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Dissecting the urban footprint of unplanned settlements shaping macroinvertebrate communities in Wuye River, Abuja, Nigeria

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Urbanization poses a significant threat to river ecosystems, causing widespread degradation of river health. This study investigates the devastating effects of urbanization on river health, with a focus on the Wuye River in Abuja, Nigeria, and dissects the urban footprint of unplanned settlements on macroinvertebrate communities. Over a six-month period (January–June 2021), we conducted a comprehensive analysis of physicochemical characteristics and macroinvertebrates at four stations, shedding light on the far-reaching consequences of unplanned urban settlements on river ecosystems. The results revealed significant deviations from optimal water quality parameters with reference to WHO guidelines. Station 3, located in unplanned urban settlement, exhibited elevated nitrate concentrations (13.0 mg/L) and heightened turbidity levels (23.6 NTU), indicating compromised water quality. Station 2, located in planned urban settlements, displayed lower nitrate values and turbidity levels. pH values ranged from 7.4 to 7.7 across all stations, suggesting minimal impact on river acidity. Canonical Correspondence Analysis (CCA) showed strong relationships between species abundance and environmental variables. Axis 2 was associated with *Naucoris* sp., *Velia caprai*, *Chironomus transvalensis*, and *Cricotopus* sp., and was influenced by dissolved oxygen, sulphate, phosphate, nitrate, and turbidity. Axis 1 was linked to seasonally influenced factors, including temperature and electrical conductivity. CCA indicated that Stations 1 and 2 had higher pH concentrations, favouring species like *Melanoides tuberculatus*, *Appasus* sp., *Neritina lubricate*, *Bugilies* sp. and *Bulinus globosus*. The findings highlight urgent need for effective management and conservation strategies in water treatment, urban planning and conservation policies to mitigate urbanization's impacts on river health.

Keywords Urbanization, River health, Macroinvertebrates, Water quality, Sustainable urban planning

Urbanization is a pervasive and accelerating global phenomenon, profoundly altering land use patterns, biodiversity, and water systems at an unprecedented scale[1]. The unchecked growth of unplanned urban settlements, characterized by inadequate infrastructure, insufficient waste management, and lack of environmental oversight, exacerbates environmental degradation, including habitat destruction, pollution, and changes in water quality[2]. These alterations can have far-reaching and devastating consequences for aquatic biodiversity, particularly macroinvertebrates, which serve as crucial indicators of ecosystem health and play a vital role in maintaining the delicate balance of aquatic ecosystems[3].

The rapid urbanization of tropical regions has led to the proliferation of unplanned settlements, which can have devastating effects on local ecosystems, particularly tropical rivers[4–6]. These settlements can lead to increased water pollution, habitat destruction, and altered flow regimes, ultimately affecting macroinvertebrate communities[7–9]. Specifically, urbanization has been linked to declines in macroinvertebrate diversity and abundance in tropical streams[3]. Furthermore, the impacts of unplanned urban settlements on macroinvertebrate communities can be exacerbated by climate change, deforestation, and agricultural runoff[10]. For instance, research has demonstrated that changes in land use and climate can lead to shifts in macroinvertebrate community composition in afrotropical streams[11]. Anthropogenic land-use impacts, such as deforestation and urbanization,

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can significantly alter the size structure of macroinvertebrate assemblages[12]. Furthermore, land-use changes can lead to simplification of lotic environments, resulting in reduced biodiversity and altered ecosystem function[13].

The unplanned urban settlement has a profound impact on aquatic ecosystems, leading to a cascade of detrimental effects, including the loss of sensitive aquatic species, invasion of pest species, degradation of water quality, modification of stream channels, disruption of natural flow regimes, and reduction of habitat values within the waterway and associated riparian zone[14,15]. Furthermore, urban river pollution poses significant livelihood risks to marginal communities, threatening their economic well-being and resilience[16].

Urbanization's far-reaching impacts on rivers and streams have been assessed using a diverse array of physical, chemical, and biological indicators[17,18]. Among these, macroinvertebrates play a vital role in maintaining the delicate balance of aquatic habitats, serving as both ecological and economic indicators of environmental health[19]. The structure of benthic macroinvertebrate communities provides valuable insights into recent environmental events, offering a precise and localized snapshot of ecosystem conditions[20]. Moreover, benthic macroinvertebrates exhibit high variability, allowing them to integrate the effects of short-term environmental fluctuations, making them an effective tool for characterizing rivers and streams worldwide[21].

Freshwater pollution, driven by human activities, imperils environmental sustainability and socioeconomic development in Abuja, underscoring the need to examine the urban footprint on river ecosystems. River ecosystems face multifaceted threats, including domestic and industrial activities, unregulated land use, and landscape alteration, leading to biotic and physical deterioration[22]. In Nigeria, land use changes, unsustainable agricultural practices, and agro-industrial activities have cumulative impacts on freshwater ecosystems, altering macroinvertebrate composition and abundance[23,24]. The conversion of natural habitats for agricultural expansion and infrastructure development leads to habitat destruction, soil erosion, and increased sedimentation. Unsustainable agricultural practices result in nutrient pollution, disrupting the delicate balance of aquatic ecosystems. Agro-industrial activities introduce pollutants, including pesticides and heavy metals, which accumulate in water bodies and impact aquatic life[25]. These impacts alter species richness, diversity, and functional traits, compromising the ecological integrity of Nigeria's freshwater ecosystems[26,27].

This study harnesses the proven value of aquatic macroinvertebrates as water quality indicators, integrating biological, physical, and chemical parameters to assess the environmental conditions of Wuye River[23]. Rapid urbanization in Nigeria, characterized by inadequate regulation and enforcement, has led to widespread environmental degradation and biodiversity loss[28]. The proliferation of unplanned urban settlements, marked by poor sanitation and inadequate waste management, poses a significant threat to Wuye River's ecological integrity and its diverse plant and animal species.

The relationship between unplanned settlements and macroinvertebrates remains shrouded in uncertainty. Specifically, the impact of inadequate waste management, altered hydrology, and pollution on macroinvertebrate diversity, abundance, and community composition is poorly understood[4,29]. The cumulative effects of multiple stressors in these environments on macroinvertebrate populations are also unknown, leaving a critical knowledge gap in our understanding of these ecosystems. This knowledge gap highlights the need for targeted research to inform evidence-based management strategies that can mitigate these impacts and protect the ecological integrity of vital aquatic ecosystems, particularly in tropical regions, like Wuye River. This study aims to dissect the impact of unplanned urban settlements on macroinvertebrate communities in Wuye River, Abuja, Nigeria, and understand how these settlements shape their assemblage patterns. By examining the effects of urbanization on macroinvertebrate communities, this study will provide insights into the conservation and management of aquatic ecosystems in urbanizing landscapes.

Materials and methods

Description of the study area

The study area is the Wuye River, located in the Federal Capital Territory (FCT), Nigeria, which falls within the Savannah Zone vegetation of West Africa. The Federal Capital Territory (FCT), covering 7315 square kilometers and situated slightly west of Nigeria's geographical center, has a hot, humid tropical climate. The region experiences a distinct climate with three main seasons: a warm and humid rainy season from April to October, a blistering dry season, and a brief harmattan period characterized by dust haze and dryness, occasioned by the Northeast trade wind. The mean annual temperature ranges from 30 to 37 °C, with a total annual rainfall of 1650mm, peaking between July and September, which leads to flooding in the region. The area lies within the geographical coordinates of 9° 01′ 13° N and 7° 24′ 52E (Fig. 1), with a temperature range that fluctuates between 12 and 40 °C. Wuye District is one of the fourteen residential districts of Phase II in the Federal Capital Territory Abuja, grouped in sector B alongside Utako, Jabi, and Dakibiyu Districts. The area is easily accessible through the Nnamdi Azikiwe expressway and Jabi Road.

The river catchment area

The Wuye River flows through the northern part of the Federal Capital Territory (FCT) at Bwari, coursing westward towards Kpeyi with its length spanning over 143 km across the breadth of the FCT. A tributary of the Wuye River drains eastward at the central part of Abuja, converging with the main river. The river then traverses the length of Kuje and Gwagwalada towns, ultimately emptying into the Gurara River, which in turn flows into the River Niger (Fig. 1).

The Wuye River is a vital ecological asset supporting local communities in the Federal Capital Territory (FCT), Nigeria. Its catchment area encompasses diverse land uses, including built-up areas, irrigation farmlands, and recreational sites. The built-up areas comprise formal, informal, and mixed settlements, including residential and business districts such as Ushafa, Kubwa, Gwagwa, Tashia, Gwarimpa, Gosa, and Kuje. These areas contribute to the river's water quality and highlight the need for effective management practices. Irrigation farmlands are constantly in operation throughout the year, further impacting the river's water quality. Recreational sites along

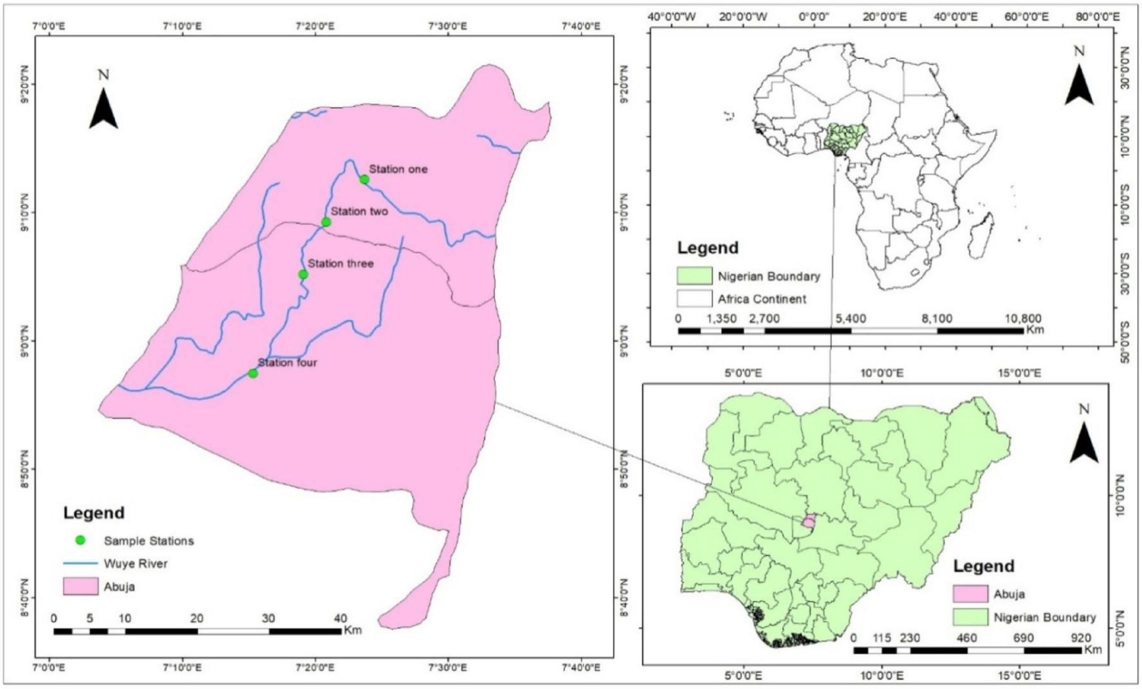

Fig. 1. Map of the study area showing the sampling stations in Wuye River. *Source*: Remote Sensing/ Geographical information system (GIS) Laboratory, Geography Department, FUTMINNA, (2023)[30].

Station	Coordinates	Elevation (m)	Altitude (m)	Land use	Riparian vegetation	Human impact
1. Ushafa (Unplanned)	9° 12′ 34.62 "N, 7° 23′ 42.35" E	526	812	Irrigation farming, minimal vegetation	Scanty, dominated by *Vossia cuspidate*, etc	Informal settlement, river use for domestic purposes
2. Kubwa (Planned)	9° 09′ 15.74" N, 7° 20′ 48.84" E	419	975	Staple crop farming, solid waste disposal	Marginal, patches along riverbank	Planned settlement, waste management issues
3. Tashia (Unplanned)	9° 05′ 11.16" N, 7° 19′ 06.35" E	373	469	Cassava fermentation, domestic use, fishing	Marginal, dominated by *Ludwigia decurrens*, etc	Unplanned development, significant solid waste dumping
4. Kiyami (Planned)	8° 57′ 27.20" N, 7° 15′ 18.10" E	297	641	Sand mining, block molding, agriculture	Marginal, dominated by *Ipomoea aquatica*, etc	Planned settlement, construction activities, bank erosion

Table 1. Characteristics of the sampling stations of Wuye River, Abuja, Nigeria.

the river are used for swimming, angling, boating, and bait-digging, underscoring the river's socio-cultural significance. The river network is situated within the Savannah Zone vegetation of West Africa, characterized by a mosaic of floristic species. The vegetation cover is influenced by the region's climate, with a warm, humid rainy season promoting lush vegetation growth and a dry harmattan season causing vegetation dormancy.

Dominant tree species in the area include *Gmelina arborea, Parkia biglobosa, Khaya senegalensis, Mangifera indica, Terminalia ivorensis, Delonix regia, Spathodea campanulata, Nauclea latifolia, Azadirachta indica, Rocinodendron heudelotii*, and *Nauclea diderrichii*. These species contribute to the region's biodiversity and ecological balance.

Sampling stations

The four sampling stations on Wuye River with their coordinates, elevation, Altitude, land use, riparian vegetation and human impact is shown in Table 1.

Sampling station 1 (Ushafa-unplanned settlement)

The sampled location features secondary vegetation, rocks, and boulders, with scanty riparian vegetation dominated by *Vossia cuspidate, Cyrtosperma senegalense, Rhynchospora corymbosa, Kylingia erecta,* and *Paspalum orbiculare*. Vegetation spreading over the water body includes *Ipomoea aquatic* and *Commelina nudiflora*. In stream species are dominated by *Eleocharisna umaniana*, with pockets of *Bacopa monieri*. The riparian zone and in stream are dominated by rocks and boulders. The closest settlement, Ushafa community, is informal and relies on the river for domestic purposes and irrigation farming. The river serves as a vital source of water for the community, highlighting the importance of effective water management practices.

Sampling station 2 (Kubwa-Planned settlement)
This location is notable for the physical evidence of solid waste disposal from the bridge and other parts of the riverbanks, including stale food, paper, plastic, and other waste materials. The river, approximately 300 m wide, meanders through Kubwa town, stretching for several kilometers. The adjacent land area surrounding the sampling location is devoid of vegetation, instead dominated by staple crop farming, including maize, tomatoes, pepper, African spinach, and pumpkin leaves. In contrast, the riparian and in stream areas are predominantly covered with boulders, rocks, and stones. However, patches of marginal vegetation can be observed along the riverbank.

Sampling station 3 (Tashia-unplanned)
This community is characterized by unplanned development, with significant amounts of solid waste dumped along the riverbanks. The selection of this station was influenced by the community's unplanned nature and its reliance on the river for various activities. At this location, the river flows through the community under overhead bridges connecting neighbouring communities. The riparian zones on both sides of the river are dominated by marginal vegetation, including *Ludwigia decurrens, Ipomoea aquatic, Hydrolea glabra,* and *Commelina nudiflora*. However, the area is also heavily impacted by human activities, with rocky stones and boulders clogged with solid waste, including polythene bags and plastics, and significant erosion caused by gullies.

Sampling station 4 (Kiyami-planned settlement)
This station is uniquely situated at the confluence of the Wupa River and Usuman River, stretching through the northern part of the FCT at the Ushafa axis and meandering through Kyami District. The sampling location is characterized by a rocky island and surrounding marginal vegetation, including *Ipomoea aquatica* and *Hydrolea glabra*. The riparian zone of the river is dominated by large boulders and stones. The closest community, Gbesa settlement, is located within a 1 km radius. The extent of scouring and bank erosion in the area indicates a lack of vegetation shading, while the presence of woody debris provides important habitat for many species.

Station 4. Urbanization meets nature: A glimpse of the sampling station, where human development and vibrant vegetation coexist.

Water sampling
Water samples were collected from four stations along the Wuye River over a period of six months. Temperature, electrical conductivity, pH, and dissolved oxygen levels were measured *in-situ* using a digital multimeter (Model-85, YSI), a portable dissolved oxygen meter (Model DO210, Extech Instruments), and a handheld HANNA Instruments device.

Additional water samples were collected in acid-washed containers and preserved in a refrigerator to prevent hydrolysis and oxidation[31]. These samples were transported to the laboratory in ice-packed cooler boxes and analyzed for nitrate, phosphate, sulphate, and turbidity within 24 h of collection[32].

Macroinvertebrate sampling, preservation and processing
Monthly kick samples of macroinvertebrates were collected over a six-month period using a D-frame net with a 250 µm mesh size. Sampling took place at the littoral portion of the river, covering an approximately 25 m stretch.

During each visit, four 3-min samples were taken to encompass various substrata (vegetation, sand, and gravel biotypes) and flow regime zones (vegetation, riffles, runs, and pools). This multi-habitat sampling approach ensured a comprehensive representation of the macroinvertebrate community. Collected samples were preserved in 70% ethanol to prevent degradation and contamination. In the laboratory, samples were washed through a 250 µm mesh sieve to remove sand and other debris. Macroinvertebrate species were then carefully picked from the substrate using forceps and a microscope. Identification of macroinvertebrate species was conducted using regional keys and pictorial guides[33], and expert assistance from macroinvertebrate taxonomists/specialists[27]. This multi-step approach ensured accurate and reliable identification of species.

Data analysis

Water quality parameters

Descriptive statistics (mean, median, range, and percentages) were performed in Excel 2019 to summarize physicochemical parameter data. Analysis of variance (ANOVA) was applied to assess spatial variation among the four sampling sites. One-way ANOVA was used since parameters were presented in sites and monthly basis, with means of four and six groups respectively[34]. Line graphs illustrated spatiotemporal variation in physicochemical parameters. Post-hoc ANOVA tests were conducted for parameters with significant differences ($p < 0.05$) to determine which months showed significant variation.

Macroinvertebrate distribution and abundance

Alpha diversity metrics (Shannon index, Equitability, Taxa richness) were computed using PAST software[35] to assess macroinvertebrate community structure. Bar graphs illustrated spatial and temporal variations in alpha diversity metrics. Pie charts showed abundance and percentages of macroinvertebrates by site, highlighting dominant taxa. Dominant orders, families, and species were illustrated using bar charts to identify key components of the macroinvertebrate community. ANOVA tested differences in alpha diversity among sites and months to identify spatiotemporal patterns.

Relationship between macroinvertebrates and physicochemical characteristics

Canonical correspondence analysis (CCA) tested correlations between dominant macroinvertebrate taxa and physicochemical parameters to identify environmental drivers of community structure. Focused principal component analysis (FPCA) investigated relationships between dominant species and physicochemical parameters[36]. FPCA revealed exact correlations between variables, providing insight into the relationships between macroinvertebrates and their environment. CCA and FPCA results were graphically illustrated to show relationships between dominant species and environmental variables, highlighting key associations and potential causal links.

Results

Spatial and temporal variations physicochemical variables of the Wuye River

The physicochemical variables of the Wuye River exhibited significant spatial and temporal variations ($p < 0.05$), highlighting the dynamic nature of the river's water quality (Table 2). pH levels fluctuated between 6.28 (Station 1) and 8.4 (Station 2), with notable differences between April (8.15) and May (7.95) and the other months. Temperature levels varied spatially, with Station 3 recording the highest temperature (29.4 °C) and Station 2 recording the lowest temperature (25.8 °C), indicating thermal gradients across the river. Turbidity levels showed significant spatial and temporal variations ($P < 0.05$), with the lowest values recorded in April (9.1–3.9 NTU) and the highest value in June (40 NTU), suggesting changes in sediment transport and water clarity. Electrical conductivity values fluctuated, with the highest values recorded at stations 1 and 3 in January (331.1 µS/cm) and May (247 µS/cm), respectively, indicating variations in ionic concentrations. Dissolved oxygen levels showed no significant variations ((P < 0.05) between January, February, and May (6.25–8.44 mg/L), and between March, April, and June (5.37–5.48 mg/L), suggesting relatively stable oxygen conditions. Nitrate levels displayed distinct patterns, with Station 4 consistently recording the highest values (11.3–13 mg/L) and Station 2 recording the lowest values (4.5–5.5 mg/L), indicating spatial differences in nutrient availability. Sulphate concentrations

Variables	January	February	March	April	May	June	Pr(> F)
pH	7.20 ± 0.10^{a}	6.99 ± 0.51^{ac}	7.09 ± 0.19^{ad}	8.15 ± 0.17^{b}	7.95 ± 0.41^{b}	7.72 ± 0.35^{ab}	0.000
Temp (°C)	27.77 ± 0.94	27.13 ± 0.13	27.41 ± 0.42	27.97 ± 1.54	28.02 ± 0.45	27.77 ± 1.02	0.705
DO (mg/l)	8.44 ± 1.90^{ab}	7.93 ± 2.05^{ab}	5.48 ± 0.51^{b}	8.22 ± 1.47^{a}	6.25 ± 0.86^{ab}	5.37 ± 0.60^{b}	0.011
Turbidity (NTU)	27.91 ± 3.27^{b}	20.41 ± 1.33^{ab}	24.85 ± 2.24^{b}	7.77 ± 2.63^{a}	22.25 ± 11.02^{ab}	21.45 ± 13.84^{ab}	0.025
EC µS/cm	234.77 ± 80.12^{ab}	215.85 ± 7.67^{a}	194.17 ± 10.93^{c}	127.25 ± 54.75^{abc}	171.50 ± 56.94^{ac}	133 ± 54.88^{bc}	0.044
Nitrates (mg/l)	160.55 ± 47.83	122.39 ± 16.37	159.75 ± 47.44	7.740 ± 2.83	515.11 ± 774.01	124.04 ± 18.67	0.355
Phosphates(mg/l)	1.63 ± 0.60^{a}	5.54 ± 3.41^{ab}	4.37 ± 5.30^{ab}	12.41 ± 9.70^{b}	0.48 ± 0.33^{a}	0.44 ± 0.24^{a}	0.018
Sulfates (mg/l)	19.50 ± 6.68	23.01 ± 4.99	24.71 ± 9.13	21.25 ± 6.07	23.00 ± 1.91	23.25 ± 3.09	0.849

Table 2. The temporal variation of the physicochemical characteristics of Wuye River, from January to June, 2021. The values that carry the same superscript is an indication that there is no significant difference ($P < 0.05$) between them (Tukey Honest Test). Physicochemical variables abbreviations: pH = Hydrogen ions, Temp = Temperature, EC = Electrical Conductivity, DO = Dissolved Oxygen.

also varied, with the highest value recorded at Station 1 in March (35.31 mg/L) and the lowest value at Station 3 in January (13.5 mg/L), with Station 4 recording high values in January, February, April, May, and June (24.5–29.5 mg/L), highlighting temporal and spatial variations in sulphate levels.

Macroinvertebrate assemblage in Wuye River

The macroinvertebrate assemblage in the Wuye River revealed a fascinating array of species. A survey conducted from January to June 2021 uncovered a total of 4947 individuals, representing 4 classes, 17 orders, 44 families, and 62 species (Table 3). The order Odonata emerged as the most diverse, with 14 species, followed closely by Coleoptera with 11 species. The family Libellulidae stood out with 5 species, showcasing the river's rich biodiversity. Spatial distribution analysis showed that Station 1 harboured the highest number of macroinvertebrates (1532 individuals), while Station 2 had the lowest (981 individuals). *Cricotopus* sp. dominated the landscape, being the most abundant species at all stations, with a range of 254 to 327 individuals. In contrast, *Melanoides tuberculatus* and *Appasus* sp. were scarce, with a range of 22 to 71 individuals. Temporal analysis revealed a dynamic pattern, with *Cricotopus* sp. exhibiting maximum abundance in most months, with a range of 59 to 313 individuals. Meanwhile, *Appasus* sp. and *Melanoides tuberculatus* remained consistently rare, with a range of 7–67 individuals.

Spatial and temporal variations in species diversity and evenness

Spatially, the Shannon and Equitability Indices values decreased from Station 1 to Station 4. The maximum values were recorded at Station 1, with a Shannon index of 3.11 and an Equitability index of 0.76. In contrast, the minimum values were recorded at Station 4, with a Shannon index of 2.75 and an Equitability index of 0.69. This suggests that Station 1 had the highest species diversity and evenness, while Station 4 had the lowest (Fig. 2).

Temporally, the Shannon and Equitability Indices values varied across the months. The maximum Shannon index value was recorded in May, with a value of 2.88. The maximum Equitability index value was recorded in February, with a value of 0.76. Conversely, the minimum values for both indices were recorded in March, with a Shannon index value of 2.57 and an Equitability index value of 0.71. This indicates that species diversity and evenness were highest in May and February, and lowest in March (Fig. 3).

Spatial and temporal variation of taxa richness

The maximum taxonomic richness of macroinvertebrates was recorded at Station 1 (58), followed by Station 4 (55), Station 3 (53), and minimum at Station 2 (50) (Fig. 4). Temporally, taxonomic richness was highest in May (52), April (49), and January (48), while the lowest values were recorded in February (35), March (37), and June (39) (Fig. 5).

Macroinvertebrate-environment relationships

A Focused Principal Component Analysis (FPCA) in R software revealed correlations between abundant macroinvertebrates and environmental variables, indicated by a red circle for significant correlations. *Bulinus globosus* was strongly positively correlated with pH (red circle), but strongly negatively correlated with Electrical Conductivity and Turbidity. *Chironomus transvalensis* and *Cricotopus* sp. were significantly influenced ($P < 0.05$) by pH (red circle) and negatively correlated with Electrical Conductivity (Fig. 6, 7 and 8). *Melanoides tuberculatus* was weakly correlated with physicochemical characteristics, except for a strong negative correlation with Electrical Conductivity. *Neritina rubricate* and *Appasus* sp. were positively influenced by pH (red circle) and strongly negatively correlated with Electrical Conductivity and Turbidity, highlighting significant relationships ($P < 0.05$) between macroinvertebrates and environmental variables in the study area.

The Canonical Correspondence Analysis (CCA) revealed that the first two axes accounted for over 90% of the variation in the dataset, with Axes 1, 2, and 3 explaining 79.41%, 15.87%, and 4.71% of the ordination, respectively. The corresponding Eigen values were 0.0597, 0.0119, and 0.0004. The CCA triplot showed that Electrical Conductivity and pH were strongly positively correlated with *Melanoides tuberculatus, Appasus* sp., *Melanoides moerchi, Neritina lubricate, Bugilies* sp., and *Bulinus globosus* in stations 1, 2, and 3, whereas sulphate, phosphate, nitrate, turbidity, dissolved oxygen, and temperature were strongly negatively correlated with *Naucoris* sp., *Velia caprai, Cricotopus* sp., and *Chironomus transvalensis* in station 4, indicating distinct macroinvertebrate community patterns across different environmental conditions (Table 4 and Fig. 9).

Discussion

The spatial and temporal variations in physicochemical parameters of the Wuye River, such as pH, temperature, turbidity, electrical conductivity, dissolved oxygen, nitrates, and sulphates, are consistent with findings from other studies[26,27,37]. These variations can be attributed to factors such as seasonal changes, precipitation, and human activities, particularly in the context of unplanned settlements in urban areas[38,39].

The urban footprint of unplanned settlements in Abuja, Nigeria, has significantly impacted the water quality of the Wuye River. The fluctuations in pH levels, for instance, may be due to changes in aquatic plant growth, decomposition, and photosynthesis, which are in turn affected by the influx of pollutants from nearby settlements[40]. Similarly, the variations in temperature and turbidity may be influenced by factors such as precipitation, and sediment transport, which are exacerbated by the lack of proper drainage systems in unplanned settlements[41]. Agricultural runoff from nearby farms introduces pesticides, herbicides, and fertilizers into the river, further exacerbating water quality issues[42].

In contrast, the planned settlement stations (2 and 4) showed relatively stable and better water quality parameters compared to the unplanned settlement stations (1 and 3). This is likely due to the presence of proper drainage systems, waste management infrastructure, and regulated human activities in planned settlements, as opposed to the lack of such infrastructure and unregulated human activities in unplanned settlements, which are often characterized by inadequate waste disposal, open defecation, and increased pollution loads[16,43,44]. For

Class	Order	Family	Taxa	Code	S1	S2	S3	S4
Bivalvia	Unionida	Unionidae	*Lampsilis* sp.	Lam			16	27
	Sphaeriida	Sphaeridae	*Sphaerium* sp.	Sph				2
Gastropoda	Caenogastropoda	Thiaridae	*Melanoides moerchi*	Mel	29	28	2	14
			Melanoides tuberculatus	Met	71	5	22	34
		Pachychilidae	*Potadoma* sp.	Poa	3			1
		Unimidae	*Unima* sp.	Uni	6	6	7	5
	Basommatophora	Planorbidae	*Planorbula* sp.	Pla	32			
		Lymnaeidae	*Radix* sp.	Rad	18			1
	Archeogastropoda	Neritidae	*Neritina rubricate*	Ner	133	89	11	48
Insect	Odonata	Aeshnidae	*Aeshna* sp.	*Aes*	5	1	8	5
		Coenagrionidae	*Coenagrion* sp.	Coe	14	9	8	1
			Pseudagrion sp.	Pse	29		1	
		Calopterygidae	*Calopteryx* sp.	*Cal*	1	13	8	8
		Platycnemididae	*Mesocnemis*	Mes	4	2	9	
			Platycnemid sp.	Plt	2	2	2	3
		Corduliidae	*Cordulex* sp.	Cor	2	6	5	6
		Gomphidae	*Genigomphus* sp.	Gen	2	15	12	16
			Lestinogomphus sp.	Les	25	1	11	6
		Libellulidae	*Nymphilla* sp.	Nym	13	8	5	2
			Zyxomma sp.	Zyx	8	2	2	3
			Brachythemus leucostica	Bra	26	18	21	9
			Bradinopyga sp.	Brl	18	13	13	12
			Urothermis sp.	Uro	3	2	5	12
	Trichoptera	Psychomyiidae	*Psychomyia* sp.	Psc			3	
		Hydropsychidae	*Mauostemum capenses*	Mau	7	3		2
			Aethaloptera maxima	Aet	7	2	3	3
		Barbarochthonidae	*Barbarochthon* sp.	Bar	9			
	Ephemeroptera	Baetidae	*Cloeon* sp.	Clo	1	2	2	3
			Bugilliesia sp.	Bug	52	37	43	14
			Baetis sp.	Bae	19	1	11	3
			Pseudocloeon	Psd	15	4	6	6
		Oligoneuriidae	*Oligoneux* sp.	Oli	3	2		3
		Caenidae	*Caenis aenum*	*Cae*	4	1	2	3
	Basommatophora	Planorbidae	*Bulinus globosus*	Bul	213	119	196	13
	Coleoptera	Elmidae	*Promerisia* sp.	Pro	6	2	4	3
		Gyrinidae	*Orectogyrus* sp.	Ore	9	9	5	4
		Dytiscidae	*Philaccolus* sp.	Phi	2	8	15	4
			Philodytes sp.	Pho	11	1	15	8
			Hyphydrus sp.	Hus	5	12	4	3
			Cybister sp.	Cyb	2	1	3	
			Coelhydrus sp.	Coh	6	5	6	3
		Hydrophilidae	*Helochares* sp.	Hel	6	6	5	1
			Hydrophiilus sp.	Hyp	7	8	5	4
		Hydraenidae	*Hydrophilia* sp.	Hyh	5	3	4	
		Noteridae	*Hydrocanthus* sp.	Hyd	5	2	5	3
	Diptera	Psychodidae	*Psychodid* sp.	Psy	1			1
		Tabanidae	*Tabanus* sp.	Tab	1			3
		Chironomidae	*Chironomus transvalensis*	Chir	171	13	163	236
			Cricotopus sp.	Cri	254	26	231	327
		Culicidae	*Culex* sp.	Cul	1	14	1	5
	Arhynchobdellida	Hirudinidae	*Hirudinea medicinalis*	Hir	6	5	6	37
	Hemiptera	Belostomatidae	*Appasus* sp.	App	87	42	36	33
		Hydrometridae	*Hydrometra* sp.	Hyo	1	6	7	11
		Gerridae	*Gerris* sp.	Ger	9	5	4	1
		Veliidae	*Velia caprai*	Vel	26	25	16	33
		Corixidae	*Micronecta* sp.	Mic	3	1	3	1
Continued								

Class	Order	Family	Taxa	Code	S1	S2	S3	S4
		Naucoridae	*Naucoris* sp.	Nau	27	17	12	85
		Nepidae	*Nepa* sp.	Nep	11	5	2	5
	Plecoptera	Perlidae	*Neoperla* sp.	Neo	1		7	1
	Lepidoptera	Noctuidae	*Polymixis* sp.	Pol	2	3	2	4
Malacostraca	Amphipoda	Crangonyctidae	*Stygobromus* sp.	Sty			1	3
	Decapoda	Potamonautidae	*Sudanonaules floweri*	Sud	3	2	2	1
Total	17	44	62	1532	981	1115	1319	

Table 3. Distribution, composition and abundance of macroinvertebrates in the four sampling stations of Wuye River, Abuja, Nigeria.

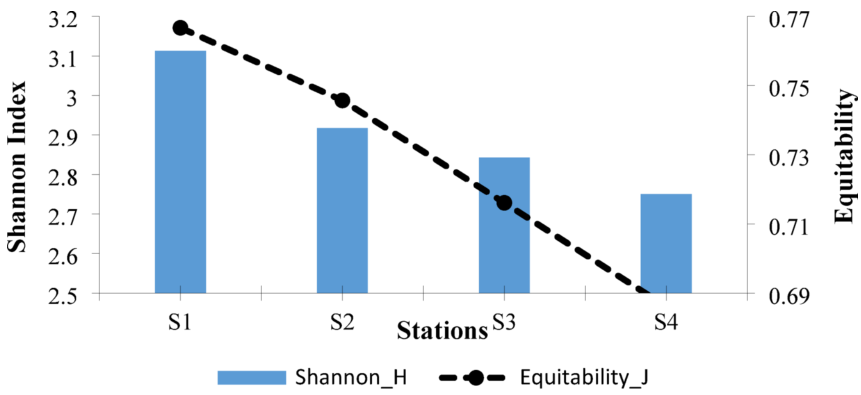

Fig. 2. Spatial Variation of Alpha Diversity Indices (Shannon, Equitability, Taxa richness) of the four Sampling Stations of Wuye River between January and June, 2021.

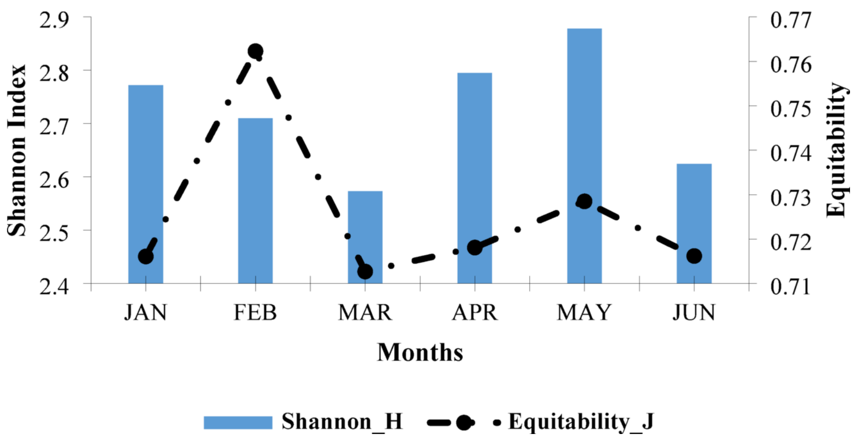

Fig. 3. Temporal Analysis of Shannon and Equitability of Sampling Station in Wuye River between January and June, 2021.

example, the nitrate levels were significantly lower ($P < 0.05$) in stations 2 and 4 compared to stations 1 and 3, indicating reduced nutrient pollution from agricultural runoff or sewage.

The concentration of sulphates in water bodies is a critical parameter in assessing water quality. Sulphates can originate from geological sources, industrial processes, agricultural activities, and wastewater disposal[45]. In planned settlements (stations 2 and 4), the variations in sulphate concentrations were less pronounced, suggesting reduced impact from geological and human activities. This can be attributed to reduce geological influence, controlled industrial activities, effective wastewater management, and limited agricultural activities[46]. For instance, a study by Teklehaimanot et al.[47] found that planned settlements with proper wastewater treatment systems had significantly lower sulphate concentrations in their water bodies. In contrast, unplanned settlements exhibited higher variations in sulphate concentrations, indicating increased geological influence, unregulated industrial activities, inadequate wastewater management, and extensive agricultural activities[45,48]. Unplanned

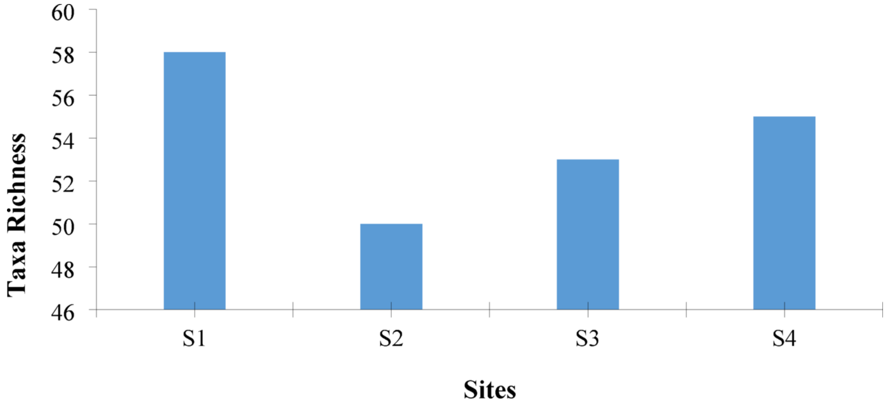

Fig. 4. Spatial Analysis of Taxa Richness in the four Sampling Stations in Wuye River between January and June, 2021.

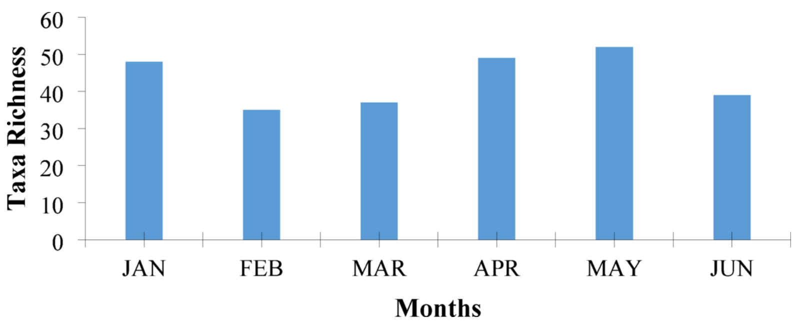

Fig. 5. Temporal Variation of Taxa Richness in the Sampling Station of Wuye River between January and June, 2021.

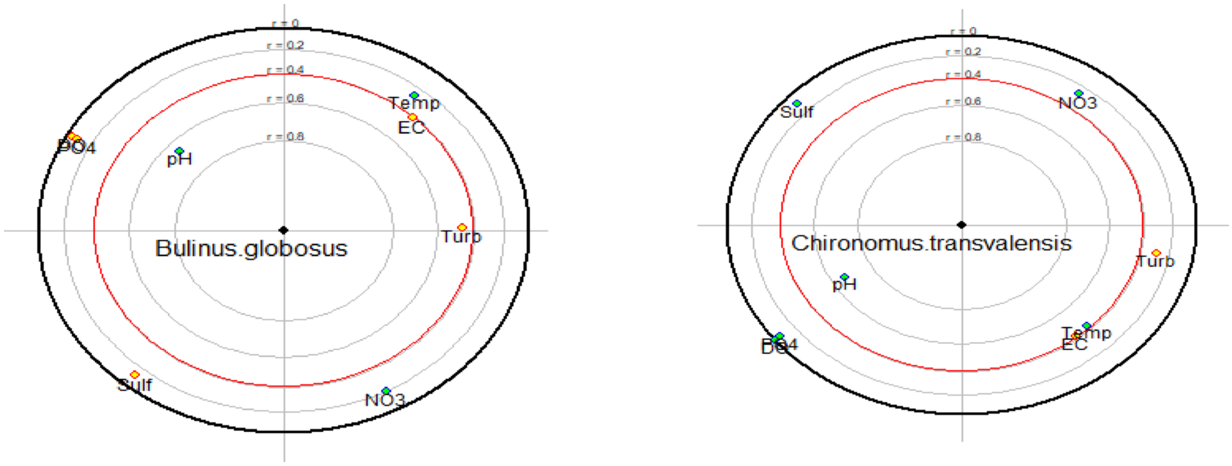

Fig. 6. Focused Principal Component Analysis (FPCA) diagram showing the correlation between *Bulinus globosus*, *Chironomus transvalensis*, *Cricotopus* sp. and *Melanoides tuberculatus* with Physicochemical variables of Wuye River.

settlements often lack proper infrastructure, leading to increased pollution loads and altered water quality parameters[49]. This knowledge will enable targeted conservation and restoration strategies in the Wuye River and comparable urban river systems by revealing how physicochemical parameters change over space and time.

The vegetation surrounding the Wuye River plays a critical role in maintaining its water quality. Vegetation absorbs and filters out pollutants, reducing their impact on water quality[50]. It also regulates runoff and sediment transport into the river, maintaining its natural sediment dynamics[40]. Furthermore, vegetation influences

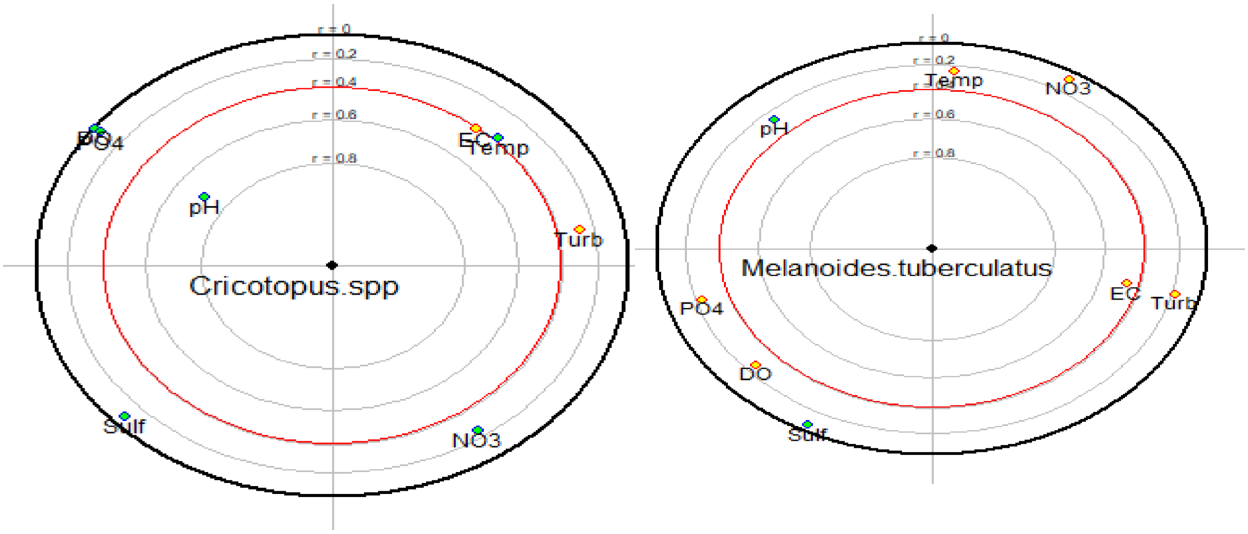

Fig. 7. Focused Principal Component Analysis (FPCA) diagram showing the correlation between *Bulinus globosus*, *Chironomus transvalensis*, *Cricotopus* sp. and *Melanoides tuberculatus* with Physicochemical variables of Wuye River.

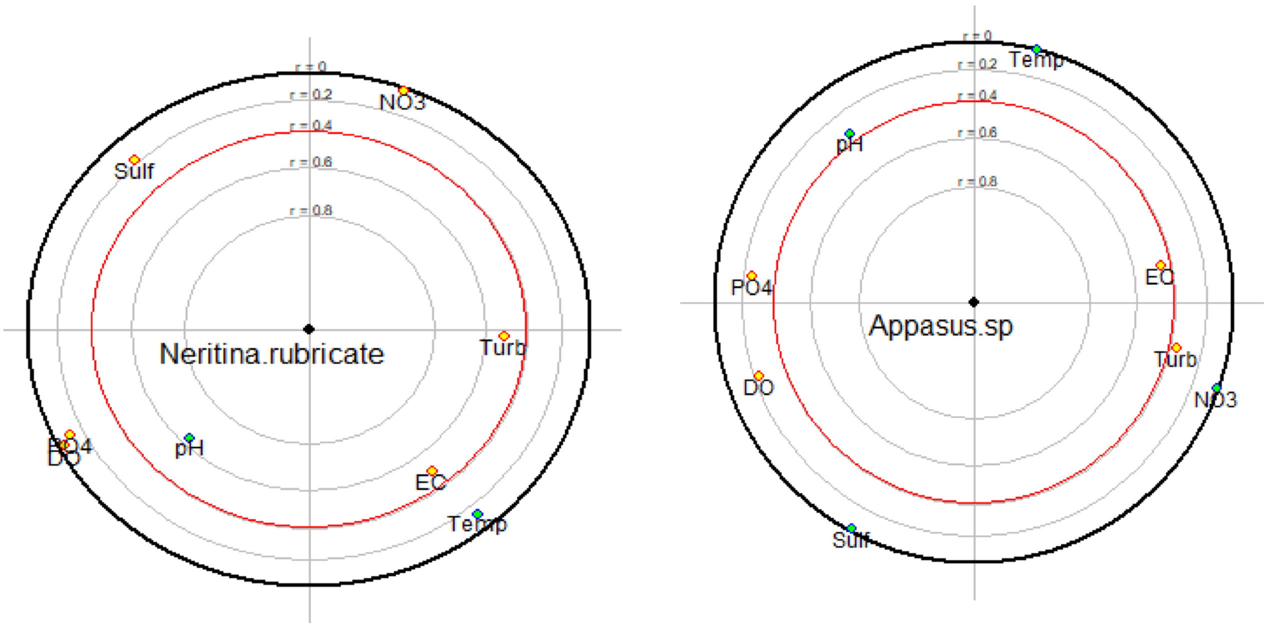

Fig. 8. Focused Principal Component Analysis (FPCA) diagram showing the Correlation between *Neritina rubricate, Appasus* sp. with Physicochemical Variables of Wuye River.

water temperature, pH, and nutrient levels, maintaining the river's natural water quality parameters[51,52]. The vegetation surrounding the Wuye River varies significantly across different stations and plays a crucial role in maintaining its water quality. Station 1 is characterized by a sparse mix of grassland and shrubland vegetation, dominated by species such as Guinea grass (*Panicum maximum*) and *Chromolaena odorata*[23]. This vegetation cover provides limited buffering against pollutants and sediment, making the river more vulnerable to water quality issues. In contrast, Station 2 is surrounded by a dense mix of parkland and garden vegetation, featuring trees like *Eucalyptus camaldulensis* and ornamental plants. This vegetation cover provides effective buffering and filtering of pollutants, contributing to the relatively stable water quality parameters at this station[53,54]. Station 3 is surrounded by a mix of farmland and woodland vegetation, with crops like maize (*Zea mays*) and trees like *Vitex madiensis*. The farmland vegetation introduces agricultural runoff and sediment into the river, while the woodland vegetation provides some buffering and filtering of pollutants[42]. Station 4 is surrounded by a dense mix of riparian and woodland vegetation, featuring trees like *Terminalia catappa* and riparian plants like *Cyperus*

Variables	Axis 1	Axis 2	Axis 3
Eigen values	0.0597	0.011934	0.003542
% Explained	79.41	15.87	4.712
pH	0.440505	0.230522	− 0.911451
Temperature (°C)	− 0.18766	− 0.69409	0.764763
Dissolved Oxygen (mg/L)	− 0.5024	− 0.18969	− 0.782368
Turbidity (NTU)	− 0.64382	− 0.12696	− 0.690181
Conductivity (μS/cm)	0.471934	− 0.53303	0.723303
Nitrates (mg/L)	− 0.9786	0.129107	0.230212
Phosphates (mg/L)	− 0.89301	0.320706	0.364205
Sulfates (mg/L)	− 0.87122	0.504891	0.061971

Table 4. Weighted Intraset correlations of environmental variables with the first three axes of canonical correspondence analysis (CCA) in Wuye River.

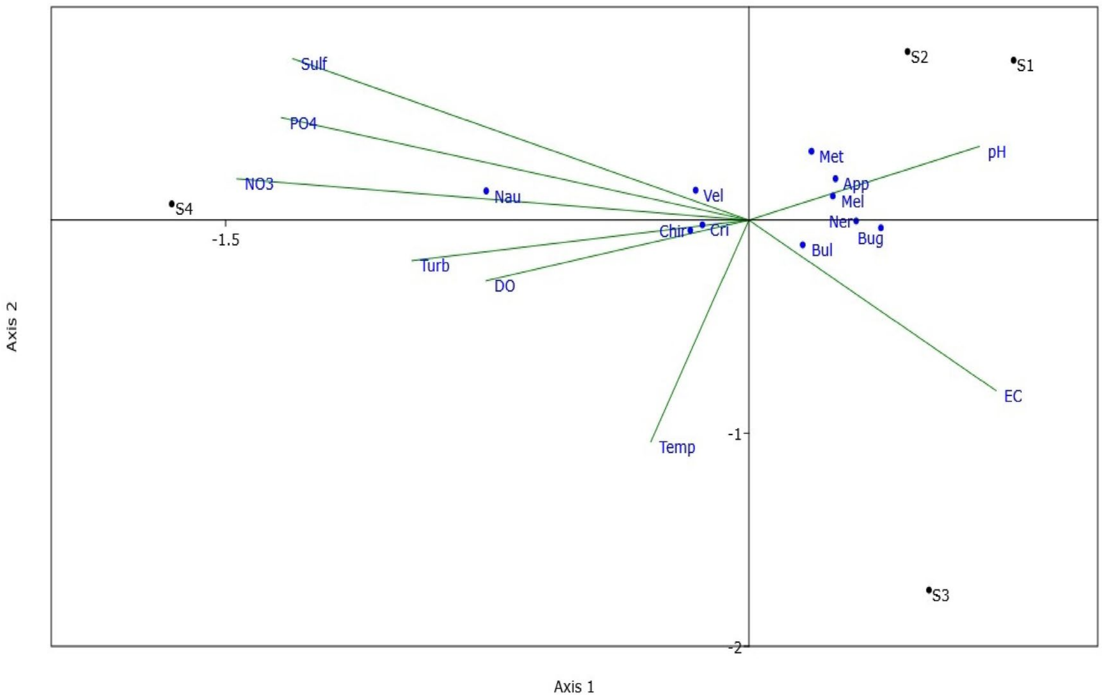

Fig. 9. The Triplot of the Canonical Correspondence Analysis (CCA) Axes of Macroinvertebrate Taxa, Environmental Variables and the Sampling Stations of Wuye River.

papyrus. This vegetation cover provides effective buffering and filtering of pollutants, maintaining the river's natural sediment dynamics and water quality[55,56].

Urbanization-induced variations in macroinvertebrate communities across four stations in the Wuye River, Abuja, Nigeria

The comprehensive survey of macroinvertebrates conducted revealed a diverse assemblage of species. The distribution of macroinvertebrates varied significantly ($P < 0.05$) across the four stations, each with unique environmental characteristics shaped by urbanization. Station 1 (Ushafa-Unplanned) exhibited a remarkably diverse and evenly distributed macroinvertebrate community, characterized by a Shannon index of 3.11 and Equitability index of 0.76. The numerical dominance of *Cricotopus* sp., with a population range of 254–327 individuals, is consistent with recent research on urban freshwater ecosystems[57]. The riparian zone's marginal vegetation, comprising *Vossia cuspidate* and *Cyrtosperma senegalense*, alongside secondary vegetation, rocks, and boulders, created a heterogeneous habitat that supported a wide range of macroinvertebrate taxa[58]. However, the scarcity of *Melanoides tuberculatus* and *Appasus* sp. suggests their intolerance to environmental perturbations[23]. The ubiquity of *Cricotopus* sp. across various environmental conditions underscores its adaptability and ecological plasticity[59], making it a key species in this urban freshwater ecosystem. In contrast, Station 2 (Kubwa-Planned), situated near an industrial area, exhibited significantly ($P < 0.05$) reduced species diversity and evenness, with a Shannon index of 2.75 and an Equitability index of 0.69. This diminished biodiversity is likely attributable to anthropogenic stressors, including pollution and habitat degradation[60]. The station's surroundings were characterized by overt signs of solid waste disposal and scant vegetation cover, with intensive staple crop farming predominating in the adjacent land area. This environmental context suggests a high level of habitat modification and disturbance, leading to a decline in macroinvertebrate community integrity and resilience[61]. Station 3 (Tashia-Unplanned), situated in proximity to a bustling market area, exhibited a distinctive species assemblage, marked by an exceptionally high abundance of Libellulidae (5 species). This phenomenon suggests a potential adaptation to organic pollution, as Libellulidae are known to thrive in environments with high levels of nutrient enrichment[62]. The station's surroundings were characterized by marginal vegetation, including *Ludwigia decurrens* and *Ipomoea aquatica*, which are often indicative of disturbed or altered ecosystems[58]. Furthermore, significant solid waste dumping and erosion were observed, leading to habitat degradation and increased sedimentation. This environmental context likely favours the dominance of tolerant species, such as Libellulidae, which can exploit the available resources and adapt to the prevailing conditions[63]. Station 4 (Kiyami-Planned), located in close proximity to a residential area, exhibited the lowest macroinvertebrate abundance, with a limited range of 22–71 individuals. This paucity of macroinvertebrates may be attributed to habitat modification and fragmentation, which can lead to population isolation and reduced species richness[64]. The station's environment was characterized by rocky islands and surrounding marginal vegetation, including *Ipomoea aquatica* and *Hydrolea glabra*, which are often indicative of disturbed or altered ecosystems[58]. Furthermore, the presence of sand mining, block molding, and construction activities in the vicinity likely contributed to habitat degradation, increased sedimentation, and reduced water quality[23]. These anthropogenic stressors can have detrimental effects on macroinvertebrate communities, leading to reduced abundance and diversity[57].

Macroinvertebrate-environment relationships in Wuye River: a multivariate analysis

The FPCA and CCA analyses reveal significant relationships ($P < 0.05$) between macroinvertebrates and environmental variables in the study area[65,66]. These findings have important implications for ecological studies and conservation efforts. Macroinvertebrates exhibit distinct community patterns across different habitats, indicating sensitivity to changes in water quality, habitat structure, and other ecological factors[67]. Species-specific responses to these factors are also evident, with unique correlations between species and variables such as nutrient levels, substrate type, and flow regime[19].

Environmental gradients, such as water chemistry and physical characteristics, shape macroinvertebrate community composition[68]. Certain macroinvertebrates exhibit strong correlations with specific environmental variables, suggesting adaptation to distinct habitats. For instance, *Bulinus globosus* is well-suited to alkaline environments with high pH levels[69], whereas *Chironomus* sp. demonstrates remarkable tolerance to diverse water chemistry conditions[70]. The triplot analysis reveals (Fig. 9) that environmental gradient, including electrical conductivity, pH, and nutrient levels, influence macroinvertebrate community patterns[24,27,60,67]. Certain species can serve as indicators of environmental conditions, such as *Melanoides tuberculatus* and *Appasus* sp. for high electrical conductivity and pH levels, and *Naucoris* sp. and *Velia caprai* for high nutrient levels and low dissolved oxygen[71]. These insights can inform conservation and management strategies, enabling effective identification of suitable habitats and monitoring of environmental shifts that may affect macroinvertebrate communities[72].

Implications of urbanization on Wuye River ecosystems

The results of this study highlight the significant impact of urbanization on the macroinvertebrate communities in tropical rivers. The observed declines in species richness and abundance, as well as changes in community composition, are consistent with previous studies on the effects of urbanization on freshwater ecosystems[4,16,73].

Comparisons with case studies from other regions suggest that the impact of urbanization on river health can vary significantly depending on factors such as land use patterns, population density, and environmental policies. For example, a study on urban streams in the United States found that impervious surface cover was a major driver of changes in macroinvertebrate communities[14], whereas in our study, the dominant factor was the alteration of flow regimes.

The long-term trends of urbanization's impact on river health are a concern, as continued urban expansion is likely to exacerbate the observed declines in biodiversity and ecosystem function. However, restoration strategies such as the creation of artificial wetlands, re-vegetation of riparian zones, and implementation of best management practices for stormwater runoff can help mitigate these impacts[74,75].

In the context of tropical regions, where urbanization is often rapid and unplanned, it is essential to develop effective strategies for managing urban river ecosystems. This may involve integrating green infrastructure into urban planning, promoting community engagement and education, and developing policies that prioritize environmental protection[76].

Conclusion

This study examined the effects of unplanned urban settlements on macroinvertebrate communities in the Wuye River, Abuja, Nigeria. The results revealed a significant relationship between macroinvertebrates and environmental variables, highlighting their sensitivity to changes in their environment, particularly water quality. The study found that urbanization has significantly impacted the Wuye River, leading to increased levels of pollutants, altered water chemistry, and changed physical characteristics. These changes have, in turn, affected the composition of macroinvertebrate communities.

Furthermore, the study emphasized the importance of vegetation cover and type in shaping macroinvertebrate communities. Different vegetation types were found to support different macroinvertebrate communities, underscoring the need to preserve and restore vegetation cover along the Wuye River. The study's findings have important implications for urban planning in Abuja. To mitigate the negative impacts of urbanization on macroinvertebrate communities, urban planning should prioritize the protection and restoration of natural habitats, preservation of water quality, and consideration of urbanization's impact on aquatic ecosystems. This can be achieved through the implementation of sustainable urban planning practices, such as green infrastructure, buffer zones, and wastewater management systems.

Data availability

The datasets used during the current study will be made available from the corresponding author on reasonable request.

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Declarations

Competing interest
The authors declare no competing interests.

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