International Journal of Zoology Studies
www.zoologyjournals.com
ISSN: 2455-7269
Received: 03-10-2025, Accepted: 02-11-2025, Published: 17-11-2025
Volume 10, Issue 4, 2025, Page No. 53-62

Assessment of the impact of water quality parameters on macroinvertebrates in Owena River, South Western Nigeria

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Abstract
This study investigated the macroinvertebrate community structure and physico-chemical parameters of Owena River, Ondo State with the aim of providing information on the water quality and macroinvertebrate community of the river. Sampling of water and macroinvertebrates was carried out four times (twice each season) between December, 2022 and September, 2023. Water samples were collected in 1L sterilized bottles and some physico-chemical parameters such as; temperature, pH, total dissolved solids (TDS), dissolved oxygen (DO) and electrical conductivity (EC) were determined on site using a Multi 3630 IDS digital meter. Macroinvertebrates were collected using a long-handled D-frame net and hand-picking method. The collected specimens were preserved in 70% ethanol and later identified to the lowest taxonomic level using appropriate taxonomic keys and guides. ANOVA and paired T-tests were conducted to assess the spatio-temporal variations in the distribution of the macroinvertebrates and physico-chemical parameters of the water. Canonical Correspondence Analysis (CCA) was used to establish the relationships between the macroinvertebrates and physico-chemical parameters. A total of 1,243 specimens distributed in 3 classes and 52 genera were recorded. The Odonates were dominant while *Pseudagrion hamoni* was the most abundant species. Most of the parameters did not show significant difference ($P > 0.05$) in the spatio-temporal variations. The low number of the sensitive insect species, the dominance of pollution tolerant species coupled with relatively low level of dissolved oxygen and high BOD suggests the presence of mild pollution in Owena River.

Keywords: Macroinvertebrates, Owena River, diversity, pollution, water quality

Introduction

Healthy freshwater environments are essential for providing water for drinking, agriculture, manufacturing, energy, and transport (Bashir *et al*., 2020). These ecosystems also offer habitats to a diverse array of aquatic species (Yie *et al*., 2022) [47]. In fact, tropical inland water bodies are regarded as important resources for the preservation and protection of ecological diversity worldwide (Shyam, 2023). However, these waterbodies face considerable vulnerability due to increasing human activities that disrupt their ecosystem integrity and functioning. Both human-driven actions and natural forces pose significant threats to the biodiversity of inland waterbodies, emerging as a pressing global concern in today's era (Singh *et al*., 2020) [44]. In Nigeria, the situation is particularly aggravated by high levels of pollution resulting from various human activities, which have further led to the destruction or degradation of aquatic ecosystems by various exotic species.

Owena River is one of the largest and most important waterbodies in Southwestern Nigeria. Apart from being the major source of potable water, the river also provides fishery resources and auxiliary functions to the inhabitants of the surrounding communities. The importance of the river informed the decision of the Federal Government to construct a dam sited approximately 14 km upstream from the old Owena water scheme through the Benin-Owena River Basin Development Authority for the provision of potable water, water for irrigation, fisheries, as well as hydro-electric power supply (Adeleke *et al*, 2024) [4]. However, in recent years, this river has been subjected to diverse anthropogenic disturbances that could potentially affect its water quality, including runoff from surrounding farmlands, washing of clothes, open defecation, direct deposition of domestic wastes, and fishing activities.

Macroinvertebrates constitute an integral part of aquatic ecosystems and have both economic and ecological values. They serve as model organisms for studying the structure and operations of freshwater ecosystems due to their plentiful numbers, prolific reproduction, quick generational turnover, substantial biomass, and swift colonization of freshwater environments (Adeleke *et al*, 2024) [4]. These insects are known to be several times more numerous and diverse than other animals that co-exist with them in the aquatic environment, such as fish, amphibians, and crustaceans. The presence of aquatic insects in waterbodies also serves as a food source for fishes and other aquatic invertebrates, while some aquatic insects take part in nutrient recycling in the aquatic ecosystem (Chae *et al*., 2000).

The distribution of aquatic organisms is mainly influenced by biotic and physico-chemical changes in the quality of water. Although there is a degree of variability in the level of sensitivity of macroinvertebrates to changes in water quality, moderately tolerant species can reside in waters with mild pollution, while highly sensitive aquatic insect species will only reside in waters with good quality. This variation in their level of sensitivity to pollution has made them useful agents in the monitoring of environmental quality, implying that the community structure of aquatic insects accurately represents the environmental state of the aquatic environment in which they live. For instance, the presence of dragonfly, damselfly, and dobsonfly nymphs in aquatic environments could suggest mild pollution, whereas the occurrence of midge larvae, water boatmen, and backswimmers, which are pollution-tolerant species might indicate strong pollution in the aquatic environment. The combination of bio-monitoring and physico-chemical analysis of water parameters has been adjudged to be more accurate and reliable in the assessment of water quality. This method has been widely used successfully in developed countries but is yet to be fully exploited in water quality assessment protocols in Nigeria (Arimoro & Muller, 2010). The significance of Owena River and the various anthropogenic disturbances around it necessitate an investigation into its water quality using this integrated approach. This study seeks to use a combination of bio-indicators and physico-chemical parameters in the assessment of the water quality of Owena River. This comprehensive assessment protocol is expected to provide a more reliable and precise evaluation of the river's ecological status.

Materials and Methods

Study Area

The study was conducted in Owena River, located within the Idanre/Owena Local Government Area of Ondo State, Southwestern Nigeria. The area spans latitudes 7°17′N to 8°15′N and longitudes 5°01′E to 5°45′E, with an elevation of 249 m above mean sea level. Owena River is a perennial, free-flowing waterbody characterized by a rocky substratum and abundant detrital material (Olawusi-Peters, 2019) [37]. The river averages 40 m in width and 9 m in mean depth. The surrounding vegetation is typical of a tropical rainforest zone, featuring tall trees with dense canopies along the riparian areas. The climate is tropical, with distinct wet (April–October) and dry (November–March) seasons, exhibiting slight annual variations. Annual rainfall ranges from 1150 to 1780 mm, relative humidity averages 87.5% in the dry season and 92.6% in the wet season, and ambient temperatures range from 20°C to 30°C (mean: 27°C) (Komolafe and Arawomo, 2008).

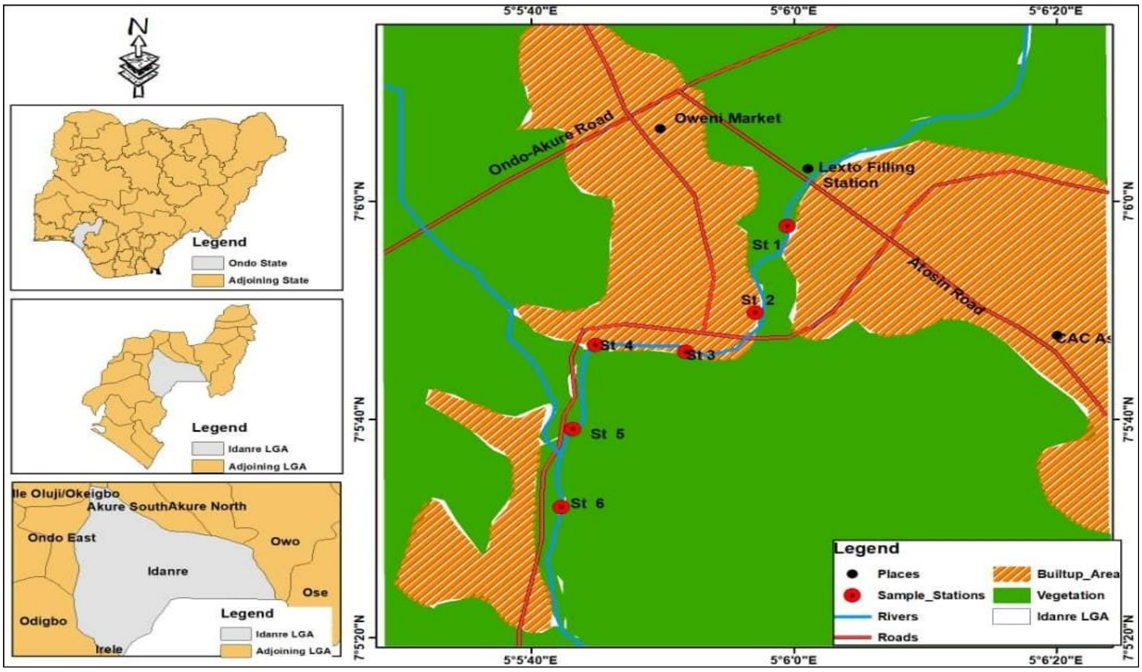

Fig 1: Map of the study area showing the location of the six sampling stations (St1-St6) on Owena River, Southwestern Nigeria

Six sampling stations were selected along the river to encompass diverse microhabitats and reaches. Sampling was performed quarterly over a period spanning December 2022 to September 2023, with four collections each during the wet and dry seasons which occurred between 0800 and 1100 GMT at each station. Aquatic insects were collected using long-handled D-frame nets and direct searching methods as appropriate. Collected specimens were transferred to a white tray for sorting, where they were separated from debris and other particles using forceps. Sorted insects from each station were preserved in labeled bottles containing 70% ethanol. Identification to the lowest feasible taxonomic level was achieved through macroscopic and microscopic examination using a VZE/VZF series trinocular zoom stereo microscope, supplemented by taxonomic keys and guides (Suhling *et al*., 2014).

Water samples were collected by submerging 1-L plastic bottles with the mouth oriented against the flow just below the surface (APHA, 2012) [1]. Samples were labeled in the field with station numbers and collection dates. In situ measurements included pH, temperature, and electrical conductivity (EC) using Electrical conductivity on site using a Multi 3630 IDS. Transparency, elevation, and water depth were also assessed on-site using standard protocols. Laboratory analyses for dissolved oxygen (DO), total dissolved solids (TDS), nitrate, phosphate, sulphate, alkalinity, magnesium, calcium, biological oxygen demand (BOD), and water hardness were conducted following established standard methods.

Data Analysis

Data were analyzed using descriptive and inferential statistics. Variations in aquatic insect abundance and physico-chemical parameters across stations were evaluated with one-way analysis of variance (ANOVA) and T-Test at a significance level of $p < 0.05$, followed by Tukey's post hoc test for mean separation, using SPSS version 22.0. Diversity of aquatic insects was quantified using Shannon-Wiener (H′), Simpson (1-D), and Margalef indices, computed with PAST version 4.0 software. Canonical correspondence analysis (CCA) was employed to examine relationships between physico-chemical parameters and macroinvertebrate assemblages in Owena River.

Results

Taxonomic Composition and Abundance of Macroinvertebrates

A total of 1,243 specimens of macroinvertebrates distributed in Two (2) phyla, four (4) classes, ten (10) orders, twenty-seven (27) families and Fifty-eight (58) genera were recorded in Owena River during this study. Arthropoda was the dominant phylum as it accounted for Three (3) Classes and Seven (7) Orders, Twenty-four (24) families and Fifty-two (52) genera. Mollusca accounted for One class, Three (3) orders, Three (3) families and Six (6) genera. The Insecta class is the most diverse Class as it was represented by Five (5) orders, twenty-one (21) families and Forty-nine (49) genera while Malacostraca was the least diverse class represented by One (1) order, One (1) family and One (1) individual (Table 1).

Table 1: Taxonomic composition of macroinvertebrates recorded in Owena River, Southwestern Nigeria

Phylum	Class	Order	Families	Genus/species
Arthropoda	Arachnida	Araneae	Pisauridae	*Dolomedes* sp. *Thalassius sp.*
			Tetragnathidae	*Tetragnatha* sp.
	Insecta	Coleoptera	Gyrinidae	*Orectogyrus* sp.
				Orectogyrus sp. B.
		Ephemeroptera	Heptageniidae	*Afronurus* sp.
				Notonurus sp.
			Leptophlebiidae	*Adenophlebiodes* sp
			Oligoneuriidae	*Elassoneuria candida*
			Tricorythidae	*Tricorythus* sp.
		Hemiptera	Belostomatidae	*Sphaerodema* sp.
				Limnogeton sp.
			Gerridae	*Eurymetra* sp.
				Limnogonus sp.
			Hebridae	*Hebrus* sp.
			Hydrometridae	*Hydrometra* sp.
			Naucoridae	*Laccocoris* sp.
				Neomacrocoris sp.
			Nepidae	*Laccotrephes* sp.
				Ranatra sp.
			Notonectidae	*Erithares* sp.
			Veliidae	*Rhagovelia* sp.
		Odonata	Calopterygidae	*Phaon iridipennis*
			Chlorocyphidae	*Chlorocypha curta*
				Chlorocypha pyriformosa
			Coenagrionidae	*Agriocnemis maclachlani*
				Agriocnemis sp. B
				Ceriagrion sp.
				Elattoneura sp.
				Pseudagrion glaucum
				Pseudagrion hamoni
				Pseudagrion melanicterum
			Gomphidae	*Lestinogomphus* sp. *Paragomphus sp.*
			Libellulidae	*Atoconeura* sp.
				Brachythemis leucosticte
				Crocothemis erythrae
				Neodythemis sp.
				Olpogastra lugubris
				Orthetrum chrysostigma
				Orthetrum Julia
				Palpopleura lucia
				Palpopleura Portia
				Trithemis annulata
				Trithemis arteriosa
				Urothemis assignata
				Zygonoides sp.
			Macromiidae Platycnemididae	*Zygonyx natalensis Phyllomacromia sp. Mesocnemis singularis*
	Malacostraca	Plecoptera Decapoda	Perlidae Potamonautidae	*Neoperla* spio *Sudanonautes aubryi*
Mullusca	Gastropoda	Architaenioglossa Lymnaeida Sorbeoconcha	Ampullaridae Planorbidae Thiaridae	*Lanistes varicus Biomphalaria sp. Bulinus sp. Helisoma sp. Lymnaea sp Melanoides tuberculata*

The spatial distribution of the macroinvertebrates across the sampling stations is as presented in Table 2.

Table 2: Spatial distribution of macroinvertebrates in the Sampling Stations in Owena River, Southwestern Nigeria

Order	Genus/Species	St 1	St2	St3	St4	St6	St6	Total
Araneae	*Dolomedes* sp.	3	0	2	2	7	1	15
	Thalassius sp.	2	8	0	0	6	6	22
	Tetragnatha sp.	0	0	0	0	0	5	5
Architaenioglossa	*Lanistes varicus*	0	0	0	0	6	2	8
Coleoptera	*Orectogyrus* sp.	128	5	0	0	5	0	138
	Orectogyrus sp. B	0	0	2	0	9	0	11
Decapoda	*Sudanonautes aubryi*	0	0	2	0	0	0	2
Ephemeroptera	*Afronurus* sp.	2	0	0	1	0	0	3
	Notonurus sp.	1	1	0	2	0	1	5
	Adenophlebiodes sp.	2	0	0	1	0	0	3
	Elassoneuria candida	2	1	0	0	0	0	3
	Tricorythus sp.	0	0	0	1	0	0	1
Hemiptera	Sphaerodema sp.	10	6	15	3	10	5	49
	Limnogeton sp.	0	0	0	1	1	0	2
	Eurymetra sp.	1	0	0	0	0	0	1
	Limnogonus sp.	1	0	0	3	0	0	4
	Hebrus sp.	0	0	0	0	1	0	1
	Hydrometra sp.	1	1	0	3	0	3	8
	Laccocoris sp.	2	7	4	0	0	1	14
	Neomacrocoris sp.	6	0	0	0	0	0	6
	Laccotrephes sp.	0	0	1	0	0	0	1
	Ranatra sp.	6	7	8	2	2	1	26
	Erithares sp.	0	1	1	1	2	0	5
	Rhagovelia sp.	7	0	0	0	0	2	9
Lymnaeida	*Biomphalaria* sp.	0	1	0	0	0	0	1
	Bulinus sp.	0	0	0	6	0	2	8
	Helisoma sp.	0	7	0	0	0	8	15
	Lymnaea sp.	0	0	0	0	6	0	6
Odonata	*Phaon iridipennis*	0	0	7	1	1	1	10
	Chlorocypha curta	1	0	4	1	0	2	8
	Chlorocypha pyriformosa	4	1	9	4	4	5	27
	Agriocnemis maclachlani	0	0	2	6	2	1	11
	Agriocnemis sp. B	0	0	0	1	2	0	3
	Ceriagrion sp.	0	0	0	4	0	0	4
	Elattoneura sp.	0	0	0	1	3	0	4
	Pseudagrion glaucum	8	11	10	7	6	5	47
	Pseudagrion hamoni	48	62	52	34	21	23	240
	Pseudagrion melanicterum	6	20	13	4	13	7	63
	Mesocnemis singularis	11	15	9	9	8	19	71
	Lestinogomphus sp.	0	0	1	0	0	0	1
	Paragomphus sp.	0	1	0	0	0	0	1
	Phyllomacromia sp.	1	0	0	0	1	1	3
	Atoconeura sp.	0	0	1	0	0	0	1
	Brachythemis leucosticte	0	0	0	0	21	0	21
	Crocothemis erythrae	0	1	0	0	1	3	5
	Neodythemis sp.	0	0	0	1	0	0	1
	Olpogastra lugubris	7	5	1	0	0	1	14
	Orthetrum chrysostigma	3	5	0	4	4	0	16
	Orthetrum Julia	1	0	0	0	0	0	1
	Palpopleura lucia	0	0	0	0	1	0	1
	Palpopleura Portia	0	0	0	0	1	0	1
	Trithemis annulate	0	3	2	0	1	0	6
	Trithemis arteriosa	4	12	4	16	10	3	49
	Urothemis assignata	0	0	0	0	10	3	13
	Zygonoides sp.	0	4	0	0	0	1	5
	Zygonyx natalensis	1	1	2	0	0	0	4
Plecoptera	*Neoperla spio*	6	13	1	0	0	0	20
Sorbeoconcha	*Melanoides tuberculata*	49	55	27	18	29	42	220
	Total	324	254	180	137	194	154	1243
	Total Percentage	26.06	20.43	14.48	11.02	15.60	12.38	100
	Number of Taxa	29	26	24	27	30	27	28

Station 1 had the highest abundance of macroinvertebrates as it accounted for 324 specimens (26.06%) while Station 2 followed closely with 254 specimens (20.43%). The least abundance of macroinvertebrates was recorded in Station 4 which accounted for 137 specimens (11.02%).

Temporally, the highest number of the specimens were recorded in March, 2023 with a total of 448 macroinvertebrate individuals while the lowest count was in September, 2023 in which 234 individuals were recorded. The following taxa; *Melanoides tuberculata*, *Notonurus* sp., Sp*haerodema* sp., *Laccocoris* sp., *Ranatra* sp., *Phaon iridipennis, Chlorocypha curta*, *Pseudagrion glaucum, Pseudagrion hamoni*, *Mesocnemis singularis*, *Orthetrum chrysostigma* and *Trithemis arteriosa* were recorded throughout the duration of the study. *Melanoides tuberculata* was the most abundant in December, 2022 with 69 specimens while *Orectogyrus sp* dominated the collections in March, 2023 with 89 specimens. June and September, 2023 were dominated by *Pseudagrion hamoni* with 55 and 92 specimens respectively. Three specimens *Melanoides tuberculata, Orectogyrus* sp.and *Pseudagrion hamoni* were recorded in disproportionally large numbers across the sampling periods in this study. The highest abundance of *Melanoides tuberculata* (69) and *Pseudagrion glaucum* (29) were observed in December, 2022 while lowest number was recorded in June, 2023. The highest number of *Pseudagrion hamoni* (92) was recorded in September, 2023 while the lowest number (29) was recorded in December, 2022. However, the maximum number of *Orectogyrus* sp. was recorded in March, 2023 but none was recorded in September, 2023. The highest number of *Mesocnemis singularis* was recorded in March, 2023 while the lowest number was recorded in December, 2022. Similarly, the highest number of *Laccocoris* sp.was recorded in December, 2022 while the lowest number was recorded in March, 2023. Equally high abundance of *Ranatra* sp and *Agriocnemis maclachlani* were recorded in December, 2022 while low abundance was observed in March, 2023. Notably, twelve species (*Melanoides tuberculata, Notonurus* sp., *Sphaerodema* sp., *Laccocoris* sp., *Ranatra* sp., *Phaoniridipenis*, *Chlorocypha curta*, *Pseudagrion glaucum*, *Pseudagrion hamoni*, *Mesocnemis singularis*, *Orthetrum chrysostigma* and *Trithemis arteriosa*) were consistently recorded for all the sampling periods. However, twenty-two species (*Biomphalaria* sp., *Lymnaea* sp., *Sudanonautes aubryi*, *Dolomedes* sp., *Tetragnatha* sp., *Afronurus* sp., *Adenophlebiodes* sp., *Tricorythus* sp., *Limnogeton* sp., *Eurymetra* sp., *Hebrus* sp., *Hydrometra* sp., *Laccotrephes* sp., *Ceriagrion* sp., *Lestinogomphus* sp., *Paragomphus* sp., *Atoconeura* sp., *Crocothemis erythraea*, *Neodythemis* sp., *Orthetrum julia*, *Palpopleura lucia* and *Palpopleura portia*) were recorded once in the entire sampling period (Table 3).

Macroinvertebrates were more abundant in the dry season with a total of 753 specimens as against 490 specimens recorded in the wet season. Eight (8) species (*Biomphalaria* sp., *Lymnaea* sp. *Dolomedes* sp., *Tetragnatha* sp., *Limnogeton* sp., *Eurymetra* sp., *Paragomphus* sp. and *Brachythemis leucosticta*) were recorded only in the wet season while twenty one (21) species (*Sudanonautes aubryi* , *Afronurus* sp., *Adenophlebiodes* sp., *Elassoneuria candida*, *Tricorythus* sp., *Hebrus* sp., *Hydrometra* sp., *Neomacrocoris* sp., *Laccotrephes* sp., *Erithares* sp., *Rhagovelia* sp., *Ceriagrion* sp., *Lestinogomphus* sp., *Phyllomacromia* sp., *Atoconeura* sp., *Crocothemis erythraea*, *Neodythemis* sp., *Orthetrum julia*, *Palpopleura lucia*, *Palpopleura portia* and *Neoperla spio* were recorded only in dry season. Twenty-nine (29) species (*Lanistes varicus*, *Bulinus* sp., *Helisoma* sp., *Melanoides tuberculata*, *Thalassius* sp., *Orectogyrus* sp., *Orectogyrus* sp. B, *Notonurus* sp., *Sphaerodema* sp., *Limnogonus* sp., *Laccocoris* sp., *Ranatra* sp., *Phaon iridipennis*, *Chlorocypha curta*, *Chlorocypha pyriformosa*, *Agriocnemis maclachlani*, *Agriocnemis* sp. B, *Elattoneura* sp., *Pseudagrion glaucum*, *Pseudagrion hamoni*, *Pseudagrion melanicterum*, *Mesocnemis singularis*, *Olpogastra lugubris*, *Orthetrum chrysostigma*, *Trithemis annulata*, *Trithemis arteriosa*, *Urothemis assignata*, *Zygonoides* sp. and *Zygonyx natalensis*) were recorded in both the wet and dry seasons.

Table 3: Temporal distribution of macroinvertebrates in Owena River, Southwestern Nigeria

Order	Genus/Species	December 2022	March 2023	June 2023	September 2023	Total
Araneae	*Dolomedes* sp.	0	0	0	15	15
	Thalassius sp.	14	6	2	0	22
	Tetragnatha sp.	0	0	5	0	5
Architaenioglossa	*Lanistes varicus*	4	2	2	0	8
Coleoptera	*Orectogyrus* sp.	26	89	23	0	138
	Orectogyrus sp. B	9	0	0	2	11
Decapoda	*Sudanonautes aubryi*	0	2	0	0	2
Ephemeroptera	*Afronurus* sp.	3	0	0	0	3
	Notonurus sp.	1	1	1	2	5
	Adenophlebiodes sp.	3	0	0	0	3
	Elassoneuria candida	1	2	0	0	3
	Tricorythus sp.	1	0	0	0	1
Hemiptera	Sp*haerodema* sp.	25	19	3	2	49
	Limnogeton sp.	0	0	0	2	2
	Eurymetra sp.	0	0	0	1	1
	Limnogonus sp.	1	1	0	2	4
	Hebrus sp.	1	0	0	0	1
	Hydrometra sp.	8	0	0	0	8
	Laccocoris sp.	4	3	4	3	14
	Neomacrocoris sp.	5	1	0	0	6
	Laccotrephes sp.	1	0	0	0	1
	Ranatra sp.	14	3	5	4	26
	Erithares sp.	4	1	0	0	5
	Rhagovelia sp.	2	7	0	0	9
Lymnaeida	*Biomphalaria* sp.	0	0	0	1	1

	Bulinus sp.	6	0	2	0	8
	Helisoma sp.	0	8	7	0	15
	Lymnaea sp.	0	0	6	0	6
Odonata	*Phaon iridipennis*	1	3	2	4	10
	Chlorocypha curta	1	3	3	1	8
	Chlorocypha pyriformosa	8	12	7	0	27
	Agriocnemis maclachlani	6	0	2	3	11
	Agriocnemis sp. B	1	0	0	2	3
	Ceriagrion sp.	0	4	0	0	4
	Elattoneura sp.	0	2	2	0	4
	Pseudagrion glaucum	29	9	3	6	47
	Pseudagrion hamoni	21	72	55	92	240
	Pseudagrion melanicterum	16	28	19	0	63
	Mesocnemis singularis	3	34	19	15	71
	Lestinogomphus sp.	0	1	0	0	1
	Paragomphus sp.	0	0	1	0	1
	Phyllomacromia sp.	1	2	0	0	3
	Atoconeura sp.	0	1	0	0	1
	Brachythemis leucosticte	0	0	12	9	21
	Crocothemis erythrae	0	5	0	0	5
	Neodythemis sp.	0	1	0	0	1
	Olpogastra lugubris	4	9	0	1	14
	Orthetrum chrysostigma	3	6	6	1	16
	Orthetrum Julia	0	1	0	0	1
	Palpopleura lucia	0	1	0	0	1
	Palpopleura Portia	0	1	0	0	1
	Trithemis annulate	0	4	2	0	6
	Trithemis arteriosa	7	24	14	4	49
	Urothemis assignata	0	11	2	0	13
	Zygonoides sp.	0	1	1	3	5
	Zygonyx natalensis	0	1	3	0	4
Plecoptera	*Neoperla spio*	2	18	0	0	20
Sorbeoconcha	*Melanoides tuberculata*	69	49	43	59	220
	Total	305	448	256	234	1243
	No of Taxa	35	40	29	23	58

Diversity Indices of Macroinvertebrates in Owena River

The spatial variation in the diversity of macroinvertebrates across the sampled stations is as presented in Table 4. The highest number of taxa (30) was recorded in Station 5 while the least (24) was recorded in Station 3. The highest value for Simpson, Shannon-Wiener (H) and Evenness indices were recorded in Station 5 while the least values were obtained in Station 1. The highest value for Margalef index was obtained in Station 5 while the least was in Station 3. Temporally, the maximum diversity of species was recorded in March, 2023 while minimum diversity was obtained in September, 2023. However, the highest values for evenness and Margalef indices were observed in June, 2023 and March, 2023 respectively while the least were obtained in September, 2023 (Table 5). Simpson, Shannon-Weiner (H), Evenness and Margalef indices revealed higher diversity of macroinvertebrates in the dry season (Table 5).

Table 4: Diversity of macroinvertebrates along the sampled stations in Owena River, Southwestern Nigeria

Index	St1	St2	St3	St4	St5	St6
Number of Taxa	29	26	24	27	30	27
Number of Individuals	324	254	180	137	194	154
Dominance Index	0.2042	0.125	0.1273	0.1027	0.06479	0.1193
Simpson Index	0.7958	0.875	0.8727	0.8973	0.9352	0.8807
Shannon Index	2.248	2.565	2.556	2.771	3.028	2.674
Evenness Index	0.3266	0.4998	0.5367	0.5917	0.6888	0.5367
Margalef Index	4.844	4.515	4.429	5.285	5.505	5.162

Table 5: Diversity of macroinvertebrates along the sampling periods in Owena River, Southwestern Nigeria

Index	December2022	March2023	June2023	September2023
Number of Taxa	35	40	29	23
Number of Individual	305	448	256	234
Dominance Index	0.08801	0.09486	0.09982	0.2271
Simpson Index	0.912	0.9051	0.9002	0.7729
Shannon Index	2.919	2.84	2.758	2.07
Evenness Index	0.529	0.4277	0.5436	0.3445
Margalef Index	5.944	6.388	5.049	4.033

Table 6: Spatial variations in the Physico-chemical parameters of Owena River, Southwestern Nigeria

Parameter	MEAN±SD						ANOVA	
	ST1	ST2	ST3	ST4	ST5	ST6	F	P
DO (mg/l)	7.02±0.53	6.79±0.34	6.88±0.47	6.45±1.05	6.52±1.30	6.71±0.36	0.316	0.896
Ph	8.19±0.46	8.10±0.37	8.06±0.31	8.01±0.20	7.93±0.23	8.01±0.26	0.309	0.900
TDS (mg/l)	85.00±5.60	85.50±5.60	86.75±5.74	86.00±3.30	85.75±6.02	85.75±6.02	0.043	0.998
Temp (^{0}C)	28.20±4.30	28.53±4.69	28.32±5.48	28.83±3.60	28.28±3.99	28.30±4.43	0.010	0.999
BOD (mg/l)	1.85±2.44	1.99±2.18	2.85 ± 0.40	2.50 ± 0.68	2.05 ± 0.45	1.61±1.98	0.013	0.999
EC (µS/cm)	127.30±7.88	127.83±8.67	129.65±4.86	128.03±8.56	128.98±9.50	13.93±8.71	0.044	0.998
PO_4^{3-} (mg/l)	0.08±0.02	0.08±0.02	0.08±0.02	0.08±0.01	0.08±0.01	0.08±0.01	0.027	0.999
Mg^{2+} (mg/l)	4.75±1.24	4.1±0.76	3.79±0.28	4.74±0.54	4.55±0.88	4.54±0.34	1.056	0.416
Ca^{2+} (mg/l)	8.03±0.55	8.05±0.90	8.75±0.28	8.41±0.15	7.93±0.51	7.74±0.55	1.798	0.164
SO_4^{2-} (mg/l)	5.16±0.01^a	5.16±0.01^a	4.89±0.52^{ab}	4.58±0.01^{ab}	5.52±0.01^{bc}	5.51±0.01^c	11.810	0.000***
NO_3^- (mg/l)	5.73±3.65	6.98±4.89	4.90±3.03	2.82±1.23	7.90±5.55	6.92±5.50	0.735	0.606
Alkalinity (mg/l)	271±14.17^a	266.25±11.56^{ab}	236±25.56^{ab}	287±7.39^b	238.25±22.04^b	246±20.26^b	5.185	0.004**
Water Hardness (mg/l)	39.53±6.46	36.95±5.37	37.39±1.71	40.47±2.56	38.48±4.83	37.94±2.52	0.388	0.850

** indicates significant difference ($p < 0.01$), *** indicates significant difference ($p < 0.001$) different superscript letters on the same row indicates significant difference based on Tukey's HSD Post-hoc Test.

Table 7: Temporal variations in the physico-chemical parameters of Owena River, Southwestern Nigeria Hardness (mg/l)

Parameter	Dec-22	Mar-23	Jun-23	Sep-23	F	P
DO (mg/l)	6.07±0.93a	6.43±0.20ab	7.04±0.32bc	7.36±0.29c	7.483	0.002**
Ph	7.99±0.17a	8.14±0.13b	8.39±0.17b	7.68±0.09c	24.840	5.980***
TDS (mg/l)	79.17±2.86a	83.67±0.52a	90.17±0.75b	90.17±0.75c	72.490	6.380***
Temp (°C)	33.87±0.44b	24.97±1.09a	29.96±0.95c	24.83±1.08c	131.200	2.527***
BOD (mg/l)	5.31±0.48a	0.83±0.41b	0.76±0.42b	0.52±0.37b	177.200	1.427***
EC (µS/cm)	118.65±3.92a	125±0.69a	134.75±1.05b	134.73±1.38c	79.420	2.767***
PO_4^{3-} (mg/l)	0.07±0.01a	0.08±0.01a	0.09±0.01b	0.10±0.01b	19.120	4.320***
Mg^{2+} (mg/l)	3.78±0.30a	3.95±0.48a	5.02±0.58b	4.90±0.71b	8.446	0.001***
Ca^{2+} (mg/l)	7.75±0.53a	7.72±0.54a	8.61±0.32b	8.53±0.28b	7.373	0.002**
SO_4^{2-} (mg/l)	5.19±0.34	5.23±0.36	5.07±0.42	5.04±0.48	0.3176	0.813
NO_3^- (mg/l)	4.36±1.73a	4.03±1.09b	4.29±2.32b	10.82±5.48b	6.600	0.003**
Alkalinity (mg/l)	252.33±33.31	274.7±13.78	252.7±22.21	250±23.76	1.361	0.283
Water	34.87±2.07a	35.48±2.31a	42.11±2.05b	41.39±2.58b	17.090	9.673***

** indicates significant difference ($p < 0.01$), *** indicates significant difference ($p < 0.001$), different superscript letters on the same row indicates significant difference based on Tukey's HSD Post-hoc Test.

Table 8: Temporal variations in the physico-chemical parameters of Owena River, Southwestern Nigeria

Parameter	MEAN±SD				ANOVA	
	Dec-22	Mar-23	Jun-23	Sep-23	F	P
DO (mg/l)	6.07±0.93^a	6.43±0.20^{ab}	7.04±0.32^{bc}	7.36±0.29^c	7.483	0.002**
Ph	7.99±0.17^a	8.14±0.13^b	8.39±0.17^b	7.68±0.09^c	24.840	5.980***
TDS (mg/l)	79.17±2.86^a	83.67±0.52^a	90.17±0.75^b	90.17±0.75^c	72.490	6.380***
Temp (^{O}C)	33.87±0.44^b	24.97±1.09^a	29.96±0.95^c	24.83±1.08^c	131.200	2.527***
BOD (mg/l)	5.31±0.48^a	0.83±0.41^b	0.76±0.42^b	0.52±0.37^b	177.200	1.427***
EC (µS/cm)	118.65±3.92^a	125±0.69^a	134.75±1.05^b	134.73±1.38^c	79.420	2.767***
PO_4^{3-} (mg/l)	0.07±0.01^a	0.08±0.01^a	0.09±0.01^b	0.10±0.01^b	19.120	4.320***
Mg^{2+} (mg/l)	3.78±0.30^a	3.95±0.48^a	5.02±0.58^b	4.90±0.71^b	8.446	0.001***
Ca^{2+} (mg/l)	7.75±0.53^a	7.72±0.54^a	8.61±0.32^b	8.53±0.28^b	7.373	0.002**
SO_4^{2-} (mg/l)	5.19±0.34	5.23±0.36	5.07±0.42	5.04±0.48	0.3176	0.813
NO_3^- (mg/l)	4.36±1.73^a	4.03±1.09^b	4.29±2.32^b	10.82±5.48^b	6.600	0.003**
Alkalinity(mg/l)	252.33±33.31	274.7±13.78	252.7±22.21	250±23.76	1.361	0.283
Water Hardness (mg/l)	34.87±2.07^a	35.48±2.31^a	42.11±2.05^b	41.39±2.58^b	17.090	9.673***

** indicates significant difference ($p < 0.01$), *** indicates significant difference ($p < 0.001$), different superscript letters on the same row indicates significant difference based on Tukey's HSD Post-hoc Test.

Discussion

Distribution and Abundance at Each Station

Macroinvertebrate distribution and abundance varied across sampling stations in Owena River, reflecting habitat quality and mild pollution. All stations showed presence and high abundance of pollution-tolerant groups like Odonata (dominant order, due to adaptability and pollution tolerance; Žganec *et al*., 2020) [49], Sorbeoconcha (indicative of organic waste pollution; Iyiola and Asiedu, 2020) [27], and Hemiptera (linked to abundant food sources like periphyton in nutrient-rich environments; Akawo *et al*., 2021) [14]. *Melanoides tuberculata* (invasive gastropod) and *Pseudagrion hamoni* (dominant odonate, preferring dense riparian vegetation for perching and oviposition; Adu *et al*., 2022) [5] were recorded in large numbers across all stations, with variations attributed to habitat structure differences among river reaches (Abbati *et al*., 2020). *Orectogyrus sp.* (Coleoptera) was abundant particularly in Station 1, supported by food availability, suitable substratum, and increased light penetration promoting primary production

(Doeurk *et al*., 2023; Akinpelu *et al*., 2024) [15]. Low abundance of sensitive EPT taxa (Ephemeroptera, Plecoptera, Trichoptera) across stations suggested pollution load, consistent with studies in similar landscapes (Mohammed *et al*., 2020; Karim *et al*., 2021) [28, 34]. Libellulidae family dominated Odonata, owing to global widespread tolerance to pollution (Karim *et al*., 2021) [28].

Temporal and Spatial Distribution
Temporally, macroinvertebrate abundance and diversity were higher in the dry season than the wet season, due to stable habitats, consistent growth conditions, and less sediment instability from rainfall and stormwater influx, which displaces organisms in wet periods (Mohammed *et al.,* 2020) [34]. Similar patterns were reported in Nigerian and West African studies (Addo-Bediako, 2020; Adeleke *et al*., 2024) [4, 6]. Spatially, distribution varied along river reaches: upper reaches showed general richness; middle reach had potential stressors (e.g., high temperature); lower reach exhibited higher nitrate influences from household waste (Akachukwu *et al*., 2023) [10, 11]. Variations stemmed from habitat quality differences, agricultural runoff altering community structures, and riparian vegetation density (Aliu *et al*., 2020) [13]. Overall, the river was taxa-rich compared to similar Nigerian waterbodies (Amusan and Abubakar, 2023) [8, 9] and international ones (Malakane *et al*., 2020; Gao *et al*., 2023) [25, 31].

Diversity Indices at Each Station
Diversity indices indicated high species richness but moderate evenness in Owena River, suggesting dominance by certain taxa and potential ecological imbalances from stressors. Shannon-Weiner Index ranged from 2.248 to 3.028, and Margalef Index from 4.429 to 5.505 across stations (Iyiola and Asiedu, 2020) [27]. Station 5 was the most diverse, slightly dominated by *Melanoides tuberculata*, likely due to conditions favoring pollution-tolerant taxa from agricultural activities and domestic discharges (Akindele *et al*., 2019) [12]. Canonical correspondence analysis (CCA) showed strong correlations between macroinvertebrate communities and environmental variables, confirming physicochemical influences on structure (Akindele *et al*., 2019) [12].

Physicochemical Parameters in Relation to Each Station
Physicochemical parameters were consistent with tropical Nigerian waterbodies (Aliu *et al*., 2020; Amusan, 2023) [8, 9, 13] and international studies (Madilonga *et al*., 2021; Masime *et al*., 2022) [30, 32]. Station 4 had lower dissolved oxygen (DO) due to higher temperature, lack of riparian vegetation reducing shade, and sewage discharge increasing microbial oxygen consumption via organic matter decomposition and eutrophication (Poff *et al*., 2021; Ogbeibu *et al.,* 2023) [36]. Middle reach stations recorded highest temperature and lowest DO, emphasizing temperature's inverse effect on DO (Ogbeibu *et al.,* 2023) [36]. Lower reach stations showed higher nitrate from household waste and wet-season agricultural runoff (Okey-wokeh *et al.,* 2021; Akachukwu *et al*., 2023) [10, 11]. Across stations, pH was neutral to slightly alkaline (7.93–8.13), higher in dry season from photosynthetic CO2 reduction (Okoya *et al.,* 2020; Akachukwu *et al*., 2023) [10, 11, 38]; temperature varied with riparian density, higher in dry season (Okoya *et al*., 2020) [38]; TDS low overall due to vegetation absorbing nutrients and no industrial discharge, but higher in wet season from weathering and runoff (Kavindra *et al.,* 2020 [40]; Lemessa *et al*., 2023); BOD low (indicating fairly clean water), higher in dry season from decomposer activity (Zhong *et al*., 2021; Akachukwu *et al.,* 2023) [10, 11]; EC higher in wet season from ion influx via runoff (Ubuoh *et al*., 2022) [46]; phosphate consistent, indicating eutrophication from fertilizers and waste (Ubuoh *et al*., 2022) [46]; nitrate highest in wet season/lower reach (Musa *et al*., 2022) [33]; sulphate moderately low, higher in dry season from decomposition (Musa *et al*., 2022) [33]; alkalinity high in dry season from low dilution (Akachukwu *et al*., 2023) [10, 11]; total hardness low, influenced by Ca2+/Mg2+ from natural processes, lower in dry season (Titilawo *et al*., 2019). These parameters correlated with macroinvertebrate distributions, with pollution-tolerant taxa thriving amid mild impairments.

Conclusion
The study on Owena River revealed a moderately diverse macroinvertebrate community indicative of mild anthropogenic pollution, with high species richness but moderate evenness. Dominance by pollution-tolerant taxa such as Odonata (particularly Libellulidae and Pseudagrion hamoni), Sorbeoconcha (e.g., Melanoides tuberculata), and Hemiptera across all stations, coupled with low abundance of sensitive EPT groups, underscores habitat alterations from agricultural runoff, sewage discharge, and domestic waste which can be traced to run-off from surrounding agricultural lands, refuse dumps and sewage from residences within the river basin.
Overall, Owena River maintains ecological integrity comparable to similar systems (e.g., Ogun and Osun Rivers; Akindele *et al*., 2019 [12]; Amusan and Abubakar, 2023) [8, 9], but ongoing human activities pose risks of eutrophication and biodiversity loss. Sustainable management, including riparian vegetation restoration and pollution control, is recommended to preserve this taxa-rich ecosystem for aquatic health and community use.

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