COMMUNITY STRUCTURE OF MACROINVERTEBRATES IN LAKE ASA, ILORIN, NIGERIA

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ABSTRACT

The integrity of Lake Asa's water quality depends on how various macroinvertebrate communities make their living more diversified, and contribute to complex food webs. In addition, the macroinvertebrate community are significantly used as indicator organisms to detect the pollution impacts in aquatic ecosystems. In this study, the diversity and community structure of macroinvertebrate and their relationship with environmental variables in Lake Asa, Ilorin, Nigeria, from February 2023 to February 2025. The study yielded 1421 individuals belonging to 3 phyla, 4 classes and 26 genera. The Bivalvia community, comprising 39.5% of the total taxonomic groups with Sphaerium sp. as the dominant macroinvertebrate species represented more than 15% of the total macroinvertebrate taxa and diversity indices were detected significant variations (p<0.05) among stations by the Kruskal-Wallis ANOVA, whereas Shannon-Wiener Diversity Index (H´) assessed moderate pollution, Evenness index (J) assessed uniform distributions of macrobenthic community, and environmental variables showed acceptable condition for the productivity of Lake Asa. Non-metric multidimensional scaling (nMDS) reveals distinct community structures among macroinvertebrate samples. Within macroinvertebrate communities, Canonical Correspondence Analysis (CCA) provided insights and interpretations of the relationships between species and environmental gradients. The macroinvertebrate community was most influenced by temperature, organic matter, DO, pH and EC.

Keywords: Community structure, Macroinvertebrates, Environmental variables, Lake Asa

INTRODUCTION

The assessment of biological diversity in freshwaters and its most important element, taxonomic diversity, plays a very significant role as the basis for nature protection. Different measures of biodiversity are often used in the biological assessment of freshwaters.

Benthic macroinvertebrates are a key biological indicator of the ecological quality of freshwater ecosystems worldwide, as they can detect pollution and ecosystem degradation (Vourka *et al.,* 2023). Benthic macroinvertebrates, mainly consisting of aquatic insects, mites, molluscs, crustaceans, and annelids, are most often used in monitoring lotic systems (Bonada *et al.*, 2006; Carter *et al.*, 2006). Furthermore, to protect the ecological integrity of aquatic environments, identifying changes in biological conditions is crucial for successful assessment (Karaouzas *et al.*, 2019; Riato *et al.*, 2020) because such changes cause alterations in the composition and structure of the aquatic community (Clarke, 2000; Smolders *et al.*, 2003; Oller and Goitia, 2005). As a result, understanding the spatiotemporal patterns of benthic macroinvertebrate populations will help us better comprehend their ecological processes,

as well as bioassessment and management. Important attributes of communities include diversity, richness, density, frequency, abundance, and dominance (Magurran, 2013). Routine biomonitoring often classifies ecosystem states through biotic indices that succinctly summarise species assemblage information, facilitating comparisons to reference states or systems (Diaz *et al.*, 2004). The classification of ecological integrity based on biotic indices generally focuses on specific taxonomic groups (Pawlowski *et al.*, 2018).

There have been numerous studies demonstrating the importance of evaluating macroinvertebrate assemblages based on their traits in contrast to their taxonomy (Resh *et al.,* 1994; Statzner *et al.,* 1994). The use of species traits in environmental monitoring has been aided by the establishment of several easily accessible databases listing the traits of macroinvertebrates (Vieira *et al.,* 2006; USEPA, 2012; Schmidt-Kloiber and Hering, 2015). Although using species traits in environmental monitoring will help generalize the response of macroinvertebrate assemblages across geographies and provide a mechanistic understanding of species distributions. Benthic macroinvertebrates have been used to evaluate the effects of various anthropogenic stressors at all levels of biological organization. At the organism level, the changes in growth and reproduction and rates of morphological deformities have been evaluated as responses to increased pollution (Martin *et al.,* 2007; Di Veroli *et al.,* 2014).

The links between the physical and chemical properties of water are important for the composition, abundance, distribution, diversity, development, reproduction, and movements of macroinvertebrate organisms. Different organisms have varying tolerances to increases or decreases in physical and chemical levels, and they tend to exclude especially vulnerable individuals. Spatial and temporal patterns show that macroinvertebrate species prefer specific levels of substrate types. When adequate dissolved oxygen and suitable substrate are present, many macroinvertebrate species, especially insects and crustaceans, can speed up the microbial breakdown of dead organic material. Since organic detritus is consumed by several species, most freshwater ecologists broadly classify these consumers into functional feeding groups (Cummins *et al.*, 1995).

River Asa, a major tributary of the Niger River, is the main watercourse in the Federal Republic of Nigeria and plays a vital role in the hydrology of Ilorin, a city located in North-Central Nigeria. The river was dammed in 1977 by the Kwara State Government. Lake Asa is nourished by four tributaries, with the River Asa being the primary inflow. The lake covers an area of 302 hectares (Araoye, 2009). However, it faces both direct and indirect pollution caused by human activities, and over time, the lake has undergone significant modification. A preliminary survey identified several sources of pollution, including agricultural runoff containing pesticides and herbicides, industrial effluents, domestic waste, and wastewater from fish farms within its catchment. Over 80% of the catchment area consists of a mix of disturbed and undisturbed vegetation, while around 47% of the sublittoral zone is covered by macrophytes, mainly water hyacinth.

Despite the recognized ecological importance of benthic macroinvertebrates, their community in Lake Asa has been comparatively understudied. The ecological information on the impact of environmental factors on macroinvertebrate community patterns in Lake Asa remains insufficient, scarce or unstudied. Therefore, the present investigation is the first wide-ranging two-year study to understand the ecological characteristics of macroinvertebrate communities and their relation with environmental factors. This study aims to investigate the composition, functional distribution, and diversity of macroinvertebrates in Lake Asa stations and to assess the ecosystem health of the Lake Asa using the macroinvertebrate Family Biotic Index. The specific objectives of this research are: (i) to evaluate the seasonal variations in the benthic macroinvertebrate community of Lake Asa about diverse land-use practices within its catchment and (ii) to identify the environmental factors influencing the biomass fluctuations of macroinvertebrate taxonomic groups across selected sampling stations. The findings of this study are crucial for the effective management of Lake Asa's water quality monitoring and management, providing valuable insights for

sustainable management and conservation strategies.

MATERIALS AND METHODS

Study Area and Sampling Stations: Lake Asa, situated in Ilorin, Kwara State, Nigeria, is located at 8°20'N, 4°33'E, encompassing a surface area of 302 hectares and reaching a maximum depth of 14 meters. Ilorin's climate is classified as humid tropical, characterized by distinct wet (March to October) and dry (November to February) seasons (Ogundiran and Fawole, 2014). The annual rainfall is 1150 ± 250 mm, and the annual temperature ranges from 25 to 28.9°C, with relative humidity of between 65 and 80%.

Sampled Stations: Three sampling stations were strategically selected along the lake, as depicted in Figure 1.

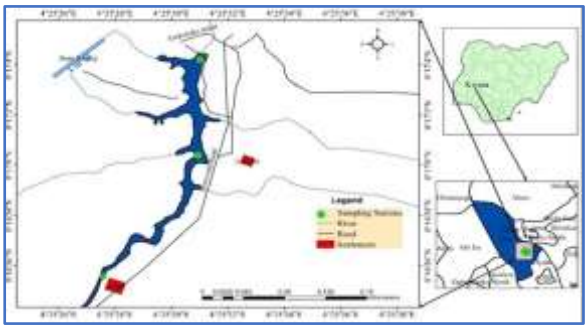


Figure 1: Map of Lake Asa and location of the sampling stations *(Source: Muhibbu-Din and Oladipo, 2025)*

The upstream station (Afon) is located 2.5 kilometres from the midstream station (Laduba). The intervening catchment area is characterized by a mosaic of disturbed and undisturbed vegetation, with prominent human activities such as water abstraction for fish farming, industrial use and cattle grazing. The midstream Laduba Station is situated 2.0 kilometres from the downstream (Dam Station). The catchment areas of both the Dam and Laduba Stations are subject to a range of anthropogenic pressures, including fish farming, fishing activities, cattle rearing, domestic, fish farm wastewater disposal and agricultural runoff.

At all stations, profiles of water temperature, pH, TDS, EC and DO (mg/l) were obtained with a HI 98129 HANNA probe meter and water transparency (cm) or light penetration in water was measured with a Secchi disc.

Field Sampling Procedure and Physicochemical Parameter Analysis: Sampling was conducted bi-monthly from February 2023 to February 2025 at three stations in Lake Asa (Figure 1) to collect benthic macroinvertebrates and water samples for the analysis of physicochemical parameters. One (1) litre of water sample was collected at each sampling in a clean plastic bottle. The plastic was rinsed with lake water before sampling. Water quality parameters were analyzed according to the standard methods outlined in Clesceri *et al.* (1999). Thirteen physicochemical parameters were assessed. Water samples for the determination of chemical oxygen demand (COD), total nitrogen (TN), total phosphate (TP), sulphate (SO_4^{2-}), total organic carbon (TOC), and organic matter (OM) were collected in 2-litre plastic bottles, while samples for biological oxygen demand (BOD) were collected in 250 ml dark glass bottles. Before sample collection, each bottle was meticulously rinsed several times with distilled water. At each sampling station, the water column was allowed to stabilize before collecting samples. Bottles were then rinsed thrice with lake water, followed by the collection of water samples from a depth of 10 cm below the water surface. Collected samples were appropriately labelled, sealed airtight, and transported to the laboratory in insulated containers with ice packs.

Macroinvertebrate Analysis: Benthic macroinvertebrates were sampled from three sampling stations bi-monthly with a D-net (size 0.25 m× 0.25 m, pore diameter 500 µm) was mounted in the appropriate position, with a lower frame fixed at the bottom of the Lake sampling station. Individual stones were picked and washed over a sampling net and the substrates were disturbed for at least 1 min by dislodging organisms to direct the macroinvertebrates into the net with the natural flow (Cuffney *et al.,* 1993). The protocol was repeated several times within a 100-m lake reach, covering a variety of velocity regimes and habitat forms until a total area of 1 m^2 had been sampled.

During each sampling, four replicates were taken from each station. Then, the macroinvertebrates were sorted and preserved in 70% alcohol and 4% formalin, depending on the type of organisms. The collected macroinvertebrates were sorted, counted and identified using a binocular microscope (×6 magnification) according to the standard keys (McCafferty, 1983; Borror *et al,* 1989; Ward, 1992; Clesceri *et al.*, 1999; Engblom and Lingdell, 1999; Dar *et al.,* 2002; Bouchard, 2004; Subramanian and Sivaramakrishnan, 2007; Merritt *et al.,* 2008; Bhagat, 2013). As diversity indices are increasingly used to assess the health of the habitats, univariate measures included abundance (N), and the number of macroinvertebrate species (S), diversity (Shannon, 1948), richness (McIntosh, 1967), and evenness (Pielou, 1969) were calculated (where p is the proportion of abundance *ith* species from the total abundance of benthic species; S is the total number of macroinvertebrate species). The Kruskal-Wallis ANOVA test (using free statistical software, Paleontological Statistics, PAST) (Hammer *et al.*, 2001) was used to find the significant ($p<0.05$) differences in the abundance of trophic groups among stations.

A Bray-Curtis similarity matrix was computed using abundance data for each macroinvertebrate community among stations (Bray and Curtis, 1957), from which the non-metric multidimensional scaling (nMDS) ordination plot was generated to analyze differences in the community structure of macroinvertebrates. Analyses of similarity (ANOSIM) with 9999 permutations were computed with square-root transformed abundance data to test the hypothesis that the communities (i.e., structure and function) are not significantly dissimilar during the study period for the connections of Lake Asa stations. Canonical correspondence analysis (CCA) was selected as the unimodal response model (Ter Braak and Prentice, 1988) to explore the relationships between assemblage structure and a suite of environmental variables. This multivariate technique allows one to directly relate the pattern of community variation to environmental variables (Ter Braak and Prentice, 1988). These CCAs were done using density data sets of the macroinvertebrate community and the environment. Analyses were done using the PAST (Hammer *et al.*, 2001) and Microsoft Excel for statistical analysis.

Biotic Index: The family biotic index (FBI) (Hilsenhoff, 1988), which is a weighted average: Among them, n_i is the number of individuals (genus or species level) of the i^{th} taxon, and N is the total number of individuals in the sample, t_i is the tolerance value from the relationship in Table 1.

Table 1: Classification scheme of soft bottom benthic habitat based on BentiX Index

Pollution Classification	BentiX	Ecological Quality Status
Normal/Pristine	4.5≤ BentiX<6.0	High
Slightly Polluted	3.5≤ BentiX<4.5	Good
Moderately Polluted	2.5≤ BentiX<3.5	Moderate
Heavily Polluted	2.0≤ BentiX<2.5	Poor
Azoic	0	Bad

The tolerance value refers to the tolerance of living organisms to the environmental stress in time and space, reflecting the relative ability of living organisms to survive and reproduce under the interference of environmental stress (Whittier and Van Sickle, 2010). The criteria for evaluating the water quality are shown in Table 2.

Table 2. Water quality based on Family Biotic Index (FBI) values from Hilsenhoff (1988)

Family Biotic Index	Water Quality
0.00-3.75	Excellent
3.76-4.25	Very good
4.26-5.00	Good
5.01-5.75	Fair
5.76-6.50	Fairly poor
6.51-7.25	Poor
7.26-10.00	Very poor

RESULTS

Physicochemical Parameter of Lake Asa Water: The mean ± standard error values of thirteen physicochemical parameters measured in Lake Asa water across seasons and stations, alongside the acceptable standards for aquaculture and domestic water supply are

presented wet and dry seasons on Tables 3 and 4 respectively. One-way ANOVA indicated significant seasonal variations in all analysed water physical and chemical parameters.

Water temperature fluctuated between 24.03 – 29.20 °C, with the maximum recorded at the Dam Station during the dry season of November 2024 – March 2025 and the minimum at Laduba Station during the wet season of April – October 2024. Spatial differences in water temperature were observed across all stations. Notably, water temperatures recorded during the wet season of April – October 2024 exceeded the acceptable water quality standard.

Water transparency exhibited significant seasonal variation, ranging from 35.46 to 201.00 cm. The highest transparency was observed at the Dam Station during the dry season of November 2024 – March 2025, while the lowest was at the Laduba Station during the wet season of April – October 2024. Spatial variations in transparency were evident across stations. Only the transparency value recorded at Laduba Station during the wet season of April – October 2024 fell within the acceptable standard; all other recorded values were below the standard.

Water pH ranged from 6.40 to 8.93, with the minimum at Laduba Station during April – October 2025 and the maximum at Afon Station during November 2023 - March 2024. All recorded pH values were within the acceptable water quality standard.

The total dissolved solids (TDS) concentrations ranged from 33.03 to 285 mg/L, with the minimum at the Dam Station during April - October 2024 and the maximum at the Dam Station during November 2024 – March 2025. All recorded TDS concentrations were within the acceptable water quality standard.

Total Phosphorus (TP) concentrations ranged from 0.01 to 2.19 mg/L, with the minimum at Dam Station during April - October 2024 and the maximum at Dam Station during November 2024 - March 2025. All recorded TP concentrations were within the acceptable water quality standard.

Dissolved Oxygen (DO) concentrations ranged from 6.24 to 9.3 mg/L, with the minimum at Dam Station during April – October 2025 and the maximum at Dam Station during April – October 2024. All recorded DO concentrations were within the acceptable water quality standard.

Biochemical Oxygen Demand (BOD) levels ranged from 1.93 to 11.3 mg/L, with the lowest at the Dam Station during April - October 2023 and the highest at the Dam Station during November 2023 - March 2024. All recorded BOD levels were within the acceptable water quality standards, except for the minimum value at the Dam Station during April – October 2023, which was below the standard.

Chemical Oxygen Demand (COD) ranged from 0.6 to 228.5 mg/L, with the minimum at the Laduba Station during April – October 2023 and the maximum at the Afon Station during November 2024 - March 2025. The majority of recorded COD exceeded the acceptable water quality standard.

Electrical Conductivity (EC) ranged from 66.5 to 502 µS/cm, with the lowest value at Dam Station during April – October 2024 and the highest at Laduba Station during November 2024 - March 2025. All recorded EC readings remained within the acceptable water quality standards.

Sulphate concentrations ranged from 7.3 to 71.8 mg/L, with the minimum at Dam Station during April – October 2024 and the maximum at Afon Station during April - October 2024. All recorded sulphate concentrations were within the acceptable water quality standard.

Total Nitrogen (TN) concentrations ranged from 0.17 to 1.9 mg/L, with the minimum at Laduba Station during April - October 2023 and the maximum at Dam Station during April - October 2024. All recorded TN concentrations exceeded the acceptable water quality standard.

Organic Matter (OM) concentrations ranged from 15.2 to 35.1 mg/L, with the minimum at Afon Station during April - October 2024 and the maximum at Afon Station during November 2024 - March 2025. All recorded OM concentrations exceeded the acceptable water quality standard.

Total Organic Carbon (TOC) concentrations ranged from 8.8 to 20.4 mg/L, with the minimum at Afon Station during April - October 2024 and the maximum at Afon Station during November 2024 – March 2025. All recorded TOC concentrations exceeded the acceptable water quality standard.

Table 3: Wet seasons spatial variation in physicochemical parameters of Lake Asa, Ilorin, Nigeria

Season	Wet 2023			Wet 2024			Water quality Standard
Stations	Dam	Laduba	Afon	Dam	Laduba	Afon	
Temperature (^{0}C)	27.9 ± 0.1	27.5 ± 0.11	28.4 ± 0.00	24.76 ± 0.57	24.03 ± 0.51	24.90 ± 0.00	25 - 30^{0}C (FAO, 2006)
Transparency (cm)	51 ± 0.00	50 ± 0.00	75 ± 0.00	41.13 ± 0.25	35.46 ± 0.05	47.33 ± 0.28	30-40 (Santhosh and Sing, 2007)
pH	7.35 ± 0.00	7.88 ± 0.00	7.4 ± 0.00	6.80 ± 0.00	6.40 ± 0.00	6.53 ± 0.57	6-9 (PHILMINAQ, 2006)
TDS (mgL^{-1})	162 ± .281	186 ± 2.21	157 ± 3.51	33.03 ± 3.57	71.53 ± 5.48	101.20 ± 3.29	<500 (USEPA, 2006)
TP (mgL^{-1})	0.85 ± 0.01	0.86 ± 0.11	0.63 ± 0.00	0.01 ± 0.00	0.3 ± 0.00	0.15 ± 0.00	0.01-3 (Piper *et al.*, 1982)
DO (mgL^{-1})	6.24 ± 0.00	6.69 ± 0.00	7.69 ± 0.00	9.3 ± 0.00	8.1 ± 0.00	7.3 ± 0.00	≥ 4 (Santhosh and Sing, 2007)
BOD (mgL^{-1})	1.93 ± 0.00	2.04 ± 0.00	2.6 ± 0.00	2.9 ± 0.00	6.7 ± 0.00	5.1 ± 0.00	3-20 (Boyd, 2003)
COD (mgL^{-1})	1.2 ± 0.00	0.6 ± 0.00	0.8 ± 0.00	35.1 ± 0.00	118.5 ± 0.00	228.5 ± 0.00	< 50 (Santhosh and Sing, 2007)
EC (µS/cm)	242 ± 0.06	278 ± 0.03	235 ± 0.01	66.5 ± 0.4	151.36 ± 0.55	201.46 ± 1.68	1000 (FEPA, 1991)
SO_4^{-2} (mgL^{-1})	16.5 ± 0.00	19 ± 0.00	17.1 ± 0.00	7.3 ± 0.00	53.5 ± 0.00	71.8 ± 0.00	250 (WHO, 2004)
TN (mgL^{-1})	0.72 ± 0.2	0.17 ± 00.8	0.28 ± 0.1	1.9 ± 0.00	1.24 ± 0.00	1.12 ± 0.00	0.1 (FEPA, 1991)
OM	20.5 ± 0.00	23.7 ± 0.00	18.4 ± 0.00	33.1 ± 0.12	24.3 ± 0.01	15.2 ± 0.01	>10 (BCMECCS 2019)
TOC	11.9 ± 0.00	13.7 ± 0.00	10.6 ± 0.00	19.2 ± 0.21	14.1 ± 0.11	8.8 ± 0.02	>10 (BCMECCS 2019)

Table 4: Dry seasons spatial variation in physicochemical parameters of Lake Asa, Ilorin, Nigeria

Stations	Dry 2024			Dry 2025			Water Quality Standard
	Dam	Laduba	Afon	Dam	Laduba	Afon	
Temperature (^{0}C)	28.2 ± 0.57	27.5 ± 0.00	27.0 ± 0.21	29.2 ± 0.57	27.5 ± 0.34	28.5 ± 0.00	25 - 30^{0}C (FAO, 2006)
Transparency (cm)	196 ± 0.00	176 ± 0.00	138 ± 0.00	201 ± 0.00	196 ± 0.00	158 ± 0.00	30 - 40 (Santhosh and Sing, 2007)
pH	8.33 ± 0.00	8.45 ± 0.00	8.93 ± 0.00	8.50 ± 0.00	8.65 ± 0.00	8.83 ± 0.00	6-9 (PHILMINAQ, 2006)
TDS (mgL^{-1})	275 ± 1.57	270 ± 0.31	261 ± 4.32	285 ± 1.57	280 ± 0.31	281 ± 4.32	<500 (USEPA, 2006)
TP (mgL^{-1})	1.45 ± 0.00	0.68 ± 0.00	1.00 ± 0.00	2.19 ± 0.00	1.83 ± 0.00	1.66 ± 0.00	0.01 - 3 (Piper *et al.*, 1982)
DO (mgL^{-1})	8.12 ± 0.00	9.2 ± 0.00	7.33 ± 0.00	9.21 ± 0.00	8.31 ± 0.00	7.91 ± 0.00	≥ 4 (Santhosh and Sing, 2007)

BOD (mgL^{-1})	11.3 ± 0.00	9.9 ± 0.00	6.36 ± 0.00	7.13 ± 0.00	5.94 ± 0.00	7.48 ± 0.00	3-20 (Boyd, 2003)
COD (mgL^{-1})	72 ± 0.00	106.5 ± 0.00	36.1 ± 0.00	132 ± 0.00	126.5 ± 0.00	96.1 ± 0.00	≤ 50 (Santhosh and Sing, 2007)
EC (µS/cm)	411 ± 1.43	402 ± 0.04	389 ± 0.02	641 ± 1.41	502 ± 0.07	409 ± 0.03	1000 (FEPA, 1991)
SO_4^{-2} (mgL^{-1})	14.5 ± 0.00	16 ± 0.00	18.2 ± 0.00	19.5 ± 0.00	26 ± 0.00	27.2 ± 0.00	250 (WHO, 2004)
TN (mgL^{-1})	0.68 ± 0.21	0.84 ± 0.01	0.78 ± 0.00	0.99 ± 0.21	1.42 ± 0.01	1.08 ± 0.00	0.1 (FEPA, 1991)
OM	22.7 ± 0.00	23.2 ± 0.00	25.4 ± 0.00	32.7 ± 0.00	25.2 ± 0.00	35.1 ± 0.00	>10 (BCMECCS 2019)
TOC	13.1 ± 0.00	13.4 ± 0.00	14.7 ± 0.00	19.1 ± 0.00	14.6 ± 0.00	20.4 ± 0.00	>10 (BCMECCS 2019)

However, significant variation was found in all physicochemical parameters among stations in Lake Asa ($p<0.05$).

Macroinvertebrate Community and Abundance: A total of 1421 individuals were estimated, identified and belonged to 3 phyla (Mollusca, Arthropoda and Annelida) (Figure 2) and 4 classes (Bivalves, Gastropoda, Insecta and Oligochaeta) (Figure 3), and 18 order (Figure 4).

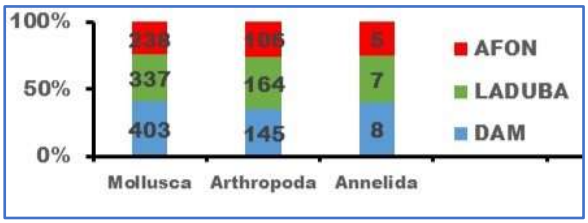


Figure 2: Macroinvertebrate phylum composition at stations in Lake Asa, Ilorin, Nigeria

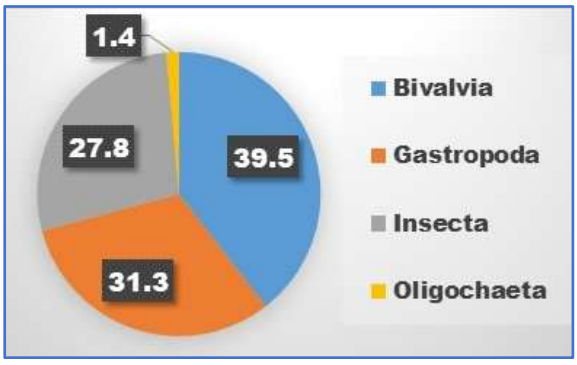


Figure 3: Macroinvertebrates taxonomic group (classes) composition in Lake Asa, Ilorin, Nigeria

Mollusca was the most abundant group, which had 26 genera (approximately 70.8% of the total individual number), the Bivalves constituted 39.5% of the total individual number, while the Gastropoda constituted 31.3% of the total individual number. The phylum Arthropoda is dominated by the class Insecta, which has 29 families (approximately 27.8% of the total individual number). The phylum Annelida is made up of the class Oligochaeta, which has approximately 1.4% of the total number. Table 5 shows the Lake Asa benthic macroinvertebrate distribution and occurrence in stations and seasons during the study period.

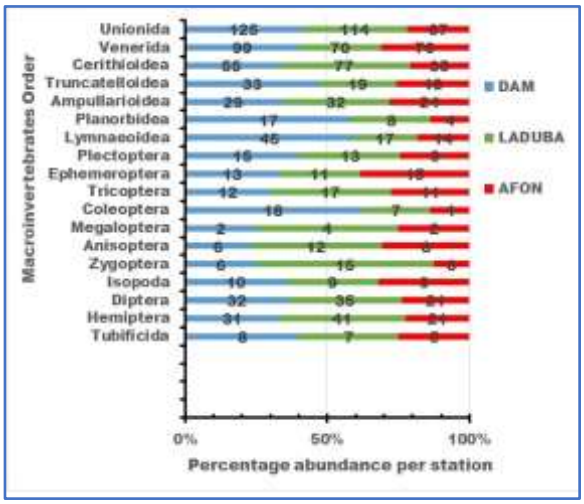


Figure 4: Macroinvertebrate order taxon composition at stations in Lake Asa, Ilorin, Nigeria

Non-Metric Multidimensional Scaling (nMDS): nMDS ordination plot generated by the method Bray-Curtis distance matrix using the abundance data of macroinvertebrate species at each station displays similarity and clear separation between the samples from each station (Figure 5).

The samples from neighbouring stations tend to cluster together. It was used to analyze the differences in the community structure of

macroinvertebrates. For the community structure, samples from Laduba overlapped with Dam and Afon samples; Dam samples are partially similar to Afon samples, but mainly overlapped. Samples from Dam and Afon are mostly clustered in the Laduba sample, with a few overlaps from each.

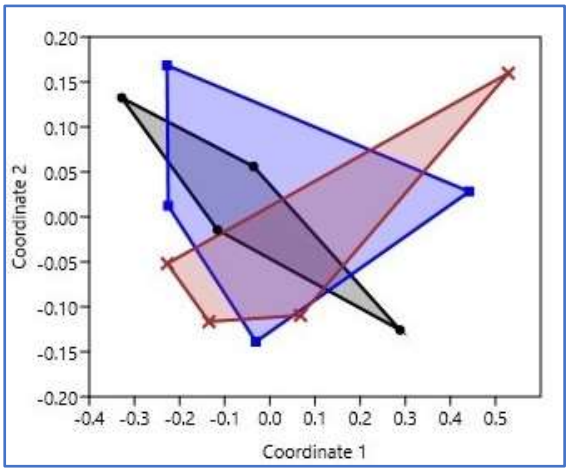


Figure 5: Non-metric multidimensional scaling (nMDS) ordination plot of macroinvertebrate data in Lake Asa at the 3 stations. *Data square-root transformed. Key for the stations: black dots= Dam; blue Square= Laduba; red cross plus= Afon (stress =0.08)*

Similarities of Taxa: ANOSIM did not detect significant differences in the structural similarities of the communities (ANOSIM: R = 0.3805; p = 0.0001), while the dissimilarities of the communities tended to be low during the study period. In pairwise comparison, the R value close to 1 (Dam vs Afon) indicates a high separation with a high effect between the abundance levels and occurrence, while the R value close to 0 (Laduba vs Dam) indicates a low separation with a small effect on abundance levels. This same for Laduba vs Afon.

DISCUSSION

Physicochemical Parameter: A mixture of factors influences macroinvertebrate communities, and not one factor is known as a prime element of ecology defined by Gray and Elliott (2009). The values of water temperature, EC, TDS, OM, TOC, TN, TP, COD, BOD, Sulphate, pH, DO, and water transparency between Lake Asa stations were significantly varied during the present study ($p<0.05$). The recorded water temperature during the 2024 wet season was lower than during other seasons. The results of this study are similar to the results reported by Mustapha and Omotoso (2005). Four parameters (transparency, TOC, OM, TN) consistently exceeded acceptable water quality standards. Six parameters (DO, pH, TDS, TP, EC, and Sulphate) were consistently within acceptable standards. Three parameters (BOD, COD, and Temperature) showed variability across stations and seasons. Most macroinvertebrate studies have shown EC, TDS, and OM to be key factors in the construction of macroinvertebrate communities (Brown *et al.,* 2000; Gaudêncio and Cabral, 2007; Hanekom, 2011). The TOC, TP, TN and OM concentrations observed favour bivalves, gastropods and pollution-tolerant insect occurrence in Lake Asa. A pH of 6.5 to 9.0 would be appropriate (Svobodova *et al.*, 1993) except in the wet season of the year 2024, which is acidic. In this study, the value of DO is similar to the findings of Rahman *et al.* (2008), Mozumder *et al.* (2014) and Akter *et al.* (2016). Water transparency influences the abundance and diversity of macroinvertebrates life.

Macroinvertebrate Community Composition and Abundance: Macroinvertebrate abundance and taxonomic richness for each station and sampling period (season) are presented in Table 5. Distribution of the macroinvertebrates community of Lake Asa comprised three phyla (Mollusca, Arthropoda and Annelida), four classes (Bivalvia, Gastropoda, Insecta and Oligochaeta), 18 orders, and 30 families (Table 5). Bivalves were dominant in all the stations during the study period, which yielded a total of 561 ind./$m^{2,}$ comprising 39.5% of the total abundance. Similar findings were observed by Hamid *et al.* (2021), where bivalves are highly abundant and dominant. They are used as bio-indicators of sediment as they can provide information on available sources of organic carbon, matter and sediment acidity, sediment hypoxia and anoxia of Lake Asa and changes in decomposition pathways in the sediment food webs. The highest density (226 ind./m^2) of macroinvertebrates was found in Dam Station during the 2023 wet season, while the lowest (51 ind./m^2) was at Laduba and Afon Stations during the 2024 dry season.

Dam Station of Lake Asa was dominated by Galba sp. during the study period, with 23 ind./m^2, also *Diplodontites* sp., *Sphaerium* sp.,

Table 5: Spatial-temporal occurrence of benthic macroinvertebrate in Lake Asa, Ilorin, Nigeria

Season	2023 Wet			2023 Dry			2024 Wet			2024 Dry		
Taxon/ Station	Dam	Laduba	Afon	Dam	Laduba	Afon	Dam	Laduba	Afon	Dam	Laduba	Afon
Bivalvia												
Diplodon sp.	-	+	+	-	-	+	-	+	+	-	+	-
Rhipidodontini sp.	+	+	+	+	+	+	-	+	+	+	+	-
Monocondylaea sp.	++	++	+	+	++	-	_	_	+	+	-	-
Diplodontites sp.	++	+	-	-	-	-	-	-	-	+	-	+
Anodontites sp.	+	++	+	-	+	+	+	+	-	-	-	+
Mycetopoda sp.	+	++	+	+	++	+	-	+	+	+	+	+
Eupera sp.	+	+	++	-	-	+	-	+	-	+	+	+
Musculium sp.	+	-	+	++	++	+	+	+	+	-	-	-
Sphaerium sp.	++	++	++	++	+	++	+	+	-	+	+	+
Pisidium sp.	+	+	+	+	-	+	+	+	-	+	-	-
Polymesoda sp.	+	+	+	+	++	-	-	+	-	+	+	-
Neocorbicula sp.	+	+	+	-	-	+	+	-	+	-	-	-
Corbicula sp.	+	+	+	+	-	+	+	-	+	+	-	-
Gastropoda										+	+	-
Aylacostoma sp.	++	++	+	++	++	+	-	+	-	-	-	-
Pachychilus sp.	+	++	+	-	-	+	-	-	-	+	-	-
Doryssa sp.	+	+	+	-	+	++	+	+	-	+	+	+
Idiopyrgus sp.	+	+	-	-	-	-	+	-	-	+	-	-
Pterides sp.	+	-	+	+	++	-	-	+	-	-	-	-
Cochliopina sp.	-	-	+	++	-	-	++	-	-	+	+	-
Felipponea sp.	+	++	+	-	-	+	++	-	-	+	-	-
Pomacea sp.	+	+	-	+	-	-	-	+	++	+	-	+
Chilina sp.	++	+	+	-	-	+	+	-	++	+	+	-
Physa sp.	++	+	-	-	+	-	-	-	+	+	+	+
Galba sp.	++	+	+	-	-	-	+	-	-	-	-	-
Lymnaea sp.	++	+	+	+	-	-	-	+	++	+	+	+
Pseudosuccinea sp.	+	+	+	+	++	-	+	-	+	-	-	-
Arthropoda												
Peltoperlidae	+	+	+	+	+	-	+	-	-	+	-	-
Perlidae	+	-	+	+	+	-	-	+	-	+	+	+
Pteronarcyidae	+	+	+	-	-	+	+	-	-	-	-	-
Capniidae	+	-	-	-	-	+	-	-	-	+	-	+
Ephemerellidae	+	+	-	-	-	-	-	-	-	-	-	+
Baetidae	+	+	+	+	-	+	+	-	-	+	+	+
Isonychidae	-	+	+	+	-	-	-	-	-	+	-	+
Heptageniidae	-	-	+	+	+	+	-	-	-	-	-	-
Glossosomatidae	+	-	+	-	-	-	-	+	-	-	-	-
Apatania	-	-	+	-	+	+	-	-	-	+	-	-
Rhyacophilidae	-	+	+	+	-	+	-	-	-	+	+	-
Brachycentridae	+	-	-	-	-	+	+	-	+	-	+	-
Elmidae	++	+	-	+	-	+	-	+	-	-	-	-
Psephenidae	+	+	-	+	+	+	-	-	-	+	-	-
Corydalidae	+	-	-	-	-	-	-	+	-	-	-	-
Aeshnidae	+	-	+	-	-	+	-	-	+	+	-	-
Gomphidae	+	+	+	-	-	-	+	-	+	-	-	+
Lestidae	+	+	+	-	+	-	+	-	-	-	+	+
Coengrionidae	+	+	-	-	-	-	+	-	-	-	-	-
Asellidae	+	+	-	+	+	-	-	-	-	+	+	+
Chironimidae	+	+	+	++	++	+	++	+	+	+	+	+
Simullidae	+	-	-	+	+	+	+	+	+	+	+	+
Tipulidae	-	+	-	-	+	+	+	+	-	+	+	+
Athericidae	+	+	-	+	+	++	-	-	-	-	+	+
Corixidae	+	+	+	-	-	-	+	-	-	+	-	+

Naucoridae	+	+	+	-	-	-	-	+	-	-	-	-
Belostomatidae	-	+	+	+	+	-	+	-	-	+	-	-
Gerridae	+	+	+	-	+	-	+	+	-	-	-	-
Nepidae	-	-	+	-	-	-	+	-	-	-	-	-
Annelida												
Tubificidae	+	-	-	-	+	-	+	-	-	+	+	+

Key: *(>10) Abundant: +++; (5-10) Common ++; (1-4) Occasional +; Absent; -*

Biomphalaria sp. and Elmidae were abundant with 13 ind./m^2. *Aylacostoma* sp. dominates the Laduba Station with 19 ind./m^2, *Pachychilus sp.* and *Sphaerium* sp. were abundant with 12 ind./m^2. *Sphaerium* sp., *Pisidium* sp., Chironomidae and Asellidae dominate the Afon Station of Lake Asa with 10 ind./m^2. Other macroinvertebrates occurs occasionally and rarely at stations in seasons.

Diversity Indices: Macroinvertebrate taxonomic richness, diversity and evenness for each station and sampling period are present in Table 6. In the present study, the Lake Asa waters are highly used for irrigation, fish farming, domestic and industrial water supply purposes. Domestic, industrial discharge, runoffs from catchment farm fields and cattle rearing are guilty of the pollution of Lake Asa. Diversity indices for a freshwater such Lake Asa describe the response of its macroinvertebrate community to the quality of its environment (waters) in terms of species richness (number of species), abundance (total number of organisms) and evenness (distribution of individuals among the species), based on the hypothesis that impacted lake systems or catchments have a lower diversity (Metcalfe, 1989). These diversity indices (species richness, total diversity and evenness) are often applied on an individual basis (Shannon and Weaver, 1964; Hill, 1973). They have previously been used in the United States to assess water quality and as a comparative ecological tool to evaluate tropical streams and rivers (Ometo *et al.,* 2000).

Ruus *et al.* (2019) established the following relation between the indices and the different ecological levels according to what is recommended by the Water Framework Directive: High status: >4; Good status: 4 – 3; Moderate status: 3 – 2; Poor status: 2 – 1; Bad status: 1 – 0.

According to Watanabe *et al.* (1999), the species diversity index (H) value ranged from >3, indicating clean water, from 1 to 3, indicating moderately and < 1, indicating heavily polluted conditions of the water. Therefore, the impact of pollution is moderate at all stations in Lake Asa (2.9). According to Mozumder *et al.* (2014), the Evenness index (J) takes a value between 0 and 1. When the value is getting closer to 1, it means that the individuals are distributed equally. In the present study, the Evenness Index of the Dam and Laduba Stations (0.86 and 0.82) indicates equal distribution of macroinvertebrates, while the Afon Station (0.59) indicates unequal distribution of macroinvertebrates at the station. According to Margalef (1956), higher diversity values reflect the suitability of the habitat for the organism. It has no limit value, and it shows a variation depending on the number of species. Margalef's Index of the Dam and Laduba Stations (3.1 and 3.25) are suitable habitats for macroinvertebrates, allowing diverse macroinvertebrate species to exist, indicating suitable environmental variables of the stations. Afon Station (1.25) indicates heavy pollution, station environmental conditions suitable only for pollution-tolerant taxa such as the chironomids, simuliids and *Biomphalaria* sp.

Relationship Between Lake Asa Macroinvertebrates Community and Physicochemical Parameters: The macroinvertebrates data were reduced by nMDS to 2 surrogate variables (Coordinate 1 and Coordinate 2) with a 2D stress, which provides a potentially useful 2D picture and a fair presentation of the original data. All stations are clustering into the same areas, as demonstrated in the nMDS plot ellipses (Figure 5). A group-average linked method was used in clustering (Clarke and Warwick, 1994) to confirm similarity among stations. In CCA triplots, analysis can provide a large number of insights and valuable interpretations, and such methods of direct gradient analyses are well suited to examine the relationships between environmental gradients and response variables (e.g., species). The vector length of the environmental variables indicates

the strength of the variable in describing macroinvertebrate communities considering all stations where macroinvertebrate was collected. The longest vector of temperature showed a significant correlation with Oligochaete. Thus, temperature designates the distance of each station from the lake inflow, and the station ranking is consistent with the direction of the arrow (Ter Braak and Verdonschot, 1995). The inferred abundance of a species is maximal if the site point coincides with the species point and decreases in all directions the farther away from the site point (Ter Braak and Verdonschot, 1995). As stated by Ter Braak and Verdonschot (1995), taxon that belongs to a particular class are scattered around the class point, simply because, by definition, each class is at the centroid of the station that it contains.

Macroinvertebrate taxa have different abilities to tolerate water temperature (Hawkins *et al.,* 1997; Brittain *et al.,* 2003; Gustafson, 2008) and other water chemical parameters concentration (environmental variables). As demonstrated in Figure 6, Lake Asa water temperature and organic matter (OM) have a positive correlation, which influences the abundance and occurrence of Oligochaetes at Dam Station during the study period. The water temperature influence on Oligochaete is higher than that of OM. These indicate temperature and OM have little or no influence on other macroinvertebrate taxa distribution and occurrence at Dam Station. pH has a more positive correlation than the Lake Asa water sulphate, DO, TOC, and COD concentrations on the Bivalves at the dam and Laduba Station, as represented on the CCA triplot. The TDS has a positive correlation with insect abundance and occurrence in all three stations at Lake Asa.

In Figure 5, gastropods occurrence is most positively correlated with EC at Afon Station, also water TN and TP concentrations had a positive correlation with less influence on Gastropods distribution at the same station. In addition, some ecological features varied between Lake Asa systems, but these were evident in a few community structures at Dam Station. This is also reflected in the ANOSIM results, which suggested similar macroinvertebrate communities in the stations across Lake Asa, in terms of community structure. This highlights the fact that community differences were due to naturally disrupted ecosystems from various types of human stressors, as reported by Rader *et al.* (2008).

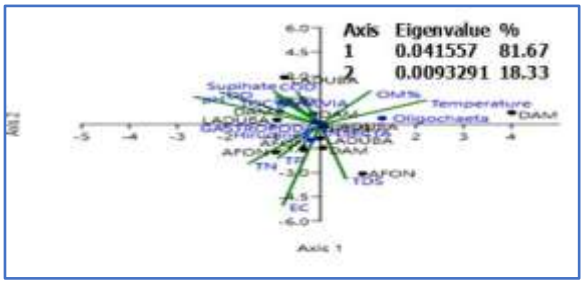


Figure 5: CCA triplot showing effects of environmental variables on macroinvertebrate community structure in Lake Asa. *The figure displays the relationships among stations (black dot), taxon (blue dot), and environmental variables (lines)*

Conclusion: Among the major taxa groups identified in the current study, bivalves were numerically dominant in the macroinvertebrate communities, providing the information for analysis of faunal assemblages in the sediment environment. Within the macroinvertebrate community, *Sphaerium* sp., as the dominant macroinvertebrate species, represented more than 15% of the total macroinvertebrate taxa. In contrast, Shannon-Wiener Diversity Index (H´) assessed moderate pollution, Evenness index (J) assessed uniform distributions of macroinvertebrate community, and environmental variables showed acceptable conditions for the productivity of Lake Asa. Both species composition and abundance of macroinvertebrate groups were influenced by temperature, organic matter, and pH; however, the intervening changes within the macroinvertebrate community (as indicated by CCA analysis) contributed only slightly to these changes. Therefore, the outcome of the current study shows that the macroinvertebrate community significantly responded to the variability of environmental factors. However, combinations of these factors may produce a pattern to interpret, but no single factor can affect the environment and community structure. Sediment parameters and biotic interactions were not examined in this study, which is also important factors of the patterns of community structure in Lake Asa. Further investigations are required, considering these factors, which may help to get a better understanding of the

causations behind the patterns examined in the current study.

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