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The intensity of human-induced impacts on the distribution and diversity of macroinvertebrates and water quality of Gbako River, North Central, Nigeria

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Abstract The intensity of human-induced impacts on the distribution and diversity of macroinvertebrates and water quality of Gbako River, North Central, Nigeria, was evaluated monthly for 6 months using modified kick sampling techniques. Four study stations were selected along the river course (upper reaches of less human impacts through mid-reaches with relative high human impacts to lower reaches of less human impacts), designated as Stations 1, 2, 3, and 4. Water temperature (23.10–30.00 °C), flow velocity (0.10–2.40 m/s), pH, conductivity (32.00–110.00 µS/cm), and alkalinity (7.50–10.50 mg/L) were similar in all the stations sampled. However, BOD (2.20–6.00 mg/L) and nitrates (0.50–1.67 mg/L) were significantly higher ($p < 0.05$) in Station 3. A total of 676 individuals from 41 invertebrate taxa in 27 families from nine orders were collected from the four stations during the study. Aquatic insects represented 85.4 % of the taxa and 76.6 % of all individuals collected. The rest of the fauna was composed of Mollusca, Crustacea, and Gastropoda. Ten macroinvertebrate taxa, *Philaccolus*, *Pseudocloeon*, *Bugilliesia*, *Calopteryx*, *Coenagrion*, *Brachythemis leucostica*, *Gomphus*, *Hydrometra*, *Sphaerudx*, and *Potadoma* species, were found in all the four sampled stations. The overall abundance of benthic invertebrates was not significantly different ($P > 0.05$) among the sampling stations. Stations 2 and 3 with higher human disturbance recorded lower richness when compared with the less disturbed stations (1 and 4). Furthermore, the marginally high nutrient levels (phosphate and nitrate) obtained at these stations are an indication that the water body is becoming stressed with organic input and increasing levels of anthropogenic activities. The CCA ordination revealed strong relationships between species abundances and measured environmental variables. The low relative abundance of Ephemeroptera–Plecoptera–Tricoptera (EPT) taxa indicated that the environmental conditions were relatively stressed, along the whole stations. However, the abundance of mayflies (Ephemeroptera), Coleoptera (*Gyrinus*, *Dytiscus*), and Anisoptera in all the sites studied is an indication that the sites are relatively free from gross pollution, especially at the upper reaches. Overall, relatively less human impacts in some of the study stations and the heterogeneous nature of the stations served as suitable habitat for a more diverse benthic fauna. This could be responsible for the high abundance (number of individuals) and diversity of benthic invertebrates that was recorded in this study. This study revealed that macroinvertebrate communities responded to changes in disturbance as well as water quality along the river stations.

Keywords Macroinvertebrates · Water quality · Anthropogenic activities · Gbako River · Nigeria

1 Introduction

Macroinvertebrate organisms form an integral part of an aquatic environment and are of ecological and economic importance as they maintain various levels of interaction between the community and the environment (Dobson et al. 2002). According to Marques et al. (2003), knowledge of the structure of the benthic macroinvertebrate community provides precise and local information on

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recent events, which can be seen in their assemblages. The use of invertebrates and fish as bioindicators of water quality has been advocated by several researchers (de Villiers and Thiart 2007; Nyenje et al. 2010; PACN 2010; Arimoro et al. 2015).

Benthic macroinvertebrates show high variability and are able to integrate the effects of short-term environmental variations which have been used in characterizing rivers and streams in many parts of the world (Barbour et al. 1999). Since macroinvertebrates have limited mobility and can stay in an area without moving away easily, the type of the macroinvertebrate fauna obtained may be used as indicator of the status of the water quality of aquatic system at that location. Similarly, the life cycles of macroinvertebrate fauna may last for a year or more and this is reflected in the type of the benthic fauna in aquatic system due to the effect of the pollutant rather than chemical analysis of the water (Yagow et al. 2006). The long-term impacts of pollutant in aquatic ecosystem may be shown in the type of macroinvertebrate found in that system. This may be used in the classification of the ecological integrity of that aquatic environment (Chirhart 2003).

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 and Ikomi 2008; 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 and landscape alteration, have led to both biotic and physical deterioration of river ecosystems (Nyenje et al. 2010; PACN 2010). In Nigeria, land use changes on various catchments and unsustainable agriculture coupled with agro-industrial activities and rapid urbanization pose threats to the well-being of aquatic ecosystems and alters the composition and abundance of macroinvertebrates (Arimoro and Ikomi 2008; Andem et al. 2014; Akaahan 2014; Arimoro et al. 2015).

The anticipated further industrialization of Bida and its environs and increased urbanization of the population within the Gbako River catchment may result in further deterioration in the water quality of the river. Therefore, there is an urgent need for proactive measures in order to incorporate the increasing water demand and pollution problems into management plans so as to conserve the river and its biota. In this study, the increasing human impacts on the water quality and macroinvertebrate communities were investigated to ascertain the bioindicators of water quality degradation and catchments disturbance.

2 Materials and methods

2.1 Description of study area

River Gbako (06°.05′–06°.15′N; 09°.00′–09°.15′E) is located at Badeggi in Katcha Local Government Area of Niger State. The river flows to a lower level in a channel on land from north to south and flows through Gbako, Shiroro, Chanchanga, Katcha, Baro, Logunma. The study site lies within the Savannah region in North Central Nigeria. It is characterized by two seasons (rainy and dry season). The rainy season is from April to October, while the dry season is from November to March. For the pursuant of this research, the study area was divided into four stations, namely:

2.1.1 Station 1

This station is located at Badeggi. Water velocity at this station is low (mean value = 0.064 m/s) when compared to other stations. The vegetation cover is thick with a dense tunnel of trees and consists mainly of emergent macrophytes and floating plants such as *Nymphaealotus*. The marginal vegetation is composed mainly of *Cocos nucifera*, *Havea brasiliensis*, and *Raphia vinifera*. This station was classified as undisturbed since it was relatively free from human activities probably because of its located at the outskirts of the town. Substratum composition is muddy and silt.

2.1.2 Station 2

Station 2 is at Jibo. It is located under a non-motorable bridge. Aquatic vegetation not thick as much as Station I. Water velocity is relatively higher than Stations 1 and 3 (mean value = 0.109 m/s). It represents the shallowest of the chosen stations (0.303 m). The vegetation consists mainly of *Commelina* spp., *Nymphaea* spp., *Pistia stratiotes*, and *Panicum repens*. Artisan fishing, washing of clothes, and bathing are the major human activities that take place here. This station was categorized as moderately disturbed. Substratum composition in this station is loamy.

2.1.3 Station 3

Station 3 is located in Katcha town, under a motorable bridge. It is 0.37–0.70 m deep with flow velocity of 0.021–0.100 m/s. It has open vegetation, thereby receiving thermal radiation directly from sunlight. The vegetation consists mainly of terrestrial plants including *Musa* sp. and shrubs such as *Acrosticuum aureum*. Artisan fishing and grazing constitute majority of human activities here. Apart from these, the catchment has several rice farms and other cash crops accounting for runoff of fertilizers and agrochemicals into the river. Other human activities include washing of clothes and bathing. This station was classified as heavily disturbed owing to several human activities or high human presence. Substratum composition is mainly loamy and clay.

2.1.4 Station 4

Station 4 is located in Chiji outskirts. The location is also in an open place with large size. This station represents the duo of deepest (mean depth of 0.958 m) and the highest flow velocity (mean flow velocity of 0.210 m/s) of all the chosen stations. The vegetation consists mainly of *Commelina* sp. and *Nymphaea* sp. The site is relatively free from human activities, being situated far from human settlement. The substratum composition is mainly sand and silt.

2.2 Water sampling for physical and chemical variables

Water samples were collected monthly between July and December, 2013, at each station. Surface water temperatures were recorded with a thermometer. Conductivity, pH, total alkalinity, dissolved oxygen (DO), and biochemical oxygen demand (BOD_5) were determined according to APHA (1998) methods. Water velocity measured in mid-channels on three occasions by timing a float (average of three trials) as it moved over a distance of 10 m (Gordon et al. 1994). Depth was measured in the sample area using a calibrated stick. Nitrate–nitrogen (NO_3–N) and phosphate–phosphorus (PO_4–P) were measured spectrophotometrically after reduction with appropriate solutions (APHA 1998). Substratum composition in each 25 m sampling reach was estimated visually as percentage of silt, loam, and sand (Ward 1992).

2.3 Macroinvertebrate sampling

Kick samples of macroinvertebrates were collected monthly (July–December, 2013) with a D-frame net (500-µm mesh) within an approximately 25-m wadeable portion of the river. Four 3-min samples were taken on each sampling visit to include all different substrata (vegetation, sand, and gravel biotypes) and flow regime zones (riffles, runs, and pools). The four samples were then pooled, representing a single sample for each site. Samples collected from the net were preserved in 70 % ethanol. In the laboratory, samples were washed in a 500-mm mesh sieve to remove sand and macroinvertebrates were sorted using a stereoscopic microscope (magnification ×10). All animals were separated and enumerated and identified under a binocular dissecting microscope. Macroinvertebrate species were identified using available keys (Day et al. 2002; de Moor et al. 2003; Arimoro and James 2008), and keys from elsewhere; Merritt and Cummins (1996) as well as assistance from macroinvertebrate taxonomist/specialists.

2.4 Data analysis

The range, mean, and SD for each physical and chemical variable were calculated per station. Summary of biological metrics including abundance, number of taxa, Shannon diversity index, evenness, Margalef's index and 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 program SP DIVERS (Ludwig and Reynolds 1988). The Student's *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 Gbako 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 (ter Braak 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 <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.

3 Results

3.1 Physicochemical factors

The mean values of the physical and chemical parameters of the study stations are summarized in Table 1. Water temperature ranged from 23.10 to 27.5 °C, while the depth ranged from 21.0 to 107.0 cm. Gbako River is slightly acidic to neutral water with pH values ranging from 6.10 to 7.70. The flow velocity ranged from 0.1 to 2.4 m/s. The river is also not well oxygenated with dissolved oxygen (DO) level ranging from 4.03 to 5.57 mg/L, while the biological oxygen demand (BOD) level ranged from 2.20 to 6.00 mg/L. High levels of conductivity were recorded in the four stations at some points (ranged between 32.00 and 110.00 µS/cm). The values for alkalinity, phosphate, and nitrates ranged from 7.50 to 10.50 mg/L, 0.07 to 1.40 mg/L, and 0.50 to 1.67 mg/L, respectively. Water temperature, flow velocity, pH, conductivity, and alkalinity were similar in both stations sampled, while depth, dissolved oxygen, BOD, phosphates, and nitrates were significantly higher ($P < 0.05$) along the stations but did not show wide variation.

3.2 Macroinvertebrate assemblages and distribution

A total of 676 individuals from 41 invertebrate taxa in 27 families from nine orders were collected from the four stations during the study. Aquatic insects represented 85.4 % of the taxa and 76.6 % of all individuals collected (Table 2). The rest of the fauna was composed of molluscs and crustaceans. Ten macroinvertebrate taxa, *Philaccolus*, *Pseudocloeon*, *Bugilliesia*, *Calopteryx*, *Coenagrion*, *Brachythemus leucostica*, *Gomphus*, *Hydrometra*, *Sphaerudx*, and *Potadoma* species, were found in all the four sampled stations. The overall abundance of benthic invertebrates was not significantly different ($p = 0.480$, $F_{cal} = 0.8438$, $F_{tab/crit} = 2.9011$) among the stations (Fig. 1).

Table 1 Summary of physicochemical characteristics at the study stations Gbako River, Niger State, Nigeria, July–December, 2013

	Station 1	Station 2	Station 3	Station 4	*F* ANOVA	*p* value
Water temperature (°C)	26.67 ± 0.422a (25.00–28.00)	27.5 ± 0.671a (25.00–30.00)	26.02 ± 0.920a (23.10–28.00)	26.17 ± 0.527a (24.00–27.5)	1.021	0.404
Depth (cm)	32.00 ± 3.055ab (27.00–47.00)	26.33 ± 2.060b (21.00–33.00)	31.67 ± 4.104ab (21.00–46.00)	56.17 ± 12.644a (21.00–107.00)	3.739[a]	0.028
Flow velocity (m/s)	0.75 ± 0.563a (0.60–0.90)	1.02 ± 0.280a (0.20–2.10)	0.95 ± 0.195a (0.10–1.40)	1.35 ± 0.327a (0.20–2.40)	1.099	0.373
pH	6.80 ± 0.192a (6.10–7.42)	7.15 ± 0.117a (6.80–7.49)	7.28 ± 0.114a (6.90–7.70)	7.06 ± 0.149a (6.50–7.47)	1.866	0.168
DO (mg/L)	5.47 ± 0.180a (5.00–6.10)	4.03 ± 0.250b (3.10–5.00)	4.08 ± 0.280b (3.20–5.20)	5.57 ± 0.275a (4.70–6.50)	11.424[a]	1.39E−04
BOD (mg/L)	3.10 ± 0.238a (2.30–3.90)	4.82 ± 0.202b (4.20–5.40)	5.05 ± 0.319b (4.10–6.00)	2.82 ± 0.178a (2.20–3.30)	22.898[a]	1.12E−06
Conductivity (µS/cm)	55.83 ± 11.226a (32.00–110.00)	71.33 ± 7.915a (48.00–100.0)	61.83 ± 7.300a (40.00–90.00)	64.67 ± 8.098a (44.00–100.00)	0.539	0.661
Alkalinity (mg/L)	9.54 ± 0.244a (8.70–10.03)	10.05 ± 0.120a (9.60–10.50)	9.92 ± 0.105a (9.60–10.20)	9.45 ± 0.401a (7.50–10.20)	1.370	0.281
Phosphate (mg/L)	0.11 ± 0.0220a (0.06–0.20)	1.02 ± 0.099b (0.75–1.40)	0.83 ± 0.081b (0.61–1.10)	0.21 ± 0.104a (0.07–0.71)	29.297[a]	1.21E−04
Nitrates (mg/L)	0.60 ± 0.014a (0.55–0.64)	1.56 ± 0.016b (1.50–1.60)	1.46 ± 0.080b (1.20–1.67)	0.57 ± 0.019a (0.50–0.62)	157.99[a]	1.15E−07

DO dissolved oxygen, *BOD* biological oxygen demand

Data are the mean ± SE derived from monthly values with minimum and maximum values in parenthesis. Different lowercase letters in a row show significant differences ($p < 0.05$) indicated by Turkey's HSD significant difference tests

[a] Significantly calculated *F* value detected by ANOVA

Table 2 The overall composition, abundance, and distribution of macroinvertebrate taxa in Gbako River, Niger State, July–December, 2013

Taxon	Code	Station 1	Station 2	Station 3	Station 4	All stations
Order Coleoptera						
Family Dytiscidae						
Philaccolus sp.	Phi	1	7	7	1	16
Canthoyporus sp.	Can	1	3	–	–	4
Cybister sp.	Cyb	2	1	–	–	3
Philodytes sp.	Phl	10	–	4	1	15
Coelhyrus sp.	Coe	1	1	–	5	7
Hyphydrus sp.	Hyp	–	7	–	–	7
Family Gyrinidae						
Orectogyrus sp.	Ore	7	5	–	2	14
Family Notonelidae						
Hydrocanthus sp.	Hyd	2	2	–	2	6
Family Corixidae						
Micronecta sp.	Mic	–	–	–	2	2
Family Hydraenidae						
Hydrophilia sp.	Hyr	2	3	–	–	5
Family Aeshnidae						
Aeshnx sp.	Aes	–	1	–	–	1
Family Hydrophilidae						
Helochares sp.	Hel	–	1	4	8	13
Hydrophilus sp.	Hyo	–	3	–	8	11
Elmida larva						
Elmid	Elm	–	3	3	–	6
Total		26	37	18	29	110
Order Ephemeroptera						
Family Baetidae						
Pseudocloeon sp.	Pse	8	3	5	1	17
Bugillisia sp.	Bug	15	22	40	37	114
Cloeon sp.	Clo	1	1	2	–	4
Family Oligoneuriidae						
Oligoneux sp.	Oli	2	–	–	1	3
Family Polymitarcyidae						
Polymix sp.	Pol	–	–	–	3	3
Total		26	26	47	42	141
Order Zygoptera						
Family Calopterygidae						
Calopteryx sp.	Cal	9	11	13	4	37
Family Coenagrionidae						
Coenagrion sp.	Coe	4	4	4	11	23
Family Platycnemididae						
Platycnemid sp.	Pla	–	3	–	–	3
Mesocnemis sp.	Mes	–	–	2	–	2
Total		13	18	19	15	65
Order Anisoptera						
Family Libellulidae						
Bradinopyga sp.	Bra	2	22	–	17	41
Brachythemus leucostica	Brl	14	5	26	17	62
Xyxomma sp.	Xyx	1	1	–	–	2
Family Gomphidae						
Gomphus sp.	Gom	6	1	3	2	12

Table 2 continued

Taxon	Code	Station 1	Station 2	Station 3	Station 4	All stations
Lestinogomphus sp.	Les	3	–	1	–	4
Family Corduliidae						
Cordulex sp.	Cor	2	2	–	1	5
Total		28	31	30	37	126
Order Hemiptera						
Family Hydrometridae						
Hydrometra sp.	Hyd	2	2	2	6	12
Family Nepidae						
Nepa sp.	Nep	2	–	5	–	7
Family Velidae						
Velia caprai	Vec	–	11	25	18	54
Total		4	13	32	24	73
Order Diptera						
Family Psychodidae						
Psychodid sp.	Psy	1	–	–	–	1
Family Tabanidae						
Tabanus sp.	Tab	–	–	1	–	1
Total		1	–	1	–	2
Order Mollusca						
Gastropoda						
Neritina rubricate	Ner	1	14	13	–	28
Family Sphaeriidae						
Sphaerudux sp.	Sph	1	2	3	2	8
Family Thiaridae						
Potadoma	Psc	1	7	3	2	13
Family Unimidae						
Unima sp.	Uni	–	1	6	2	9
Total		3	24	25	6	58
Order Crustacea						
Family Potamanthidae						
Sudanonanles sp.	Pot	1	–	1	–	2
Amphipoda	Amp	17	–	30	51	98
Total		18	–	31	51	100
Order Plecoptera						
Family Perlidae						
Neoperla sp.	Neo	1	–	–	–	1
Total no. of taxa/species (*S*)		29	29	23	24	
Total sum of individuals (*N*)		120	149	203	204	676

Coleoptera was represented by the highest number of families (eight) (Dytiscidae, Gyrinidae, Notonelidae, Corixidae, Hydraenidae, Aeshnidae, Hydrophilidae, and Elmidae) collected, comprising of fourteen (14) different taxa. They constituted 16.3 % (110 individuals) of the total number of individuals collected (Fig. 2). The highest number (37 individuals) of Coleoptera individuals was collected from Station 2, while the least (18 individuals) was collected in Station 3 (Fig. 4). *Philodytes* was the predominant taxa of Coleoptera occurring in very high numbers in Station 2 with no member collected in Station 2. Coleoptera taxa, *Philaccolus*, was found to be the only Coleopteran that appeared in all the stations sampled, while the family, Aeshnidae, was found in only Station 2 in a very few numbers.

Ephemeroptera was represented by three families (Baetidae, Oligoneuriidae, and Polymitarcyidae) and five different taxa. This was the only member of the EPT-sensitive invertebrates that was found abundant in the

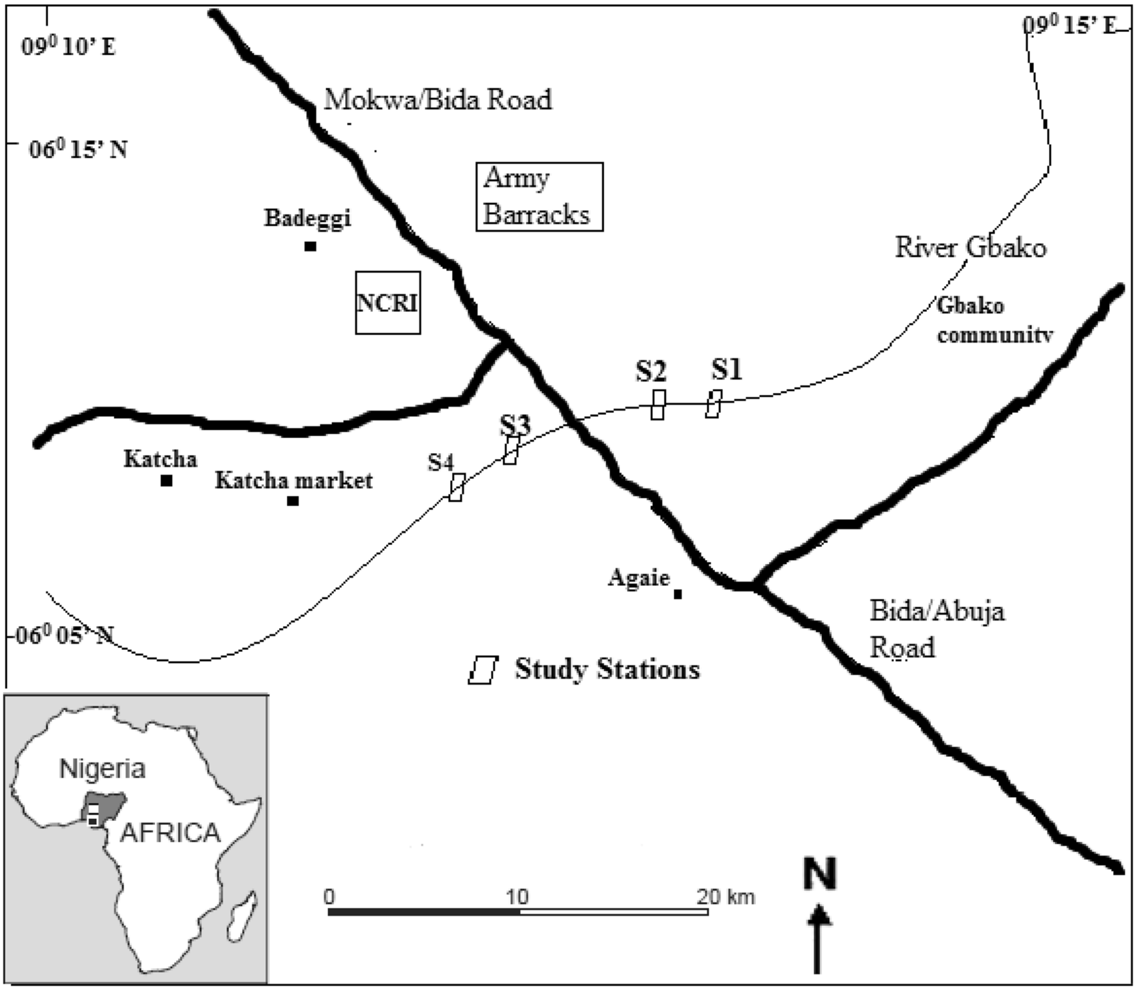

Fig. 1 Map of Gbako River showing the study stations. *Inset*: Africa showing the location of Niger State

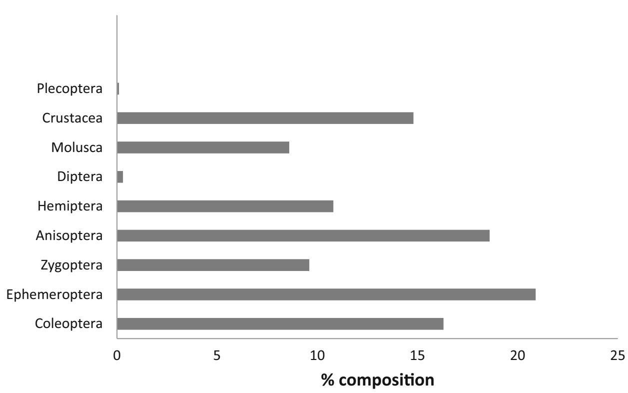

Fig. 2 Percentage contribution of the different groups of macroinvertebrates in Gbako River, Niger State, July–December, 2013

sampled stations. Ephemeroptera was also the most abundant group of invertebrate sampled in all the stations, with 20.9 % contribution and consequent 141 individuals.

The family, Baetidae, stood out in numbers with over 90 % of the overall Ephemeroptera order sampled in all the stations, while, inversely, the families Oligoneuriidae and Polymitarcyidae contributed the least numerical strength of the Ephemeroptera order. The taxon, *Bugilliesia*, was the most abundant Baetidae in numbers. *Pseudocloeon* and *Bugilliesia* species were found to be present in all the sampled stations.

The order Zygoptera had 9.6 % representation with 65 individuals in all the sampled stations. It was made up of three families (Calopterygidae, Coenagrionidae and Platycnemididae) and four taxa/species. Two taxa, *Calopteryx* and *Coenagrion*, were found to be present in all the four stations, while *Platycnemid* and *Mesocnemis* taxa appeared only in Stations 2 and 3, respectively.

Anisoptera had a significant impact in the numerical strength of the overall sampled invertebrates. It represented the second to the highest (Coleoptera) in number, with 126 individuals and consequent 18.6 % constitution of the overall sampled invertebrates. It was represented by four families (Libellulidae, Aeshnidae, Gomphidae and Cordulidae) and six different genera/taxa. The taxa, *Brachythemus* *leucostica*, was found in all the sampled stations, while *Lestinogomphus* was found in only Station 1.

The Hemipterans had a significant amount in the overall number of sampled invertebrates. They were composed of 10.8 % of the entire sampled invertebrates, with 73 individual members. Stations 3 and 4 had the highest (34) and lowest (4) numbers of sampled Hemipterans, respectively. They were composed of three families, namely, Hydrometridae, Nepidae and Velidae. The representatives of the families, Hydrometridae and Velidae, were observed in all the four stations.

The Dipterans were very poorly represented throughout the stations with two families (Psychodidae and Tabanidae) and only one taxon for each of the families, and these were observed in Stations 2 and 3, respectively. They had a 0.3 % representation in the overall sampled invertebrates.

The order Mollusca was composed of 58 individuals. It was made up of 8.6 % composition of the overall sampled invertebrate organisms. Four families with one taxon each were identified. The taxa, *Sphaerudux* and *Pachymelania aurita*, were found in all the stations sampled. Crustaceans were represented by 100 individuals and constituted about 14.8 % of the overall invertebrates. The paucity of Plecoptera in the study was evident with the presence of *Neoperla* sp. of the family, Perlidae, that was represented by only one individual in Station 1.

The percentage species composition in the different sampling stations is shown in Fig. 3. Stations 1 and 2 jointly contributed the highest percentage of species (27.6 % each), followed by Station 4 (22.9 %), while Station 3 recorded the least.

The distribution of major benthic macroinvertebrate taxa is shown in Fig. 4. The total number of taxa and m^2), 29 (149 ind/m^2), 23 (203 ind/m^2), and 24 (204 ind/m^2), respectively, making Stations 1 and 2 the highest joint contributors of taxa and Station 3 the least contributor of taxa. Station 4 contributed the highest number of individuals sampled (204 ind/m^2), followed closely by Station 3 (203 ind/m^2), while Station 1 accounted for the least (120 ind/m^2).

3.3 Diversity, evenness, dominance, taxon richness, and similarity indices

A summary of taxon richness, diversity, evenness, dominance, and similarity indices of macrobenthic invertebrates at Gbako River study stations from July to December, 2013, is shown in Table 3. Station 1 exhibited the highest taxa richness (5.849) closely followed by that from Station 2 (5.596). Stations 3 and 4 recorded much lower values of 1.614 and 1.68, respectively, making Station 3 the station with the lowest taxa richness. The order of increase in diversity followed from Station 4 through Station 1 with values of 2.301, 2.396, 2.624, and 2.875, respectively. The highest value of evenness (0.6265) was recorded in Station 2 followed closely by Station 1 (0.6114) and then Station 3 (0.5708), while the lowest value of evenness was recorded in Station 4. The value of dominance for the four stations was not far away from each other, with Station 2 having the highest (0.9239) value, while Station 4 had the lowest value (0.8741). The highest values for taxon richness and Shannon diversity were recorded in Station 1, while the lowest value for Shannon diversity, evenness, and Simpson's dominance was recorded in Station 1.

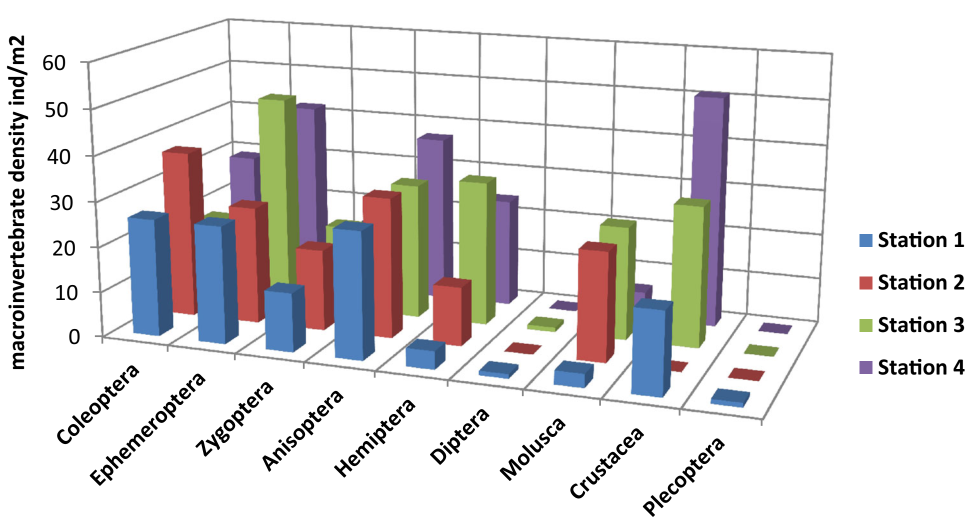

Fig. 3 Distribution of major benthic macroinvertebrate taxa along the stations of Gbako River, Niger State, July–December, 2013

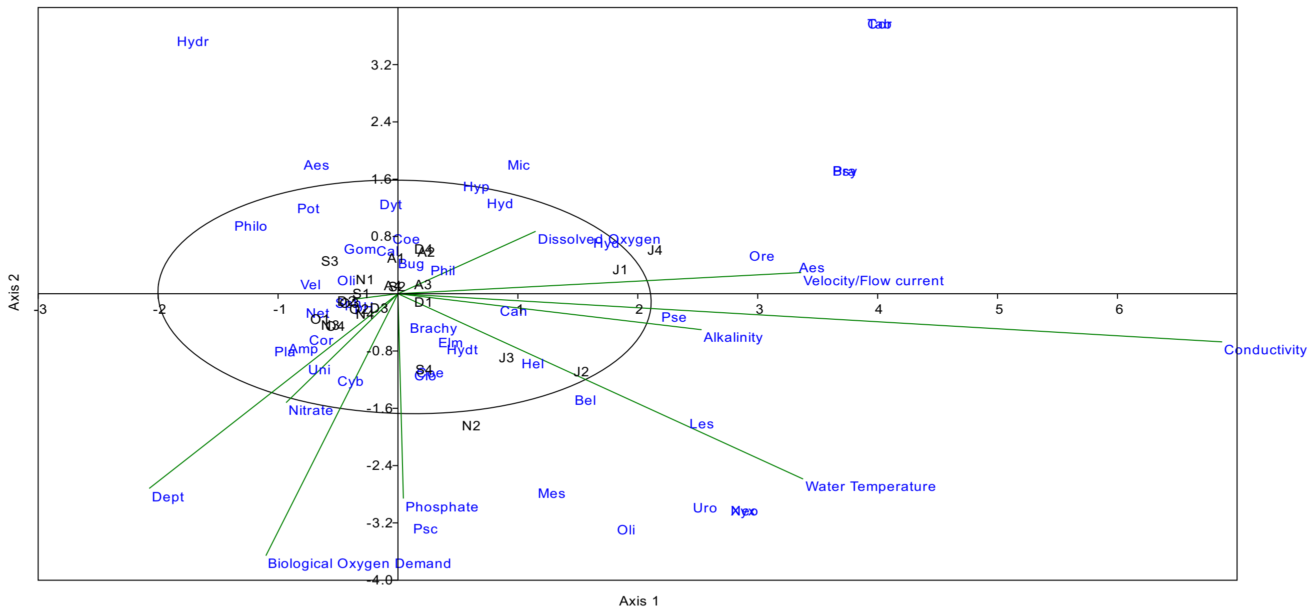

Fig. 4 Triplot of first and second CCA axes of macroinvertebrate taxa, environmental variables, and their corresponding sampling stations. Scale in SD units is −1 to 1 for both the invertebrate and environmental variable scores. Full names for abbreviation codes of invertebrate taxa are given in Table 2. Monthly code: *J* July, *A* August, *S* September, *O* October, *N* November, *D* December; Station numbers: 1, 2, 3, 4

Table 3 Taxon richness, diversity, evenness, and dominance indices of benthic macroinvertebrates in Gbako River, Niger State, July–December, 2013

	Station 1	Station 2	Station 3	Station 4
No. of taxa/species (*S*)	29	29	23	24
No. of individuals (*N*)	120	149	203	204
Taxa richness (*d*) (Margalef's index)	5.849	5.596	4.141	4.325
Shannon diversity (*H*)	2.875	2.624	2.396	2.301
Evenness index (*E*)	0.6114	0.6265	0.5708	0.4963
Simpson dominance (*C*)	0.9231	0.9236	0.8939	0.8741

3.4 Macroinvertebrates and environmental relationships

The relationship between macroinvertebrates and environmental variables is shown in Fig. 4 and Table 4. The extent of variation or inertia in macroinvertebrate assemblage composition in the studied stations of Gbako River was equivalent to 0.481 for axis 1, 0.276 for axis 2, and 0.238 for axis 3. The CCA ordination revealed strong relationships between species abundances and measured environmental variables. The first canonical axis (axis 1) accounted for 27.3 % of the variation in the data set, the second axis (axis 2) accounted for 15.67 % of the variation in the data set, while the third axis (axis 3) accounted for 13.51 % of the data set. An unrestricted Monte Carlo permutation test indicated that all canonical axes were significant ($p < 0.05$). The main environmental gradient (axis 1) was determined by temperature, flow velocity, conductivity, alkalinity, and phosphate. The second environmental gradient (axis 2) was determined by depth, pH, BOD, and nitrate. The third environmental gradient showed strong correlation with temperature, DO, BOD, and phosphate (Fig. 4; Table 4). Most of the samples taken from Station 2 were positioned on the right, while the most of the samples from Stations 1, 3, and 4 were positioned around the center of the CCA graph.

4 Discussion

4.1 Chemistry of Gbako River

The physicochemical qualities of water, immediate substrate of occupation, and food availability are important factors affecting the abundance of benthic invertebrates (Reuda et al. 2002; Nelson and Roline 2003; Arimoro and Ikomi

Table 4 Weighted intraset correlations of environmental variables with the axes of canonical correspondence analysis (CCA) in Gbako River, Niger State

Variable	Axis 1	Axis 2	Axis 3
Eigenvalue	0.481	0.276	0.238
Variation of species data explained (%)	27.3	15.67	13.51
Temperature	**0.42**	−0.01	**−0.42**
Dept	−0.24	**−0.46**	0.028
Flow velocity	**0.43**	−0.14	0.18
pH	−0.02	−0.36	0.25
Dissolved oxygen	0.14	0.30	0.41
Biological oxygen demand	−0.13	−0.38	**−0.47**
Conductivity	**0.86**	0.01	−0.03
Alkalinity	0.31	−0.01	−0.07
Phosphate	**0.45**	−0.12	−0.39
Nitrate	−0.29	0.32	0.26

Significance of the axis by the Monte Carlo permutation test is given by $F = 1.763$ ($p < 0.05$). All canonical axes were significant. Values in bold indicate significant difference at $p < 0.05$

2008; Arimoro and Muller 2010). The physicochemical parameters of Gbako River presented the river as fairly good quality water. However, water conditions were better in the upstream station (Station 1) and further downstream (Station 4) than in the middle reaches (Stations 2 and 3). High concentrations of dissolved oxygen, lower nutrient, and BOD levels in Stations 1 and 4 indicated that the water at Stations 1 and 4 was only slightly disturbed by anthropogenic activities as confirmed by the distance of these stations from human settlement. On the contrary, lower concentrations of dissolved oxygen, higher nutrient, conductivity levels, and BOD levels in Stations 2 and 3 inferred that the two stations were perturbed, probably due to the influx of washing detergents, organic wastes, and other pollutants, owing to the massive anthropogenic activities that were observed. It has been reported in a number of studies that intense human activities resulting from discharge of organic pollutants into streams lead to increase in nutrient levels and in biological oxygen demand which in turn affects the distribution and abundance of benthic invertebrates (Bauernfeind and Moog 2000; Dickens and Graham 2002; Walsh 2000; Walsh et al. 2002; Arimoro et al. 2007; Gómez et al. 2008; Masese et al. 2009; Gichana et al. 2015; Mwedzi et al. 2016). The mean air and water temperatures obtained are typical of African tropical Rivers (Masese et al. 2009; Andem et al. 2014).

4.2 Macroinvertebrate assemblages

Majority of the animals recorded in this study are widely distributed elsewhere in Nigeria (Ikomi et al. 2005; Arimoro et al. 2007, 2015; Imoobe 2008). A total of 41 taxa of macroinvertebrates were recorded in this study at Gbako River. This number is much higher than the total of invertebrate species reported from perturbed and grossly polluted rivers in northern Nigeria (Adakole and Annune 2003; Emere and Nasiru 2009; Akaahan 2014). Relatively, less human impacts in the study stations, in contrast to other water bodies that are used for dumping of human wastes and other pollution agents, could be responsible for the high abundance (number of individuals) and diversity of benthic invertebrates that was recorded in this study. The high abundance (number of individuals) and diversity of benthic invertebrates recorded in this study could also be attributed to the heterogeneous nature of the vegetation of the littoral zone of the study stations, which, of course, served as suitable habitat for a more diverse benthic fauna.

The dominant benthic macroinvertebrates in Gbako River were the aquatic insects. This observation is similar to the observation of Imoobe (2008) in Ologe Lagoon, Nigeria, and that of Arimoro et al. (2015), but differs from the dominance by mollusks reported in Lagos Lagoon and Porto Novo Creek (Ajao and Fagade 2002). These differences in the dominance of benthic invertebrates are linked to the environmental conditions of the various water bodies. The abundance of Ephemeroptera, Coleoptera, and Anisoptera in all the stations is an indication that these sites are relatively free from gross pollution. It has been reported that the species of Coleoptera is found in mostly very clean waters (Merritt and Cummins 1996; Andem et al. 2014). The presence of coleoptera in an aquatic system, along with other less tolerant species such as Ephemeroptera, Plecoptera, Tricoptera, and Odonata has been observed to reflect clean water conditions (Miserendino and Pizzolon 2003). Ephemeropterans were the most dominant group with Baetidae being the dominant family and *Bugilliesia* sp. being the preponderant species.

The abundance of mayflies, Coleopteran (*Gyrinus* spp., *Dytiscus* spp.), and Anisoptera in all the stations studied is an indication that the sites are relatively free from gross pollution. Related studies conducted in similar freshwater bodies in Nigeria (Edokpayi et al. 2000; Edema et al. 2002; Ikomi et al. 2005; Arimoro et al. 2007) and elsewhere (Walsh et al. 2002; Reuda et al. 2002; Nelson and Roline 2003; Miserendino and Pizzolon 2003; Azrina et al. 2006; Odume et al. 2012) have associated the presence of these organisms in a site to clean water conditions. These species are very sensitive to reductions in dissolved oxygen and are not found in areas where oxygen levels are consistently low. Therefore, these organisms are proposed here as indicators of fairly clean water conditions in Gbako River and could also be used in biomonitoring assessment of similar freshwater bodies in northern Nigeria.

The ubiquity of the anisopterans could be attributed to the covering of the water body by floating vegetation, which must have created suitable habitat for the macroinvertebrates. In this study, only one species of stonefly (Plecoptera) was collected in Station 1. This, however, is not strange as Dobson et al. (2002) had earlier reported the paucity of stonefly nymphs in tropical African streams.

4.3 Macroinvertebrates relationship with environmental variables

This study revealed that macroinvertebrate communities responded to changes in water quality along the river stations. The better (highest) diversity, dominance, and taxa richness at Station 1 and can be attributed to high water quality and good habitat quality of the station. The plausible reason for this is that human activities were drastically reduced there as also confirmed with the environmental variables. This may be an indication that the substratum was more stable than the other study stations. The forest vegetation that surrounded Station 1 was a good source of allochthonous organic matter for stream biota as well as helped maintain low water temperatures and provided diverse habitats for a variety of macroinvertebrates, leading to increased diversity.

Canonical correspondence analysis (CCA) separated the less impacted from the more impacted sites and also showed that the invertebrate fauna was significantly associated with environmental factors of Gbako River. The CCA identified conductivity as an important variable structuring the macroinvertebrate assemblages. Stations 2 and 3 had the highest values for conductivity, nitrates, and phosphates, while Stations 1 and 4 had higher dissolved oxygen levels and lower levels of conductivity, nitrates, and phosphates between them than other stations. The combination of variables might be used to identify and describe the multi-scale stressor. The correlation of many environmental variables with the axis was relatively high with the CCA but was not statistically significant. However, these perceived and estimated significances may be the results of the unmeasured environmental variables. Stations 1 and 4 had more of the sensitive benthic invertebrates than Stations 2 and 3 as they were favored by higher dissolved oxygen levels and lower levels of conductivity, nitrates, and phosphates. High values of nitrates and phosphates indicate eutrophication. Eutrophication will in turn lead to oxygen depletion in the water body, and this condition would affect macrobenthic invertebrate assemblages since they are reliant on oxygen availability. The dominance of molluscs in Stations 2 and 3 could be regarded as early warning signals of pollution loads that can degrade water quality and the general health of the ecology. Species diversity, richness, dominance, and evenness indices at the various sampling stations throughout the 4 months sampling reflected the water quality of each of the stations. High species diversity at the upstream station (Station 1) was factored by unpolluted or unimpacted conditions, while the lower species diversity in the other stations could represent environmental stress due to anthropogenic (human) activities in these areas.

This study provides information on the present status of water quality and baseline survey of macrobenthic fauna of Gbako River, thereby forming the foundation for long-term assessment and for the use of bioindicators for environmental monitoring and management of this system. The increase in pollution in some selected sections of the river (Stations 2 and 3) needs to be taken care of by applying appropriate corrective measures to keep the water quality of the stretch in good condition. In addition, the abundance and diversity of organisms reported for the entire stretch of the river indicate that Gbako River is a fairly clean water body and the indicator organisms identified could be used in biomonitoring assessment of similar freshwater bodies in northern Nigeria.

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