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Pertubation of Road Construction and Inorganic Sedimentation on the Macroinvetebrate Fauna in the Midstream Segment of Qua Iboe River, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The massive road construction projects in the drainage basin of Qua Iboe River (Nigeria) seriously affect the environment with elevated levels of some physico-chemical variables in perturbed segments of the river. The road construction resulted in elevated levels of the three pollution parameters (turbidity, bed load and suspended load which also had significant effect on the

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macroinvertebrate species richness and diversity in the perturbed zone, Biotic scores and biomass of macroinvertebrates were lower at perturbed than unperturbed zones. The three zones of the midstream segment of the stream were heterotrophic (P/R < 1.0) due to high turbidity, high silt load and suspended organic matter occasioned by the massive road development and maintenance across the drainage basin in the study area.

Keywords: Road construction; inorganic sedimentation; macroinvetebrate fauna; midstream and Qua Iboe River.

1. INTRODUCTION

The effects of road development are known to result in the inflow of suspended organic matter, silt, organic debris and inorganic sedimentation into streams and rivers [1]. It also results in creating and accentuating storm water runoff which may result in flash floods with the attendant consequences which include the dislodgement of macroinvertebrates benthic macrofauna and other aquatic biota [2,3,4].

The construction, maintenance and rehabilitation of roads are known to also cause widespread environmental degradation [5,6]. There is a growing concern and awareness that road development has major environmental impacts including damage to sensitive ecosystems, loss of breeding and nursery grounds, silting of waterways and outright degradation of aquatic ecosystems [3]. The watershed and stream ecosystems within the road corridor are particularly impacted by the road construction activities including stream biotic and abiotic conditions [2,3]. The pertubations reported include those resulting from sedimentation, habitat degradation, inputs of pollutants from construction materials among others [7]. There is paucity of information on the effect of road development on the water quality and macroinvertebrate fauna in the numerous rivers and streams in Nigeria following massive road development in recent years. This study was conceived to address this lacuna of information.

2. MATERIALS AND METHODS

2.1 Study Area

The Qua Iboe River ($7^0 20^1$ – 8^0 20^1 W and 4^0 30 ^{1}- 5^0 30^1N) is the major hydrographic feature that drains the landscape of Akwa Ibom State, east of the Niger Delta (Nigeria). It drains a catchment area of about 7092 km^2 and empties into the Atlantic Ocean through the Bight of Bonny without any delta formation. The river bed is exploited almost along its length for various purposes including sand and gravel extraction. Three zones were selected along the midstream reaches of the river where massive road development has been going on for the past ten years. The zones include Ikot Ekpene (Zone 1), Ibagwa (Zone 2) and Etim Ekpo (Zone 3). The study was carried out for two years (January 2019 – December, 2020) and samples were collected bimonthly throughout the study period. At each of the three study zones two areas were selected namely, an unperturbed area with no human activity (control) and a highly perturbed area with intense human activity including massive road development, sand and gravel extraction, among others. Each zone comprised of three sites which were 300m apart and composite samples were collected and then pooled together.

The pollution parameters –turbidity, bed load and suspended load were determined using in-situ Hatch kit for turbidity and suspended load while bed load was determined using methods described in [8].

2.2 Sediments Particle Size

Sediment samples were collected using corer at shallow portions and Erkman grab at the deeper portions. Sediment particle size was analysed by sieving the sediment samples through sieves of various mesh sizes dried at 105^{0}C for 24h and separated using the Went worth scale. The dry weight of each fraction was noted and the median particle diameter (Md Ø) was evaluated.

Total Suspended Solids (TSS) and Total Dissolved Solids (TDS) were determined by the filtration method. The bed load was regarded as the sieve fraction ≤ 2 m in diameter which can be moved by currents within the boundary layer during normal stream discharge [8]. Water temperature, Dissolved Oxygen (DO), conductivity and pH were measured in situ while other determinations were made following methods described in APHA [9]. Composite and triplicate samples were taken at 300m apart at several locations which constitute a zone.

2.3 Macroinvertebrate Composition

The macroinvertebrate composition was evaluated to establish the pertubations of the road construction on the environment including species density and diversity macroinvertebrate species density and diversity. The difference in density at the perturbed zone was compared with the unperturbed zone (which served as Control). Invertebrates in the littoral zone, riffles, and shallow pools were sampled with a hand net and a rectangular 0.55 mm mesh Griffin net using the method of Hynes [10] and corer while benthic invertebrates in the deeper portions were sampled with Erkman grab. Invertebrates at each site were taken within a marked quadrat. ($5m^2$) Samples collected were sieved to remove debris and sorted to remove invertebrates. Macroinvertebrates were initially preserved in 5% formalin and later transferred to isopropyl alcohol. They were later identified to a variety of taxonomic levels, after which they were oven – dried at 70 ^{0}C for 5h and weighed. Average density and biomass per zone were obtained.

2.4 Production Respiration Ratio

The production – respiration ratio (P/R) was determined at 6 h intervals and the P/R ratio calculated using the formula given by Pavletic et al. [11] as follows:

$$\frac{P}{R} = \frac{(D_2 - D_1 + (N_1 - N_2) + ((\Delta d - \Delta n)}{N_1 - N_2 - \Delta n} \quad (1)$$

Where:

D_1 – average O_2 measured in the morning at the onset of photosynthetic activity,

D_2 – average O_2 measured at the end of photosynthetic activity,

N_1 – average O_2 concentration at the beginning of the dark period,

N_2 – average O_2 concentration at the end of the dark period,

Δ d= d_2 – d_1, where: Δ d = the amount of O_2 diffused from water into the atmosphere by day; d_2– d_1 = the difference between the value of O_2 at the end (d_2) and at the beginning (d_1) of the light phase.

Δ n= n_1 – n_2, where: Δ n = the amount of O_2 diffused into the water by night, n_1- n_2, the difference between the value of O_2 at the beginning (n_1) and the end (n_2) of the dark phase.

2.5 Biotic Index

The analysis of the biotic index (BI) was carried out using the system of Tuffery and Verneaux [12], which is a modification of the Trent Biotic Index of Woodiwiss [13]. The macroinvertebrates were sorted into groups whose size depended on the ease of their identification. The zones were classified on the basis of the presence or absence of key invertebrate groups and the diversity of the fauna. On the basis of this method, clean water zones (unperturbed zone) score an index of 10 and the Figure decreases with increase in pollution level.

2.6 Statistical Analysis

The differences in mean values of the pollution parameters together with differences in seasonal values were examined using paired t-test and statistical Software package (Appleworks). The index of species diversity (d) was calculated to characterize the integrated richness and evenness of distribution of the macroinvertebrates using Shannon's diversity formula:

$$d = -\sum (ni / n) \log_2 (ni / n_2) \quad (2)$$

Where:

d = diversity per individual,

ni = number of individuals of each species,

n = total number of individuals of all species.

The dissimilarity index (DI) was also calculated using the formula given by Levandowsky [14] as follows:

$$\mathrm{D1} = 1 - S\sum (\min x_{1i}.\ x_{2i}) / S\sum (\max x_{1i}, x_{2i}) \quad (3)$$

i=1

Where:

x_{1i}, x_{2i} = values of relative abundance of ith taxon in two respect communities (1 and 2),

S = total number of species.

A DI value of 0 indicates identical communities while a value of 1 indicates communities which are totally different from each other.

Differences in mean relative density and biomass of macroinvertebrates between groups and zones were examined using statistical software package (Appleworks). Correlation analysis was performed to investigate the relationship between the density of invertebrate groups and the pollution parameters.

3. RESULTS AND DISCUSSION

3.1 Water Quality / Sediment Characteristics

The water quality and Sediment characteristics varied between the different zones with the bottom in Zone I dominated by coarse sand (49. 5%) fine sand (32.7%) while silt / mud constituted 17.80%. Zone 2 was dominated by coarse sand (44.70%) and fine sand (29.80%); Zone 3 was dominated by fine sand (43.60%) and coarse sand (26.80%) while silt/mud constituted 29.60%. Water quality at Zone I was characterized by neutral water, low ionic content, and moderate oxygenation (4.60 ± 0.5mg dm^{-3}). The pollution parameters (TSS, TDS, BOD_5) were lowest at the unperturbed than the perturbed zones.

Values of some of the parameters including TSS, TDS and DO were higher in the perturbed zones. Conductivity which is an index of ionic richness was different significantly between the unperturbed and perturbed zone and also exhibited pronounced temporal variations.

3.2 Macroinvertebrate Species

A total of twenty five species of macroinvertebrates in 8 major taxa were collected including Hemiptera, Coleoptera, Odonata, Diptera, Ephemeroptera, Plecoptera, Crustacea, and Annelida (Table 2). The number of taxa collected and the diversity differed among the sampling times and seasons. Species richness was generally higher in the unperturbed than in the perturbed zones. However, density was higher in the perturbed zones which recorded the preponderance of pollution – tolerant species of *Tipulidae, Chironomidae, Tubificidae,* and other taxa. One of the dominant invertebrate order was Diptera with three species and most abundant in Zones 2 and 3 (Table 2).

Among the Dipterans, *Chironomus plumosus* was the most widespread, constituting 39.65% of all invertebrates with 159 indiv. m^{-2} in the perturbed zone and 15 indiv m^{-2}in the unperturbed zone Density of Diptera was significantly higher in the perturbed zone (F=8.50, df =18, ($P < 0.05$) than in other ones. The Plecoptera, with 2 species, had a mean density of 3 indiv. m^{-2} *(*Table 2*).* Odonata had 3 species recorded in the three zones. The annelids (2 species) were dominated by *Tubifex tubifex,* recorded only in the perturbed zones with mean density of 129 indiv. m^{-2}. Hemiptera (5 species) had the highest density at the unperturbed zone 1.

Ephemeroptera (5 species) were widespread in the three zones with pollution –tolerant species of Baetidae recorded at zone 2. Coleoptera (4 species) occurred predominantly in Zones 2 and 3. The only crustacean, *Sudanonautes africanus,* occurred in Zone 1 only.

The index of species diversity was lowest in the perturbed and highest in the unperturbed zone. However, species diversity for Diptera was highest in the perturbed zone because of the proliferation of the midge larvae (chironomidae). The diversity indices for Ephemeroptera and Hemiptera were higher in the unperturbed than perturbed zone. Seasonal trends in taxa distribution at the 3 zones showed a remarkably higher density during the dry season. The biomass (dry weight) differed significantly between seasons, sampling times, and zones. There was difference between perturbed and unperturbed zones in species diversity density and biomass but generally not significant.

The mean values of the Dissimilarity Index (DI) between Zones 1 and 2 indicated that the communities were completely different (Table 3). DI values between Zones 1 and 3 indicated that the communities were moderately similar, while the values between zones 2 and 3 where the lowest, indicating almost identical communities.

3.3 Production Respiration Ratio

The P/R ratio for the unperturbed was zone 0.83 ± 0.23 during low discharge and 0.58 ± 0.12 during a high discharge, depicting heterotrophic conditions ($P/R < 1$). The three zones were heterotrophic ($P/R < 1.0$). During both seasons, due to the high silt and total suspended organic matter especially at the perturbed zones (Table 1).

Table 1. Mean values of physico-chemical parameters in the three zones in the midstream segment of Qua Iboe River Nigeria

Parameters	Zone 1		Zone 2		Zone 3	
	Unperturbed	**Perturbed**	**Unperturbed**	**Perturbed**	**Unperturbed**	**Perturbed**
Water temperature (°C)	26.70±1.29	26.80±0.80	27.20±1.10	26.70±0.73	27.1±0.28	26.7±0.70
Depth (m)	1.85±0.65	1.80±0.80	3.24±0.35	3.30±060	3.5±0.96	3.60±0.54
Turbidity (cm)	Clear water	Clear water	30.40±1.20	35.20±1.55	32.50±1.36	36.80 ±1.85
Current velocity (cm sec^{-1})	39.40±2.10	41.35±2.20	30.56±1.50	39.20±1.00	43.10±2.05	40.20±0.56
pH	6.8±0.17	6.60±0.20	6.70±0.13	6.58±0.18	6.80±0.14	6.50±0.4
Conductivity (µS cm-1)	22.57±3.47	30.43±2.68	65.08±5.20	70.20±3.40	71.22±4.49	80.69±4.20
Dissolved Oxygen (DO) (mg dm-3)	4.60±0.5	3.20±0.75	4.85±0.50	2.80±0.75	3.50±0.17	2.56±0.38
Total suspended solids (TSS) (mg dm-3)	82.68±6.68	129.80±8.60	228.49±18.20	256.94±20.30	220.60±5.60	283.40±12.90
Total dissolved solids (TDS) (mg dm-3)	8.68±1.33	10.68±3.20	15.46±1.47	21.69±2.85	20.90±0.90	32.68±3.80
Biochemical oxygen Demand(BOD5) (mg dm-3)	2.64±0.33	5.20±1.20	3.70±0.50	6.48±1.36	3.20±0.50	8.25±2.10
Production – Respiration	Heterotrophic	Heterotrophic	Heterotrophic	Heterotrophic	Heterotrophic	Heterotrophic
Heterotrophic (P/R) ratio	P/R<1.0	P/R<1.0	P/R<1.0	P/R<1.0	P/R<1.0	P/R<1.0
P/R value	0.73	0.69	0.72	0.68	0.88	0.72

Table 2. Diversity, standing crop, and biomass of macroinvertebrate taxa in the midstream segment of Qua Iboe River Nigeria

Invertebrate Group/Parameter	Zone 1		Zone 2		Zone 3	
	Unperturbed	Perturbed	Unperturbed	Perturbed	Unperturbed	Perturbed
Hemiptera						
Species richness	4	3	5	4	5	3
Diversity (d)	2.60	2.56	2.84	1.35	2.89	1.80
Density (indiv. m^{-2})	7	3	4	2	4	2
Dry weight (g m^{-2})	0.65	0.39	0.43	0.20	0.52	0.27
Coleoptera						
Species richness	4	2	4	3	3	3
Diversity (d)	2.68	1.86	2.70	1.93	2.57	1.25
Density (indiv. m^{-2})	4	3	4	2	3	3
Dry weight (g m^{-2})	0.74	0.38	0.94	0.19	0.28	0.25
Odonata						
Species richness	3	2	2	-	2	1
Diversity (d)	2.43	1.89	1.69	2.20	1.73	0.68
Density (indiv. m^{-2})	3	2	3	2	3	3
Dry weight (g m^{-2})	0.38	0.18	0.22	0.10	0.14	0.15
Annelida						
Species richness	-	2	-	2	-	2
Diversity (d)	-	0.88	-	1.63	-	1.83
Density (indiv. m^{-2})	-	19	-	17	-	18
Dry weight (g m^{-2})	-	0.82	-	0.62	-	0.87
Plecoptera						
Species richness	2	1	2	2	2	1
Diversity (d)	1.59	0.73	1.65	1.74	1.69	0.86
Density (indiv. m^{-2})	3	2	1	2	3	2
Dry weight (g m^{-2})	0.58	0.32	0.11	0.26	0.29	0.18
Ephemeroptera						
Species richness	4	3	5	4	5	3
Diversity (d)	2.40	2.20	3.60	2.50	3.50	2.94
Density (indiv. m^{-2})	4	3	4	2	3	3
Dry weight (g m^{-2})	0.85	0.29	0.93	0.18	0.25	0.28

Invertebrate Group/Parameter	Zone 1		Zone 2		Zone 3	
	Unperturbed	**Perturbed**	**Unperturbed**	**Perturbed**	**Unperturbed**	**Perturbed**
Diptera						
Species richness	2	3	3	3	2	3
Diversity (d)	1.20	2.26	0.73	3.26	1.18	3.76
Density (indiv. m^{-2})	11	34	18	22	15	32
Dry weight (g m^{-2})	0.10	0.18	0.30	0.82	0.15	0.93
Crustacea						
Species richness	1	-	-	-	-	-
Diversity (d)	-	-	-	-	-	-
Density (indiv. m^{-2})	2	-	-	-	-	-
Dry weight (g m^{-2})	-	-	-	-	-	-
Dry weight	0.10	-	-	-	-	-

Table 3. Dissimilarity index (DI) of invertebrate communities between pairs of zones

Season / stream habitat	ZONES		
	1 and 2	1 and 3	2 and 3
Dry season (low discharge)	0.74	0.59	0.45
Wet season (low discharge)	0.68	0.63	0.23
Riffle	0.84	0.47	0.39
Pool	0.69	0.39	0.25
Littoral zone	0.73	0.48	0.28
Benthos	0.84	0.56	0.23
Annual mean index per pair of zones	0.75	0.52	0.32

Table 4. Correlation coefficients between dependent variable (community parameters) and some water quality (independent) variables

Water quality	Species Diversity	Species Richness	Biomass DW (g m^{-2})	Density (indiv. m^{-2})
TSS	-0.7846***	-0.5226*	-0.6224	-0.7229**
Bed load	-0.8529***	-0.6273*	-0.5859**	0.6245*
Current Velocity	0.0725	0.0224	0.3215	0.1765
Turbidity	-0.9324***	-0.5228*	0.1223	0.8246***
TDS	0.4250	0.2227	0.0733	0.5234

*DW – dry weight; * - ($P < 0.05$); ** $P < 0.01$; *** $P < 0.001$*

3.4 Relationship between Biological Variables and Water Quality

The correlation between species diversity and TSS, bed load (bottom particulate deposits), and turbidity was significantly negative (Table 4). A significant negative relationship also existed between species richness and bed load, and also between biomass, TSS, and bottom deposits. Invertebrate density also correlated significantly with TSS, bottom deposits, and turbidity (Table 4).

The mean biotic index (BI) score in the unperturbed zone was 8.9 which is an indication of good water quality. Mean Biotic Index score of 3.50, for the perturbed zone indicated a highly stressed or polluted environment.

3.5 Discussion

The physico-chemical parameters exhibited remarkable variation in response to road construction and inorganic sedimentation with pronounced seasonal variations caused by hydrometeorological variables [15,16]. The water quality parameters were affected by the increased load of pollutants in the perturbed zone [17]. Based on the BOD classification system of Hynes [18], the perturbed zones can be regarded as fairly polluted. This can be attributed to the organic effluents, toxic substances from road construction which increase the rate of microbial activity, resulting in high oxygen demand [19]. The in-stream sand excavation and input of sediments from organic and inorganic sources in the perturbed zones resulted in a significant increase in silt load and turbidity with resultant reduction in invertebrate species richness in the perturbed zone.

The macroinvertebrate fauna in the midstream segment of Qua Iboe River was dominated numerically by Insecta, mainly Diptera, represented by pollution – tolerant members of Chironomidae, Tipulidae and the sludge worm *Tubifex tubifex* (Naididae). The numerical dominance of the perturbed zone by these pollution - tolerant species - and the low biotic index score are indicative of a stressed environment occasioned by the road construction and the resultant inorganic sedimentation. The road construction resulted in elevated levels of the pollution parameters (turbidity, suspended load, bed load and BOD) which also had a significant effect on the macroinvertebrate species richness and diversity in the perturbed zone. Sedimentation of silt and other organic and inorganic particles caused by road construction is known to interfere with respiratory and feeding activity and with filter-feeding mechanisms in invertebrates [8,20,21, 22,23].

4. CONCLUSION

This study undertaken to evaluate the pertubations of road construction and sedimentation on the macroinvertebrate fauna in the midstream region of Qua Iboe River in Nigeria revealed the negative effect of this activity and also adds credence the relevance of both pre and post environmental impact assessment studies projects embarked in any environment. The high levels of pollution parameters and presence of pollution-tolerant organisms in the study area confirmed that the ecosystem in perturbed.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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