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Anthropogenic impact on water chemistry and benthic macroinvertebrate associated changes in a southern Nigeria stream

Francis O. Arimoro · O. Nelson Odume · Samson I. Uhunoma · Augustine O. Edegbene

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Abstract The Ogba River in southern Nigeria is an important water resource for its riparian communities. This study evaluates impact of anthropogenic influences on the Ogba River using water chemistry and macroinvertebrate data sets obtained over a period of 6 months between January and June 2012. Four stations, stations 1–4, characterised by various human activities were chosen along the river. Organic wastes from domestic and industrial sources were the major point sources of pollutants. Station 2 where the municipal wastewater drains into the river had elevated values of flow velocity, BOD_5, sulphate, phosphate, nitrate and sodium. Based on the canonical correspondence analysis (CCA), 5-day biochemical oxygen demand (BOD_5), sulphate, nitrate and phosphate were the main factors that help to shape the macroinvertebrate assemblage structure of the Ogba River. Macroinvertebrates clustered strongly by stations than by seasons indicating that water quality differences between the stations were responsible for the observed differences in the biotic assemblage. The preponderance of naidid oligochaetes, baetid nymphs and certain tolerant dipteran taxa including chironomids and ceratopogonids at all four stations was an indication that the entire water body was stressed. The odonates were the single most abundant taxa; their dominance could be attributed to the vegetative nature of the stream, favouring odonate colonisation. Overall, the responses of macroinvertebrates to stress were reflected by the different assemblage structures recorded at the four study stations. Substrate and microhabitat obliteration and poor water quality appeared to be the factors responsible for the observed assemblage structure in the Ogba River.

Keywords Physicochemical variables · EPT organisms · Pollution-tolerant taxa · Human activities · Nutrients

F. O. Arimoro (✉) · A. O. Edegbene
Applied Hydrobiology Unit, Department of Biological Sciences, Federal University of Technology, P.M.B 65, Minna, Nigeria
e-mail: f.arimoro@futminna.edu.ng

O. N. Odume
Unilever Centre for Environmental Water Quality, Institute for Water Research, Rhodes University, P.O Box 94, Grahamstown 6140, South Africa

S. I. Uhunoma
Department of Animal and Environmental Biology, Delta State University, P.M.B. 1, Abraka, Nigeria

A. O. Edegbene
Department of Biological Sciences (Applied Hydrobiology and Fisheries Unit), Jigawa State University, P.M.B. 048, Kafin Hausa, Nigeria

Introduction

Freshwater bodies are increasingly being studied for their uniqueness in conservation and sustainability of several species of global significance. However, freshwater pollution by human activities is becoming a matter of serious concern threatening environmental sustainability and further social–economic development in sub-Saharan Africa (Arimoro et al. 2008a; de Villiers

and Thiart 2007; Nyenje et al. 2010; PACN 2010). Several uses of river ecosystems including laundry, water source for drinking, irrigation, hydropower generation as well as activities on rivers' catchments such as unregulated land use, landscape alteration, have led to both biotic and physical deterioration of river ecosystems (Nyenje et al. 2010; PACN 2010; Kujawa and Glińska-Lewczuk 2011). A major source of water pollution in Nigeria is the discharges of untreated and inadequately treated municipal and industrial effluents into rivers. These discharges have caused serious ecological alteration of water resources in Nigeria (e.g. Arimoro and Ikomi 2008). Most rivers in Nigeria, particularly those in urban and semi urban cities are now being used for discarding both solid and liquid wastes. These high-polluting activities are now threatening the sustainability and functionality of freshwater ecosystems in Nigeria (Arimoro 2009; Arimoro and Oganah 2010), and the Ogba River where this study was undertaken is no exception.

The Ogba River is impacted by municipal and industrial wastewater effluents from the Benin City, and the influences of the effluent on the benthic fauna as well as the water chemistry have not been thoroughly studied. Since benthic macroinvertebrates are widely used for river health monitoring, they were employed in this study to evaluate the impact of the anthropogenic activities on the biotic integrity of the Ogba River. Macroinvertebrates, in comparison with other faunistic groups, offer several advantages as indicators of river health. First, they have a worldwide distribution with species that are differentially sensitive to changes in environmental conditions including nutrient enrichment—a major outcome of wastewater effluent discharges (Li et al. 2010; Arimoro 2011; Odume et al. 2012). Second, in Sub-Saharan Africa, there is a growing interest in the use of macroinvertebrates for assessing river health (Arimoro et al. 2008b; Masese et al. 2009; Arimoro 2009; Wolmarans et al. 2014). Third, because macroinvertebrates can easily be sampled with inexpensive equipment, they are an ideal group of organisms for monitoring river health in developing countries where the availability of finance often impedes such studies. Fourth, sub-lethal responses of macroinvertebrates have been used as early warning signal of deteriorating water quality (Masese et al. 2009; Odume et al. 2012).

The spatiotemporal functional and structural compositions of macroinvertebrate assemblage in any stream system can be influenced by human activities (Arimoro et al. 2012; Zajac et al. 2013). In the face of changing and intensifying human activity in catchments draining into the stream, there is a need to assess the current status of water quality and benthic invertebrate fauna assemblage in the river and to test protocols for future monitoring. It was hypothesised that because of the increasing human activities in the catchments of the Ogba River, the macroinvertebrate assemblage structure at the impacted station would differ significantly from those at the less impacted stations in the river ecosystem.

Although studies on faunistic characterisation in relation to anthropogenic impacts in urban streams are abounds in developed countries, in developing countries such as Nigeria, where social–economic development is prioritised over environmental concerns, such studies are sparse. The present study therefore contributes baseline information on which environmental as well as water resource managers can base their planning when approving development around the studied river system—enabling sustainable management of the Ogba River. The objective of this study was to assess the impact of anthropogenic influences on the water chemistry and macroinvertebrate assemblages of the Ogba River, Edo State, Nigeria.

Materials and methods

Study area and sampling stations

The Ogba River is a first-order (1°) river, on the outskirts of Benin City, Nigeria, located between latitudes 6° 16′ N and 6° 19′ N and longitude 5° 34′ E (Fig. 1). The 42-km-long river has its origin in Ekewan and flows southeast to join the Ossiomo River and then the Benin River, which discharges into the Atlantic Ocean. The Ogba River catchment is in the tropical rain forest region of southern Nigeria. The region is characterised by the wet and dry seasons. The wet season starts in late March and ends in mid October with a short dry period in August that usually lasts for 2 to 3 weeks. The dry season starts in late October and ends in mid March. The catchment of the river usually receives abundant rainfall (2000–3500 mm) during the wet season, and vegetation is characterised mostly by tropical forest and swamps. The mean annual temperature is about 27 °C, with less than 4 °C variation. The main urban centre in the vicinity of the river is Benin City with a population of about

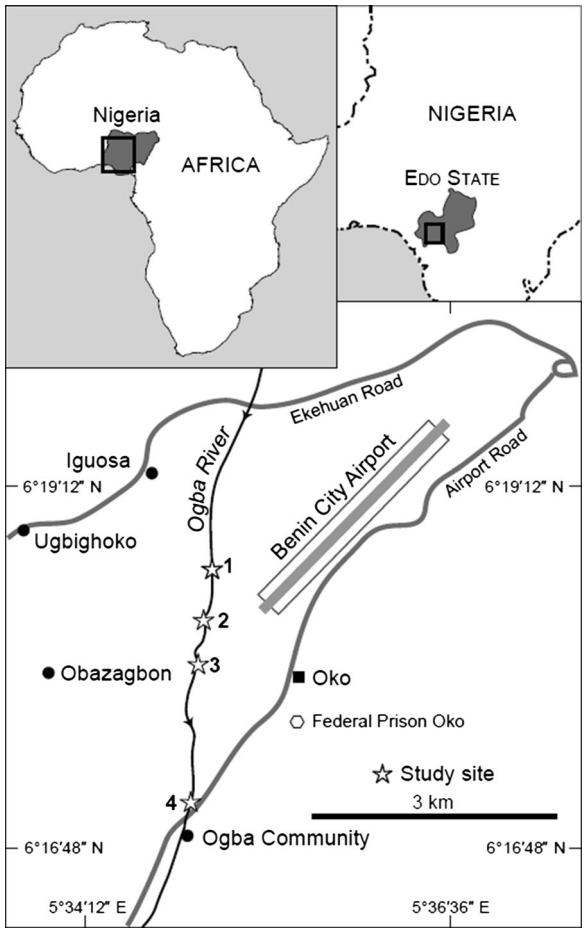

Fig. 1 Map of Benin City showing locations of sampling stations 1–4 in the Ogba River

1.2 million people. Benin City is the commercial centre of Edo State, and effluent from the city into the river is the main anthropogenic stressor influencing both water and biotic quality of the river.

This study was carried out in the upper reaches of the Ogba River between the Ogbe Ibuya and Ogba community. Four sampling stations were selected for the study. At Station 1, situated in Ogbe Ibuya, the river is openly flowing with a few aquatic macrophytes and marginal vegetation. However, further upstream, the river is completely covered by dense growth of aquatic macrophytes. No human activity was observed at this site during the study period. Station 2 was also located at OgbeI buya, about 0.66 km downstream of station 1. The Benin City municipal wastewater drainage system discharges into the river at station 2. A concrete obstacle had been constructed at this site to slow down the flow of the wastewater before entering into the river. Station 3, behind Oko Open Prison, about 0.6 km downstream of station 2, was characterised by human activities including bathing, washing and farming by the prison inmates. Station 4 was situated at the bridge in Ogba Community, about 2 km downstream of station 3. Human activities at station 4 include bathing, laundry, washing of vehicles as well as religious activities including traditional worship and water baptism.

Water sampling

Water samples were collected monthly over a period of 6 months between January and June 2012 at each station. Sampling was designed so that samples were collected in both dry (January–Mach) and wet seasons (April–June).On site, during each sampling event, subsurface water temperatures, dissolved oxygen (DO), temperature-corrected electrical conductivity (EC), total dissolved solids (TDS), pH, depth and flow velocity were measured. A mercury-in-glass thermometer was used for measuring temperature. A HANNA HI 9828 multi-probe metre manufactured by HANNA instruments was used for measuring values of DO, EC, TDS and pH. Average mid-channel water velocity was measured in three replicates by timing a float as it moved over a distance of 10 m (Gordon et al. 1994). Depth was measured in the sample area using a calibrated rod. Water samples were collected in 1-l plastic acid-washed bottles and transported to the laboratory in a cooler box containing ice. In the laboratory, water samples were analysed for nitrate, BOD_5, sulphate, phosphate and sodium according to APHA (1998) methods. Analysis of all samples commenced within 24 h of sampling. Substratum composition in each 25-m sampling reach was estimated visually as percentage of silt, sand, stone and clay including percentage macropytes, coarse particulate organic matter (CPOM) and woods/logs (Ward 1992).

Macroinvertebrate sampling and processing

At each station, using a 0.09-m^2 surber sampler with a 250-μm mesh, macroinvertebrates were collected from a 100-m stream reach comprised of three microhabitats, i.e. pools, riffles and runs, identified according to Jeffries and Mills (1990). To avoid bias due to spatial variations or patchiness, three random samples were collected from each of the three microhabitats by establishing a transect at each sampling reach with five

equally spaced points from which a sampling point was selected using random numbers. This procedure was replicated three times for each microhabitat, making nine samples per reach and then the replicates pooled to form one composite sample per station per sampling event. Samples from the three microhabitats per sampling event per site were pooled into one composite sample to avoid artificial effects of pseudo-replication since the reason for the replicate samples from each microhabitat was to ensure that all microhabitats were adequately sampled. The samples were preserved in 10 % formaldehyde solution and transported to the laboratory for sorting and identification.

In the laboratory, samples were washed through a 250-μm mesh sieve, sorted and counted using a stereomicroscope. Sorted macroinvertebrates were identified to the lowest taxonomic level possible, mostly genus, according to Merritt and Cummins (1996), Day et al. (2002) and De Moor et al. (2003). Reference was also made to the taxonomic lists of species known to be present in Nigeria (e.g. Arimoro and James 2008; Arimoro et al. 2012). Voucher specimens were preserved in 75 % ethanol and stored in the collections at the Department of Animal and Environmental Biology, Delta State University, Abraka, Nigeria.

Data analyses

The range, mean and standard deviation for each physical and chemical variable was calculated per station. Summary of biological metrics including abundance, number of taxa, Shannon diversity index, evenness, Margalef's index as well as physical and chemical variables were compared between stations using one-way analysis of variance (ANOVA). Prior to ANOVA, the assumptions of normality and homogeneity of variance were tested using the Shapiro–Wilk and Levene's tests, respectively. When it was found that these assumptions were violated, data were log (x+1) transformed, except for pH. Fixed effect ANOVAs were performed using dates as replicates. Significant differences between stations indicated by ANOVA (p<0.05) were followed by Tukey's post hoc HSD test. Taxa richness (Margalef's index), diversity (Shannon index) and evenness indices were calculated using the computer BASIC programmeSP DIVERS (Ludwig and Reynolds 1988). The student t test was used to evaluate a significant difference between the wet and dry seasons in terms of macroinvertebrate composition collected during the study period from the Ogba River. Cluster analysis based on Bray–Curtis similarity index was used to ascertain whether macroinvertebrate assemblage distribution was influenced mostly either by differences in sampling stations or seasons. Cluster analysis was performed on log (x+1) transformed macroinvertebrate abundance data. t test and cluster analysis were performed using PAST statistical package (Hammer et al. 2001).

Canonical correspondence analysis (CCA) was used to evaluate relationships between macroinvertebrate communities and environmental variables using PAST statistical package (Hammer et al. 2001). CCA is a powerful tool for simplifying complex data sets, and, being a direct gradient analysis, it allows integrated analysis of both taxa and environmental data (terBraak and Smilauer 2002). Prior to the final CCA, variables exhibiting high multi-colinearity (Pearson correlation r>0.80, p<0.05) were removed. Rare species, occurring less than 1 % of sampling event at each sampling station, were not included in the CCA. Physical and chemical variables used for the CCA analysis were also log (x+1) transformed to prevent the undue influences of extreme values on the final CCA ordination. Species–environment correlation coefficients provided a measure of the explanation of community patterns by individual physical and chemical variables. A Monte Carlo permutation test with 199 permutations (Jckel 1986) was used to assess the significance of the first three canonical axes.

Results

Environmental variables

Substrate composition, habitat quality including macrophyte composition and catchment size of the sampling stations of the Ogba River are shown in Table 1. Substrate compositions at the four sampling stations include silt, sand, clay, mud, vegetation (macrophyte and woody debris) and stones. In all the sampling stations, sand, mud and clay were the dominant substrate types. Percent woody debris and CPOM constituted less than 45 % of the in-stream microhabitats at all sampling stations.

The mean and standard deviation of the physical and chemical variables at each sampling station are also shown in Table 1. Mean flow velocity was significantly

Table 1 Environmental factors measured at the four sampling stations of Ogba River, (January–June 2012) showing substrate composition and habitat quality including physicochemical parameters (n=6)

Variable	Station 1	Station 2	Station 3	Station 4	FEPA* Maximum permissible limits	SON** Maximum permissible limits
Silt (%)	15	25	20	15		
Sand (%)	20	20	25	25		
Mud (%)	25	25	20	25		
Clay (%)	25	25	25	25		
stones	15	5	10	10		
Macrophytes (%)	15	20	15	25		
Wood/logs (%)	25	35	30	25		
CPOM (%)	15	0	10	5		
Canopy cover (%)	60	45	55	50		
Catchment size (km^2)	40	45	45	53		
Temperature (°C)	25.11±2.33^a (23.4–31.4)	25.66±2.43^a (23.1–32.0)	24.95±3.42^a (22.9–31.9)	25.56±3.74^a (23.20–31.7)		
Depth (cm)^A	85.83±4.13^a (71.0–104.0)	41.5±5.58^b (21.0–62.0)	70.1±10.23^c (40.0–113.0)	76.91±5.26^{ac} (52.0–98.0)	–	–
Flow velocity (cm s^{-1})^A	14.05±1.79^a (10.8–25.6)	48.99±3.89^b (28.2–65.6)	47.25±1.95^b (37.7–53.0)	46.26±1.61^b (37.7–51.4)	–	–
pH	6.78 (5.4–7.5)	6.23 (5.7–6.9)	6.83 (5.9–8.1)	6.45 (5.7–7.2)	6.0–9.0	6.5–8.5
Electrical conductivity (μS cm^{-1})^A	50.6±11.22^a (23.3–116.5)	45.73±4.06^b (33.4–69.7)	47.6±3.67^b (31.0–74.7)	40.8±6.18^c (29.3–78.2)	–	1000
Total dis. solids (mg l^{-1})	30.11±6.33^a (14.5–66.4)	27.66±2.43^a (20.1–41.8)	28.95±3.42^a (19.2–44.9)	26.96±3.74^a (18.1–47.0)	2000	500
Dissolved oxygen (mg l^{-1})	5.59±0.25^a (4.9–6.9)	5.53±0.15^a (4.8–6.0)	5.95±0.13^a (5.4–6.5)	5.78±0.16^a (4.9–6.3)	5	–
BOD_5 (mg l^{-1})^A	2.16±0.15^a (1.7–3.0)	4.13±0.15^b (3.5–4.8)	4.04±0.23^b (2.9–4.8)	2.56±0.24^c (1.7–3.9)	10	–
Sulphate (mg l^{-1})^A	2.83±0.30^a (1.98–4.11)	6.06±0.10^b (5.49–6.39)	0.90±0.03^c (0.76–1.00)	0.66±0.02^d (0.60–0.72)	200–400	100
Phosphate (mg l^{-1})^A	1.08±0.01^a (1.00–1.11)	1.24±0.03^a (1.12–1.44)	0.23±0.12^b (0.10–1.10)	0.86±0.17^c (0.10–1.18)	5	–
Nitrate (mg l^{-1})^A	0.02±0.01^a (0.001–0.05)	0.13±0.05^b (0.004–0.3)	0.04±0.01^c (0.02–0.08)	0.03±0.01^{ac} (0.011–0.06)	20	50
Sodium (mg l^{-1})^A	1.27±0.02^a (1.15–1.35)	1.88±0.15^b (1.38–2.80)	1.64±0.06^{bc} (1.29–1.82)	1.40±0.04^{ac} (1.23–1.56)	–	200

Values are mean±SD; range in parenthesis. Different superscript letters in a row show significant differences (p<0.05) indicated by Tukey honest significant difference (HSD) tests

^{A} Significantly calculated F value detected by ANOVA

*Nigerian Water Quality Standard for Inland Surface Water. FEPA (Federal Environmental Protection Agency) (1991)

**Nigerian Standard for Drinking Water Quality. Standards Organisation of Nigeria (SON), 2007

lower at station 1 compared with stations 2, 3 and 4 with significantly higher values (p<0.05). Mean concentrations of BOD_5, sulphate, phosphate, nitrate and sodium were significantly higher at stations 2 and 3 than at stations 1 and 2 (p<0.05). There were no statistically significant differences in the values of pH, electrical conductivity, TDS and DO among the four sampling stations.

Macroinvertebrate assemblages

A total of 2882 macroinvertebrate specimens comprising 73 taxa belonging to 12 orders and 38 families were collected over the study period (Table 2). The relative abundance of taxonomic groups at the order level revealed that the dipterans were the commonest in the study area (Fig. 2) occurring at

Table 2 Distribution and abundance of benthic macroinvertebrate in Ogba River, Niger Delta, January–June 2012

Order	Family	Taxon	Code	Station			
				1	2	3	4
Nematoda	Dorylaimidae	*Dorylaimus* sp.	Dor	4	11	14	5
Oligochaeta	Naididae	*Chaetogaster limnaei*	Cha		22	12	
		Dero digitata	Der	8	54	13	
		Nais communis	Nai		8		16
		Pristina aequiseta	Pri		23	16	
		Stylaria lacustris	Sty		42	13	
	Tubificidae	*Tubifex tubifex*	Tub		76		
Decapoda	Atyidae	*Caridina africana*	Car	23		12	8
	Palaemonidae	*Macrobrachium dux*	Mac	6			4
Gastropoda	Melaniidae	*Melanoides* sp.	Mel	2	3		7
	Pilidae	*Pila* sp.	Pil		4	6	8
Arachnida	Tetragnathidae	*Tetragnatha* sp.	Tet	6	2	7	8
Ephemeroptera	Baetidae	*Baetis* sp.	Bae	72	16	34	35
		Bugilliesia sp.	Bug	6		16	7
		Cloeon aeneum	Clo	12		8	
		Pseudocloeon cylindrica	PseC	12			10
		Pseudocloeon nr pisces	PseP	12		42	40
		Crassabwa sp.	Cra				6
	Tricorythidae	*Tricorythus* sp.	Dic	9		7	12
	Leptophlebiidae	*Adenophlebiodes* sp.	Ade	15		8	18
		Thraulus sp.	Thr	13		6	
		Choroterpes sp.	Cho			4	
	Caenidae	*Caenis cibaria*	Cae	52		36	12
Trichoptera	Hydroptilidae	*Leptonema* sp.	Lep			12	9
	Leptoceridae	*Leptocerina* sp.	Let	12	6	12	
		Athripsodes sp.	Ath	2	7		
Lepidoptera	Crambidae	*Nymphula stratiotata*	Nym	4		2	
Hemiptera	Naucoridae	*Naucoris obscuratus*	Nau	7		4	12
	Veliidae	*Velia caprai*	Vel	1	4	5	8
	Nepidae	*Ranatra* sp.	Ran		6	4	
		Laccotrephes sp.	*Lac*	1		4	
	Belostomatidae	*Appasus* sp.	App	16	24		6
	Gerridae	*Naboandelus africanus*	Nab	8		1	4
	Pleidae	*Plea* sp.	Ple	12		8	
Coleoptera	Dystiscidae	*Methles* sp.	Met	12			
		Philodytes sp.				4	
		Canthyporus sp.	Can	6		5	
		Hyphydrus sp.	Hyp	9	2	1	19
		Cybister sp.	Cyb	3	6		7
		Coelhydrus sp.	Coe	3		12	
		Philaccolus sp.	Phi			21	13
	Hydrophilidae	*Hydrophilus* sp.		12			
		Amphiops sp.	Amp	8	2	6	

Table 2 (continued)

Order	Family	Taxon	Code	Station			
				1	2	3	4
	Notonectidae	*Hydrocanthus* sp.	Hyd	12		16	4
		Cathydrus sp.				7	
	Gyrinidae	*Orectogyrus* sp.		16	5		18
Odonata	Libellulidae	*Brachythemis lacustris*	Bra	3			2
		Sympetrum sp.	Sym	5		8	
		Zyxomma sp.	Zyx	16			
	Gomphidae	*Lestigomphus* sp.	Les	12		4	13
		Ictinogomphus terax	Ict	4		4	7
	Macromiidae	*Macromia* sp.	Mac	0	0	4	0
	Coenagrionidae	*Enallagma* sp.	Ena	18	24	45	23
		Lestes plagiatus	Les	89	62	72	69
		Agriocnemis pinheyi	Agr	11	8	10	16
		Coenagrion sp.	Coe	24	2	47	11
	Calopterygidae	*Phaoniridipennis*	Pha	0	0	2	5
Diptera	Chironomidae	*Chironomus transvaalensis*	Chi	17	201	52	19
		Cryptochironomus sp.			18		
		Pentaneura sp.	Pen	4	12	12	5
		Tanypus sp.	Tan		19	4	
		Tanytarsus sp.		12			10
		Orthocladiinae	Ort		34	12	
		Stenochironomus sp.	Ste	6	72	48	
		Polypedilium sp.	Pol		3	9	4
		Cricotopus sp.	Cri	18	24	14	18
	Tabanidae	*Tabanus* sp.			8		
	Syrphidae	*Eristalis* sp.	Eri		94	3	
	Tipulidae				8	4	8
	Simuliidae	*Simulium* sp.	Sim		8	7	4
	Athericidae	*Atherix* sp.		6		2	
	Culicidae	*Culex pipiens*	Cul		35	2	
	Ceratopogonidae	*Allaudomyia* sp.	For	4	6	8	15
				645	961	751	525

all sampling stations. Oligochaetes were among the dominant taxa at stations 2 and 3 (Fig. 2, Table 2). All the six species of oligochaetes were represented at station 2. Higher abundance of Ephemeroptera, Coleoptera and Odonata were recorded at stations 1 and 4 compared with stations 2 and 3. Overall, there were significant differences in abundance (no. of individuals) between the stations and the sampling periods ($p<0.05$) (Table 3).

Spatiotemporal dynamics in population density

Of the total number of individual macroinvertebrates recorded during the entire study period, 54.6 % were recorded in the dry season (January–March) and the remaining 45.4 % were recorded in the wet season (April–June). The highest abundance was recorded during the dry season month of March at stations 2 and 3 and in July (wet season) at station 1 (Fig. 3). Station 4

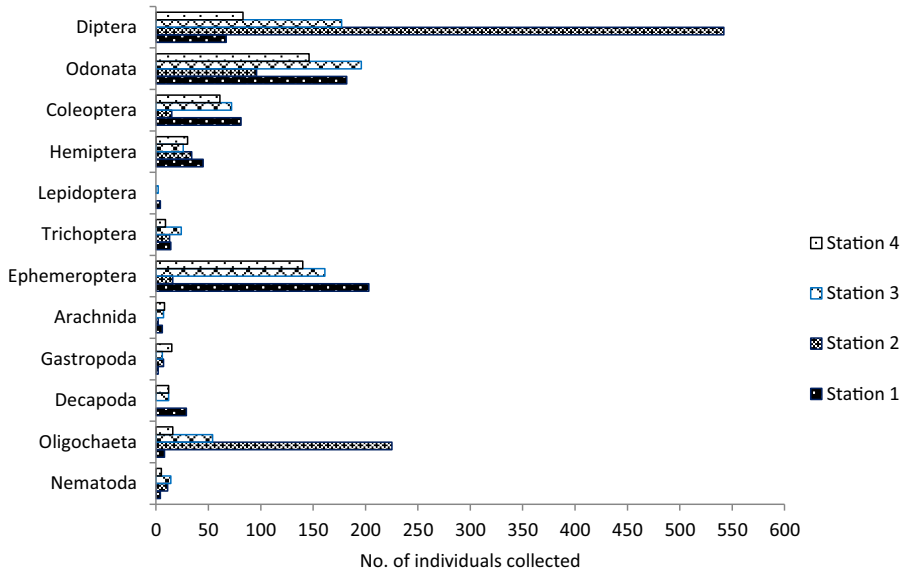

Fig. 2 Distribution and abundance of selected groups of macroinvertebrates in the sampling stations of the Ogba River during the study periods (January–June 2012)

did not show much temporal variation in macroinvertebrate abundance. Generally, in most instances, slightly higher abundances were recorded in the dry season (January–March) than during the wet season (April–June). Student *t* test indicated no significant difference between the two sampling seasons, the dry and wet, in terms of macroinvertebrate relative abundance ($p>0.05$).

Diversity, evenness, dominance and similarity indices

Summaries of biological metrics including abundance, number of taxa, Shannon diversity, evenness and Margalef's indices calculated for the four sampling stations are shown in Table 3. The mean abundance (no. of individuals) was significantly highest at station 2 than at stations 1, 3 and 4. No statistically significant differences were observed between the mean abundances at station 1 and stations 3 and 4. The overall lowest mean abundance was recorded at station 4. Shannon diversity (H') was significantly lower ($p<0.05$) at station 2 compared with stations 1, 3 and 4. No statistically significant differences were observed between the remaining three sampling stations in terms of Shannon diversity index. Margalef richness index (d) was highest at station 3, followed closely by station 1. A much lower value of 5.42±0.22 was recorded at station 2. The mean evenness (E) value was significantly lower at station 2 ($p<0.05$).

Table 3 Abundance, number of species, evenness, Shannon diversity and Margalef's indices of benthic macroinvertebrates in Ogba River, Niger Delta, January–June 2012. Value±standard error

	Station_1	Station_2	Station_3	Station_4
Abundance (no. of individuals)*	107.50 ± 3.86^{ac}	160.20 ± 8.19^{b}	$125.0\ 0\pm4.50^{a}$	86.67 ± 6.40^{c}
Taxa (species no.)*	35.50 ± 1.20^{a}	28.30 ± 1.23^{b}	37.33 ± 1.23^{a}	29.00 ± 1.03^{bc}
Shannon diversity(H')*	3.23 ± 0.05^{a}	2.80 ± 0.05^{b}	3.33 ± 0.04^{a}	3.15 ± 0.04^{a}
Evenness,*E	0.72 ± 0.02^{a}	0.61 ± 0.03^{b}	0.75 ± 0.02^{a}	0.80 ± 0.02^{a}
Margalef index (taxa richness)*(d)	7.38 ± 0.23^{a}	5.42 ± 0.22^{b}	7.53 ± 0.23^{a}	6.29 ± 0.18^{a}

Different superscript letters in a row show significant differences ($p<0.05$) indicated by Tukey honest significant difference tests

*ANOVA calculated is significantly different among the sampling stations

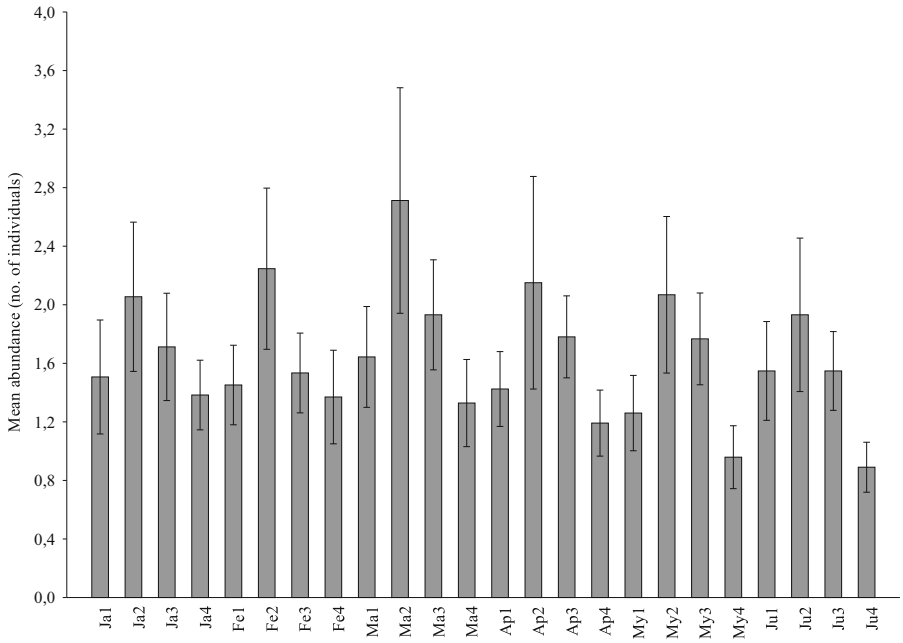

Fig. 3 Relative abundances of macroinvertebrates in the study area during dry (January–March) and wet seasons (April–June) in 2012. (*Ja* January, *Fe* February, *Ma* March, *Ap* April, *My* May, *Ju* June and numbers *1*, *2*, *3* and *4* represent the sampling stations)

Macroinvertebrates and environmental relationships

The CCA ordination revealed strong relationships between species abundances and measured environmental variables. The first two canonical axes accounted for over 80 % of the variation in the data set. The overall inertia or variance in species dispersion in the data set was 2.45. An unrestricted Monte Carlo permutation test indicated that the first three canonical axes were significant ($p<0.05$). Axis 1, which was strongly associated with oligochaetes, Baetid nymph (*Pseudocloeoncylindrica*) and *Macrobrachium*, was mostly explained by depth, DO, flow velocity, BOD_5, sulphate, phosphate and nitrate (Fig. 4, Table 4). Most of the samples taken from stations 1 and 4 were positioned on the left, whereas those from station 2 were on the right. Samples from station 3 were positioned on the left, close to the centre point of the plot. *Baetis and Choroterpes* that were not common in other sampling stations were closely associated with station 3 on the CCA plot. Axis 2 of the CCA plot was associated mainly with factors that were seasonally influenced, including temperature, TDS, depth and electrical conductivity (Fig. 5, Table 4). Dissolved oxygen, BOD_5, and phosphate were strongly associated with axis 3 (Table 4).

Generally, based on the CCA ordination plot, species such as *Tubifex tubifex*, *Stylaria lacustris*, *Athripsodes* sp., *Dero digitata*, *Chaetogaster limnaei* and *Pristina aequiseta* were characteristic indicators of the prevailing environmental conditions at station 2. These species were closely associated with increased nutrient concentrations and BOD_5. Species that were closely associated with station 3 include *Tetragnatha* sp., *Bugilliesia* sp., *Baetis* sp. and *Choroterpes* sp. Species preferring less organically polluted environment characteristics of both stations 1 and 4 include *Crassabwa* sp., *Adenophlebiodes* sp., *Tricorythus* sp., *Pseudocloeon cylindrica*, *Caridina africana*, *Caenis cibaria*, *Cloeon aeneum* and *Thraulus* sp. The cluster analysis produced based on macroinvertebrate log ($x+1$) transformed abundance data clearly showed that samples were clustered by stations rather than by seasons. Samples collected from the same stations were closely associated than samples collected from different stations in the same season (Fig. 5).

Discussion

Water chemistry

The water chemistry of aquatic ecosystems can be influenced by local physical disturbances, natural geological features, land use patterns and other human

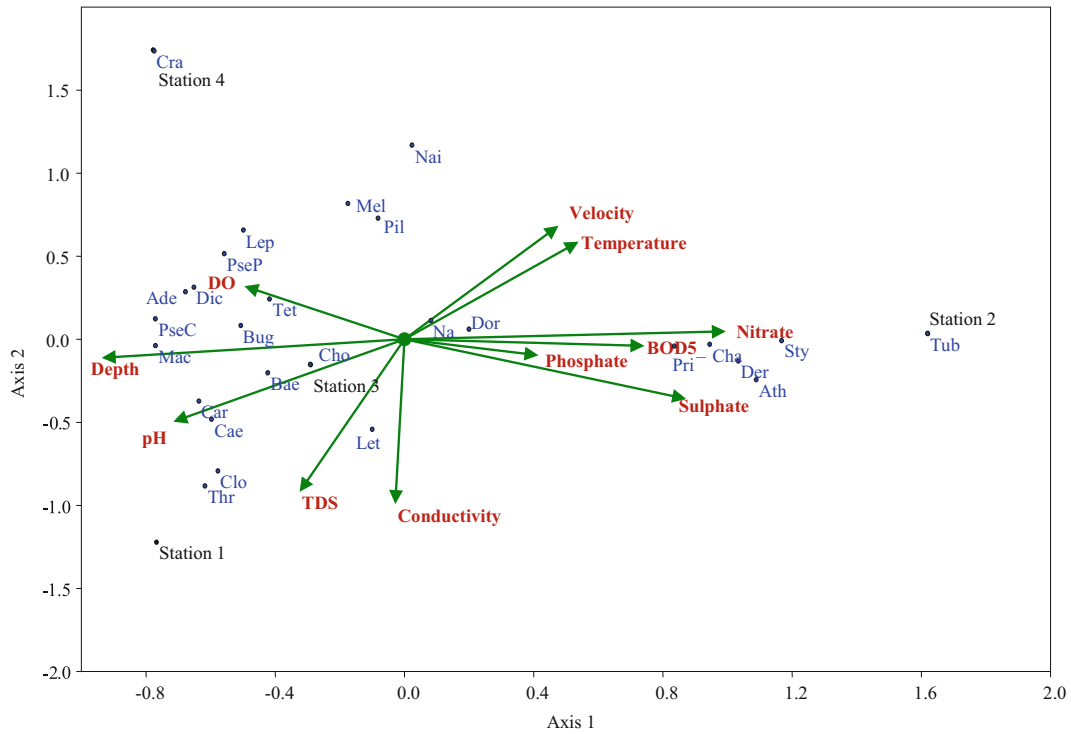

Fig. 4 Triplot of the first and second CCA axes of macroinvertebrate taxa, environmental variables and the sampling stations. Macroinvertebrate abbreviation: Tub (*Tubifex tubifex*), Sty (*Stylaria lacustris*), Ath (*Athripsodes* sp), Der (*Dero digitata*), Cha (*Chaetogaster limnaei*), Pri (*Pristina aequiseta*), Nai (*Nais communis*), Dor (*Dorylaimus* sp.), Mel (*Melanoides* sp.), Pil (*Pila* sp.), Lep (*Leptonema* sp.), PseP (*Pseudocloeon nr pisces*), Cra (*Crassabwa* sp.), Ade (*Adenophlebiodes* sp.), Dic (*Tricorythus* sp.), Tet (*Tetragnatha* sp.), PseC (*Pseudocloeon cylindrica*), Bug (*Bugilliesia* sp.), Mac (*Macromia* sp.), Bae (*Baetis*sp.), Cho (*Choroterpes*sp.), Car (*Caridina africana*), Cae (*Caeniscibaria*), Clo (*Cloeon aeneum*), Thr (*Thraulus* sp.), Let (*Leptocerina* sp.)

activities in the catchments (Sundermann et al. 2013). Influences on water chemistry can manifest themselves in the structure of aquatic fauna (Arimoro et al. 2011). To protect water resources, it is pertinent to determine factors that negatively impact on them so that mitigation measures can be proffered. The Ogba River is an important water source for domestic activities for the riparian communities. High values of electrical conductivity (23.3–116.5 μS/cm), TDS, nutrients and BOD_5 recorded during the study period are indicators of disturbances by human activities. The influx of washing detergents, organic wastes and other pollutants including run-offs from the surrounding road networks were likely responsible for the observed deterioration of the surface water quality of the river. Stations 2 and 3 had the highest mean BOD_5 values indicative of increased organic pollution at these stations when compared with stations 1 and 4. The increased BOD_5 values at stations 2 and 3 could be attributed to the municipal wastewater entering the river at station 2 and animal wastes and inorganic fertilizers used as manure in the prison farm near station 3. A river can purify itself if the BOD_5 level is below 4 mg l^{-1}, but not when it exceeds that value (Radojevic and Bashkin 1999). The nitrate values were generally low and could be an indication of a low inorganic nutrient input into the river from the surrounding catchment activities or nutrient uptake by phytoplankton and aquatic macrophytes as well as microbial activities. Nevertheless, the relatively high values of nitrate obtained at station 2 may have been caused by discharges from the Benin City municipal effluent drain. Increased nutrient concentrations at station 2 had been reported by other authors in earlier studies (Obasohan and Oronsaye 2004; Obasohan 2007; Anyanwu et al. 2013). In most parts of Africa and other developing countries, people live in the riparian zones of streams and rivers for supply of water for their daily needs, resulting in the pollution of these water bodies (Arimoro and Muller 2010).

The water chemistry and biotic quality of most aquatic ecosystems in the Niger Delta of Nigeria have been compromised because of discharges of organic and

Table 4 Weighted intraset correlations of environmental variables with the first three axes of canonical correspondence analysis (CCA) in Ogba River, Niger Delta

Variable	Axis 1	Axis 2	Axis 3
Eigen values	0.60	0.18	0.11056
Species–environment correlation	0.96	0.92	0.78
% variation of species data explained	67.50	20.10	12.4
Temperature (°C)	**0.54**	**0.59**	**0.572**
Depth (cm)	**−0.98**	−0.11	0.137
Velocity (cm s^{-1})	**0.48**	**0.68**	**−0.487**
pH	**−0.72**	**−0.50**	−0.434
Electrical conductivity (μS cm^{-1})	−0.02	**−0.99**	−0.129
Total dissolved solids (mg l^{-1})	−0.32	**−0.92**	−0.104
Dissolved oxygen (mg l^{-1})	**−0.50**	0.32	**−0.787**
Five-day biochemical oxygen demand (mg l^{-1})	**0.74**	0.01	**−0.688**
Sulphate (mg l^{-1})	**0.87**	−0.36	0.343
Phosphate (mg l^{-1})	**0.42**	−0.10	**0.888**
Nitrate (mg l^{-1})	**1.00**	0.02	0.016

Significance of the axes by the Monte Carlo permutation test is given by $F=6.13$ ($p<0.05$) All canonical axes were significant. Values in bold indicate a significant difference at $p<0.05$

inorganic materials from activities on the catchments of most freshwater bodies (Arimoro and Osakwe 2006; Arimoro and Ikomi 2008; Andem et al. 2014; Olomukoro and Dirusu 2014). In the present study, differences in flow velocity, electrical conductivity and nutrient values between the stations may have contributed to the observed differences in biotic composition between the sampling stations. Of the water chemistry variables measured in this study, phosphate is the most important limiting factor for aquatic productivity, and when used up, aquatic ecosystems can become impoverished (Wetzel 2001). The concentrations of phosphate found in this study particularly at station 2 were slightly high compared with unperturbed natural conditions (Chapman 1996; Radojevic and Bashkin 1999). Apart from anthropogenic inputs of phosphate into the river system, activities of microorganisms can release adsorbed nutrients into the water column, which can increase the overall concentration of phosphate available to plants (Correll 1998).

Macroinvertebrate species assemblages

A total of 73 macroinvertebrate species were recorded in the Ogba River during the study period. This number is

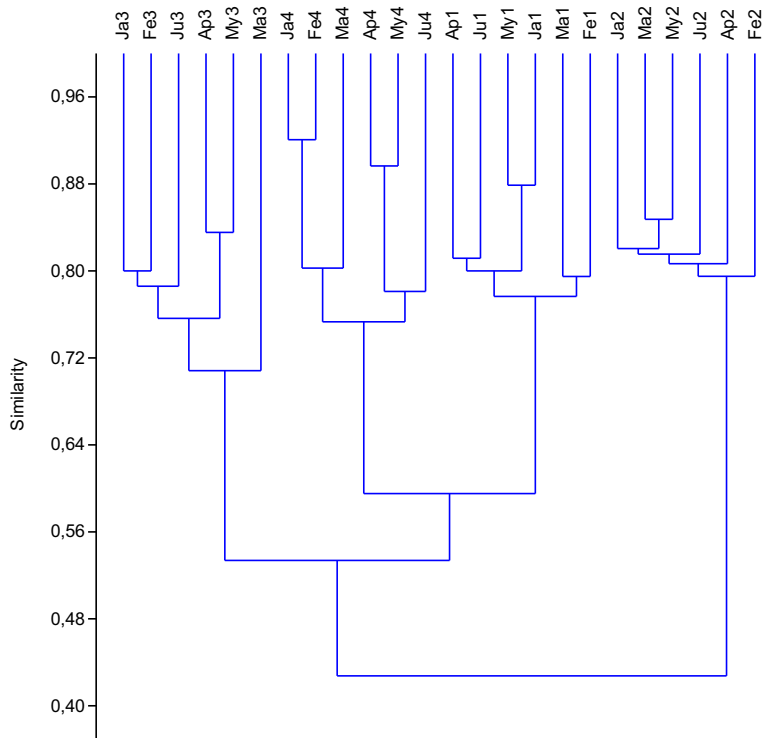

Fig. 5 Dendrogram derived from the cluster analysis (Bray–Curtis similarity index) of log (x+1) transformed macroinvertebrate abundance data in the Ogba River during the study periods (January–June 2012). *Ja* January, *Fe* February, *Ma* March, *Ap* April, *My* May, *Ju* June. Numbers *1*, *2*, *3* and *4* attached to the months represent the sampling stations

much higher than the total of invertebrate species reported from some perturbed and grossly polluted rivers in southern Nigeria (Arimoro and Osakwe 2006; Arimoro et al. 2008b; Arimoro and Ikomi 2008; Zabbey and Uyi 2014). The relatively high diversity of macroinvertebrates recorded in this study could be attributed to the heterogeneous and patchy nature of vegetation and other substrates in the river system, serving as suitable microhabitat for diverse groups of macroinvertebrates. It is also safe to argue that the organic inputs into the river favoured the propagation of oligochaetes and certain dipteran groups including chironomids, syrphinids and tipulids, which are usually dominants in organically polluted rivers. Although these taxa were not reported in previous studies, they were relatively abundant at stations 2 and 3 in this study. The presence of these taxa is a common feature of organically polluted water bodies in the Niger Delta of Nigeria (Andem et al. 2014; Olomukoro and Dirisu 2014; Ikomi and Arimoro 2014).

Of the macroinvertebrate taxa recorded in this study, the odonates were the most ubiquitous and abundant group occurring in all the sampling stations throughout the sampling periods. Odonates generally prefer aquatic vegetation as refuge, and their ubiquitous distribution in this study could be attributed to the dense coverage of the water body by floating vegetation, creating a suitable habitat for them (Arimoro et al. 2012). Higher species richness was recorded at stations 1 and 3 compared with stations 2 and 4. The favourable water chemistry conditions at station 1 and increased habitat availability at station 3 were likely the main factors accounting for the increased species richness and diversity at these two stations.

In terms of temporal assemblage variation, on the average, higher abundances of macroinvertebrates were recorded during the dry season than in the wet season. However, the *t* test did not reveal statistically significant differences between the two seasons ($p > 0.05$). Increased flow characteristics of the rainy season usually lead to a reduction in macroinvertebrate diversity in tropical streams because of effects of wash offs from surrounding catchment activities and dislodgement of taxa with no adhesive features (Arimoro and Ikomi 2008). For example, Arimoro and Ikomi (2008) recorded higher densities of macroinvertebrates in the dry season in a municipal stream in Nigeria, and these authors suggested that dry season usually favours diverse macroinvertebrate taxa because of less wash-off effects.

Relating macroinvertebrate with physical and chemical variables

CCA clearly separated the less impacted stations from the impacted ones. The CCA ordination also showed that macroinvertebrate fauna were significantly associated with environmental factors measured in Ogba River. Nitrate concentration, BOD_5 and electrical conductivity were higher at station 2 than at the other stations followed by station 3. The combination of variables might be used to identify and describe the multiple-scale stressor. The correlation of many individual environmental variables with the axes were relatively high for CCA but were not statistically significant. However, these estimated significances may be the results of the unmeasured environmental variables. Station 2 was an extreme outlier in our ordination analysis, with a very different macroinvertebrate assemblage including most of the tolerant dipteran groups such as *Cryptochironomus* spp., *Tanypus* and *Tabanus* spp. and the oligochaetes including *Nais*, *Dero*, *Stylaria*, *Dero* and *Pristina* species which were either not common or completely absent at the other stations. The dominance of naidid oligochaetes, chironomids and certain molluscs at stations 2 and 3 are indicative of deteriorating biotic and overall ecological health of the river. Several other studies have reported increases in abundance of these organisms in polluted water bodies in southern Nigeria (Arimoro et al. 2008b; Arimoro and Ikomi 2008; Arimoro et al. 2012; Andem et al. 2014; Olomukoro and Dirusu 2014). Species richness, diversity and evenness indices at the various sampling stations during the 6 months of sampling appeared to reflect the water quality conditions at each site. High species diversity at stations 1 and 4 was associated with less polluted conditions, while a lower biodiversity at stations 2 and 3 signified environmental stress due to gradual increasing human influences on the water quality condition at these sites. The relative abundance of Ephemeroptera–Plecoptera–Trichoptera (EPT) taxa was greater at stations 1 and 4 showing better water conditions than stations 2 and 3. These taxa have continuously been used as surrogates for clean water sites (Merritt and Cummins 1996).

Over the past two decades, there has been increasing evidence of impact of human activities within the Ogba

River catchment, specifically on soil erosion due to the removal of natural vegetation cover for agricultural and urban purposes (Obasohan and Oronsaye 2004; Obasohan 2007). The present study revealed that silt and sand were the dominant substrate in the catchments and once vegetation is removed, the river is easily eroded because of the nature of the soils. The catchment is now composed largely of mosaic cropland and a few tree cover as opposed to the many trees providing adequate cover in the past. Overall, land use pattern and canopy removal have led to increase erosion of the catchments of the Ogba River.

Conclusion

Rivers in the Niger Delta are globally valued for their rich biodiversity, but over the past two decades, there has been increasing urbanisation of the Niger Delta leading to perturbation of freshwater ecosystems. The Ogba River is no exception as the growing human population in the Benin metropolis influences the water and biotic quality of the river mainly because of effects of municipal effluent. This study therefore provides information on the present status of the water quality of the Ogba River and serves as a baseline survey of macroinvertebrate fauna in the river. The outcome of this study can form the foundation for long-term assessment of the river and for the use of bioindicators for the management of the river system.

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