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Comparative investigation provides further insights on how riparian deforestation and different land uses impact the distribution of freshwater macroinvertebrates in Nigerian streams

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ABSTRACT

Riparian forest loss and various land use impacts on macroinvertebrate communities in Nigerian streams remain poorly understudied. To fill this knowledge gap, a study was conducted on five streams in the southwest ecoregion of Nigeria between December 2019 and October 2021. A total of 2,077 macroinvertebrates were sampled, comprising 16 orders, 40 families, and 80 species. Aquatic insects were the most abundant, constituting 85 % of species and 73.13 % of individuals. Other specimens included Mollusca, Crustacea, Arachnida, and Annelida. Notably, Olumirin stream exhibited the highest macroinvertebrate abundance, including the stress-sensitive Ephemeroptera-Plecoptera-Trichoptera (EPT) members. The site also had the highest degree of naturalness, widest channel and dissolved oxygen (DO), but lowest electrical conductivity (EC) and total dissolved solids (TDS) compared to the other streams (Abirunmu, Awoosun, Mogimogi, and Aboto), that harbored facultative and stress-tolerant species, indicating varying degrees of disturbances. The bivariate regression analysis confirms that riparian deforestation and land use impact macroinvertebrate distribution in streams as there was an inverse relationship between EPT abundance and forest cover. Also, DO positively correlates with EPT taxa richness but inversely correlates with Coleoptera richness and Hemiptera abundance. As a result, Olumirin stream is proposed as a benchmark for evaluating freshwater ecological integrity in the region. Given the escalating anthropogenic activities in the tropics, urgent collaborative efforts are required to safeguard freshwater biodiversity, protect the riparian corridor of Olumirin stream, and restore impaired streams in the region.

1. Introduction

Numerous abiotic and biotic factors influence the organization of stream macroinvertebrate communities and the relative importance of these elements varies from one aquatic ecosystem to the next, depending on the spatial and temporal scale of inquiry (Arimoro et al., 2011). Over the years, a growing number of scientists from the Afrotropical region have taken a keen interest in monitoring the health of freshwater ecosystems, and their research often focused on using macroinvertebrates community structures

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and ecological indices to evaluate the ecological health of freshwater ecosystems, as evidenced in research conducted by Atobatele and Ugwumba (2010), Andem et al. (2012), Arimoro et al. (2011; 2015), Arimoro and Keke (2017), Odume (2020), Aliu et al. (2020), Akindele et al. (2020, 2022; 2023a,b,c), among others. Macroinvertebrates are highly valued as bioindicators due to their ability to offer crucial insights into the impacts of land-use changes, such as habitat degradation (Agboola et al., 2019), and pinpointing pollution sources (Xu et al., 2014). Additionally, macroinvertebrates are valuable groups of organisms used in making informed management decisions (Vries et al., 2021) and in assessing the overall water quality in aquatic ecosystems (Akindele et al., 2023a,b,c; Arimoro et al., 2021). Many aquatic ecologists prefer macroinvertebrates in biomonitoring studies over other aquatic animals because of their sensitivity to environmental stressors, such as pollution, habitat degradation, and flow regime alteration (Li et al., 2017). Also, being sessile animals, make them more vulnerable to changes in their environment, unlike most fishes, that can easily move to other areas if conditions become unfavorable (Xu et al., 2014). Ecologically, they are important primary consumers and decomposers, supporting the food web in lotic systems, in which fish and other advanced freshwater vertebrates, higher in the food web are often less sensitive to changes in the lower trophic levels unlike macroinvertebrates (Cummins 1973; Jiang et al., 2021). Researchers equally prefer macroinvertebrates over other bioindicators because its sampling and analysis approach is standardized and authenticated, allowing for comparability of data across different locations and time (Barbour et al., 1999). In the light of these, alteration to macroinvertebrate communities have been observed to have significant impacts on ecosystem functioning (Akamagwuna et al., 2023).

Forests and riparian vegetation play crucial role in freshwater ecosystems by providing habitat (Arimoro et al., 2011), food resources (Andem et al., 2012; Arimoro et al., 2015), assist in stream temperature regulation (Guevara et al., 2018) and nutrient cycling processes for a wide range of macroinvertebrates (Aliu et al., 2020). According to Casotti et al. (2015), riparian forests influence the availability of litter, also known as coarse particulate organic matter (CPOM), from trees which is critical for food web and biological productivity. Streams with extensive forest cover are projected to have greater CPOM as many species of macroinvertebrates feed on leaves, twigs, and other organic material that fall into the stream from surrounding forests and submerged vegetation, compared to deforested riparian corridors with attendant pronounced anthropogenic activities (Ono et al., 2020; Guevara et al., 2018; Adkins and Rieske, 2015). Moreover, riparian vegetation shelters these animals from predators, thus allow them to complete their natural life cycles (Silva-Junior et al., 2014; Arimoro et al., 2011). Furthermore, vegetation regulates the water temperature by reducing the amount of direct sunlight reaching the water surface through shading (Guevara et al., 2018). According to Luke et al. (2007), Mayer et al. (2007), and Akindele et al. (2020), riparian forests are vital sinks for sediments, nutrients, and pollutants, thus minimizing the introduction of foreign and toxic substances into aquatic systems. This therefore underscores the importance of protecting a strip of riparian vegetation as a buffer zone for aquatic systems against the influx of nutrients and pollutants from neighboring terrestrial areas and human activities. On the flip side, the removal of vegetation from riparian corridors and their subsequent conversion to farmlands and grazing lands can have significant impacts on biological water quality in freshwater systems (Allan, 2004; Arimoro et al., 2011; Mbonimpa et al., 2016; Akinpelu et al., 2019; Tromboni et al., 2019). Deforestation and other human land uses, including agricultural practices, have been reported to have negative effects on aquatic ecosystems and their associated biota, such as macroinvertebrates (Mwedzi et al., 2016; Ono et al., 2020) These impacts include a reduction in the availability of CPOM and the eventual elimination of fine particulate organic matter (FPOM) that is formed from shredding activities of macroinvertebrates (Voshell, 2002; Bastos and Casotti, 2014).

Afrotropical streams are known for their rich biodiversity (Akindele et al., 2020; 2022; 2023b). However, deforestation of their riparian corridors can cause significant changes to the physical and chemical properties of water by impacting habitat quality, eliminate their food resource through introduction of pollutants, and ultimately affecting the distribution and abundance of macroinvertebrates (Arimoro et al., 2011; 2015; 2021; Aliu et al., 2020). Deforestation and human land use practices can lead to a significant decline in macroinvertebrate populations in lotic systems as a result of the reduced availability of certain food resources that macroinvertebrate functional groups prefer (Adedapo et al., 2023). Numerous studies have established the importance of riparian forest cover in maintaining freshwater ecosystems and the macroinvertebrate community structures in lotic systems in temperate ecological zones (e.g., Guevara et al., 2018; Broeck et al., 2019; Marques et al., 2021). Similarly, researchers in the Neotropics have proposed that conserving forests near water bodies can minimize the negative impacts of environmental dynamics on aquatic macroinvertebrate diversity (Dala-Corte et al., 2020; Addo-Bediako et al., 2023). Despite the recognized significance of riparian forests in maintaining freshwater ecosystems in temperate regions and the Neotropics, their impact on macroinvertebrate biodiversity and water quality in Sub-Saharan African streams, particularly in Nigeria, remains insufficiently studied. Existing research from Nigeria has inadequately attributed the main drivers of biodiversity loss in lotic systems to deforestation-induced reduction in shading, while focusing more on factors such as temperature changes, climate change, habitat degradation through pollution, alteration of faunal abundance, and disruption of essential food resources (Arimoro et al., 2011; 2015; 2021; Adedapo et al., 2023).

The growing human population in Osun State, Southwest Nigeria, has resulted in increased demand for land and water, leading to encroachment into riparian corridors and posing serious threats to the health of freshwater ecosystems. While some studies have investigated the effects of environmental stressors on macroinvertebrates and biological water quality in rivers and lakes from this region (e.g., Aiwerioghene et al., 2016; Asibor, 2015; Edward and Ugwumba, 2011), there is still a lack of information on the distribution of freshwater macroinvertebrates in response to different forest cover and various land use specifically in streams. The objective of this study is to address the existing knowledge gap by examining the distribution of macroinvertebrates in streams within a Southwestern ecoregion State of Nigeria, where varying degrees of forest cover and human activities are present. By doing so, this research aims to provide valuable insights into the relationship between macroinvertebrates and the level of riparian forest cover, as well as anthropogenic interferences in the region. Based on naturalness indices (Mereta et al., 2013; Akindele et al., 2023c) and biological metrics of Arimoro et al. (2021), it was hypothesized that, riparian forested sites that have not been impacted by human activity will have higher abundance and richness of macroinvertebrate taxa, including the EPT-taxa, vice-versa. The study's relevance is in its contribution towards the achievement of UN Sustainable Development Goals (SDGs) 15, which seeks to safeguard terrestrial and inland freshwater ecosystems for long-term use (Ait-Kadi, 2016).

2. Materials and methods

2.1. The study areas

This study focuses on five streams situated in the tropical rainforest area of Osun State, Southwest Nigeria, namely: Abirunmu, Awoosun, Mogimogi, Oluminrin, and Aboto streams (Fig. 1). The State, located within latitude 7.0° and 9.0° N, and longitude 2.8° and 6.8° E, has a total land area of approximately 8602 km^2 and an elevation of 300–600 m above sea level. The terrain is predominantly

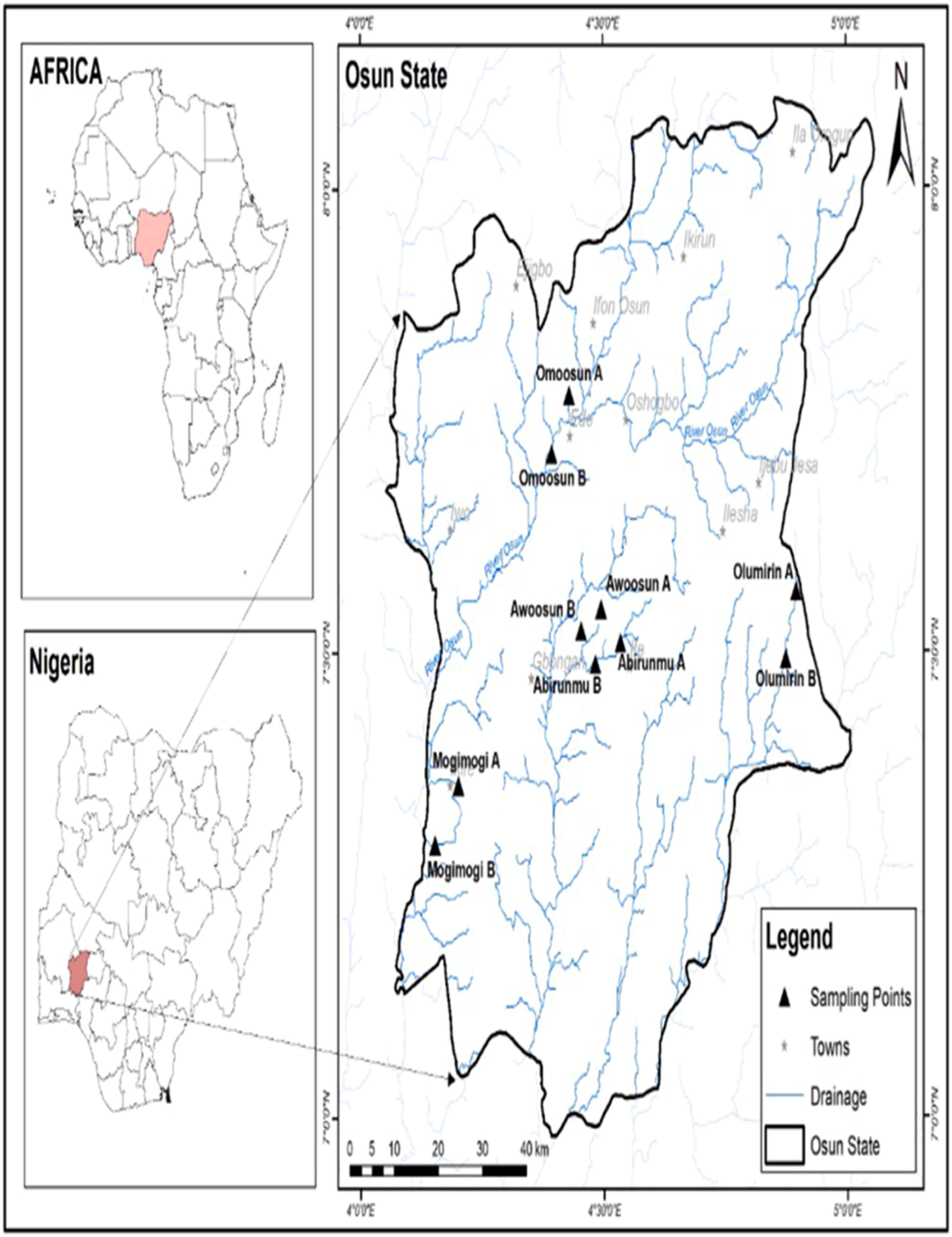

Fig. 1. Map of Nigeria showing the location of the sampled streams in Osun State and the sampling stations.

gentle and undulating, with two distinct seasons - a wet season (April to October) and a dry season (November to March) (Hussaini and Matazu, 2023). The average annual rainfall ranges from 1125 mm in derived savannah to 1475 mm in the rain forest belt, while the mean temperature varies from 27.2 °C in June to 39.0 °C in December (Sofoluwe et al., 2011). The region's soil types are diverse, with clay, sand and laterite being the most common constituents. Agriculture is the primary source of livelihood in this region (Fasona et al., 2018). In order to investigate the effects of riparian deforestation and different land uses on macroinvertebrate communities, streams from various locations in Osun State that shared similar physiographic conditions, substrate types, and aquatic orders, with differing anthropogenic factors were selected. Two sampling stations were established in each stream, one in the upper reach and the other in the lower reach. Table 1, provides the grid coordinates (latitude and longitude) and altitudes of the sampling points in each of the streams.

2.2. Stream description

The Abirunmu stream, situated in the western section of Obafemi Awolowo University Campus, Ile-Ife, has its source in an aquifer within a forest ecotone. Flowing steadily downstream, it eventually merges with the Opa River. The communities residing along the stream heavily depend on its water for various activities, including agricultural irrigation, palm kernel processing, and open grazing. The vegetation surrounding the stream can be described as a moderate open forest, with a canopy cover ranging from 10 % to 40 %. Over the stream, *Theobroma cacao* trees form a sparse canopy, while submerged and floating macrophytes such as *Nymphaea lotus, Eichhornia crassipes, Lemna pausicostata, Eichornia* sp., *Typha* sp., *Oxystigma manni, Xylopia* sp., *Pycreus lanceolatus*, and algae (*Chlorophyta* sp.) can be found in both sampling stations. During June (early rainy season) and October (late dry season), some inundation occurs. The stream's substrate primarily consists of silt and sand sediments, with a notable presence of dead macrophytes and wood debris.

Awoosun stream derives its primary source of water from seepage of an aquifer below a dense *Bambusa* sp. flora, as well as precipitation and surface run-off. The substratum consists of rock, cobbles, clay, and silt. However, the area surrounding the stream has experienced extensive deforestation due to bush fires and activities of herders, particularly during the dry season. Despite this, the burnt pastureland quickly recovers during the wet season. Human activities in the vicinity of the stream include farming, sand excavation, dumping of domestic wastes and the establishment of a camp for nomadic herdsmen and their animals, located around 10 m away from the stream. Cattle frequently graze on riparian vegetation and drink from the stream, leading to noticeable excrement and footprints around the area. The forest surrounding the stream is classified as an open forest, it ranged between 10 and 20 %, consisting of grasses and rushes. The submerged vegetation in the area includes *Musa paradisiaka, Nymphaea* sp., *Azolla* sp., *Scirpus jacobi, Vossia cuspidate, Utricularia* sp., and *Salvinia* sp.

The Mogimogi stream, despite sharing a similar origin with the Abirunmu and Awoosun streams, exhibits a distinct characteristic of slow flow regime and ultimately drains into the Osun River. Unfortunately, human activities have significantly impacted this stream due to its close proximity to farmland and human settlements. These activities include farming, domestic waste disposal, water abstraction for concrete block-molding, abattoir operations, grazing activities, poultry effluent discharge, and aquaculture. Deplorably, some sections of the stream have been transformed into unsightly and foul-smelling "latrines." This not only detracts from its visual appeal but also contributes to an unpleasant odor. Furthermore, the stream's canopy cover is less than 10 %, leaving it exposed to direct solar radiation. The presence of macrophytes such as *Lemma* sp., *Utricularia* sp., and *Salvinia* sp. has been observed along the stream banks, indicating the limited diversity of plant species in the area. Riparian plants, including *Bambusia* sp., *Musa paradisiaka*, palm trees (*Arecaceae*), and *Elaeis guineensis*, provide fragmented shade over the stream. The substratum composition primarily consists of clay, silt, and a small amount of sand sediment, which is transported into the stream through surface runoffs.

The Oluminrin Stream is a swiftly flowing watercourse that meanders through a densely wooded area. The stream derives its water from the world-famous Erinjesha waterfall, which tumbles down the hillsides before flowing into the stream. The stream culminates in a plunge pool at the hills' lowest layer, where the water slows before continuing its journey. The course of the stream is rocky, with eroded rocks, sand, cobble, and decayed wood debris and leaves from the riparian corridor making up the substratum. The location of the stream meets the criteria for a Category III protected area (natural monuments) established by the International Union for Conservation of Nature and Natural Resources (Dudley, 2008), highlighting its ecological significance. The stream is heavily shaded by a

Table 1
The grid coordinates (latitudes and longitudes) and altitudes of sampled streams in Osun State, Southwest Nigeria.

Stream	Location in Osun State	Sampling Station	Grid Coordinates		Altitude (m)
			Longitude	Latitude	
Abirunmu	Ile-Ife	Upstream	N07°30.633	E004°30.065	239
		Downstream	N07°30.498	E004°29.982	237
Awoosun	Ipetumodu	Upstream	N07°31.247	N004°28.993	248
		Downstream	N07°30.954	N004°28.364	228
Mogimogi	Apomu	Upstream	N07°20.192	N004°12.085	226
		Downstream	N07°20.506	N004°11.247	205
Olumirin	Erinjesha	Upstream	N07°56.494	N004°90.662	463.5
		Downstream	N07°56.494	N004°89.971	295.5
Aboto	Ede	Upstream	N07°45.386	N004°25.393	272
		Downstream	N07°45.348	N004°26.318	269

range of tall and economically important trees, including *Chlorophora excelsa, Ceiba pentandra, Commelina nodiflora, Pentaclethra macrophylla, and Afzelia belle,* that formed layers of canopy ranging above 70 %. The thick canopy cover makes the area a dense forest that provides a natural habitat for a diverse array of flora and fauna. Various submerged and floating macrophytes, including *Nymphaea* sp., *Azolla* sp., *Utricularia* sp., *Salvinia* sp., *Oxystigma manni, Xylopia* sp., and algae (*Chlorophyta* sp.), thrive in the stream's clear waters. In ensuring the preservation of the stream's natural beauty and ecological importance, human activities such as research, tourism, and recreational activities are carefully controlled and regulated.

The Aboto stream, unlike the Mogimogi stream, is a swiftly flowing headwater stream that flows into the Osun River from a forest ecotone situated behind the military barracks in Ede, Osun State. However, the area surrounding the Aboto stream exhibits visible signs of deforestation, primarily due to farming activities, resulting in a canopy cover of less than 20 %. Anthropogenic activities related to land use in the vicinity of the stream include irrigation, grazing activities, water extraction for washing, concrete block molding, abattoir services, and various uses such for spiritual exercise and bathing. These activities have collectively contributed to the degradation of the stream's ecosystem. The Aboto stream hosts a limited number of floating macrophytes, such as *Oxystigma manni* and *Matrogyna ciliata,* with sparse distribution of *Gliricidia sepium* trees offering little fragmented shade along the stream bank. Consequently, the stream environment is characterized as an open forest. The substratum of the Aboto stream is composed of rocks, and silty-clay sediments.

2.3. Field sampling, in-situ determinations and environmental variables

Field sampling took place between December 2019 and October 2021, spanning the early and peaks of the two dominant seasons in the study area (dry and wet). Sampling months were: December 2019 (early dry season), March 2020 (late dry season), June 2020 (early rainy season), October 2020 (late rainy season), December 2020 (early dry season), March 2021 (late dry season), June 2021 (early rainy season), and October 2021 (late rainy season).

The naturalness method (Mereta et al., 2013), combined with Arimoro et al. (2021) biological integrity criteria, was used to evaluate the impact of riparian deforestation near the streams. The assessment considered various criteria to determine the naturalness of the streams under investigation. These criteria included riparian vegetation removal, in-channel structure, grazing activities, agricultural practices, and dumping of wastes. In assigning scores to the naturalness criteria, the method described by Mereta et al. (2013) and Akindele et al. (2023c) was followed. The scoring system consisted of three levels: '1′ represented minimal or no disturbance, '2′ indicated moderate disturbance, and '3′ indicated a high level of disturbance. A detailed description of the naturalness criteria and their corresponding metric scores can be found in Table 2, while Table 3 presents the results of the naturalness assessment of the streams under study. The percentage proportion of vegetation cover to the width of each stream, as well as the substratum composition, were determined visually (Kennedy and Addison, 1987; Addo-Bediako, 2021). The average time it took a float to traverse across a distance of 10 m, was used to calculate flow velocity (Seidu et al., 2019). The depth of the streams was determined by using a wooden rod that is graduated in meters, while the width of the streams was measured with a meter tape at the broadest point of the streams for each station and sampling period (Keke et al., 2020). The following physicochemical water parameters were measured using a digital meter (Multi 3630 IDS, WTW/Xylem Analytics, Germany): water temperature, pH, dissolved oxygen (DO), electrical conductivity (EC), and total dissolved solids (TDS). Water samples were also collected for analysis of nitrate, phosphate and organic matter.

Macroinvertebrate samples were collected at the same time from various substrate types, microhabitats (such as vegetation, stones, sand, and gravels), and flow regime zones. A D-frame net (500 m mesh) was also employed along a 10-meter-long wade-able length of each of the streams as part of the kick sampling approach. Manual searching was also done by collecting wood debris and removing specimens from it. Some macroinvertebrates were seen to stick closely to rocky substrates and trailing plants and were collected by examining the microhabitats as described by Akindele et al. (2022). Average of 30 min was spent per sampling point in each of the streams throughout the study period (Buss et al., 2015). For each of the upstream and downstream spots, all of the samples were combined to form a single sample. Collected samples were preserved in 70 % ethanol before proceeding to the laboratory.

Table 2
Criteria used for assessing the naturalness of the study streams, adapted from Mereta et al. (2013) and Akindele et al. (2023c).

Naturalness criterion	Metric score		
	1	2	3
Riparian vegetation removal	None or <10 % of vegetation removed within 50 m from the river	10–50 % of vegetation removed within 50 m from the river	>50 % of vegetation removed within 50 m from the river
Grazing	Little or none	Moderate	High
Farming	None at > 50 m from the river	At < 50 m from the river	Within the river channel
Waste dumping	None	At the river bank	Within the river channel
Water abstraction	None	Domestic water abstraction only	Industrial water abstraction
In-channel structure	None	At the river bank	Within the river
Naturalness criterion description	None impacted	Moderately impacted	Severely impacted

Table 3
Naturalness of the investigated streams based on riparian forest cover and land use practice of the studied location in Osun State Southwest Nigeria.

Naturalness Parameter/Score	Streams				
	Abirunmu	Awoosun	Mogimogi	Olumirin	Aboto
Riparian vegetation removal Naturalness score	2	2	3	1	3
In-channel structure Naturalness score	2	2	3	1	3
Grazing activities by Herders (Naturalness Score)	2	2	3	1	3
Agricultural practices (Naturalness Score)	2	2	3	1	3
Dumping of wastes Naturalness score	2	2	3	1	3
Overall average Naturalness	**2**	**2**	**3**	**1**	**3**

2.4. Laboratory analysis

Turbidity was determined in the laboratory using APHA (2015), while biological oxygen demand (BOD) was measured after five days of incubation in a dark cupboard using the Multi 3630 IDS digital meter. Nitrate and phosphate were analysed spectrophotometrically after reduction with appropriate solutions (APHA, 2015). The collected macroinvertebrate samples were washed in a 500-µm mesh and sieved in order to remove sand before sorting them out. Separation, enumeration and identification of all the organisms caught were carefully carried out under a trinocular zoom dissecting microscope (VZE/VZF Parco China). Identification of macroinvertebrate species was done by using Afrotropical identification keys such as Day et al. (2002), de Moor et al. (2003), Arimoro and James (2008), Merritt and Cummins (1996), and expert assistance.

2.5. Statistical analysis

The study employed a range of statistical tests, analytical tools, and biodiversity indices to investigate various aspects related to macroinvertebrates in the studied streams. These aspects included spatial fluctuations, responses to environmental factors, and the impact of riparian deforestation. The analysis involved examining data on environmental variables, macroinvertebrates, and water quality using established statistical techniques such as the Shapiro-Wilk test, One-Way Analysis of Variance, Kruskal-Wallis's test, as well as correlation and regression analysis. Normality of the environmental variable dataset was assessed using the Shapiro-Wilk test, as outlined in Appendix 1. One-Way Analysis of Variance was employed for datasets with a normal distribution, while non-parametric Kruskal-Wallis's test was used for datasets that did not conform to normality. The Kruskal-Wallis's test was specifically used to investigate spatial variations in macroinvertebrate diversity due to the dataset's failure to meet parametric assumptions. Biodiversity indices, such as species richness, abundance, Margalef index, Shannon-Wiener index, and evenness, were determined based on the dataset of aquatic macroinvertebrates. These indices provided insights into the impact of riparian deforestation on the studied streams by measuring taxonomic composition, abundance, and diversity.

Canonical Correspondence Analysis (CCA), a widely used technique for simplifying multidimensional data, was employed to identify associations between macroinvertebrate communities and environmental variables (Braak and Smilauer 2002). To ensure compliance with parametric assumptions, the physicochemical dataset was log-transformed using the formula $\log(x + 1)$ due to non-normal distribution. Outliers that could significantly influence the analysis were eliminated prior to conducting the CCA. The significance of the canonical axes was assessed using a Monte Carlo permutation test with 99 permutations. As the physicochemical data did not exhibit a significant relationship with the macroinvertebrate community in the CCA analysis, a correlation and regression analysis were performed on a case-by-case basis. This analysis aimed to determine which environmental and water quality variables, as well as biological and naturalness metrics, were influenced by riparian deforestation in the study. All data analysis were carried out using R Version 4.22 and PAST software (Version 4.12).

3. Results

3.1. Land use and physicochemical variables of the investigated streams

Tables 2 and 3 provided significant findings regarding the naturalness criteria and the diverse levels of human influence on deforestation extent and land use patterns in the examined streams. The observed physical characteristics reveal distinct features among the five streams examined, as the riparian corridor of Olumirin stood out as the only stream with a primary forest, indicating its relatively undisturbed condition. In contrast, Awoosun exhibited grasslands and brushes, indicating a more transformed landscape, while Abirunmu, Mogimogi, and Aboto displayed secondary forests, suggesting different degrees of human perturbation. The analysis of percentage forest cover further highlights these differences, as Olumirin stream exhibited the highest percentage, emphasizing its exceptional conservation status. Abirunmu and Awoosun ranked second and third, while Mogimogi and Aboto streams occupied the fourth and fifth positions respectively. In the majority of the study sites, agricultural practices and garbage disposal were prevalent, highlighting the influence of human activities on the surrounding environment. However, it is noteworthy that Olumirin stream exhibited no indications of these practices in its vicinity, suggesting a relatively undisturbed ecosystem. Water abstraction was observed in the majority of the study sites, excluding Abirunmu and Awoosun. Similarly, washing activities were noted in all streams, except for Abirunmu and Olumirin, suggesting that these particular sites experienced relatively lower levels of these human activities.

Furthermore, herders were present in all study sites, except for Olumirin, which stood out as the sole location devoid of any signs of human habitation. Table 4, provides a comprehensive overview of the physicochemical and environmental characteristics observed during the study period. The results clearly demonstrate significant spatial variations ($p < 0.05$) in multiple parameters, involving the channel width, DO, TDS, and EC among the streams, as shown in Figs. 2–5. The Mogimogi stream exhibited the narrowest water channel width, whereas the Oluminrin stream had the widest, which was statistically significant ($p<0.05$) based on Tukey's post hoc test. DO equally exhibited significant spatial variation ($p < 0.05$), as Oluminrin stream displayed the highest concentration, while Awoosun stream had the lowest concentration according to Tukey's post hoc test. The TDS values significantly varied ($p < 0.05$) across the streams, with the highest value observed at Aboto and the lowest values found at the Oluminrin stream as confirmed by the one-way ANOVA and the Tukey post-hoc test. The EC concentration also showed significant variation ($p < 0.05$) as revealed through Tukey's post hoc test. Highest concentration was recorded at Aboto stream and the lowest at the Olumirin stream.

3.2. *Macroinvertebrate assemblages in the five streams*

A total of 2077 individuals representing 80 species from 5 phyla, 7 classes, 16 orders, and 40 families were sampled from the five streams investigated (Table 5). Aquatic insects dominated the distribution of fauna, followed by molluscs, crustaceans, arachnids, and annelids. Hemiptera had the highest number of families (8) among the insects, while the least number of families (one each) were observed in nine orders including Plecoptera, Trichoptera, Unionida, Venerida, Lymnaeida, Architaenioglossa, Sorbeochoncha, Opisthopora, and Tricladida. The species *Melanoides tuberculata, Sudanonautes africanus, Rhagovelia* sp., *Pseudagrion* sp., *Paragomphus genei*, and *Orthetrum* sp. were found in all of the investigated streams. However, *Sudanonautes africanus, Elassoneuria candida, Rhagovelia* sp., *Pseudagrion* sp., *Orthetrum* sp., and *Lanistes varicus* were particularly noteworthy for contributing to over 100 individuals in total abundance of fauna across the streams. Olumirin recorded highest macroinvertebrates abundance while Mogimogi recorded the lowest. Table 6, provides an outline of the primary taxonomic categories commonly employed to evaluate the biological and ecological condition of freshwater systems. The data shows the patterns in the distribution of macroinvertebrate abundance in the following order: Olumirin>Abirunmu>Awoosun>Aboto>Mogimogi. Regarding the abundance of Ephemeroptera, Plecoptera, and Trichoptera taxa (EPT), Olumirin showcased the highest EPT abundance, followed by Awoosun, Aboto, Abirunmu, while Mogimogi recorded the lowest. Odonata and Coleoptera displayed a similar trend, with the highest abundance observed in Abirunmu and lowest abundance in Mogimogi. Dipterans were generally scanty throughout the collection, with the highest abundance found in Aboto and the lowest in both Abirunmu and Awoosun. Notably, Dipterans were absent in Mogimogi. Hemiptera exhibited the highest abundance in Awoosun, whereas Olumirin had the lowest abundance among the streams. Decapoda, on the other hand, recorded the highest abundance in Olumirin, with Aboto displaying the lowest abundance. Lastly, Mollusca exhibited the highest abundance in Aboto and the lowest in Olumirin. In respect to richness, Olumirin recorded the highest EPT taxa richness while Mogimogi and Awoosun recorded the lowest. Odonata richness was highest in Abirunmu and lowest in Aboto. Coleopterans recorded highest richness in Awoosun and lowest in Olumirin stream. Dipterans richness was generally insignificant in the whole collection but were totally absent in Mogimogi. Among the investigated streams, Abirunmu exhibited the highest overall taxa richness, indicating a greater variety of species present, while Mogimogi had the lowest taxa richness. Highest Odonata richness was recorded at Abirunmu, while the lowest richness was at Aboto. Coleopterans and Hemipterans, Awoosun exhibited the highest richness, indicating a greater diversity of these insect groups, whereas Olumirin had the lowest richness for these taxa. Dipterans, on the other hand, displayed generally insignificant richness across the entire collection, but were entirely absent in Mogimogi. Decapoda richness was generally consistent across all the streams, except for

Table 4
Spatial variation in the physicochemical/Environmental water parameters for the investigated streams in Osun State, Southwest Nigeria (December 2019 – October 2021).

Physicochemical Parameters	Streams (Mean ± SD)						ANOVA	
	Abirunmu	Awoosun	Mogimogi	Olumirin	Aboto	F or H	df	P
Depth (m)	0.56 ± 0.63	0.33 ± 0.25	0.33 ± 0.33	0.27 ± 0.06	0.36 ± 0.28	0.783	39	0.544
Width (m)	**2.22 ± 1.35^{ab}**	**2. 20 ± 1.27^{ab}**	**1.43 ± 1.05^{b}**	**3.88 ± 1.20^{a}**	**3.21 ± 1.30^{ab}**	**4.202**	**39**	**0.008****
Flow Rate (m/s)	0.12 ± 0.10	0.35 ± 0.13	0.09 ± 0.12	0.14 ± 0.16	0.35 ± 0.15	0.565	39	0.693
Discharge (m^3/s)	0.20 ± 0.35	0.25 ± 0.51	0.15 ± 0.26	0.15 ± 0.08	0.24 ± 0.28	3.12	39	0.538
Water Temperature (°C)	24.04 ± 3.93	24.13 ± 3.99	26.83 ± 5.78	24.59 ± 1.94	26.92 ± 1.72	1.030	39	0.413
Dissolved Oxygen (mg/l)	**6.05 ± 1.67^{ab}**	**5.73 ± 1.46^{b}**	**6.18 ± 1.06^{ab}**	**7.59 ± 0.38^{a}**	**6.55 ± 0.80^{ab}**	**17.16**	**39**	**0.002****
TDS (mg/l)	**79.06 ± 12.87^{ab}**	**69.25±21.35^{bc}**	**109.50±27.95^{ab}**	**23.56±3.48^{c}**	**120.06±62.82^{a}**	**9.428**	**39**	**4E-05*****
Conductivity (EC) (μScm^{-1})	**117.84±18.98^{a}**	**115.81±34.70^{a}**	**164.03±41.73^{a}**	**35.13±5.11^{b}**	**177.84±94.46^{a}**	**8.916**	**39**	**7E-05*****
pH	6.75 ± 1.36	6.89 ± 1.36	6.87 ± 1.36	7.32 ± 0.39	7.56 ± 0.29	4.187	39	0.381
BOD (mg/l)	1.82 ± 1.23	1.49 ± 0.95	1.87 ± 1.11	2.78 ± 1.86	1.36 ± 0.70	1.430	39	0.240
Turbidity (NTU)	13.04 ± 4.27	21.65 ± 13.01	31.32 ± 29.49	10.57 ± 4.49	22.56 ± 10.78	2.014	39	0.095
Nitrate (mg/l)	2.82 ± 3.37	4.16 ± 3.18	5.37 ± 2.01	3.89 ± 2.02	6.70 ± 2.97	2.014	39	0.113
Phosphate (mg/l)	0.06 ± 0.09	0.05 ± 0.05	0.06 ± 0.05	0.03 ± 0.01	0.04 ± 0.01	7.198	39	0.126
Organic matter (mg/l)	0.36 ± 0.08	0.36 ± 0.07	0.37 ± 0.07	0.43 ± 0.09	0.44 ± 0.03	2.009	39	0.115

*Indicates significant difference at $p < 0.05$,.
** indicates significant difference at $p < 0.01$,.
*** indicates significant difference at $p < 0.001$. Different superscript letters on the same row indicate significant differences ($P < 0.05$) among the sites as revealed by Post Hoc test.

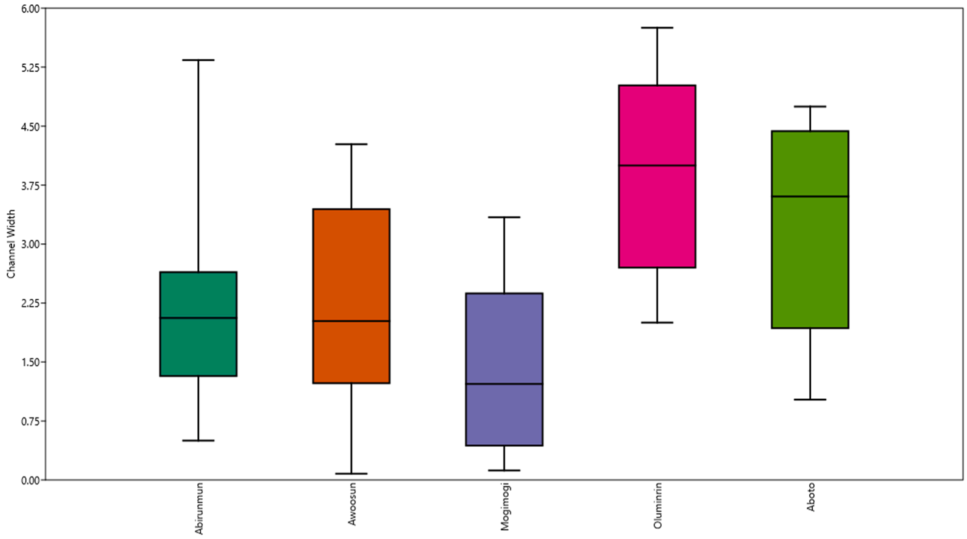

Fig. 2. Channel width boxplot showing variations across streams.

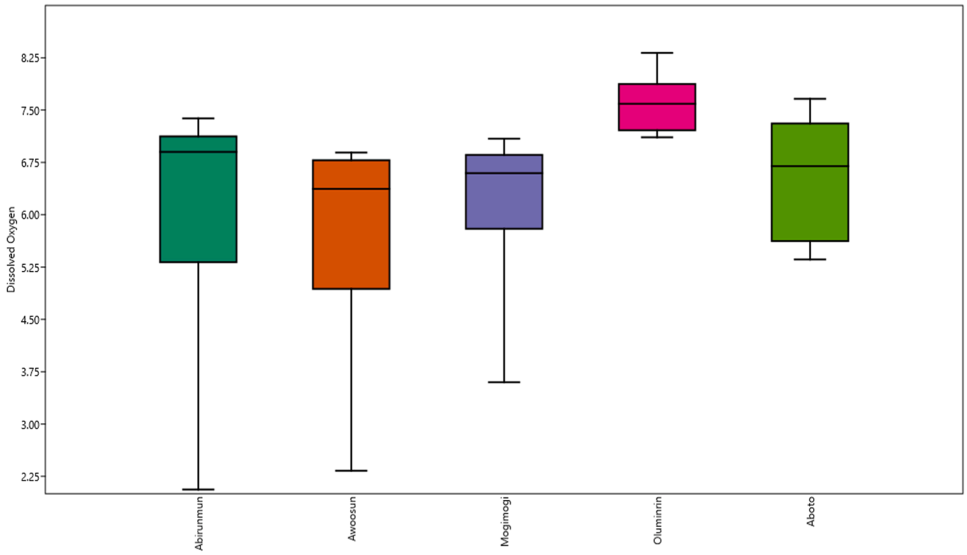

Fig. 3. Boxplot showing variations in dissolved oxygen (DO) concentration across streams.

Abirunmu, where it differed. Mollusca recorded highest richness at Aboto, indicating a greater variety of mollusk species, while Mogimogi had the lowest richness in this taxonomic group. On Shannon Diversity, Olumirin displayed the highest value, indicating a greater overall diversity of species within that stream. Conversely, Mogimogi had the lowest, suggesting a lower species diversity. Taxa Dominance was highest in Mogimogi and lowest in Awoosun. Pielou's Evenness was highest in Aboto, suggesting a relatively balanced distribution of species in that stream, conversely, Abirunmu had the lowest Pielou's Evenness, indicating a less even distribution of species. Margalef, recorded highest value in Awoosun, indicating a higher species richness adjusted for the number of individuals, while Mogimogi had the lowest, suggesting a lower species richness when considering individual abundances.

Appendix 2 displays the CCA axes, which depict the relationship between physicochemical variables and macroinvertebrates in the streams that were analyzed. All of the parameters listed in the Appendix table showed a spatial significant difference ($p < 0.05$). The Triplot in Fig. 6 illustrates the first and second CCA axes of macroinvertebrate taxa, environmental variables, and their respective sampling sites, indicating that, Axes 1 and 2 accounted for 71.2 % of the variation in macroinvertebrate distributions across the studied streams. The correlation between macroinvertebrate distribution and environmental factors varied across different stream locations. At Oluminrin, which was a forested site, the distribution of macroinvertebrates was influenced by channel width, DO, and BOD. The following taxa showed a relationship with the aforementioned environmental factors: *Caridina africana, Zygonyx natalensis, Elassoneuria candida, Enochrus* sp., *Afrobrianax ferdyi, Umma* sp., *Leptonema* sp., *Notonurus* sp., *Adenophlebia* sp., *Chlorocypha* sp.,

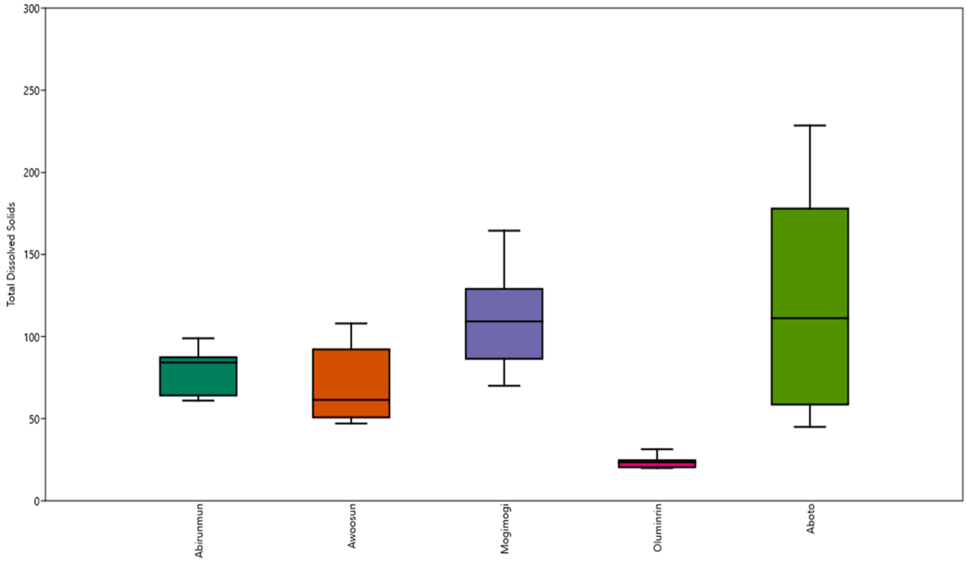

Fig. 4. Boxplot showing variations in Total dissolved solids (TDS) concentration across streams.

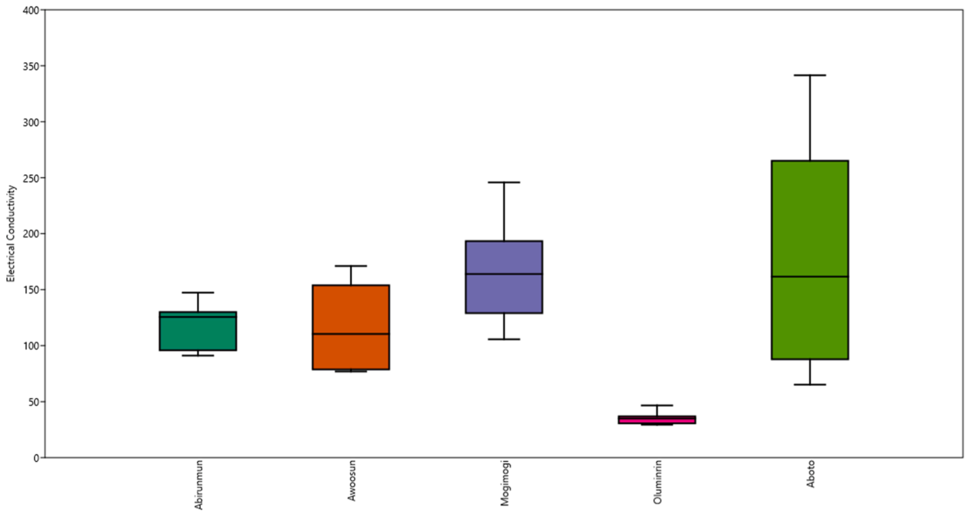

Fig. 5. Boxplot showing variations in Electrical conductivity (EC) concentration across streams.

Neomacrocoris sp., *Sudanonautes africanus, Ictinogomphus* sp., and *Laccotrephes* sp. At Awoosun stream, a location with grasses and rushes, taxa involving *Suragina* sp., *Afronurus* sp., *Notonecta* sp., *Eurymetra natalensis, Euthraulus* sp., *Neomacrocoris* sp., *Limnophila* sp., *Orectogyrus specularis,* and *Phaon iridipennis* were associated with water depth and phosphate. In the deforested Mogimogi site, *Sudanonautes africanus, Laccotrephes* sp., *Phaon iridipennis, Lestinogomphus* sp., and *Paragomphus genei* were correlated to nitrates, temperature, pH, and organic matter. Turbidity and flowrate were the two physiochemical parameters that dictated the distribution of *Cybister* sp., *Orectogyrus* sp., *Limnogonus* sp., *Pseudagrion* sp., and *Tetrathemis* sp., in the deforested Aboto stream, while at Abirunmu, which was dominated by secondary open forest, *Lanistes varicus, Sudanonautes africanus, Tenagogonus* sp., and *Bradinopyga* sp. were associated with water discharge, TDS and EC. Table 7 presents a comprehensive correlation and bivariate regression analysis that sheds light on the intricate connections between water quality parameters, macroinvertebrate biological metrics, and the naturalness of the study streams concerning deforestation impacts. The findings from the analysis unveil several noteworthy correlations. Specifically, DO exhibited a positive correlation with EPT taxa richness, while demonstrating an inverse correlation with Coleoptera richness and Hemiptera abundance. Moreover, TDS and EC displayed significant negative correlations with EPT abundance, Decapoda abundance, and overall species abundance. Furthermore, the biological metrics, namely EPT abundance and overall macroinvertebrate abundance, exhibited negative relationships with various naturalness parameters, including riparian vegetation removal, in-channel structure, grazing activities, dumping of refuse, and agricultural practices.

Table 5
The overview of total macroinvertebrates taxa richness and abundance in the study streams in Osun State Southwest Nigeria (December 2019-October 2021).

Phylum	Class	Order	Family	Species	ABR	AWS	MOG	OLM	ABT	Total
Arthropoda	Arachnida	Araneae	Dictynidae	*Dolomedes* sp.	7	3	3	–	1	14
	Malacostraca	Decapoda	Atyidae	*Caridina africana*	–	–	–	54	–	54
			Potamonautidae	*Sudanonautes africanus*	27	45	38	88	13	211
				Sudanonautes sp. B	–	4	4	–	2	10
	Insecta	Coleoptera	Dytiscidae	*Cybister* sp.	1	2	14	–	4	21
				Philaccolus sp.	–	–	2	–	14	16
			Elmidae	*Stenelmis* sp.	2	–	–	3	–	5
			Gyrinidae	*Aulonogyrus* sp.	2	5	–	–	3	10
				Dineutus sp.	–	16	–	–	7	23
				Orectogyrus specularis	64	22	3	–	7	96
				Orectogyrus sp. B	10	3	2	–	14	29
			Hydrophilidae	*Enochrus* sp.	1	15	–	5	–	21
				Hydrophilus sp.	–	1	13	–	–	14
			Psephenidae	*Afrobrianax ferdyi*	–	–	–	35	–	35
			Scirtidae	*Cyphon* sp.	–	8	–	–	–	8
		Diptera	Athericidae	*Suragina* sp.	–	–	–	2	1	3
			Chironomidae	*Chironomus* sp.	–	–	–	–	5	5
			Limoniidae	*Limnophila* sp.	1	–	–	–	–	1
			Tabanidae	*Tabanus* sp.	–	1	–	–	–	1
			Tipulidae	*Tipula* sp.	–	–	–	1	–	1
		Ephemeroptera	Baetidae	*Acanthiops* sp.	1	–	1	7	–	9
				Pseudocloeon sp.	–	–	–	–	1	1
			Heptageniidae	*Afronurus* sp.	–	–	–	1	–	1
				Notonurus sp.	1	2	–	3	–	6
			Leptophlebiidae	*Adenophlebia* sp.	–	–	–	24	1	25
				Adenophlebiodes sp.	–	–	–	7	–	7
				Aprionyx sp.	–	–	1	–	–	1
				Euthraulus sp.	3	–	3	–	–	6
			Oligoneuridae	*Elassoneuria candida*	6	41	–	81	16	144
		Hemiptera	Belostomatidae	*Sphaerodema* sp.	11	9	11	–	18	49
			Gelastocoridae	*Nerthra* sp.	3	–	–	–	–	3
			Gerridae	*Eurymetra natalensis*	–	6	4	–	–	10
				Tenagogonus sp.	1	6	6	–	1	14
				Limnogonus sp.	–	4	–	–	1	5
			Hydrometridae	*Hydrometra* sp.	1	–	–	–	–	1
			Naucoridae	*Aneurocoris* sp.	–	–	–	–	1	1
				Macrocoris sp.	–	4	–	–	–	4
				Neomacrocoris sp.	3	2	–	–	4	9
			Nepidae	*Laccotrephes* sp.	–	4	–	3	5	12
				Ranatra sp.	5	–	–	–	–	5
			Notonectidae	*Anisops* sp.	2	2	–	–	–	4
			Veliidae	*Rhagovelia* sp.	27	42	45	22	11	147
		Odonata	Calopterygidae	*Phaon iridipennis*	–	6	1	2	3	12
				Umma sp.	1	4	–	37	–	42
			Chlorocyphidae	*Chlorocypha curta*	5	2	–	–	–	7
				Chlorocypha sp. B	9	17	3	31	–	60
			Coenagrionidae	*Agriocnemis* sp.	1	1	–	–	–	2
				Pseudagrion sp.	62	20	54	12	46	194
			Gomphidae	*Crenigomphus* sp.	2	–	–	–	3	5
				Ictinogomphus sp.	4	1	1	13	–	19
				Lestinogomphus sp.	1	7	–	5	5	18
				Microgomphus sp.	–	–	1	–	–	1
				Tragogomphus sp.	2	–	–	21	–	23
				Paragomphus genei	25	8	4	9	2	48
			Macromiidae	*Phyllomacromia* sp.	3	1	–	–	–	4
			Libellulidae	*Diplacodes* sp.	–	–	–	–	6	6
				Bradinopyga sp.	–	–	–	–	2	2
				Nesciothemis sp.	3	16	2	–	4	25
				Palpopleura sp.	–	–	1	–	–	1
				Pantala flavescens	–	–	–	4	–	4
				Aethriamantha sp.	–	2	–	–	–	2
				Olpogastra lugubris	5	5	–	1	–	11
				Orthetrum sp.	13	22	12	36	30	113
				Trithemis arteriosa	14	20	3	–	17	54
				Sympetrum fonscolombii	3	–	–	2	–	5
				Tetrathemis sp.	26	1	5	–	2	34
				Zygonoides sp.	8	1	–	3	–	12

(*continued on next page*)

Table 5 (*continued*)

Phylum	Class	Order	Family	Species	ABR	AWS	MOG	OLM	ABT	Total
				Zygonyx natalensis	1	–	3	9	–	13
		Plecoptera	Perlidae	*Neoperla* sp.	6	3	–	26	3	38
		Trichoptera	Hydropsychidae	*Aethaloptera maxima*	–	–	–	9	–	9
				Cheumatopsyche sp.	–	–	–	1	–	1
				Hydropsyche sp.	–	–	–	1	–	1
				Leptonema sp.	2	–	–	40	1	43
Mollusca	Bivalvia	Unionida	Iridinidae	*Aspatharia dahomeyensis*	–	–	–	–	1	1
		Venerida	Cyrenidae	*Corbicula Africana*	–	–	–	–	6	6
	Gastropoda	Lymnaeida	Planorbidae	*Bulinus* sp.	1	5	–	–	–	6
		Architaenioglossa	Ampullariidae	*Lanistes varicus*	46	22	–	14	31	113
		Sorbeoconcha	Thiaridae	*Melanoides tuberculata*	4	1	31	3	52	91
Annelida	Oligochaeta	Opisthopora	Lumbricidae	*Lumbricus* sp.	–	–	1	2	–	3
Platyhelminthes	Turbellaria	Tricladida	Planariidae	*Planaria* sp.	–	–	–	6	–	6
Taxa richness					**45**	**44**	**29**	**38**	**38**	**80**
Total abundance					**426**	**412**	**272**	**623**	**344**	**2077**

KEY: ABR = Abirunmu, AWS = Awoosun, MOG = Mogimogi, OLM = Oluminrin, ABT = Aboto,.

Table 6
Macroinvertebrate abundance and Taxa richness of the five selected streams in Osun State Southwest Nigeria.

Metrics	Streams				
	Abirunmu	Awoosun	Mogimogi	Oluminrin	Aboto
Total macroinvertebrate abundance	426	412	272	623	344
EPT abundance	17	46	4	160	21
Odonata abundance	188	134	86	114	120
Coleoptera abundance	80	52	34	43	49
Diptera abundance	1	1	–	3	6
Hemiptera abundance	53	79	66	25	41
Decapoda abundance	27	49	42	162	15
Mollusca abundance	51	28	31	17	90
EPT taxa richness	5	3	3	10	4
Odonata taxa richness	19	17	12	13	11
Coleoptera taxa richness	6	8	5	3	6
Diptera taxa richness	1	1	–	2	2
Hemiptera taxa richness	8	9	4	2	7
Decapoda taxa richness	1	2	2	2	2
Mollusca taxa richness	3	3	1	2	4
Shannon Diversity	16.42	18.37	12.86	18. 13	16.79
Taxa Dominance	1.45	1.14	2.19	1.16	1.33
Pielou's Evenness	5.38	5.69	5.54	5.55	5.83
Margalef (Taxa richness)	24.34	29.01	15.67	25.67	23.12

4. Discussion

This study examines the influence of deforestation and human-made land activities on the distribution of freshwater macroinvertebrates in Nigerian streams. The results demonstrate that various types of riparian deforestation and anthropogenic land uses disrupt the physical, chemical, and biological characteristics of freshwater ecosystems, causing significant changes in macroinvertebrate communities. Fasona et al. (2018) emphasize the prevalence of agricultural practices in Osun State, Southwest Nigeria, which have led to the conversion of primary forests to secondary forests. Additionally, intensive farming in these areas has transformed these forests into pastures, as observed in the Awoosun stream during this investigation. In respect to similar studies by Mereta et al. (2013) and Akindele et al. (2023c), in this study, the ecological characteristics of the study sites showed notable variations. Olumirin stood out as the most ecologically stable site due to its wide riparian zone, high canopy cover exceeding 70 %, limited human interference, and thriving native vegetation. It achieved a naturalness score of 1, indicating strong ecological integrity. Abirunmu and Awoosun had secondary forests like *Theobroma cacao* and *Musa paradisiaca* plantations, indicating human encroachment and resulting in reduced canopy cover of 10–40 % and 10–20 % respectively, due to agriculture, waste disposal, and grazing. These sites were transitional between pristine and disturbed conditions, scoring 2 in overall naturalness. In contrast, Mogimogi and Aboto showed pronounced signs of riparian deforestation with canopy cover less than 10 % and 20 % respectively, along with intense human land use activities. They received a naturalness score of 3, signifying significant disturbances.

This study revealed interconnected findings regarding the spatial variation in physicochemical variables within the studied streams and their relationship to deforestation. Campbell (1993), Davies-Colley (1997), and Cortés-Guzmán et al. (2022) found that forested streams possess certain characteristics, such as wider channels, high DO levels, and good water quality, contributing to efficient nutrient cycling. Lorion and Kennedy (2009) also noted that forested streams provide abundant benthic habitats, supporting diverse

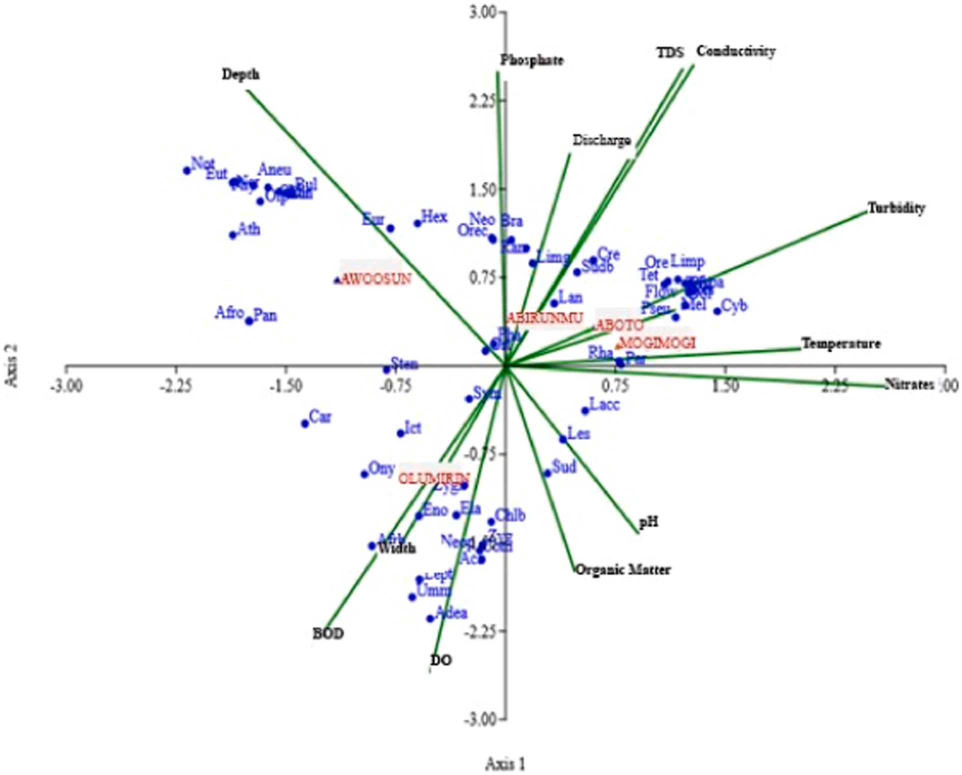

Fig. 6. Triplot of first and second axes of the Canonical Correspondence Analysis (CCA) of macroinvertebrate taxa, environmental variables and their corresponding sampling stations.

Key: Not= Notonecta sp., Eut= *Euthraulus* sp., Chl= *Chlorocypha* sp., Ath= *Suragina* sp., Afro= *Afronurus* sp., Eur= *Eurymetra natalensis,* Hex= *Hexatoma* sp., Din= *Dineutus* sp., Car= *Caridina africana.,* Ony= *Tragogomphus* sp., Ict= *Ictinogomphus* sp., Afrb= *Afrobrianax ferdyi*, Eno= *Enochrus* sp., Lept= *Leptonema* sp., Neo= *Neomacrocoris* sp., Orec= *Orectogyrus specularis*, Um=*Umma* Sp., Aden= *Adenophlebia* sp., Neop= *Neoperla* sp., Aca= *Acanthiops* sp., Chir= *Chironomus* sp., Sud= *Sudanonautes* sp., Lac= *Laccotrephes* sp., Les= *Lestinogomphus* sp., Pla= *Planaria* sp., Phy= *Phyllomacromia* sp.*,* Pseu= *Pseudagrion* sp., Cyb= *Cybister* sp., Limp= *Limnogonus* sp., Tet= *Tetrathemis* sp., Suda= *Sudanonautes africanus,* Cre= *Paragomphus genei*., Ran= *Ranatra* sp., Limg= *Tenagogonus* sp., Ore= *Orectogyrus* sp., Bul= *Bulinus* sp., Olp= *Olpogastra lugubris*, Chl= *Chlorocypha curta*, Aneu= *Aneurocoris* sp., Pha= *Phaon iridipennis; Sten= Stenelmis* sp.

Table 7
Correlation and bivariate regression showing some water quality variables and naturalness parameters that affected the macroinvertebrate community of the studied streams from Osun State Southwest Nigeria.

WQV	Biological Metrics	Pearson's r	p	Regression equation
DO	EPT taxa richness	0.9116	0.0311	$y = 4.255x-22.117$
DO	Coleoptera richness	−0.8925	0.0416	$y = 2.2612x+20.117$
DO	Hemipteran abundance	−0.9172	0.0282	$y = 26.931x+225.89$
TDS	EPT abundance	−0.9066	0.033	$y = 1.5679x+179.88$
TDS	Decapoda abundance	−0.8884	0.0439	$y = 1.178x+676.43$
TDS	Species abundance	−0.9415	0.0168	$y = 3.2512x+676.43$
EC	EPT abundance	−0.9259	0.0239	$y = 1.0892x+187.02$
EC	Decapoda abundance	−0.9043	0.035	$y = 0.8156x+154.61$
EC	Species abundance	−0.9572	0.0106	$y = 2.2481x+689.96$
Naturalness Parameters	**Biological metrics**	**Spearman's r**	**p**	
Riparian vegetation removal	EPT abundance	−0.94868	0.0325	–
Riparian vegetation removal	Overall macroinvertebrate abundance	−0.94868	0.0338	–
In channel structure	EPT abundance	−0.94868	0.0352	–
In channel structure	Overall macroinvertebrate abundance	−0.94868	0.0364	–
Grazing activities	EPT abundance	−0.94868	0.0328	–
Grazing activities	Overall macroinvertebrate abundance	−0.94868	0.0332	–
Dumping of refuse	EPT abundance	−0.94868	0.0352	–
Dumping of refuse	Overall macroinvertebrate abundance	−0.94868	0.0348	–
Agricultural practice	EPT abundance	−0.94868	0.0477	–
Agricultural practice	Overall macroinvertebrate abundance	−0.94868	0.0345	–

WQV= Water Quality Variable.

macroinvertebrate populations. Remarkably, the observation at Olumirin stream, a forested site with the widest channel, highest DO concentration and the highest macroinvertebrate count, aligns with these established research findings. The presence of DO in aquatic environments serves as a crucial indicator of their overall health, with its absence potentially signaling underlying stress (Akindele and Liadi, 2014; Arimoro et al., 2011; 2021). The higher DO content observed at Olumirin stream can be attributed to the cascading waterfalls, that facilitate the mixing of atmospheric air from the dense surrounding forests. Hamid and Rawi (2009), Mello et al. (2018), emphasized the positive influence of forests cover on DO levels in streams, as it provides shades, reducing direct sunlight penetration into the water, thus enhancing the capacity of water to hold DO. Additionally, canopy provided by the riparian forests at Olumirin is suspected to play a role in mitigating two key factors: excessive algal growth, which can deplete the DO through decomposition processes, and the impact of solar energy-induced evaporation on the stream (Allan et al., 2021; Ferreira et al., 2023). In contrast, the lowest recorded DO at Awoosun site can be credited to some factors, which include, absence of riparian forests covers to mitigate evaporation rates, reduced photosynthetic activity and increased organic input through surface runoff, caused by erosion, thus impairing microbial decomposition with attendant elevated BOD. Wantzen and Mol (2013), Mbonimpa et al. (2016), Tromboni et al. (2019) connected reduced DO content in streams and rivers to effects of riparian deforestation. Nevertheless, the mean DO concentrations recorded across all streams in this study were above the minimum 5 mg/L recommended for proper functioning of freshwater ecosystems (Chapman and Kimstach, 2006). The TDS in the streams consist primarily of HCO_3^-, CO_3^{2-}, Cl^-, PO_4^{3-}, and NO_3^-, as well as Ca^{2+}, Mg^{2+}, Na^+, K^+, and Mn^{2+} ions, along with organic matter, salt, and other particles (Mahananda et al., 2010). Stream sites characterized by increased riparian deforestation and anthropogenic land use, such as Mogimogi and Aboto, exhibited higher TDS levels in this study. This suggests a significant influx of ions into the streams due to surface runoffs caused by various human activities, including deforestation, chemical use in agriculture, wood collection for energy, waste disposal, sand mining, poultry waste discharge, and abattoir activities. Wantzen and Moi (2013), Ligeiro et al. (2013) and Mushtaq et al. (2019) have linked elevated TDS concentrations in streams and rivers to surface runoffs resulting from deforestation for farmland and mining. However, the Oluminrin stream recorded the lowest TDS value, which could be attributed to the buffering effect of riparian forests against the surface runoffs and the regulated human activities carried out through conservation efforts. The lowest EC value recorded at Olumirin stream can be attributed to the presence of layered forest cover, which effectively reduces evaporation impact on the stream. In contrast, the highest EC values at Aboto and Mogimogi can be attributed to higher temperatures resulting from excessive riparian deforestation due to farming and other associated pronounced anthropogenic activities. The findings of Mwedzi et al. (2016) support this observation, linking elevated EC levels in aquatic ecosystems to increased sedimentation caused by soil erosion due to riparian deforestation. However, despite the variations in EC observed in this study, all values remained below the suggested limit of 1000 μScm^{-1} set by the World Health Organization (WHO, 2011). This indicates that although the streams experienced different levels of anthropogenic influence and riparian deforestation, their water quality still falls within acceptable ranges.

Forests significantly impact aquatic ecosystems, affecting their physical, chemical, and biological characteristics (Arimoro et al., 2011). The highest macroinvertebrate abundance at Olumirin is linked to factors like suitable water quality, diverse microhabitats, organic matter from forests, and limited human disturbances. Studies by Negishi and Richardson (2003), Braccia and Voshell (2006), Silva-Arajo et al. (2020), Giraldo et al. (2022), Edegbene et al. (2022a), and Akindele et al. (2022) confirm that, streams with rich riparian forest corridors have higher macroinvertebrate densities, greater taxonomic richness, and more stable community structures, as forest regulates water temperature, primary productivity, nutrient cycling, and provide shelter for macroinvertebrates. Conversely, the extensive deforestation of riparian corridors and human activities in Aboto and Mogimogi are associated with decreased and the lowest recorded levels of macroinvertebrate abundance. This observation is consistent with the conclusions drawn in studies conducted by Dudgeon et al. (2006), Lorion and Kennedy (2009), Ligeiro et al. (2013), and Neto et al. (2015), as these studies linked the decline in macroinvertebrate populations in freshwater systems to riparian deforestation, habitat degradation, and water pollution. Also, the impact of riparian deforestation and related land use activities can be seen in the abundance and richness of various taxa found in sampled streams. Arimoro et al. (2021) and Edegbene et al. (2022a) emphasized the importance of EPT taxa as reliable indicators to assess the impact of stress on water bodies. This study establishes a clear relationship between the abundance of EPT taxa and the impact of deforestation in the studied streams. The forested Oluminrin site recorded the highest abundance and taxonomic richness of EPT taxa, while sites like Awoosun and Mogimogi, which experienced intense riparian deforestation and anthropogenic activities, exhibited a decline in both EPT taxa abundance and richness. Previous studies by Gessner et al. (2010), Allan et al. (2021), and Adedapo et al. (2023), also attributed high EPT populations in lotic systems to forested environments with sufficient shade, complex habitat structures, consistent organic matter input, and good water quality - characteristics found in the Olumirin site. Conversely, the low EPT abundance in Mogimogi and the lowest EPT richness in Mogimogi and Awoosun streams can be attributed to the absence of habitat heterogeneity, insufficient food resources, and poor water quality resulting from deforestation and anthropogenic land use of those sites. This observation supports the declaration by Lorion and Kennedy (2009) that even localized deforestation can disrupt the taxonomic composition and overall diversity of sensitive macroinvertebrate EPT taxa. The lowest abundance of Odonata in Mogimogi stream and the lowest richness in Aboto can be attributed to riparian deforestation-related activities (Šigutová et al., 2019; Carvalho et al., 2021). The highest abundance and richness of Coleoptera (beetles) in Abirunmu and Awoosun streams may be linked to increased light penetration, stimulating primary production and providing more plant debris and macrophytes as food for beetles. Riparian deforestation can enhance primary production, benefiting beetles that rely on detritus or algae as food sources, as noted by Ward (1992), Hershey et al. (2010), and Fugère et al. (2018). Interestingly, Olumirin stream showed the lowest richness of Coleoptera. This can be explained by reduced light penetration created by riparian forests, limiting primary production and decreasing the decomposition of organic matter, as proposed by Davies et al. (2008). Additionally, based on field observation, the rocky terrain of the Olumirin stream is suspected to lack suitable substrate for beetle colonization, leading to reduced shelter availability and subsequent decline in their abundance and diversity. Conversely, the reduced presence of Coleoptera in Mogimogi stream can be attributed to factors such as stream bank destabilization caused by extensive grazing and riparian deforestation, primarily resulting from farming activities. This aligns with the insights provided by Yoshimura (2012) in a related study. Diptera had the lowest representation in this study. Mezgebu et al. (2019) and Cano et al. (2018) have noted that, Dipterans thrive in agricultural landscapes near water, which explains their highest abundance in Aboto, an agricultural site. Interestingly, Dipterans were completely absent in the Mogimogi stream, providing further evidence of the significant impact of riparian deforestation and human disturbances in that area. According to Benstead et al. (2003) and Kasangaki et al. (2008), absence of insects like Dipterans in stream systems can be attributed to the loss of suitable habitat for crucial life cycle processes, including breeding, sheltering, and food sources, which are disrupted by riparian deforestation. The differing levels of abundance and richness of Hemiptera in the Awoosun and Olumirin sites further emphasize the impact of riparian deforestation and land use variations on the distribution of freshwater macroinvertebrates. In Awoosun, the highest abundance and richness of Hemipterans can be attributed to the deforested nature of the riparian corridor, allowing unrestricted access to solar radiation, and the habitat's heterogeneity, which creates microhabitats such as leaf packs, woody debris, and exposed substrates. This aligns with Crawford (1981) classification of Hemipterans as ectothermic insects that benefit from increased light availability, leading to heightened activity and reproductive success. In contrast, the lowest abundance and richness observed in Olumirin can be attributed to the lack of suitable breeding grounds in the highly forested environment. Moreover, Silva-Junior et al. (2014), Oyekanmi et al. (2017) mentioned that, riparian forests are vital for providing shelter and potential prey for Decapoda invertebrates, thereby promoting their abundance in freshwater ecosystems. In Oluminrin site, the dense forests contributed to the highest abundance of Decapoda due to the presence of leaf litter and wood debris. In contrast, the lowest abundance of Decapoda in Aboto stream can be attributed to the scarcity of leaf deposits and wood debris caused by extensive riparian deforestation. The presence of abundant gastropods (Mollusca) in the deforested Aboto stream is expected due to the increased exposure to solar radiation, which stimulates the growth of periphyton, a crucial food source for gastropods. On the other hand, the lowest abundance of gastropods observed in Olumirin may be attributed to insufficient algae availability, as the dense forest canopy limits the growth of periphyton. This observation aligns with the findings of Bae and Park (2020) and Ono et al. (2020). Moreover, this study also reveals the impact of deforestation on taxa richness and diversity. Mogimogi shows the lowest richness and diversity due to extensive deforestation and abusive land use. This finding agrees with prior research by Ligeiro et al. (2013), and Garcia et al. (2017), indicating that, agricultural deforestation harms macroinvertebrate diversity by degrading habitats and reducing food resources. In contrast, Awoosun and Olumirin exhibit high diversity due to organic matter from submerged macrophytes and riparian forest corridors, respectively. In Mogimogi, the low diversity is linked to habitat degradation from grazing and farming. Marques et al. (2021) reinforces these findings, showing that converting forested land to pasture and agriculture significantly reduces macroinvertebrate density and diversity. The distribution of macroinvertebrate taxa in forested and deforested sites within the CCA is influenced by various physicochemical and environmental factors. In Olumirin site, *Neoperla* sp., *Adenophlebia* sp., *Acanthiops* sp., *Ictinogomphus* sp., and *Caridina africana* is influenced by factors such as channel width, DO levels, and organic inputs, consistent with previous studies by Edegbene et al. (2014), Oyekanmi et al. (2017), Akamagwuna et al. (2019), Maina et al. (2020); and Liman (2021), documenting their occurrence in forested lotic environments with high DO levels and abundant food sources. In deforested sites, the presence of tolerant species like *Orectogyrus* sp., *Pseudagrion* sp., *Spaerodema* sp., *Philaccolus* sp., and *Melanoides tuberculata* can be attributed to the availability of microhabitats and suitable organic inputs resulting from riparian deforestation. Temperature, water flow, water discharge, EC, TDS, and turbidity also play significant roles by aiding decomposition and circulation of organic matter, serving as a food source for these taxa. Ligeiro et al. (2013) and Addo-Bediako (2023) established a connection between macroinvertebrate species distribution, riparian deforestation, and anthropogenic activities.

The regression analysis provides further evidence supporting the impact of riparian deforestation and land use changes on the distribution of macroinvertebrates in freshwater systems. The positive correlation between the DO levels and the EPT taxa richness can be attributed to several environmental factors, including the presence of forest cover that contributes to cooler water temperatures aiding DO solubility, thus creating a favorable environment for EPT taxa. Conversely, the negative correlation observed between the DO levels and Coleoptera richness and Hemiptera abundance can be attributed to higher water temperature caused by deforestation of the riparian corridors, as well as high nutrient levels in the system through surface runoffs provoked by various agricultural-related land use (Edegbene et al., 2019; 2022b; Akamagwuna et al., 2023). The research findings unveil a noteworthy inverse association between TDS and EC levels and the abundances of EPT, Decapoda, and the overall diversity of species in the studied streams. This compelling correlation strongly implies that heightened TDS and EC concentrations, often originating from soil erosion due to the removal of riparian vegetation, exert a detrimental influence on water quality and the ecological wellness of these sensitive aquatic organisms. In essence, this investigation observed that increased TDS and EC levels in Mogimogi and Aboto consistently resulted in reduced populations of EPT, Decapoda, and other species within these two streams. In stark contrast, the Olumirin site exhibited the opposite trend, underscoring the ecological significance of maintaining riparian vegetation for the distribution of macroinvertebrates in streams. thus, this observation equally emphasized the pivotal role played by riparian vegetation in sustaining the ecological balance of these aquatic ecosystems. These findings resonate with the research conducted by Peralta et al. (2020) and Fekadu et al. (2022), who have likewise linked this phenomenon to the routine occurrences in streams experiencing surface runoffs driven by riparian deforestation. Consequently, the negative significant relationships displayed by several naturalness parameters, involving the removal of riparian vegetation, alterations in the in-channel structure, grazing activities, refuse dumping, and agricultural practices, with two of the macroinvertebrate metrics, which are, the overall macroinvertebrate abundance and the sensitive EPT, could be ascribed to some factors involving riparian deforestation, habitat destruction, nutrient disruption, sedimentation, pollution, and changes in ecosystem dynamics. According to Samways et al. (2011), Ligeiro et al. (2013), Tromboni et al. (2019), and Ono et al. (2020), the removal of riparian vegetation from watersheds significantly decreases the abundance of macroinvertebrates, including the sensitive EPT, as a result of loss of organic matter and detritus, habitat destruction, increased surface water temperature, and disruption of nutrient dynamics. Similar inverse relationship between alteration in the in-channel structure and macroinvertebrate abundance, including the sensitive EPT in this study, could also be linked to deforestation of the stream corridors, reduced organic matter input, loss of suitable habitats, sedimentation, and nutrient pollution. This equally corroborates the observations of Neto et al. (2015), Guevara et al. (2018), Marques et al. (2021), and Peralta et al. (2020), in a similar study. However, intensive grazing has negative effects on riparian vegetation and soil compaction, leading to erosion, sedimentation, and nutrient load in streams, which in turn have a detrimental effect on the macroinvertebrate community as opined by Agouridis et al. (2005) and Hopfensperger et al. (2006). Additionally, pollutants and the decomposition of organic matter negatively affect water quality, oxygen levels, and the survival of EPT and other macroinvertebrates, causing water pollution, oxygen depletion, habitat degradation, nutrient imbalance, and toxicity of the aquatic environment, as explained by Liman (2021). In addition, riparian deforestation caused by agricultural practices within watersheds, as discussed by Giraldo et al. (2022), and Akamagwuna et al. (2023) contribute to the decline in macroinvertebrate abundance, including the sensitive EPT, due to clogging of their sensitive organs, as a result of sedimentation caused by soil erosion, nutrient runoff, and eventual habitat fragmentation.

5. Conclusion

The study has revealed significant insights into the impact of riparian deforestation and diverse land uses on the distribution of macroinvertebrates in stream ecosystems. Farming and grazing practices have led to the removal of riparian forests and submerged vegetation, leaving stream channels vulnerable to detrimental human influences that have adverse effects on the physical, chemical, and biological qualities of the water. Among the study locations, Olumirin stream stands out as the most pristine and ecologically intact site, boasting the highest levels of integrity across all indices due to its protective measures against deforestation. In contrast, Mogimogi and Aboto have suffered severe riparian deforestation and land use pressures, while Abirunmu and Awoosun represent transitional sites between natural and affected conditions. The study proposes Olumirin stream as a reference point for evaluating freshwater ecological integrity in the southwest region of Nigeria. Urgent action is essential to sustainably preserve the ecological integrity of Olumirin stream and to collaborate with relevant authorities to prevent further degradation of other affected stream sites, thereby safeguarding the biodiversity they host. This necessitates raising awareness among riparian communities about the consequences of human activities on these invaluable natural resources and actively engaging in restoration efforts. Swift and decisive action is imperative to protect the ecological integrity of these streams for the benefit of both present and future generations.

Declaration of competing interest

We (Authors) hereby declare that we have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix 1. Results of the Shapiro Wilk test on the physicochemical/environmental variable in the streams sampled

Physicochemical Parameter	Normality Test	Abirunmu	Awoosun	Mogimogi	Oluminrin	Aboto
Depth	Shapiro-Wilk W	0.7549	0.8671	0.7647	0.8949	0.8385
	p(normal)	0.009241	0.1412	0.01187	0.2597	0.07273
Width	Shapiro-Wilk W	0.8722	0.9821	0.9397	0.9702	0.9102
	p(normal)	0.1583	0.9726	0.6078	0.8994	0.3556
Flow Rate	Shapiro-Wilk W	0.9426	0.8701	0.9213	0.9866	0.9321
	p(normal)	0.6369	0.151	0.4402	0.9879	0.5354
Discharge	Shapiro-Wilk W	0.5801	0.5011	0.5435	0.931	0.8282
	p(normal)	9.285E-05	1.064E-05	3.426E-05	0.5251	0.05682
Temperature	Shapiro-Wilk W	0.6002	0.7116	0.8681	0.9095	0.8296
	p(normal)	0.0001598	0.003046	0.1444	0.3506	0.05884
DO	Shapiro-Wilk W	0.749	0.768	0.7485	0.9427	0.9312
	p(normal)	0.007964	0.0129	0.00786	0.6377	0.5272
TDS	Shapiro-Wilk W	0.8875	0.8689	0.9613	0.8364	0.924
	p(normal)	0.222	0.1469	0.8221	0.06924	0.4633
EC	Shapiro-Wilk W	0.8875	0.9038	0.9605	0.8692	0.9209
	p(normal)	0.2216	0.3126	0.8147	0.1479	0.4374
pH	Shapiro-Wilk W	0.7485	0.8252	0.8187	0.7405	0.9595
	p(normal)	0.007854	0.05296	0.04522	0.006414	0.8053
BOD	Shapiro-Wilk W	0.7864	0.8148	0.9258	0.957	0.9208
	p(normal)	0.02043	0.04114	0.4787	0.7814	0.4365
Turbidity	Shapiro-Wilk W	0.949	0.9328	0.6803	0.9612	0.9121
	p(normal)	0.7014	0.5421	0.001347	0.821	0.3689
Nitrate	Shapiro-Wilk W	0.7416	0.9401	0.9817	0.6194	0.8229
	p(normal)	0.006587	0.6125	0.971	0.0002674	0.05
Phosphate	Shapiro-Wilk W	0.5091	0.7391	0.7157	0.9173	0.9116
	p(normal)	1.328E-05	0.006186	0.003383	0.4082	0.3657
Organic Matter	Shapiro-Wilk W	0.9039	0.95	0.9436	0.8648	0.9388
	p(normal)	0.3131	0.7109	0.6469	0.1338	0.5997

Appendix 2. Intra-set correlations of physicochemical variables with the axes of canonical correspondence analysis (CCA) in the selected streams of Osun state Southwest Nigeria. All the listed variables were significantly different ($p < 0.05$)

Variable	Axis 1	Axis 2	Axis 3
Eigen value	0.5198	0.4508	0.222
% Variation of species data explained	38.11	33.05	16.28
Width	−0.211707	−0.593558	−0.0139479
Discharge	0.0864684	0.603343	0.384444
DO	−0.0870589	−0.872451	−0.386126
TDS	0.331401	0.899719	−0.344984
Conductivity	0.353416	0.912068	−0.272133
BOD	−0.362155	−0.845137	−0.0436076
Nitrates	0.873197	0.0737013	−0.472869

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