RESEARCH ARTICLE

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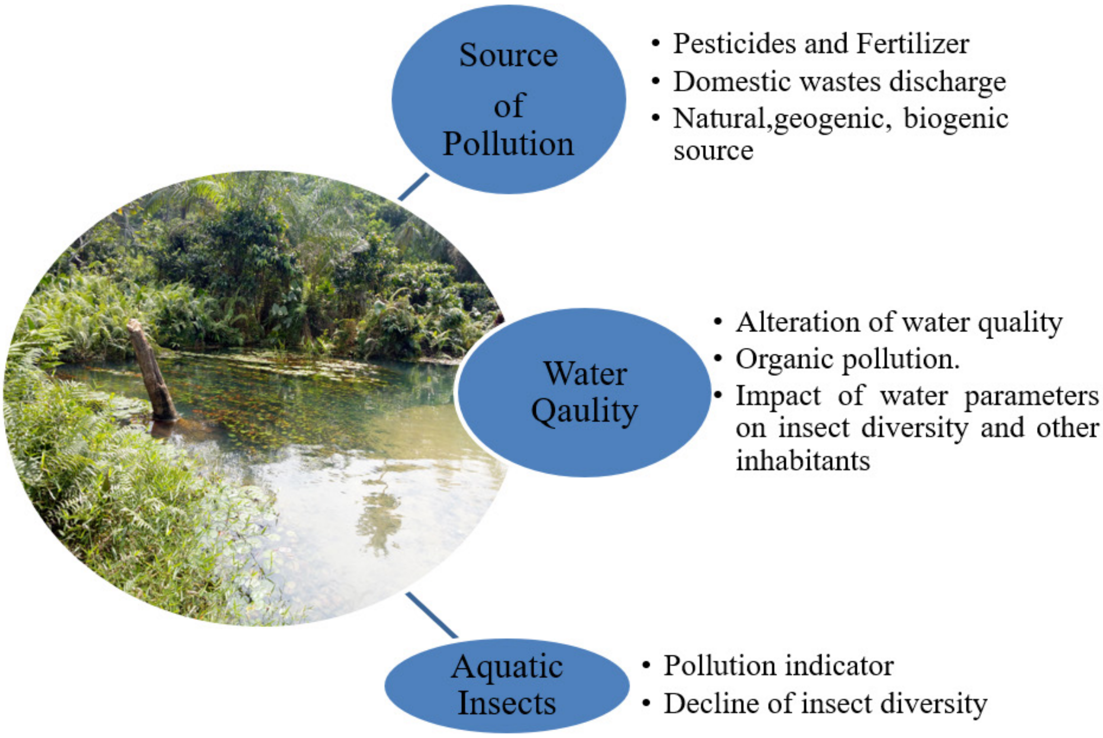


**Highlights**

- Anthropogenic activities and surface runoffs are major factors contributing to the reservoir water quality.
- Dissolved oxygen, biochemical oxygen demand, nitrate and phosphate influenced the abundance of aquatic invertebrates.
- Odonata was the most abundant insect group inhabiting the reservoir.
- Pollution-intolerant groups such as Ephemeroptera, Plecoptera and Trichoptera were not recorded indicating water pollution.

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# Characterization of physicochemical parameters and insect composition in a reservoir in Northern Akwa Ibom State, Nigeria

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**Abstract:** This study was conducted in a reservoir located in Mbiabet Ikot Udo community, Northern Akwa Ibom State, Nigeria, to assess the physicochemical status, composition and abundance of aquatic insects. Samples were collected from June 2022 to January 2023 and all the parameters were evaluated using standard methods. The results revealed that temperature ranged from 22.7 to 30.6°C, TDS (153 – 238 $mgL^{-1}$), EC (153 – 238μ$Scm^{-1}$), TDS (97.9 –152.3$mgL^{-1}$), pH (6.3 – 8.1), DO (2.22 – 5.14 $mgL^{-1}$), TSS (1.62 – 6.34 $mgL^{-1}$), $NO^-_3$ (1.53 – 5.68 $mgL^{-1}$), $PO^-_4$ (2.18 – 4.16 $mgL^{-1}$), $Mg^{2+}$ (3.92 – 5.36 $mgL^{-1}$), $Ca^{2+}$ (5.39 – 8.13 $mgL^{-1}$), $Na^+$ (0.72 – 2.37 $mgL^{-1}$), $K^+$ (0.68 – 1.48 $mgL^{-1}$), BOD (1.34 – 6.46 $mgL^{-1}$), Ni (0.001 – 0.08 $mgL^{-1}$),Fe (0.1 – 0.3 $mgL^{-1}$), Pb (0.003 – 0.008 $mgL^{-1}$), Cu (0.01 – 1.3 $mgL^{-1}$) and Cd (0.002 – 0.008). There were significant temporal variations in some of these parameters. However, all the parameters were within the acceptable limits, except for TSS, BOD, DO, Ni, Cu and Fe. A total of 185 species of aquatic insects, in five taxonomic orders and 10 families, were recorded. Odonata had the highest percentage (40.5%), followed by Hemiptera (25.0%), and Diptera had the lowest percentage (8.6%). The dominant family was Aeshnidae (18.9%) while the least percentage was from Pleidae (1.1%). The analysis revealed that parameters such as temperature, DO, pH, $Ca^{2+}$, EC, TDS and Cu negatively influenced the abundance of aquatic insects coupled with seasonal influence.

***Keywords***: aquatic management; aquatic insects; water quality; reservoir.

## INTRODUCTION

Reservoirs are aquatic ecosystems, playing a significant role by supporting aquatic biota. The physical and chemical properties of aquatic ecosystems determine the distribution and production of aquatic life, including insect fauna. Aquatic insects are a group of arthropods that live in or spend part of their life cycle in water globally (Pennak, 1978). Freshwater aquatic insects inhabit river and stream beds, lakes and reservoirs and are associated with various types of substrates such as mineral sediments, detritus, macrophytes and filamentous algae (Rosenberg & Resh, 1993; Onyenwe et al., 2018). Aquatic insects are essential elements in lentic and lotic trophic webs, involving energy flow and nutrient cycling (Whiles & Wallace, 1997). They are protein sources to higher aquatic organisms including fish, insectivorous birds and some insect species such as praying mantises, robber flies, lady bugs and hornets (Merritt & Cummins, 1996). Most taxa of aquatic insects have been reported in related studies as biological indicators of organic pollution in aquatic ecosystems (Arimoro & Muller, 2010; Edegbene et al., 2015 & Jonah et al., 2020a). The taxa such as Ephemeropterans, Plecoepterans and Trichopterans etc. are known to be pollution-sensitive, and strictly inhabit unpolluted water bodies. However, some species in the families like Ceratopogonidae, Chironomidae, and Thaumaleidae are well known for pollution tolerance, hence often considered as indicators of organic pollution of water (Arimoro & Ikomi, 2009; Oku et al., 2014; Jonah & Akpan, 2021). Water quality characteristically plays a significant role in insect community structure and polluted water poses physiological stress on aquatic biota (Oku et al., 2014; Onyenwe et al., 2018). Substrate type, macrophytes and food availability are common factors that provide basis for insect diversity (Arimoro & Ikomi, 2009; Buss et al., 2014; Esenowo et al., 2015; Jonah et al., 2020b). Water bodies are subjected to increasing pollution loads through surface runoff, from agricultural landscapes and resultant change is often seen in the shift of water quality parameters and the inhabitant biota. The studied reservoir was created to enhance agricultural activities in the area for food sustainability; currently it serves as a source of water for irrigation, drinking and fishing grounds for the indigenous communities. The major activities around the reservoir are intense agricultural activities, fishing inside the water and laundry. These anthropogenic activities, coupled with surface runoff could impair the quality of water, which in turn alters the biological composition. Therefore, this study aimed to investigate the aquatic insect composition, its numerical abundance, and the physicochemical status of the reservoir.

## MATERIALS AND METHODS

### *Description of Study area*

This reservoir is located in Mbiabet Ikot Udo ($5^0$ 20’12 N; $7^0$ 48’12 E), Northern Akwa Ibom State, Nigeria (Fig.1). The reservoir was created in 2000 by the Niger Delta Development Commission (NDDC) in corroboration

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with Niger Delta River Basin Development Authority (NDBDA), to facilitate or improve agricultural activities and rural development through irrigation and assist the rural farmers in processing food crops. The substrate is muddy at the leftwing, while the rightwing is gravel mixed with sand. Elephant grass (*Pennisetum purpureum*), water lettuce (*Pistia stratiotes*) and water hyacinth *Pontederia crassipes*) were the most abundant macrophytes.

***Samples collections and analysis***

The water samples were collected once a month between June 2022, and January 2023, using 1 L plastic bottle. The water sample for the heavy metals evaluation were collected with 500mL polyethylene bottles, acidified with nitric acid (HNO3) immediately after collection, and then taken to the laboratory for analysis. The physicochemical parameters were analysed using standard methods (AOAC, 2000; APHA, 2005). Parameters such as water temperature, electrical conductivity (EC), hydrogen ion (pH) and dissolved oxygen (DO) were measured *in-situ*. Mercury-in-glass thermometer (0 – 100 $^{o}$C) was used to determine water temperature, electrical conductivity (EC) was determined using HANNA instruments (Model HI 98303), total dissolved solids (TDS) was derived using TDS=Ke × EC (Ke is correlation factor = 0.64), hydrogen ion (pH) was determined using portable pH meter (JENWAY 3505), dissolved oxygen (DO)was determined using portable DO Meter (Hanna H 19146 – 04 Model), total suspended solids (TSS) were determined by gravimetric method, nitrate($NO^-_3$) by turbidimetric method, phosphate ($PO^-_4$) by UV spectrophotometric, magnesium ($Mg^{2+}$) and calcium ($Ca^{2+}$) analyzed using atomic absorption spectrometric method, sodium ($Na^+$) and potassium ($K^+$) were determined using flame photometric method while biochemical oxygen demand ($BOD_5$) was determined after 5 days using Azide modification of Winklers' method. Heavy metals like nickel (Ni), iron (Fe), lead (Pb), copper (Cu) and cadmium (Cd) were measured using atomic absorption spectrophotometer with their respective wavelength.

The insects were collected with a sweep net of 250 µm mesh size. The net was used to sweep across the water surface for about 5 to 10 min and aquatic macrophytes were on the banks of the reservoir. The contents of the net were emptied into a white enamel tray for visibility and sorting, and the collected insects were stored in plastic containers and preserved with 90% alcohol labelled according to the months. The aquatic insects were identified using a dissecting microscope and relevant taxonomic keys: Pennak (1978), Meritt & Cummins, (1996) and Gerber & Gabriel (2002).

***Data analysis***

Aquatic insect data and physicochemical parameters were subjected to descriptive statistics. One-way ANOVA was used to assess monthly variations of the physicochemical parameters and aquatic insects, with a significant difference at $p < 0.05$. The source of significant differences between monthly values was determined by the Tukey Pairwise test. Diversity indices of aquatic insects between the months were determined using Shannon-Wiener diversity index (H), Margalef's index (d) for species richness and Pielou's evenness index (E) for species Evenness. Canonical correspondence analysis (CCA) was used to evaluate relationships between the aquatic group and physicochemical parameters. The analysis shows the influence of physicochemical parameters on the group of organisms; also helps to identify which water

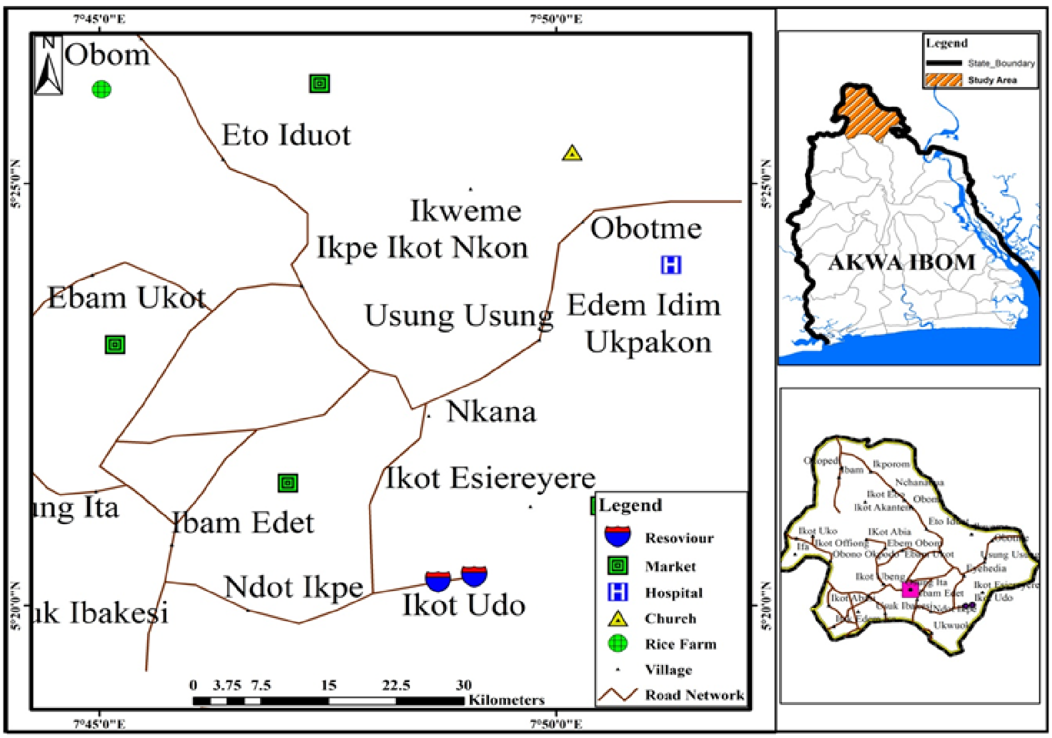


**Figure 1:** Map of Akwa Ibom state showing Ini Local Government Area with the study area.

variable exerts a greater influence on these organisms. All statistical analyses were performed with PAST statistical package (Version 3.24) (Hammer et al., 2001). The relative abundance (%) of aquatic insect species was calculated according to George et al. (2020) as follows:

$$RA\ (\%) = n/N \times 100$$

Where;

n = the total number of individuals of each aquatic insect species.

N = the total number of individuals of the entire aquatic insect species.

## RESULTS

***Physicochemical parameters***: The mean and range values were summarized in Table 1. The water temperature values ranged between 22.76 and 30.60°C (mean = 26.47°C). The maximum temperature was recorded in October 2022 while the minimum was recorded in June 2022. October and November 2022 temperature values were significantly (ANOVA, p = 0.03) higher than June and August 2022 values. The electrical conductivity values ranged between 153.0 and 238.0 µScm$^{-1}$ (mean = 194.1µScm$^{-1}$). The maximum value was recorded in October 2022 while the minimum was recorded in July 2022. There were no significant temporal variations (ANOVA, p = 0.16). The total dissolved solids values ranged from 97.9 – 152.3mgL$^{-1}$ (mean = 124.2mgL$^{-1}$). The maximum value was recorded in October 2022 while the minimum was also recorded in July 2022.There were no significant temporal variations (ANOVA, p = 0.42) as observed in electrical conductivity. The pH values ranged between 6.3 and 8.1 (mean = 7.3). The maximum value was recorded in June 2022 while the minimum was recorded in August 2022. No significant variations were observed (ANOVA, p = 0.51). The dissolved oxygen values ranged between 2.22 and 5.14 mgL$^{-1}$ (mean = 3.29 mgL$^{-1}$). The maximum value was recorded in November 2022 while the minimum was in June 2022. The value recorded in November 2022 was significantly higher than the values recorded between June and August 2022 (ANOVA, p = 0.001).

The values for total suspended solids ranged between 1.62 and 6.34mgL$^{-1}$ (mean = 2.56 mgL$^{-1}$). The maximum value was recorded in September 2022 while the minimum was in December 2022. The values recorded in December 2022 and January2023 were significantly (ANOVA, p = 0.0001) lower than August and September 2022 values. The values for nitrate ranged between 1.53 and 5.68 mgL$^{-1}$ (mean = 2.98mgL$^{-1}$). The maximum value was recorded in June 2022 while the minimum value was in November 2022. The values recorded between June and August 2022 were significantly (ANOVA, p = 0.04) higher than November 2022 and January 2023 values. The values for phosphate ranged between 2.18 and 4.16 mgL$^{-1}$ (mean = 3.22mgL$^{-1}$). The maximum value was recorded in June 2022 while the minimum value was in November 2022. The values recorded in June and July 2022 were significantly

**Table 1:** Minimum, maximum and mean values (±standard error) of physicochemical parameters recorded in the reservoir in Northern Akwa Ibom State, Nigeria and permissible levels according to the National Environmental Regulations (FMEnv).

| Parameters | Symbol | Unit | Minimum value | Maximum Value | Mean±SE | *FMEnv (2011) |
|---|---|---|---|---|---|---|
| Temperature | Temp. | °C | 22.76 | 30.60 | 26.47±0.13 | – |
| Elect. conduct. | EC | µs/cm$^{-1}$ | 153 | 238 | 194.1±5.13 | 1000 |
| Tot. dis. solids | TDS | mgL$^{-1}$ | 97.9 | 152.3 | 124.2±3.58 | 500 |
| Hydrogen ion | pH | | 6.3 | 8.1 | 7.3±0.56 | 6.5 – 8.5 |
| Diss. Oxygen | DO | mgL$^{-1}$ | 2.22 | 5.14 | 3.29±0.36 | >6.0 |
| Tot. sus. Solids | TSS | mgL$^{-1}$ | 1.62 | 6.34 | 2.67±0.56 | 0.25 |
| Nitrate | $NO^{-}_{3}$ | mgL$^{-1}$ | 1.53 | 5.68 | 2.98±1.15 | 9.1 |
| Phosphate | $PO^{-}_{4}$ | mgL$^{-1}$ | 2.18 | 4.16 | 3.22±1.03 | 3.5 |
| Magnesium | $Mg^{2+}$ | mgL$^{-1}$ | 3.92 | 5.36 | 4.42±0.13 | 40 |
| Calcium | $Ca^{2+}$ | mgL$^{-1}$ | 5.39 | 8.13 | 6.73±0.55 | 180 |
| Sodium | $Na^{+}$ | mgL$^{-1}$ | 0.72 | 2.37 | 1.55±0.12 | 120 |
| Potassium | $K^{+}$ | mgL$^{-1}$ | 1.18 | 2.48 | 1.77±0.52 | 50 |
| Bio. oxy. dem. | BOD | mgL$^{-1}$ | 1.34 | 6.46 | 4.19±0.61 | 3.0 |
| Nickel | Ni | mgL$^{-1}$ | 0.01 | 0.08 | 0.03±0.01 | 0.01 |
| Iron | Fe | mgL$^{-1}$ | 0.1 | 0.3 | 0.2±0.01 | 0.05 |
| Lead | Pb | mgL$^{-1}$ | 0.003 | 0.008 | 0.004±0.001 | 0.01 |
| Copper | Cu | mgL$^{-1}$ | 0.01 | 1.30 | 0.60±0.16 | 0.001 |
| Cadmium | Cd | mgL$^{-1}$ | 0.002 | 0.008 | 0.004±0.001 | 0.005 |

*FMEnv (2011) - National Environmental (Surface and Groundwater Quality Control) Regulations

(ANOVA, p = 0.03) higher than November 2022 value. The magnesium values ranged between 3.92and 5.36mgL$^{-1}$ (mean = 4.42mgL$^{-1}$). The maximum value was recorded in January 2023 while the minimum was in August 2022. There was no significant variation (ANOVA, p = 0.35). The calcium values ranged between 5.39 and 8.13mgL$^{-1}$ (mean = 6.73mgL$^{-1}$). The maximum value was also recorded in January 2023 while the minimum was in August 2022.The were significant variation (ANOVA, p = 0.0001) between the values. The sodium values ranged between 0.72 and 2.37mgL-$^{1}$ (mean = 1.55mgL$^{-1}$). The maximum value was also recorded in January 2023 while the minimum was in August 2022. The values recorded in December 2022 and January 2023 were significantly (ANOVA, p = 0.0001) higher than the value in August 2022.The potassium values ranged between 1.18 and 2.48mgL$^{-1}$(mean = 1.77mgL$^{-1}$). The maximum value was recorded in July 2022 while the minimum was in December 2022. The value recorded in July 2022 was significantly (ANOVA, p = 0.0001) higher than other months. The biochemical oxygen demand values ranged between 1.34 and 6.46 mgL$^{-1}$ (mean = 4.39 mgL$^{-1}$). The maximum value was recorded in June 2022 while the minimum was in November 2022.The value recorded in July 2022 was significantly higher (ANOVA, p = 0.04) than the values recorded in November 2022 and January 2023. The nickel values ranged between 0.01 and 0.08mgL$^{-1}$ (mean = 0.02mgL$^{-1}$). The maximum value was recorded in December 2022 while the minimum was in August 2022. There was a significant (ANOVA, p = 0.03) variation between the months. The iron values ranged between 0.1 and 0.3mgL$^{-1}$ (mean = 0.2mgL$^{-1}$). The maximum value was recorded in January 2023 while the minimum was in July 2022. There was a significant (ANOVA, p = 0.001) difference. The lead values ranged between 0.003 and 0.008mgL$^{-1}$ (mean = 0.003mgL$^{-1}$). The maximum value was recorded in January2023 while the minimum was in June 2022.There was a significant (ANOVA, p = 0.0001) difference. The copper value ranged between 0.01 and 1.3mgL$^{-1}$ (mean = 0.6mgL$^{-1}$). The maximum value was recorded in December 2022 while the minimum was in June 2022. The December 2022 value was significantly (ANOVA, p = 0.0001) higher than other months. The cadmium values ranged between 0.002 and 0.008 mgL$^{-1}$ (mean = 0.004mgL$^{-1}$). The maximum value was recorded in September 2022 while the minimum was in December 2022. No significant (ANOVA, p = 0.23) variation was observed.

***Aquatic Insect composition***

A total of 185 individual aquatic insects, from five taxonomic orders, 10 families and 14 taxa were recorded. The order Odonata was the most abundant taxonomic group; accounting for 40.5%, followed by Hemiptera (25.0%), Coleoptera (15.6%), Megaloptera (10.3%) and the lowest was Diptera, with 8.6% of total population (Table 2). The species *Anax junius* was the most abundant, accounting for 18.9% while the lowest was *Neoplea striola* (1.1%). A higher number of aquatic insects was recorded in November 2022 (38 individuals, 20.5%), followed by 29 individuals with 15.7% each recorded in December 2022 and January 2023 while the lowest was recorded in June 2022 (15, 8.1%; Table3). Analysis of variance (ANOVA) revealed significant (p = 0.001) variation in the distribution of aquatic insects.

The Shannon-Weiner diversity index values ranged between 0.8314 and 2.04; the highest value was recorded in November 2022 while the lowest was in August 2022. Margalef index value (2.474) recorded in November 2022 was also higher than other months while the lowest value (0.8314) was in August 2022. The Pielou's evenness values for June 2022 (0.9397) and January 2023 (0.9183) were high and closer to one (1) compared to other months while the lowest value (0.6329) was in December 2022 (Table 3). The Dominance value for August 2022 (0.5234) was high compared to other months while the lowest values (0.1579) and (0.1938) were recorded in November 2022 and January 2023 respectively. The species *Anax junius* and *Damselfly nymph* were the highest distributed species, recorded in seven and six months respectively, followed by *Erythrodiplax fusca* (five months), while *Neoplea striola* and *Harmonia axyridis* were the least, recorded only in one month each (December and June, 2022). Hemipteran (*Aquarius remigis, Neoplea striola, Nepa apiculata* and *Ranatra linearis*) were mostly not present between June and September 2020.

The order of abundance across the months within the families recorded was as follows, Aeshnidae (18.9%) > Hydrophilidae (14.1%) > Nepidae (12.4%) > Gerridae (11.4%) > Coenagrionidae and Libellulidae (10.8%) > Sialidae (10.3%) > Simuliidae (8.6%) > Coccinellidae (1.6%) > Pleidae (1.1%) as shown in Table 4.

***Relationship between environmental variables and the insects groups***

A good relationship between the aquatic insects and physico-chemical parameters was observed as shown in canonical correspondence analysis (CCA) ordination. The strongest explanatory factors were phosphate, nitrate, pH, calcium, electrical conductivity, total dissolved solids, copper, temperature, dissolved oxygen, and biochemical oxygen demand.

The CCA triplot revealed that nitrate and phosphate exerted a greater positive influence on the abundance of Coleoptera when compared with the positive influence exerted by cadmium and potassium on the Megaloptera group while pH and calcium negatively influenced the abundance of Diptera; and electrical conductivity, total dissolved solids, copper, temperature, and dissolved oxygen negatively influenced the abundance of Hemiptera and Odonata. On the other hand, the strongest explanatory factors temporally were nitrate, biochemical oxygen demand, phosphate, calcium, copper, dissolved oxygen and temperature. The nitrate, biochemical oxygen demand and phosphate positively influenced the abundance of Coleoptera in June, July 2022 and January 2023. Copper, dissolved oxygen and temperature exerted a greater negative influence on Hemiptera in November and December 2022; calcium exerted a negative influence on Diptera in October 2022, while potassium positively influences the abundance of Megaloptera in August 2022 (Fig. 2).

**Table 2:** Composition and relative abundance (RA) of aquatic insect species recorded from the reservoir in Northern Akwa Ibom State, Nigeria.

| Insects order | Family | Species (taxa) | Total | Relative Abundance (%) |
|---|---|---|---|---|
| Odonata | Aeshnidae | *Anax junius* (Drury 1773) | 35 | 18.9 |
| | Coenagrionidae | *Damselfly nymph* (Hagen 1861) | 13 | 7.1 |
| | Coenagrionidae | *Enallagma erbium* **(**Hagen 1861 **)** | 7 | 3.8 |
| | Libellulidae | *Erythrodiplax fusca* (Rambur 1842) | 17 | 9.2 |
| | Libellulidae | *Palpopleura jucunda* (Rambur 1842) | 3 | 1.6 |
| | | **Total** | **75** | **40.5** |
| Hemiptera | Gerridae | *Aquarius remigis* (Say 1832) | 21 | 11.4 |
| | Pleidae | *Neoplea striola* (Fieber 1844) | 2 | 1.1 |
| | Nepidae | *Nepa apiculata* (Uhler 1862) | 6 | 3.3 |
| | Nepidae | *Ranatra linearis* (Linnaeus 1758) | 17 | 9.2 |
| | | **Total** | **46** | **25.0** |
| Coleoptera | Hydrophilidae | *Hydrobius larvae*( Linnaeus 1758) | 10 | 5.4 |
| | Hydrophilidae | *Hydrobius fuscipes*(Linnaeus 1758) | 16 | 8.6 |
| | Coccinellidae | *Harmonia axyridis* (Pallas 1773) | 3 | 1.6 |
| | | **Total** | **29** | **15.6** |
| Diptera | Simuliidae | *Simulium larvae* (Latreille 1802) | 16 | 8.6 |
| Megaloptera | Sialidae | *Sialis bilobata* (Whiting 1991) | 19 | 10.3 |
| | | **Total** | **35** | **18.9** |
| | | **Total number of individuals** | **185** | **100** |

**Table 3:** Temporal variations of abundance and diversity of aquatic insects recorded in the reservoir in Northern Akwa Ibom State, Nigeria over a period of 8 months (June, 2022 – January, 2023).

| | **Sampling months** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **June** | **July** | **Aug.** | **Sept.** | **Oct.** | **Nov.** | **Dec.** | **Jan.** |
| *Anax junius* | 2 | - | 3 | 11 | 3 | 1 | 12 | 3 |
| *Damselfly nymph* | - | 1 | 2 | 4 | 1 | 4 | 1 | - |
| *Enallagma erbium* | 3 | - | - | 1 | - | 2 | 1 | - |
| *Erythrodiplax fusca* | - | 2 | - | 3 | - | 5 | 2 | 5 |
| *Palpopleura jucunda* | - | - | - | 1 | 1 | 1 | - | - |
| *Aquarius remigis* | - | - | - | - | - | 8 | 8 | 5 |
| *Neoplea striola* | - | - | - | - | - | - | 2 | - |
| *Nepa apiculata* | - | - | - | - | 3 | 2 | 1 | - |
| *Ranatra linearis* | - | - | - | - | 5 | 10 | 2 | - |
| *Hydrobius larvae* | 2 | 2 | - | - | - | - | - | 6 |
| *Hydrobius fuscipes* | 5 | 5 | - | - | 3 | 3 | - | - |
| *Harmonia axyridis* | 3 | - | - | - | - | - | - | - |
| *Simulium larvae* | - | - | - | 6 | - | 2 | - | 8 |
| *Sialis bilobata* | - | 6 | 11 | - | - | - | - | 2 |
| No. of species | 5 | 5 | 3 | 6 | 6 | 10 | 8 | 6 |
| No. of individual | 15 | 16 | 16 | 26 | 16 | 38 | 29 | 29 |
| Rel. abundance (%) | 8.10 | 8.64 | 8.64 | 14.1 | 8.64 | 20.54 | 15.67 | 15.67 |
| Shannon H | 1.547 | 1.424 | 0.8314 | 1.49 | 1.652 | 2.04 | 1.622 | 1.707 |
| Margalef index | 1.477 | 1.443 | 0.7213 | 1.535 | 1.803 | 2.474 | 2.079 | 1.485 |
| Evenness e^H/S | 0.9397 | 0.8311 | 0.7655 | 0.7396 | 0.8693 | 0.7691 | 0.6329 | 0.9183 |
| Dominance_D | 0.2267 | 0.2734 | 0.5234 | 0.2722 | 0.2109 | 0.1579 | 0.2652 | 0.1938 |

**Table 4:** Relative abundance of aquatic insect families recorded from the reservoir in Northern Akwa Ibom State, Nigeria.

| S/N | Insect family | Occurrence (N) | Percentage abundance (%) |
|---|---|---|---|
| 1 | Aeshnidae | 35 | 18.9 |
| 2 | Hydrophilidae | 26 | 14.1 |
| 3 | Nepidae | 23 | 12.4 |
| 4 | Gerridae | 21 | 11.4 |
| 5 | Coenagrionidae | 20 | 10.8 |
| 6 | Libellulidae | 20 | 10.8 |
| 7 | Sialidae | 19 | 10.3 |
| 8 | Simuliidae | 16 | 8.6 |
| 9 | Coccinellidae | 3 | 1.6 |
| 10 | Pleidae | 2 | 1.1 |
| | | **∑N = 185** | **100** |

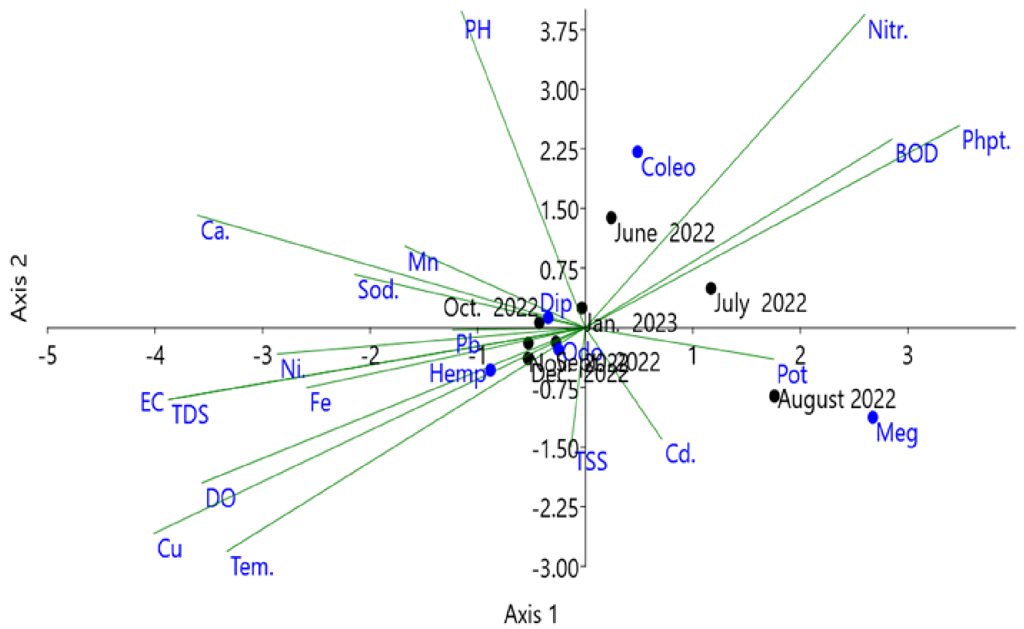


**Figure 2:** Canonical correspondence analysis (CCA) ordination showing relationships between aquatic insects groups, months and physicochemical parameters (Phpt- Phosphate, Nitr - Nitrate, pH – hydrogen ion, Ca - calcium, EC- Electrical conductivity, TDS - Total dissolved solids, Cu-Copper, Tem.-Temperature, DO- Dissolved oxygen, BOD- Biochemical oxygen demand, Ni-Nickel, Fe- Iron, Sod.- Sodium, Mn- Magnesium, Pot.- Potassium, Cd– Cadmium, Pb-Lead, Coleo-Coleopteran, Meg–Megaloptera, Dip-Diptera, Hemp- Hemiptera, Odo-Odonata, Jan. January and Oct.- October.

## DISCUSSION

The water quality exhibited significant temporal variation, which was influenced by anthropogenic and seasonal factors. The mean values of some of the physicochemical parameters are within the recommended limits while DO, $BOD_5$, TSS, Ni, Fe and Cu exceeded the limits set by FMEnv (2011). The low DO values recorded are an indication of the deterioration of water quality, coupled with its lentic nature (Oku et al., 2014; Onyenwe et al., 2018). The low value of DO record in June 2022 could be due to the introduction of organic pollutants through surface runoffs from the surrounding agricultural landscape as the rains sets in. The elevated value of DO in November 2022 suggests an increase in photosynthetic activities of algae and macrophytes during the dry season, releasing DO into the water (Kale, 2016). The values were significantly lower than 6.0 $mgL^{-1}$ set by FMEnv (2011) and lower than 5.15 $mgL^{-1}$ mean value recorded by Yusuf (2020) in Nasarawa Reservoir, Nigeria. $BOD_5$ had an inverse trend of the DO; a higher value was recorded in June 2022 at the expense of DO; attributed to the decomposition or biodegradation of organic matter, dead and decaying materials in the water body (Ling et al., 2017a; Jonah et al., 2020b). $BOD_5$ is an indicator of organic pollution in a water body and affects water quality (Nwankwo et al., 2014). Studies affirmed that higher concentrations of $BOD_5$ resulted in a reduction of DO values (Mahre et al., 2007; Jonah et al., 2020a). The values between June and August 2022 were significantly higher than the recommended value (3.0 mgL-$^{1}$) set by FMEnv (2011) and the mean value (1.35 mgL-$^{1}$) recorded by Yusuf (2020) in Nasarawa reservoir, Katsina State, Nigeria. The mean and temporal values of total suspended solids exceeded the limit (0.25 mgL-$^{1}$) recommended by FMEnv (2011), this could be attributed to the abundance of decaying matter and the lentic nature of the water. The maximum value recorded at the peak of the rainy season (September 2022) suggests the largest volume of water via runoff into the water accompanied by solids particles. The elevated values in June 2022 for pH, nitrate and phosphate were ascribed to the seasonal influence (Anyanwu et al. 2022a; Jonah & Archibong, 2022) while the higher concentrations of magnesium, calcium and sodium in dry month (January 2023) are ascribed to many factors such as reduction of volume water, reduced rainfall, high temperature and evaporation (Ling et al., 2017b). Calcium ion is one of the major inorganic substances present in nearly all water systems attributable to its easy solubility from all rocks, including limestone, chalk, dolomite and gypsum (Bartram & Ballance, 1996). The values of EC and TDS were slightly varied across the months, the higher values were recorded in October 2022 which might have been influenced by the season (Girardi et al., 2016). Ewa et al. (2011) in a related study reported that a high level of EC usually corresponds to a high value of TDS. TDS indicates the concentrations of dissolved ions and minerals in water (Alhadithi, 2018). It is made up primarily of inorganic salts such as calcium, magnesium, potassium, bicarbonates, chlorides and sulphates and very minute amounts of organic matter (Shareef & Aziz, 2023). The mean value was within the limits of FMEnv (2011) standard. The EC and TDS mean values were higher than the 84.51 – 86.92 µs/cm$^{-1}$ and 41.83 – 43.86 mgL$^{-1}$ reported by Ibrahim et al. (2009) in Kontagora reservoir, Niger state and Yusuf (2020) in Nasarawa reservoir (222.8 µs/cm$^{-1}$ and 28.25mgL$^{-1}$), Katsina State, Nigeria. The higher mean concentrations of metallic elements such as Ni, Fe and Cu suggest geological weathering and dissolution of numerous minerals beneath the earth's surface (Akinola et al., 2015), coupled with reduction of volume water and low precipitation to dilute the concentration of these parameters during the dry season (Kumar et al., 2006; Ling et al., 2017b). Nickel (Ni) can be found naturally in rocks and soil; weathering of these rocks and soils as well as mineral leaching could be the possible sources of Ni in the water body (Gautam et al., 2014). It could also be attributed to the geogenic effect exacerbated by anthropogenic activities in the area (Ullah et al., 2022; Jonah & Anyanwu, 2023). The intense use of phosphate fertilizer in agricultural activities in the area could also be a major source of heavy metals pollution (Tibugari et al., 2020; Jastrzebska et al., 2021). The higher concentration of heavy metals in dry months (December 2022 and January 2023) could suggest geogenic sources influenced by season. Higher atmospheric temperature, evaporation and lack of precipitation result in the concentration of metallic elements (Rasheed, 2008). The values for Cu and Ni were higher compared to 0.037 to 0.041 mgL-$^{1}$ (Cu) and 0.006 to 0.007 mgL-$^{1}$ (Ni) recorded by Adeogun & Fafioye (2011) in a related study.

Habitat structures such as water quality characteristics, substrate type, macrophytes, water velocity and food availability significantly affect the abundance of aquatic insects (Buss et al., 2004; Zabbey & Hart, 2006; Arimoro & Ikomi, 2009; Esenowo et al., 2015; Jonah et al., 2020c). The 185 individuals recorded were low compared with the 306 recorded by Esenowo et al. (2015) in Uwa-West/ Ikot Ebak River, Nigeria, but in line with the findings of Onyenwe et al. (2018) who recorded 185 individuals of aquatic insects in Anya River, South East Nigeria. The 14 species (taxa) recorded were poor compared with 19 taxa reported by Edegbene et al. (2015) in River Chanchaga, Niger State, Nigeria. The low species recorded could be attributed to the effect of high nutrients load, low DO, and higher $BOD_5$ exacerbated by season. The findings were corroborated by the findings of Atobatele et al. (2005); Zabbey & Hart, (2006); Xiong et al. (2016) and Arimoro et al. (2017) that observed consequences of direct and/or indirect pollution arising from human activities usually result in low biodiversity of aquatic organisms. The abundance of aquatic insects from November 2022 to January 2023 could be attributed to favorable water quality such as high DO, low nutrients (nitrate and phosphate), suitable water temperature, food availability and low precipitation (Atobatele et al., 2005; Arimoro & Ikomi, 2009; Adeogun & Fafioyer, 2011; Jonah et al., 2020a; Jonah et al., 2020b). On the other hand, the low abundance of insects during the rainy months (June - August and October) could be attributed to unfavourable shifts in water levels and some parameters exacerbated by season. Flooding and high surface runoffs from land use into the water body pose a negative impact on aquatic biota. According to McCabe (2011), the reduction of aquatic macro-invertebrate abundance by more than half, usually occurs after heavy rain falls. The findings contradicted Ling et al. (2017a) which observed that high input of nutrients during the early rains of May and June support aquatic biota. The absence of pollution-intolerant species (Ephemeropterans, Plecopterans and Trichopterans) suggests deterioration of water quality (Arimoro & Ikomi, 2009; Esenowo et al., 2015) and the higher occurrence of Odonata and Hemipterans may bebecause most species in these group are pollution tolerant (Voshell, 2019), while the poor abundance of Megaloptera could linked to water quality parameters (Rosenberg & Resh, 1993; Zebbey & Hart, 2006). According to Shekhar et al. (2008), Shannon-Weiner diversity index, a value greater than 4 is clean water bodies; between three and four indicate slightly polluted water, while severely polluted waters fall below two. The Shannon-Wiener index values were below two, except in November 2022, and Margalef index was also high in November, 2022. The low values of Shannon-Wiener and Margalef index suggest to unstable or perturbed condition of the environment.

Canonical correspondence analysis (CCA) has been used to evaluate the co-existing relationships between environmental variables and aquatic biota (Jonah et al., 2020d; Anyanwu et al., 2022b). The length of the lines in the triplot is an indication of the quantitative effect of water variables. The lines are ordered based on fit for each separate environmental variable and also point in the direction of the maximum change in the relative abundance of the insect group. The distance rule states that the lines of physicochemical parameters closer to the insect group direction tend to exert a higher effect on the abundance of such organisms than those farther from the organisms (Ter Braak, Verdonschot, 1995).The CCA triplot revealed that nitrate and phosphate exerted a greater positive influence on the Coleoptera abundance while pH and calcium negatively influence the abundance of Diptera; and electrical conductivity, total dissolved solids, copper, temperature and dissolved oxygen negatively influence the abundance of Hemiptera and Odonata. The positive association between nitrate and phosphate with Coleoptera suggests favorable concentrations of these parameters to the insect group, which support their survival and abundance. One the contrary, the observed negative association of pH and calcium with Diptera, and electrical conductivity, total dissolved solids, copper, temperature and dissolved oxygen with Hemiptera and Odonata could suggests that the concentrations of these parameters influenced their abundance. These could be attributed to season, surface runoffs, indiscriminate dumping of waste into the water and other illicit anthropogenic activities within the watershed, which could be deleterious to the ecosystem.

## CONCLUSION

The study revealed that the concentration some of physicochemical parameters such as dissolved oxygen, total suspended solids, phosphate, biochemical oxygen demand, nickel, iron and copper exceeded acceptable limits. Parameters (pH, copper, electrical conductivity, total dissolved solids, calcium, dissolved oxygen and temperature) exert a greater negative influence on the abundance of insect composition compared with other water parameters. The temporal variations in the insect composition were observed, which season, rainfall patterns and different levels of human activities might influence. The absence of pollution- sensitive insect groups (Ephemeropterans, Plecoepterans and Trichopterans) that strictly inhabit unpolluted water bodies and the remarkably low ecological diversity indices further revealed that the water body was highly disturbed.

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## DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

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