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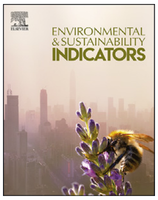

Achieving sustainable river water quality for rural dwellers by prioritizing the conservation of macroinvertebrates biodiversity in two Afrotropical streams

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ABSTRACT

Motivated by the UN Global Sustainable Development Goals on achieving sustainable freshwater ecosystem, this study was undertaken to examine two important water bodies in north central Nigeria (Baka Jeba and Penyan Rivers) protected locally by the rural community and serving as sources of water supply, for biodiversity conservation and protection. The status of macroinvertebrate biodiversity as important variable in assessing the environmental health and suitability of the water quality of the rivers was evaluated for a period of 8 months, between February and September 2017 using standard methods. The mean values of Physicochemical variables recorded during the study period revealed that the nutrient loads (nitrites and phosphates levels) was relatively low for both streams as well as conductivity levels (<82 μS/cm). Dissolved oxygen values indicated that the water bodies were well aerated with values ranging between 5.21 and 7.83 mg/l in both the dry and wet seasons. A total of 65 invertebrate taxa from 34 families in 10 orders were recorded during the study, dominated by aquatic insects with a few representation of decapods and gastropods, and Arachnids were sporadically present. The overall abundance of macroinvertebrates was not significantly different ($p > 0.05$) among the sampling stations with number of individuals caught ranging between 1208 and 1728 per station. Of the major faunal groups, Ephemeroptera contributed the highest percentage of individuals ($>29\%$) in both streams. Generally, Beka Jeba Stream contained more diverse taxa of macroinvertebrates compared to Penyan Stream. The Ephemeroptera-Trichoptera-Odonata (ETO) were the dominant groups collected in the river systems indicating fairly good water quality conditions. The Chironomids and other tolerant macroinvertebrate larvae were only sporadically present. Overall, the values of the physical and chemical parameters (low BOD, low nutrient levels and high dissolved oxygen) obtained for the two rivers and the wide diversity of sensitive macroinvertebrates portends the water body to be of good quality. Therefore utmost care should be taken to conserve and preserve these species as indicators of water quality by reducing the impact of key drivers of declines in macroinvertebrate biodiversity, including habitat degradation and pollution.

1. Introduction

The management, exploitation and sustainable use of freshwater bodies is of great importance to the life of any society and one of the challenges to be met by future generations. The preservation and protection of good water quality, both sanitary and environmental, is paramount, since it depends largely on the conservation of biodiversity (Fernández-Díaz et al., 2008; Ishaku et al., 2011; Arimoro and Keke, 2017).

In most developing nations, the overarching problem of the government's reduced ability to monitor aquatic ecosystems as a result of severe government cutbacks to environmental programs is a major setback. There is also inadequate water quality monitoring to address the complex and emerging environmental and sustainability issues currently impacting the society (de Wet and Odume 2019). Therefore, there is the need to recognize the conservation of macroinvertebrates biodiversity as an effective tool in planning and supporting management processes towards sustainability of water resources.

Studies on biomonitoring are often based on the sampling of an area and the subsequent analysis of collected specimens to provide

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information on pollution status of the water body and ecological condition for both local and large scale programs (Morse et al., 2007; Buss et al., 2015). Generally, water quality may be monitored by observing the composition of freshwater macroinvertebrates of a given “test” community with that of an actual or hypothetical community in a waterway known to be relatively unpolluted. Furthermore, macroinvertebrates can be used to determine aquatic life stressors, set pollutant load reductions, and indicate possible remediation successes (Nieto et al., 2017; Zabbey and Arimoro 2017).

The functionality of streams can be affected in different ways through the loss of biodiversity. The efficiency of stream communities to capturing essential resources, producing biomass, decomposing, and recycling essential nutrients is affected by biodiversity loss (Nieto et al., 2017). Throughout time, ecosystem functions are unable to stabilize owing to biodiversity loss (Cardinale et al., 2012). In some areas particularly in Europe and North America, the establishment of protected freshwater areas is still very important in the conservation of invertebrates (Brooks et al., 2006; Loucks et al., 2008; Le Saout et al., 2013; Watson et al., 2014). Presently, Nigeria has no formally established freshwater or marine protected area and this is rather unfortunate (HOMEF, 2020). On few occasions when issues of freshwater protected areas are discussed, invertebrates are not considered in the plan, even when their need has been shown to be important in providing freshwater ecosystem services (Edegbene et al. 2019, 2020). This lack of consideration of invertebrate biodiversity in conservation planning is in fact not limited to Africa as it has been identified as a global problem with over a million species of invertebrates known, only 3500 species of arthropods are protected in the world (Baillie et al., 2004; Brooks et al., 2006). From the foregoing, global conservation priority is far from being able to incorporate large diverse invertebrate taxa. However, there is a gradual buildup of attention and urgency to protect freshwater ecosystems and the services that they provide in the face of numerous stressors threatening biodiversity especially in the tropics (Poff et al., 2012; Godet and Devictor, 2018). In a recent study in the neotropics, scientists have demonstrated that the detrimental effects of environmental change on macroinvertebrate biodiversity can be drastically reduced by protecting riparian vegetation around streams (Dala-Corte et al., 2020).

One of the major challenges facing the rural communities in Africa is access to water supply which has great influence on the health, economic productivity and quality of life of the people (Ishiaku et al., 2011). Utilizing macroinvertebrate diversity to estimate the ecological quality of water bodies is perhaps one of the most effective and less expensive technique that is currently being used (Patang et al., 2018). Government efforts aimed at realising the UN Global Sustainable Development Goals 3 (Health), 6 (Water and Sanitation), 11 (cities and communities), and 15 (inland freshwater ecosystems) would grossly be undermined if pollution and deteriorating water quality of surface resources are not urgently addressed. We therefore argue that achieving sustainable river quality for rural dwellers is possible if the conservation of macroinvertebrates biodiversity in running water bodies are prioritized.

Baka-Jeba and Penyan rivers are the main water sources of most parts of Paiko and Lapai areas of Niger state, Nigeria. The two villages, alongside other neighbouring villages use these rivers for ‘almost all their water requirements’, either directly or indirectly. They constitute very important source of portable water for their riparian communities and for extensive fishery activities serving as a spawning and nursery ground for a number of fish species. Our interest in this research emanated from observing the community efforts geared towards the protection of these water bodies, as laundry and other human activities are prohibited along the water courses. In addition, there are no industries along the stream catchment.

We therefore embarked on detailed studies of the status of the macroinvertebrate diversity in the streams. We envisaged that by prioritizing the conservation of macroinvertebrate biodiversity in these two streams, it could lead to sustainable river water quality which would translate to good water quality available for the rural communities who depend solely on the streams for their source of water supply.

2. Materials and methods

2.1. Description of the study area

The Baka Jebba River (9.043678N, 6.56334 E) is a tributary of Chanchaga River while the Penyan River (9.393043 N, 6.614677 E) is a small stream arising from an aquifer in a small forest ecotone north of Niger State. Both rivers are located at Lapai Local Government Area of Niger State, Nigeria (Fig. 1). The study sites lie within the Guinea Savannah region in North Central Nigeria, characterized by two seasons (rainy and dry season). The rainy season is from April to November while the dry season is between November and March. Three stations each, selected in a targeted manner based on accessibility and at an equal distance of 3 km apart in Penyan River and 5 km apart in Baka Jebba River were chosen for the study.

The Baka Jebba River station BJ1 is located approximately 5 km from the Chanchaga River. Aquatic vegetation is sparsely distributed here, consisting of a few submerged and floating macrophytes (*Ceratophyllum submersum*, *Nymphaea lotus*, *Eichhornia crassipes and Utricularia* sp.). The streambed here is more of sand and clay with few fallen leaves. The marginal vegetation is composed mainly of shrubs (dominated by *Piliostigma thonningii)* and few trees such as *Adansonia digitata, Daniellia oliveri* and *Isoberlina tomentosa*. There is substantial reduced human activities at this site, probably because it is situated far from human settlement. Station BJ2 is located approximately 5 km downstream of Station BJ1.The vegetation consists mainly of *Nymphaea* sp., *Commelina* sp., *Panicum repens*, and *Pistia stratiotes.* The streambed here is composed mainly of silt, sand and less of clay. Human activity here is mainly artisanal fishing by a few community groups. Station BJ3 is located approximately 5 km from BJ2. The streambed consists of sand mixed with clay. The marginal vegetation is composed of shrubs (*Boscia senegalensis, Nauclea latifolia, Boscia senegalensis* and *Urena lobata)* and few trees (*Vitellaria paradoxa, Ficus sur* and *Gmelina arborea*). Again, artisanal fishing is the main human activity in this area with a few peasant fishermen.

The Penyan River is a small shallow stream of approximately 45 km long. Three stations (PN1, PN2, and PN3) were selected at a distance of 3 km apart. All the stations were similar with few aquatic vegetation mainly *Ceratophyllum submersum*, and *Nymphaea lotus*. Human activities are drastically reduced at all the sites as the rural communities make use of the water directly for drinking and watering of livestock as well as for irrigation farming. Because of the usefulness of both streams to the communities, there is prohibition of activities that may likely contaminate the water bodies.

2.2. Environmental variables

Sampling for water quality parameters and macroinvertebrates were carried out in the two streams at monthly intervals between February and September 2017, covering part of the dry and rainy seasons respectively. Physicochemical parameters were measured at each sampling station of the two streams using standard methods. The substratum composition at each sampling site was estimated visually as percentage of silt, loam, clay and sand within a 100 m sampled reach.

Qualitative evaluation index (QHEI) was used to provide empirical and quantitative evaluation of physical habitat (Rankin, 2006). The QHEI is composed of six principal metrics, i.e., substrate, in stream cover, channel morphology, riparian zone, pool quality, riffle quality and gradient with a score of 100 representing the maximum possible QHEI site score. The QHEI for each site is a sum of all individual metric summed to provide the total QHEI station score. Habitat characterization was carried out at a reach of 100m in each sampling site. Measurements of in stream parameters including width, depth, flow and substrate were taken and this was followed by description of the stream and summary of

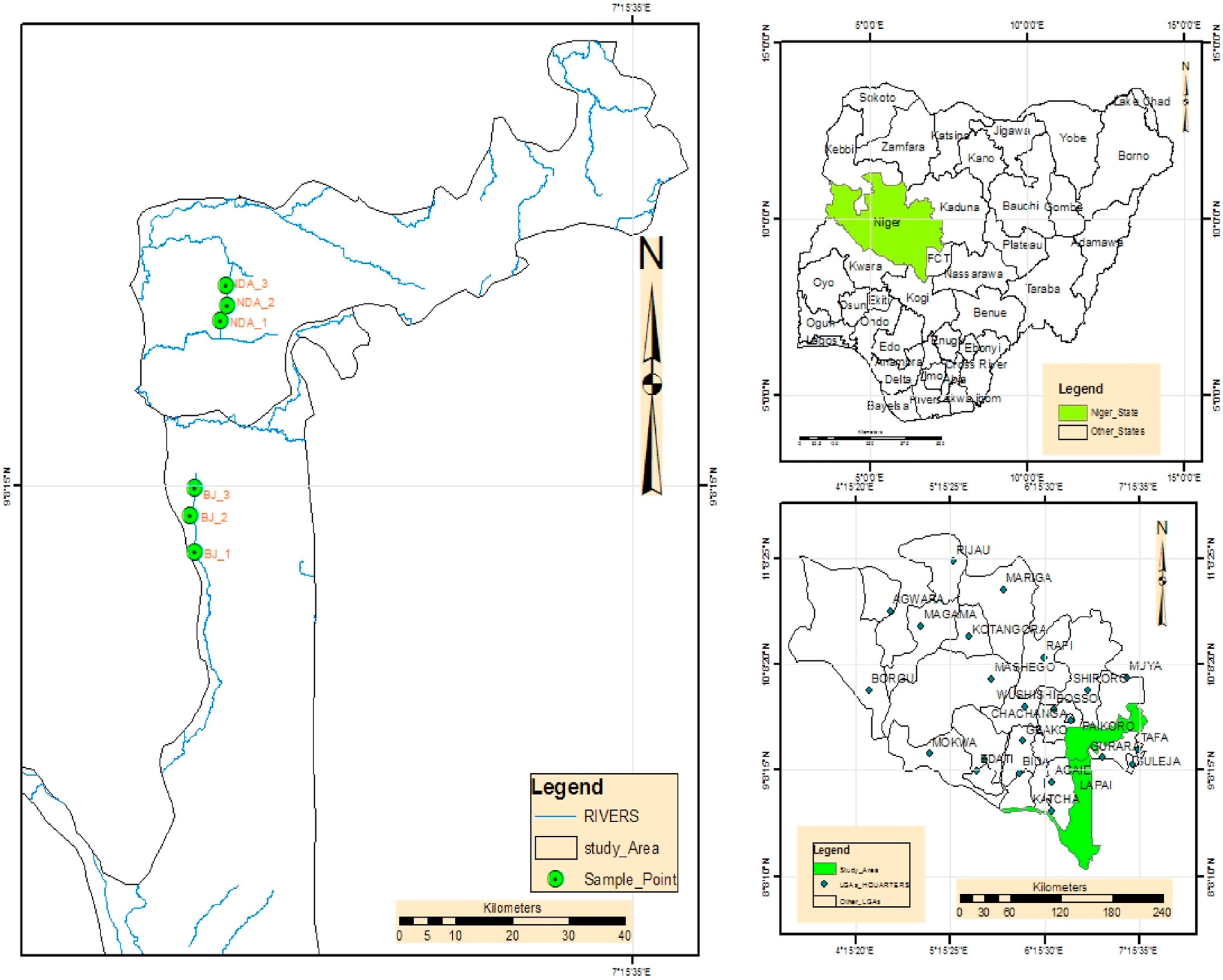

Fig. 1. Map of Baka-Jeba and Penyan Rivers, Niger State, Nigeria showing the sample locations.

aquatic plants. Depth was measured in the sample area using a calibrated rod while flow velocity was measured in the mid channel by timing a float (average of three trials) on three occasions as it moved over a distance of 10 m. Other parameters measured included dissolved oxygen (using a YSI 55 dissolved oxygen meter), temperature, pH, and conductivity (using a Hanna HI 991300/1 m). Water samples were taken for analysis of nitrate and phosphate. Measurements were achieved spectrophotometrically after reduction with appropriate solutions (APHA 2015). Alkalinity and biological oxygen demand (BOD_5) were determined in the laboratory using APHA (2015) methods.

2.3. *Macroinvertebrates sampling*

Four different macroinvertebrate samples were taken at each sampling station covering all different substrate, microhabitat (i.e. vegetation, stones, sand and gravels) and flow regime zones by a 3-min kick sampling method using a D-frame net (800 μm mesh) along a 100 m long wade able stretch of the stream. This modified Kick net sampling strategy was evaluated using a semi-quantitative sampler of 0.5 m^2 quadrant (Lazorchak et al., 1998). Test sampling was performed prior to the main study and four replicates were established to be good enough to capture the maximum number of different macroinvertebrate taxa. The operator and the net moved upstream for the required duration of time for collection of the organisms as the substrate was disturbed. For detailed collection of macroinvertebrates fauna around the sampling area, manual collection of wood particles and removal of specimens was adopted. Some macroinvertebrates that adhered tightly to stony substrates and trailing vegetation missed by kick net sampling were collected by this method, which also involved very close visual inspection. Furthermore, care was taken to include all possible microhabitats over representative sections of the river. The four samples were then pooled, representing a single sample for each station including collections from other methods described above. Samples collected from the net were preserved in 70% ethanol. In the laboratory, samples were washed in a 500-μm mesh sieve to remove sand and macroinvertebrates were sorted using a stereoscopic microscope (magnification x10). All organisms caught were separated, enumerated and identified under a binocular dissecting microscope. Identification of macroinvertebrate species were achieved by using available regional keys (Day. et al. 2002; de Moor., et al. 2003; Arimoro and James 2008), and keys from North America; Merritt and Cummins (1996).

2.4. *Data analysis*

Environmental and macroinvertebrates data were evaluated according to stations and seasons to reveal the spatio-temporal patterns of macroinvertebrate assemblages in relation to environmental variables. The total number of individuals, number of taxa (S), and relative abundance of species were assessed. The environmental data (physicochemical variables) were expressed as means and the standard error according to the stations and seasons. The diversity function in PAST software (version 3.2) was used to analyze for macroinvertebrate indices, such as Shannon diversity (H′), Margalef diversity index and Evenness index (E). These were used to determine changes in the invertebrate structure between the sampling stations and between seasons during the study period. Data were tested for normality using a *Shapiro-Wilk* normality test prior to performing the statistical analyses. Since the data were not normally distributed, log (x+1) transformation was applied to equalize variances. The significance of differences in the values of the physicochemical parameters and macroinvertebrates abundance among the sampling stations and between seasons was calculated using one-way ANOVA and independent sample *t*-test, respectively. A comparison between stations was performed with a one-way ANOVA and Tukey's *post hoc* test, with results from the eight sample dates used as replicates within a station ($n = 8$) after tests for normality were fulfilled. Seasonal variation in physicochemical parameters and faunal abundance between the dry and wet seasons were examined by applying the *t*-test to compare each set of samples from the six sampling stations. Macroinvertebrate metrics were used in assessing the biological integrity of the streams including abundance measures, composition measures (%) and diversity indices were determined and compared between the two streams.

Canonical correspondence analysis (CCA) was used to evaluate relationships between macroinvertebrate communities and environmental variables using PAST software. It has been established that CCA being a direct gradient analysis, allows integrated analysis of both taxa and environmental data, therefore it is a powerful tool for simplifying complex data sets (ter Braak and Smilauer, 2002). In addition, variables were log-transformed (log $[x+1]$) before CCA analysis to prevent outliers from unduly influencing the ordination. A measure of how well variation in community composition could be explained by individual environmental variable is provided by the species–environment correlation coefficients extracted from the CCA analysis. To assess the significance of the canonical axes extracted, a *Monte Carlo* permutation test with 99 permutations was used.

3. Results

3.1. Environmental variables

Both streams are located in Guinea Savannah with less trees for most part of their length, canopy not exceeding 42%. The land use pattern in the area is mainly agriculture. The mean values of physicochemical variables recorded during the study period are presented in Table 1. All the physicochemical variables examined showed significant variation between seasons ($p < 0.05$) except temperature, pH and DO. Higher mean values of nitrate, phosphate, conductivity and depth were recorded during the wet season, whereas conductivity and water temperature values increased during the dry season. All physicochemical variables except water temperature also showed a statistical significant difference among sampling stations ($p < 0.05$). Generally, the nutrient loads

Table 1
Environmental variables measured at the sampling stations of Baka-Jeba and Penyan streams of Niger State, Nigeria (February–September 2017) showing habitat quality, including physicochemical parameters (n = 8).

Variable	Sampling stations							
	BJ1	BJ2	BJ3	PN1	PN2	PN3	Dry season	Wet season
Features of the reach	Constrained	Constrained	unconstrained	Constrained	unconstrained	Constrained		
Riparian vegetation	native	native	native	Native	native	native		
Land use	Agriculture	Bush fallow	Agriculture	Bush fallow	Agriculture	Agriculture		
Substrate type	Sand and clay	Silt and sand	Sand and clay	Sand and clay	Sand and clay	Sand and clay		
Canopy cover (%)	42	25	20	30	20	20		
Qualitative habitat evaluation index (QHEI)	78	74	72	78	72	75		
Water temperature(°C)	24.92 ± 0.27 (24.00–26.00)	26.10 ± 0.04 (25.00–27.00)	27.34 ± 0.24 (25.00–27.00)	24.01 ± 0.10 (24.00–27.00)	25.34 ± 0.40 (23.00–28.00)	25.34 ± 0.19 (24.00–27.00)	26.12 ± 0.19^{a}	25.04 ± 0.24^{a}
[b]Depth (cm)	18.53 ± 2.44 (16.00–26.00)	32.12 ± 4.22 (3–55.00)	25.34 ± 3.32 (24.00–32.00)	23.30 ± 5.34 (12.00–29.00)	28.33 ± 5.74 (23.00–41.00)	21.40 ± 3.05 (18.00–29.00)	23.41 ± 4.87^{a}	28.45 ± 4.46^{a}
[b]Flow velocity (m/s)	0.52 ± 0.23 (0.49–0.59)	0.76 ± 0.34 (0.40–0.90)	0.72 ± 0.43 (0.30–0.90)	0.80 ± 0.22a (0.56–0.97)	0.26 ± 0.14 (0.18–0.68)	0.55 ± 0.24 (0.16–0.94)	0.32 ± 0.19^{a}	0.64 ± 0.22^{b}
pH	6.6 (5.9–6.8)	6.8 (6.2–7.1)	6.5 (5.8–6.7)	6.4 (6.1–7.1)	6.5 (6.2–6.9)	6.4 (5.8–6.9)	6.3^{a}	6.4^{a}
DO (mg/L)	6.26 ± 1.29 (6.31–7.02)	6.31 ± 2.04 (6.00–6.95)	5.23 ± 1.02 (5.87–6.20)	6.72 ± 2.02 (6.02–7.83)	6.10 ± 1.53 (5.60–6.36)	5.74 ± 1.04 (5.21–6.02)	6.01 ± 2.14^{a}	5.87 ± 1.47^{a}
[b]BOD_5 (mg/L)	2.06 ± 0.23^{a} (1.61–3.61)	4.92 ± 0.10^{b} (3.50–5.19)	2.02 ± 0.80^{a} (2.40–3.10)	3.01 ± 0.3^{ab} (2.10–3.32)	4.73 ± 0.36^{b} (3.19–5.10)	4.00 ± 0.43b (3.06–4.56)	3.34 ± 1.07^{a}	2.67 ± 0.87^{b}
[b]Conductivity(μS/cm)	21.54 ± 3.21 (15.00–26.00)	44.21 ± 2.47 (33.00–56.0)	49.35 ± 11.10 (3–7-)	28.00 ± 3.37 (22.00–33.00)	65.37 ± 11.38 (41.00–83.0)	46.19 ± 7.20 (43.00–82.00)	48.75 ± 11.45^{a}	33.02 ± 7.83^{b}
[b]Alkalinity mg/l	4.32 ± 2.41 (3.30–8.78)	6.23 ± 2.44 (9.10–13.70)	12.01 ± 7.23 (4.30–21.60)	5.27 ± 1.18 (4.01–7.76)	9.90 ± 1.45 (9.65–11.06)	10.34 ± 1.76 (6.05–14.67)	4.27 ± 8.44^{a}	7.46 ± 2.11^{b}
[b]Phosphate (mg/L)	0.19 ± 0.08 (0.11–0.21)	0.35 ± 0.17 (0.22–0.48)	0.42 ± 0.21 (0.20–0.60)	0.12 ± 0.06 (0.10–0.17)	0.42 ± 0.19 (0.26–0.59)	0.47 ± 0.25 (0.28–0.66	0.21 ± 0.07^{a}	0.32 ± 0.16^{b}
[b]Nitrates (mg/L)	0.40 ± 0.28 (0.10–0.63)	0.45 ± 0.25 (0.20–0.69)	0.62 ± 0.32 (0.20–0.84)	0.19 ± 0.09 (0.10–0.27)	0.32 ± 0.12 (0.25–0.44)	0.44 ± 0.17 (0.39–0.53)	0.19 ± 0.09^{a}	0.48 ± 0.12^{b}

[b] Significant at $p < 0.05$ (KW, df = 5) Data are the means ± SE derived from monthly values with minimum and maximum values in parentheses. Different superscriptletters in a row show significant differences ($P < 0.05$) indicated by Turkey's HSD significant difference tests.

(nitrites and phosphates levels) was relatively low for both streams as well as conductivity levels (<82 μS/cm). Dissolved oxygen values indicated that the water bodies were well aerated with values ranging between 5.21 and 7.83 mg/l in both the dry and wet seasons.

3.2. Flagship species, macroinvertebrate assemblages and distribution in Baka Jeba and Penyan Rivers

A total of 65 invertebrate taxa from 34 families in 10 orders were

Table 2

Mean number of macroinvertebrate taxa caught at each sampling stations during the period of the sampling at Baka Jeba and Penyan streams (the total number caught for the dry and wet season is also provided at the last two columns).

Order	Family	Taxon		Baka Jebba Stream			Penyan Stream			Total no. of individuals caught in each season	
			code	BJ1	BJ2	BJ3	PN1	PN2	PN3	Dry season	Wet season
Oligochaeta	Naididae	*Dero digitata*	Der	3.50	3.00	1.50	5.75	–	0.75	48	66
		Nais communis	Nai	–	1.50	0.75	–	–	–	11	7
		Pristina aequiseta	Pri	–	11.00	4.00	3.00	1.50	1.00	89	75
		Stylaria lacustris	Sty	5.50	10.50	5.75	3.50	6.00	7.00	198	106
Decapoda	Potamonautidae	*Sudanonautes* sp.	Car	3.50	–	1.50	–	–	–	13	27
Gastropoda	Sphaeriidae	*Sphaerudux* sp	Sph	0.50	–	2.75	5.75	3.00	5.00	78	58
	Thiaridae	*Potadoma* sp.	Pot	3.00	4.00	–	–	–	–	22	34
		Melanoides tuberculata	Mel	11.25	16.75	14.00	3.00	5.75	5.50	183	265
Araneae	Pisauridae	*Thalassius* sp.	Tha	3.00	3.25	–	8.50	–	–	67	49
	Tetragnathidae	*Tetragnatha* sp.	Tet	1.50	1.50	0.50	5.75	–	–	40	34
Ephemeroptera	Baetidae	*Afroaetis* sp.	Bae	18.00	11.25	14.00	16.25	19.50	14.00	467	277
		Bugilliesia sp	Bug	1.50	6.25	4.00	–	–	–	67	27
		Cloeon sp 1	Clo	14.00	6.75	11.75	–	–	–	193	67
		Cloeon sp 2	Clo	–	–	–	–	11.25	3.00	65	49
		Pseudocloeon nr pisces	Pse	13.50	10.75	10.50	–	–	–	166	112
		Crassabwa sp.	Cra	6.00	1.75	–	8.50	3.00	4.00	120	66
	Tricorythidae	*Dicercomyzon* sp.	Dic	3.00	–	3.75	–	1.75	–	47	21
		Tricorythus sp.	Tri	2.00	3.50	–	–	–	–	18	26
	Leptophlebiidae	*Adenophlebiodes* sp.	Ade	–	6.00	4.50	5.25	3.75	4.75	123	71
		Thraulus sp.	Thr	8.25	–	6.50	–	–	1.50	63	67
		Choroterpes sp.	Cho	–	0.25	1.00	2.00	–	–	25	1
	Polymitarcyidae	*Polymix* sp.	Pox	2.00	–	0.50	0.50	1.50	–	12	24
	Oligoneuridae	*Oligoneux* sp.	Oli	1.50	1.00	2.00	–	–	–	22	14
	Caenidae	*Caenis* sp.	Cae	13.00	3.00	9.00	13.75	11.25	8.00	297	167
Trichoptera	Hydroptilidae	*Leptonema* sp.	Lep	3.00	–	3.00	–	–	–	12	36
		Polymorphanisus sp.	Pol	–	–	–	0.75	–	2.25	10	14
	Leptoceridae	*Leptocerina* sp.	Let	3.00	1.50	–	–	–	–	23	11
		Athripsodes sp	Ath	–	–	–	5.75	3.00	1.75	54	30
Hemiptera	Naucoridae	*Naucoris obscuratus*	Nau	1.50	–	3.00	–	–	–	34	2
		Macrocoris sp	Mac	–	–	–	3.25	11.25	3.00	97	43
	Nepidae	*Ranatra* sp	Ran	1.50	–	0.75	2.00	–	–	12	22
		Laccotrephes sp	Lac	0.25	–	1.00	–	–	0.50	2	12
	Belostomatidae	*Appasus* sp.	App	4.00	6.00	–	–	5.75	11.00	146	68
	Gerridae	*Naboandelus africanus*	Nab	2.00	–	0.25	2.25	4.25	–	56	14
	Pleidae	*Plea* sp.	Ple	3.00	–	2.00	16.50	11.25	20.25	165	259
Coleoptera	Dystiscidae	*Methles* sp.	Met	3.00	–	–	–	–	–	13	12
		Philodytes sp.	Phi	–	–	1.00	–	1.50	4.00	19	34
		Canthyporus sp.	Can	1.50	–	1.25	7.75	4.50	–	75	45
		Hyphydrus sp.	Hyp	3.25	0.50	–	–	1.50	–	24	18
		Cybister sp.	Cyb	1.50	1.50	–	3.50	–	4.50	38	50
		Coelhydrus sp.	Coe	13.25	–	3.00	11.00	16.25	–	237	113
		Philaccolus sp.	Phi	–	–	11.00	11.00	19.50	–	152	180
	Hydrophilidae	*Amphiops* sp.	Amp	7.00	5.50	8.75	5.25	4.50	19.50	235	169
	Notonectidae	*Hydrocanthus* sp.	Hyd	3.00	–	4.00	–	5.00	–	32	64
		Cathydrus sp	Cat	–	–	3.50	–	11.00	–	60	56
	Gyrinidae	*Orectogyrus* sp.	Ore	4.00	–	–	6.25	–	8.50	88	62
Odonata	Libellulidae	*Orthetrum* sp.	Ort	6.00	2.00	3.75	–	–	–	28	66
		Sympetrum sp.	Sym	1.25	–	2.00	–	–	–	13	13
		Zyxomma sp.	Zyx	–	–	–	8.50	–	10.00	74	74
	Gomphidae	*Lestigomphus* sp.	Les	6.50	0.25	1.00	–	5.75	–	59	49
	Corduliidae	*Cordulia* sp.	Cor	3.50	–	–	–	–	6.00	42	34
	Coenagrionidae	*Enallagma* sp.	Ena	–	–	–	2.00	6.00	3.50	25	67
		Pseudagrion sp.	Pse	3.00	–	–	–	–	–	14	10
		Coenagrion sp.	Coe	6.00	0.50	11.75	–	–	–	68	78
	Calopterygidae	*Calopteryx* sp.	Cal	1.00	–	3.25	–	–	5.75	34	46
Diptera	Chironomidae	*Chironomus* sp.	Chi	4.00	9.00	6.00	6.50	5.75	11.00	252	83
		Pentaneura sp.	Pen	1.00	3.00	3.00	3.25	4.25	4.75	99	55
		Tanypus sp.	Tan	–	–	–	–	4.50	0.50	22	18
		Tanytarsus sp.	Tat	–	–	–	–	5.75	3.00	36	34
		Orthocladiinae	Ort	3.00	8.50	3.75	–	–	–	69	53
		Polypedilium sp.	Pol	–	–	–	1.00	0.50	2.00	6	23
	Tipulidae		Tip	–	2.00	1.00	–	–	–	16	8
	Simuliidae	*Simulium* sp.	Sim	4.00	2.00	2.00	3.00	5.75	3.75	89	75
	Athericidae	*Atherix* sp.	Arx	1.50	–	–	–	–	–	12	0
	Ceratopogonidae	*Alladomyia* sp.	For	6.00	6.75	5.50	3.00	5.75	4.75	128	126
										5104	3936

recorded during the study, dominated by aquatic insects with a few representation of decapods, oligochaetes and gastropods. Arachnids were only sporadically present (Table 2). A total of 56 species was recorded in Baka Jeba Stream and 46 in Penyan stream. The total number of taxa found at the three sampling stations (i.e. BJ1, BJ2, BJ3) in Baka Jeba Stream were 48, 32 and 43 respectively, while for the Penyan Stream (i.e. PN1. PN2, PN3) were 32, 33 and 32 respectively (Table 3). The following species were all present at Penyan Stream but completely missing in macroinvertebrates collection from Baka Jeba Stream; *Tanytarsus* sp., *Tanypus* sp. *Zyxomma* sp., *Cloeon* sp 2, *Polymorphanisus* sp., *Athripsodes* sp, *Macrocoris* sp., *Enallagma* sp. *Polypedilium* sp. On the other hand a total of 19 species found in Baka Jeba Stream were absent in Penyan Stream (*Nais communis, Sudanonautes* sp., *Potadoma* sp. *Cloeon* sp 1, *Bugilliesia* sp., *Pseudocloeon nr pisces, Tricorythus* sp. *Oligoneux* sp., *Leptonema* sp. *Leptocerina* sp., *Naucoris obscuratus, Methles* sp., *Orthetrum* sp., *Sympetrum* sp., *Pseudagrion* sp., *Coenagrion* sp., Orthocladiinae, Tipulidae, *Atherix* sp.).

The overall abundance of macroinvertebrates was not significantly different ($p > 0.05$) among the sampling stations with number of individuals caught ranging between 1208 and 1728 per station. However, there was significant differences obtained in the diversity values obtained among the sampling stations (Table 3). An *aposteriori* test for multiple comparison showed that the diversity in BJ1 and BJ3 were similar and different from the diversities at BJ2, PN1, PN2 and PN3, which were similar to each other. Some rare species recorded were; Ephemeroptera (*Choroterpes* sp.,) Trichoptera (*Polymorphanisus* sp.), Hemiptera (*Laccotrephes* sp) Coleoptera (*Methles* sp.), Odonata (*Pseudagrion* sp., and *Sympetrum* sp. and Oligochaete (*Nais communis*).

Table 3
Macroinvertebrate metrics used in assessing the biological integrity of Baka Jeba and Penyan River, Niger State.

	Beka Jeba	Penyan Stream	Both streams combined
Abundance measures			
Number of individuals	4400	4640	9040
Ephemeroptera	1608	1066	2674
Trichoptera	82	108	190
Decapoda	40	–	40
Chironomidae	328	422	750
Oligochaete	750	225	975
Chironomidae + Oligochaete	1078	272	1350
Coleoptera	613	1163	1776
Hemiptera	404	528	932
Gastropoda	416	224	640
ETO	2104	1554	3658
Composition measures (%)			
%Ephemeroptera	36.5	57.6	29.6
%Trichoptera	1.9	4.1	2.1
%Decapoda	0.9	0.9	0.4
%Chironomidae	7.5	16.2	8.3
%Oligochaete	17.0	21.0	6.6
%Chironomidae + Oligochaete	24.5	29.1	14.9
%Coleoptera	13.9	38.3	19.6
%Hemiptera	9.2	20.1	10.3
%Gastropoda	9.5	13.8	7.1
%ETO	47.8	78.8	40.5
Richness measures			
Total number of taxa	56	46	65
No.of Ephemeroptera	13	9	14
No.of Trichoptera	2	2	4
No.of Decapoda	1	–	1
No.of Chironomidae	3	5	6
No.of Oligochaete	4	3	4
No.of Chironomidae + Oligochaete	7	8	10
No.of Coleoptera	11	10	11
No.of Hemiptera	6	6	7
No.of Gastropoda	3	2	3
No.of ETO	20	15	27
Diversity Index			
Evenness	0.670	0.717	0.677
Shannon diversity	3.626	3.496	3.784
Simpson dominance	0.964	0.962	0.970
Margalef index	7.496	7.611	7.026

Of the major faunal groups, Ephemeroptera contributed the highest percentage of individuals (>29%) at all streams. The relative abundances for Hemiptera, Coleoptera, Gastropoda, Oligochaeta and Chironomids were >15%. Generally, Beka Jeba Stream contained more diverse taxa of macroinvertebrates compared to Penyan Stream (Table 3). A total of 27 Ephemeroptera-Trichoptera-Odonata (ETO) taxa was recorded with Barka Jeba (20) and Penyan(15) recording appreciable number of Ephemeroptera-Trichoptera-Odonata taxa. Preponderant species identified in this study include the Ephemeroptera, *Caenis* sp. *Crassabwa* sp and *Afrobaetis* sp. that were present in all the sampling stations.

3.3. Spatio-temporal dynamics in population density of macroinvertebrates

An overall 56.5% was recorded in the dry season and the remaining 43.5% recorded in the wet season for the total number of individual macroinvertebrates recorded during the entire study. There were wide variations in total macroinvertebrate abundance ($p < 0.05$) among months suggesting strong seasonal effects, however, the timing of maximum and minimum abundances varied slightly among stations. Higher abundances were recorded during the dry season month of March at BJ1, BJ3 and PN2 and in June (wet season) at PN3. Abundance of macroinvertebrates between the dry season (February to April) and wet season (May to September), did not differ statistically ($p > 0.05$) using the student *t*-test ($t$stat $= 1.39 > t$ critical $= 1.66$).

3.4. Diversity, evenness, dominance and similarity indices

A summary of the diversity and dominance indices calculated for the six stations sampled is given in Table 4. Taxon richness, calculated as Margalef index (d), was highest (6.31) at Station BJ1, followed closely by BJ3. The Margalef index was similar for all the stations in Penyan Stream. Shannon diversity (H') varied slightly from 3.11 to 3.54 in all the sampling stations. Evenness values were similar at all stations but slightly higher at PN1 (0.705–0.781). Simpson's dominance values and Equitability values were also similar in all sampling stations.

3.5. Macroinvertebrates and environmental relationships

There was a fairly strong relationship established by the CCA analysis between species abundances and environmental variables. The first two canonical axes accounted for 55.6% of the variation in the data set. The overall inertia or variance in species dispersion in the data set was 0.95. All the canonical axes were significant ($p < 0.05$) as indicated by the unrestricted Monte Carlo permutation test. The main environmental gradient (Axis 1) was determined by pH and Nitrate (Fig. 2, Table 5). Most of the samples taken from Penyan Stream were positioned on the left, whereas those from Beka Jeba Stream were on the right. The second environmental gradient was associated mainly with factors that changed seasonally, as shown by Flow Velocity and BOD (Fig. 2, Table 5). The third axis showed strong correlation with parameters measured except depth, pH and BOD.

4. Discussion

4.1. Environmental variables

The Baka Jeba and Penyan streams are two unique water bodies found in the Guinea savannah belt of Nigeria with few trees for most part of their length, and canopy cover not exceeding 42%. The QHEI index for all the sampling sites was between 72 and 78% indicating slightly impaired sites using Barbour et al. (1999) habitat characterization. These water bodies flow through rural settlements who depend daily on the water bodies for their regular water supply. The high concentrations of

Table 4
Taxon richness, diversity, evenness and dominance indices of macroinvertebrates in Baka Jeba and Penyan streams (February 2017 to September 2017).

	BJ1	BJ2	BJ3	PN1	PN2	PN3
Taxa_S	48	32	43	32	33	32
Individuals	1728	1202	1471	1467	1694	1480
Dominance_D	0.03739	0.05407	0.0416	0.04779	0.04742	0.0535
Simpson_1-D	0.9626	0.9459	0.9584	0.9522	0.9526	0.9465
Shannon_H	3.544	3.116	3.406	3.218	3.244	3.155
Evenness_eˆH/S	0.7212	0.7049	0.7011	0.7809	0.777	0.7328
Menhinick	1.155	0.923	1.121	0.8355	0.8018	0.8318
Margalef	6.305	4.371	5.758	4.252	4.304	4.247
Equitability_J	0.9156	0.8991	0.9056	0.9286	0.9278	0.9103
Fisher_alpha	9.149	6.04	8.295	5.775	5.811	5.764
Berger-Parker	0.08333	0.1106	0.07682	0.08998	0.09209	0.1095

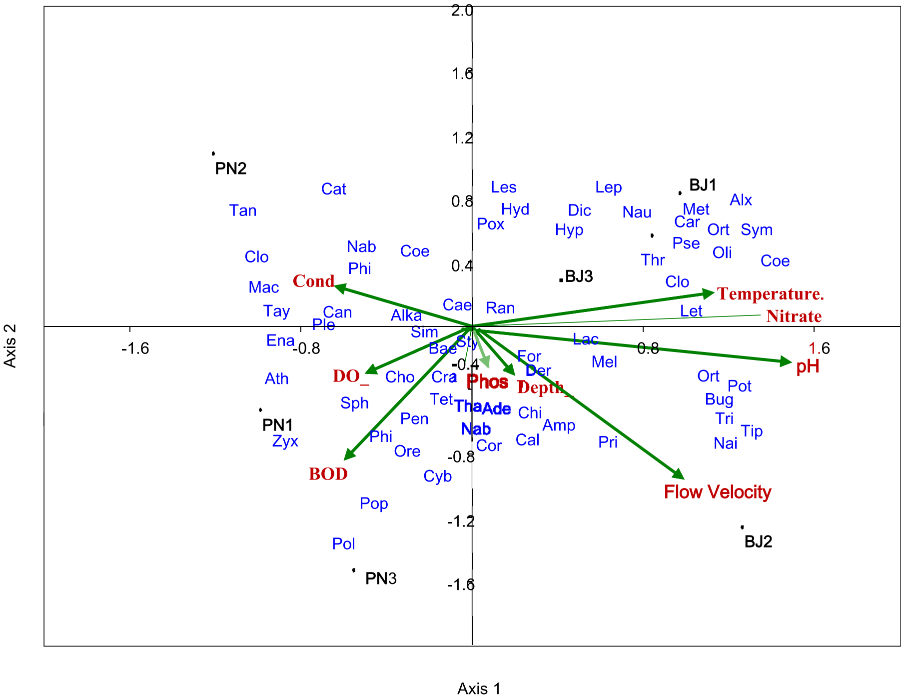

Fig. 2. Triplot of first and second CCA axes of macroinvertebrate taxa, environmental variables and their corresponding sampling stations. The scale in SD units is −2 to 2 for both the macroinvertebrate and environmental variable scores. The full name for the abbreviation codes of macroinvertebrate taxa are given in Table 2.Key environmental variable, (Cond-Conductivty, BOD- Biochemical Oxygen demand, Sampling station in Barka Jeba Stream BJ1, BJ2, and BJ3; Sampling stations on Penyan Stream PN1, PN2 and PN3).

Table 5
Weighted intraset correlations of environmental variables with the axes of canonical correspondence analysis (CCA) in Baka Jeba and Penyan streams. Significance of the axes by the Monte Carlo permutation test is given by $F = 4.86$ ($p < 0.05$). All canonical axes were significant. Values in bold indicate significant difference at $p < 0.05$

Variable	Axis 1	Axis 2	Axis 3
Eigen value	0.33135	0.19935	0.1724
Species-Environment Correlation	0.94	0.91	0.90
% variation of species data explained	34.74	55.64	73.71
Temperature	**0.566835**	0.10542	**−0.51713**
Depth	0.100535	−0.15728	−0.11154
Flow Velocity	0.421555	**−0.52576**	**0.567903**
pH	**0.752766**	−0.07342	–466
Dissolved Oxygen	−0.25213	−0.15013	**0.693387**
Biological Oxygen Demand	−0.30096	**−0.42207**	−0.35407
Conductivity	−0.32367	0.124537	**−0.67516**
Alkanity	−0.19468	0.077734	**−0.70821**
Phosphate	−0.01734	−0.12429	**−0.93036**
Nitrate	**0.674747**	0.03372	**−0.57409**

dissolved oxygen, low nutrient levels (Phosphate and Nitrate) and BOD levels indicate that the water at both streams were only slightly disturbed by human activities. This is unlike what happens in most parts of Africa and other developing countries were nearby streams and rivers are polluted as a result of daily human activities (Beyene et al., 2008). It is noteworthy that the CCA analysis did identify temperature as an important variable structuring the macroinvertebrate assemblages within the region of study, although only slight differences were noted. Surface water temperatures indicated slight variation with macroinvertebrate density.

4.2. Species assemblages

A total of 65 macroinvertebrate species were recorded for both streams in the study. The relatively high diversity of macroinvertebrates recorded in this study compared to other studies conducted within the region (Keke et al., 2020) could be attributed to the relatively good ecological integrity of the streams. Also, the heterogeneous vegetation of the streams served as suitable microhabitat for a more diverse macroinvertebrate fauna (Arimoro et al., 2011; Dala-Corte et al., 2020). Notably, human impacts in the catchment of the streams are not as intense as those for other water bodies within Niger state, Nigeria, which serves as receptors of dumping wastes, and cattle grazing (Keke et al., 2020). Ephemeropterans were the most ubiquitous and abundant group of aquatic invertebrates found in the present study, being recorded at all the sampling stations. This could be attributed to the fairly good water quality of the sampling stations and suitable refuge habitat for these invertebrates (Brito et al., 2020). The dominant macroinvertebrates were mostly aquatic insects (Ephemeroptera, Coleoptera, Hemiptera, Diptera and Odonata), Oligochaetes and few gastropods. This is similar to the observations of Arimoro and Keke (2017) and Keke et al. (2020) in some streams in Niger State. Generally, the favourable water conditions in these streams coupled with increased habitat availability must have accounted for this increase in species diversity. Ephemeroptera, *Caenis* sp. *Crassabwa* sp and *Afrobaetis* species were present in all the sampling stations and are species indicative of good ecological integrity. They therefore could be used as flagship species to raise support for biodiversity conservation in Baka Jeba and Penyan streams. The use of the flagship species concept could be very helpful in conservation programmes targeted at macroinvertebrates as it will inspire people to provide money for conservation (Jepson and Barua, 2015). Based on the abundance and diversity values and sensitive groups of macroinvertebrates especially the Ephemeroptera, Trichoptera and Odonata groups recovered in our study, we can categorize the streams as relatively unpolluted. This findings is consistent with the report of Patang et al. (2018) in a similar unperturbed tropical stream in Indonesia.

Although, on average, higher abundances of macroinvertebrates were recorded during the dry season than in the wet season. Consistent with this finding, Arimoro and Keke (2017) found higher abundances of macroinvertebrates in the dry season within the same region of this study. The heavy rainfall in this area during the wet season destabilizes the substrate, being washed off with the coming floods. However during the dry season, the substrate stabilizes with gradual buildup of macroinvertebrate abundance. Liu et al. (2020) linked this to the reduction of the water level and concomitant change of nutrients in the dry season.

4.3. Multivariate analysis

Canonical correspondence analysis showed even distribution of invertebrate fauna closely associated with many environmental variables in the streams. The correlation of many individual environmental variables with the axes were not statistically significant even though they were relatively high for CCA. However, these estimated significances may not be unconnected with the results of the unmeasured environmental variables. Only 56% of the variation in the macroinvertebrates was explained by the ordination, indicating that unmeasured variables such as resource availability, (e.g. periphyton, organic matter, detritus) and biotic interactions (e.g. predation, competition) could also be important in structuring the stream macroinvertebrate communities. The occurrence of *Nais* sp., chironomids and certain molluscs in the streams could be regarded as early warning signals of pollution loads that can degrade water quality and overall ecological health (Ladrera et al., 2019).

Species richness, diversity, and evenness indices at the various sampling stations during the eight months of sampling appeared to reflect good water quality conditions at each site. High species diversity in these water bodies are associated with un-impacted or unpolluted conditions (Arimoro and Ikomi 2009). These findings, although encouraging, in no way preclude the need to use primary macroinvertebrate data in global conservation prioritization as they become available. This is because reports indicate that aquatic systems usually feature poorly in existing conservation templates (Brooks et al., 2006). The findings from this research, therefore stresses the need to use macroinvertebrates data in streams for conservation prioritization.

4.4. Macroinvertebrates biodiversity and water quality

Analysis of biointegrity data adopted in this study to identify actual conservation targets and priorities at Baka Jeba and Penyan streams indicated that the upper reaches are suitable sites for emphasis as priorities for biodiversity conservation. Actually, it is through the conservation of actual sites that biodiversity will ultimately be preserved or lost (Brooks et al., 2006). Therefore, global conservation prioritization should be drawn to a much finer scale which inadvertently should be the primary concern for conservation planning. The continuous exploitation of the water resources of the Baka Jeba and Penyan streams is essential but maintaining good river quality is paramount. This will depend largely on the conservation of biodiversity (Mantyka-Pringle et al., 2016). It has also be argued in a recent study in the neotropics that the protection of riparian vegetation around streams is important in maintaining aquatic biodiversity and in reducing the negative effects of environmental disturbance on freshwater ecosystems (Dala-Corte et al., 2020).

We advocate making these two streams and their catchment as freshwater protected areas, which is of course a major strategy for conserving freshwater macroinvertebrates in the whole of Nigeria. Remarkably, the conservation planning of macroinvertebrate biodiversity in streams is enhanced by clear cut management plans (Brito et al., 2020). These management plans should include but not limited to; rehabilitation and adaptation strategies, increased protection of riparian vegetation in order to prevent soil erosion and siltation, integrated catchment management; strict action against human encroachments of waterways of these streams and increased awareness of the flood pulse concept, an ecologically significant phenomenon particularly relevant to tropical river systems (Mantyka-Pringle et al., 2016; Sundar et al., 2020). There is also substantial evidence to prove that even small amounts of catchment or riparian deforestation removes sensitive macroinvertebrates from neotropical streams (Brito et al., 2020; Dala-Corte et al., 2020).

Currently, the growing need for potable water and the alarming human population increase in Lapai and Paikoro Local Government areas where these rivers are located, calls for concerted efforts to preserve and protect these unique ecosystems. Although the challenges may appear insurmountable, we propose that successes can be achieved if the results from this investigation are modelled to meet the increasing human needs and to minimize biodiversity loss. Unprotected freshwater bodies around the globe are faced with unsustainable water abstraction, widespread habitat loss and degradation, increased levels of pollution, and a proliferation of invasive species (Garrick et al., 2017). The community network monitoring system put in place in the area (some group of persons appointed by the community head to monitor the streams) is a welcome development, in helping to create awareness for the need of better water and land-use practices. This kind of community participation in water quality monitoring can be an initial step forward in reducing deficits generated by economic growth and urbanization by stimulating citizens to have a greater voice in governance and public policies (Angelstam et al., 2013). Elsewhere, the implementation of participatory monitoring programs in neotropical urban streams by students has proven to be effective and economically viable tool to change social perception regarding environmental issues (França et al., 2019).

Therefore, we are of the view that this report will be the beginning of a series of research that would provide the necessary scientific evidence to inform environmental and development decision makers for policies to help set priorities for biodiversity with respect to achieving sustainable river water quality for the communities and for other pristine or near pristine streams in Nigeria (Edegbene et al., 2019, 2020). Efforts are currently being put in place globally to halt and reverse the global decline of freshwater biodiversity through research, data synthesis, conservation, education, outreach, and policymaking (Darwall et al., 2018). The data obtained from this investigation will in no doubt be a huge contribution to this mission, especially coming from the Afrotropical region where there is paucity of information on invertebrate biodiversity and conservation. Protection of these streams from both natural and man-made risks, is key to the viability of economic activity on the streams, the protection of human settlements, and the survival of many plant and animal species.

5. Conclusion

We demonstrated from this study that macroinvertebrates from our streams can be used as surrogates for water quality. The majority of taxa we encountered were those described for streams of good ecological integrity with a few rare species. As expected, rare taxa appear to be unmistakably associated with good water quality, which highlights the importance of conserving these freshwater habitats. The conservation of macroinvertebrates biodiversity and maintaining a good microhabitat should be prioritized, to avoid degradation of the water quality, maintain biodiversity and safeguard the ecosystem services that water management ultimately depends on. Targeted management of biodiversity would be part of broad strategies towards the sustainable water security in the rural communities.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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