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Aquatic Macrophyte Diversity, Distribution and Community Structure Along River Ethiope, Delta State, Nigeria

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ABSTRACT

Aquatic macrophytes are important components of freshwater ecosystems, contributing to biodiversity conservation, habitat provision, nutrient cycling, and ecosystem functioning. This study assessed the diversity, distribution, and community structure of aquatic macrophytes along River Ethiope, Delta State, Nigeria. Ten sampling stations were surveyed using a 0.5 × 0.5 m quadrat, supplemented with snorkelling and free-diving observations to document submerged vegetation. Physicochemical parameters were measured *in situ*, aquatic macrophyte abundance was estimated using diversity indices. About 22 taxa were identified across the study area. The genus *Nymphaea* was the most represented group, while *Nymphaea lotus* (Maroon Morph) was the most widely distributed taxon, occurring at all sampling stations (100%). Species richness varied from 2 taxa at Sapele to 17 taxa at Oria. Shannon diversity (H') ranged from 0.524 at Sapele to 2.595 at Oria, while Simpson diversity (1 − D) ranged from 0.340 to 0.938. Evenness values were generally high (0.755–1.000), indicating relatively balanced species distributions across most stations. Stations within the Abraka axis and Oria supported the highest diversity and vegetation cover, whereas Sapele exhibited reduced richness and diversity. Variations in macrophyte distribution and diversity appeared to correspond with differences in habitat characteristics, hydrological conditions, and levels of anthropogenic disturbance, including dredging, agriculture, waste disposal, and recreational activities. The findings demonstrate that River Ethiope supports a relatively diverse aquatic macrophyte community with considerable spatial variation in composition and distribution. This study provides baseline ecological information that will be useful for biodiversity conservation, ecosystem management and monitoring.

Keywords: Aquatic macrophytes; biodiversity; diversity indices; Community structure; River Ethiope; spatial distribution.

INTRODUCTION

Freshwater ecosystems are among the most productive and biologically diverse environments on Earth, supporting a wide range of ecological processes and providing essential ecosystem services to human societies. Despite occupying a relatively small proportion of the global landscape, freshwater habitats support disproportionately high levels of biodiversity and contribute significantly to fisheries production, water supply, transportation, recreation, nutrient cycling, and ecological stability. The structure and functioning of these ecosystems are strongly influenced by aquatic vegetation, particularly aquatic macrophytes, which constitute one of the most important biological components of inland waters (Wetzel, 2001; Warfe and Barmuta, 2006; Havel et al., 2015).
Aquatic macrophytes include submerged, emergent, floating-leaved, and free-floating plants that are adapted to life in aquatic environments and contribute substantially to primary productivity, nutrient cycling, sediment stabilization, and habitat formation.
Aquatic macrophytes perform numerous ecological functions that support freshwater biodiversity and ecosystem resilience. They provide spawning grounds, nursery habitats, feeding areas, and refuge for fishes, aquatic invertebrates, amphibians, reptiles, and water birds, while also serving as substrates for planktonic organisms and microbial biofilms (Wetzel, 2001; Beckett et al., 1992; Havel et al., 2015). Dense macrophyte stands can attenuate water movement, reduce sediment resuspension, improve water clarity, and enhance oxygen availability through photosynthetic activity (Kemp and Murray, 1986; Zhu et al., 2015). Through nutrient uptake and storage, aquatic macrophytes contribute to water quality improvement and can help suppress harmful algal blooms by reducing nutrient availability and altering ecological interactions within aquatic systems (van Donk and van de Bund, 2002; Netzbrytska et al., 2022). Recent studies have also highlighted the potential role of aquatic macrophytes in phytoremediation through the accumulation and sequestration of nutrients, heavy metals, and other contaminants from polluted aquatic environments (Okewole et al., 2023). Macrophytes such as Eichhornia crassipes, Pistia stratiotes, and Nymphaea spp. have demonstrated particular efficacy in absorbing heavy metals and excess nutrients, offering eco-friendly alternatives to chemical remediation approaches (Rai, 2008; Agbogidi & Ogbemudia, 2023).
Beyond their ecological importance, aquatic macrophytes provide significant economic and environmental benefits. They support fisheries production by enhancing habitat complexity, contribute to shoreline stabilization, facilitate carbon sequestration, and serve as indicators of ecosystem condition and environmental change (Dienye et al., 2017; NOAA Fisheries, 2020; Turner et al., 2020). Consequently, changes in macrophyte composition and distribution often reflect alterations in environmental quality and can provide valuable information for freshwater monitoring and management programmes.
The diversity and distribution of aquatic macrophytes are influenced by a complex interaction of physical, chemical, and biological factors. Water depth, current velocity, light penetration, substrate characteristics, nutrient availability, dissolved oxygen concentration, temperature, salinity, and pH are among the major environmental variables that determine species occurrence and abundance (Istvanovics et al., 2008; Barinova et al., 2024). In South-South Nigeria, spatial variation in physicochemical parameters has been shown to

significantly influence aquatic ecosystem conditions along river systems (Akawo et al., 2025). Hydrological conditions often influence the establishment and persistence of aquatic vegetation, while biological interactions such as competition and grazing may further affect community structure. At the same time, increasing anthropogenic pressures including dredging, sand mining, agricultural runoff, waste disposal, shoreline modification, and urban development can alter aquatic habitats and disrupt macrophyte communities (Neale et al., 2023; Vukov et al., 2026). Because aquatic macrophytes respond sensitively to such environmental changes, they are widely used as indicators of ecological status in freshwater ecosystems.

River Ethiope is one of the most important freshwater river systems in southern Nigeria. The river originates from a spring source near Umuaja in Delta State and flows through several communities before eventually connecting with the Benin River system. The river is renowned for its remarkable clarity, ecological significance, and socioeconomic importance. It supports domestic water use, fisheries, transportation, tourism, recreation, agriculture, and numerous cultural activities within surrounding communities. The river channel exhibits substantial spatial variation in depth, width, flow conditions, and riparian vegetation, creating diverse habitats capable of supporting varied aquatic plant communities. However, increasing anthropogenic activities, including dredging, sand mining, fishing, agriculture, waste disposal, and recreational use, have intensified along many sections of the river, with documented consequences for substrate stability, water clarity, and aquatic vegetation structure (Barinova et al., 2024; Vukov et al., 2026).

Previous investigations have documented the occurrence and diversity of aquatic macrophytes in selected sections of River Ethiope. For example, Agbogidi et al. (2017) investigated how seasonal water dynamics influence aquatic plants along the River Ethiope at Umutu only, Agbogidi et al. (2022) provided a checklist of macrophyte taxa and their distribution across selected river sections (upstream (umuaja), mid-stream (Abraka) and downstream (Amukpe). Similarly, Onochie and Amarie (2023) examined spatial variation in aquatic plant communities at the river source and highlighted the influence of hydrological conditions on vegetation establishment. Although these studies have contributed valuable baseline information, they were primarily focused on species occurrence and diversity patterns within specific sections of the river. Comprehensive documentation of the entire aquatic macrophyte community across multiple reaches, including detailed habitat characterization, physicochemical conditions, anthropogenic disturbances, species frequency of occurrence, community diversity indices, and high-quality photographic documentation for taxonomic verification, remains limited.

Furthermore, increasing anthropogenic pressures, including dredging, agriculture, aquaculture, recreational activities, waste disposal, and shoreline modification, have continued to alter habitats along River Ethiope, making updated ecological assessments necessary. Since aquatic macrophyte communities respond rapidly to environmental change, periodic inventories are essential for detecting changes in biodiversity and ecosystem condition. The present study therefore provides an updated assessment of aquatic macrophyte diversity, spatial distribution, community structure, frequency of occurrence, and associated environmental conditions along ten representative stations of River Ethiope. In addition, the study presents a comprehensive photographic catalogue of all recorded taxa to facilitate species verification, support future ecological monitoring, and provide a valuable taxonomic reference for researchers, conservation practitioners, and freshwater resource managers in Nigeria.

MATERIALS AND METHODS

Study Area

This study was conducted along River Ethiope in Delta State, Nigeria. River Ethiope is one of the most important freshwater rivers in southern Nigeria and serves as a source of domestic water, fisheries resources, recreation, transportation, and cultural activities for surrounding communities. The river originates near Umuaja in Ukwuani Local Government Area and flows through several communities before discharging into the Benin River system.

Ten sampling stations were selected along the river based on accessibility, habitat characteristics, vegetation occurrence, and levels of anthropogenic activities. The stations included Umuaja, Umutu, Umukwata (Ebedei), Obiaruku, Abraka Beach 1, Abraka Beach 2, Abraka Beach 3, Oria, Okpara Waterside, and Sapele. Geographic coordinates of each station were recorded using a Global Positioning System (GPS) in a mobile smart phone. The selected stations represented a range of environmental conditions and anthropogenic influences, including dredging, fishing, agriculture, aquaculture, recreation, cassava processing, waste disposal, palm oil production, and traditional cultural activities.

The location of the sampling stations is shown in Figure 1 and 2.

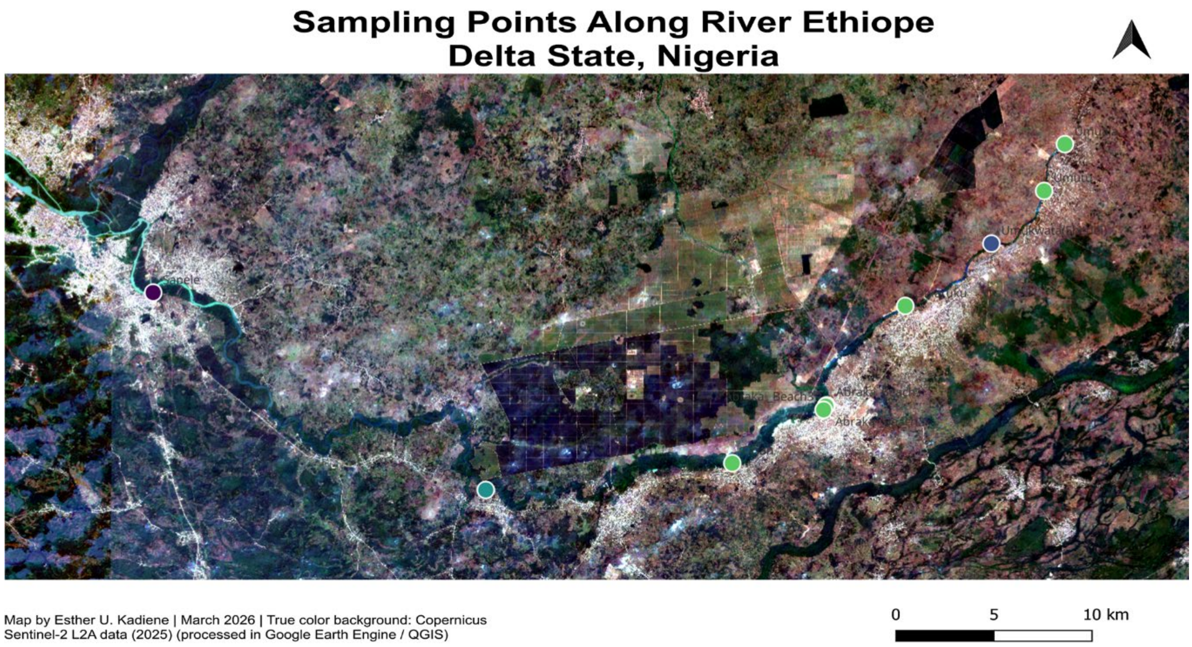

Figure 1: Satellite map of River Ethiope showing sampling points

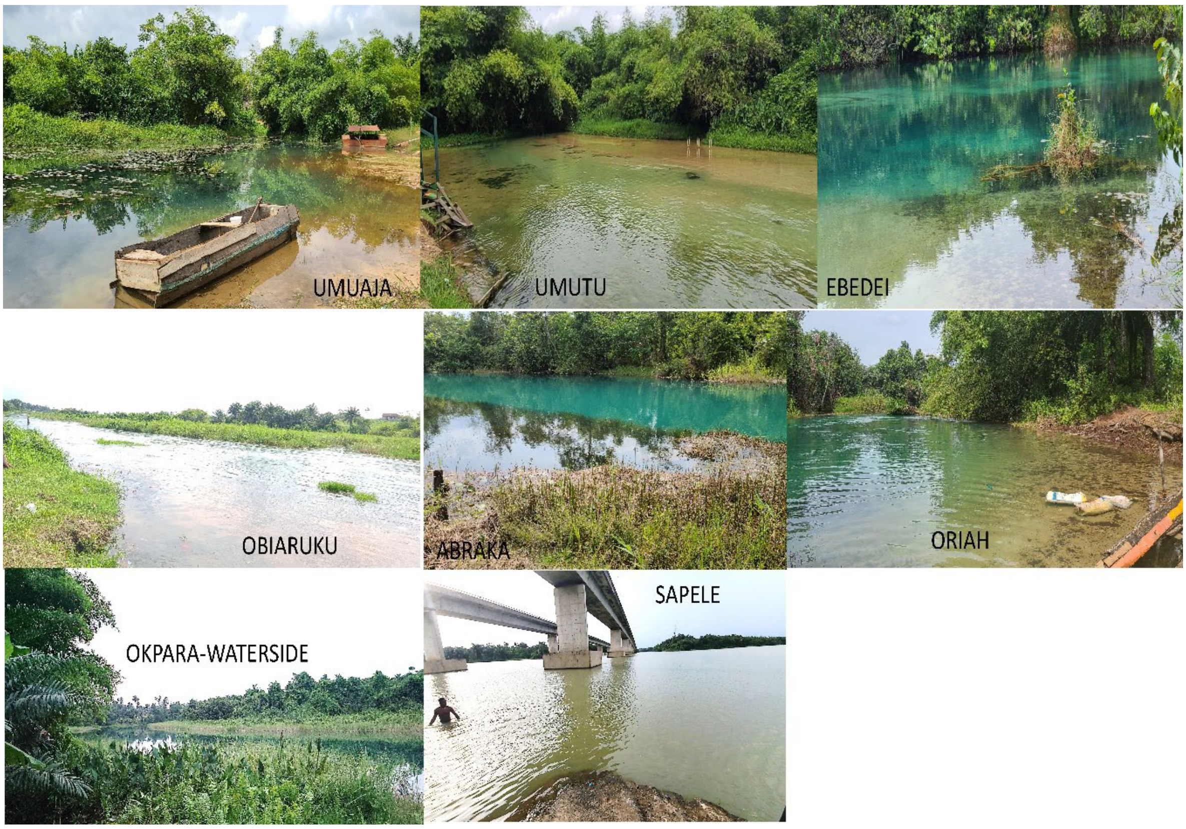

Figure 2: Representative views of sampling sites along River Ethiope, Delta State, Nigeria. Sites include (top row, left to right): Umuaja, Umutu, and Ebedei; (middle row): Obiaruku, Abraka, and Oria; (bottom row): Okpara Waterside and Sapele

Sampling Design and Field Survey

Field sampling was conducted from March to May, 2025, along selected sections of River Ethiope. At each station, aquatic macrophytes were surveyed within representative vegetation stands located along the river margins and shallow-water habitats.

A 0.5 m × 0.5 m quadrat (50 cm × 50 cm) was used to assess aquatic vegetation. Between three and five quadrats were randomly placed within vegetated areas at each station, depending on the size and width of the sampling site. All aquatic macrophyte taxa occurring within each quadrat were recorded, and their percentage cover was visually estimated. Species that could not be confidently identified in the field were photographed and assigned provisional names pending further examination (Figure 3).

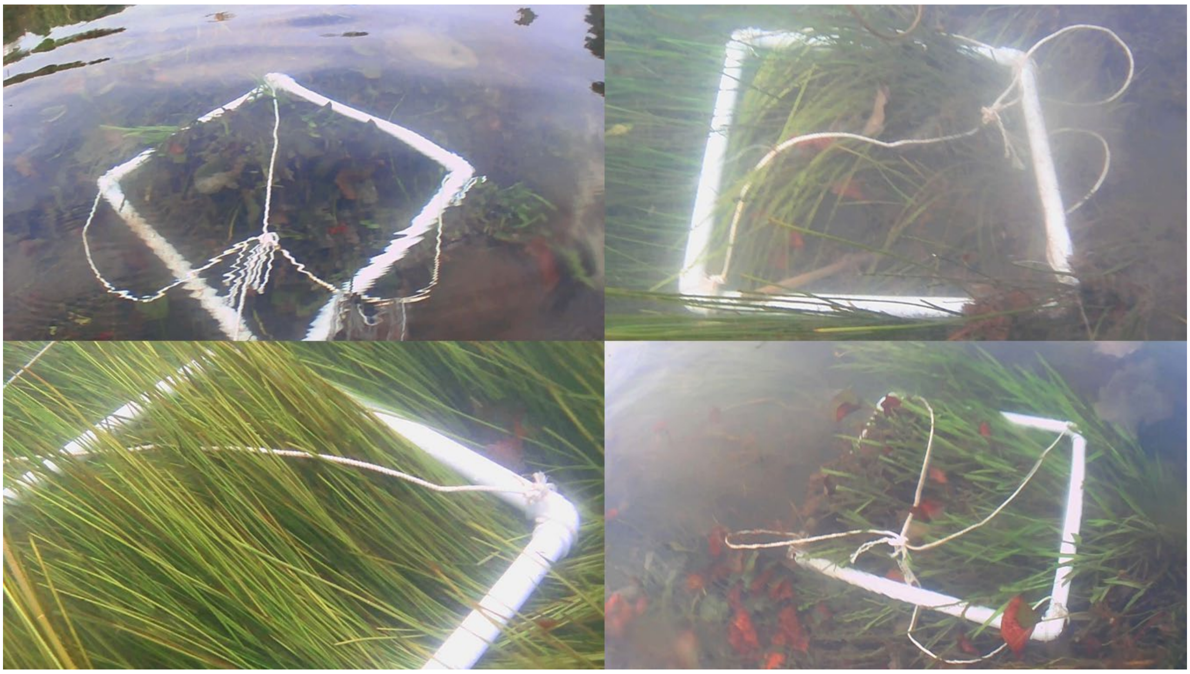

Figure 3: Sampling specie biodiversity using quadrat at the sampling sites along the river ethiope

Submerged aquatic vegetation was surveyed through direct underwater observations using snorkelling and free-diving techniques where water depth and visibility permitted. Observations obtained from quadrat sampling and underwater surveys were integrated to characterise the aquatic macrophyte community at each station.

Field observations were also made on habitat characteristics and anthropogenic activities occurring at each station. Information recorded included dredging activities, fishing operations, recreational use, agricultural practices, aquaculture activities, waste disposal, cassava processing, palm oil production, water current conditions, and traditional cultural activities that could potentially influence aquatic macrophyte distribution.

Identification of Aquatic Macrophytes

Aquatic macrophytes were identified using morphological characteristics observed in the field and from photographic records. Identification was carried out using available floristic guides, taxonomic keys, online botanical databases, and relevant literature.

Taxa that could not be confidently assigned to species level were designated as morphospecies (Morphospecies 1–3). Where species identification remained uncertain, the designation "cf." was used to indicate probable affinity to a particular taxon while acknowledging uncertainty in identification. Scientific nomenclature was verified using accepted taxonomic references where applicable.

Estimation of Aquatic Macrophyte Cover

The abundance of each aquatic macrophyte taxon was estimated visually using percentage cover classes within each quadrat following standard vegetation survey procedures (Mueller-Dombois and Ellenberg, 1974; Kent, 2012). Percentage cover was categorised into five classes in Table 1

Table 1: Classification of Percentage Cover

Cover Category	Estimated Cover (%)
Absent	0
Sparse	1–10
Low	11–25
Moderate	26–50
Dense/High	>50

The cover-class approach was adopted because several aquatic macrophytes formed dense clonal stands, making direct counting of individual plants difficult and potentially unreliable. Cover estimates from quadrat observations and field assessments were used to assign a station-level cover category for each recorded taxon.

Measurement of Physicochemical Parameters

Physicochemical parameters were measured in situ at each sampling station using portable water quality meters. Water temperature (°C), pH, dissolved oxygen (DO; mg L^{-1}), oxidation-reduction potential (ORP; mV), electrical conductivity (EC; µS cm^{-1}), and total dissolved solids (TDS; ppm) were measured according to standard procedures.

Water depth was determined using a measuring tape attached to a weighted sinker and float at representative points within each station. Measurements were recorded immediately during field sampling to minimise temporal variation.

Data Analysis

To facilitate quantitative analysis, cover categories were converted to numerical midpoint values (Table 2), commonly used in vegetation studies (Kent, 2012).

Table 2. Numerical Midpoint for Cover Categories

Cover Category	Numerical Value
Absent	0
Sparse (1–10%)	5
Low (11–25%)	18
Moderate (26–50%)	38
Dense/High (>50%)	75

The transformed values were used as abundance estimates for diversity analyses.

i. Species richness (S) was calculated as the total number of taxa recorded at each station.

ii. The Shannon–Wiener diversity index (H′) was calculated according to Shannon and Weaver (1949):
$H' = -\Sigma(p_i \ln p_i)$
where pi represents the proportional abundance of species i relative to the total abundance at a station.

iii. Simpson's dominance index (D) was calculated following Simpson (1949):
$D = \Sigma(p_i^2)$

iv. Simpson diversity was expressed as:
$1 - D$

v. Pielou's evenness index (J) was calculated according to Pielou (1966):
$J = H'/\ln(S)$
where S represents species richness.

vi. Frequency of occurrence (FO%) was calculated to determine the distribution of taxa among sampling stations using:
FO (%) = (Number of stations in which a species occurred ÷ Total number of stations surveyed) × 100

Descriptive statistics were used to summarise physicochemical parameters, while diversity indices and frequency of occurrence were used to evaluate spatial patterns in aquatic macrophyte communities along River Ethiope.

RESULTS AND DISCUSSION

Sampling Stations and Anthropogenic Activities

The sampling stations exhibited varying degrees of anthropogenic disturbance and hydrological characteristics (Table 3). Recreational activities were common at several stations, particularly within the Abraka axis and Umutu. Agricultural activities were observed at Umukwata (Ebedei), Oria, and Okpara Waterside, while dredging activities occurred at Obiaruku, Abraka Beach 3, and Sapele. Fishing activities were recorded at Oria and the Abraka stations.
Hydrological conditions also varied among stations. Strong to very strong currents were observed at Umutu, Obiaruku, Abraka Beach 3, Oria, and Sapele, whereas Umuaja and Okpara Waterside exhibited relatively calm conditions. Umukwata (Ebedei) was the deepest station and contained submerged woody debris, while Oria was characterized by extensive aquatic vegetation and a shallow vegetated channel connected to the main river.

Table 3. Description of Sampling Stations and Observed Anthropogenic activities along River Ethiope, Delta State, Nigeria

Station	Coordinates (Lat, Long)	Dominant Activities	Hydrological Characteristics
Umuaja	5.9415, 6.2313	Recreation; abandoned dredging site; traditional spiritual activities	Slow water current
Umutu	5.91597, 6.21987	Recreation	Strong water current
Umukwata (Ebedei)	5.88711, 6.191145	Agriculture; oil company activities	Deep water; calm conditions; low current; fallen trees present
Obiaruku	5.8527, 6.1436	Dredging; washing; swimming	High water current
Abraka Beach 1	5.798354, 6.100563	Recreation; fishing; waste disposal; cassava processing	Moderate to strong current
Abraka Beach 2	5.797575, 6.10011	Recreation; fishing; aquaculture activities	Moderate to strong current
Abraka Beach 3	5.795900, 6.099076	Recreation; active dredging; construction activities	Very strong current; narrow channel sections
Oria	5.76628, 6.048937	Fishing; agriculture; cassava processing	Shallow vegetated channel; wide river section; strong current
Okpara Waterside	5.7519, 5.91345	Palm plantation; cassava farming; palm oil processing	Wide channel; calm water; slightly turbid; low current
Sapele	5.85998, 5.730949	Active dredging; traditional spiritual activities	Wide river; very strong current; highly turbid water

Composition of Aquatic Macrophytes

A total of 22 aquatic macrophyte taxa belonging to eight families were recorded along River Ethiope (Table 4). The identified taxa included emergent, submerged, and floating-leaved macrophytes. Representative photographs of the recorded species are presented in Figures 4–25. The family Nymphaeaceae was represented by four taxa, namely *Nymphaea micrantha*, *Nymphaea cf. jamesoniana*, *Nymphaea lotus* (Green Morph), and *Nymphaea lotus* (Maroon Morph) (Figures 6–9). Members of the Hydrocharitaceae, including *Vallisneria americana*, *Vallisneria cf. nana*, and *Elodea* sp., were also recorded (Figures 11, 15 and 22).

Figure 4: Common name - Giant Spike-rush; Scientific Name - *Eleocharis interstincta*

Figure 5: Common name - Giant Hairgrass or Umbrella Hairgrass; Scientific Name - *Eleocharis vivipara*

Figure 6: Common name - Water Lilly; Scientific name - *Nymphaea micrantha*

Figure 7: Common name - Water Lilly; Scientific name - *Nymphaea* sp. *Cf. jamesoniana* Planch

Figure 8: Common name - Water Lilly (White Egyptian Lotus or Tiger Lotus); Scientific name - *Nymphaea lotus* L. (Wild-Type, Green Floating Morph)

Figure 9: Common name - Water Lilly (White Egyptian Lotus or Tiger Lotus); Scientific name - *Nymphaea lotus* L. (Wild-Type, Maroon/Dark purple Floating Morph (A) and (Submerged Juvenile / Transition Morph) (B)**)**

Figure 10: Common name: cf. African Water Onion; Scientific name: *Crinum* sp

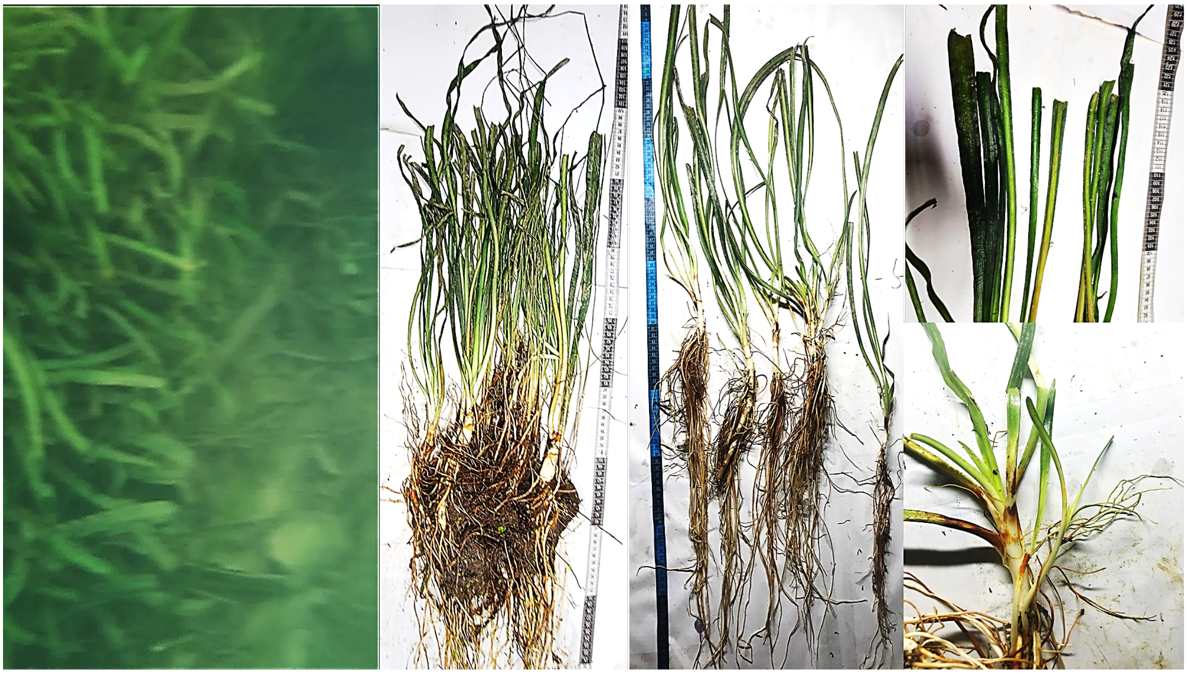

Figure 11: Common name - Tape-grass or eelgrass; Scientific name - *Vallisneria americana*

Figure 12: Common name - *cf.* Bladderwort**;** Scientific name - *cf. Utricularia* sp

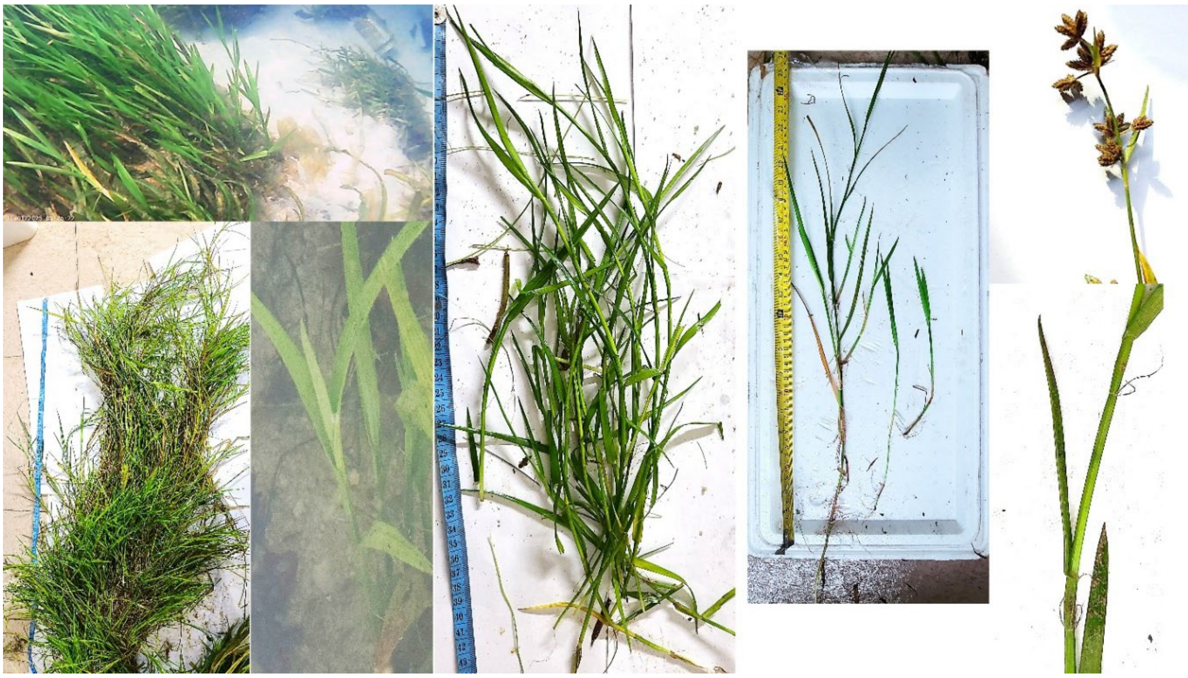

Figure 13: Common name - *cf.* bulrushes or club-rushes; Scientific name - *Bolboschoenus* sp. (upright, long-leaf form)

Figure 14: Common name - *cf.* bulrushes or club-rushes; Scientific name - *Bolboschoenus* sp. (creeping, compressed-node form)

Figure 15: Common name - Wild celery or eelgrass; Scientific name - *Vallisneria* sp. *cf. nana*

Figure 16: Morphospecie 1 (MS1)

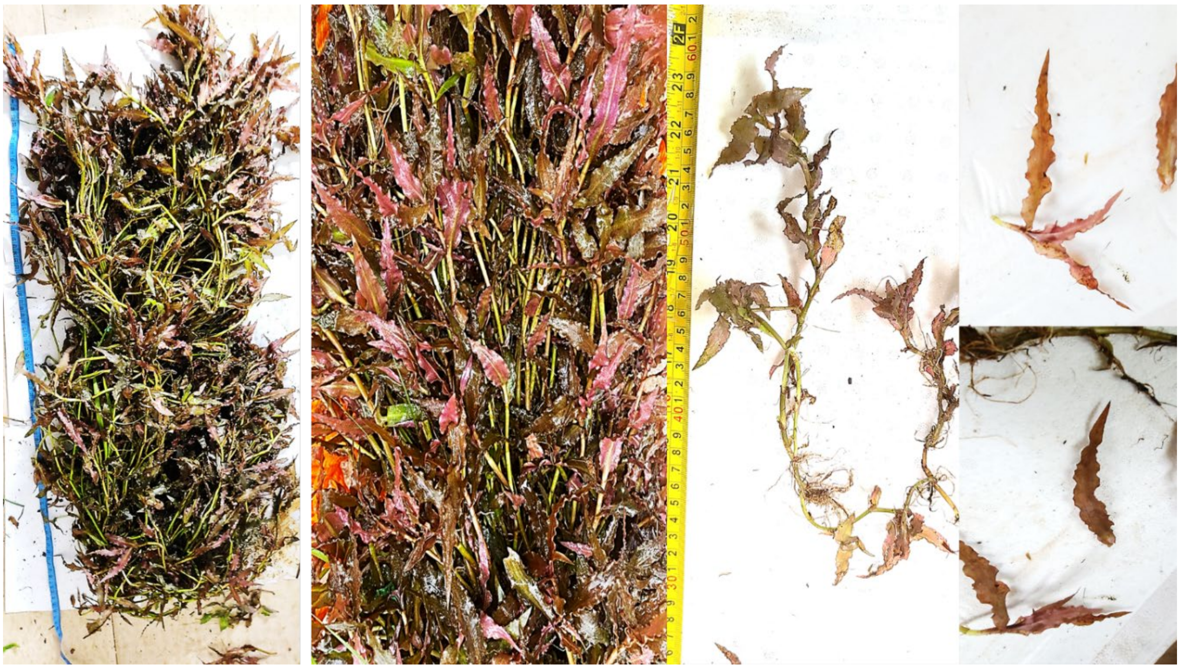

Figure 17: Common name - Curly-leaf pondweed; Scientific name - *Potamogeton crispus*

Figure 18: Morphospecie 2 (MS2)

Figure 19: Common name - Dwarf Anubias; Scientific name - *Anubias* sp

Figure 20: Common name - Arrowhead; Scientific name - *Sagittaria* sp

Figure 21: Common name - *cf.* Widgeon grass; Scientific name - *cf. Ruppia sp*

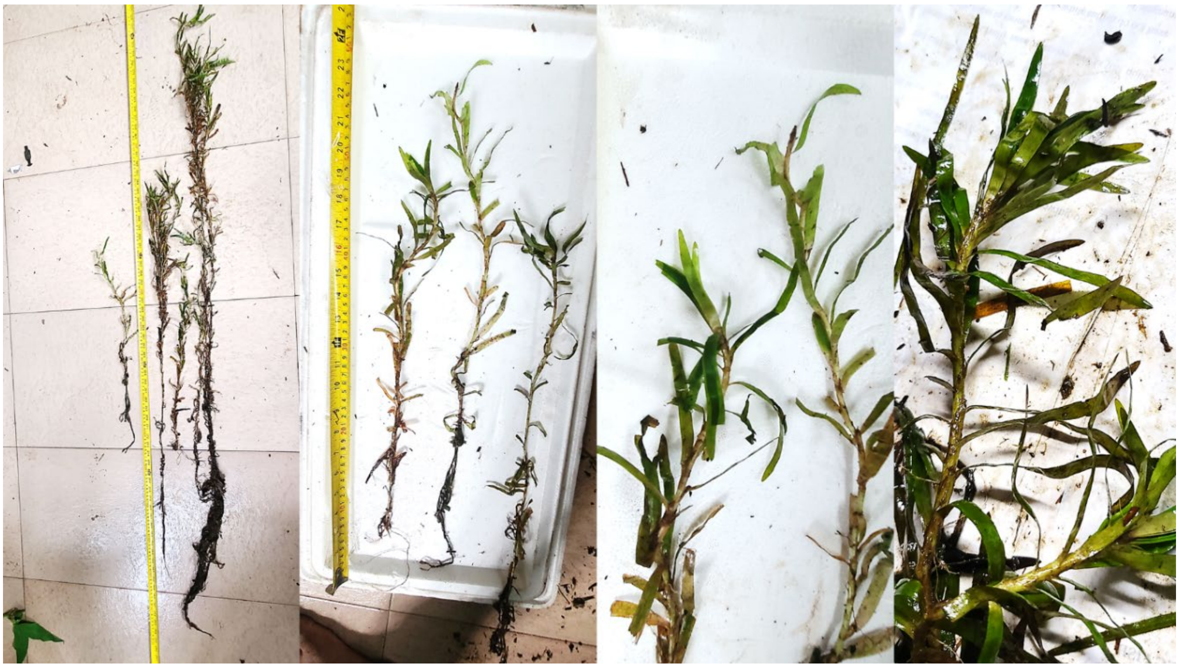

Figure 22: Common name - Waterweed; Scientific name - *Elodea sp*

Figure 23: Common name - Bladderwort; Scientific name - *Utricularia* sp

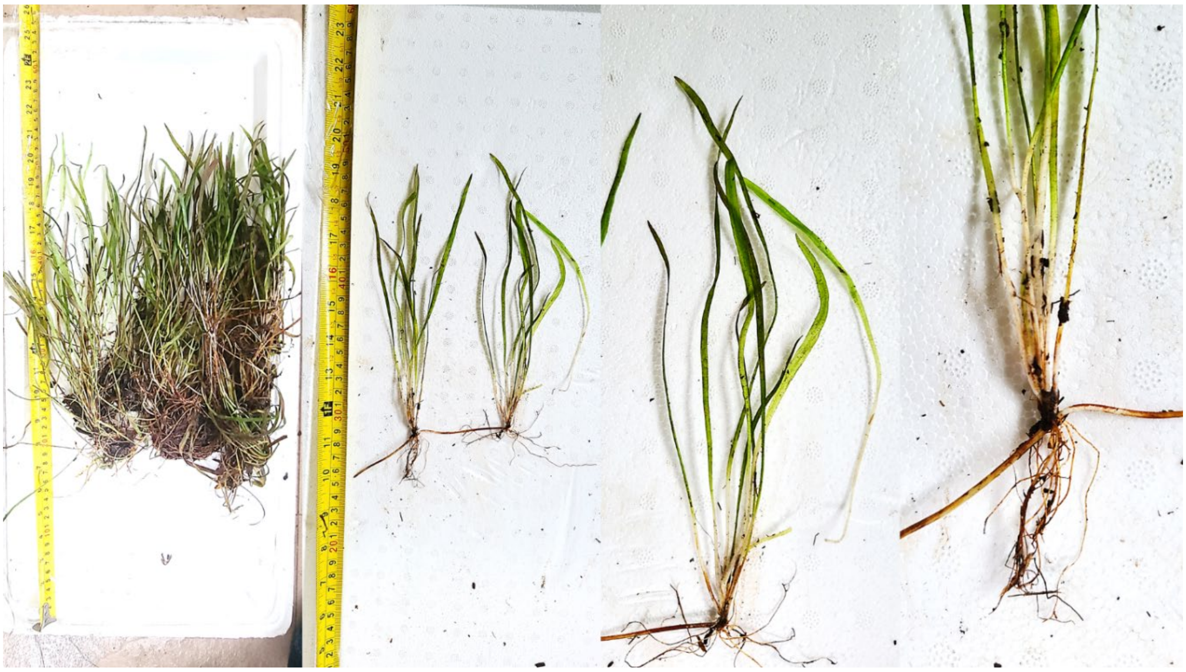

Figure 24: Common name - Straight Vallis; Scientific name - *Vallisneria* sp

Figure 25: Morphospecie 3 (MS3)

Table 4: Summary of Aquatic Macrophyte Species Recorded at the Sampled Stations along River Ethiope

S/N	Phylum (Group)	Class	Family	Species	Common Name
1	Tracheophyta (Angiosperms)	Liliopsida	Cyperaceae	*Eleocharis interstincta*	Spike-rush
2	Tracheophyta (Angiosperms)	Liliopsida	Cyperaceae	*Eleocharis vivipara*	Giant Hairgrass
3	Tracheophyta (Angiosperms)	Magnoliopsida	Nymphaeaceae	*Nymphaea micrantha*	Water Lily
4	Tracheophyta (Angiosperms)	Magnoliopsida	Nymphaeaceae	*Nymphaea* cf. *jamesoniana*	Water Lily
5	Tracheophyta (Angiosperms)	Magnoliopsida	Nymphaeaceae	*Nymphaea lotus* L. (Green Floating Morph)	Water Lily

S/N	Phylum (Group)	Class	Family	Species	Common Name
6	Tracheophyta (Angiosperms)	Magnoliopsida	Nymphaeaceae	*Nymphaea lotus* L. (Maroon Floating Morph)	Water Lily
7	Tracheophyta (Angiosperms)	Liliopsida	Amaryllidaceae	*Crinum* sp.	African Water Onion
8	Tracheophyta (Angiosperms)	Liliopsida	Hydrocharitaceae	*Vallisneria americana*	Eelgrass
9	Tracheophyta (Angiosperms)	Magnoliopsida	Lentibulariaceae	cf. *Utricularia* sp.	Bladderwort
10	Tracheophyta (Angiosperms)	Liliopsida	Cyperaceae	*Bolboschoenus* sp. (upright, long-leaf form)	Bulrush / Club-rush
11	Tracheophyta (Angiosperms)	Liliopsida	Cyperaceae	*Bolboschoenus* sp. (creeping, compressed-node form)	Bulrush / Club-rush
12	Tracheophyta (Angiosperms)	Liliopsida	Hydrocharitaceae	*Vallisneria* cf. *nana*	Wild Celery
13	Tracheophyta (Angiosperms)	Unknown	Unknown	Morphospecies 1 (MS1)	Unidentified Aquatic Plant
14	Tracheophyta (Angiosperms)	Liliopsida	Potamogetonaceae	*Potamogeton crispus*	Curly-leaf Pondweed
15	Tracheophyta (Angiosperms)	Unknown	Unknown	Morphospecies 2 (MS2)	Unidentified Aquatic Plant
16	Tracheophyta (Angiosperms)	Liliopsida	Araceae	*Anubias* sp.	Dwarf Anubias
17	Tracheophyta (Angiosperms)	Liliopsida	Alismataceae	*Sagittaria* sp.	Arrowhead
18	Tracheophyta (Angiosperms)	Liliopsida	Ruppiaceae	cf. *Ruppia* sp.	Widgeon Grass
19	Tracheophyta (Angiosperms)	Liliopsida	Hydrocharitaceae	*Elodea* sp.	Waterweed
20	Tracheophyta (Angiosperms)	Magnoliopsida	Lentibulariaceae	*Utricularia* sp.	Bladderwort
21	Tracheophyta (Angiosperms)	Liliopsida	Hydrocharitaceae	*Vallisneria* sp.	Straight Vallis
22	Tracheophyta (Angiosperms)	Unknown	Unknown	Morphospecies 3 (MS3)	Unidentified Aquatic Plant

Physicochemical Characteristics of Sampling Stations

The physicochemical characteristics of River Ethiope varied among the ten sampling stations (Table 5). Water temperature ranged from 27.85°C at Okpara Waterside to 30.50°C at Umukwata (Ebedei). The pH values ranged from 5.10 at Abraka Beach 2 to 7.20 at Umutu, indicating slightly acidic to near-neutral conditions throughout the study area. Electrical conductivity remained constant at 15 µS cm^{-1} across all stations.

Dissolved oxygen concentrations varied from 3.50 mg L^{-1} at Okpara Waterside to 8.85 mg L^{-1} at Obiaruku. Oxidation-reduction potential (ORP) ranged from 19.33 mV at Umutu to 128.50 mV at Okpara Waterside. Total dissolved solids (TDS) ranged from 6.67 ppm at Oria to 15 ppm at Umuaja. Water depth varied considerably, with the deepest station recorded at Umukwata (Ebedei) (3.7 m) and the shallowest at Obiaruku (0.3 m).

Table 5: Physicochemical Parameters for River Ethiope along the 10 Stations

Station	pH	EC (µS/cm)	Temp. (°C)	ORP (mV)	DO (mg/L)	TDS (ppm)	Depth (m)
Umuaja	6.8	14.0	28.0	22.5	6.8	15.0	1.8
Umutu	7.2	14.2	29.3	19.3	8.3	9.7	1.8
Umukwata (Ebedei)	5.9	15.0	30.5	41.0	8.4	9.0	3.7
Obiaruku	5.8	15.0	28.6	104.0	8.9	10.0	0.3
Abraka_Beach1	5.2	15.0	29.3	93.0	5.9	7.0	0.6
Abraka _Beach2	5.1	14.8	28.4	107.0	6.1	8.0	0.4
Abraka _Beach3	5.4	14.5	29.4	103.0	6.8	7.0	0.6
Oria	6.1	14.0	28.4	100.3	6.1	6.7	0.7
Okpara Waterside	5.7	15.0	27.9	128.5	3.5	7.0	1.7
Sapele	6.3	15.2	29.2	100.0	6.8	7.0	1.0

Spatial Distribution and Frequency of Occurrence of Aquatic Macrophytes

Aquatic macrophyte distribution varied considerably among stations (Table 6). Several taxa exhibited broad distributions throughout the river system, while others were restricted to a few locations. *Nymphaea micrantha*, *Nymphaea* cf. *jamesoniana*, and *Nymphaea lotus* (Green Morph) occurred in nine of the ten sampling stations, while *Nymphaea lotus* (Maroon Morph) was recorded at all stations. *Vallisneria americana* occurred in eight stations, whereas *Eleocharis interstincta*, *Bolboschoenus* sp. (upright form), and *Vallisneria* cf. *nana* were each recorded in seven stations. The Abraka stations and Oria exhibited the highest concentration of aquatic vegetation, with several species showing moderate to dense cover (>26%). Dense stands of *Eleocharis interstincta*, *Nymphaea* spp., *Vallisneria americana*, and *Bolboschoenus* sp. were particularly common in these areas. In contrast, Sapele exhibited the lowest vegetation abundance and species occurrence, with only two taxa recorded and generally low cover values.

The frequency of occurrence of aquatic macrophytes varied substantially among taxa (Figure 26). *Nymphaea lotus* (Maroon Morph) was the most widespread taxon, occurring at all sampling stations (100%). *Nymphaea micrantha*, *Nymphaea* cf. *jamesoniana*, and *Nymphaea lotus* (Green Morph) each occurred at 90% of the stations, while *Vallisneria americana* occurred at 80% of the stations. Intermediate frequencies were observed for *Eleocharis interstincta*, *Bolboschoenus* sp. (upright form), and *Vallisneria* cf. *nana*, each occurring at 70% of the stations. *Crinum* sp. and *Sagittaria* sp. were present in 60% of the stations, whereas *Eleocharis vivipara* occurred in 30% of the stations. Several taxa exhibited restricted distributions. *Potamogeton crispus*, *Elodea* sp., *Ruppia* sp., and *Bolboschoenus* sp. (creeping form) occurred at only 20% of the stations, while Morphospecies 1–3, *Anubias* sp., *Utricularia* sp., and *Vallisneria* sp. were each recorded at only one station (10%).

Table 6: Spatial Distribution (✓ (Present) and − (Absent)) of Aquatic Macrophytes Recorded along River Ethiope

Species	Umuaja	Umutu	Umukwata (Ebedei)	Obiaruku	Abraka B1	Abraka B2	Abraka B3	Oria	Okpara Waterside	Sapele
Eleocharis interstincta	–	–	–	✓	✓	✓	✓	✓	✓	✓
Eleocharis vivipara	–	✓	–	✓	✓	–	–	–	–	–
Nymphaea micrantha	✓	✓	✓	✓	✓	✓	✓	✓	✓	–
Nymphaea cf. jamesoniana	✓	✓	✓	✓	✓	✓	✓	✓	✓	–
Nymphaea lotus (Green Morph)	✓	✓	✓	✓	✓	✓	✓	✓	✓	–
Nymphaea lotus (Maroon Morph)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Crinum sp.	–	✓	✓	–	–	✓	✓	✓	✓	–
Vallisneria americana	–	✓	✓	✓	✓	✓	✓	✓	✓	–
cf. Utricularia sp.	–	–	–	–	✓	✓	✓	✓	–	–
Bolboschoenus sp. (upright)	–	✓	–	✓	✓	✓	✓	✓	✓	–
Bolboschoenus sp. (creeping)	–	–	–	–	–	–	–	✓	✓	–
Vallisneria cf. nana	–	✓	–	✓	✓	✓	✓	✓	✓	–
Morphospecies 1	–	–	–	–	–	–	–	✓	–	–
Potamogeton crispus	–	✓	–	✓	–	–	–	–	–	–
Morphospecies 2	–	✓	–	–	–	–	–	–	–	–
Anubias sp.	–	✓	–	–	–	–	–	–	–	–
Sagittaria sp.	–	–	✓	–	✓	✓	✓	✓	✓	–
cf. Ruppia sp.	–	✓	–	✓	–	–	–	–	–	–
Elodea sp.	–	–	–	–	–	–	–	✓	✓	–
Utricularia sp.	–	–	–	–	–	–	–	✓	–	–
Vallisneria sp.	–	–	–	–	–	–	–	✓	–	–
Morphospecies 3	–	–	–	–	–	–	–	✓	–	–

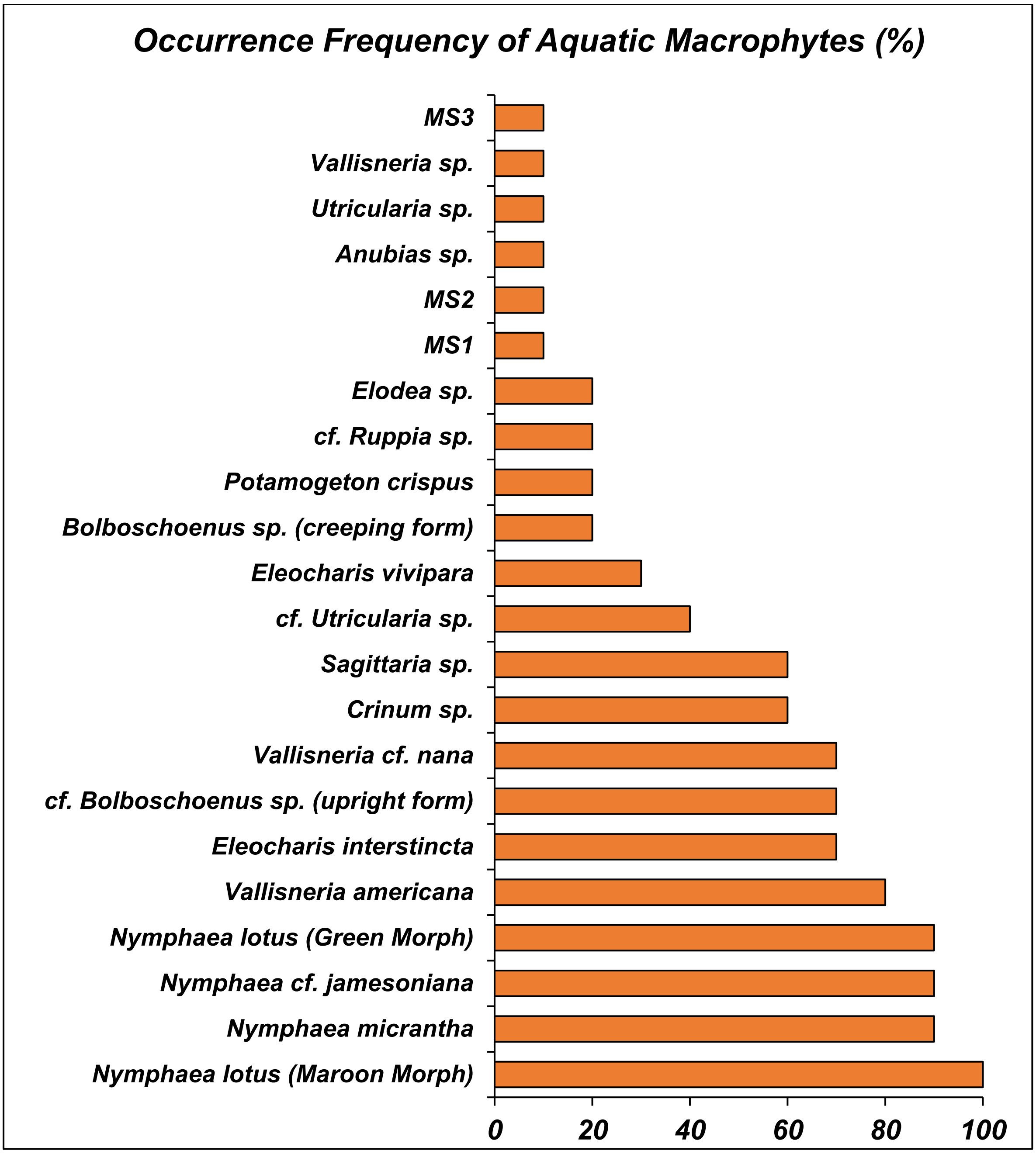

Figure 26: Frequency of occurrence (%) of aquatic macrophyte taxa recorded across ten sampling stations along River Ethiope, Delta State, Nigeria. Frequency was calculated as the percentage of stations in which each taxon occurred. Taxa are ordered from lowest to highest frequency

Diversity Indices of Aquatic Macrophytes

Species richness varied markedly among sampling stations (Table 7). The highest richness was recorded at Oria, where 17 taxa were observed, followed by Umutu (13 taxa) and Okpara Waterside (12 taxa). The lowest richness was recorded at Sapele, where only two taxa were present.

The Shannon–Wiener diversity index (H′) ranged from 0.524 at Sapele to 2.595 at Oria. High diversity values were also recorded at Okpara Waterside (H′ = 2.453), Umutu (H′ = 2.406), Abraka Beach 2 (H′ = 2.347), Abraka Beach 3 (H′ = 2.346), and Abraka Beach 1 (H′ = 2.336). Moderate diversity values were recorded at Obiaruku (H′ = 2.266) and Umukwata (H′ = 1.946), while Umuaja recorded a lower value of 1.386.

Simpson diversity (1−D) showed a similar pattern, ranging from 0.340 at Sapele to 0.938 at Oria. High Simpson diversity values were also observed at Okpara Waterside (0.910), Umutu (0.902), Abraka Beach 2 (0.902), Abraka Beach 1 (0.900), and Abraka Beach 3 (0.900). Pielou's evenness index (J) ranged from 0.755 at Sapele to 1.000 at both Umuaja and Umukwata (Ebedei). Most stations exhibited high evenness values (>0.90), indicating relatively balanced distributions of vegetation cover among taxa. The lower evenness value recorded at Sapele suggests increasing dominance by a limited number of species.

Table 7. Diversity Indices of Aquatic Macrophytes Recorded at Sampling Stations along River Ethiope

Station	Species Richness (S)	Total Cover	Shannon-Wiener Index (H′)	Simpson Dominance (D)	Simpson Diversity (1−D)	Pielou Evenness (J)
Umuaja	4	300	1.386	0.250	0.750	1.000
Umutu	13	539	2.406	0.098	0.902	0.938
Umukwata (Ebedei)	7	126	1.946	0.143	0.857	1.000
Obiaruku	11	412	2.266	0.116	0.884	0.945
Abraka Beach 1	11	694	2.336	0.100	0.900	0.974
Abraka Beach 2	11	731	2.347	0.098	0.902	0.979
Abraka Beach 3	11	640	2.346	0.100	0.900	0.978
Oria	17	630	2.595	0.062	0.938	0.916
Okpara Waterside	12	236	2.453	0.090	0.910	0.987
Sapele	2	23	0.524	0.660	0.340	0.755

Spatial Patterns of Diversity and Community Structure

Distinct spatial patterns were observed along River Ethiope. Oria supported the highest species richness and diversity, coinciding with extensive aquatic vegetation and a heterogeneous habitat characterized by shallow vegetated channels and a wide river section. Similarly, the Abraka stations supported diverse macrophyte communities with moderate to dense vegetation cover. Conversely, Sapele exhibited the lowest richness, diversity, and evenness values. This station was characterized by active dredging, high turbidity, strong water currents, and extensive human disturbance. The reduced diversity observed at this station suggests that habitat modification and disturbance may influence aquatic macrophyte distribution and community structure within River Ethiope.

Discussion

The present study documented 22 aquatic macrophyte taxa distributed across ten sampling stations along River Ethiope. The recorded flora comprised submerged, emergent, and floating-leaved species, reflecting the habitat heterogeneity of the river system. The dominance of species belonging to the genera *Nymphaea*, *Vallisneria*, *Eleocharis*, and *Bolboschoenus* suggests that River Ethiope provides suitable environmental conditions for a wide range of aquatic plants. Aquatic macrophytes are important structural components of freshwater ecosystems, contributing to primary production, nutrient cycling, sediment stabilization, and habitat provision for aquatic organisms (Wetzel, 2001; Warfe and Barmuta, 2006). The occurrence of multiple growth forms observed in this study indicates a relatively diverse aquatic plant community capable of supporting ecological functions within the river ecosystem.

The species composition recorded in this study is generally consistent with previous investigations conducted along River Ethiope and other freshwater systems within the Niger Delta region. Agbogidi et al. (2022) reported diverse macrophyte assemblages along River Ethiope, while Onochie and Amarie (2023) documented several aquatic plant species at the river source. Similarly, Oyareme and Osaji (2021) observed considerable variation in aquatic macrophyte communities within the Abraka section of the river. The occurrence of several species previously reported from River Ethiope supports the view that the river remains an important refuge for freshwater aquatic vegetation despite increasing anthropogenic pressures.

The frequency-of-occurrence analysis revealed considerable differences in species distribution among stations. *Nymphaea lotus* (Maroon Morph) was the most widely distributed taxon, occurring at all sampling stations, while *Nymphaea micrantha*, *Nymphaea* cf. *jamesoniana*, and *Nymphaea lotus* (Green Morph) occurred at 90% of the stations. Similarly, *Vallisneria americana* was recorded at 80% of the stations. The widespread occurrence of these taxa suggests broad ecological tolerance and adaptation to the range of environmental conditions present within River Ethiope. Species with wide distributions often possess physiological and morphological characteristics that enable them to persist across varying hydrological conditions, water depths, and substrate types (Chambers et al., 2008; Maranho et al., 2024). In contrast, several taxa, including Morphospecies 1–3, *Anubias* sp., *Utricularia* sp., and *Vallisneria* sp., were recorded at only a single station. Restricted occurrence patterns may reflect habitat specialization, limited dispersal opportunities, localized environmental conditions, or competitive interactions with more dominant species. Similar patterns of widespread and restricted species distributions have been reported in other freshwater macrophyte communities where habitat heterogeneity creates distinct ecological niches (Petruzzella et al., 2018; Barinova et al., 2024).

Substantial variation in species richness and diversity was observed among sampling stations. Oria recorded the highest species richness (17 taxa) and the highest Shannon diversity index (H′ = 2.595), whereas Sapele exhibited the lowest richness (2 taxa) and lowest diversity (H′ = 0.524). The high diversity observed at Oria (H′ = 2.595; 17 taxa) likely reflects habitat heterogeneity, specifically the combination of shallow vegetated channels connected to a wider river section, which creates varied niches for species with different light requirements, current tolerances, and substrate preferences (Warfe & Barmuta, 2006; Chambers et al., 2008). The extensive vegetation cover documented at this station (Table 6) further supports the role of habitat complexity in promoting species coexistence. Habitat heterogeneity is widely recognized as an important driver of aquatic plant diversity because it increases the availability of ecological niches and promotes species coexistence (Warfe and Barmuta, 2006; Chambers et al., 2008).

The Abraka stations also supported relatively high diversity values, with Shannon indices exceeding 2.3 and evenness values approaching unity. These findings indicate relatively balanced macrophyte communities in which no single species overwhelmingly dominated the vegetation assemblage. High evenness values generally reflect stable communities characterized by relatively equitable distribution of abundance among species (Pielou, 1966; Magurran, 2004). The combination of moderate water depth, suitable light availability, and diverse habitat conditions may have contributed to the maintenance of these diverse communities. Conversely, the low diversity recorded at Sapele may reflect the influence of environmental disturbance. Field observations indicated active dredging operations, high turbidity, strong water currents, and intensive human activities at this station. Dredging and sediment disturbance can alter substrate characteristics, reduce water clarity, increase suspended solids, and limit light penetration required for aquatic plant growth. Reduced light availability is a major factor limiting the distribution of aquatic macrophytes, particularly submerged species (Orth et al., 2010; Istvanovics et al., 2008). Although statistical relationships were not examined in the present study, the low richness and diversity observed at Sapele suggest that habitat disturbance may influence aquatic vegetation patterns within the river.

The physicochemical characteristics recorded during the study generally fell within ranges reported as suitable for tropical freshwater macrophytes. Water temperature (27.85–30.50°C) and pH (5.10–7.20) were consistent with values reported from other macrophyte-rich systems in the Niger Delta region (Agbogidi et al., 2022; Oyareme & Osaji, 2021), and other South-South Nigerian rivers (Akawo et al., 2025). Dissolved oxygen concentrations were moderate to high across most stations (3.50–8.85 mg L^{-1}), although the lower value at Okpara Waterside may reflect reduced photosynthetic activity or enhanced organic decomposition at that station. Dissolved oxygen concentrations were generally moderate to high across most stations, although lower values were observed at Okpara Waterside. The pH values indicated slightly acidic to near-neutral conditions, which are typical of many freshwater systems in the Niger Delta region. Environmental variables such as temperature, dissolved oxygen, pH, water depth, and flow conditions are known to influence macrophyte growth and community composition (Istvanovics et al., 2008; Barinova et al., 2024). However, because no correlation analyses were performed, the observed diversity patterns should be interpreted as potential associations rather than direct causal relationships.

Anthropogenic activities were evident throughout the study area and varied among stations. Dredging activities were observed at Obiaruku, Abraka Beach 3, and Sapele, while agricultural activities occurred at Umukwata, Oria, and Okpara Waterside. Recreational activities, fishing, cassava processing, aquaculture operations, and waste disposal were also recorded at several locations. Such activities can alter habitat structure, modify nutrient dynamics, increase sediment loading, and affect water quality, thereby influencing aquatic plant communities (Dienye et al., 2017; Vukov et al., 2026). The present study documented spatial associations between anthropogenic activities and macrophyte community patterns; however, the observational design precludes causal attribution. The correlations between dredging, agriculture, and reduced diversity (e.g., at Sapele) are suggestive but not definitive. Quantifying the direct effects of specific disturbances on macrophyte communities through before-after-control-impact designs, replicated experimental approaches, or long-term monitoring represents a critical direction for future research (Vukov et al., 2026).

The ecological significance of the aquatic macrophyte communities documented in this study extends beyond plant diversity alone. Aquatic vegetation provides habitat complexity that supports fishes, aquatic invertebrates, and other organisms, thereby contributing to overall ecosystem productivity and biodiversity (Beckett et al., 1992; Warfe and Barmuta, 2006). Macrophytes also contribute to nutrient retention, sediment stabilization, carbon storage, and water quality improvement (Kayranli et al., 2010). Consequently, maintaining diverse aquatic macrophyte communities is important for sustaining the ecological integrity of River Ethiope.

CONCLUSION

This study documented 22 identified aquatic macrophyte taxa across ten stations along River Ethiope, revealing substantial spatial variation in species composition, diversity, and community structure. The river supports a relatively diverse aquatic macrophyte flora dominated by Nymphaea, *Vallisneria, Eleocharis*, and *Bolboschoenus* species, with growth forms spanning submerged, emergent, and floating-leaved categories.

Oria and the Abraka stations emerged as biodiversity hotspots, supporting the highest species richness and diversity indices, while Sapele exhibited severely depauperate macrophyte communities associated with active dredging and intensive anthropogenic disturbance. The widespread occurrence of Nymphaea lotus (Maroon Morph) across all stations suggests broad ecological tolerance, whereas restricted distributions of *Anubias* sp., *Utricularia* sp., and morphospecies indicate habitat specialization or limited dispersal capacity.

These findings establish critical baseline data for River Ethiope and highlight the sensitivity of aquatic macrophyte communities to habitat modification. The results support the integration of macrophyte surveys into routine biomonitoring programmes for the river and underscore the need for (i) regulated dredging practices that minimize sediment suspension and habitat destruction; (ii) riparian buffer zones to reduce agricultural runoff and waste disposal impacts; (iii) continued monitoring of aquatic vegetation at established stations to detect temporal trends; and (iv) further taxonomic resolution of unidentified morphospecies. Given the ecological and socioeconomic importance of River Ethiope, maintaining diverse macrophyte communities is essential for sustaining fisheries productivity, water quality, and overall ecosystem integrity in this important Niger Delta freshwater system.

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