# Abundance and Distribution of Benthic Macroinvertebrates and Plankton in the Okulu Aleto River, Eleme, Rivers State, Nigeria

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DOI: 10.56201/ijgem.vol.11.no4.2025.pg50.65

***Abstract***

*Freshwater ecosystems in the Niger Delta region are increasingly threatened by industrial pollution, which can disrupt aquatic biodiversity and ecosystem functions. This study aimed to assess the abundance and distribution of benthic macroinvertebrates and plankton in the Okulu Aleto River, Eleme, Rivers State, Nigeria, to evaluate the ecological impacts of varying pollution levels. Using an experimental research design, samples were collected from six strategically selected locations including: upstream, midstream, downstream, effluent discharge site, and two control sites, representing a gradient of anthropogenic influence. Stratified random sampling was employed to ensure representative spatial coverage. Key results showed a complete absence of plankton and benthic macroinvertebrates in the effluent-impacted site, while control sites recorded the highest taxa richness (up to six taxa) and organism counts (up to 18 individuals). Diversity indices, including Shannon's index and Simpson's diversity, were highest at control and composite stations (Shannon's H up to 1.61, Simpson's 1-D up to 0.82) and lowest downstream and at effluent sites, indicating reduced ecological health in polluted areas. Elevated physicochemical parameters such as electrical conductivity (up to 17,070 µS/cm) and biochemical oxygen demand correlated with diminished biodiversity. The findings conclude that industrial effluents significantly degrade aquatic biodiversity and water quality, emphasizing the need for continuous monitoring and pollution control to protect riverine ecosystems in the Niger Delta.*

***Key Words:*** *Benthic Macroinvertebrates, Plankton Diversity, Industrial Pollution, Water Quality, Ecological Assessment.*

## 1. Introduction

Aquatic ecosystems serve as intricate and dynamic environments that support a wide array of biodiversity and perform essential ecological functions. Rivers, in particular, are vital components of the freshwater system, acting as lifelines that connect terrestrial and marine habitats (smith *et al*.,2023). Among the many biological indicators employed in the assessment of aquatic ecosystem health, benthic macroinvertebrates and plankton (both phytoplankton and zooplankton) are especially important due to their sensitivity to environmental changes, relatively sedentary lifestyles, and essential roles in aquatic food webs (El Hayany *et al*., 2022; Corami *et al*., 2022).

Benthic macroinvertebrates—invertebrate organisms that dwell on or near the bottom substrates of water bodies—play critical roles in nutrient cycling, organic matter decomposition, and serve as prey for higher trophic levels, including fish and amphibians (Pironti *et al*., 2021). Similarly, plankton, comprising the microscopic flora (phytoplankton) and fauna (zooplankton) suspended in the water column, are primary producers and consumers that initiate the aquatic food chain (Gärtner *et al*., 2021). The composition, abundance, and distribution of these communities offer valuable insights into water quality, pollution levels, and ecological integrity.

In Nigeria, the increasing pace of industrialization, urban expansion, and anthropogenic activities such as oil refining, agriculture, and improper waste disposal have imposed significant stress on freshwater ecosystems (Ben, 2022; Igbani *et al*., 2024). The Okulu Aleto River, situated in Eleme Local Government Area of Rivers State, exemplifies a water body exposed to these pressures. The river serves not only as a habitat for aquatic life but also as a source of water for domestic, industrial, and agricultural purposes. However, its proximity to industrial complexes such as petrochemical plants and oil refineries makes it particularly vulnerable to contamination from effluents, hydrocarbons, and heavy metals, all of which have the potential to disrupt the ecological balance of the river (Anetor *et al*., 2022).

Despite the ecological and socio-economic importance of the Okulu Aleto River, there is a dearth of comprehensive data on the biological communities inhabiting its waters, particularly in relation to benthic macroinvertebrates and plankton. These organisms are widely recognized as reliable indicators of water quality due to their differing tolerances to pollutants and changing environmental conditions. The study of their abundance and spatial distribution not only reflects the health of the aquatic environment but also provides a foundation for informed environmental management and conservation strategies.

Previous studies in the Niger Delta region have documented anthropogenic stressors on freshwater systems, particularly concerning heavy metal contamination, hydrocarbon pollution, and eutrophication (Olarinmoye *et al*., 2020; Olubusoye *et al*., 2023). However, there remains a dearth of research specifically addressing the structure and variability of benthic and planktonic communities in smaller rivers such as the Okulu Aleto. These biological assemblages, when assessed in combination, provide comprehensive insight into both the short-term and long-term effects of pollution, as plankton respond quickly to water quality changes while macroinvertebrates reflect cumulative environmental conditions (Gärtner *et al*., 2021).

In light of global efforts to conserve biodiversity and maintain ecosystem services, particularly in developing countries facing rapid environmental change, this research is both timely and significant. It aligns with broader ecological assessments and conservation frameworks that emphasize the use of bioindicators as practical tools for monitoring environmental quality (Nuhu *et al*., 2022). Furthermore, the findings from this study will be relevant to policymakers, environmental scientists, and local communities seeking to balance development with the preservation of aquatic ecosystem health in the Niger Delta region and beyond.

This research therefore seeks to evaluate the abundance and distribution of benthic macroinvertebrates and plankton in the Okulu Aleto River with the objective of establishing baseline ecological data, identifying potential environmental stressors, and assessing the degree of anthropogenic impact on this vital freshwater ecosystem. By investigating seasonal and spatial variations across different sampling stations along the river's course, this study aims to contribute valuable information that can support water resource management, guide regulatory policies, and foster sustainable use of the river system.

## 2. Methodology

This study adopts an experimental research design to systematically evaluate the abundance and distribution of benthic macroinvertebrates and plankton in the Okulu Aleto River, located in Eleme Local Government Area, Rivers State, Nigeria (Kalaronis *et al*., 2022). The design facilitates the assessment of ecological responses across gradients of anthropogenic influence. A stratified random sampling technique was employed to ensure spatial coverage and comparability among sites exposed to varying levels of pollution and human activity.
Six sampling locations were strategically selected based on proximity to industrial discharge points, urban runoff, and relatively undisturbed environments, as follows:

- Upstream Site (04°48'39.6"N, 007°06'33.9"E) – Characterized by low human and industrial activity, this site served as a reference point for background ecological conditions.
- Midstream Site (04°48'37.0"N, 007°06'29.9"E) – Located adjacent to areas with moderate industrial and domestic discharges, this site reflects a transitional ecological zone subject to intermediate anthropogenic impact.
- Downstream Site (04°48'36.4"N, 007°06'26.4"E) – Receiving runoff and discharge from both upstream and midstream sections, this site represents a cumulative impact zone, where pollution load is expected to peak.
- Effluent Site (04°48'38.7"N, 007°06'36.6"E) – This location is directly influenced by industrial effluent discharge, allowing for targeted assessment of point-source pollution effects on aquatic biota.
- Control Site 1 (04°48'33.1"N, 007°06'21.1"E) and
- Control Site 2 (04°48'34.3"N, 007°06'32.3"E) – These sites are spatially removed from major pollution sources and were selected to establish baseline ecological conditions, facilitating comparison with impacted areas.

This stratification enabled a comprehensive analysis of how environmental stressors influence the composition, diversity, and distribution of benthic macroinvertebrates and plankton across different sections of the river. The integration of geographic coordinates further enhances spatial precision and repeatability in future monitoring studies.

### Study Area

Okulu Aleto, River, situated in the Eleme Local Government Area of Rivers State, is a freshwater system serving domestic, economic, and recreational purposes, and providing a habitat for fish and other aquatic life. The river originates in Ogale, flows through Agbonchia and Aleto, and empties into Bonny River via Okrika creeks. Industrial activities around the river include petrochemical and fertilizer operations (Indorama petrochemical), sand mining, and an abattoir processing facility. (Akinwumiju *et al*., 2020).
The study area is shown in Fig 2.1 below:

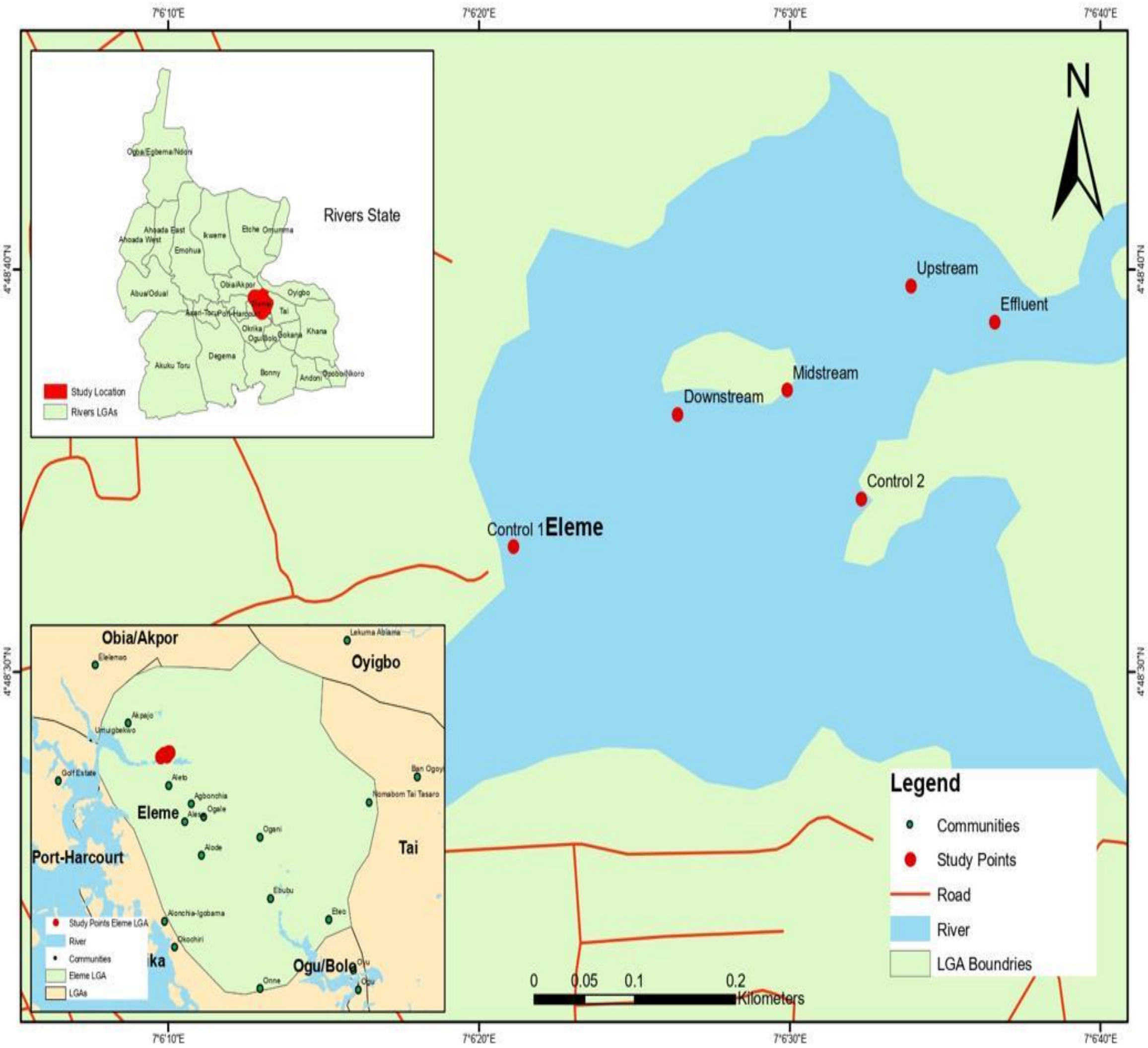


Fig 2.1 Study Area

**Table 1.1: Coordinates of the Study Area**

| Location | Latitude (N) | Longitude (E) |
|---|---|---|
| Upstream | 04°48'39.6" | 007°06'33.9" |
| Downstream | 04°48'36.4" | 007°06'26.4" |
| Midstream | 04°48'37.0" | 007°06'29.9" |
| Effluent | 04°48'38.7" | 007°06'36.6" |
| Control 1 | 04°48'33.1" | 007°06'21.1" |
| Control 2 | 04°48'34.3" | 007°06'32.3" |

**Table 3.2: Summary of Analytical Methods**

| Parameters | Methods |
|---|---|
| **Physicochemical** | |
| pH, Temperature, Turbidity, Conductivity Salinity, Total dissolve solids (TDS) | WTW Multi 340i/set Meter |
| Total Suspended Solids (TSS) | Gravimetric |
| COD | Dichromate($K_2Cr_2O_7$)Titration |
| Polycyclic Aromatic Hydrocarbons (PAHs) | Gas Chromatography (GC) |
| **Biological** | |
| $BOD_5$, DO | WTW Oxitop kit |
| Benthos | Identification (Microscope) |
| Planktons | Identification (Microscope) |
| Microplastics | (FTIR) |
| Biomarkers | Ion scanning (GCMS) |

**Source: APHA, (2017)**

Benthic macroinvertebrates were sampled using a kick sampling technique with a D-frame dip net of 500 µm mesh size. Sampling was performed over a 1 m² area at each site by disturbing the substrate manually while sweeping the net through the water for a standardized duration of 3–5 minutes (Shruti *et al.*, 2021). Collected organisms were transferred into labeled sample bottles containing 70% ethanol for preservation and transported to the laboratory for identification and enumeration. Identification was carried out to the lowest possible taxonomic level using standard identification keys and guides (Kabir *et al.*, 2021)

Phytoplankton samples were collected using a Van Dorn water sampler at surface and mid-depths. A volume of 500 mL from each sampling point was filtered through a 20 µm plankton net and preserved in Lugol's iodine solution. Zooplankton were sampled using a vertical haul of a 55 µm mesh size plankton net, hauled from the river bottom to the surface. Collected samples were preserved in 4% formalin and stored in labeled sample bottles. Plankton were identified and enumerated using a light microscope at 100x–400x magnification, with identification done using keys such as those by Botes (2003) and APHA (2017).

Physicochemical parameters were taken at each sampling station to establish correlations with biological data. The following parameters were measured: Temperature (using a mercury-in-glass thermometer), pH (using a handheld pH meter), Dissolved Oxygen (DO) (using a portable DO meter), Electrical Conductivity (EC) (using a conductivity meter), Turbidity (using a Secchi disk or turbidity meter).

Water samples were also collected in clean, labeled bottles for laboratory analysis of: Biochemical Oxygen Demand (BOD), Total Dissolved Solids (TDS), Nitrates, phosphates, and heavy metals (using spectrophotometry and AAS)

## 3. Result

**Table 3.1a: Hydrobiology Results of phytoplankton check**

| Phytoplankton Checklist | Control 1 Water | Control 2 water | Effluent water | Up stream water | Mid water stream | Down Stream Water | Composite water |
|---|---|---|---|---|---|---|---|
| **Bacillariophyceae** | | | | | | | |
| Cocconeis sp. | **3** | **1** | | **2** | | | |
| Rhoicosphenia curvata | **1** | **1** | | | | **3** | |
| Diatoma sp. | **2** | **2** | | | | | **3** |
| Navicula dicephala | **1** | **4** | | | | | **5** |
| Plagiotropis sp | **4** | | | | **4** | | **5** |
| Fragilaria sp | | | | | | | **5** |
| Detonula confervaceae | **3** | **2** | | | **1** | | |
| leptocylindricus sp | **5** | **31** | | **4** | **3** | **4** | |
| Biddulphia sp | | **2** | | | | | **3** |
| Nitzschia sp | **4** | | | **3** | **3** | | **2** |
| Melosira sp. | **2** | **1** | | | **2** | | |
| Fragilariopsis sp | | | | **2** | | | |
| **Cyanophyceae** | | | | | | | |
| Oscillatoria tenuis | | | | **3** | **3** | **4** | |
| Phormidium papyraceum | **3** | **1** | | | **1** | **4** | |
| Rhodomonas sp | | | | | | | **3** |
| Lyngbya sp | | **1** | | | | | **3** |
| Anabaena | | | | | | | **2** |
| **Chlorophyceae** | | | | | | | |
| Cosmarium sp. | | **2** | | | | | **4** |
| Ulothrix sp. | **3** | **3** | | | | | **2** |
| Spirogyra sp | **8** | **12** | | **3** | **4** | **3** | **6** |
| Cladophora sp | **3** | **2** | | **4** | **12<br>3** | **4** | **6** |
| **Dinophyceae** | | | | | | | |
| Prorocentrium lima | | | | | | | **3** |
| Dinopyphysis sp | | | | | | | **2** |
| **Xanthophyceae** | | | | | | | |
| Ophocytium sp | | | | | | | **2** |
| **Zygnematophyceae** | | | | | | | |
| Mougeotia sp | | **1** | | | **2** | **3** | |

**Table 4.3.1b: Phytoplankton Diversity Index:**

| Phytoplankton Diversity Index | Control 1 Water | Control 2 water | Eff luent water | Up stream water | Mid water stream | Down Stream Water | Comp osite water |
|---|---|---|---|---|---|---|---|
| Taxa_S | **13** | **16** | **0.00** | **7** | **11** | **7** | **16** |
| Individuals | **42** | **39** | **0.00** | **21** | **38** | **25** | **56** |
| Dominance_D | **0.078** | **0.112** | **0.00** | **0.11** | **0.131** | **0.110** | **0.056** |
| Simpson_1-D | **0.922** | **0.888** | **0.00** | **0.891** | **0.869** | **0.890** | **0.944** |
| Shannon_H | **2.57** | **2.602** | **0.00** | **2.056** | **2.273** | **2.056** | **2.827** |
| Evenness_e^H/S | **1.005** | **0.844** | **0.00** | **1.117** | **0.8823** | **1.117** | **1.056** |
| Margalef | **3.211** | **4.094** | **0.00** | **1.971** | **2.749** | **1.864** | **3.726** |
| Equitability_J | **1.002** | **0.939** | **0.00** | **1.057** | **0.9478** | **1.057** | **1.02** |

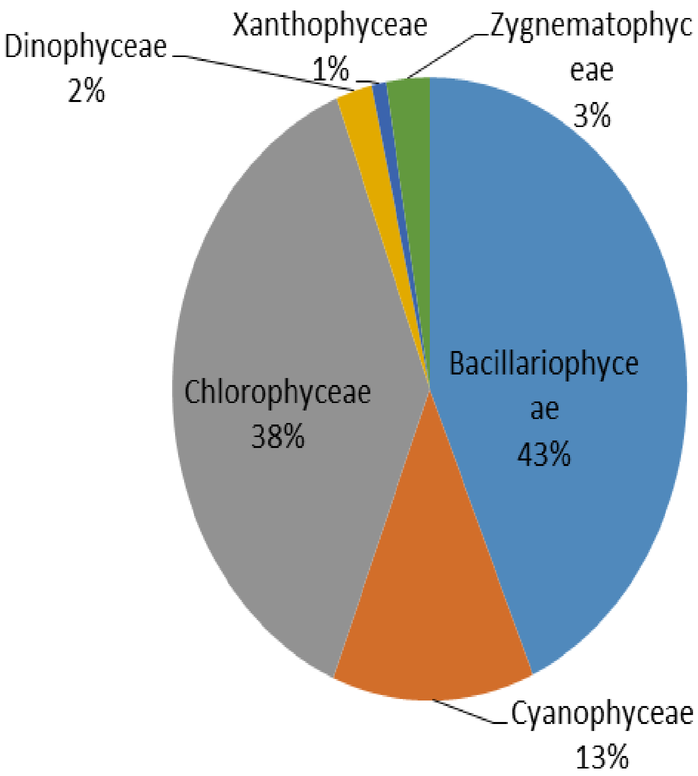


**Fig: 3.1 Percentage Composition of Phytoplankton**

**Table 3.2 .1 Physiochemical Parameters of all water Samples**

| S/N | Parameters | NUPRC Limit | Indorama control 1 surf water | Indorama control 2 surf water | Indorama Effluent surf water | Indorama Upstream surf water | Indorama Midstream surf water | Indorama Down stream surf water | Indorama Composite surf water |
|---|---|---|---|---|---|---|---|---|---|
| | Units ( Mg/L) | | | | | | | | |
| 1 | pH | 6.5-8.5 | 6.75 | 7.31 | 6.41 | 6.65 | 6.27 | 6.39 | 6.6 |
| 2 | Temperature(0C) | N/A | 27.2 | 27.2 | 27.2 | 27.2 | 27.3 | 27.3 | 27.4 |
| 3 | Electrical Conductivity(µs/cm) | | 946 | 950 | 6330 | 8900 | 15440 | 17070 | 13740 |
| 4 | Total Dissolve solids(mg/l) | | 47.3 | 47.5 | 316.5 | 445 | 772 | 853.5 | 687 |
| 5 | Dissolve Oxygen(DO) (mg/l) | | 2.33 | 2.52 | 1.79 | 2.11 | 1.64 | 2.34 | 1.17 |
| 6 | BiochemicalOxygenDemand(BOD)mg/l | | 0.11 | 0.11 | 0.99 | 0.44 | 0.28 | 0.86 | 0.13 |
| 7 | Chemical Oxygen Demand (COD)mg/l | | 224 | 352 | 256 | 352 | 192 | 288 | 320 |
| 8 | Salinity (ppm) | | 10.6 | 10.4 | 8110 | 9790 | 9910 | 10.2 | 10090 |

**Table 3.4.2: Physiochemical parameters of all Sediment Samples**

| S/N | Parameters And units (mg/kg) | NUPCC Limit | Indorama Control 1 sediment | Indorama Control 2 sediment | Indorama Effluent sediment | Indorama Upstream sediment | Indorama Midstream sediment | Indorama Downstream sediment | Indorama Composite sediment |
|---|---|---|---|---|---|---|---|---|---|
| 1 | pH | 6.5-8.5 | 6.96 | 6.68 | 6.68 | 6.54 | 6.83 | 6.85 | 6.94 |
| 2 | Temperature(0C) | N/A | 27.2 | 27.2 | 27.2 | 27.2 | 27.3 | 27.3 | 27.2 |
| 3 | Electrical Conductivity(µs/cm) | | 1000 | 997 | 2500 | 1715 | 2090 | 829 | 873 |
| 4 | Salinity(ppm) | | 557 | 590 | 660 | 544 | 725 | 478 | 465 |

**Table 3.3a: Hydrobiology results of zooplankton check**

| Zooplankton Checklist | Control 1 Water | Control 2 water | Effluent water | Up stream water | Mid water stream | Down Stream Water | Composite water |
|---|---|---|---|---|---|---|---|
| **ROTIFERA** | | | | | | | |
| Keratella valga | **3** | **4** | **0** | | | | |
| Branchionus forficula | | **1** | **0** | | | **4** | **3** |
| Lindia torulosa | **5** | **2** | **0** | **4** | **4** | | **2** |
| Branchiobdellioda sp | **4** | **3** | **0** | | **3** | **3** | **4** |
| | | | | | | | |
| **PROTOZOANS** | | | | | | | |
| Tintinopsis sp | | | **0** | | **2** | | |
| **INSECTA** | | | **0** | | | | |
| Odonata | **6** | **4** | **0** | | **5** | **4** | |
| **CRUSTACEA** | | | **0** | | | | |
| | | | | | | | |
| **Copepoda** | | | | | | | |
| Cyclops sp. | **3** | **1** | | **5** | | **3** | **1** |
| Encyclops sp. | | | | | | | |
| Naupli | **7** | **4** | | **5** | **0** | | **3** |
| Evadne tergstina | | | | | **2** | | |
| | | | | | | | |
| **Cladocera** | | | | | | | |
| Chydorus gibbus | **1** | **2** | | **2** | **3** | | **4** |
| Rhynchotalona sp | | | | | | **2** | **3** |
| **Arachnid** | | | | | | | |
| water mite | **1** | **2** | | | **5** | | |
| **Pisces** | | | | | | | |
| fish larvae | **1** | **2** | | | | | |

**Table 3.3b: Zooplankton Diversity Index:**

| Zooplankton Diversity Index | Control 1 Water | Control 2 water | Effluent water | Up stream water | Mid water stream | Down Stream Water | Composite water |
|---|---|---|---|---|---|---|---|
| Taxa_S | **9** | **10** | **0.00** | **4** | **7** | **5** | **7** |
| Individuals | **31** | **25** | **0.00** | **16** | **24** | **16** | **20** |
| Dominance_D | **0.125** | **0.083** | **0.00** | **0.225** | **0.125** | **0.158** | **0.116** |
| Simpson_1-D | **0.875** | **0.917** | **0.00** | **0.775** | **0.877** | **0.842** | **0.884** |
| Shannon_H | **2.126** | **2.380** | **0.00** | **1.427** | **2.011** | **1.706** | **2.028** |
| Evenness_e^H/S | **0.931** | **1.080** | **0.00** | **1.042** | **1.067** | **1.101** | **1.085** |
| Margalef | **2.33** | **2.796** | **0.00** | **1.082** | **1.888** | **1.443** | **2.003** |
| Equitability_J | **0.967** | **1.034** | **0.00** | **1.05** | **1.034** | **1.06** | **1.042** |

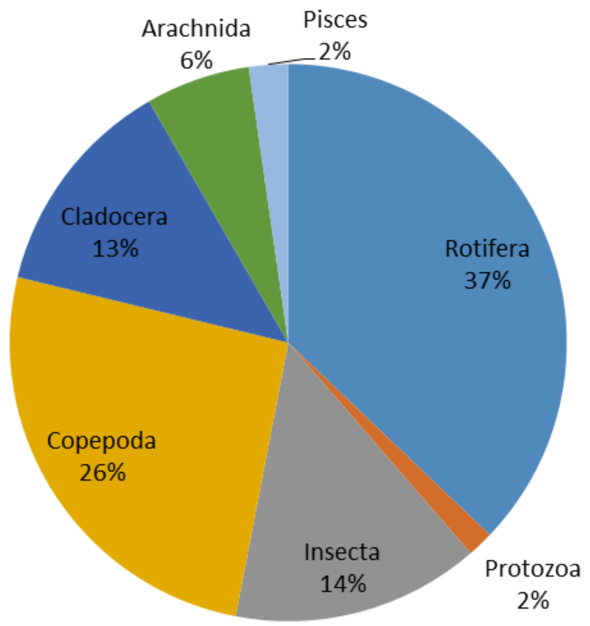


**Figure 3.2: Percentage Composition Zooplankton**

**Table 3.4a Hydrobiology results for Benthic macroinvertebrates**

| Macroinvertebrates Checklist | Control 1 Sed | Control 2 Sed | Eff luent Sed | Up stream Sed | Mid stream Sed | Down Stream Sed | Comp osite Sed |
|---|---|---|---|---|---|---|---|
| **Insecta** | | | | | | | |
| **Chironomidae** | | | | | | | |
| Chironomis sp | **8** | **5** | **0** | **3** | **2** | | **2** |
| Simulidae | **4** | **2** | **0** | | | **3** | **1** |
| Polycentropus sp | **1** | | | | | | |
| Sialis sp | **1** | | | **2** | | | |
| **Annelida** | | | | | | | |
| **Oligochaeta** | | | | | | | |
| Ophidonais sp | **1** | **2** | **0** | **3** | | | **3** |
| Uninais umcinata | | | | | **1** | | |
| Tubifex sp | **3** | **3** | **0** | | **4** | **5** | **2** |
| **Pisces** | | | | | | | |
| Alestes sp | | | | | | **1** | |

**Table 3.4b: Macroinvertebrates Checklist Diversity Index**

| Macroinvertebrates Checklist | Control 1 sed | Control 2 Sed | Eff luent Sed | Up stream Sed | Mid stream Sed | Down Stream Sed | Comp osite Sed |
|---|---|---|---|---|---|---|---|
| Taxa_S | **6** | **4** | **0.00** | **3** | **3** | **3** | **4** |
| Individuals | **18** | **12** | **0.00** | **8** | **7** | **9** | **8** |
| Dominance_D | **0.242** | **0.227** | **0.00** | **0.25** | **0.333** | **0.361** | **0.179** |
| Simpson_1-D | **0.758** | **0.773** | **0.00** | **0.75** | **0.667** | **0.639** | **0.8214** |
| Shannon_H | **1.614** | **1.434** | **0.00** | **1.207** | **1.099** | **1.0448** | **1.508** |
| Evenness_e^H/S | **0.837** | **1.048** | **0.00** | **1.115** | **1.000** | **0.951** | **1.130** |
| Margalef | **1.730** | **1.207** | **0.00** | **0.962** | **1.028** | **0.910** | **1443** |
| Equitability_J | **0.9007** | **1.034** | **0.00** | **1.099** | **0.9999** | **0.9539** | **1.088** |

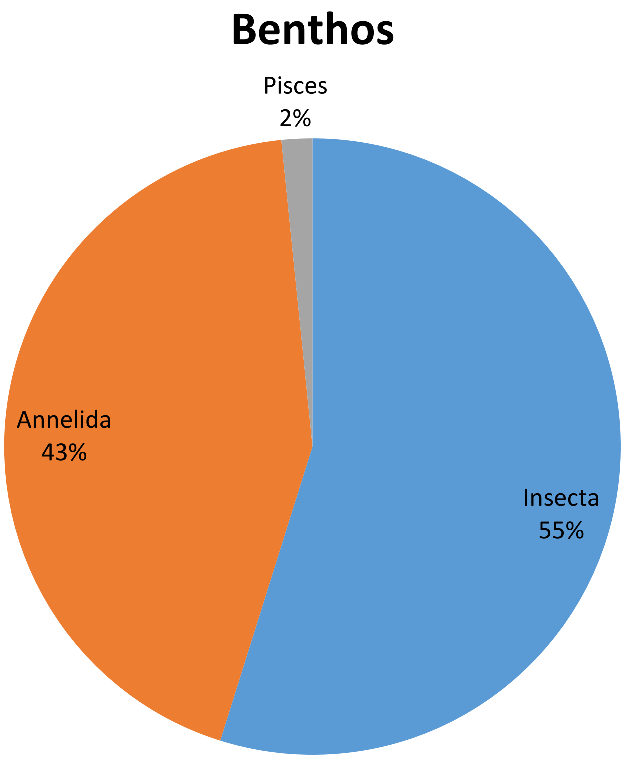


**Figure 3.3: Percentage Composition Benthos**

## 4 Discussion

### Abundance and Distribution of Planktons and Benthic Macro Invertebrate in Okulu Aleto River.

The distributional patterns and diversity indices of phytoplankton observed in the Okulu Aleto River reflect both natural ecological variability and anthropogenic disturbances across different sampling points. The results (Table 3.1a) indicate a marked dominance of the Bacillariophyceae group—particularly *Navicula dicephala*, *Cocconeis* spp., and *Diatoma* spp.—especially in control and upstream stations. This dominance is consistent with recent findings in Niger Delta freshwater systems, where diatoms have been identified as reliable indicators of good water quality and balanced nutrient availability (Ngodigha et al., 2025; Alagoa et al., 2023).

The exclusive presence of *Rhoicosphenia curvata* and *Fragilaria* spp. in downstream and control samples, respectively, suggests spatially driven ecological variability and responses to localized water quality. *Navicula* and *Leptocylindricus* were among the most widespread genera, with *Leptocylindricus* peaking in control water 2, implying relatively stable physicochemical conditions in that station. Conversely, the complete absence of phytoplankton in the effluent water points to acute ecological degradation likely caused by industrial pollutants, a pattern also observed by Umunnakwe et al. (2020) in Port Harcourt's Ntanwogba Creek, where effluent-dominated waters were nearly devoid of phytoplankton and benthic life.

Members of Cyanophyceae, notably *Oscillatoria tenuis* and *Phormidium papyraceum*, exhibited resilience in midstream and downstream waters—indicative of their known tolerance for eutrophic and organically enriched environments. Similar trends were documented in the Orashi River by Ngodigha, Uyi, and Deekae (2025), who reported cyanobacteria blooms in sections influenced by human and industrial discharges. The presence of *Anabaena* exclusively in downstream stations is indicative of elevated nutrient input—especially nitrogen and phosphorus—known to promote cyanobacterial proliferation in polluted waters (Egun & Oboh, 2025).

The Chlorophyceae group, comprising *Spirogyra* spp. and *Cladophora* spp., showed widespread distribution, with dominance in control and midstream waters. These taxa are generally associated with moderate organic pollution and are often indicators of early-stage eutrophication (Alagoa et al., 2023). Additionally, the presence of Dinophyceae such as *Prorocentrum lima* and *Dinophysis* spp., and Xanthophyceae like *Ophocytium* spp., predominantly in downstream samples, suggests increasing physicochemical stress downstream, possibly due to cumulative industrial effluents, a condition similarly reported in the Lower Nun River (Kiriye & Alagoa, 2022).

Phytoplankton diversity indices (Table 3.1b) further substantiate these observations. Composite and control stations recorded higher Simpson's and Shannon's diversity values, indicative of healthy and more balanced communities. In contrast, midstream and upstream waters exhibited lower diversity, implying mild to moderate ecological stress. This aligns with findings from the Orashi and Bonny River systems, where phytoplankton diversity was inversely related to pollution intensity (Ngodigha et al., 2025; Alagoa et al., 2023).

Evenness and equitability values remained relatively stable across most stations, suggesting a uniform distribution of species within each site, except in effluent-dominated waters. The complete absence of phytoplankton in effluent water is ecologically significant—it may represent a dead zone characterized by toxic conditions that suppress primary productivity, as also observed by Umunnakwe et al. (2020) in Port Harcourt creeks.

**Water Quality Variability and Pollution Indicators**

The physicochemical profile of surface water samples (Table 3.2a) from the Okulu Aleto River reveals significant deviations from the NUPRC permissible limits, especially in sites proximal to effluent discharge. pH levels ranged from 6.27 (midstream) to 7.31 (control 2), largely within permissible limits (6.5–8.5), though slightly acidic conditions in effluent and downstream waters suggest localized acidification possibly from industrial runoff. Electrical conductivity (EC) and total dissolved solids (TDS) were exceptionally elevated in effluent (EC = 6330 µS/cm, TDS = 316.5 mg/L), midstream (EC = 17070 µS/cm, TDS = 853.5 mg/L), and downstream stations (EC = 13740 µS/cm, TDS = 687 mg/L), indicating high ionic concentrations, a known marker of industrial pollution (Woke et al., 2020; Nduka et al., 2023).

Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) values were highest in effluent (BOD = 0.99 mg/L, COD = 256 mg/L) and midstream waters, showing a strong presence of biodegradable and chemical pollutants. Dissolved oxygen (DO) levels fell below ecological thresholds in effluent (1.79 mg/L) and downstream (1.64 mg/L) samples, suggesting oxygen depletion—an alarming signal for aquatic life sustainability (Chindah & Nduaguibe, 2022; Alagoa et al., 2023). Elevated salinity values in effluent (8110 ppm), midstream (9910 ppm), and downstream (10090 ppm) stations further underscore saline intrusion or contamination from industrial activities, possibly linked to petrochemical processes.

**Sediment Characteristics and Contamination Insights**

Sediment samples (Table 3.2b) show comparable trends, with electrical conductivity exceeding NUPRC limits in effluent (2500 µS/cm), midstream (2090 µS/cm), and upstream (1715 µS/cm) sediments. These elevated EC values suggest accumulated pollutants within the benthic layer, which can serve as long-term contaminant reservoirs (Ngodigha et al., 2025). Salinity concentrations peaked in midstream sediment (725 ppm), reinforcing the pattern of saline enrichment across impacted zones. Although pH and temperature readings remained within acceptable ranges across sediment stations, persistent conductivity and salinity anomalies in effluent and midstream samples raise concerns about the sediment's buffering capacity and potential to remobilize pollutants under changing environmental conditions (Edegbene et al., 2020; Chukwu et al., 2022).

The sediment contamination aligns with the degradation of water quality, indicating a dual-phase pollution scenario affecting both the water column and benthic zones of the river. These observations mirror findings from other Niger Delta water bodies impacted by petrochemical and industrial discharge, emphasizing the need for continuous ecological monitoring and enforcement of discharge regulations (Ibigoni et al., 2024; Ogbonda et al., 2022).

**Zooplankton Distribution and Diversity Assessment**

The analysis of zooplankton communities across sampled water bodies revealed significant spatial variation influenced by proximity to effluent discharge. Table 3.3a showed that while some species like *Keratella valga* and Fish larvae were restricted to control samples, indicative of more pristine conditions, other taxa such as *Lindia torulosa* and *Chydorus gibbus* demonstrated broader tolerance, occurring across multiple sites excluding effluent zones. Notably, no zooplankton was recorded in the effluent water, signaling possible acute pollution stress, a finding consistent with earlier studies that reported reduced faunal presence in heavily industrialized aquatic systems in the Niger Delta (Woke et al., 2020; Ngodigha et al., 2025). Table 3.3b further confirmed this, as effluent water recorded zero taxa richness and abundance, with diversity indices such as Shannon (H) and Simpson's (1-D) peaking in less disturbed areas like control 2 water, implying healthier ecological conditions (Edegbene et al., 2020; Ibigoni et al., 2024). Composite and downstream waters showed moderate diversity and evenness, suggesting some resilience or mixing effects. These patterns reinforce the ecological sensitivity of zooplankton to pollution and validate their use as bioindicators in environmental monitoring of petrochemical-impacted waters.

**Distribution of Benthic Macroinvertebrates**

Table 3.4a highlights the composition and distribution of benthic macroinvertebrates across different sediment sites. The Insecta group was the most represented, with *Chironomis sp.* dominating in control and stream-associated sediments, especially in control 1, suggesting its tolerance for moderate organic enrichment. *Simulidae* and *Sialis sp.* were found in fewer locations, while *Polycentropus sp.* was restricted to control 1, reflecting habitat specificity. The Annelida group, particularly *Ophidonais sp.* and *Tubifex sp.*, showed broader tolerance, with *Tubifex* notably absent only in effluent sediment, reinforcing its role as a pollution-tolerant species (Edegbene et al., 2020). The absence of organisms in the effluent sediment indicates poor ecological conditions, likely due to toxic or oxygen-depleting contaminants from industrial discharge, as supported by Woke et al. (2020).

**Diversity and Ecological Implications**

As presented in Table 3.4b, sediment biodiversity indices reinforce the observed distribution patterns. Control 1 sediment had the highest taxa richness and organism count, reflecting better environmental quality. In contrast, effluent sediment showed no benthic life, signaling extreme ecological stress. Composite sediment had the most balanced distribution, as seen in its highest Simpson (1-D), evenness (e^H/S), and equitability (J) indices, pointing to a relatively stable habitat. Downstream and midstream sediments showed moderate diversity, although downstream had higher dominance (D), suggesting a few species dominated the area. These findings confirm that sediment biodiversity declines with increased industrial influence, aligning with past assessments of sediment pollution impacts in the Niger Delta (Ngodigha et al., 2025; Ibigoni et al., 2024).

## 4. Conclusion

This study assessed the abundance and distribution of plankton and benthic macroinvertebrates in the Okulu Aleto River, Eleme, Rivers State, Nigeria, to evaluate the ecological status of the river system under industrial pressure. The findings reveal significant spatial variability in biological communities, physicochemical water quality, and sediment characteristics, driven primarily by proximity to effluent discharge from industrial sources.

Phytoplankton distribution indicated that Bacillariophyceae (especially *Navicula*, *Cocconeis*, and *Diatoma* spp.) dominated relatively pristine areas such as the control and upstream stations, signaling good water quality. In contrast, Cyanophyceae (e.g., *Oscillatoria* and *Anabaena* spp.) were more prevalent in midstream and downstream zones, suggesting eutrophic and polluted conditions. The complete absence of phytoplankton in effluent stations points to acute ecological degradation, likely resulting from toxic industrial discharges.

Similarly, zooplankton and benthic macroinvertebrates exhibited clear distributional trends. Zooplankton taxa such as *Keratella valga* and fish larvae were restricted to control sites, while tolerant species like *Lindia torulosa* and *Chydorus gibbus* were found across various points but excluded from effluent sites. No zooplankton or benthic macroinvertebrates were recorded in effluent water or sediment, indicating toxic conditions that are unsupportive of aquatic life. Benthic macroinvertebrates, particularly Insecta and Annelida, were present in varying degrees at other stations, with diversity and abundance declining progressively from control to downstream and absent in effluent areas.

The physicochemical parameters further support the biological evidence, with elevated EC, TDS, BOD, COD, and salinity values in effluent and midstream waters exceeding national permissible limits. These indicators confirm industrial pollution as a dominant stressor. Sediment analysis echoed similar trends, with higher conductivity and salinity values in impacted zones, suggesting long-term contamination and the potential for pollutant remobilization.

Furthermore we discovered that, the Okulu Aleto River is ecologically degraded downstream and near effluent outfalls, as evidenced by diminished biodiversity, altered species composition, and impaired water and sediment quality. The study underscores the utility of plankton and benthic macroinvertebrates as sensitive bioindicators of aquatic ecosystem health. Urgent regulatory intervention, continuous ecological monitoring, and enforcement of industrial discharge limits are recommended to safeguard the river's biodiversity and restore ecological balance.

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