BIOLOGY INSIGHTS

MIDITERRANEAN JOURNALS

2022, Volume 1, ID 612
Original Research
DOI: 10.55085/bi.2022.612

Macroinvertebrates of Wupa River, Abuja, Nigeria: Do environmental variables pattern their assemblages?

Blessing Odafe Omovoh [a,b*], Francis Ofurum Arimoro [b], Adesola Victoria Anyanwale [b], Evans Chidi Egwim [c], Gift Ochonogor Omovoh [b,d], Frank Chukwuzuoke Akamagwuna [e], Hajara Zakari [f], Augustine Ovie Edegbene [e,f]

[a] Department of Forestry, Federal Ministry of Environment, Plot 393/394 Augustus Aikhomo Way, Utako, Abuja, Nigeria.
[b] Department of Animal Biology, Federal University of Technology, Minna, Nigeria.
[c] Department of Biochemistry, Federal University of Technology, Minna, Nigeria.
[d] Environment Assessment Department, Federal Ministry of Environment, Independence Way, South Central Business District, Abuja, Nigeria.
[e] Institute for Water Research, Rhodes University, Grahamstown (Makhanda), South Africa.
[f] Department of Biological Sciences, Federal University of Health Sciences, Otukpo, Nigeria.

Received: 01 Dec 2021
Revised: 18 Jan 2022
Accepted: 10 Feb 2022
Published: 07 Mars 2022

Academic Editor:
Luis Oswaldo Viteri Jumbo

Correspondence: Augustine Ovie Edegbene, Department of Biological Sciences, Federal University of Health Sciences, Otukpo, Nigeria.
Email: ovieedes@gmail.com

Cite this article as: Omovoh BO, Arimoro FO, Anyanwale AV, Egwim EC, Omovoh GO, Akamagwuna FC, Zakari H, Edegbene AO. Macroinvertebrates of Wupa River, Abuja, Nigeria: Do environmental variables pattern their assemblages?. Biol Insights. 2022;1:612. [https://doi.org/10.55085/bi.2022.612]

Authors' contributions
The participation of each author corresponds to the criteria of authorship and contributorship emphasized in the Recommendations for the Conduct, Reporting, Editing, and Publication of Scholarly work in Medical Journals of the International Committee of Medical Journal Editors. Indeed, all the authors have actively participated in the redaction, the revision of the manuscript, and provided approval for this final revised version.

Acknowledgments
None.

Funding
No funding was received from any organization to conduct the present study.

Conflict of interest
The authors declare that there is no conflict of interest regarding the publication of this article.

ABSTRACT

Macroinvertebrates, alongside physico-chemical variables, were sampled and analyzed for nine months between April and December 2019 in three Stations (Stations 1, 2 and 3) in the Wupa River, Abuja, Nigeria. The stations were selected to represent an increasing pollution gradient from Station 1 < Station 2 < Station 3. Our result showed that Station 1 had the lowest mean values of physico-chemical variables, except conductivity and DO. Except for temperature (26.83±0.33ºC), BOD (13.05±0.77 mg/l) and pH (6.91- 7.80) that were highest in Station 2, all other physico-chemical variables had their highest mean values in Station 3. The principal component analysis revealed that axis 1, with a variance of 64.41%, explained more variation in terms of physico-chemical variables than axis 2. Temperature and pH were positively correlated with Station 2, while turbidity and phosphate were strongly positively correlated with Station 3. A total of 49 macroinvertebrate taxa and 5,814 individuals were recorded during the study period. Station 1 (3.038) had the highest macroinvertebrate individuals, followed by Station 2 (1.794). *Bulinus globusus* with 759 individuals was the most predominant taxon in the area. The canonical correspondence analysis (CCA) showed that axis 1 explained 86.98% of the ordination variance while axis 2 explained 13.02%. The two axes showed no significant correlation between macroinvertebrate taxa and physico-chemical variables. The CCA triplot showed that *Melanoides moerchi*, *Culex* sp., and *Oligoneux* sp. are surrogates for biomonitoring the Wupa River. We recommend further studies to be conducted along the entire stretch of the river to confirm our present results.

Keywords: Macroinvertebrate Assemblage, *Melanoides moerchi*, CuIex sp., Sulphate, Biomonitoring, Multivariate Ordination, Wupa River.

INTRODUCTION

Rivers in Nigeria have consistently suffered from a high level of pollution occasioned by human activities related to increasing population, agricultural activities, industrialization, and urbanization [1, 2]. Urbanization and industrialization are implicated as major stressors causing the degradation of riverine systems [2, 3, 4]. Urbanization and industrialization result in stormwater return flow, sewage disposition, agricultural runoffs, and effluent discharges. This problem causes water quality impairment and biodiversity decline of freshwater ecosystems, causing serious management issues for water quality managers and policymakers. If not tackled urgently, it could have a grave effect on the riverine system's community structure and functionality [5].

Various aquatic biota phytoplankton, zooplankton, macroinvertebrates, and fishes are routinely employed to monitor the impacts of human activities on rivers [2, 6, 7]. Among the aquatic biota employed in assessing riverine system health, macroinvertebrates are the most explored groups [8, 9, 10]. Macroinvertebrates respond differentially to pollution, and they are easily collected from wadeable and non-wadeable rivers and streams [7, 11]. They display varying sensitivity to pollution, with the intolerance of macroinvertebrates dominating pristine systems and the tolerant macroinvertebrates increasing in polluted systems [2, 12]. As such, macroinvertebrate association with environmental variables is used to determine their level of intolerance or tolerance to environmental degradation [12]. For instance, macroinvertebrate that positively associates with pollution indicating environmental variables (e.g., sulphate, phosphate, and conductivity) are considered pollution tolerant taxa [2, 9]. Given this, we assessed the structural assemblage of macroinvertebrates in the Wupa River, Abuja, Nigeria, to ascertain whether environmental variables pattern their assemblage in the river.

The Wupa River is a municipal river that flows through Nigeria's Federal Capital Territory (FCT). The river is subjected to a varying degree of anthropogenic activities resulting from the teeming population in the FCT. Anthropogenic activities such as household wastes, industrial effluents, and stormwater return flow from nearby unplanned towns are the main sources of pollution in the river catchment. Despite the increasing recognition of water quality degradation and biodiversity decline in the Wupa River from these activities, there is a shortage of studies to assess the severity of anthropogenic activities. We aimed to provide a baseline insight into how environmental variables linked to human activities structure the distribution patterns of macroinvertebrates in the study area. We hypothesized that environmental variables associated with increasing human activities in the Wupa River pattern macroinvertebrates assemblage structure.

METHODS

Study area and stations description

The study area is located in Nigeria's Federal Capital Territory (FCT), and it falls within the Savannah vegetation belt of the West African sub-region. The area covers 7,315 square km and is characterized by two seasons; wet and dry seasons. The wet season is between April and September, and the dry season is between October and March. About 60% of the annual rainfall occurs during July and September, which leads to flooding of the Wupa River and nearby rivers in the FCT [7]. The annual rainfall and temperature of the area are 1650mm and 30-37^{o}C, respectively [7]. The river takes its source from the Gurara River and traverses over three-quarters of the breadth of planned (formal) and unplanned (informal) areas of the FCT. The river stretches through the northern part of FCT at Bwari and splits at Ushafa, with the first arm flowing eastward towards its length stretches over 143km across the breadth of FCT.

For this study, we marked out three stations based on their accessibility and pollution gradient (Figure 1). Station 1 (Gwongwola community), located on latitude 9^{o} 01' 50.83’’N and longitude 7^{o} 24' 49.74’’E with an elevation of 410 m and altitude of 619 m. The station is relatively perturbed with diverse human activities around the station catchment ranging from bathing, washing, and agriculture. Station 2 is located within the interception of latitude 9^{o} 01' 50.83’’N and longitude 7^{o} 24' 49.74’’E with a total elevation of 380 m and altitude of 1.38 km. A sewage water treatment plant is situated along the catchment of Station 2. Station 2 is more perturbed than Station 1 due to the effluent being discharged from the sewage treatment plant. Station 3, a more perturbed station than Stations 1 and 2, is located within Idu solid waste dump site, and it is situated in the interception of latitude nine 9^{o}01'08.27"E and longitude seven 7^{o}20'42.76"E of the equator with a total elevation of 366 m and altitude of 1.60 km.

Physico-chemical variables

Physico-chemical variables and macroinvertebrates were collected monthly for nine months between April 2019 and December 2019. The analyzed physicochemical variables were temperature, conductivity, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), turbidity, sulphate, and phosphate. The temperature was measured with mercury in a glass thermometer, and turbidity was measured using a turbidimeter and was measured in a nephelometric turbidity unit (NTU). Conductivity and pH were measured using handheld HANNA Instruments Woon socket RI USA made by HANNA Ltd, Europe (Romania). Dissolved oxygen was measured with a portable dissolved oxygen meter (Model DO210, Extech Instruments, United States of America. Five 50 ml sterile bottles were used to collect separate water at each sampling station to analyze BOD, sulphate, and phosphate. BOD, sulphate, and phosphate were determined following [13] methods in the laboratory. For the determination of BOD, one of the five sterile bottles used in collecting water samples was fixed with Winkler solution A (Manganese (II) Sulphate) and Winkler solution B (Potassium

Iodide) to stop biological reactions in the water sample collected. At the laboratory, the sterile bottle was placed inside a dark cupboard for five days, and

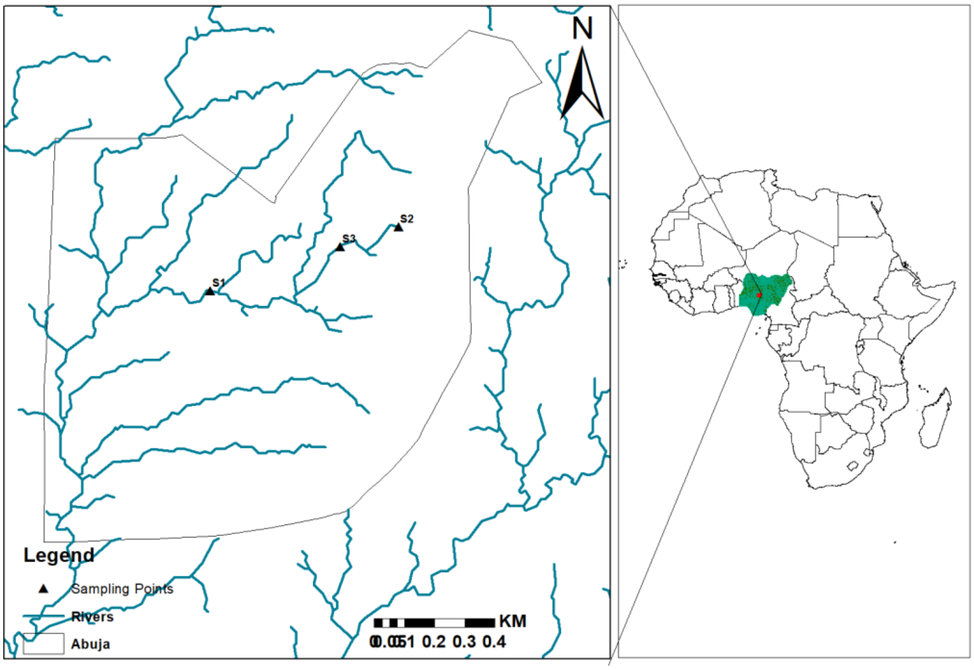

Figure 1: Map of the study area showing the sampled stations.

thereafter, DO concentration was determined. The final BOD concentration was determined by subtracting DO on the first day from DO on the fifth day. We mixed 50 ml of the water sample collected into 10 ml of glycerol-alcohol solution for sulfate determination. Then the absorbance was measured against a blank at a wavelength of 380-420nm [13]. After which, the absorbance was measured after 30 minutes in mg/l.

We determined phosphate following the stannous chloride method [13]. We added a drop of phenolphthalein indicator to 100 ml of the water sample collection and then 4 ml of ammonium molybdate reagent, and it was allowed to mix thoroughly. Finally, phosphate concentration was read using the calibration curve prepared in mg/l.

Macroinvertebrates

A modified kick sampling net made of D-frame with a mesh size of 500 µm was used to collect macroinvertebrates per station on each sampling expedition as described earlier in [4]. Kicking per station was done four minutes in all the representative biotopes per station. The biotopes include mud, sand, silt, and vegetation to complement the kick sampling exercise. Random handpicking of visible macroinvertebrates was done in all stations for 10 minutes per station. Edegbene and Arimoro [14] had earlier pointed out the importance of handpicking to complement the kick sampling exercise, as it helps in collecting macroinvertebrates that would have been missed during kicking. Finally, all samples collected with a kick net and handpicking were pooled together as one composite sample and persevered in 70% alcohol for further processing in the laboratory. Collected macroinvertebrates were sorted at the laboratory using a handheld lens and confirmed with a light microscope at X10 magnification. Macroinvertebrates identification was made to the lowest possible taxonomic level using available identification keys in Nigeria [15, 16]. Further, taxonomic literature available in Nigeria [7, 9] were also consulted. Confirmation of taxonomic resolution was done using the taxonomic key from elsewhere [17]. Dr. Augustine Ovie Edegbene and Dr. Frank Chukwuozuoke Akamagwuna also confirmed some of the taxa.

Data analyses

Descriptive statistics, mean, standard error, and range were performed on the physico-chemical variables. One-way analysis of variance (ANOVA) was calculated to determine the differences in the mean values of the physico-chemical variables. Before ANOVA, we tested the assumptions of ANOVA using Shapiro Wilk's and Levene's tests. Tukey post hoc test was used to confirm station means of physico-chemical variables that differed significantly.

A principal component analysis (PCA) was constructed to determine the correlation between physico-chemical variables and sampled stations. The PCA was also used to confirm the pollution gradient from Stations 1 to 3. Canonical correspondence analysis (CCA) was used to explore the relationship between physico-chemical variables and macroinvertebrate taxa along the station's pollution gradient. Before taxa datasets were subjected to CCA, a detrended correspondence analysis (DCA) was used to test for the dataset linearity, and the DCA test returned with a gradient length of >3 [18]; hence CCA was deemed suitable for the analysis. Further, to confirm the level of significance between the CCA axes, a Monte-Carlo permutation test at 999 permutations was conducted. All analyses were conducted by either the R-programming platform [19, 20] or PAST [21].

RESULTS

Physico-chemical variables

Generally, except for conductivity and DO, the lowest mean values of physico-chemical variables were recorded in Station 1 (Table 1). Temperature (26.83+0.33°C), pH (6.91- 7.80) and BOD (13.05+0.77 mg/l) had their highest mean values in Station 2 (Table 1). The DO mean value was highest in Station 1 (9.72+0.30 mg/l) (Table 1) whereas the mean values of turbidity (19.38+1.10 NTU), sulphate (26.14+2.84 mg/l) and phosphate (8.31+2.51mg/l) were highest in Station 3 (Table 1). ANOVA showed that except BOD with P-value = 0.0004706, all physico-chemical variables did not differ significantly between the Stations (Table 1). Tukey's HSD test revealed that BOD mean value increased significantly in Stations 2 and 3 than in Station 1 ($P < 0.05$; Table 1).

Table 1: Means, standard errors, and ranges (in parenthesis) of physico-chemical variables in Wupa River, Abuja, Nigeria. P-value and F-value as revealed by one-way analysis of variance (ANOVA). Physico-chemical variables per station with the same superscript letters show no significant differences (P>0.05) as revealed by post hoc test (Tukey Honestly Significant Difference, HSD).

Variables	Station 1	Station 2	Station 3	P-value	F-value
Temperature (°C)	26.71±0.39 (25.12-28.20)^{a}	26.83±0.33 (25.19 - 28.20)^{a}	26.30±0.47 (24.18- 27.80)^{a}	0.1053	2.0516
Conductivity (µS/cm)	211.50±7.91 (177.8- 242.9)^{a}	205.07±12.80 (163 – 272)^{a}	204.30±5.80 (173- 231.9)^{a}	0.8497	0.484654
pH	(6.89-7.15)	6.91- 7.80)	6.41- 7.22)	0.3041	1.31523
DO (mg/l)	9.72±0.30 (7.64- 10.61)^{a}	9.30±0.62 (6.84- 11.94)^{a}	9.60±0.76 (7.28+12.61)^{a}	0.3846	1.14977
BOD (mg/l)	9.14±0.80 (6.21- 13.4)^{a}	13.06±0.77 (10.61- 16.6)^{b}	12.11±0.83 (8.60- 17.18)^{b}	0.0004706	7.09569
Turbidity (NTU)	13.34±1.62 (8.6-20.9)^{a}	15.04±1.41 (9.6- 21.6)^{a}	19.38±1.10 (15.17- 24.8)^{a}	0.05374	2.53748
Sulphate (mg/l)	7.96±1.02 (3.19- 12.14)^{a}	15.48±1.03 (12.11- 19.84)^{bc}	26.14± 2.84 (14.8- 41.6)^{c}	0.5341	0.907445
Phosphate (mg/l)	0.58±0.09 (0.19- 0.92)^{a}	0.77±0.09 (0.26- 1.02)^{a}	8.31±2.51 (0.25- 18.28)^{a}	0.4136	1.0976

Correlation of physico-chemical variables with sampled stations

The Principal Component Analysis (PCA) result of the correlation of physico-chemical variables with sampled stations showed the variance of component 1 of the PCA was 64.41%, and that of component 2 was 35.58%. The eigenvalues of components 1 and 2 were 5.15 and 2.85, respectively. Temperature and pH were positively correlated with Station 2 (Figure 2). Turbidity and phosphate were strongly positively correlated with Station 3, and conductivity was strongly negatively correlated with Station 1 (Figure 2). Sulphate, DO, and BOD were not correlated with any sampled stations (Figure 2).

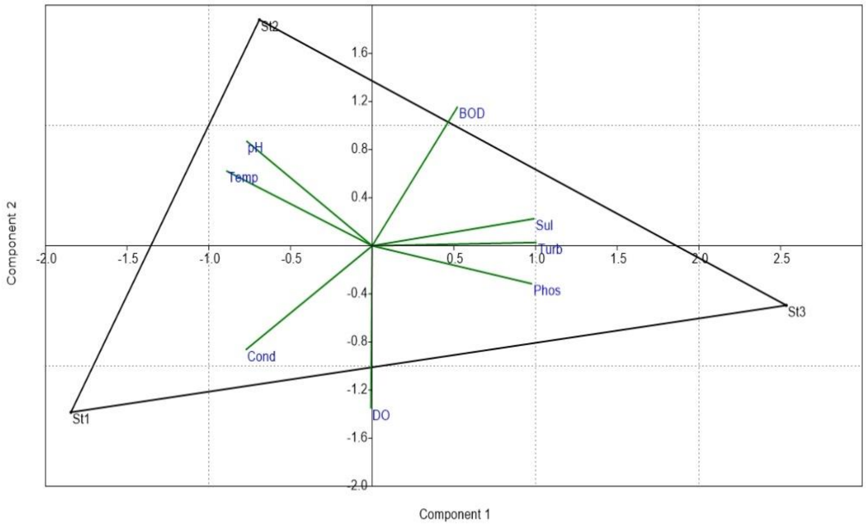

Figure 2: Correlation matrix of PCA showing the relationships between physico-chemical variables and macroinvertebrate taxa in the sampled stations of Wupa River, Abuja, Nigeria. Physico-chemical variables abbreviations: Temp = water temperature, Cond = conductivity, Turb = turbidity, DO = dissolved oxygen, BOD = biochemical oxygen demand, Sul = sulphate, Phos = phosphate.

Structural assemblage of macroinvertebrates

A total of 49 macroinvertebrate taxa were recorded in this study (Table 2). Macroinvertebrate individuals were highest in Station 1 (3.038), followed by Station 2 (1.794), and Station 3 had the lowest macroinvertebrate individuals (982). The overall macroinvertebrate taxa collected in the entire study period was 5.814 (Table 2). The most abundant taxa were *Bulinus globusus* with 759, with 473 and 311 individuals in Stations 1, 2, and 3, respectively (Table 2). Other preponderant taxa include *Neritina rubricata* with 335, 244, and 191 individuals in Stations 1, 2, and 3, respectively. *Appasus* sp. with 393, 190, and 68 individuals in Stations 1, 2, and 3, respectively, and *Melanoides tuberculatus* with 256, 152, and 25 individuals in Stations 1, 2, and 3, respectively (Table 2). On the other hand, the least preponderant macroinvertebrate collected during the entire study period was *Psychodid* sp. with 2, 1, and 0 individuals in stations 1, 2, and 3 respectively, followed by *Micronecta* sp. with 3, 1, 1 individual in Stations 1, 2 and 3, respectively (Table 2).

Table 2: Structural assemblage of macroinvertebrates in Wupa River, Abuja, Nigeria.

Taxa	Taxa code	Station 1	Station 2	Station 3
Lestinogomphus sp.	Les	109	46	18
Genigomphus sp.	Gom	65	41	11
Aeschna sp.	Aes	5	2	0
Cordulex sp.	Cor	8	4	2
Urothermis sp.	Uro	1	6	12
Bradinopyga sp.	Bra	62	35	21
Brachythemus_leucostica	Brl	111	56	31
Nymphilla sp.	Nym	31	10	3
Caloptery sp.	Cal	53	33	19
Platycnemid sp.	Pla	4	4	1
Mesocnemis sp.	Mes	3	1	1
Caenagrion sp.	Coe	34	18	8
Baetis sp.	Bas	39	8	11
Pseudocloeon sp.	Pse	25	18	13
Cloeon sp.	Clo	8	6	2
Bugilliesia sp.	Bug	140	92	55
Caenis aenum	Cae	19	7	2
Polymix sp.	Pol	4	3	1
Oligoneux sp.	Oli	5	2	3
Neoperla sp.	Neo	4	2	2
Cybister sp.	Cyb	4	2	3
Coelhydrus sp.	Col	10	7	2

Hydrocanthus sp.	Hyd1	7	6	4
Micronecta sp.	Mic	3	1	1
Hydrophyilia sp.	Hyr	9	4	4
Helochares sp.	Hel	21	16	7
Hyphydrus sp.	Hyp	10	4	2
Philaccolus sp.	Phi	16	14	8
Phlodytes sp.	Phl	21	15	10
Orectogyrus sp.	Ore	19	14	8
Promerisia sp.	Prs	8	4	4
Psychodid sp.	Psy	2	1	0
Culex sp.	Cus	49	24	16
Tabanus sp.	Tas	2	2	2
Sudanonaules floweri	Suf	2	2	3
Aethaloptera maxima	Aet	12	10	0
Mauostemum capenses	Mau	18	4	0
Nepa sp.	Nes	16	12	8
Hydrometra sp.	Hyd2	21	14	7
Velia caprai	Vec	91	68	29
Gerris sp.	Ges	19	6	3
Appasus sp.	App	393	190	68
Naucoris sp.	Nas	75	39	4
Hirudinea medicinalis	Hir	18	10	4
Bulinus globosus	Bul	759	473	311
Neritina rubricata	Ner	335	244	191
Melanoides tuberculatus	Met	256	152	25
Melanoides moerchi	Mem	96	53	39
Unima sp.	Uni	16	9	3
Taxa total		**3038**	**1794**	**982**

Relationship between physico-chemical variables, stations and macroinvertebrates taxa

The CCA Axes 1 and 2 explained 86.98% and 13.02% of the ordination, respectively. Axes 1 and 2 eigenvalues were 0.032 and 0.00048, respectively. The Monte-Carlo permutation test revealed no significant differences in the first two axes of the CCA correlation with macroinvertebrate taxa and physico-chemical variables (P>0.05). Sulphate, phosphate, and turbidity were strongly positively correlated with the following macroinvertebrate taxa: *Melanoides moerchi*, *Hydrophyilia* sp., *Cybister* sp., *Culex* sp., *Bradinopyga* sp. and *Oligoneux* sp. (Figure 3). In Stations 2 and 3; Hydrocanthus sp., Neritina rubricata, Philaccolus sp., *Phlodytes* sp., *Orectogyrus* sp., and *Bugilliesia* sp. were strongly positively associated with BOD (Figure 3).

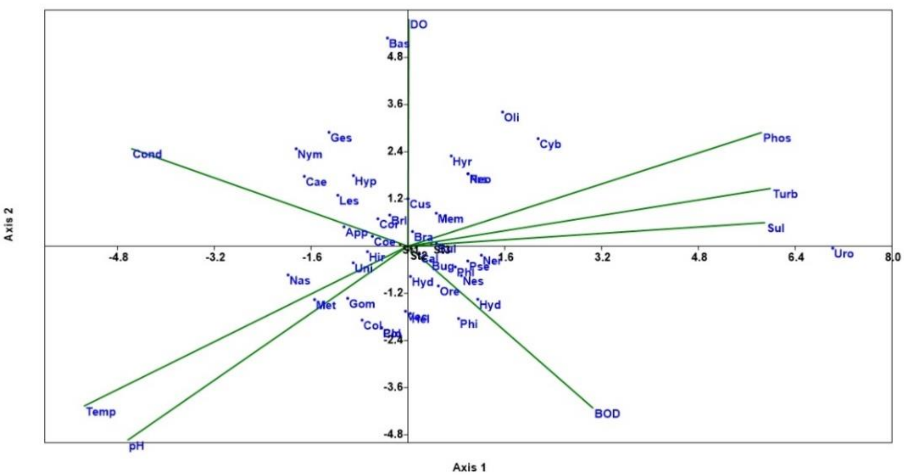

Figure 3: First and second CCA axes of macroinvertebrate taxa, physico-chemical variables in the sampled stations of Wupa River, Abuja, Nigeria. **Physico-chemical variables abbreviations:** Temp = water temperature, Cond = conductivity, Turb = turbidity, DO = dissolved oxygen, BOD = biochemical oxygen demand, Sul = sulphate, Phos = phosphate. **Macroinvertebrate taxa codes**: see Table 2.

DISCUSSION

In this study, we examined how selected environmental variables influence the distribution pattern of macroinvertebrates in the Wupa River, FCT, Nigeria. We recorded a concomitant increase in pollution indicating Physico-chemical variables such as BOD, sulphate, and phosphate in Stations 2 and 3, portraying the degradation level at these stations. Similar results have been reported in other studies in the study area [22, 23]. Osimen et al. [23] in their study reported elevated values of phosphate and BOD in areas subjected to human activities in the Ojirami riverine system. The study further asserted that elevated values of pollution indicating physico-chemical variables posed a severe ecological risk to macroinvertebrate structural assemblage in aquatic systems. On the other hand, DO concentration was higher in Station 1, indicating that the station is less perturbed compare to the remaining two stations. Increased DO has been consistently used as a benchmark to measure relatively unperturbed sites [9, 24, 25].

The principal component analysis (PCA) revealed that the eight physico-chemical variables used to predict the level of perturbation experienced by the three stations explained over 98% of the total variance of all the PCA axes. A recent study reported over 70% of the total variance of the entire PCA axes. It was judged to be sufficient to conclude the environmental variables' reliability in constructing the PCA [2]. Other studies have also recommended a variance fluctuation between 70% and 90% to conclude the reliability of environmental variables used in constructing multivariate plots [26]. Overall, the PCA results provided more evidence to support our findings. Stations 2 and 3 appear to be more polluted than Station 1 as BOD, temperature, sulphate, turbidity, and phosphate are strongly associated with Stations 2 and 3.

A total of 5.814 macroinvertebrate individuals belonging to 49 taxa were recorded in the Wupa River and favorably compared with the total number of macroinvertebrate individuals and taxa recorded in perturbed riverine systems in the Northern part of Nigeria [7, 25, 27]. The assemblage structure of macroinvertebrates in this study closely followed the gradients of pollution explained by the physico-chemical variables revealed by the PCA. We recorded the highest number of macroinvertebrate individuals in Station 1 (3.038), Station 2 (1.794), and Station 3 (982). This confirms that the assemblage patterns of macroinvertebrates are explained by variation in physico-chemical variables. This result is congruent with a similar study conducted in a river in the Southern part of Nigeria [2].

The CCA constructed was able to point out taxa that can be suggested as biological monitoring surrogates in riverine systems in Northern Nigeria. *Melanoides moerchi*, *Culex* sp., *Oligoneux* sp. assemblage structure were patterned by sulphate, phosphate, and turbidity in Stations 2 and 3, the relatively perturbed stations. It further confirmed the deterioration level of Stations 2 and 3, which had a low representation of *Neoperla* sp. with two individuals each. Four individuals of *Neoperla* sp. were recorded in Station 1, indicating that Station 1 is less perturbed than the remaining two stations. It has been reported that macroinvertebrate taxa in the Order Plecoptera (e.g., *Neoperla* sp.) are intolerant of pollution and are one of the first to disappear in perturbed riverine systems [9, 10, 27].

CONCLUSION

We examined how environmental variables pattern the structural assemblage of macroinvertebrates in the Wupa River, Abuja, Nigeria. Our results showed that physico-chemical variables played a key role in macroinvertebrates' assemblage structure as revealed from the PCA and confirmed by CCA constructed. Physico-chemical variables such as sulphate, phosphate, BOD, and turbidity were relatively higher in Stations 2 and 3 than Station 1. Macroinvertebrate taxa such as *Melanoides moerchi*, *Culex* sp., and *Oligoneux* sp. were recommended as surrogate for biological monitoring of riverine systems in the study area and Northern Nigeria in general. We recommend that a more comprehensive study be conducted along the whole stretch of the river to confirm our present result

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