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RESEARCH ARTICLE

Effects of effluent discharges from a cement factory on the ecology of macroinvertebrates in an Afrotropical river

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Abstract

Cement factory waste water impacts on the ecology of macroinvertebrate assemblages of the Oinyi River, North Central area of Nigeria, were evaluated bi-monthly for 1 year as part of a study to understand the effects of pollution processes in the lotic system that may initiate the development of policy and improved regulation. Three sampling stations, each 100 m long, were selected along 11-km stretch of the river. Station 1, located upstream of the discharge point from the cement factory plant; station 2, immediately downstream of the effluent discharge point; and station 3, 4 km downstream, were sampled. The waste water from the cement effluent factory impacted negatively on the water chemistry by elevating the levels of some heavy metals (Mn, Zn, Cu, and Ni), and other physicochemical parameters such as turbidity, chemical oxygen demand (COD), conductivity, and total suspended solid. A total of 81 macroinvertebrate taxa combined were recorded from the river. The community structure, diversity, and abundance depicted distinct variation between the effluent-impacted site, and the upstream station as the most sensitive macroinvertebrate taxa such as *Neoperla* and *Cheumatopsyche* species was completely missing from the effluent-impacted site. The preponderance of some dipteran taxa (*Tanypus* sp., *Eristalis tenax*, *Simulum* sp., *Empis* sp., and *Atherix* sp.) and drastic reduction in the Ephemeroptera-Plecoptera-Trichoptera (EPT) organisms in the impacted station is an indication that the chemical components of the cement effluent waste water were lethal to some aquatic forms. Extrapolations from canonical correspondence analysis (CCA) results revealed that turbidity, conductivity, BOD, orthophosphate-phosphorus, and heavy metals were strongly associated with the impacted station. Generally, the community structure of station 1 was more diverse with more sensitive taxa, different from those of stations 2 and 3, which were prone to intense human activities. The need for careful consideration of the water quality and indicator organisms is important for restoration of this river.

Keywords Freshwater macroinvertebrates · Heavy metals · Environmental variables · Cement effluent · Nigeria

Introduction

Aquatic pollution arising from the indiscriminate discharges of wastes into rivers are indeed critical issues of water management in Nigeria (Arimoro et al. 2015a; Edegbene et al. 2019) and in most developing nations (Azizullah et al. 2011; Incera et al. 2017; Nsabimana and Hirwa 2018; Mwedzi et al. 2020). This effect of pollution in receiving water bodies is exacerbated due to the alarming increase in human population and rapid industrialisation over the years. Outside Africa, there have been studies investigating macroinvertebrate communities in running waters contaminated by active and abandoned mining as well as other industrial activities using macroinvertebrate community taxonomic resolution at the taxa, family, and order levels and Ephemeroptera-Plecoptera-Trichoptera (EPT) indices for impact detection (Al-Shami et al. 2011; Wright and Ryan 2016; Erasmus et al. 2020).

Elsewhere in Europe, macroinvertebrate multimetric indices have been used successfully to measure ecological health of streams with special consideration of the water and sediment characteristics impacted by various anthropogenic activities (Mondy et al. 2012; Pallottini et al. 2017). Some of these indices have proved to be very useful in fulfilling the requirements of the EU Water Framework Directive in measuring ecological

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health which is a deviation from the globally accepted reference state assessments. Even for the neotropical regions, a recent study in Paraná and São Francisco River Basins, southeastern Brazil, has indicated the usefulness of stream multimetric index in assessing the ecological health of streams affected by various anthropogenic impacts (Silva et al. 2017). Therefore, the assessment of rivers through use of aquatic assemblages becomes essential to evaluate the current ecosystem condition and to establish recovery measure (Feio et al. 2021).

Cement production in most developing nations including Nigeria is on the increase playing significant roles in the building sector and more importantly in enhancing economic development of the country. However, the attendant risk associated with its waste water discharge is high and may impact on the stream biota (Olaleye and Oluyemi 2010) due to the presence of varying proportions of the toxic and poisonous mixtures of dissolved and suspended solids (Arimoro et al. 2015b). The particulate matter deposition arising from cement flue dust also constitutes major atmospheric pollution problem (Olaleye and Oluyemi 2010), affects the total microfungi taxa number and frequency in soils (Biyik et al. 2005), and elevates the heavy metal content of sediments (Ogedengbe and Oke 2011; Arimoro et al. 2015b). Cement effluent discharge is generated from cooling process equipment and wet scrubbing kiln stack emission for recovering cement kiln dust during cement manufacturing operations, and as runoff water from the outdoor areas. Cement factory effluent contains complex mixture of chemicals varying over time, mainly processed water, dissolved solids (potassium and sodium hydroxide, chlorides, and sulphates), suspended solids (calcium carbonate), and waste heat (Vyas and Waoo 2019). When mixed with the receiving water, it may obviously lead to changes in pH, temperature, colour, suspended solids, conductivity, and biological oxygen demand (BOD_5), with possible negative impact on the aquatic biota and ecosystem health (Aga et al. 2020).

The impacts of cement waste water on water quality of receiving rivers have been studied extensively (Ani et al. 2011; Meme et al. 2014; Arimoro et al. 2015b; Ipeaiyeda and Obaje 2017;.Nsabimana and Hirwa 2018; Arachchige et al. 2019; Aga et al. 2020); however, there is paucity of information on the response of aquatic biota to the cement effluent discharge. One such rare study in the tropics (Olaleye and Oluyemi 2010), however, reported poor plankton taxa richness and composition in a cement factory catchment related obviously to the damaging effects of exposure of the plankton to the toxic heavy metal–enriched cement particulate deposition. The advantage of using aquatic organisms as bioindicators of water quality rather than physicochemical measurements to evaluate the quality of water bodies is that aquatic organisms integrate information about the environment over time and take into account indirect relationships, whereas physicochemical tests give only more punctual information (Testi et al. 2009). Among the many aquatic biota used as bioindicators of water quality, macroinvertebrates have proved very useful and appropriate for most biomonitoring programmes (Resh 2008). Also, their sensitivity to various impacts resulting from anthropogenic and industrial sources has proved to be very reliable (Arimoro 2009; Arimoro et al. 2015a; Edegbene et al. 2020).

Oinyi River, like most other running water bodies in Africa, serves as an important source for domestic, agricultural, and industrial purposes. The river presently is prone to industrial pollution from a cement plant located within its catchment at Obajana community. There have been studies to ascertain the water quality status of the river using physicochemical analysis (Meme et al. 2014; Arimoro et al. 2015b; Ipeaiyeda and Obaje 2017). However, there is dearth of information on the response of macroinvertebrates to the cement effluent discharge both for the river and globally. Therefore, this study aims at determining the environmental variables and macroinvertebrate communities in the cement effluent–impacted site, and, secondly, at giving a comparative account of the same ecological characteristics upstream and downstream of the impacted site, with a view to ameliorating or minimising effects on the aquatic biota and to strengthening policy regulation and implementation.

Materials and methods

Description of the study area and sampling stations

The Oinyi River is a slow-moving valley floor river located in Kogi State, North Central, Nigeria. The river is about 177 km long, flowing southwest (223°) of Abuja, the Nigerian capital city, with a catchment situated between longitude 6.43 (6° 25′ 60″ E) and latitude 7.92 (7° 55′ 0″ N) (Fig. 1). A full description of this water body and river catchment is provided in Arimoro et al. (2015b).

The study was undertaken bi-monthly for a 1-year period between October 2011 and August 2012 at three sampling stations, each 100 m long which were selected along 11-km stretch of the river. Station 1, located upstream of the discharge point from the cement factory plant; station 2, immediately downstream of the effluent discharge point; and station 3, 4 km downstream, were sampled. Full description of the stations is provided in Arimoro et al. (2015b). Generally, the catchment of the river is mainly agriculture and related farm uses with the riparian vegetation described as mainly native. The Oinyi River is located in a rocky plain for most part of its length

Physicochemical parameters

At each sampling station, surface water was examined in situ for temperature, pH, electrical conductivity (EC), and total dissolved solids (TDS) using the Hanna HI 991300/1 multi-

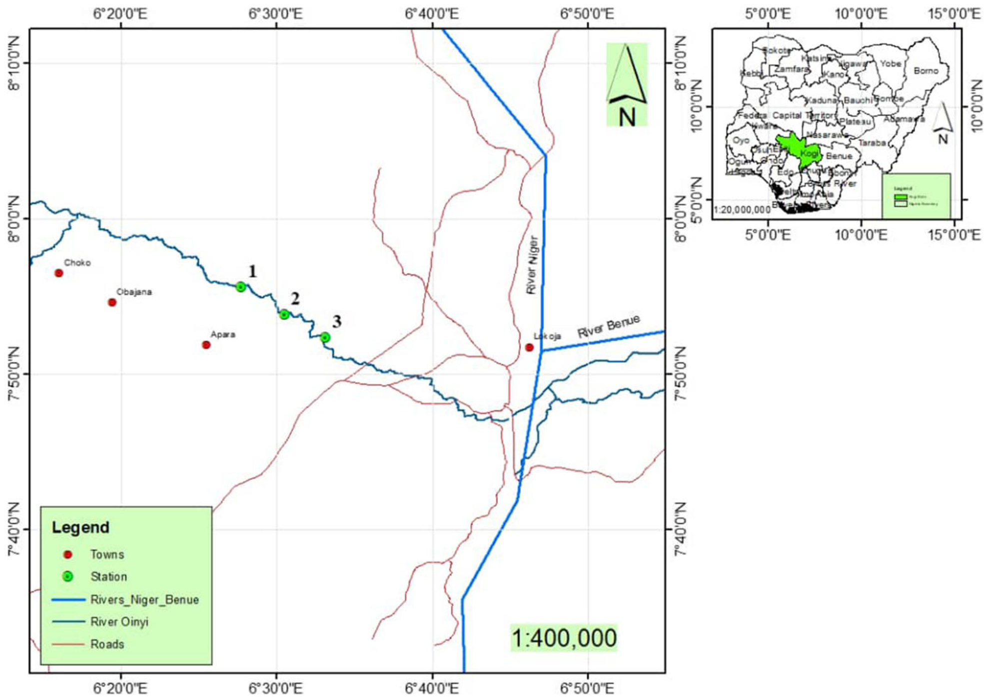

Fig. 1 Map of the Oinyi River showing the study stations. Inset: Location of Kogi State in Nigeria. The orange star indicates the position of the location of the cement factory

probe metre. Other parameters like turbidity and dissolved oxygen (DO) were measured using portable turbidity metre HI 93102 and the YSI 55 dissolved oxygen metre, respectively. Additional water samples were collected at each sampling station and taken in sealed 2-L cans to the laboratory for analyses. Nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), ammonia-nitrogen (NH_3-N), and orthoorthophosphate-phosphorus-phosphorus (PO_4-P) were analysed spectrophotometrically after reductions in appropriate reagents according to APHA (1998) methods. Five-day BOD_5, chemical oxygen demand (COD), colour, and total suspended solids (TSS) were also determined according to APHA (1998) methods.

Heavy metal analysis of sediments

Sediment samples collected from the field were wrapped with polythene bags and kept in ice cooler box before transportation to the laboratory. In the laboratory, the sediment samples were air-dried and sieved with a 200-μm sieve before sediment analysis. A mixture of hydrofluoric, nitric, perchloric, and sulphuric (HF–HNO_3–$HClO_4$–H_2SO_4) acids was used to digest 1 g of the bottom sediment from each sampling. Thereafter, the clear digest was diluted to 50 ml with distilled water and subsequently analysed for cadmium, chromium, copper, lead, iron, manganese, nickel, and zinc, using the air-acetylene flame atomic absorption spectrophotometre (AA) (Perkin-Elmer A3100). The atomic absorption spectrophotometer was fitted with D2 background correction devices.

Habitat quality

The qualitative habitat evaluation index (QHEI) was employed in the evaluation of the habitat quality at each sampling location. QHEI is a physical habitat index which is designed to provide a subjective quantitative evaluation of important lotic macrohabitats (Rankin 2006). The metrics that make up the index are substrate, in-stream cover, channel morphology, riparian zone, pool quality and riffle quality, and gradient (altogether six) are assessed, scored, and summed to give a maximum score of 100 for each sampling location. A reach of 100 m was selected at each sampling location where habitat characterisation was undertaken, including the description of stream hydraulics, aquatic plants, width, depth, flow, and substrate type and composition. Mid-channel mean flow velocity was measured on three occasions by timing a float as it moved over a distance of 10 m. Depth was measured in three portions within the sampling reaches and averaged using a calibrated rod.

Macroinvertebrate sampling

Macroinvertebrates at each sampling station were collected bimonthly by sweeping a handheld net with a mesh size of 250 μm through different substrates including sediments, stones, and vegetation within an approximately 25-m^2 wadeable portion. Four 3-min samples were taken on each sampling visit for each sampling station, pooled together to make a single sample. This was a semiquantitative sampling technique, standardised by area and time. Macroinvertebrates collected were preserved in 70% ethanol and transported to the laboratory for sorting. A light and stereo dissecting microscope was used in the identification of the preserved animals to their different taxa and counted. All macroinvertebrate taxa were identified using regional available keys (Day et al. 2002; de Moor et al. 2003; Arimoro and James 2008) as well as the help of a few taxonomists to the lowest possible level of identification, species or genus.

Data analysis

Data on physicochemical parameters of the surface water and heavy metals for the six sampling regime were averaged, and standard deviation was extrapolated using PAST software. Macroinvertebrates caught for each sampling regime, and stations were added together. Macroinvertebrate community attributes (Metrics), environmental variables of stations, were compared using one way ANOVA on log (x + 1)-transformed data. ANOVAS (fixed-effect) were performed using dates as replicates. In addition, significant ANOVAS ($P < 0.05$) were followed by post hoc (Tukey honest (HSD) tests to identify differences between station means. The relationships between macroinvertebrate communities and environmental variables were evaluated using canonical correspondence analysis (CCA) in PAST statistical package (Hammer et al. 2001). Before using CCA, variables that covaried with other variables (Pearson correlation $r > 0.80$, $P < 0.05$) were removed. Rare taxa (< 1% at a sampling site) were not included in the CCA. Although all environmental variables were included in the early CCA ordinations, those variables with high variance inflation factors (VIF > 20 indicating very strong multicollinearity) were eliminated from the analyses. In addition, variables were log-transformed {log (x + 1)} before the CCA to prevent extreme values (outlier) from unduly influencing the ordination. The canonical axes extracted were tested for significance using the Monte Carlo permutation test with 199 permutations. Margalef's index of taxa richness (d), Shannon-Weiner's index (H) of general diversity, and equitability index (E) were used to determine taxa richness, taxa diversity, and evenness respectively using the PAST software. Other indices used include number of EPT and Chironomidae taxa richness measures and number of individuals of EPT and Chironomidae as abundance measures

Results

Environmental variables

The habitat features and the means and standard deviation of the physicochemical variables at each of the sampling station are shown in Table 1. The QHEI employed for analysis indicated that the habitat conditions were more favourable in stations 1 and 3. The bottom substrate was mostly sand and clay except for station 2 that had appreciable proportion of silt. The streambed and banks at station 2 were modified by deposition of sediments and channelization as a consequence of cement industry. Typical trees around the study area include *Alstonia boonei*, *Gmelina arborea*, *Ficus capensis*, *Khaya senegalensis*, *Parkia biglobosa*, *Daniellia oliveri*, and *Vitellaria paradoxa.* There was an increase in the values of total dissolved solids (TDS), colour, EC, COD, and turbidity at station 2 (the station receiving effluent of cement discharges). Also, pH was slightly higher in station 2 being more alkaline than the other stations. The waters of the Oinyi River were well aerated with dissolved oxygen levels ranging from 6.02 to 7.01 mg/l and BOD values were lower than 2.5 mg/l. Biological oxygen demand was not significantly different among the sampling stations ranging between 2.05 and 2.89mg/l. Similarly, surface water temperature and depth did not vary significantly in all the sampling stations ranging from 24.00 to 27.00 °C and 0.23 to 0.40 m, respectively. For some of the nutrients (nitrite-nitrogen, nitrate-nitrogen), concentrations were significantly higher in station 2 compared with the other stations while orthoorthophosphate-phosphorus-phosphorus was higher in station 3.

Also, important to note here was that there were also noticeable seasonal variations in physicochemical parameter values with pH, biological oxygen demand, chemical oxygen demand, ammonia, and temperature which were relatively higher during the dry season. On the other hand, dissolved oxygen and flow velocity recorded higher values during the rainy season.

Heavy metal characteristics of sediment sample

Apart from iron and lead, the concentrations of the other heavy metals (Fe, Mn, Zn, Cu, and Ni) were significantly higher ($p < 0.05$) in the sediments of station 2 as compared with stations 1 and 3 (Table 2). Also, the peak values of all analysed heavy metals were recorded in the dry season months (late October to March) when the water depth and flow were drastically reduced.

Macroinvertebrate community structure and distribution

A total of 8225 individuals of 81 macroinvertebrate taxa, representing 11 orders in 41 families, were caught during the study. The class Insecta with members of the order Odonata was the most abundant group followed by the phylum Mollusca. Trichoptera was prominent in station 1 with over 490 individuals caught (Table 3). Other major groups included Coloeoptera, Hemiptera, Ephemeroptera, and Diptera (Fig. 2a). Plecoptera and Lepidoptera were only sporadically

Table 1 Environmental factors measured at the sampling stations of Oinyi River during the study period

Environmental variables	Station 1	Station 2	Station 3	Dry season	Wet season
Features of the reach	Constrained	Unconstrained	Unconstrained		
Riparian vegetation	Native	Native	Native		
Land use	Agriculture	Agriculture/cement factory	Forestry/agriculture		
Substrate type	Silt/sand	Silt/sand	Sand/clay		
Canopy cover (%)	60	60	70		
Qualitative habitat evaluation index (QHEI)	80	54	67		
pH	7.2 (7.2–7.3)	7.6 (7.2–7.8)	7.0 (6.8–7.0)	7.0	7.2
EC* (μS/cm)	111.60 ± 0.46^{a} (110.00–113.10)	210.65 ± 0.41^{b} (209.00–211.70)	106.95 ± 0.13^{a} (106.60–107.50)	134.34 ± 10.45^{a}	183.07 ± 13.07^{b}
Colour (Pt. Co)*	2.47 ± 0.15^{a} (2.00–2.89)	5.51 ± 0.13^{b} (5.00–5.83)	3.63 ± 0.20^{c} (3.00–4.10)	3.34 ± 0.77^{a}	4.98 ± 0.86^{b}
Turbidity (NTU)*	15.38 ± 0.13^{a} (15.00–15.76)	22.44 ± 0.11^{b} (22.00–22.70)	14.44 ± 0.16^{a} (14.00–14.86)	15.34 ± 4.13^{a}	18.33 ± 7.52^{b}
TSS (mg l^{-1})*	46.47 ± 0.51^{a} (45.00–48.00)	52.37 ± 0.48^{b} (51.00–54.00)	50.23 ± 0.46^{ab} (48.90–51.60)	48.34 ± 9.47^{a}	51.67 ± 7.84^{b}
TDS (mg l^{-1})*	56.42 ± 0.21^{a} (55.80–57.00)	107.57 ± 0.29^{b} (107.00–108.80)	53.67 ± 0.32^{a} (52.70–54.60)	63.34 ± 11.07^{a}	82.67 ± 12.87^{b}
DO (mg l^{-1})	6.63 ± 0.09 (6.40–7.01)	6.11 ± 0.02 (6.02–6.17)	6.39 ± 0.05 (6.30–6.60)	6.01 ± 2.14^{a}	5.87 ± 1.47^{a}
BOD_5 (mg l^{-1})*	2.80 ± 0.03^{a} (2.70–2.89)	2.70 ± 0.03^{a} (2.6–2.78)	2.14 ± 0.03^{b} (2.05–2.23)	2.67 ± 0.44^{a}	2.46 ± 0.81^{b}
COD (mg l^{-1})*	14.37 ± 0.21^{a} (13.60–15.02)	24.18 ± 0.18^{b} (23.70–24.87)	13.01 ± 0.07^{a} (12.8–13.20)	14.91 ± 3.07^{a}	19.32 ± 4.16^{b}
Ammonia-nitrogen (NH_3-N) (mg l^{-1})*	0.01 ± 0.00^{a} (0.01–0.02)	0.00 ± 0.00^{b} (0.00–0.00)	0.01 ± 0.00^{a} (0.00–0.02)	0.01 ± 0.00	0.01 ± 0.01
Nitrite-nitrogen (NO_2-N)	0.01 ± 0.00^{a} (0.01–0.02)	0.05 ± 0.01^{b} (0.02–0.09)	0.01 ± 0.00^{a} (0.01–0.02)	0.04 ± 0.02^{a}	0.02 ± 0.01^{b}
Nitrate-nitrogen (NO_3-N) (mg l^{-1})*	0.03 ± 0.01^{a} (0.01–0.04)	0.06 ± 0.01^{b} (0.04–0.09)	0.05 ± 0.01^{c} (0.03–0.06)	0.05 ± 0.02^{a}	0.04 ± 0.01^{b}
Orthophosphate-phosphorus (PO_4-P) (mg l^{-1})*	0.64 ± 0.03^{a} (0.57–0.73)	0.24 ± 0.02^{b} (0.19–0.30)	1.67 ± 0.14^{c} (1.32–2.05)	0.69 ± 0.07^{a}	1.22 ± 0.527^{b}
Temperature (°C)	25.92 ± 0.36 (24.80–27.00)	25.74 ± 0.28 (25.00–26.60)	25.05 ± 0.31 (24.00–26.00)	26.12 ± 0.19^{a}	25.05 ± 0.24^{a}
Width (m)	2.28 ± 1.02 (2.10–2.35)	3.27 ± 1.02 (2.60—4.55)	2.30 ± 1.333 (2.20–.4.55)	2.96 ± 0.97^{a}	2.43 ± 0.08^{a}
Depth (m)	0.28 ± 0.02 (0.24–0.35)	0.27 ± 0.02 (0.23–0.34)	0.30 ± 0.03 (0.25–0.40)	0.27 ± 0.07^{a}	0.28 ± 0.08^{a}
Flow velocity (ms^{-1})*	0.24 ± 0.04^{a} (0.24–0.35)	0.11 ± 0.03^{b} (0.08–0.16)	0.19 ± 0.06^{c} (0.14–0.29)	0.22 ± 0.09^{a}	0.19 ± 0.08^{b}

Note: Physicochemical variable values are mean ± SD, range in parenthesis.*Significant differences indicated by ANOVA. Different superscript letters in a row show significant differences ($p < 0.05$) indicated by Tukey honest significant difference tests. *EC* electrical conductivity, *TSS* total suspended solids, *TDS* total dissolved solids, *DO* dissolved oxygen, *BOD_5* biological oxygen demand, *COD* chemical oxygen demand

present represented by one taxon each (Fig. 2b). Worthy of note is that no stonefly nymph was caught at station 2 in the entire study (Fig. 2a). The total number of individuals recovered at stations 1, 2, and 3 were 2909, 2428, and 2888, respectively. Similarly, the number of taxa in stations 1, 2, and 3 were 44, 44, and 49, respectively. Of the major faunal groups, the phylum Mollusca contributed the highest percentage of individuals with *Melanoides tuberculata* being the most ubiquitous and preponderant taxa. Abundances of most groups were significantly different ($P < 0.05$) among the stations. Dipteran larvae such as *Tanypus* sp., *Eristalis tenax*, *Simulum* sp., *Empis* sp., and *Atherix* sp. were common at the cement effluent discharge station (station 2). At stations 1 and 3, pollution-sensitive taxa were better represented with EPT taxa contributing more than 19% of the relative abundances. Members of the class Gastropoda dominated the studied area in terms of individual occurrence while the class Insecta dominated in terms of taxa and diversity (Table 3). Generally, more macroinvertebrates were caught during the dry season (Dec., Feb., and Apr) with a total of 5059 individuals accounting for 61.5% which was significantly different (tstat = 3.11, $P(T <= t)$ one-tail = 0.0011) from the wet season (Jun., Aug.,

Table 2 Amounts of iron, manganese, zinc, copper, chromium, cadmium, lead, and nickel in the streambed sediments at the three sampling stations of Oinyi River, Kogi State, Nigeria (n = 6)

Heavy metal (mg/kg)	Station 1	Station 2	Station 3	Dry season	Wet season
Fe*	204.77 ± 1.50^{a} (200.00–208.60)	93.11 ± 0.21^{b} (92.40–93.80)	214.17 ± 4.35^{a} (213.00–215.40)	187.17 ± 7.35^{a} (173.00–215.40)	102.17 ± 8.15^{b} (92.40–214.80)
Mn*	51.37 ± 0.19^{a} (50.8–52.02)	115.27 ± 0.16^{b} (114.8–115.8)	42.71 ± 0.22^{c} (42.01–43.2)	77.25 ± 6.19^{a} (43.2–115.8)	54.27 ± 7.16^{b} (42.01–114.8)
Zn*	1.44 ± 0.02^{a} (1.40–1.49)	6.16 ± 0.03^{b} (6.07–6.26)	1.36 ± 0.02^{a} (1.30–1.42)	4.16 ± 1.03^{a} (1.45–6.26)	2.16 ± 1.23^{b} (1.30–6.07)
Cu*	1.71 ± 0.01^{a} (1.67–1.74)	3.34 ± 0.01^{b} (3.30–3.39)	1.84 ± 0.02^{a} (1.80–1.89)	2.31 ± 1.01^{b} (1.74–3.39)	1.83 ± 1.02^{a} (1.67–3.30)
Cr	0.31 ± 0.01^{a} (0.25–0.35)	0.37 ± 0.02^{a} (0.30–0.45)	0.36 ± 0.01^{a} (0.32–0.40)	0.33 ± 0.11^{a} (0.30–0.45)	0.37 ± 0.02^{a} (0.30–0.45)
Cd	0.16 ± 0.02^{a} (0.10–0.20)	0.19 ± 0.01^{a} (0.15–0.24)	0.17 ± 0.02^{a} (0.12–0.23)	0.18 ± 0.04^{a} (0.12–0.24)	0.17 ± 0.05^{a} (0.10–0.23)
Pb*	0.38 ± 0.02^{a} (0.30–0.44)	0.33 ± 0.01^{c} (0.29–0.38)	0.50 ± 0.02^{b} (0.40–0.55)	0.35 ± 0.11^{a} (0.29–0.47)	0.41 ± 0.22^{a} (0.30–0.55)
Ni*	4.74 ± 0.03^{a} (4.65–4.80)	5.60 ± 0.13^{b} (5.20–6.00)	3.85 ± 0.08^{c} (3.5–4.03)	5.15 ± 1.13^{b} (4.70–6.00)	4.85 ± 1.98^{a} (3.5–6.00)

Note: Metal concentrations are mean ± SD, range in parenthesis. *Significant differences indicated by ANOVA. Different superscript letters in a row show significant differences ($p < 0.05$) indicated by Tukey honest significant difference tests

and Oct.). Most of the gastropods were however predominant in the wet season.

The faunal diversity and dominance indices for the three sampling are depicted in Table 3. Taxa richness (Margalef index) was highest at station 3 (6.02) followed by station 2 (5.52). Shannon diversity and Menhinick indices also followed similar trend. Stations 2 and 3 had the same evenness value (0.93) higher than that of station 1. Simpson dominance index was similar in all the sampling stations ranging between 0.96 and 0.98.

Macroinvertebrates and physicochemical variable relationship

The CCA ordination showed a good relationship between macroinvertebrate taxa distribution and measured physicochemical variables (Fig. 3). The strongest explanatory factors were flow velocity, BOD_5, and dissolved oxygen. Fifty-six percent of variation in the taxa abundance data was accounted for by the environmental variables measured in axis 1. The macroinvertebrate taxa and the selected set of environmental variables based on the first and sum of all canonical eigenvalues was however not significant ($P > 0.05$) by the Monte Carlo permutation test. The CCA triplot of macroinvertebrates and physicochemical variables based on the first two axes extracted explained 56.68% of the variation in axis 1 and 43.32% in axis 2. The eigenvalues of axes 1 and 2 were 0.437 and 0.334, respectively (Table 4). CCA axis 1 revealed a gradient primarily concerned with pollution. This was determined by QHEI, turbidity, BOD_5, DO, and NH_3-N (Table 4). Samples taken from stations 1 and 3 are positioned on the right whereas those from station 2 are on the left. According to the CCA ordination (Fig. 3), *Neoperla* sp.; *Hydropsyche longifurca*; *Elassoneuris* sp.; *Afronurus* sp.; *Nymphula* sp.; *Parecnomina* sp.; and *Phyllomacromia picta* and to a lesser extent *Cheumatopsyche thomasetti*, *Bugilliesia* sp., *Plea* sp., and *Diplacodes lefebvrill* were strongly associated with station 1. On the other hand, *Eristalis tenax*, *Atherix* sp., *Tanypus* sp., *Simulium* sp., and *Empis* sp. were strongly associated with station 2. The second axis of CCA ordination (Fig. 3) revealed a gradient primarily associated with microhabitat and water quality. The environmental variables that best correlated with this were QHEI, nitrate, DO, BOD_5, total suspended solids (TSS), and orthophosphate-phosphorus. Extrapolation from the CCA ordination indicated that the macroinvertebrate abundance was negatively correlated to water depth and BOD and positively correlated with DO and flow velocity.

Macroinvertebrates and sediment heavy metal relationship

The CCA ordination showed a good relationship between macroinvertebrate taxa distribution and assessed heavy metals (Fig. 4). The strongest explanatory factors were Mn, Fe, Ni, Zn, Cu, Pb, and Cd in decreasing order of magnitude. The macroinvertebrate taxa and the selected set of sediment heavy

Table 3 The occurrence, abundances, and diversity indices of macroinvertebrates at the sampling stations in Oinyi River, Nigeria (the total number caught for the dry and wet season is also provided at the last two columns)

Order	Family	Taxon	Code	Station			Season	
				1	2	3	Dry	Wet
Ephemeroptera	Tricorythidae	*Tricorythus* sp.	Tri	-	-	50	32	18
	Heptageniidae	*Afronurus* sp.	Afr	18	-	54	47	25
	Oligoneuridae	*Elassoneuris* sp.	Ela	50	-	44	50	44
	Caenidae	*Caenis cibaria*	Cae	27	-	42	37	32
	Baetidae	*Baetis* sp.	Bae	-	27	-	15	12
		Bugilliesia sp.	Bug	41	-	17	32	26
		Cloeon sp.	Clo	32	-	-	14	18
		Pseudocloeon sp.	Pse	41	36	-	47	30
	Ephemerythidae	*Ephemerythus* sp.	Eph	-	-	45	36	9
Plecoptera	Perlidae	*Neoperla* sp.	Neo	*54*	-	*36*	58	32
Trichoptera	Hydropsychidae	*Hydropsyche longifurca*	Hyd	81	-	59	89	51
		Aethaloptera maxima	Aes	68	104	-	101	71
		Cheumatopsyche thomasetti	Che	104	-	45	102	47
		Cheumatopsyche afra	Cha	45	-	-	43	2
		Amphipsyche scottae	Amp	-	41	-	35	6
		Macrostemum capense	Mac	41	54	59	67	87
		Parecnomina sp.	Par	67	-	-	59	8
		Polymorphanisus bipunctatus	Pol	-	-	45	32	13
	Pholopotamidae	*Dolophilodes urceolus*	Dol	93	-	50	67	76
Lepidoptera	Crambidae	*Nymphula* sp.	Nym	-	*57*	*27*	48	36
Hemiptera	Pleidae	*Plea* sp.	Ple	61	43	50	75	79
	Nepidae	*Ranatra* sp.	Ran	72	-	77	65	84
	Gerridae	*Naboandelus africanus*	Nab	-	-	63	56	7
		Gerris sp.	Ger	-	-	50	16	34
	Belostomatidae	*Appasus* sp.	App	63	44	91	138	60
	Veliidae	*Rhagovelia* sp.	Rha	87	-	68	98	57
		Angilia sp.	Ang	-	41	50	63	28
		Tenagovelia sp.	Ten	63	43	-	78	28
	Corixidae	*Corixa* sp.	Cor	-	-	57	44	13
Coleoptera	Haliphidae	*Haliphus* sp.	Hal	68	51	55	154	20
	Limnichidae	*Limnichites* sp.	Lim	-	-	47	45	2
	Gyrinidae	*Dineutus* sp.	Din	45	-	-	28	17
		Orectogyrus sp.	Ore	68	-	-	49	19
	Naucoridae	*Naucoris* sp.	Nau	-	54	41	77	18
	Dystiscidae	*Hydrovatus* sp.	Hydr	63	41	-	74	30
		Hyphydrus sp.	Hyp	-	36	-	28	8
		Nebrioporus sp.	Neb	27	-	-	16	11
	Notonectidae	*Cathydrus* sp.	Cat	-	-	41	10	31
		Hydrocanthus sp.	Hydro	57	36	-	74	19
	Hydrophilidae	*Enochrus* sp.	Eno	-	50	50	83	17
		Laccobius sp.	Lac	-	45	45	66	24
	Hydraenidae	*Mesoceration languidum*	Mes	-	68	-	52	16
		Discozantaena genuvela	Dis	-	41	-	29	12
		Prostetops grandiceps	Pro	59	63	59	114	67
Odonata	Corduliidae	*Phyllomacromia picta*	Phy	23	-	59	57	25
		Hermicordulia olympica	Herm	-	54	-	38	16

Table 3 (continued)

Order	Family	Taxon	Code	Station			Season	
				1	2	3	Dry	Wet
	Coenagrionidae	*Pseudagrion spematum*	Pseu	72	95	113	160	120
	Libellulidae	*Trithemis werneri*	Trit	36	59	68	77	86
		Orthetrum caffrum	Ort	-	45	41	65	21
		Parazyxomma flavicans	Para	49	86	50	121	64
		Diplacodes lefebvrill	Dipl	45	-	86	97	34
		Brachythemis leucosticta	Brac	24	-	-	21	3
		Notiothemis jonesi	Not	-	36	-	27	9
		Chalcostephia flavifrons	Cha	45	39	-	77	7
		Trithemis dorsalis	Trith	-	-	41	7	34
	Gomphidae	*Neurogomphus sp*	Neu	36	50	-	30	56
		Phyllogomphus brunneus	Phyl	-	-	50	39	11
		Paragomphus genei	Parg	-	-	41	37	4
		Crenigomphus rennei	Cre	41	41	50	78	54
		Ceratogomphus pictus	Cer	47	33	45	79	46
		Notogomphus praetorius	Notp	-	50	-	50	0
	Platycnemididae	*Allocnemis leucosticta*	All	-	-	50	43	7
		Mesocnemis sp.	Mesn	-	36	-	26	10
	Aeshnidae	*Aeshna minuscula*	Aes	97	63	-	105	55
		Anax inperator	Ana	-	45	-	33	12
	Lestidae	*Lestes plagiatus*	Les	17	-	54	45	26
	Chlorolestidae	*Chlorolestes fasciatus*	Chl	-	-	50	37	13
Diptera	Syrphidae	*Eristalis tenax*	Eri	-	46	77	101	22
	Atheridae	*Atherix* sp.	Ath	-	54	-	31	23
	Chironomidae	*Tanypus* sp.	Tan	-	107	-	78	29
	Chironomidae	*Chironomus* sp.	Chi	-	27	-	23	4
	Simulidae	*Simulium* sp.	Sim	23	50	63	77	59
	Dixidae	*Dixa* sp.	Dix	45	-	-	45	0
	Emphididae	*Empis* sp.	Emp	-	83	-	56	27
Pulmonata	Planorbidae	*Bulinus truncatus*	Bul	181	-	63	46	198
		Biomphalaria pfeifferi	Bio	180	72	131	132	251
		Afrogyrus rodriguezensis	Afro	-	86	-	45	41
Prosobranchia	Thiaridae	*Melanoides tuberculata*	Mel	387	135	122	386	258
Caenogastropoda	Ampullaridae	*Pila wernei*	Pil	66	61	-	27	100
		Pila ovate	Plo	-	-	104	44	60
		Lanistes varicus	Lan	-	-	113	76	37
		Total no. of individuals		2909	2428	2888	5059	3166
		No. of taxa		44	44	49		
		Dominance_D		0.04	0.03	0.02		
		Simpson_1-D		0.96	0.97	0.98		
		Shannon_H		3.53	3.71	3.82		
		Evenness_e^H/S		0.78	0.93	0.93		
		Menhinick index		0.82	0.89	0.91		
		Margalef index		5.39	5.52	6.02		
		EPT (no. of individuals)		762	262	546		
		Chironomidae (no. of individuals)		0	134	0		
		EPT taxa		14	5	12		
		Chironomidae taxa		0	2	0		

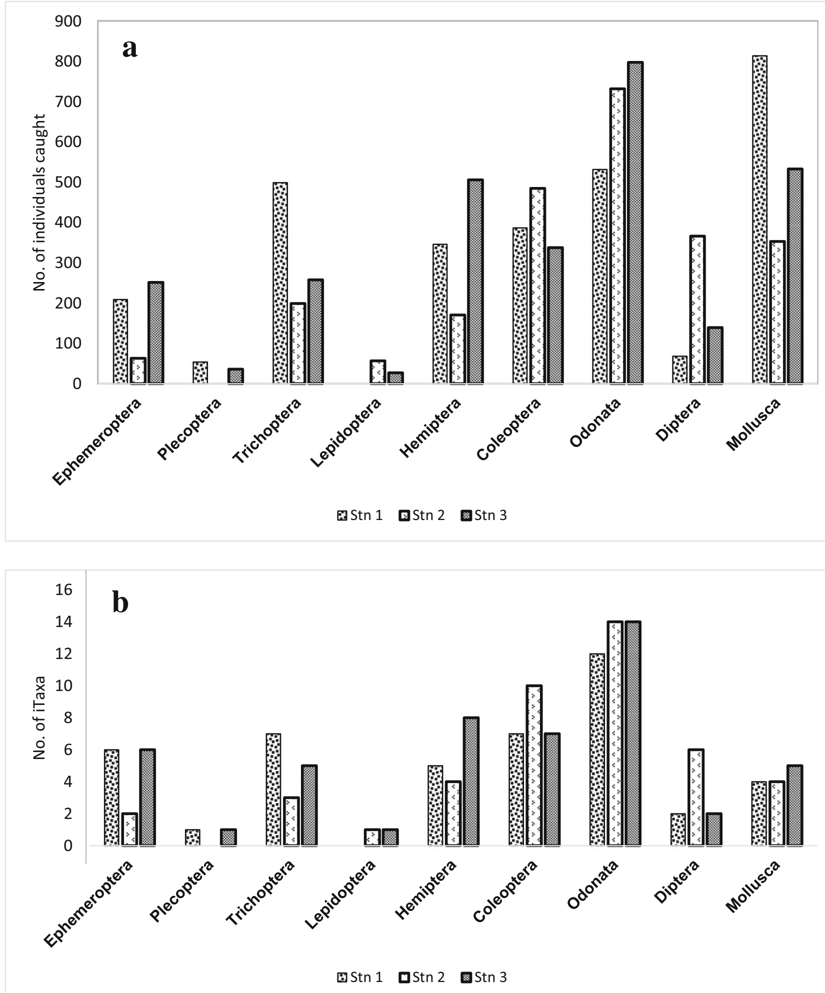

Fig. 2 **a** Number of macroinvertebrates (abundance) in the various sampling stations of Oiniyi River, North Central Nigeria. **b** Number of macroinvertebrates taxa (diversity) in the various sampling stations of Oiniyi River, North Central Nigeria

metals based on the first and sum of all canonical eigenvalues were however not significant ($P > 0.05$) by the Monte Carlo permutation test. The CCA triplot of macroinvertebrates and environmental variables based on the first two axes extracted explained 56.68% of the variation in axis 1 and 43.32% in axis 2. The eigenvalues of axes 1 and 2 were 0.437 and 0.334, respectively (Table 5). CCA axis 1 revealed a gradient with Mn, Zn, Cu, Cd, and Cr (Table 5) positioned on the left whereas Fe and Pb were positioned to the right. Accordingly to the CCA ordination (Fig. 4), iron was a prominent metal in station 1 in strong association with *Neoperla* sp., *Hydropsyche longifurca*, *Elassoneuris* sp., *Afronurus* sp., *Nymphula* sp., *Parecnomina* sp., and *Phyllomacromia picta* and to a lesser extent *Cheumatopsyche thomasetti*, *Bugilliesia* sp., *Plea* sp., and *Diplacodes lefebvrill*. On the other hand, Pb was a prominent metal in station 3 and strongly associated with *Ephemerythus* sp., *Polymorphanisus bipunctatus*, *Phyllogomphus brunneus*, and *Chlorolestes fasciatus*. Most of the heavy metals (Mn, Zn, Cu Cd, and Cr) analysed in the CCA was dominant in station 2 and was strongly associated to *Eristalis tenax*, *Atherix* sp., *Tanypus* sp., *Simulium* sp., and *Empis* sp.

Discussion

Environmental variables, sediment, and water quality

The high deposit of dust particles at station 2 (cement effluent discharge site) resulted in high turbidity and discoloration of the surface water. The values of TDS, colour, EC, COD, and turbidity at station 2 are an indication that the discharges from the cement factory were mainly inorganic, causing pollution to the receiving water body. Also, pH was slightly higher in station 2 being more alkaline than the other stations. Biological oxygen demand was not significantly different among the sampling stations ranging between 2.05 and 2.89 mg/l. The high levels of EC and TDS portend an abnormal situation that could pose health risk to aquatic organisms. If elevated beyond acceptable limits, they could affect internal fluid regulation by affecting the osmotic balance in the organisms (Dallas and Day 2004; Rahmanian et al. 2015). The waters of the Oinyi River were well aerated with optimum DO concentrations and low BOD. This depicts the fact that the sources of pollution of this water body were not largely

Table 4 Axis eigenvalues and weighted intraset correlation between axes and environmental variables following canonical correspondence analysis of macroinvertebrate taxa abundance data in Oinyi River, Nigeria

	Axis 1	Axis 2
Eigenvalue	0.437	0.334
Taxa-environment correlation	0.75	0.82
% variation of taxa explained	56.68	43.32
Correlation with axes		
Canopy cover (%)	**0.731**	− 0.657
QHEI	**0.683**	**0.754**
Colour_	**− 0.775**	− 0.658
Turbidity	**− 0.982**	− 0.221
Total suspended solid (TSS)	− 0.560	**− 0.848**
Dissolved oxygen (DO)_	**0.714**	**0.724**
Biological oxygen demand (BOD_5)	**− 0.628**	**0.756**
NH_3N	**0.956**	0.324
Nitrate	− 0.532	**− 0.865**
Phosphate	**0.888**	− 0.428
Temperature	− 0.583	**0.792**
Depth	**0.914**	− 0.374
Flow_velocity	**0.773**	0.661

Note: Significance of the axes by the Monte Carlo test is given: P values for the Monte Carlo permutation test axis 1: P = 0.5743; axis 2: P = 0.7921. Values in bold indicate significant difference at P < 0.05

Table 5 Axis eigenvalues and weighted intraset correlation between axes and heavy metals following canonical correspondence analysis of macroinvertebrate taxa abundance data in Oinyi River, Nigeria

	Axis 1	Axis 2
Eigenvalue	0.437	0.334
Taxa-heavy metal correlation	0.81	0.77
% variation of taxa explained	56.68	43.32
Correlation with axes		
Iron	**0.975**	0.258
Manganese	**− 0.983**	− 0.219
Zinc	**− 0.961**	− 0.311
Copper	**− 0.933**	− 0.392
Chromium	− 0.374	**− 0.940**
Cadmium	**− 0.808**	**− 0.616**
Lead	**0.896**	− 0.413
Nickel	**− 0.972**	0.202

Note: Significance of the axes by the Monte Carlo test is given: P values for the Monte Carlo permutation test axis 1: P = 0.545; axis 2: P = 1.000. Values in bold indicate significant difference at P < 0.05

organic. The higher orthoorthophosphate-phosphorus-phosphorus levels at station 3 may not be unconnected with the various anthropogenic activities taking place there including flow from agricultural landscape. Substantial increases in nutrients in rivers and streams are attributable to strong anthropogenic effects (Dodds and Smith 2016). The high

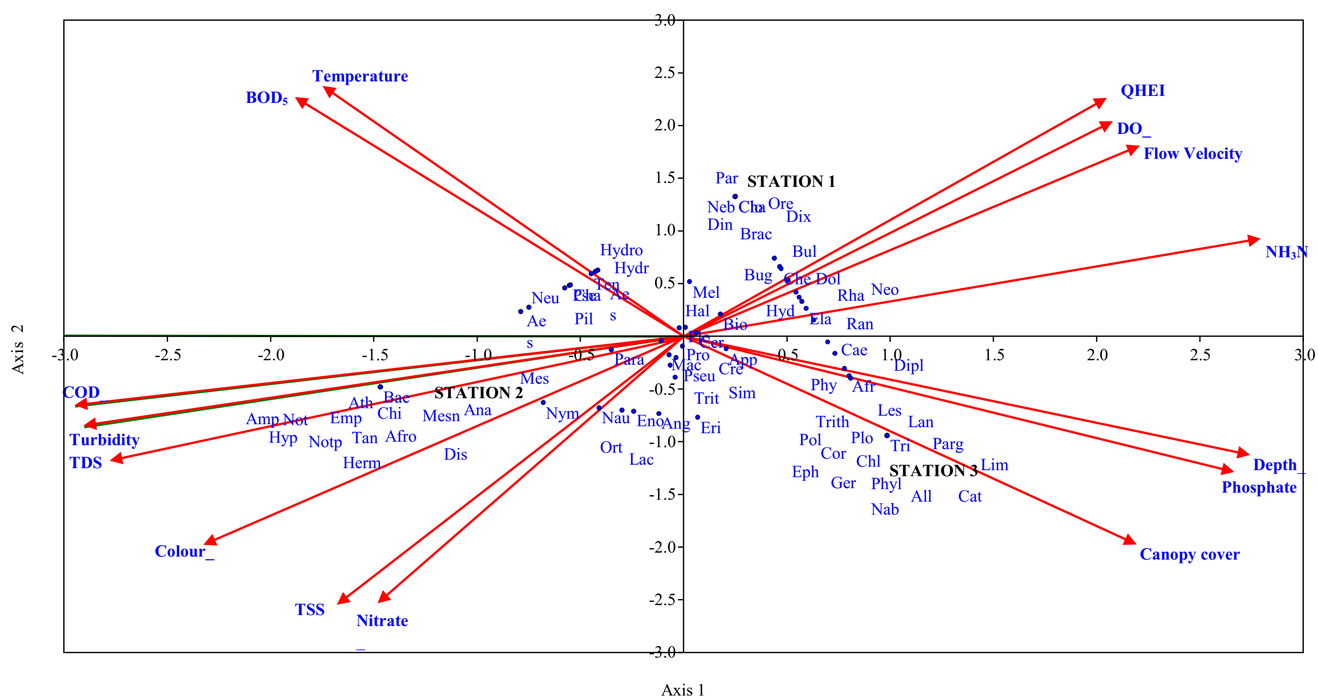

Fig. 3 Triplot of first and second CCA axes of macroinvertebrate taxa, environmental variables, and their corresponding sampling stations. The scale in SD units is − 3 to 3 for both the macroinvertebrate and environmental variable scores. The full names for the abbreviation codes of macroinvertebrate taxa are given in Table 2 (% of axis 1 explained is 56.68 and axis 2 is 43.32)

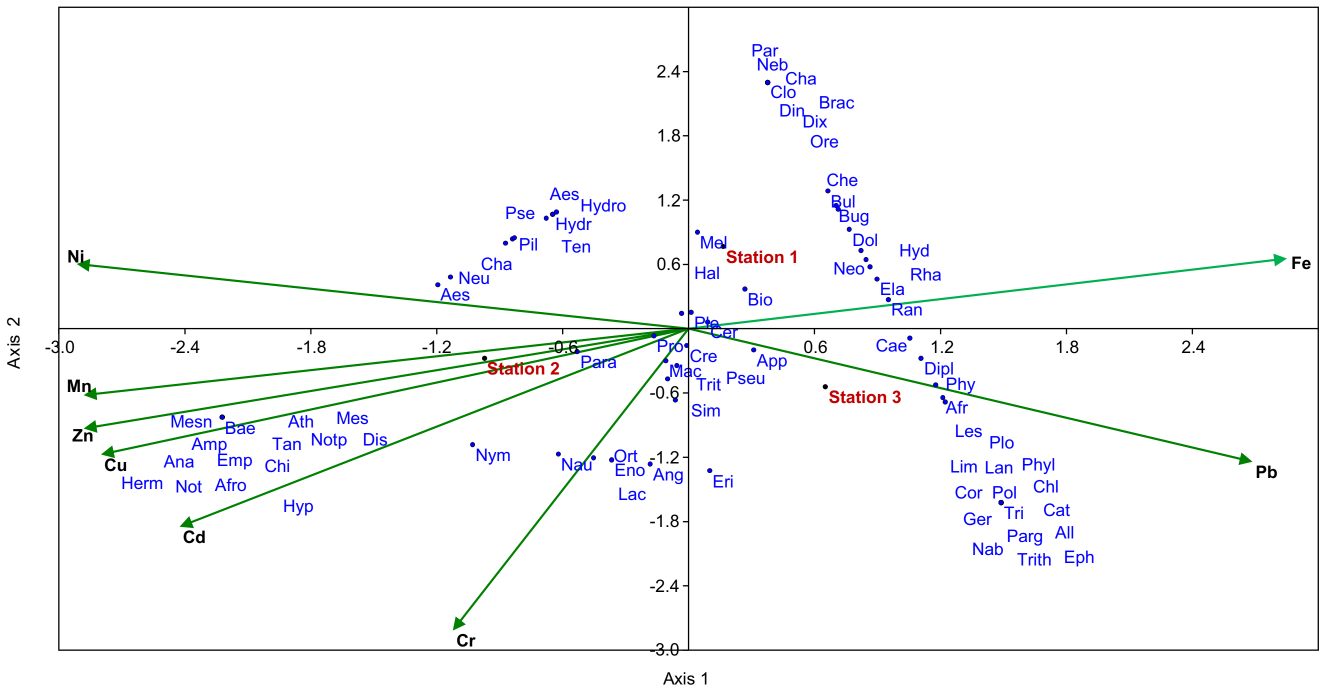

Fig. 4 Triplot of first and second CCA axes of macroinvertebrate taxa, environmental variables, and their corresponding sampling stations. The scale in SD units is − 3 to 3 for both the macroinvertebrate and environmental variable scores. The full names for the abbreviation codes of macroinvertebrate taxa are given in Table 2 (% of axis 1 explained is 56.68 and axis 2 is 43.32)

conductivity values recorded in the study especially during the dry season could be attributed to the concentration effect of dissolved ions, as a result of reduced water volume. The cement discharge-impacted station (station 2) contained significantly elevated levels of suspended silt when compared to the other two stations. Sediments contaminated with cement discharge may probably have led to the death of macroinvertebrates by decreasing the availability of habitat and food, by impeding burrowing, and by clogging respiratory structures (Couceiro et al. 2010, 2011; Desrosiers et al. 2019).

The significantly higher values of heavy metals at station 2 compared with stations 1 and 3 are indicative of the cement effluent, altering the sediment and water chemistry. Ions of some heavy metals including Fe, Mn, and Pb can sorb in appreciable amounts on the body surface of aquatic invertebrates and bind themselves to the cuticle while Zn, Cu, and Cr may accumulate within cells, mainly in cytosol (Golovanova 2008; Leung et al. 2017). Although the levels of most of the heavy metals observed were below the consensus-based threshold effect concentrations (MacDonald et al. 2000), care should be taken to keep this at minimal as further increase may become toxic to sensitive taxa.

Macroinvertebrate community structure and distribution

The Oinyi River supports a diverse assemblage of macroinvertebrate fauna. The number of taxa recorded (81 Taxa) far exceeds what have been reported from similar studies conducted in the north central region (Arimoro and Keke 2017; Keke et al. 2020; Arimoro et al. 2021). This may be due to the heterogeneous nature of the microhabitats in the river, especially the presence of variable substrate composition (sand, silt, debris/organic detritus), vegetation, stones, rocks etc. (Graça et al. 2004; Gleason et al. 2018). Odonata dominance in the river could be attributed to their morphological and physiological adaptations to the various habitats, availability of food, and sustained reproduction. *Pseudagrion spematum* was the most abundant odonate and is known to colonise all kinds of environments including polluted waters (Abdul et al. 2017). Stonefly nymph (Plecoptera) complete absence at the cement effluent discharge station is an indication that they are very sensitive organisms and are usually the first group of macroinvertebrates to be lost from freshwater systems after relatively minor nutrient enrichment, degradation of habitat, or changes in aquatic thermal regimes (DeWalt and Ower 2019). The relatively high density of the molluscs, *Melanoides tuberculata*, in the river is expected, as being the most dominant freshwater gastropods worldwide, with its successful invasion strategies and prevalence in different environments (Farani et al. 2015; Abdelhady et al. 2018). The preponderance of dipteran larvae such as *Tanypus* sp., *Eristalis tenax*, *Simulum* sp., *Empis* sp., and *Atherix* sp. at the cement effluent discharge station (station 2) is an indication of pollution as these organisms are known to strive well in effluent-impacted river (Odume et al. 2016). Generally, more macroinvertebrates were caught during the dry season than the wet season except for the gastropods. The heavy rainfall in this area during the wet season destabilises the substrate and dislodges the benthic organisms. However, during the dry season, macroinvertebrates gradually begin to build up their population as a result of the increase in stability of the bottom substrate. This also may be linked to the reduction of the water level and concomitant change of nutrients in the dry season (Liu et al. 2020).

Macroinvertebrates and environmental relationship

The variations in environmental variables indicate that higher macroinvertebrate abundance at the Oinyi River may be attributed to the shallow, fast-flowing, and stony riffle microhabitats prevalent in the water course. Similar observations were reported by Csercsa et al. (2019) in some temperate streams. The CCA also revealed that COD, turbidity, TDS, nitrate, colour, and TSS were positively correlated with station 2 and these were factors responsible for pollution with the associated taxa (*Eristalis tenax*, *Atherix* sp., *Tanypus* sp., *Simulium* sp., and *Empis* sp.). This study therefore indicates that these taxa are powerful predictors of water quality and can be used to detect degradation in water and habitat quality due to cement effluent pollution. Already, there have been recent studies conducted in the North Central Nigeria to identify these surrogate taxa as tools for conservation and management of biodiversity (Arimoro and Keke 2021; Arimoro et al. 2021).

The taxa richness, number of EPT taxa, and number of EPT individuals revealed the decimating impact of the cement effluent on communities of macroinvertebrates. Reduced values of these indices and an increased in dominance index at station 2 are similar to the typical response of macroinvertebrate communities to organic and inorganic pollutants (Cain et al. 1992; Gómez et al. 2008; Arimoro 2009).

Conclusion

The continuous discharges of cement waste water into the river compromised water quality with elimination of sensitive macroinvertebrate taxa. The impacted station had elevated values of COD, turbidity, TSS, and heavy metals (Mn, Zi, Cu, and Ni) attributable to the chemical nature of the waste water. The impacts of cement effluent in the Oinyi River basin must be checked to avoid the extinction of sensitive taxa, which are already declining in population as observed during this study. Furthermore, detailed study with more stations upstream and downstream of the impacted site should be undertaken to fully document changes in water quality and community structure of macroinvertebrates in the river that might call for improved regulation and policy development.

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Availability of data and materials Not applicable

Author contribution FOA designed the study, performed data analysis, and wrote the manuscript. FKM designed the study and performed the sample collection. UNK wrote and edited the manuscript.

Declarations

Ethics approval and consent to participate Not applicable

Consent for publication Not applicable

Competing interests The authors declare no competing interests.

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