Development of macroinvertebrate multimetric index for ecological evaluation of a river in North Central Nigeria

A. O. Edegbene ⬤ · **L. A. Elakhame · F. O. Arimoro ·
E. C. Osimen · O. N. Odume**

Abstract A macroinvertebrate-based multimetric index was developed for River Chanchaga, North Central Nigeria. Macroinvertebrates and physicochemical variables were sampled seasonally between March 2017 and February 2018 from four stations: station 1 (least impacted control station) and three downstream stations 2, 3 and 4. A total of 29 macroinvertebrate metrics in four categories, richness, abundance, composition and diversity, were evaluated for their potential to discriminate between the stations, seasonal stability and redundancy. Of the 29 metrics, only 13 fulfilled all criteria and were then integrated into the final Chanchaga multimeric index (MMIchanchaga). Application of the newly developed multimetric index revealed that water quality at stations 2 and 3 was fair and that of station 4

was poor. Water quality deteriorated slightly during the rainy season compared with the dry season. In terms of the individual component metrics, EPT richness, EPT (%) and Shannon diversity were highly sensitive to water quality impairment. The Bray–Curtis similarity measure revealed that stations 2 and 3 were more similar compared with the similarity between other stations. Overall, the newly developed multimetric index proved useful and represents the first important step in such index development in Nigeria.

Keywords % EPT · Multimetric index · Environmental deterioration · Biomonitoring · MMIchanchaga · River Chanchaga

A. O. Edegbene
Department of Biological Sciences (Applied Hydrobiology and Fisheries Unit), Sule Lamido University, Kafin Hausa, Nigeria

A. O. Edegbene (✉) · O. N. Odume
Unilever Centre for Environmental Water Quality, Institute for Water Research, Rhodes University, P.O. Box 94, Grahamstown 6140, South Africa
e-mail: ovieedes@gmail.com

e-mail: edegbeneaugustine.ovie@jsu.edu.ng

L. A. Elakhame · E. C. Osimen
Department of Zoology, Ambrose Alli University, Ekpoma, Nigeria

F. O. Arimoro
Department of Animal Biology (Applied Hydrobiology Unit), Federal University of Technology, Minna, Nigeria

Introduction

The heightened deterioration of freshwater ecosystems and their catchments has affected their capacity to provide clean and reliable sources of water and to maintain the natural hydrological cycle and biological dynamics (MEA 2005; UN-Water 2011). The escalating deterioration in the quality of freshwater resources implies that there is an urgent need to develop tools, methods and approaches for reliably quantifying the impact of human-induced activities on freshwater ecosystems. The development of such tools would allow for urgent and target management actions so that appropriate rehabilitation and/or mitigation measures can be taken. Aquatic biota are reliable indicators of impact of human-induced activities on freshwater ecosystems

because they reside in the system, integrating the combined effects of physical, chemical and biological stressors (Shull et al. 2019). Of the different aquatic biota, macroinvertebrates are commonly used for assessing the effects of ecological state of water bodies (Rosenberg and Resh 1993; Bonada et al. 2006; Odume et al. 2012); deterioration and a variety of biological monitoring (biomonitoring) approaches have been developed based on them, e.g. single biotic index, multivariate and multimetrics (Bonada et al. 2006).

Biomonitoring of aquatic ecosystem using benthic invertebrate multimetric index is an approach which combines a collection of metric and indices of macroinvertebrates, e.g. abundance, composition, richness, diversity and more recently trait attributes to assess water quality conditions in freshwater ecosystem (Bonada et al. 2006; Monaghan and Soares 2012; Odume et al. 2012; Mereta et al. 2013; Shull et al. 2019). The strength of the multimetric approach is that it combines multiple metrics deemed to be sensitive to changes in water quality deterioration. Owing to the strength of the multimetric approach, globally, multimetric indices (MMIs) are becoming widespread as means of monitoring water quality conditions. In Europe, North America, South America and Australia, aquatic organisms have been used to develop multimetric indices in a bid to monitor the ecological health conditions of the aquatic systems (e.g. Barbour et al. 1999; Smith et al. 1999; Hawkins et al. 2000; Baptista et al. 2007; Golfieri et al. 2018). However, in Africa, the approach has received little attention (e.g. Odume et al. 2012; Mereta et al. 2013; Kaaya et al. 2015; Dallas et al. 2018) as the science of biomonitoring is still not well developed in many parts of the African continent; Nigeria is no exception.

Water quality monitoring in Nigeria relies chiefly on analysis of physicochemical variables and basic analysis of biotic distribution in relation to pollution gradient (Arimoro and Ikomi 2009; Arimoro et al. 2015; Edegbene et al. 2015; Edegbene 2018). However, physicochemical analysis alone as a means of monitoring water quality condition has been criticised because they cannot give a comprehensive picture of the state of water bodies. Again, physicochemical analysis is not cost-effective unlike the macroinvertebrate sample collection and analysis; it requires a lot of analytical skills and finances to carry out such analysis. In instances where

physicochemical analysis is complemented with biotic analysis, such analyses have not yielded the needed results because they are not directly linked to management. Thus, the development of a multimetric index for the River Chanchaga in Niger State in the North Central part of Nigeria is of paramount importance at this time. The multimeric index significance is bordered on the fact that despite such similar indices being widely used globally, not a single multimetric index to the best of our knowledge exists for any water body in Nigeria; hence, this gap therefore needs to be filled.

River Chanchaga, a tributary of one of the major rivers in Nigeria, River Niger, is a water body located at the capital city of Niger State, Minna, Nigeria. Because of its uniqueness, the river serves many purposes such as means of potable water supply, waste disposal and industrial sites. Households around the river catchment depend on the water for domestic use, means of livelihood as they engage in farming and fishing activities and sometimes mining activities. The river has been subjected to varied degrees of pollution loads occasioned by human-induced activities. Therefore, this study is aimed at developing a macroinvertebrate-based multimetric index to monitor the water quality condition and ecological health of the River Chanchaga, North Central Nigeria.

Materials and methods

The study area

River Chanchaga is located in the southern part of Niger State, Nigeria (Fig. 1). The river originates from Mutundaya in Shiroro Local Government Area and flows southward through Zhabyala, Tunga Waya, Chanchaga, Korokpan and Ekwuti and terminates at Gedege where it joins the River Niger. It lies between latitudes 8° 43′ N to 9° 40′ N and longitudes 6° 12′ E to 6° 47′ E of the equator. The tributaries of River Chanchaga include Rivers Guduko, Gorax and Gbako. Human activities on the river and its catchment include gold mining, sand dredging, bathing, washing, farming, irrigation activities, indiscriminate defaecation and fishing. River Chanchaga is used by the Niger State Water Board as its main water source to the city of Minna and the surrounding areas.

Climate of the study area

The river is in the tropics with mean annual temperature of 30.2 °C, relative humidity of 61% and annual rainfall ranging between 1200 mm and 1300 mm (Edegbene et al. 2015). The vegetative cover reflects that of guinea savanna zone, characterised by sparsely distributed trees species, shrubs and dominated by grassland. The area shows two distinct seasons: the rainy and the dry seasons. The rainy season occurs from April to October and the dry season from November to March (Edegbene et al. 2015). The rainy season is usually characterised by excessive rainfall during the peak of the season while the dry season portrays a sparse distribution of rainfalls to no rainfall towards the end of the season.

The study stations

For the purpose of this study, four well-marked stations were selected based on accessibility, macroinvertebrate habitat types, diversity and the degree of anthropogenic disturbance. The four stations were Zhabyala (station 1; latitude 9° 40′ N and longitude 6° 46′ E), Tunga Waya (station 2; latitude 9° 35′ N and longitude 6° 39′ E), Chanchaga (Water Board) (station 3; latitude 9° 31′ N and longitude 6° 32′ E) and Korokpan Communities (station 4; latitude 9° 32′ N and longitude 6° 34′ E) (Fig. 1). The study was conducted for a period of one year from March 2017 to February 2018. Water and macroinvertebrate samples were collected monthly all through the sampling period. Station 1 was enmarked the least impacted/control station based on the fact that it was devoid of much human disturbances and close to the river source. Farming and domestic activities characterised the other stations, most especially in station 3, which houses the Niger State water board authority, and station 4 where there is gold mining activities. Station 2 is mainly characterised by farming activities because of its location in the farm settlements of the Gbagi people of Niger State, Nigeria.

Environmental variables

Physicochemical parameters were sampled on each sampling expedition. Air and water temperatures, dissolved oxygen (DO), electrical conductivity (EC), pH, water depth and flow velocity were measured. Air and water temperatures were measured with mercury-in-glass thermometer while dissolved oxygen, EC and pH were measured using HANNA HI 9828 multiprobe metre manufactured by HANNA manufacturers. Average mid-channel flow velocity was measured in three replicates by timing a float as it moved over a distance of 10 m with a stopwatch (Gordon et al. 1994). Water depth was measured in the sample area using a calibrated rod measured in metres. Transparency was measured using a secchi disc (Edegbene and Arimoro 2012). Water samples were collected in 1-l plastic acid-washed bottles and transported to the laboratory in a cooler box containing ice. In the laboratory, water samples were analysed for biochemical oxygen demand (BOD_5), alkalinity, nitrate, sulphate and phosphate according to (APHA 1998) methods. Analysis of all samples commenced within 24 hours of sampling.
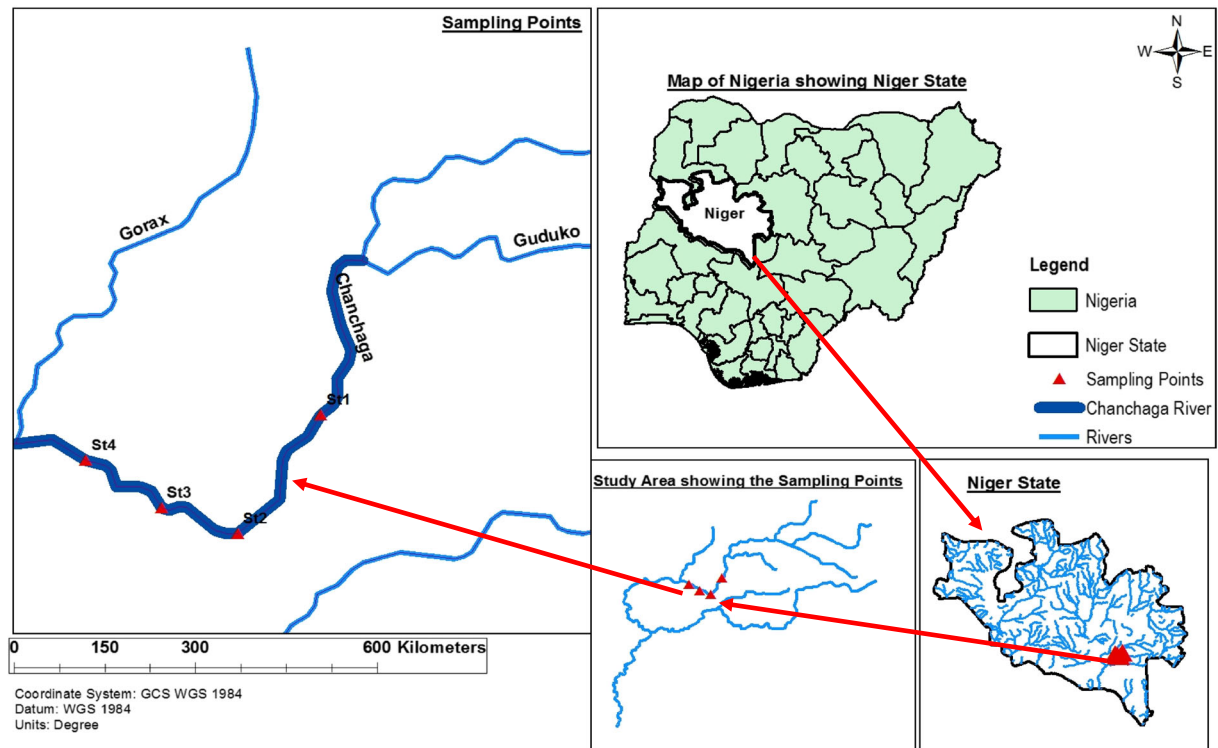
Macroinvertebrate sampling

Macroinvertebrate samples were collected by using a 3-min kick method with a squared-frame net of 14.63 square feet (1.36 m^2, 800-μm mesh) along an approximate 25-m-long wadeable stretch of the river. Four different samples were taken at each sampling station, which covered different substrates (gravel, clay, sand and silt) and flow regime zones.

Live sorting was done in the field immediately after sample collection from the river. At each sampling station, macroinvertebrate samples were placed in a white enamel tray for easy identification of any moving organism. Freed moving macroinvertebrates were then collected with the aid of forcep and placed in sample bottles that contain 70% alcohol for further identification and references at the laboratory. Macroinvertebrates were identified using keys described by Cranston (2000) and Gerber and Gabriel (2002), after which abundance count was undertaken.

Chanchaga multimetric index (MMIchanchaga) development

Twenty-nine metrics in four groups which include taxa abundance (absolute number of macroinvertebrate individuals), taxa composition (relative abundance), taxa richness and diversity indices which include Shannon wiener index, Margalef index, Simpson diversity and evenness (Odume et al. 2012; Meretal et al. 2013) were selected (Table 1). The Chanchaga multimetric index (MMIchanchaga) was developed using macroinvertebrate taxonomic metrics, which have been identified as

Fig. 1 Map of the study area showing the sampling stations of River Chanchaga

indicating sensitivity of the macroinvertebrate community in the River Chanchaga, i.e. they were strongly correlated with water physicochemical variables and enabled discrimination of station 1 from the downstream stations 2, 3 and 4. The asterisked metrics in the Table 1 were incorporated in the development of the multimetric index.

Data analyses

Mean and standard deviation (SD) for each physicochemical variable were calculated per station. Physicochemical variables were compared between stations and months using two-way analysis of variance (ANOVA). Significant differences between stations indicated by ANOVA ($p < 0.05$) were followed by post hoc honestly significant difference (HSD) test. ANOVA and post hoc tests were performed using PAST Statistical Package (Hammer et al. 2001).

To assess the performance of the metrics, their discriminatory potential and their correlations with water physicochemical variables were used for the evaluation of the metrics as adapted from Odume et al. (2012). Metric discriminatory potential was defined as the potential of a metric to discriminate between station 1 (control station) from stations 2, 3 and 4. Box and whisker plots were used to evaluate the metric discriminatory potential, using the degree of overlap of medians and the interquartile ranges (IQRs) between station 1 (control station) and downstream stations (Odume et al. 2012). Two levels of metric discriminatory potentials were considered satisfactory. Firstly are those metrics which show overlap in interquartile range (IQR) between station 1 (control station) and stations 2, 3 and 4 (Odume et al. 2012), while the second level of discriminatory potential are those metrics which show an overlap in the IQRs, but the medians were outside the IQRs (Odume et al. 2012). Metrics that showed discriminatory potentials between station 1 (control station) and the other three stations of the macroinvertebrate metric selected were further subjected to multiple comparison analysis using Kruskal–Wallis test (Odume et al. 2012).

Table 1 Selected taxonomically based macroinvertebrate metrics measures of absolute abundance, relative abundance, richness and diversity applied to macroinvertebrate data collected at the River Chanchaga, Niger State, Nigeria, during the study period (March 2017–February 2018). Metrics were selected based on taxonomic composition and self-adoption. Metrics were defined according to Odume et al. (2012) and Mereta et al. (2013). + indicate that the metric increases with deteriorating water quality, and − indicates that metric decreases with deteriorating water quality

Metrics	Definition	Predicted response to deteriorating water quality
Abundance measure		
EPT abundance	Absolute number of individuals in Ephemeroptera, Plecoptera and Trichoptera	−
Ephemeroptera abundance	Absolute number of individuals in Ephemeroptera	−
ETOC abundance	Absolute number of individuals in Ephemeroptera Trichoptera, Odonata and Coleoptera	−
Chironomidae + Oligochaeta abundance	Absolute number of individuals in Chironomidae and Oligochaeta	+
Mollusca + Decapoda abundance	Sum of the absolute number of individuals in Mollusca and Decapoda	
Diptera abundance*	Absolute number of individuals in Diptera	+
Decapoda abundance*	Absolute number of individuals in Decapoda	−
Mollusca abundance*	Absolute number of individuals in Mollusca	+
Coleoptera abundance	Absolute number of individuals in Coleoptera	−
Odonata abundance*	Absolute number of individuals in Odonata	−
Trichoptera abundance	Absolute number of individuals in Trichoptera	−
Coleoptera + Hemiptera abundance*	Sum of the absolute number of individuals in Coleoptera and Hemiptera	−
EPT/Chironomidae ratio	Ratio of EPT individuals to Chironomidae individuals	−
Measures of composition (relative abundance)		
% Chironomidae + Oligochaeta*	Percentage of individuals in Chironomidae + Oligochaeta taxa relative to the entire sample	+
% Mollusca	Percentage of individuals in Mollusca taxa relative to the entire sample	+
% Trichoptera	Percentage of individuals in Trichoptera taxa relative to the entire sample	
% Coleoptera + Hemiptera*	Percentage of individuals in Coleoptera and Hemiptera taxa relative to the entire sample	−
% ETOC	Percentage of individuals in Ephemeroptera, Trichoptera, Odonata and Coleoptera taxa relative to the entire sample	−
% Diptera	Percentage of individuals in Diptera taxa relative to the entire sample	+
% Decapoda*	Percentage of individuals in Decapoda taxa relative to the entire sample	+
% Ephemeroptera	Percentage of individuals in Ephemeroptera taxa relative to the entire sample	−
% EPT*	Percentage of individuals in Ephemeroptera, Plecoptera and Trichoptera taxa relative to the entire sample	−
Richness measures		
EPT richness*	Absolute number of taxa in EPT	−
ETOC richness	Absolute number of taxa in ETOC	−
Hemiptera + Diptera richness*	Absolute number of taxa in Hemiptera and Diptera	−
Diversity measures		
Simpson diversity	Weighted towards the abundance of commonest genus/species/taxa (Ogbeibu 2005)	−
Evenness index	Evenness of taxa within sample (Clarke and Warwick 1994)	−
Margalef index (taxa diversity index)*	Accounts for both number of taxa and individuals and is independent of sample size (Ogbeibu 2005)	−
Shannon diversity index*	Information statistics index taking account of the contribution of individual taxa to the diversity while assigning greater weight to dominant taxa (Ogbeibu 2005)	−

*Integrated metrics for the development of River Chanchaga multimetric index (MMIchanchaga)

Metric sensitivity with suitable discriminatory potential to differences in water physicochemical variables was examined using Pearson's correlation analysis (Odume et al. 2012). Before correlation and ANOVA

analyses were performed, all physicochemical variable data were logarithmically transformed to meet the assumption of normality except for pH (Odume et al. 2012), and when assumption was still not met, data were normalised.

Only metrics not significantly different between the seasons were considered seasonally stable. Metrics that were seasonally stable were further subjected to redundancy test using the Spearman's rank correlation test ($r > 0.78$; $p < 0.05$) (Baptista et al. 2007). Two or more metrics were considered redundant if the value of r is greater than or equal to 0.78 ($r \geq 0.78$; $p < 0.05$). When two or more metrics were redundant, only one of such redundant metrics was retained for integration into the multimetric index.

The retained metrics were integrated into a multimetric index. Integrating the metrics into a multimetric index requires standardising the numeric values of each metric because the different metrics, e.g. EPT (%), EPT richness, Diptera abundance and percent Chironomidae + Oligochaeta are based on different numeric scales (Table 1). The numeric values of the retained metrics were standardised by dividing the range of metric values into three possible scores for each metric (Baptista et al. 2007). To standardise the numeric values of the metrics, the minimum, lower quartile (25%), mid-quartile (50%), upper quartile (75%) and maximum values of each metric for station 1 (control station) assemblage distribution were calculated and used as the basis for scoring the numeric values of metrics at stations 2, 3 and 4 (Odume 2014). For metrics expected to increase in numeric value with increasing pollution, if the numeric value at stations 2, 3 and 4 (impacted stations) was lower than the upper quartile (75%) (Baptista et al. 2007) of the station 1 assemblage distribution, it was scored 5, and if it was between the upper quartile and maximum value of the station 1 assemblage, it was scored 3. A score of 1 was awarded to the metric value if it was greater than the maximum value of that metric for station 1 assemblage. Canonical correspondence analysis (CCA) was used to show the correlation between the 13 metrics integrated into the Chanchaga multimetric index and the selected environmental variables while a cluster analysis (Bray–Curtis similarity) was used to test the association of stations based on the metric components. CCA and cluster

analysis were computed using the PAST Statistical Package (Hammer et al. 2001).

Results

Environmental variables

The means, standard deviations, minimum and maximum values, ANOVA and p values of the physicochemical variables for the stations are summarised in Table 2.

Air and water temperatures were highest at station 4 with maximum value of 35 °C and 32 °C respectively. The minimum value of air temperature was recorded at station 3 (22.5 °C), and stations 1 and 3 had the lowest water temperature value (23 °C). Water temperature was not significantly different between the months sampled ($p > 0.05$). The EC mean values for stations 1, 2, 3 and 4 were 7.86 ± 1.9 µS cm^{-1}, 8.49 ± 2.46 µS cm^{-1}, 8.51 ± 2.62 µS cm^{-1} and 10.14 ± 3.13 µS cm^{-1} respectively. Electrical conductivity was not statistically significantly different between the stations ($p > 0.05$) but highly significantly different between the months sampled ($p < 0.05$). DO, BOD$_5$, alkalinity, sulphate and phosphate were statistically significantly different between the stations ($p < 0.05$) (Table 2).

Chanchaga multimetric index development for assessing the ecological health condition of River Chanchaga

Test for discrimination

Out of the 29 family-level taxonomic metrics tested, 27 metrics enabled the discrimination of station 1 from stations 2, 3 and 4 (Fig. 2). The two metrics that did not discriminate station 1 from stations 2, 3 and 4 were Trichoptera abundance and Trichoptera (%). These two metrics were removed and not analysed further.

Test for seasonality

The remaining 27 metrics after the test for discrimination were further subjected to seasonal stability test using Krukal–Wallis test. The test revealed that only Mollusca (%) showed significant difference ($p < 0.05$) between the seasons. Mollusca (%) was removed and not analysed further.

Table 2 Summary of physicochemical variables of the study stations of River Chanchaga, Niger State, Nigeria

| Variables	Station 1	Station 2	Station 3	Station 4	Months		Stations	
					F value	p value	F value	p value
Air temperature (°C)	28.88 ± 1.87 (25.0–32.0)a	30.65 ± 2.088 (24.0–33.0)b	28.17 ± 2.06 (22.5–31.5)a	30.40 ± 2.55 (24.0–35.0)b	3.06136	0.000177	11.1367	4.76E−06
Water temperature (°C)	27.17 ± 1.49 (23.0–29.2)a	28.55 ± 1.61 (25.5–31.0)b	26.92 ± 1.69 (23.0–31.0)a	28.43 ± 1.73 (26.0–32.0)b	2.01904	0.01336	8.03307	0.000115
Water depth (m)	0.38 ± 0.11 (0.18–0.62)a	0.42 ± 0.11 (0.10–0.78)a	0.45 ± 0.19 (0.12–0.88)a	0.47 ± 0.20 (0.18–0.89)a	6.17841	1.853E−09	2.96208	0.03811
Transparency (cm)	6.85 ± 2.93 (2.0–14.8)a	6.58 ± 2.16 (2.0–11.4)a	7.62 ± 5.09 (2.40–24.5)a	6.37 ± 1.92 (2.05–10.2)a	3.99211	4.294E−06	1.17016	0.3275
Flow velocity (ms^{-1})	0.30 ± 1.44 (0.03–0.56)a	0.29 ± 0.16 (0.024–0.78)a	0.35 ± 0.33 (0.033–1.49)a	0.27 ± 0.13 (0.021–0.52)a	3.67322	1.498E−05	1.09464	0.3573
Conductivity (µS cm^{-1})	7.86 ± 1.94 (4.24–12.6)a	8.49 ± 2.46 (5.0–12.5)ab	8.51 ± 2.62 (4.8–16.0)ab	10.14 ± 3.13 (5.4–19.0)b	10.2823	2.192E−14	11.432	3.572
pH	6.29 (5.2–7.3)	6.97 (6.2–7.7)	6.86 (5.2–8.0)	7.45 (6.0–8.8)				
DO (mg l^{-1})	5.74 ± 1.87 (1.1–8.2)a	4.27 ± 1.67 (1.22–7.0)b	3.83 ± 1.62 (1.25–7.2)bc	2.72 ± 1.57 (0.45–7.8)c	7.72811	1.681E−11	35.3058	6.076E−14
BOD$_5$ (mg l^{-1})	0.23 ± 0.54 (−2.185–0.89)a	0.46 ± 0.34 (−0.925–0.93)ab	0.73 ± 0.43 (−0.9–1.18)b	1.22 ± 0.64 (−0.03–2.6)c	3.8783	1.751E−10	29.5204	2.157E−12
Alkalinity (mg l^{-1})	61.37 ± 15.16 (45.0–116.42)a	62.74 ± 23.81 (34.0–112.08)a	68.86 ± 18.43 (38.0–103.45)a	89.90 ± 23.50 (46.0–134.89)b	6.93192	1.751E−10	24.5904	6.215E−11
Sulphate (mg l^{-1})	7.80 ± 6.57 (1.5–21.33)a	10.60 ± 6.82 (2.7–24.09)ab	14.38 ± 9.44 (3.0–30.44)b	16.11 ± 7.96 (6.24–32.0)b	20.9373	1.12E−22	33.1688	2.177E−13
Phosphate (mg l^{-1})	0.41 ± 0.32 (0.05–1.2)a	0.50 ± 0.59 (0.12–2.49)a	0.56 ± 0.64 (0.12–2.46)a	0.79 ± 0.87 (0.145–3.7)a	11.8677	6.103E−16	5.58825	0.001722

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

Test for redundancy

The Spearman's rank correlation coefficient revealed that the majority of the metrics were strongly correlated with each other (Table 3). The redundant metrics (i.e. metrics that were strongly correlated) were EPT abundance, Ephemeroptera abundance, EPT/Chironomidae ratio, ETOC (%), EPT (%), Ephemeroptera (%), EPT richness, ETOC abundance, Diptera abundance, Chironomidae + Oligochaeta, Mollusca + Decapoda abundance, Mollusca abundance, Decapoda abundance, Diptera (%), Coleoptera abundance, Coleoptera + Hemiptera abundance, ETOC richness, Margalef index (taxa richness), Simpson diversity, evenness index and Shannon diversity. Some of these redundant metrics were retained using the knowledge of their ecological importance (Table 1).

Integrating the selected metrics into the multimetric index

Based on the 13 selected metrics, the MMIchanchaga was then developed by calculating the minimum value, lower quartile (25%), mid-quartile (50%), upper quartile (75%) and maximum value of each metric for the station 1 assemblages, and these values were used as thresholds for separating the scores (Tables 4 and 5). The MMIchanchaga was then computed by summing the scores of the 13 component metrics, and the index value range (5–65) since 13 metrics were used ($13 \times 5 = 65$) and then quadrisected to obtain four water quality conditions: good, fair, poor and very poor (Table 5). Pristine (i.e. natural) water quality condition was omitted because the macroinvertebrate composition/assemblages used in developing the index did not come from a pristine condition, but one that was minimally disturbed.
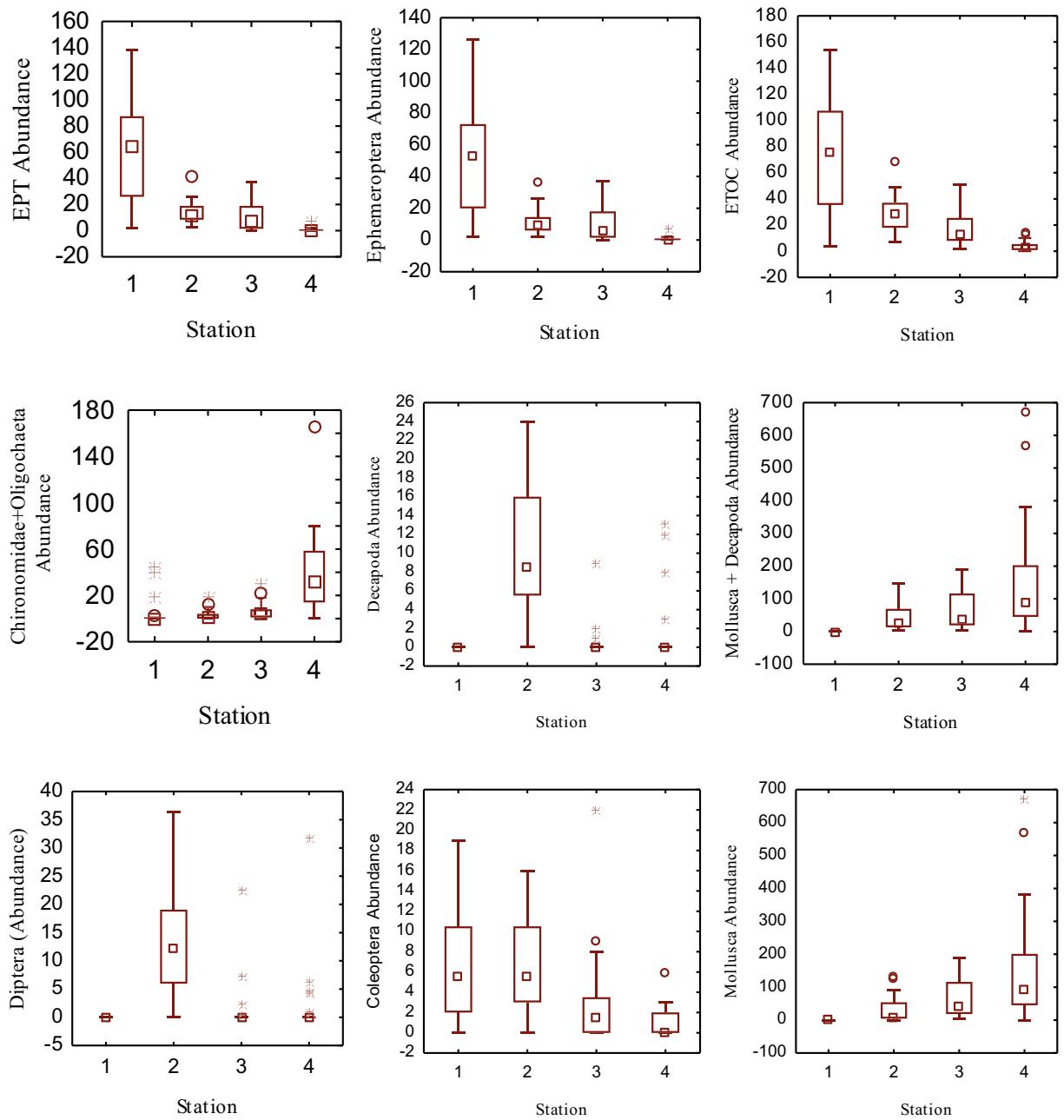
Fig. 2 Box and whisker plots for metric discrimination at the four stations in the Chanchaga River during the study period

Spatial–temporal variation in ecological condition of the impacted stations using the developed Chanchaga multimetric index

When the newly developed MMIchanchaga was used to assess the River Chanchaga ecological condition at the impaired stations over the sampling period, it rated water quality at stations 2 and 3 as fair in all the sampling months (pooled data set for the entire study period) while station 4 was rated as being of a poor water quality (Table 6). Station 2 was of a good water quality with MMIchanchaga score of 45 while station 3 had a MMIchanchaga score of 41 indicative of fair
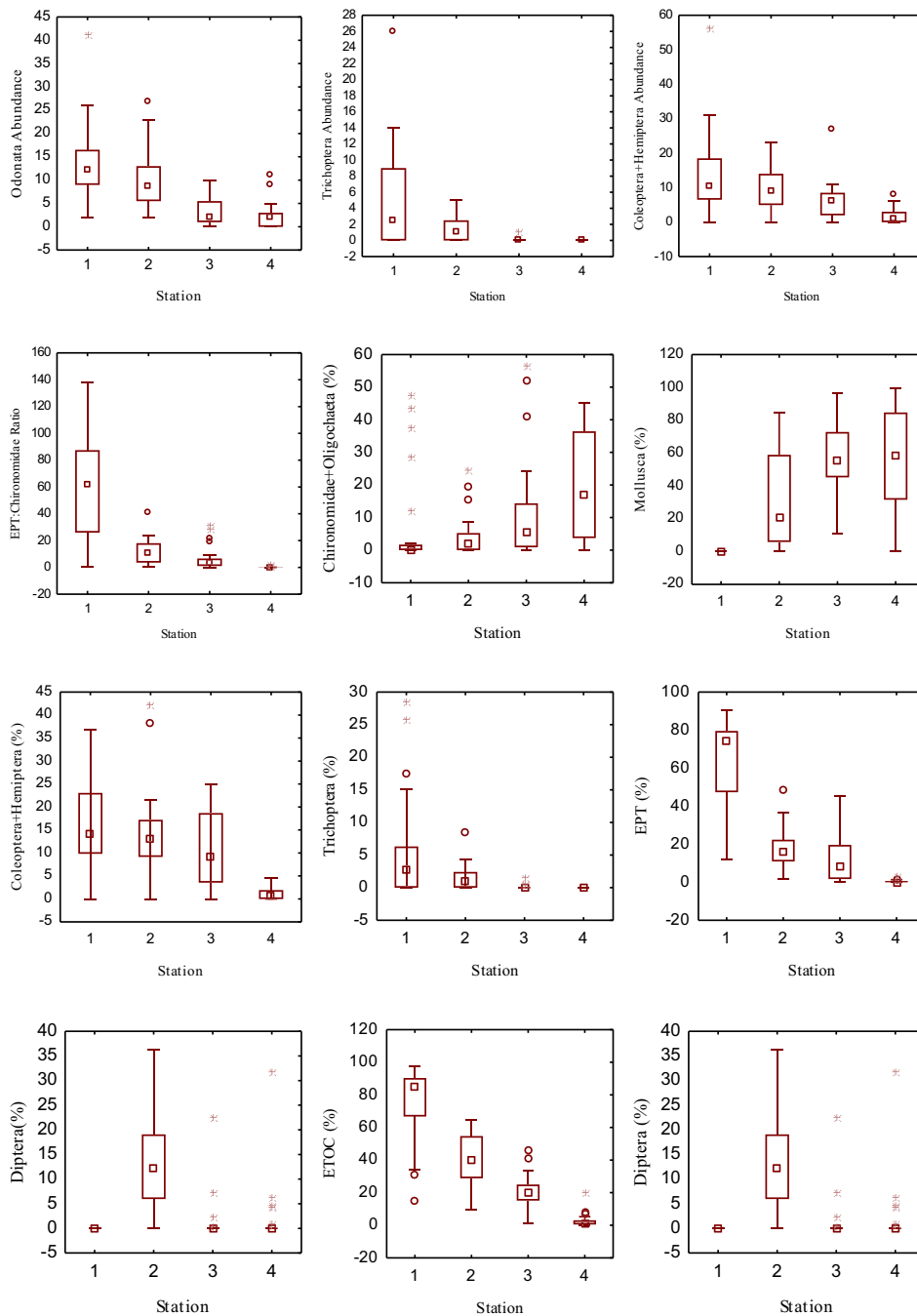
Fig. 2 (continued)

water quality (Table 6). Station 4 was heavily perturbed with MMIchanchaga score of 35, indicating a poor water quality.

Seasonally, the index indicated that the ecological condition at stations 2 and 3 during the dry and rainy seasons were fair with MMIchanchaga value of 49 and 37 for dry and 43 and 39 rainy seasons respectively unlike the deteriorated state of station 4 with MMIchanchaga values 31 and 32 for both dry and rainy season (Fig. 3).
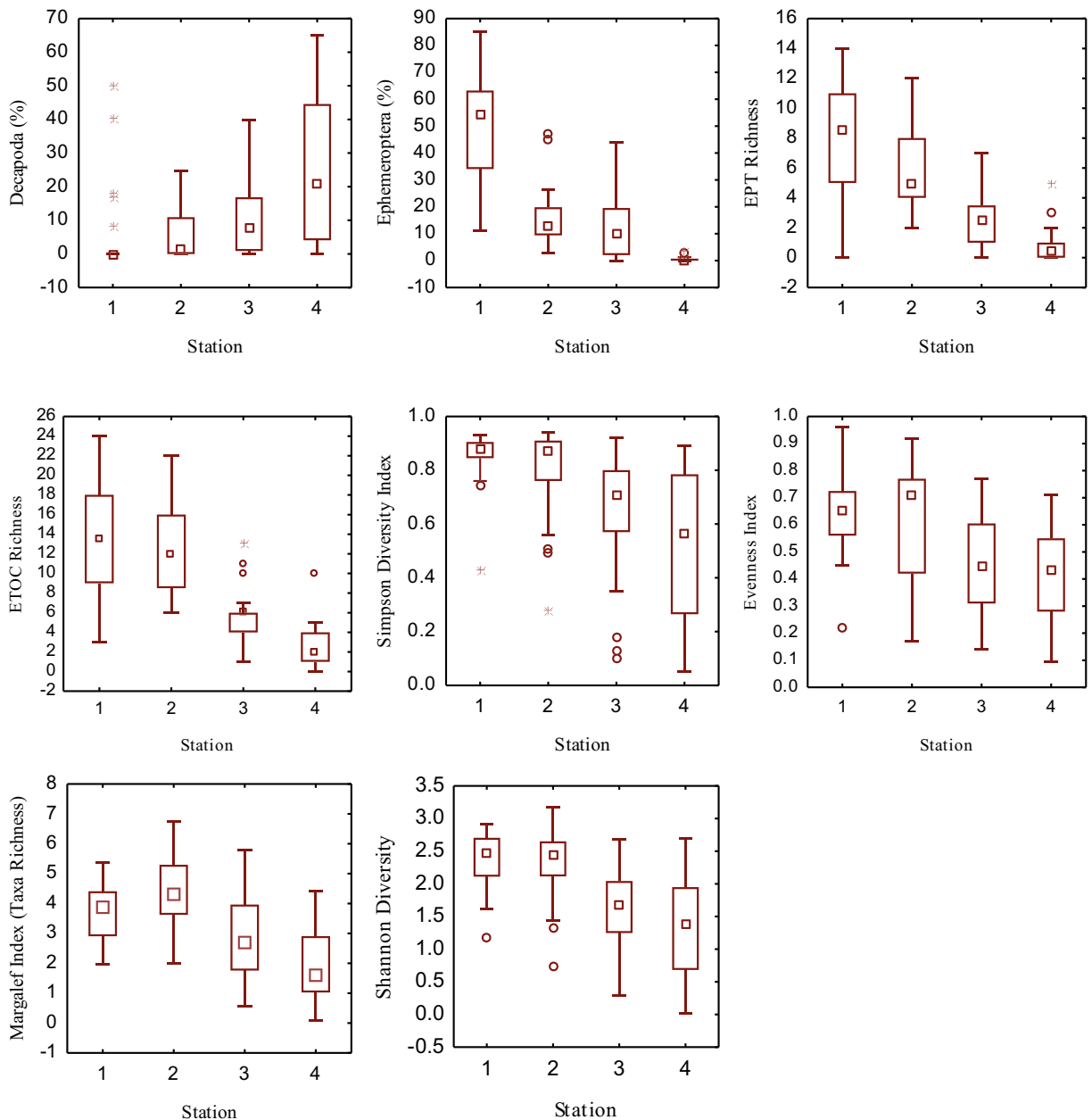
Fig. 2 (continued)

Correlating the 13 component metrics in the Chanchaga multimetric index with physicochemical variables

CCA was used to correlate the 13 metrics with the measured physicochemical variables (Fig. 4). DO was strongly correlated with pH, water depth, sulphate, phosphate, conductivity, BOD_5 and alkalinity

on axis 1. Among the metrics used for the MMIchanchaga, EPT (%) was the most strongly correlated metric to increased DO (Fig. 4). Shannon diversity, Hemiptera + Diptera richness, Margalef index, EPT richness, Coleoptera + Hemiptera (%), Odonata abundance and Coleoptera + Hemiptera abundance were also correlated with increased DO. All these metrics were mainly associated with

Table 3 Spearman's rank two-tailed correlation coefficient showing redundant macroinvertebrate metrics ($r > 0.78$, $p < 0.05$) analysed for the River Chanchaga macroinvertebrate communities during the study period. Asterisk revealed significant correlation at alpha < 0.05

	EPT abun	Eph abun	ETOC abun	Chi+Oli abun	Mol+Dec abun	Dip abun	Dec abun	Mol abun	Col abun	Odo abun	Col+Hem abun	EPT/Chi ratio	Chi+Oli (%)
EPT abun	1.00	0.99	0.97*	−0.30	−0.30	−0.28	−0.16	−0.29	0.42	0.59	0.40	0.99*	−0.35
Eph abun	0.98*	1.00	0.97*	−0.29	−0.29	−0.27	−0.16	−0.28	0.39	0.57	0.39	0.97	−0.34
ETOC abun	0.97*	0.97*	1.00	−0.31	−0.33	−0.30	−0.03	−0.33	0.57	0.73	0.55	0.94*	−0.34
Chi+Oli abun	−0.30	−0.29	−0.31	1.00	0.182	0.92*	−0.18	0.19	−0.18	−0.25	−0.14	−0.30	0.67
Mol+Dec abun	−0.30	−0.29	−0.33	0.182	1.00	0.18	−0.05	0.99*	−0.27	−0.29	−0.29	−0.28	−0.077
Dip abun	−0.28	−0.27	−0.30	0.92*	0.18	1.00	−0.14	0.19	−0.21	−0.24	−0.21	−0.27	0.53
Dec abun	−0.16	−0.16	−0.03	−0.18	−0.05	−0.14	1.00	−0.11	0.33	0.277	0.17	−0.17	−0.18
Mol abun	−0.29	−0.28	−0.33	0.19	0.99*	0.19	−0.11	1.00	−0.29	−0.29	−0.30	−0.27	−0.067
Col abun	0.433	0.40	0.57	−0.18	−0.27	−0.21	0.33	−0.29	1.00	0.54	0.80	0.38	−0.09
Odo abun	0.59	0.57	0.73	−0.25	−0.28	−0.24	0.277	−0.29	0.54	1.00	0.57	0.55	−0.26
Col+Hem abun	0.40	0.40	0.55	−0.14	−0.29	−0.21	0.17	−0.30	0.80*	0.57	1.00	0.33	−0.048
EPT/Chi ratio	0.99*	0.97*	0.94*	−0.30	−0.28	−0.27	−0.17	−0.27	0.38	0.55	0.33	1.00	−0.38
Chi+Oli (%)	−0.35	−0.34	−0.34	0.67	−0.077	0.53	−0.18	−0.067	−0.09	−0.26	−0.048	−0.38	1.00
Col+Hem (%)	0.090	0.088	0.20	−0.27	−0.46	−0.31	0.13	−0.067	−0.091	−0.256	−0.048	−0.023	−0.023
EPT (%)	0.86	0.84	0.82*	−0.37	−0.41	−0.35	−0.22	−0.40	0.26	0.48	0.26	0.86*	−0.40
ETOC (%)	0.78*	0.77	0.81	−0.42	−0.52	−0.41	0.002	−0.51	0.45	0.59	0.42	0.77	−0.36
Dip (%)	−0.18	−0.18	−0.084	−0.19	−0.13	−0.16	0.88*	−0.18	0.24	0.12	0.098	−0.19	−0.15
Dec (%)	−0.40	−0.99	−0.40	0.73	−0.055	0.76	−0.14	−0.047	−0.17	−0.29	−0.20	−0.40	0.77
Eph (%)	0.86*	0.88	0.83*	−0.38	−0.41	−0.35	−0.18	−0.40	0.27	0.47	0.28	0.85	−0.40
EPT richness	0.78*	0.77	0.81*	−0.37	−0.35	−0.36	0.13	−0.35	0.47	0.61	0.47	0.76	−0.42
ETOC richness	0.73	0.72	0.82*	−0.36	−0.36	−0.35	0.28	−0.37	0.65	0.73	0.60	0.70	−0.34
Hem+Dip rich	−0.23	−0.21	−0.18	0.54	0.141	0.60	−0.01	0.14	0.024	−0.065	0.11	−0.27	0.45
Sim div	0.29	0.26	0.36	0.059	−0.71	0.054	0.15	−0.71	0.45	0.38	0.45	0.25	0.21
Eve ind	0.089	0.068	0.16	−0.06	−0.65	−0.10	0.089	−0.65	0.34	0.20	0.34	0.08	0.16
Mar ind	0.39	0.378	0.48	−0.14	−0.39	−0.09	0.32	−0.41	0.51	0.52	0.51	0.34	−0.08
Sha div	0.33	0.31	0.43	0.05	−0.52	0.044	0.21	−0.53	0.53	0.47	0.53	0.29	0.14

	Col+Hem (%)	EPT (%)	ETOC (%)	Chi+Oli (%)	Dip (%)	Dec (%)	Eph (%)	ETOC rich	EPT rich	Hem+Dip rich	Sim div	Eve ind	Mar ind	Sha div
EPT abun	0.090	0.86	0.78*	0.78*	−0.18	−0.40	0.86*	0.73	0.78*	−0.23	0.29	0.089	0.39	0.33
Eph abun	0.088	0.84	0.77	0.77	−0.18	−0.99	0.88	0.72	0.77	−0.21	0.26	0.068	0.378	0.31
ETOC abun	0.20	0.82*	0.81	0.81	−0.084	−0.40	0.83*	0.82*	0.81*	−0.18	0.36	0.16	0.48	0.43
Chi+Oli abun	−0.27	−0.37	−0.42	−0.42	−0.19	0.73	−0.38	−0.36	−0.37	0.54	0.059	−0.06	−0.14	0.05
Mol+Dec abun	−0.46	−0.41	−0.52	−0.52	−0.13	−0.055	−0.41	−0.36	−0.35	0.141	−0.71	−0.65	−0.39	−0.52
Dip abun	−0.31	−0.35	−0.41	−0.41	−0.16	0.76	−0.35	−0.35	−0.36	0.60	0.054	−0.10	−0.09	0.044
Dec abun	0.13	−0.22	0.002	0.002	0.88*	−0.14	−0.18	0.28	0.13	−0.01	0.15	0.089	0.32	0.21

Table 3 (continued)

	Col+Hem (%)	EPT (%)	ETOC (%)	Dip (%)	Dec (%)	Eph (%)	EPT rich	ETOC rich	Hem+Dip rich	Sim div	Eve ind	Mar ind	Sha div
Mol abun	−0.40	−0.40	−0.51	−0.18	−0.05	−0.40	−0.35	−0.37	0.14	−0.71	−0.65	−0.41	−0.53
Col abun	0.52	0.26	0.45	0.24	−0.17	0.27	0.48	0.65	0.02	0.45	0.34	0.51	0.53
Odo abun	0.26	0.48	0.59	0.12	−0.29	0.47	0.61	0.73	−0.064	0.38	0.20	0.51	0.47
Col+Hem abun	0.65	0.26	0.42	0.01	−0.2	0.28	0.47	0.60	0.11	0.45	0.34	0.51	0.53
EPT/ Chi ratio	0.052	0.86	0.77	−0.19	−0.41	0.85	0.76*	0.70	−0.27	0.25	0.08	0.34	0.29
Chi+Oli (%)	−0.023	−0.40	−0.36	−0.15	0.77	−0.39	−0.42	−0.34	0.45	0.21	0.16	−0.08	0.14
Col+Hem (%)	1.00	0.22	0.44	0.22	−0.16	0.197	0.24	0.33	−0.018	0.58	0.67	0.44	0.57
EPT (%)	0.22	1.00	0.91*	−0.20	−0.44	0.93*	0.75	0.64	−0.31	0.39	0.28	0.36	0.38
ETOC (%)	0.44	0.91*	1.00	0.036	−0.43	0.876*	0.77	0.75	−0.28	0.57	0.49	0.52	0.57
Dip (%)	0.22	−0.20	0.036	1.00	−0.12	−0.15	0.032	0.15	−0.074	0.21	0.27	0.23	0.22
Dec (%)	−0.16	−0.44	−0.42	−0.12	1.00	−0.43	−0.48	−0.41	0.59	0.21	0.14	−0.08	0.14
Eph (%)	0.20	0.92	0.88*	−0.15	−0.43	1.00	0.72	0.66	−0.26	0.39	0.25	0.41	0.38
EPT richness	0.24	0.75	0.77	0.032	−0.48	0.72	1.00	0.92*	−0.18	0.41	0.18	0.68	0.50
ETOC rich	0.33	0.64	0.75	0.15	−0.41	0.66	0.92	1.00	−0.081	0.50	0.23	0.80*	0.62
Hem+Dip rich	−0.02	−0.31	−0.28	−0.07	0.59	−0.26	−0.18	−0.08	1.00	0.26	−0.02	0.35	0.33
Sim div	0.58	0.39	0.57	0.21	0.21	0.39	0.41	0.50	0.26	1.00	0.9*	0.78*	0.91*
Eve ind	0.67	0.28	0.49	0.27	0.14	0.25	0.18	0.23	−0.02	0.9*	1.00	0.71	0.70
Mar ind	0.43	0.285	0.53	0.22	−0.08	0.40	0.68	0.80	0.34	0.78*	0.71	1.00	0.8*
Sha div	0.57	0.38	0.57	0.22	0.142	0.38	0.50	0.62	0.33	0.91*	0.70	0.8*	1.00

EPT abun Ephemeroptera Plecoptera Trichoptera abundance, *Eph abun* Ephemeroptera abundance, *ETOC abun* Ephemeroptera Trichoptera Odonata Coleoptera abundance, *Chi+ Oli abun* Chironomidae + Oligochaeta abundance, *Mol+ Dec abun* Mollusca + Decapoda abundance, *Dip abun* Diptera abundance, *Mol abun* Mollusca abundance, *Col abun* Coleoptera abundance, *Odo abun* Odonata abundance, *Col+ Hem abun* Coleoptera + Hemiptera abundance, *EPT/Chi abun* Ephemeroptera Plecoptera Trichoptera/Chironomidae ratio, *Chi+ Oli (%)* percentage Chironomidae + Oligochaeta, *Col+ Hem (%)* percentage Coleoptera + Hemiptera, *EPT (%)* percentage Ephemeroptera Plecoptera Trichoptera, *ETOC (%)* percentage Ephemeroptera Trichoptera Odonata Coleoptera, *Dip (%)* percentage Diptera, *Dec (%)* percentage Decapoda, *Eph (%)* percentage Ephemeroptera, *EPT rich* Ephemeroptera Plecoptera Trichoptera richness, *ETOC rich* Ephemeroptera Trichoptera Odonata Coleoptera richness, *Hem+ Dip rich* Hemiptera + Diptera richness, *Sim div* Simpson diversity, *Eve ind* evenness index, *Mar Ind* Margalef index, *Sha Div* Shannon diversity

Table 4 Calculated metric threshold based on macroinvertebrate assemblages at station 1 for each of the 13 metrics integrated into the Chanchaga multimetric index. These thresholds enabled the separation of the assessment scores indicative of the different ecological categories

Metrics	Statistics					Score		
	Min. value	25th percentile %	50th percentile %	75th percentile %	Max. value	5	3	1
EPT (%)	11.94	49.63	74.32	79.58	90.54	> 49.63	11.94–49.63	< 11.94
EPT rich	0	5	8.5	11	14	> 5	5	< 5
Dip abun	0	0	0	0	27	0	0–27	> 27
Mar ind	1.97	2.91	3.88	4.37	5.37	≥ 2.91	1.97–2.91	< 1.97
Shan div	1.17	2.11	2.47	2.70	2.91	≥ 2.11	1.17–2.11	< 1.17
Col+Hem abun	0	6.75	10.5	18.25	56	> 6.75	0–6.75	0
Dec abun	0	0	0	0	0	–	> 0	0
Mol abun	0	0	0	0	0	0	–	> 0
Odonata abun	2	9	12	16.25	41	> 9	2–9	< 2
Col+Hem (%)	0	9.92	14.08	23.08	36.84	> 9.92	0–9.92	< 0
Dec (%)	0	0	0	0	50	–	> 0	0
Hem+Dip rich	0	2	3	4	8	< 4	4–8	> 8
Chi+Oli (%)	0	0	0	1.46	47.31	< 1.46	1.46–47.31	> 47.31

station 1 (the control station). Chironomidae + Oligochaeta (%) was closely associated with station 4 than station 1 (Fig. 4) and negatively correlated with reduced flow velocity. Mollusca abundance was negatively correlated with reduced alkalinity while transparency and Diptera abundance were positively correlated. Decapoda abundance was restricted to station 2 and was weakly negatively correlated with water and air temperatures. Sulphate and phosphate were positively correlated with Mollusca abundance at stations 3 and 4 (Fig. 4).

The eigenvalue of axes 1, 2 and 3 were 0.472, 0.099 and 0.024 respectively. The variance explained by the axes are 71.27%, 16.62% and 4.17% respectively with axis 1 capturing the majority of the variance within the data set. The Monte Carlo permutation test performed at 999 permutations revealed that the three axes were not significantly correlated ($p > 0.05$) with the physicochemical variables (Table 7).

Association of the stations based on the component metrics of the MMIchanchaga

The cluster analysis (Bray–Curtis similarity) produced based on MMIchanchaga ($\log x + 1$)-transformed test performed showed that metrics in stations 2 and 3 were more associated (similar) in the MMIchanchaga with a similarity value of about 0.60 (Fig. 5) and varied significantly from stations 1 and 4. Station 4 was less similar in the MMIchanchaga of stations 2 and 3 with a similarity value of about 0.41. Conversely, station 1 was distinctly different from the other three stations in similarity with a value of about 0.28.

Table 5 Chanchaga multimetric index (MMIchanchaga) score range indicative of different ecological and water quality categories. The range (5–65) was obtained by summing the scores of the 13 component metrics (Table 4) and then quadrisected to obtain the four ecological categories B, C, D and E/F indicative of good, fair, poor and very poor water quality

Ecological category	Very poor	Poor	Fair	Good
Water quality condition/class	E/F	D	C	B
MMIchanchaga score range	5–20	21–36	37–51	52–65

Table 6 Pooled abundance data set of the macroinvertebrate assemblage for the adopted index of River Chanchaga, Niger State, Nigeria, during the study period (March, 2017–February, 2018)

Metrics	Station 1 (control station)	Station 2	Station 3	Station 4
Diptera abundance	65	79	150	1194
Decapoda abundance	0	256	13	39
Mollusca abundance	1	789	1525	3901
Odonata abundance	322	235	81	62
Coleoptera + Hemiptera abundance	336	242	147	40
Chironomidae + Oligochaeta (%)	4.86	3.45	6.54	16.06
EPT (%)	66.50	16.98	11.20	0.32
Coleoptera + Hemiptera (%)	13.95	12.27	6.54	0.72
% Decapoda	0	12.98	0.60	0.70
EPT richness	25	20	16	4
Hemiptera + Diptera richness	15	17	19	19
Margalef index (taxa diversity index)	9.25	10.54	9.20	6.61
Shannon diversity index	3.42	2.97	2.12	1.52

Discussion

Macroinvertebrate multimetric

Studies of this kind are used to ascertain the level of perturbation going on in a water course. The overall results of this study showed that all the impacted stations revealed similar water quality condition of C indicative of fair water quality except station 4 with poor water quality, portraying water quality condition D.

The EPT richness and EPT (%) metrics significantly discriminated between the stations. The insect orders Ephemeroptera, Plecoptera and Trichoptera taxa have been shown to exhibit strong negative responses to deteriorating water quality (Baptista et al. 2007; Mereta et al. 2013; Dallas et al. 2018; Golfieri et al. 2018). Ephemeroptera, Plecoptera and Trichoptera are ecologically important groups of aquatic macroinvertebrates because of their sensitivity to pollution and are thus frequently used as indicators of water quality (Arimoro and Ikomi 2008; Edegbene and Arimoro 2012; Helson and Williams 2013; Edegbene et al. 2015). Because they are usually among the first taxonomic groups of aquatic invertebrates to recede from impaired stations (Mereta et al. 2013), they are highly relevant groups for biomonitoring. Their marked

Fig. 3 Seasonal variation in ecological health condition (river health status) of the sampled impacted stations of River Chanchaga using the developed Chanchaga multimetric index (MMIchanchaga)
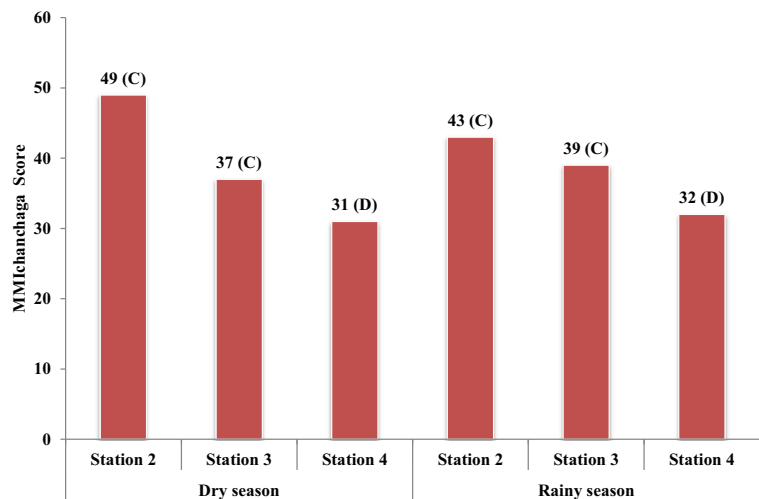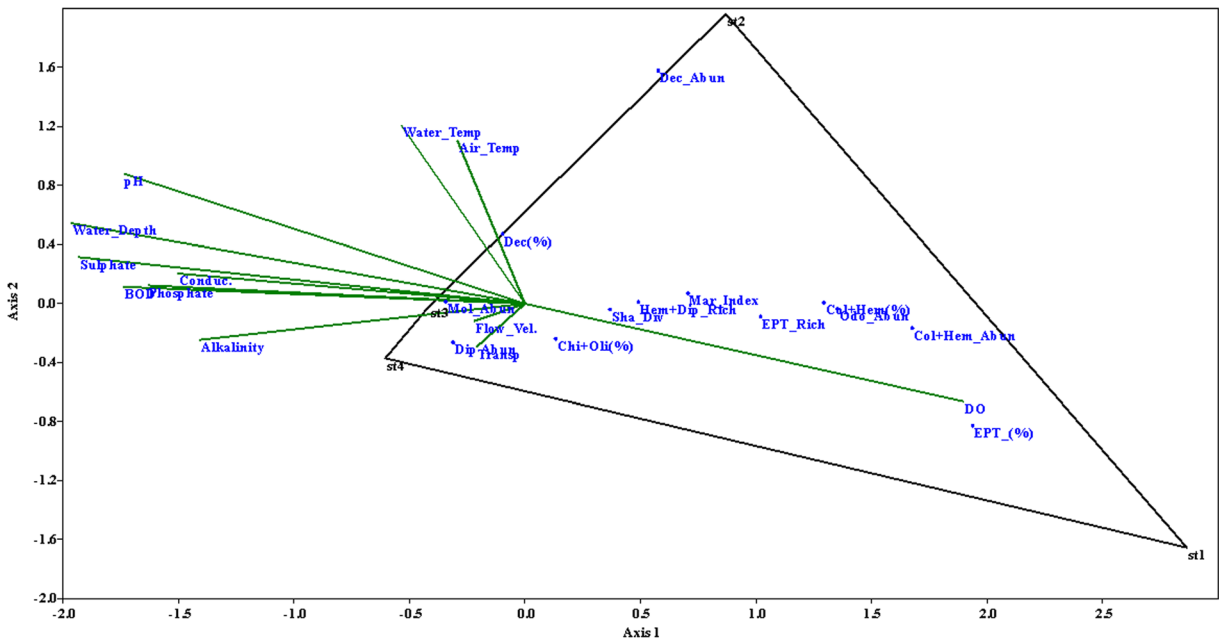
Fig. 4 Canonical correspondence analysis (CCA) triplot showing the relationship between the 13 metrics, integrated into the Chanchaga multimetric index and the water physicochemical parameters in the River Chanchaga from March 2017 to February, 2018. EPT (%) percentage Ephemeroptera Plecoptera Trichoptera, EPT Rich percentage Ephemeroptera Plecoptera Trichoptera richness, Dip Abun Diptera abundance, Mar Index Margalef index, Sha Div Shannon diversity, Col+Hem Abun Coleoptera + Hemiptera abundance, Dec Abun Decapoda abundance, Mol Abun Mollusca abundance, Odo Abun Odonata abundance, Col+Hem (%) percentage Coleoptera + Hemiptera, Dec (%) percentage Decapoda, Hem+Dip rich Hemiptera + Diptera richness, Chi+Oli (%) percentage Chironomidae + Oligochaeta, st1, st2, st3, st4 stations 1, 2, 3 and 4 respectively

Table 7 Ecological integrity (river health status) of the sampled impacted stations of River Chanchaga using the developed Chanchaga multimetric index (MMIchanchaga)

Metrics	Station 2	Station 3	Station 4
EPT (%)	3	1	1
EPT richness	5	5	1
Diptera abundance	1	1	1
Margalef index (taxa diversity index)	5	5	5
Shannon diversity index	5	5	3
Coleoptera + Hemiptera abundance	5	5	5
Decapoda abundance	3	3	3
Mollusca abundance	1	1	1
Odonata abundance	5	5	5
Coleoptera + Hemiptera (%)	5	3	3
Decapoda (%)	3	3	3
Hemiptera + Diptera richness	1	1	1
Chironomidae + Oligochaeta (%)	3	3	3
MMIchanchaga score	45	41	35
Water quality condition/river health condition	C	C	D
Ecological category	Fair	Fair	Poor
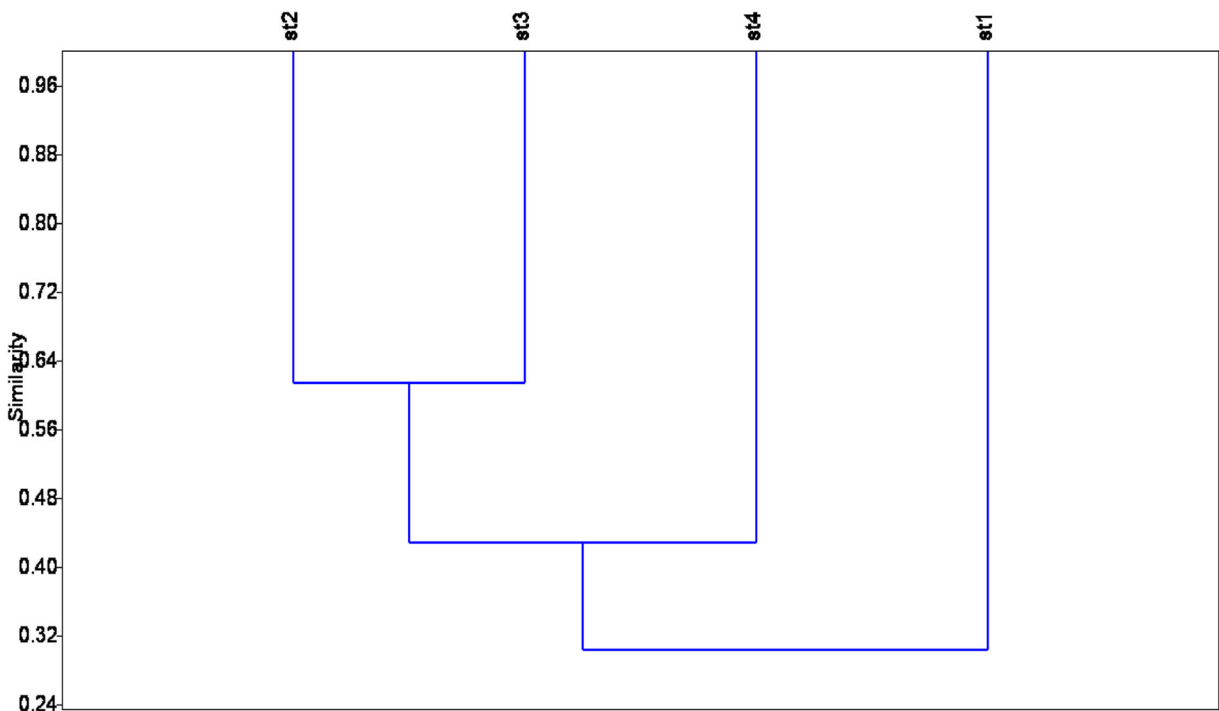
Fig. 5 Dendrogram derived from the cluster analysis (Bray–Curtis similarity index) of log $(x+1)$-transformed Chanchaga multimetric index (MMIchanchaga) of the sampled stations of River Chanchaga, Niger State, Nigeria, during the study period. st1, st2, st3 and st4 represent stations 1, 2, 3 and 4 respectively

reduction at the downstream stations most especially at station 4 in the River Chanchaga indicates impaired water quality. Organic input leading to depletion of oxygen often negatively affects the EPT taxa as most of them rely on external gills for respiration, and their populations usually decrease with decreasing oxygen concentrations (Camargo et al. 2004; Barber-James et al. 2008). Moreover, exposure of these taxa to increased degree of perturbation occasioned by aggravated level of electrical conductivity, BOD_5 and nutrient level (sulphate and phosphate) in this study could amount to adverse effect on the gills of the groups of macroinvertebrates, thus probably leading to clogging of their gills. However, among families in the Ephemeroptera order, most species of baetids are capable of tolerating moderate organic pollution accompanied by increased periphyton and phytoplankton that serve as food because most species of baetids feed on algae by collecting-gathering and scraping-exposed surfaces (Merritt et al. 1996). The effect of environmental water quality in ascertaining the deteriorating state of aquatic ecosystem river health may be viewed from the composition, abundance and diversity of the macroinvertebrates which are used as bioindicators in aquatic

ecosystems. This present study revealed that deteriorating water quality had great impact on the metrics used in developing the MMIchanchaga in all the categories of measured metrics used. This can ascertain the discrimination of the stations by majority of the measured metrics. Only Trichoptera abundance and Trichoptera (%) did not enable the discrimination of the control station from the rest of the impaired stations. The non-discrimination of the stations by the Trichoptera metrics could be attributed to their generally low abundance across all sampling stations.

All the metrics in the richness category discriminated between the study stations. Performance of the richness metrics reported in the present study had being reported earlier by Suriano et al. (2011) and Odume et al. (2012) who indicated that the metrics in the richness category usually performed well and are widely used in biomonitoring programmes.

Ephemeroptera, plecoptera and trichoptera (EPT) richness, EPT (%) and Shannon diversity in this study showed subtle difference between the polluted stations. These metrics reduced significantly at station 4, which may be indicative of a response to serious pollution occasioned by illegal gold mining activities at the station

(Edegbene et al. 2015). The three metrics of EPT richness, EPT (%) and Shannon diversity had earlier been reported by the work of Camargo et al. (2004) and Odume et al. (2012) to show negative response to impaired water quality condition. Overall, the present study indicated that these three metrics were highly sensitive to pollution.

Seasonal variation has no much effect on the strength of the multimetric index developed, as the Chanchaga multimetric index was able to classify the stations based on their ecology health condition, irrespective of seasonal effect (Zamora-Muniz et al. 1995). It can also be inferred from the station multimetric scores that the influence of human activities has a grave effect on the ecological status of the impaired stations of the river studied. Earlier studies have detected a similar trend in the station impact categories which were expressly hinged on incessant anthropogenic activities (Vlek et al. 2006; Kaaya et al. 2015; Dallas et al. 2018). It is noteworthy at this stage that human activities in the river catchments is a pointer to pollution influx in water bodies, most especially in Nigeria where the laws guiding inland waters are weakly enforced.

Conclusion

The MMIchanchaga which is the first of its kind in Nigeria represents the first important step forward in the science of biomonitoring and in developing tools that can help managers in water resource management in the country. It is thus suggested that regional indices be developed for specific ecological regions of the country rather than specific river system as in this study. Such regional metrics would take into account ecological uniqueness and differences within and between the regions. Notwithstanding, the developed MMIchanchaga is recommended as a biomonitoring diagnostic tool for assessing the ecological health conditions of rivers and streams in Nigeria.

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