period of study.

Table 1. Summary of the physico-chemical parameters during the period of study

PARAMETERS	Water Temp. ^{O}C	pH @25 ^{O}C	Salinity (‰)	DO (mg/L)	TSS (mg/L)	TDS (mg/L)	BOD (mg/L)	TOC (mg/L)	Turb. (mg/L)	Nitrates (mg/L)	Phosph. (mg/L)	Sulphates (mg/L)
STATION 1 Carter Bridge												
Min	26.50	6.60	9.60	4.00	31.50	17510.00	2.80	4.05	29.00	2.10	0.52	420.00
Max	28.50	6.70	18.90	4.90	43.50	18510.00	5.90	4.56	39.70	2.50	0.75	452.00
Mean ±SD	27.25± 0.65	6.65±0.06	14.43± 5.01	4.45± 0.47	37.5± 5.89	18010.00± 577.35	3.88± 1.44	4.30± 0.29	34.53± 5.93	2.28± 0.17	0.64± 0.12	433.50± 13.40
STATION 2 Onyingbo												
Min.	27.00	6.50	9.20	3.70	47.50	15221.00	6.50	4.80	26.20	2.80	0.55	320.00
Max.	28.50	6.60	16.20	4.78	55.50	18221.00	10.10	4.98	37.20	3.70	0.75	360.00
Mean±SD	27.75± 0.65	6.53±0.50	11.25± 3.33	4.45± 0.50	51.00± 3.31	16096.00± 1436.14	7.88± 1.64	4.89± 0.75	31.90± 6.01	3.23± 0.38	0.63± 0.10	334.00± 17.81
STATION 3 Okobaba												
Min	27.00	6.60	8.30	4.10	70.20	11230.00	4.98	5.15	28.60	2.40	0.70	130.00
Max	28.00	6.80	11.30	5.10	85.20	12230.00	8.98	8.15	40.60	3.80	0.98	160.00
Mean ±SD	27.50± 0.41	6.73±0.96	10.05± 1.50	4.58± 0.55	75.00± 6.95	11555.00± 471.70	6.73± 2.06	6.65± 1.73	34.10± 5.51	3.05± 0.60	0.81± 0.12	145.00± 12.91
STATION 4 Makoko												
Min	26.50	6.50	8.00	4.10	60.50	8720.00	5.00	2.92	27.20	3.00	1.65	210.00
Max	28.50	6.70	9.00	4.90	68.50	8920.00	10.22	7.94	38.20	3.80	1.79	310.00
Mean ±SD	27.50± 0.91	6.65±0.10	8.30± 0.48	4.53± 0.35	64.30± 3.50	8820.00± 81.65	7.36± 2.76	5.44± 2.89	32.70± 5.80	3.38± 0.35	1.73± 0.07	260.00± 52.28
STATION 5 Abule Eledu												
Min	27.00	6.50	5.00	5.10	10.30	4750.00	2.60	2.00	30.30	4.30	0.30	222.00
Max	28.50	6.60	5.10	5.60	21.30	4950.00	5.80	3.10	39.30	4.90	0.52	282.00
Mean ±SD	27.75± 0.65	6.55±0.06	5.03± 0.50	5.38± 0.26	15.75± 5.75	4825.00± 95.74	4.65± 1.46	2.53± 0.61	35.23± 4.61	4.55± 0.30	0.39± 0.10	255.00± 27.54
STATION 6 Lagoon Front												
Min	26.5	6.50	5.10	5.00	22.10	4490.00	3.70	2.00	31.50	4.70	0.53	202.00
Max	28.5	6.60	6.10	5.20	42.30	4790.00	5.93	3.35	38.50	5.80	0.86	282.00
Mean ±SD	27.75± 0.87	6.58±0.05	5.38± 0.49	5.08± 0.98	31.75± 11.06	4590.00± 141.42	4.81± 1.17	2.89± 0.63	34.75± 2.99	5.23± 0.45	0.69± 0.17	245.00± 35.00
STATION 7 Abule Agege												
Min	26.50	6.30	3.80	5.20	24.80	4122.00	7.35	3.10	35.90	7.00	0.51	225.00
Max	29.00	6.80	5.80	6.30	45.80	4822.00	10.75	4.12	48.90	8.70	0.69	275.00
Mean ±SD	27.88± 1.03	6.48±0.22	4.55± 0.96	5.68± 0.52	35.40± 11.67	4314.00± 339.94	8.65± 1.52	3.63± 0.56	42.68± 6.26	8.03± 0.72	0.61± 0.08	252.00± 25.74
STATION 8 Oworonshoki												
Min	26.50	6.40	3.00	5.10	40.40	4589.00	8.00	3.50	46.80	6.40	0.72	245.00
Max	28.00	6.70	4.80	6.10	61.40	5589.00	19.00	4.98	57.80	8.00	0.85	305.00

Mean ±SD	27.6± 0.75	6.53±0.13	3.70± 0.81	5.58± 0.55	50.85± 11.51	4889.00± 476.10	11.50± 5.07	4.32± 0.74	52.10± 5.61	7.28± 0.72	0.78± 0.06	277.00± 31.45
STATION 9 Ogudu												
Min	26.00	5.60	1.40	4.20	86.70	3030.00	15.23	6.34	58.80	9.00	1.60	303.00
Max	28.50	6.60	3.10	5.60	98.70	6030.00	35.25	8.72	63.80	9.90	1.85	365.00
Mean ±SD	27.50± 1.08	6.25±0.45	2.03± 0.78	4.75± 0.60	92.95± 6.13	3830.00± 1469.69	24.49± 9.37	7.48± 1.05	61.28± 2.36	9.40± 0.39	1.74± 0.12	333.25± 31.29
STATION 10 Agboyi												
Min	27.00	5.70	1.00	4.00	85.20	3899.00	14.50	6.50	59.10	7.80	1.50	317.00
Max	28.50	6.70	2.70	4.80	89.20	4999.00	34.65	7.95	66.50	9.50	1.72	398.00
Mean ±SD	27.68± 0.70	6.30±0.43	1.75± 0.79	4.30± 0.35	87.15± 1.64	4424.00± 607.59	22.59± 9.50	7.11± 0.73	62.53± 3.78	8.83± 0.72	1.57± 0.10	353.50± 40.70

Table 2. Numerical abundance of individuals collected for the period of study (July-October, 2019)

TAXA	JULY	AUGUST	SEPTEMBER	OCTOBER	TOTAL
Pachymelania aurita	2	21	0	0	23
Tympanotonus fuscatus	131	36	83	71	321
Tympanotonus fuscatus var radula	0	3	0	0	3
Neritina glabrata	2	4	10	10	26
Thais sp.	1	0	0	0	1
Aloides trigona	11	23	14	13	61
Crassostrea gazar	2	5	9	5	21
Iphigenia truncate	0	0	3	4	7
Clibanarius africanus	7	0	0	0	7
Nereis sp.	3	1	3	8	15
Capitella capitata	9	3	2	3	17
	168	96	124	114	502

Table 3. Spatial Variation in Ecological indices of the sampling stations for the study period

STATIONS	Carter bridge	Onyingbo	Okobaba	Makoko	Abule Agege	Lagoon Front	Abule Eledu	Oworonshoki	Ogudu	Agboyi
Taxa_S	3.00	2.00	5.00	3.00	5.00	7.00	3.00	2.00	3.00	3.00
Individuals	17.00	10.00	56.00	18.00	111.00	174.00	51.00	34.00	16.00	15.00
Dominance_D	0.35	0.52	0.59	0.35	0.60	0.43	0.62	0.56	0.45	0.50
Simpson_1-D	0.65	0.48	0.41	0.65	0.40	0.57	0.38	0.44	0.55	0.50
Shannon_H	1.07	0.67	0.81	1.07	0.84	1.21	0.65	0.63	0.88	0.86
Evenness_e^H/S	0.98	0.98	0.45	0.97	0.46	0.48	0.64	0.94	0.80	0.79
Menhinick	0.73	0.63	0.67	0.71	0.47	0.53	0.42	0.34	0.75	0.77
Margalef	0.71	0.43	0.99	0.69	0.85	1.16	0.51	0.28	0.72	0.74
Equitability_J	0.98	0.97	0.50	0.97	0.52	0.62	0.59	0.91	0.80	0.78

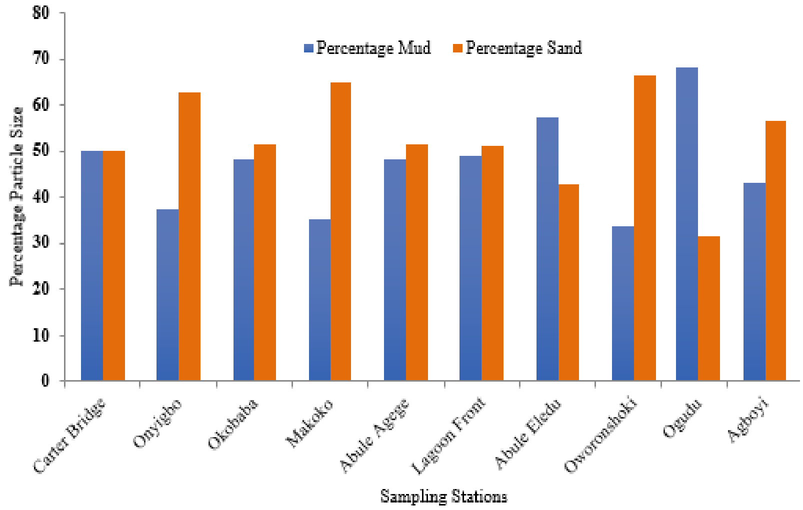

Fig 2. Mean Percentage Composition of sediment particle size during the period of study

Of the ten stations only Station 6 (Lagoon front) recorded *clibanarius africanus*. The species were completely absent in all other 9 study stations throughout the sampling period. This could be as a result of the shallowness of station 6 and availability of gastropod shells in the station. The phylum Annelida was represented by one Class, the Polychaeta, and two Species *Nerieis* sp. and *Capitella capitata.* This class constitute 6% (32) individuals of the total number of individuals collected during the period of study. *Tympanotonus fuscatus* Var *radula*, a species of the Genus *Tympanotonus*, was also recorded in Station 6 (Lagoon Front) and was also completely absent in all other 9 stations during the study period. Station 6 (Lagoon Front) recorded the highest number of individuals (174) accounting for 34.7% of the total number of individuals collected during the study period. Station 2 had the least number of individuals (10) accounting for only 1.99% of the total number of individuals collected during the period of study. The species *Tympanotonus fuscatus* recorded the highest number of individuals (Table 2) for the study period accounting for 64.5% of the individuals collected while the species *Tympanotonus fuscatus* var *radula* and *Iphigenia truncate* recorded the lowest number of individuals (3 individuals each) accounting for 0.59% each of the individuals collected during the study period. The highest number of individuals (168) was collected in July 2019 while the lowest number of individuals (96) were collected in the month of August. This could be as a result of the stability of the Lagoon flow and higher transparency due to low rainfall (Nkwoji *et al.*, 2019).

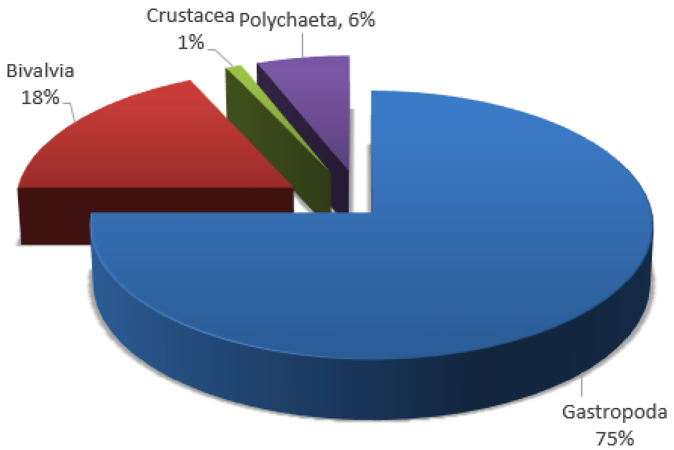

Fig 3. Percentage Class contribution in the total benthic macroinvertebrates for the period of study

Studies on the pollution tolerant nature of *Tympanotonus fuscatus* have been documented. (Kouadio *et al*, 2008; Kouadio *et al*, 2011, Nkwoji *et al*, 2016). On the other hand, the gastropod *Pachymelania aurita* , a less tolerant species (Nkwoji *et al*, 2010) was only recorded in 2 (Lagoon Front, and Abule Eledu) out of the 10 sampling stations. The absence of this species in all other stations and its relatively high abundance in Station 6 and 7 (relatively unpolluted sites) is an indication to its sensitivity to pollution in consonance with the previous observation.. Nkwoji *et al* (2010, 2016) identified the polychaetes as tolerant to pollution of the coastal waters. Station 6 (Lagoon Front) recorded the highest number of individuals (174), and this constituted 34.7% of all individuals sampled during the study. The station also recorded the highest fauna diversity and richness indices indicating the relatively unperturbed nature of the station. This could be attributed to the fact that the station experience less anthropogenic stress compared to the others. The species *Tympanotonus fuscatus* Var *radula* was collected in Station 6 (Lagoon Front). This is in consonance with Rosemary *et al* (2008) who stated that the species inhabit the mudflats of the mangrove swamps at the edges of the Lagos Lagoon. The species occurs naturally in waters with very low salinities between June and November and have a large seasonal fluctuation (Rosemary *et al*., 2008).

Conclusion: The different pollution sources have impacted negatively on the water chemistry and sediment composition of the lagoon and hence, reduced the diversity and abundance of its benthic macroinvertebrates community. The sedentary nature of this group of benthic fauna is the major reason why they are most impacted. A combined system for water quality monitoring that integrates both physicochemical analysis and biological assessment would be more effective for the evaluation of environmental degradation..

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