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Environmental Assessment of a Tropical River Using Aquatic Insect Communities and Water Quality Indicators

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ABSTRACT

The Ara River, located in Ara, Southwestern Nigeria, is the largest water body in the area. An ecological assessment of the river was conducted using aquatic insect populations and various environmental factors as indicators to assess its ability to perform crucial ecological and supporting functions. Insects were collected monthly from January to June 2021 using a long-handled D-frame net (500 µm mesh) and hand-picking when needed. Key environmental variables, including water depth, water and air temperature, flow rate, dissolved oxygen (DO), and conductivity, were measured according to standard protocols. A total of 344 aquatic insects were collected, representing 13 genera, 10 families, and 6 orders. Odonata was the most abundant order, with *Libellula* sp. being the most common species. DO levels were found to be low, while conductivity was elevated. The equitability index indicated a uniform distribution of species across the sampling sites. Analysis of canonical correspondence revealed that several species were closely associated with areas of low dissolved oxygen and high flow rates. The dominance of pollution-tolerant species, along with the low dissolved oxygen and high conductivity, indicates slight pollution in the river at the time of the study. It is essential to address pollution sources to safeguard the river's biodiversity and ensure its continued ecological functionality.

Keywords: Pollution, Aquatic insects, Distribution, Environmental variables, Ecology

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Introduction

Aquatic insects are among the most diverse and essential organisms in freshwater ecosystems. They play a significant role in the ecological processes of both standing (lentic) and flowing (lotic) waters [1]. These insects are key participants in material cycling and energy transfer within aquatic environments [2]. Many insect species serve as effective indicators of environmental health due to their varied sensitivity to contamination [3]. For example, insects from the Ephemeroptera, Plecoptera, and Tricoptera (EPT) orders are particularly sensitive to pollution, as well as to natural and human-induced environmental changes. As a result, they are a crucial part of aquatic insect communities [4]. In addition to this, the distribution, composition, diversity, rapid reproductive cycles, short generation times, and swift colonization of freshwater habitats by aquatic insects make them valuable bio-indicators of the overall health of freshwater ecosystems [5]. Consequently, understanding the species composition and distribution within these communities is essential for assessing the ecological condition of water bodies [6].

The distribution and presence of aquatic insects are primarily influenced by factors such as flow velocity, elevation, vegetation, and the physico-chemical characteristics of water bodies [7]. Variations in these environmental factors provide valuable data for bio-monitoring and ecological assessments [4]. Consequently, the structure of aquatic insect communities offers insights into the ecological processes that govern their populations and assemblages. Numerous studies have utilized aquatic insects as bio-indicators, with several significant ones focusing on their role in assessing water quality in Nigeria [8-10].

Freshwater ecosystems are highly vulnerable to environmental changes, making the regular and thorough monitoring of water quality crucial [11]. These ecosystems are vital not only for supporting diverse life forms but also for their significance to human populations and industries [12]. Monitoring is therefore necessary to assess the health of freshwater environments and ensure that water quantity and quality are maintained. The Ara River plays a key role, particularly for the residents of Ara and surrounding areas. As the largest water body in the town, it provides drinking water and supports additional functions such as irrigation and fishing. Despite the river's considerable value to the community, there has been no documented assessment of its ecological health. This study, therefore, aims to evaluate the current health of the Ara River by examining the community structure of aquatic insects concerning various environmental factors.

Materials and Methods

Study area

The Ara River, situated in Ara, Ejigbo Local Government Area, Southwestern Nigeria **(Figure 1)**, served as the focus of this study. The river is named after Ara due to its status as the largest water body in the town. Ara lies between Latitude 07° 92.8' N and 07° 93.2' N and Longitude 04° 31.2' E and 04° 31.7' E. The region is part of Nigeria's lowland tropical rainforest zone [13], once dominated by emergent trees, multiple canopies, and lianas, although much of this has now been replaced by secondary forests and derived savannahs [14]. The surrounding landscape consists of scattered forest patches, residential areas, and farmlands. Common crops in the vicinity of Ara include both annual and perennial varieties such as cassava, cocoa, oil palm, and citrus. The river is a critical water source for both domestic use and agricultural activities. For this research, 4 sampling sites were chosen along the river's course, labeled SP1, SP2, SP3, and SP4. These sites were located near the littoral zone of the river, as aquatic insects are primarily found in these areas.

Sampling procedures

Aquatic insects were collected once each month from January to June 2021 using a long-handled D-frame net with a 500 µm mesh. In addition, hand-picking and direct searching techniques were applied, especially in the shallower sections of the river. Sampling took place between 8:00 and 11:00 a.m. After collection, the insects were sorted in a white tray for identification and counted per sampling point, then preserved in 70% ethanol. Species identification was carried out to the lowest taxonomic level possible using standard identification guides such as the Water Research Commission (WRC) guide to freshwater invertebrates of Southern Africa [15] and a pictorial reference [16]. During the sampling period, environmental factors that could influence the insect community were also recorded. These factors included pH, air temperature (AT), water temperature (WT), water depth (WD), water flow velocity (WV), dissolved oxygen (DO), and electrical conductivity (EC) [17]. Temperature was measured using a Mercury-in-glass thermometer, while pH, dissolved oxygen, and conductivity were determined using a Hanna multi-probe meter (HANNA 9828). Water flow velocity was estimated using the displacement method, employing a float, meter rule, and stopwatch over a 10-meter stretch of the river [18].

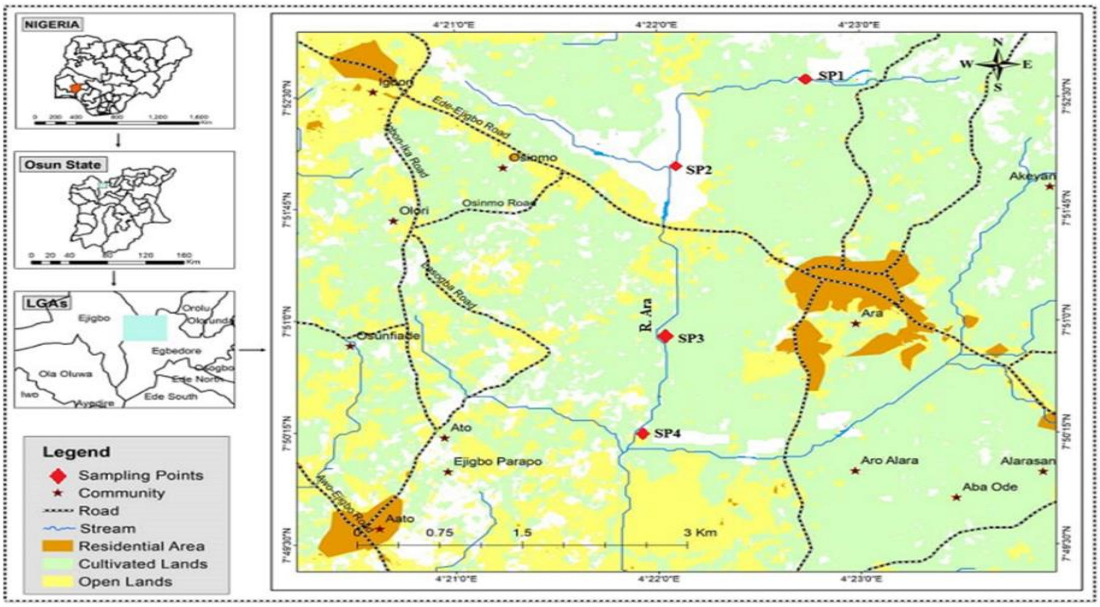

Figure 1. A map displaying the sampling point locations along the Ara River and the position of Ara in Osun State, Nigeria.

Analysis of data

The data on aquatic insects and environmental variables were analyzed through both descriptive and inferential statistics [19]. A one-way analysis of variance (ANOVA) ($P < 0.05$) was performed on the environmental variables. The T-test was applied to evaluate significant differences in these variables. The distribution and abundance of aquatic insects were assessed using various diversity indices, including Shannon-Weiner (H'), Simpson 1-D, Margalef, Evenness, and Equitability. All analyses were conducted using Paleontological Statistical Software (PAST), and graphs were generated in Microsoft Excel 2013.

Results and Discussion

A total of 344 individual aquatic insects, representing 13 genera, 10 families, and 6 orders, were collected from Ara River during this research. SP1 and SP3 each yielded 11 taxa, while SP2 and SP4 provided 10 and 12 taxa, respectively **(Table 1)**. Regarding insect abundance, SP4 had the highest count with 128 individuals, while SP3 recorded the lowest with 81. SP1 and SP2 had 81 and 72 insects, respectively. Odonata was the most abundant order, contributing 120 individuals, or 35% of the total collection **(Figure 2)**. This order was represented by 2 families: Libellulidae (62 individuals) and Coenagrionidae (58 individuals). Ephemeroptera followed with 82 individuals (23%), spread across 2 families: Caenidae (45 individuals) and Baetidae (37 individuals). Hemiptera also showed a notable presence, with 79 individuals, distributed among 3 families: Belostomatidae (27), Nepidae (23), and Notonectidae (29). Trichoptera was represented by a single taxon, *Cheumatopsyche* sp., with just 2 individuals. The most numerous taxon was *Libellula* sp., which made up 18.02% of the total collection, with 62 individuals, while *Cheumatopsyche* sp. was the least abundant at 0.58% with 2 individuals. Other recorded taxa included *Appasus* sp. (6.10%), *Diplonychus* sp. (2.32%), *Ranatra* sp. (3.78%), *Laccotrephes* sp. (2.91%), *Anisops* sp. (8.43%), *Caenis* sp. (12.50%), *Cleon* sp. (10.75%), *Enallagma* sp. (9.83%), *Ischnura* sp. (6.98%), *Culex* sp. (10.17%), and *Hydrobius* sp. (7.56%).

Richness and diversity of aquatic insects in ara river

The analysis of aquatic insect diversity revealed that SP4 exhibited the highest values for diversity indices, with Simpson 1-D (0.8690), Shannon H (2.465), and Margalef (2.671), while SP2 showed the lowest values, including Simpson 1-D (0.780), Shannon H (2.011), and Margalef (2.450). The Equitability values across the sampling points indicated a balanced distribution of the taxa within each sampling location.

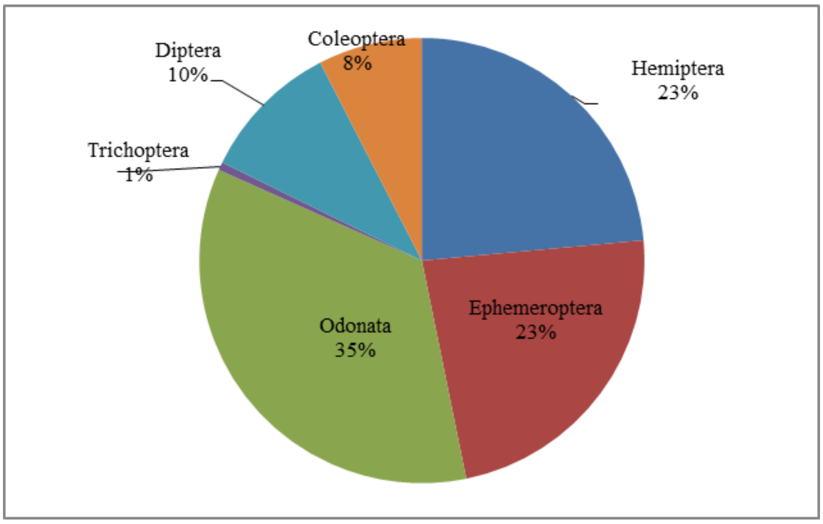

Figure 2. Distribution and abundance of insect orders in Ara River, Southwestern Nigeria.

Table 1. Absolute abundance (N) and relative abundance (ni) of aquatic insects in Ara, Southwestern Nigeria.

Taxa	SP1		SP2		SP3		SP4		Total	Occurrence (%)
	N	ni	N	ni	N	ni	N	ni		
Hemiptera[1]										
Belostomatidae[2]										
Appasus sp.[3]	9	2.61	5	1.45	2	0.58	5	1.45	21	**6.10**
Diplonychus sp.[3]	3	0.87	0	0.00	2	0.58	1	0.29	6	**2.32**
Nepidae[2]										
Ranatra sp.[3]	4	1.16	0	0.00	6	1.74	3	0.87	13	**3.78**
Laccotrephes sp.[3]	3	0.87	0	0.00	2	0.58	5	1.45	10	**2.91**
Notonectidae[2]										
Anisops sp.[3]	8	2.33	6	1.74	5	1.45	10	2.91	29	**8.43**
Ephemeroptera[1]										
Caenidae[2]										
Caenis sp.[3]	14	4.06	7	2.03	6	1.74	18	5.23	45	**12.50**
Baetidae[2]										
Cleon sp.[3]	10	2.91	6	1.74	7	2.03	14	4.07	37	**10.75**
Odonata[1]										
Libellulidae[2]										
Libellula sp.[3]	12	3.4	10	2.91	15	4.36	25	7.27	62	**18.02**
Coenagrionidae[2]										
Enallagma sp.[3]	4	1.16	8	2.33	11	3.19	12	3.49	35	**9.83**
Ischnura sp.[3]	0	0.00	10	2.91	0	0.00	13	3.78	23	**6.98`**
Trichoptera[1]										
Hydropsychidae[2]										
Cheumatopsyche sp.[3]	0	0.00	2	0.58	0	0.00	0	0.00	2	**0.58**
Diptera[1]										
Culicidae[2]										
Culex sp.[3]	8	2.32	11	3.19	3	0.87	13	3.78	35	**10.17**
Coleoptera[1]										
Hydropphilidae[2]										

Hydrobius sp.[3]	6	1.74	7	2.03	4	1.16	9	2.62	26	**7.56**
Total	**81**		**72**		**63**		**128**		**344**	**100**

[1]Order
[1]Order
[2]Family
[3]Genus

Table 2. Environmental parameters of the sampling locations in Ara, Southwestern Nigeria.

	AirTemp (°C)	Water temp (°C)	pH	Water depth (m)	DO (mg/L)	Flow rate (m/s)	EC (µS/cm)
SP1	29.2 ± 0.04[a]	27.5 ± 0.03[b]	6.70 ± 0.1 [a]	0.27 ± 0.03 [a]	5.68 ± 0.02 [a]	0.38 ± 0.02[a]	580 ± 0.51 [a]
SP2	31.5 ± 0.02[a]	30.0 ± 0.05[a]	7.00 ± 0.4 [a]	0.35 ± 0.03 [a]	5.01 ± 0.05 [a]	0.24 ± 0.03 [a]	656 ± 0.10[b]
SP3	29.5 ± 0.02[a]	29.8 ± 0.02[a]	6.80 ± 0.3 [a]	0.31 ±0.05 [a]	4.60 ± 0.05[b]	0.28 ± 0.02[b]	647 ± 0.78[a]
SP4	28.5 ± 0.05[a]	28.0 ± 0.03[a]	6.50 ± 0.4[a]	0.28 ± 0.02 [a]	6.25 ± 0.03[a]	0.45 ± 0.05[a]	540 ± 0.43[b]

Means followed by the same letter within the column are not significantly different (P > 0.05) using Tukey's test.

Environmental variables

The environmental variables across the sampling locations are summarized in **Table 2**. There were no significant differences in pH, air temperature, and water depth between the sampling points. However, considerable variations were observed for water temperature, flow rate, dissolved oxygen, and electrical conductivity (P > 0.05). SP2 had the highest recorded air (31.5 °C) and water temperatures (30.0 °C), while the lowest air temperature (28.5 °C) was found at SP4, and the lowest water temperature (27.5 °C) occurred at SP1. The greatest water depth (0.35 meters) was recorded at SP2, while SP1 had the smallest depth (0.27 m). SP4 showed the lowest pH and electrical conductivity, whereas SP2 had the highest levels of both. The highest dissolved oxygen level (6.25 mg/L) and flow rate (0.4 meters per second) were recorded at SP4.

Cluster analysis revealed that SP1 and SP4 shared a high degree of similarity in both taxonomic composition and abundance of aquatic insects **(Figure 3)**. The similarity between the sites increased with the distance between them. SP1 and SP4 were completely similar, while SP1, SP3, and SP4 showed approximately 92% similarity. The canonical correspondence analysis suggested that certain insect taxa had associations with low dissolved oxygen and high flow rate values **(Figure 4)**. Species such as *Diplonychus* sp., *Caenis* sp., *Cleon* sp., and *Anisops* sp. were associated with higher flow rates, while *Laccotrephes* sp., *Libellula* sp., and *Enallagma* sp. were linked to electrical conductivity. *Hydrobius* sp. and *Culex* sp. were connected to dissolved oxygen, and *Ranatra* sp. and *Appasus* sp. didn't show significant associations with the studied environmental variables.

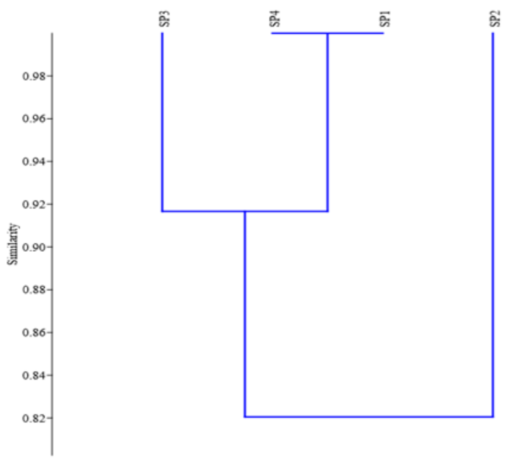

Figure 3. The cluster analysis illustrates the similarities among the sampling points based on the taxonomic composition of the aquatic insect species.

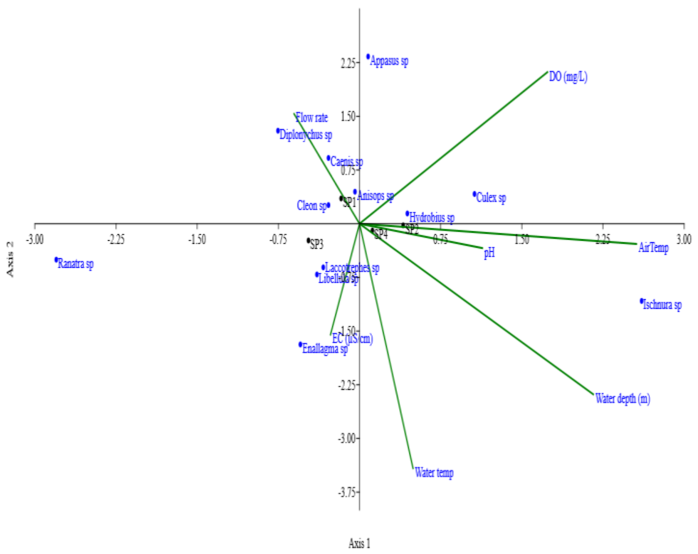

Figure 4. Canonical correspondence analysis depicting the relationship between environmental factors and the collected taxa.

The environmental variables studied did not show significant differences across the sampling points, except for electrical conductivity (P > 0.05). The physicochemical parameters measured were within the recommended ranges for freshwater ecosystems according to the World Health Organization [20]. These values also align with those found in similar tropical inland water bodies as noted in previous studies [21-23]. The higher conductivity levels at SP2 can likely be explained by the combination of lower flow rate and higher temperature. A slow flow rate allows for the accumulation of salts and minerals in the water [24], while increased temperature facilitates the solubility of minerals and speeds up the movement of ions in the water [25]. Temperature has been identified as a key factor in influencing aquatic insect populations and their diversity [26], with research suggesting that conductivity can increase by 1.9% for every 1 °C rise in temperature [27]. The highest conductivity levels were recorded at SP2, coinciding with the highest air and water temperatures. Temperature also plays a critical role in the availability of dissolved oxygen in aquatic environments [24]. As water temperature increases, it disrupts the bonds between oxygen molecules and water, leading to a decrease in dissolved oxygen concentration [28]. This may explain the variations in dissolved oxygen levels observed across the sampling sites, with the highest concentration recorded at SP1, where both air and water temperatures were the lowest. The pH values at all sampling points ranged from 6.5 to 7.00, indicating that the water quality in Ara River is good, as it remains close to neutral [9, 10]. A similar range of pH values has been observed in studies of other rivers, such as the Aahoo and Osinmo Rivers, which are similar to Ara River in terms of size and catchment area and are also located in the Southwestern region of Nigeria.

The aquatic insect taxa identified in this research have been previously documented in tropical inland water systems, such as those studied by Ogbeibu and Oribhabor [29], as well as Rotimi and Iloba [30]. Insects are known for their varied responses to different levels of pollution in aquatic habitats, a characteristic linked to their diverse sensitivities to environmental contaminants. This sensitivity is one of the reasons why insects are widely used as effective bio-indicators for assessing environmental quality [31]. Among the insect groups, Odonata was the most abundant, comprising the largest portion of the insect collection. The abundance of Odonata was somewhat surprising, as these insects are not typically known to dominate aquatic environments. While they have been found in notable numbers in some studies, they are rarely reported as the dominant group. Some examples of studies where Odonata was present in substantial numbers include [9, 32, 33]. These insects are recognized for their suitability in ecological assessments, particularly in evaluating the status of aquatic ecosystems. Due to their sensitivity to changes in habitat conditions, Odonata has become a key tool in environmental monitoring for both terrestrial and aquatic ecosystems [34]. The observed dominance of Odonata in this study may be linked to their widespread presence and their ability to tolerate varying levels of pollution. Many of the Odonata species identified here are eurytopic, meaning they not only tolerate mild pollution but also flourish in altered habitats [35].

Ephemeroptera also represented a significant portion of the insect assemblage in this research. This insect order is crucial for global water quality monitoring and assessment. Their abundance, along with their strong sensitivity to pollution, makes them valuable indicators for environmental health. Ephemeroptera are often a major part of the aquatic macroinvertebrate community, contributing significantly to the biomass and productivity of freshwater ecosystems. They are commonly found in various freshwater habitats [36]. The notable presence of Ephemeroptera in this study could be due to the stable substrates and the moderately high flow rate present in the Ara River. Previous studies have identified stable substrates and flow rate as key factors influencing Ephemeroptera diversity [1].

The Trichoptera order, represented by *Cheumatopsyche* sp., was the least abundant group found in this study. It is unusual to observe such low numbers of this species, as they are typically associated with water bodies rich in dissolved oxygen. Their sparse occurrence may indicate some pollution in the Ara River, as Trichoptera are known to be highly sensitive to contamination and generally flourish only in unpolluted environments with high oxygen levels [37]. Another possible explanation for their low numbers could be the river's relatively high flow rate, which can wash away certain species of Trichoptera, particularly those that are free-living and cannot survive in strong currents [38]. The abundance of *Culex* sp., a species known for its tolerance to polluted conditions, especially in SP4, suggests the presence of point-source pollution, likely from domestic sewage discharge. Such pollution leads to increased organic matter in the water, reducing dissolved oxygen levels and making the environment more suitable for tolerant species like *Culex* sp. According to the canonical correspondence analysis, the insects collected in this research showed a strong association with just a few environmental variables, indicating that factors such as pH, flow rate, and conductivity significantly influenced the insect community composition in the Ara River.

Conclusion

Water quality is crucial for the composition of aquatic insect communities. In Ara River, the insect population was largely composed of species that are tolerant to pollution, indicating the presence of pollution in the river during the study period. The relatively low dissolved oxygen levels and elevated conductivity further corroborated the river's pollution status. To protect the biodiversity and maintain the ecological balance of the river, it is essential to identify and address the pollution sources.

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