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Temporal and spatial variability in macroinvertebrate community structure in relation to environmental variables in Gbako River, Niger State, Nigeria

UNIQUE N. KEKE[1,2*], FRANCIS O. ARIMORO[1], YOHANNA I. AUTA[1] & ADESOLA V. AYANWALE[1]

[1]*Applied Hydrobiology unit, Department of Biological Sciences, Federal University of Technology, P.M.B. 65, Minna, Niger State, Nigeria*

[2]*Formerly of Science Laboratory Technology, Federal Polytechnic, Bida, Miger State, Nigeria*

Abstract: Temporal and spatial variability in macroinvertebrate community structure in relation to environmental variables in Gbako River, Niger State, Nigeria was evaluated monthly for a period of six 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. High concentrations of dissolved oxygen, lower nutrient and BOD levels were recorded in stations 1 and 4 while lower concentrations of dissolved oxygen, higher nutrient, conductivity levels, and BOD levels were recorded in stations 2 and 3. There was an abundance of the pollution sensitive taxa such as Ephemeroptera (mayflies), Coleopteran (*Gyrinus* spp., *Dytiscus* spp.) and Anisoptera (*Gomphus* sp., *Lestinogomphus, Cordulex* spp.) in all the stations, especially the upper and lower reaches, whereas on the other hand, some pollution tolerant species like the Crustaceas, Dipterans, Mollusca (*Neritina rubricate, Potadoma* sp.) were merely restricted to the middle reaches (stations 2 and 3). Of the total number of individual benthic invertebrates recorded during the entire study, 53% was recorded in the dry season while the remaining 47% was recorded in the wet season. However, this difference was not statistically significant ($P > 0.05$) when the student t-test ($t_{stat/cal} = 0.388$), $t_{crit} = 2.447$) for the densities and abundances of macroinvertebrates recorded during the two sampling seasons was applied. Canonical Correspondence Analysis (CCA) separated the less impacted from the more impacted sites and also showed that the invertebrate fauna was significantly ($P < 0.05$) associated with environmental factors of Gbako River. The CCA identified conductivity, depth, flow velocity, dissolved oxygen, biological oxygen demand, and phosphates as important variables structuring the macroinvertebrate assemblages. The higher number of benthic invertebrates recorded in the dry season could be attributed to the unstable nature of the substrates through inputs and influx of storm water during the rainy season months.

Key words: Abundance, anthropogenic activities, diversity index, ecological information, environmental factors, Ephemeroptera, physicochemical parameters.

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Introduction

Historically, the assessment of water quality in freshwater ecosystems has usually been through the measurement of physico-chemical variables; but such measurements alone cannot provide ecological information, because the synergistic effects of pollution on aquatic biotic community

Corresponding Author; e-mail: uniquekkn@gmail.com

may not be fully and easily assessed (Arimoro *et al.* 2015; Kasangaki *et al.* 2006; Rosenberg & Resh 1993). Among aquatic biota, macro-invertebrates are an important component of the ecosystems, because they serve as a critical intermediate pathway for the transportation and utilisation of energy and matter. Also, individual taxa respond differently to a variety of pollutants and are able to provide an indication of water quality over varying time periods (Bonada *et al.* 2006; Odume & Muller 2011; Wallace & Webster 1996). Macroinvertebrate based biomonitoring approaches, including single biotic indices such as the South African Scoring System (SASS version 5; Dickens and Graham 2002), multimetric indices such as the index of biotic integrity (IBI-12) (Böhmer *et al.* 2004) and multivariate techniques such as the Australian River Assessment System (AUSRIVAS) (Turak *et al.* 2004) have been developed and applied to assess water quality of rivers and streams (Bonada *et al.* 2006; Jørgensen *et al.* 2005). In addition, invertebrates also have potential utility in assessing other environmental pressures such as sedimentation (Extence *et al.* 2011).

The use of benthic macroinvertebrates as biological indicators has been widely applied in river quality assessment, because these organisms are affected by changes in the natural variables of rivers such as width, depth, type of substratum, water velocity, and physicochemical variables which are provoked by both natural and human activities (Nair *et al.* 1989; Rosenberg & Resh 1993). The relative importance of these factors varies among streams in relation to the spatial and temporal scale of investigation. Aquatic macroinvertebrate communities are structured by a wide range of biotic and abiotic factors. These factors act as a template for the evolution of species traits creating selection pressures that adapt species successfully to occupy the variety of biotopes within a freshwater system (Li *et al.* 2010). Given the relation between macro-invertebrate taxa and the abiotic and biotic factors present in a creek, the benthic community can be used to monitor the quality of the aquatic environment because the community has a central role in the food web (Salgado *et al.* 2007). The spatial distribution of benthic invertebrates provides a sensitive indicator of the effect of land use (Hawkins *et al.* 2000).

The influence of environmental variability on macroinvertebrate communities and many other aspects of lotic benthos, however, has scarcely been explored in most Afrotropical streams. Water bodies in Niger State are used for extensive fisheries activities and serve as spawning and nursery ground for a number of fish species, which depend largely on several macroinvertebrate organisms for survival. They are also used in the irrigation of crops as well as sources of drinking water for both human and cattle. Therefore, detailed studies are required to understand some aspects of ecology of macroinvertebrate taxa that exist therein as bioindicators to monitor the health of the water bodies. Information regarding the structure and functioning of macroinvertebrates in Gbako River on the physical and chemical status as well as the macroinvertebrates community is nonexistent. Therefore, the principal objectives of the study were to identify benthic invertebrate taxa and physicochemical variables that can act as indicators of water quality and catchment properties in time and space, and also to investigate relationships between invertebrate communities and selected environmental factors using canonical correspondence analysis (CCA).

Materials and methods

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 along a channel from north to south through Gbako, Shiroro, Chanchanga, Katcha, Baro and 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 this research, the study area was divided into four Stations. Station 1 is located at Badeggi. The vegetation cover is thick with a dense tunnel of trees and consists mainly of emergent macrophytes, namely *Nymphae, Lotus, etc.* The marginal vegetation is composed mainly of *Cocos nucifera, Havea brasiliensis, and Raphia vinifera.* This station is located at the outskirts of the town and is relatively free from human activities. Substratum composition is muddy. Station 2 is at Jibo village. It is located under a non- motorable bridge. Aquatic vegetation was not thick as much as station 1. Water velocity is higher than stations 1 and 3 (mean value = 0.109 m s^{-1}). It represents the shallowest of the chosen stations (0.303 m). The vegetation consists mainly of *Commelina* spp.,

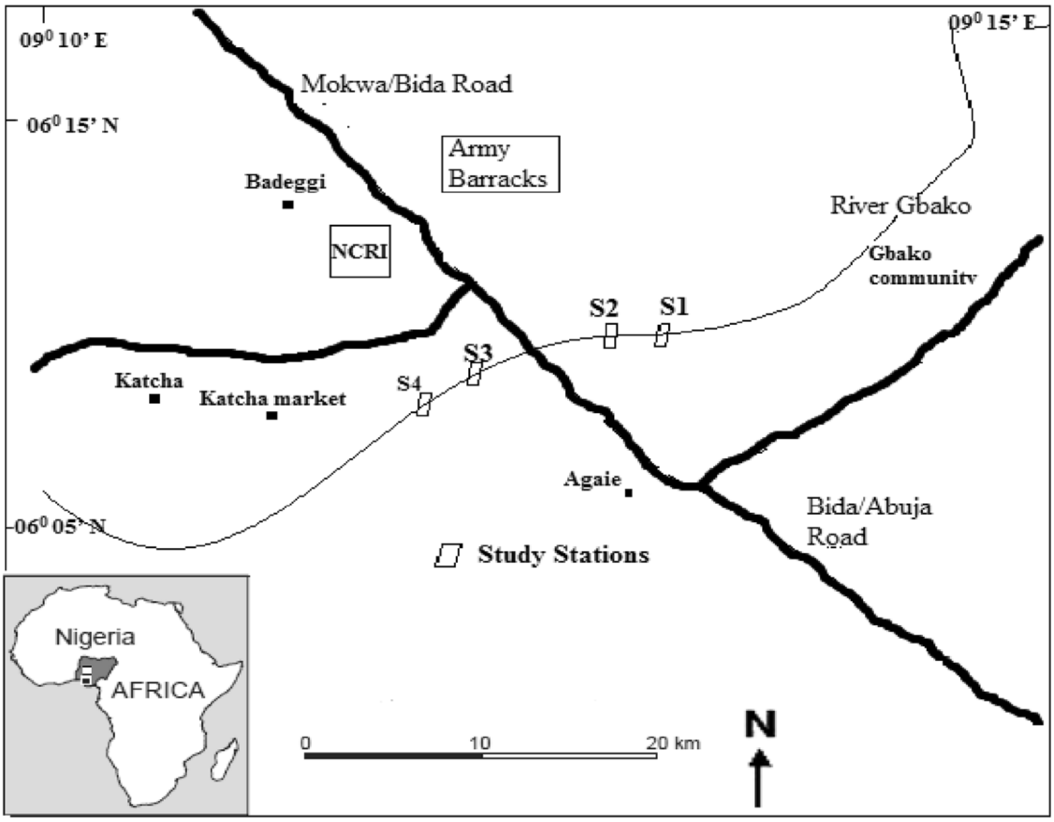

Fig. 1. Map of Gbako River showing the study stations. (Source: www.glocalimjournal.net 2014).

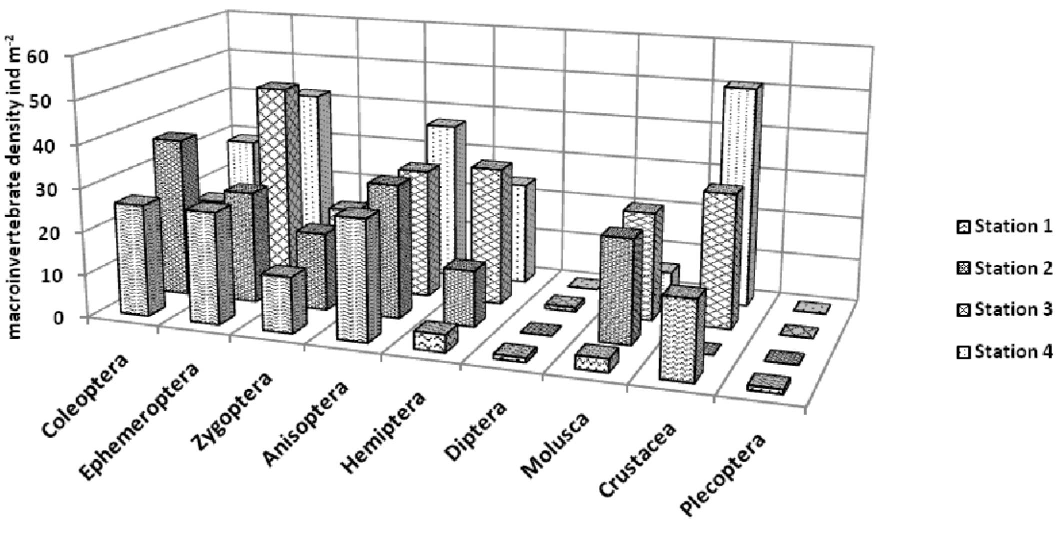

Fig. 2. Total Distribution of major benthic macroinvertebrate taxa along the Stations of Gbako river, Niger State, July to December, 2013.

Nymphaea spp., *Pistia stratiotes* and *Panicum repens*. Artisan fishing, washing of clothes, and bathing are the major human activities that occur at this station. Substratum composition in this station is loamy. Station 3 is located in Katcha town, under a motorable bridge. It is 0.37 m – 0.70 m deep with flow velocity of 0.021 m s^{-1} – 0.100 m s^{-1}. It has an open vegetation and, receives 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. Other human activities include washing of clothes and bathing. Substratum composition is mainly loamy and clay. Station 4 is located in Chiji outskirts. The location is also in an open place with large size. This station is the deepest (mean depth of 0.958 m) and has the highest flow velocity (mean flow velocity of 0.210 m s^{-1}) 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.

Water Sampling for Physical and Chemical Variables

Water samples were collected monthly between July and December, 2013 at each Station. A mercury-in-glass thermometer was used for measuring temperature. A Hanna HI 9828 multi-probe metre was used for measuring values of dissolved oxygen (DO), electrical conductivity, total dissolved solids 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 rod. Water samples were collected in 1L 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 hours of sampling.

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 lm mesh sieve to remove sand. The macroinvertebrates were then sorted using a stereoscopic microscope. 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), and keys from Merritt and Cummins (1996) as well as assistance from macroinvertebrate taxonomist/ specialists.

Data Analysis

Taxa richness (Margalef's index), diversity (Shannon index) and evenness indices were calculated using the computer BASIC programme SP DIVERS (Ludwig & Reynolds 1988). The range, mean and standard deviation for each physical and chemical variable was calculated per station. Means variables were compared between stations using one-way analysis of variance (ANOVA). Prior to ANOVA, the assumptions of normality and Means 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. 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 Gbako River. Cluster analysis based on Bray–Curtis similarity index was used to ascertain whether macroinvertebrate assemblage distribution was influen-ced 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).

Table 1. Physicochemical characteristics at Gbako River study stations, July–December, 2013.

	Station 1	Station 2	Station 3	Station 4
Water temperature (°C)	26.67 ± 0.42^{a}	27.5 ± 0.67^{a}	26.02 ± 0.92^{a}	26.17 ± 0.53^{a}
Depth (cm)	32.00 ± 3.0^{ab}	26.33 ± 2.06^{b}	31.67 ± 4.10^{ab}	56.17 ± 12.64^{a}
Flow velocity (m s^{-1})	0.75 ± 0.56^{a}	1.02 ± 0.28^{a}	0.95 ± 0.20^{a}	1.35 ± 0.33^{a}
pH	6.80 ± 0.19^{a}	7.15 ± 0.11^{a}	7.28 ± 0.11^{a}	7.06 ± 0.15^{a}
DO (mg L^{-1})	5.47 ± 0.18^{a}	4.03 ± 0.25^{b}	4.08 ± 0.28^{b}	5.57 ± 0.28^{a}
BOD (mg L^{-1})	3.10 ± 0.24^{a}	4.82 ± 0.20^{b}	5.05 ± 0.32^{b}	2.82 ± 0.19^{a}
Conductivity (µS cm^{-1})	55.83 ± 11.23^{a}	71.33 ± 7.92^{a}	61.83 ± 7.30^{a}	64.67 ± 8.10^{a}
Alkalinity (mg L^{-1})	9.54 ± 0.24^{a}	10.05 ± 0.12^{a}	9.92 ± 0.11^{a}	9.45 ± 0.40^{a}
Phosphate (mg L^{-1})	0.11 ± 0.022^{a}	1.02 ± 0.10^{b}	0.83 ± 0.08^{b}	0.21 ± 0.10^{a}
Nitrate (mg L^{-1})	0.60 ± 0.01^{a}	1.56 ± 0.02^{b}	1.46 ± 0.08^{b}	0.57 ± 0.20^{a}

Values are the means ± SE. Different superscript letters in a row show significant differences indicated by Turkey's HSD ($P < 0.05$).

Prior to the final CCA,variables exhibiting high multicolinearity (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

Physicochemical factors

The mean values and standard errors of the physical and chemical parameters of the study stations are shown in Table 1. Gbako River water is slightly acidic to neutral; also not very well oxygenated (4.03 mg L^{-1} to 5.57 mg L^{-1}), with high levels of conductivity recorded in the four stations at some points (ranged between 32.00 µS cm^{-1} to 110.00 µS cm^{-1}). Higher values of BOD were observed in Stations 2 and 3 than other stations. The highest value of BOD (6.00 mg L^{-1}) in all the stations was recorded in July in station 3 as a result of low DO value. The values for alkalinity, phosphate, and nitrate ranged from 7.50 mg L^{-1} to 10.50 mg L^{-1}, 0.07 mg L^{-1} to 1.40 mg L^{-1}, and 0.50 mg L^{-1} to 1.67 mg L^{-1}, respectively. There was no steady trend of increase or decrease in phosphate levels in all the stations. The monthly nitrate values varied among the stations. Repeated measures ANOVA showed that water temperature, flow velocity, pH, conductivity, and alkalinity were not significantly different ($P > 0.05$) in all Stations sampled. However, depth, DO, BOD, phosphate and nitrate were significantly higher ($P < 0.05$) along the stations but did not show wide variation.

Distribution and composition of macroinvertebrates community in the study area

There were a total of 676 individuals from 41 inveretebrate taxa in 27 families from 9 orders were collected from the four stations, dominated by aquatic insects. Other fauna included Molluscs and Crustaceans. 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. The highest number of families was found among Coleopterans, with eight families. The distribution of major benthic macroinvertebrate taxa is shown in Fig. 2. The total number of taxa (individuals) found at stations 1, 2, 3, and 4 were 29 (120 ind m^{-2}), 29 (149 ind m^{-2}), 23 (203 ind m^{-2}), and 24 (204 ind m^{-2}) respectively. Stations 1 and 2 were higher joint contributors of taxa and Station 3 the least important contributor of taxa. There was an abundance of pollution sensitive taxa such as Ephemeroptera (mayflies), Coleopteran (*Gyrinus* spp., *Dytiscus* spp.) and Anisoptera (*Gomphus* sp., *Lestinogomphus, Cordulex* spp.) in all the stations, especially the upper and lower reaches, whereas on the other hand, some pollution tolerant species like the Crustaceas, Dipterans, Mollusca (*Neritina*

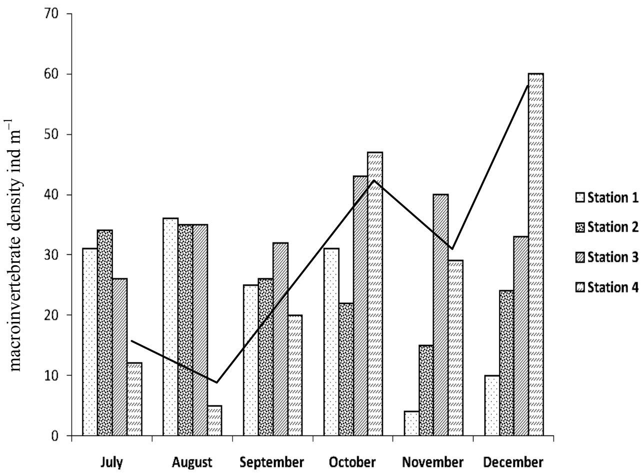

Fig. 3. Monthly variations of the macrobenthic invertebrates in the different study Stations of Gbako River, Niger State.

rubricate, Potadoma) were merely restricted to the middle reaches (stations 2 and 3). There was a paucity of Plecoptera in the study with only one individual of *Neoperla* sp. of the Perlidae in station 1.

Spatio-temporal dynamics in population density

The monthly variation of the macrobenthic invertebrates in the four different study stations is shown in Fig. 3. The relative abundance of benthic inveretebrates in the study area during dry and wet seasons in 2013 is shown in Fig. 4. The month of October (dry season) recorded the highest number (abundance) of individuals (143 ind m^{-2}) followed closely by the month of December (dry season) (127 ind m^{-2}), while the month of November (dry season) had the lowest account of individual (abundance) representatives (88 ind m^{-2}). Station 4, in the month of October (dry season), recorded the highest number of individuals (47 ind m^{-2}) while Station 1, in the month of November (dry season), recorded the lowest number (4 ind m^{-2}). ANOVA (using two-way) conducted for the months and Stations suggested that total invertetebrate abundance did neither vary significantly ($P > 0.05$) ($F_{cal} = 0.4730$, $F_{crit} = 2.9013$, $P = 0.7907$) across the months nor vary significantly ($P > 0.05$) ($F_{cal} = 0.7773$, $F_{crit} = 3.2873$, $P = 0.5247$) among the Stations. This implied that neither the Stations nor the months structured the distribution of invertebrates accounted for in this study. Of the total number of individual benthic invertebrates recorded during the entire study, 53% was recorded in the dry season while the remaining 47 % was recorded in the wet season (Fig. 4). However, this difference was not statistically significant ($P > 0.05$) when the student t-test ($t_{stat/cal} = 0.3883$), $t_{crit} = 2.447$) for the densities and abundances of macroinvertebrates recorded during the two sampling seasons was applied.

Table 2. Taxon richness, diversity, evenness and dominance indices of benthic macroinvertebrates in Gbako River, Niger State, July to December, 2013.

	Stations			
	1	2	3	4
No of Taxa/ Species (S)	29	29	23	24
No of Individuals (N)	120	149	203	204
Taxa richness (d) (Margalef's index)	5.85	5.60	4.14	4.33
Shannon Diversity (H′)	2.88	2.62	2.40	2.30
Evenness index (E)	0.61	0.63	0.57	0.50
Simpson dominance (C)	0.92	0.92	0.89	0.87

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

Taxon richness, diversity, evenness, dominance, and similarity indices of macrobenthic invertebrates, calculated for the four stations are depicted in Table 2. Taxa richness was highest in station 1 (5.8) closely followed by that from station 2 (5.6), while much lower values were recorded in stations 3 and 4 with 1.6 and 1.7, respectively. Diversity increased from station 4 through station 1 (of 2.3, 2,4, 2.6, and 2.9, respectively). Evenness value was highest in station 2 (0.63), followed closely by station 1 (0.61), then station 3 (0.57). However, the lowest value of evenness was recorded in station 4. The values of dominance for the four stations were similar. The highest value was recorded in station 2 (0.92) and the lowest value (0.87) in station 4. The highest values of taxon richness and Shannon diversity were recorded in station 1. Conversely, station 1 was the station with the lowest values of Shannon diversity, evenness, and Simpson's dominance.

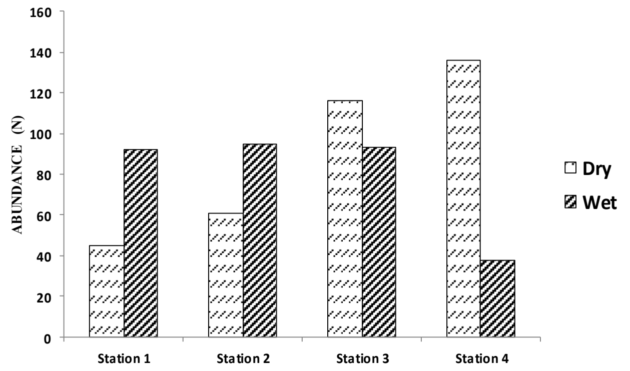

Fig 4. Relative abundances of total benthic invertebrates in the study area during dry and wet seasons in 2013.

Influence of environmental parameters on macroinvertebrate assemblages

The influence of environmental parameters on macroinvertebrate assemblages is shown in Figure 5 and Table 3. The canonical correspondence analysis (CCA) ordination also showed very significant relationships between species abundances and measured environmental parameters. The total extent of variation or inertia in macro-invertebrate assemblage composition in the studied Stations was equivalent to 1.00 eigenvalues, where 0.48, 0.28 and 0.24 were for axis 1, 2, and 3, respectively. The ten physico-chemical parameters could explain total variance of 56.5%. However, the first canonical axis accounted for 27.3% of the variation in the data set, the second axis account for 15.67% of the variation in the data set while the third axis accounted for 13.5% of the data set. All canonical axes were significant (an unrestricted Monte Carlo per-mutation test, $P < 0.05$). Temperature, flow velocity, conductivity, alkalinity and phosphate determined the main environmental gradient, while the second environmental gradient was determined by depth, pH, BOD, and nitrate. There was strong correlation between temperature, DO, BOD and phosphate, and the third environmental gradient. It was observed that the samples taken from stations 1, 3 and 4 grouped together.

Table 3. 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
Eigen value	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
DO	0.14	0.30	0.41
BoD	–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 $P < 0.05$.

Discussion

The quality of a given water body is controlled by its physical, chemical and bio-logical factors, all of which interact with one another to influence its productivity (Keke *et al.* 2015). Water quality is often affected by the discharge of organic and inorganic materials or pollutants into a water body with observable changes in the biotic community and abundance (number of individuals) and diversity (Arimoro & Ikomi 2008; Beyene *et al* 2008; Nedeau *et al.* 2003; Novotny *et al.* 2005, Arimoro *et al.* 2015; Nelson & Roline 2003; Reuda *et al.* 2002; Zabbey & Hart 2006).

In this study, the values of most water parameters of the stream (high DO, low BOD and nutrient) fell within the limits of an unpolluted environment, and were suitable for most aquatic organisms. Adequate dissolved oxygen is necessary for good water quality as oxygen is a necessary element to all forms of life (Keke *et al.* 2016). Nitrate and phosphates can reach both surface water and groundwater as a consequence of agricultural activities (including excess application of inorganic nitrogenous fertilizers and manures), wastewater disposal (Keke *et al.* 2015), and from oxidation of nitrogenous waste products in human and animal excreta, including septic tanks (Where latrines and septic tanks are poorly sited, these can lead to contamination of drinking-water sources with nitrate) (Umeham 1992). Water conditions were observed to be better in the upstream and downstream stations (station 1 and 4, respectively), than in the middle reaches (stations 2 and 3), and

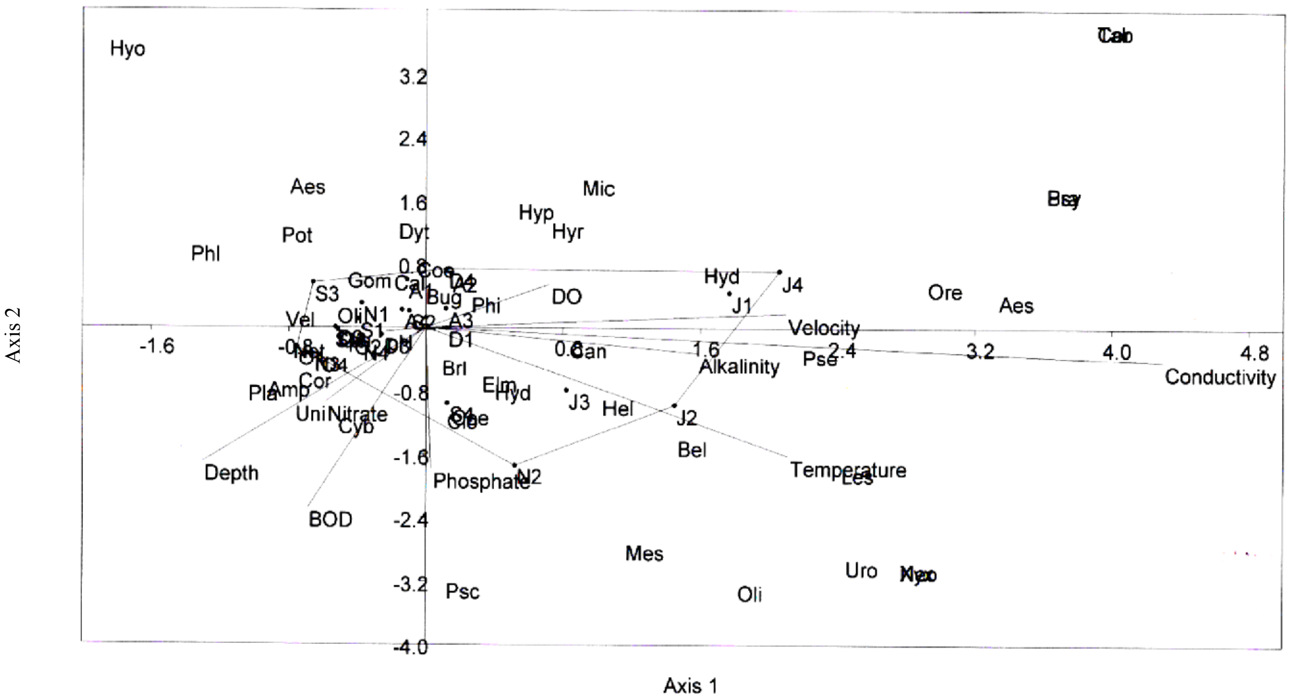

Fig. 5. Triplot of first and second CCA axes of macroinvertebrate taxa, environmental variables and their corresponding sampling Stations. Scale in SD units is -1 to 1 for both the invertebrate and environmental variable scores. Full names for abbreviation codes of invertebrate taxa are given in Table 2. Month codes: J = July, A = August, S = September, O = October, N = November, D = December; Station numbers: 1, 2, 3.

this was confirmed by the high concentrations of DO (with lower nutrient and BOD) levels in stations 1 and 4. This could be as a result of reduced human activities at these stations in contrasts to stations 2 and 3 with lower concentrations of DO, higher nutrient, conductivity levels, and BOD levels with slight perturbation, due to human activities that included washing with detergents, and other influx of organic wastes and other pollutants. Variations in the physico-chemical parameters in time and space were influenced by both natural and anthropogenic factors like rainfall patterns, material influx, and flow velocity. For BOD, in stations 1 and 4, which were only slightly disturbed by anthropogenic activities - as confirmed by the distance of this station from human settlement, BOD increased during the rainy season periods and decreased during the dry season. This could be attributed to flood water and runoff during the rainy season which brought in allochthonous materials in the water body or from the re-suspension of the autochtonous materials that had sedimented. Kolo and Oladimeji (2004) observed similar effects in Shiroro Lake. The accumulation of these materials in the water body led to decreased DO and therefore, probably explained the increased BOD.

High density of macroinvertebrates was recorded in this study; and is much higher than the total of invertebrate species reported from some perturbed and grossly polluted Rivers in Northern Nigeria (Adakole & Anunne 2003; Akaahan 2014; Emere & Nasiru 2009). Usually upland streams provide physically heterogenous habitats to support more diverse macro-invertebrate assemblages (Ghani *et al.* 2016). The high density of benthic invertebrates recorded in this study could be attributed to relatively lower anthropogenic (human) impacts in the study area as well as the presence of suitable habitats for benthic invertebrates that is provided by the diverse nature of the vegetation of the littoral zone of the various stations sampled. The macro-invertebrates of Gbako River was dominated mostly by the insect groups, and this is similar to the observations made by Imoobe (2008) and Arimoro *et al.* (2015). The presence of Coleopteran (*Gyrinus* spp., *Dytiscus* spp.), Ephemeroptera, Plecoptera, Tricoptera, Anisoptera and Odonata in any aquatic body has been reported to reflect clean water conditions (Miserendino & Pizzolon 2003). Therefore, the abundance of these organisms in the study stations is an indication that Gbako River is relatively free from gross perturbation. This is supported by related studies conducted in similar freshwater bodies in Nigeria and elsewhere (Arimoro *et al.* 2007; Arimoro *et al.* 2015; Ikomi *et* al. 2005; Nelson & Roline 2003; Reuda *et al.* 2002) which have already linked the presence of these organisms in a site to clean water conditions, since they are very sensitive to reductions in DO and are not found in areas where oxygen levels are consistently low. This study revealed that macroinvertebrate communities were factored by variations in water quality along the various reaches of the river as confirmed by higher diversity, dominance and taxa richness at station 1 as against the others.

Spatio-temporal differences in macroinvertebrate abundance (number of individuals) and diversity were recorded between the different sampling months in this study. On average, slightly higher abundances of benthic invertebrates were recorded during the dry season (53.1%) than in the wet season (47%). However, statistically, the t-test did not show any significant difference ($P > 0.05$) for the months, stations or the seasons. Increased flow during the rainy season usually leads to a reduction in macroinvertebrate diversity in tropical streams because of effects of wash off from the surrounding catchment and the dislodgement of taxa with no adhesive features (Arimoro & Ikomi 2008). This was consistent with the findings of Arimoro *et al.* (2012, 2015) and Akaahan (2014) and who also recorded higher macroinvertebrate abundance (number of individuals) and diversity in the dry season compared to the rainy season. These authors suggested that dry season usually favours diverse macroinvertebrate taxa because of less wash-off effects. Edokpayi *et al.* (2000) and Tumwesigye *et al.* (2000) are also in support of this. Conversely, Beyene *et al.* (2008) who worked on Ethiopian highland River and Arimoro *et al.* (2011) who worked on a southern Nigerian creek recorded higher abundances of benthic macroinvertebrates during the wet season than in the dry season. They suggested that this may have been a response to the reduction of environmental stresses by the rain water dilution and washout effects of the rainy season restoring those natural habitat conditions that favoured pollution-sensitive taxa.

CCA clearly differentiated the less polluted from the more polluted sites and also showed very significant relationships between species abundances and measured environmental parameters. This clearly revealed that most taxa were sensitive to environmental changes. This is in line with the observations of Bere (2014), who observed a similar trend of sensitivity in the benthic diatoms in a tropical river system in São Carlos-SP, Brazil. Conductivity, nitrate, and phosphate were identified as important variables that factored the macroinvertebrate assemblages. Stations 2 and 3 had the highest values for conductivity, nitrates and phosphates between them while stations 1 and 4 had higher DO levels and lower levels of conductivity, nitrates and phosphates between them than other stations. The correlation of many environmental variables with the axis were relatively high with the CCA but were not observed to be statistically significant. However, the perceived differences may be linked to the effects of some unmeasured environmental parameters. More of sensitive benthic invertebrates were recorded in stations 1 and 4 than stations 2 and 3 as these species are favored by higher DO levels and lower levels of conductivity, nitrates and phosphates. High concentrations of nitrates and phosphates may indicate eutrophication of the water body, which may lead to oxygen depletion in the water body, and this condition affects macrobenthic invertebrate assemblages since they are reliant on oxygen availability. The perceived presence of some pollution tolerant taxa in stations 2 and 3 could be regarded as early warning signals of pollution loads. The water quality status was reflected throughout the stations by the values recorded for species diversity, richness, dominance and evenness indices. The highest diversity, dominance and taxa richness at Station 1 and can be attributed to high water quality and good habitat quality of this station. The plausible reason for this is that human activities were drastically reduced there as confirmed with the physicochemical variables. This may be an indication that the substratum was more stable than at the other stations. The forest vegetation that surrounded station 1 was a good source of allotchthonous 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.

In conclusion, the low relative abundance of pollution sensitive organisms, especially the EPTs (Ephemeroptera – Plecoptera – Tricoptera) clearly shows that Gbako River is already stressed across its reaches. However, water quality was perturbed more during the rainy season, possibly because of the unstable nature of the substrates and the inputs of stormwater during the rainy season months, as observed by the increase in diversity and abundance during the dry season.

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Supporting Information

Additional Supporting information may be found in the online version of this article.

Table S1. The overall composition, abundance, and distribution of macroinvertebrate taxa in Gbako River, Niger State, July to December, 2013.