

Macrophytes of Dhir Beel Wetland in Assam, India in relation to its limnological factors

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ABSTRACT

*Dhir Beel, an oxbow lake in Western Assam, India, is a heaven for diverse flora and fauna, fostering a rich ecosystem in freshwater habitats. The study aimed to address pollution, encroachment, siltation, and overfishing concerns in Dhir Beel. Over a three-year period, samples were collected from five different sites for water and macrophytes. Physico-chemical parameters were assessed using the APHA method, and macrophytes were identified through a thorough identification procedure. The study revealed a total of 82 species, with dicots, monocots, and pteridophytes representing 38, 40, and 4 species, respectively. Notably, Nymphaeaceae, Poaceae, and Equisetaceae families played significant roles, occupying 11.21%, 25%, and 25% of the macrophyte composition, respectively. The emergent macrophytes monocots Poaceae were dominant in terms of species diversity, while free floating macrophyte *P. stratiotes* and *A. nilotica* were dominant. The study of diversity indicated that undisturbed sites (Site- IV and V) exhibited significant macrophyte diversity compared to polluted sites (Site-I and II), emphasizing the need for well-planned conservation efforts in this ecologically valuable oxbow lake.*

Key Words: Dhir beel, Physico-chemical, Monocots, Dicots, Macrophytes, Diversity.

Mathematics Subject Classification: 62D05, 62J10

Journal of Economic Literature (JEL) Classification : Q2, Q22, Q25

1. INTRODUCTION

Aquatic macrophytes, also known as hydrophytes or aquatic plants, are adapted to thrive both as amphibious and fully submerged in a floating state, due to the presence of aerenchyma (Agbogidi *et al.*, 2000). Macrophytes maintain the water quality as well as rich bioresources, which in turn allow retaining an excellent relationship between the diversity and ecosystem functions (Duffy *et al.*, 2017). Macrophytes are classified by their biotypes into categories such as emergent, floating, free-floating submerged, rooted submerged, and submerged with floating leaves, reflecting their interactions with the aquatic environment (Lesiv *et al.*, 2020). Macrophytes play an important role in the running of ecological restoration process owing to their own dynamic function, which are inclusive of controlling sediments resuspension (Rolland *et al.* 2015), and the facilitation of nutrient intake from the environment (Granelli and Solander, 1988). Also, they are suitable for habitat and food for aquatic animals (Wood *et al.*, 2017).

The variation in submerged macrophytes can be explained by the physical and chemical characteristics of the water column, as well as its depth and flooding, which are influenced by the

sediment nutrient source (Li *et al.*, 2018). The distribution and species composition of macrophyte vegetation were influenced more by water depth than by physico-chemical properties such as density, pH, and total nitrogen (Antunes *et al.*, 2012). The interaction between water parameters and submerged macrophytes is crucial in shaping ecosystem structure and maintaining water quality (Bornette *et al.*, 2011; Swe *et al.*, 2021). Also, the role of several elements both macro and micronutrients along with the beneficial element (Na^+ , Se, Si) are the major attributor to the diversity of submerged macrophytes (Xing *et al.*, 2015). Anthropogenic interferences often change the nutrient dynamics favoring the growth or decline of either invasive species or fall of native species thus losing the biodiversity (Sharma and Singh, 2017).

This study aims to investigate the seasonal impact of limnological factors on monocot, dicot and pteridophytes diversity in Dhir Beel of Assam, India. Freshwater wetlands, particularly those in the form of beels, play a crucial role in supporting diverse macrophyte communities. Understanding the influence of water acidity, alkalinity, nutrient levels, and elemental composition (both macro and micronutrients) on the growth and distribution of aquatic plants is essential. This research will contribute valuable insights into the dynamic interplay between limnological conditions and macrophyte diversity in Dhir Beel, providing essential knowledge for effective conservation and management strategies for wetlands in the region.

2. MATERIALS & METHODS

Study Area

Dhir beel, an Oxbow lake (Fig. 1) is located in the Western Assam of India with the coordinates (26°16'21" N, 90°22'46" E) at Chapar-Salkocha Block, Dhubri District, Assam, India.



Figure 1. Map and Google satellite imagery of the lake showing the sample collection Site(s) of macrophytes in the Oxbow lake the Dhir beel in Assam.

Table 1: Study site(s) in the Oxbow lake in Assam during the period 2016 to 2019.

(ASL- Above sea level).

Characteristics of different Sites of the Oxbow lake, Dhir beel				
Site no.	Collection spots	ASL (metre)	Specifications of Site(s)	Coordinates
I	Arrearjhar	23	Nearby Agricultural runoff: There is high probability of organic pollution and inflow of other organic inflow of the excess agricultural inputs like fertiliser and pesticides etc.	26°16 '53.33'N 90°23'28.33'E
II	Dhir Ghat NH- 31	23	Nearby Brick factory (500m): This Site is situated near approximation to a brick field.	26°16 '06.62'N 90°23'24.82'E
III	Dhir Ghat	24	Near human habitat and Market: This Site is often exposed to anthropogenic activities like bathing, livestock watering; market sewages.	26°16 '57.46'N 90°22'31.62'E
IV	Tintila	27	Near Chakrashila Wildlife Sanctuary: Tintila village	26°17 '26.51'N 90°22'29.30'E
V	Chakrashila	31	Chakrashila Wildlife Sanctuary: Touching Chakrashila W.S.	26°17 '44.68'N 90°22'33.91'E

2.1. Water sample collection

The water from the lake was collected during summer (Pre-monsoon and monsoon) and winter (Post-monsoon and winter) during the study period (of June 2016 to May 2019). Seasonality was followed after Borthakur (1986) with slight modification (Das and Sharma, 2022). Water samples were collected following after the sampling procedure of Jhingran *et al.* (1969). Samples were collected in the morning between 7:00 A.M. to 2:00 PM at a depth of 30 cm from each of the site for five times in a month (35 times in summer and 25 times in winter) following Das (2023). Limnological parameters like pH, DO, Bicarbonate (HCO_3^-), Free Carbon-dioxide (FCO_2), Total alkalinity (TA), Total hardness (TH), Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Cl^- , SO_4^{2-} , PO_4^{3-} , NO_3^- were analysed following the methods of APHA (2012) and HiMedia lab testing Kits were used to perform other physico-chemical analysis (Das, 2023).

2.2. Macrophytes Identification

Aquatic macrophytes were collected along the bank of the Oxbow lake, Dhir beel at an interval distance of 1-1.5 Km apart from one site to another. The floating macrophytes (five times per month) a total of 180 samples were collected from each of the sites following the Quadrat sampling procedures. Each site depth was one metre and ten quadrat of size was 1m^2 in all study sites randomly. Samples collected were wrapped in white paper, covered with brown paper envelope to avoid drying up. The same were quickly brought to the laboratory of the Zoology Department, University of Science and Technology Meghalaya were identified with help of a Botanist of the USTM with the use of a Catalogue (Agbogidi *et al.*, 2000) and classified from family to species level (Adoni, 1985, Cook, 1996). Vegetation sampling was followed after taking into the quadrats of each site for density, frequency and Importance Value Index (Mishra, 1969). The Importance Value Index is a

valuable tool for ecologists to assess and quantify the ecological diversity within plant communities. Its relevance lies in providing a comprehensive understanding of species' ecological roles, community structure, and responses to environmental changes, ultimately contributing to informed conservation and management strategies. Diversity indices and multifactorial analysis were done using PAST V4 software. Diversity indices were calculated using the formula:

1. Simpson Index = $(\sum ni\ ni-1/ N(N-1))$
2. Dominance Index = $1 - (\sum ni\ ni-1/ N(N-1))$
3. Shannon – Weininger Diversity Index, H- = $-\sum (ni\ N. \log_2 (niN))$

Where,

n_i = Importance value for each species

N = Total importance values

4. Berger-Parker Dominance Index = $N_{max} N$

Where,

N_{max} = Number of individuals in the most abundant species

N = Total number of individuals

5. Margalef Index = $S-1 \log N$

Where,

S = Number of species

N = Number of individuals

6. Fisher's alpha Index = $S=a*\ln (1+n/a)$

Where, S is number of taxa, n is number of individuals and a is the Fisher's alpha

7. Menhinick Index = $D = S/\sqrt{N}$

Where, S = Species and N = Number of observations

3. RESULTS

Table 2a and 2b illustrate spatial variations in water physico-chemical parameters across five sites.

Table-2a: Means of the spatial variations of the Physico-chemical parameters in five different Sites in an oxbow lake, Dhir beel during the period of June 2016 to May 2019. The notation A and B stands for the difference in between the season only while a, b & c represents variation among and within the sample of the Sites ($P < 0.05$). Observations (Summer: $n=35$; Winter: $n=25$).

Sl.Nos	Parameter ↓	Site→ Season s↓	I	II	III	IV	V
1	TR (Cm)	S	56.1±2.31 ^{Aa}	58.47±1.89 ^A a	59.14±1.14 ^A a	63.16±1.19 ^A b	64.86±1.02 ^A b
		W	64.5±3.35 ^{Ba}	65.11±4.11 ^B a	60.14±3.15 ^A b	66.42±2.16 ^B a	66.19±1.97 ^A b
2	pH	S	6.90±0.02 ^{Aa}	6.45±0.03 ^{Aa}	6.19±0.08 ^{Ab}	6.98±0.01 ^{Ac}	6.99±0.07 ^{Ac}

		W	6.14±0.07 ^{Ba}	6.18±0.04 ^{Ba}	6.18±0.07 ^{Aa}	6.57±0.02 ^{Ac}	6.41±0.01 ^{Bc}
3	DO (mg/L)	S	9.10±0.19 ^{Aa}	9.11±0.28 ^{Aa}	8.14±0.21 ^{Aa}	8.97±0.81 ^{Ab}	9.41±0.87 ^{Ac}
		W	7.15±0.8 ^{Ba}	8.14±0.75 ^{Bb}	8.45±0.37 ^{Ab}	7.91±0.38 ^{Bc}	8.01±0.14 ^{Bc}
4	BOD (mg/L)	S	3.7±0.25 ^{Aa}	3.41±0.45 ^{Aa}	2.89±0.89 ^{Aa}	4.11±1.12 ^{Ab}	5.01±1.14 ^{Ab}
		W	3.8±0.48 ^{Aa}	3.79±0.58 ^{Aa}	2.93±0.88 ^{Aa}	4.92±1.06 ^{Ab}	4.12±1.91 ^{Ab}
5	FCO ₂ (mg/L)	S	6.90±0.27 ^{Aa}	6.12±0.33 ^{Aa}	5.87±0.88 ^{Aa}	7.11±0.12 ^{Ab}	7.01±0.45 ^{Ab}
		W	7.10±0.13 ^{Aa}	6.88±0.89 ^{Aa}	5.41±0.82 ^{Aa}	6.88±0.79 ^{Aa}	6.91±0.64 ^{Aa}
6	TAL (mg/L)	S	27.6±1.84 ^{Aa}	26.6±1.87 ^{Aa}	27.11±1.07 ^{Aa}	27.82±0.88 ^{Aa}	26.11±0.24 ^{Aa}
		W	24.3±0.76 ^{Ba}	25.14±0.54 ^{Aa}	26.14±0.87 ^{Aa}	26.11±0.19 ^{Aa}	28.39±0.18 ^{Ba}
7	TH (mg/L)	S	26.0±0.91 ^{Aa}	25.14±0.84 ^{Aa}	26.01±0.14 ^{Ba}	24.16±0.57 ^{Aa}	24.76±0.42 ^{Aa}
		W	32.5±1.35 ^{Ba}	29.34±0.89 ^{Ba}	28.4±0.72 ^{Bb}	23.11±0.67 ^{Ba}	22.14±0.51 ^{Ba}
8	TDS (ppm)	S	27.3±2.01 ^{Aa}	28.13±1.99 ^{Aa}	27.89±2.14 ^{Aa}	23.11±0.67 ^{Aa}	24.01±0.51 ^{Aa}
		W	24.3±0.78 ^{Ba}	23.11±0.45 ^{Ba}	26.10±0.49 ^{Aa}	25.47±0.94 ^{Ba}	27.07±0.47 ^{Ba}
9	TSS (ppm)	S	62.6±1.87 ^{Aa}	62.17±1.37 ^{Aa}	58.14±0.85 ^{Aa}	53.72±1.10 ^{Aa}	54.67±1.19 ^{Aa}
		W	64.1±1.66 ^{Aa}	63.19±1.29 ^{Aa}	62.0±1.4 ^{Ba}	51.00±0.41 ^{Aa}	55.18±1.27 ^{Aa}
10	SC (mS/cm)	S	0.7±0.05 ^{Aa}	0.8±0.04 ^{Aa}	0.9±0.01 ^{Aa}	0.71±0.01 ^{Aa}	0.67±0.02 ^{Ab}
		W	0.5±0.04 ^{Aa}	0.4±0.04 ^{Ba}	0.5±0.04 ^{Ba}	0.81±0.06 ^{Bb}	0.89±0.09 ^{Bb}
11	SAL (ppt)	S	1.0±0.05 ^{Aa}	1.34±0.02 ^{Aa}	1.82±0.01 ^{Aa}	1.84±0.01 ^{Aa}	1.85±0.08 ^{Aa}
		W	2.14±0.08 ^{Ba}	2.29±0.09 ^{Ba}	1.87±0.09 ^{Aa}	1.62±0.09 ^{Ab}	1.64±0.07 ^{Ab}

TR: Transparency; **DO:** Dissolved Oxygen; **BOD:** Biological Oxygen Demand; **FCO₂:** Free Carbon dioxide; **TAL:** Total Alkalinity; **TH:** Total Hardness; **TDS:** Total Dissolved Solids; **TSS:** Total Suspended Solids; **SC:** Specific Conductivity; **SAL:** Salinity. **S:** Summer; **W:** Winter. **±:** Standard Deviation.

Table 2b: Means of the elements and functional groups of the ions in an Oxbow lake in five different Sites during the period of June 2016 to May 2019. The notation A and B stands for the difference in between the two seasons ($P < 0.05$). a and b represent parameter difference among and within the sites of sample collection. Observations (Summer: n=35; Winter: n=25).

Sl.N os.	Parameters ↓	Site → Seasons ↓	I	II	III	IV	V
12	Ca ²⁺ (mg/L)	S	17.9±0.34 ^{Aa}	16.27±0.74 ^{Aa}	17.72±0.61 ^{Aa}	19.45±0.81 ^{Aa}	20.11±0.73 ^{Aa}
		W	31.2±2.12 ^{Ba}	33.11±1.67 ^{Ba}	31.29±0.97 ^{Ba}	35.25±0.64 ^{Ba}	35.81±0.51 ^{Ba}
13	Mg ²⁺ (mg/L)	S	26.1±1.04 ^{Aa}	24.32±1.37 ^{Aa}	26.73±2.62 ^{Aa}	25.69±1.87 ^{Aa}	26.14±1.91 ^{Aa}

		W	11.4±1.52 ^{Ba}	10.24±1.73 ^{Ba}	8.34±0.82 ^{Ba}	7.16±0.62 ^{Bb}	6.97±0.83 ^{Bb}
14	Na ⁺ (mg/L)	S	0.6±0.02 ^{Aa}	0.7±0.03 ^{Aa}	0.5±0.01 ^{Aa}	0.3±0.01 ^{Ab}	0.2±0.01 ^{Ab}
		W	0.9±0.07 ^B	0.93±0.04 ^{Ba}	0.87±0.06 ^{Ba}	0.5±0.02 ^{Bb}	0.4±0.03 ^{Bb}
15	K ⁺ (mg/L)	S	1.2±0.06 ^{Aa}	1.3±0.04 ^{Aa}	1.14±0.08 ^{Aa}	0.98±0.06 ^{Aa}	1.17±0.04 ^{Aa}
		W	1.31±0.07 ^{Aa}	1.43±0.08 ^{Aa}	1.39±0.07 ^{Aa}	1.29±0.05 ^{Aa}	1.36±0.03 ^{Aa}
16	Zn (mg/L)	S	0.4±0.04 ^{Aa}	0.48±0.03 ^{Aa}	0.44±0.02 ^{Aa}	0.51±0.01 ^{Ab}	0.58±0.02 ^{Ab}
		W	0.7±0.01 ^{Ba}	0.69±0.2 ^{Ba}	0.74±0.02 ^{Ba}	0.82±0.03 ^{Bb}	0.85±0.04 ^{Bb}
17	Cu (mg/L)	S	0.2±0.01 ^{Aa}	0.2±0.01 ^{Aa}	ND	0.11±0.02 ^{Aa}	0.09±0.02 ^{Aa}
		W	0.1±0.01 ^{Ba}	0.1±0.01 ^{Aa}	0.1±0.01 ^a	0.12±0.03 ^{Aa}	0.13±0.03 ^{Aa}
18	N ₂ (mg/L)	S	2.5±0.11 ^{Aa}	1.71±0.66 ^{Ba}	3.91±0.63 ^{Ac}	1.84±0.37 ^{Ab}	1.73±0.23 ^{Ba}
		W	2.6±0.88 ^{Aa}	1.54±0.41 ^{Ab}	3.98±0.84 ^{Bc}	1.93±0.43 ^{Ab}	1.89±0.43 ^{Ab}
19	NO ₃ ⁻ (mg/L)	S	1.6±0.4 ^{Aa}	1.57±0.31 ^{Aa}	1.66±0.5 ^{Aa}	1.33±0.5 ^{Aa}	1.23±0.46 ^{Aa}
		W	0.3±0.002 ^{Bb}	1.34±0.57 ^{Aa}	1.49±0.6 ^{Aa}	1.41±0.41 ^{Aa}	1.29±0.39 ^{Aa}
20	PO ₄ ³⁻ (mg/L)	S	0.7±0.06 ^{Aa}	0.62±0.02 ^{Aa}	0.84±0.04 ^{Aa}	0.98±0.08 ^{Aa}	1.12±0.09 ^{Ab}
		W	0.6±0.8 ^{Aa}	0.73±0.05 ^{Aa}	0.98±0.02 ^{Aa}	1.0±0.07 ^{Aa}	1.31±0.81 ^{Ab}
21	Cl ⁻ (mg/L)	S	6.8±1.15 ^{Aa}	7.4±0.85 ^{Aa}	6.89±0.97 ^{Aa}	6.11±0.5 ^{Aa}	6.91±0.93 ^{Aa}
		W	8.08±0.34 ^{Ba}	9.15±0.75 ^{Ba}	9.62±0.56 ^{Bb}	8.37±0.24 ^{Ba}	8.23±0.94 ^{Ba}
22	SO ₄ ²⁻ (mg/L)	S	6.1±0.38 ^{Aa}	9.8±0.98 ^{Ab}	9.7±0.77 ^{Ab}	7.32±0.88 ^{Aa}	7.24±0.69 ^{Aa}
		W	12.1±0.87 ^{Ba}	15.11±0.53 ^{Bb}	16.04±0.49 ^{Bb}	11.14±0.71 ^{Ba}	12.11±0.52 ^{Ba}
23	HCO ₃ ⁻ (mg/L)	S	25.7±0.57 ^{Aa}	23.42±0.31 ^{Aa}	21.0±0.45 ^{Aa}	21.16±0.39 ^{Aa}	23.15±0.37 ^{Aa}
		W	26.5±0.61 ^{Ba}	28.31±0.82 ^{Bb}	29.61±0.76 ^{Bb}	25.11±0.47 ^{Ba}	24.16±0.63 ^{Aa}

S: Summer; **W:** Winter. **±:** Standard Deviation. **ND:** Not Determined

3.1. Determination of Ratio value

Assessed higher ratio value for Ca²⁺: Mg²⁺ was at 3.77 in the winter against 7.42 for Cl⁻:NO₃.

Exceedingly reduced value of PO₄³⁻: SO₄²⁻ assessed at 0.05.

Table 3. Ratio of certain element and active groups in the Oxbow lake water.

Sl. No.	Parameters (mg/L)	Summer	Winter
1	Ca ²⁺ : Mg ²⁺	0.71	3.77
2	Na ⁺ : K ⁺	0.51	0.40
3	NO ₃ ⁻ : PO ₄ ³⁻	1.74	1.27
4	N ₂ : PO ₄ ³⁻	1.57	2.03
5	Cl ⁻ : NO ₃ ⁻	4.60	7.42
6	PO ₄ ³⁻ : SO ₄ ²⁻	0.17	0.05

3.2. Macrophyte Diversity in the Oxbow lake, Dhir beel

A total of 82 numbers of species comprised of 38 nos. of dicot at 48.7%, 40 nos. of monocot at 51.29% and 4 species at 4.8% of Pteridophytes were recorded (Table 4). In the studied oxbow lake, dicot diversity is characterized by 17 families and 38 species, with Nymphaeaceae dominating at 11.21% (Table 5). Onagraceae and Polygonaceae closely follow at 10.52%. Menyantheceae, Convolvulaceae, and Sarcophyllaceae make up 7.89%. Nymphaeaceae boasts four annual species, while Menyantheceae, Convolvulaceae, Lentibulariaceae, Polygonaceae, and Ceratophyllaceae each present two annual species (Table 5). The dicot category's highest Importance Value Index (IVI) is attributed to *Nymphoides hydrophyllum* (5.90), succeeded by *Nelumbo nucifera* (4.89). Monocot diversity encompasses 40 species across 11 families (Table 6), with Poaceae prominent at 25%. *Cyperus compressus* and *Lemna perpusilla* stand out with the highest IVI values at 5.74 and 5.52, respectively. Pteridophyte diversity includes four families (Table 6), with Equisetum standing out at 40%, boasting the highest IVI at 6.13%.

Table 4. Brief analysis of taxa among macrophytes of the Oxbow lake, Dhir beel during the period of 2016-2019.

Taxon	Total	Dicotyledons		Monocotyledons		Dicot: Monocot	
		Total	Percent	Total	Percent		
Angiosperm	Family	28	17	60.71	11	39.29	1.54
	Genus	56	23	41.07	33	58.93	0.70
	Species	78	38	48.71	40	51.29	0.95
Pteridophytes	Family	4					

Table 5: Dicot Macrophytes collected from five different sites with IVI % index (among the dicot plants) in an Oxbow lake, Dhir beel. A to Q represents family.

Sl. No.	Species	Summe r	Winter	Reproducti ve Phase	RD %	RF%	RA%	IVI%
A.	Nymphaeaceae 11.21%	No. of Individuals per year (Means) collected						
1	<i>Euryale ferox</i> Salis	87	28	May-Jul.	1.3	1.1	1.40	3.80
2	<i>Nymphaea pubescens</i> Willd.	68	30	June-Nov.	1.1	1.2	0.98	3.23
3	<i>N. nouchali</i> Burm f.	51	17	July-Oct.	0.8	0.8	0.71	2.23
4	<i>N. rubra</i> Roxb. Ex. Salisb.	78	10	Aug.-Dec.	1	1.2	0.79	2.93
B.	Nelumbonaceae 2.67%							
5	<i>Nelumbo nucifera</i> Gaetrn.	101	45	July-Oct.	1.6	1.3	2.02	4.89
C.	Oxalidaceae 2.70%							
6	<i>Oxalis corniculata</i> L.	108	17	May-Dec.	1.4	1.4	1.37	4.11
D.	Haloragaceae 5.40%							
7	<i>Myriophyllum tetrandrum</i> Roxb.	88	14	May-Nov.	1.1	1.2	1.02	3.36
8	<i>M. tuberculum</i> Roxb.	37	60	Jan.-Dec.	1.1	0.8	1.49	3.31
E.	Onagraceae 10.72%							

9	<i>Ludwigia adscendens</i> (L.) Hara.	60	9	June-Oct.	0.8	0.9	0.64	2.29
10	<i>Ludwigia parviflora</i> Roxb.	79	10	June-Oct.	1	1.2	0.79	2.96
11	<i>L. perennis</i> L.	61	13	Aug.-Dec.	0.8	0.9	0.70	2.45
12	<i>Jussiaea repens</i> L.	66	40	Mar.-Dec.	1.2	1	1.29	3.50
F.	Trapaceae 2.85%							
13	<i>Trapa natans</i> L.	60	25	Jul.-Dec.	0.9	1.1	0.79	2.82
G.	Apiaceae 2.65%							
14	<i>Centela asiatica</i> L.	15	74	Jan.-Dec.	1	1.1	0.85	2.94
15	<i>Oenanthe javanica</i> (Bl.) DC	38	31	Mar.-May	0.8	0.8	0.72	2.27
H.	Asteraceae 5.30%							
16	<i>Enhydra fluctuans</i> DC.	48	35	Mar.-Dec.	0.9	1	0.80	2.74
17	<i>Grangea maderaspatana</i> (L) Poir.	64	25	Apr.-Nov.	1	1.1	0.85	2.94
I.	Menyanthaceae 7.89%							
18	<i>Nymphoides hydrophyllum</i> Lour.	155	24	Sept.-Nov.	2	2.1	1.79	5.90
19	<i>N. indica</i> (L.) Kuntze.	123	29	Sept.-Nov.	1.7	1.9	1.46	5.02
20	<i>N. parvifolium</i> Kuntze.	78	23	Mar.-Nov.	1.1	1.3	0.94	3.35
J.	Boraginaceae 2.65%							
21	<i>Heliotropium indicum</i> (L.) DC.	76	20	May-Aug.	1.1	1.1	0.96	3.16
K.	Convolvulaceae 7.95%							
22	<i>Ipomoea aquatica</i> Forssk.	42	126	Sept.-Feb.	1.9	2.2	1.50	5.60
23	<i>I. carnea</i> Jacq.	36	110	Sept.-Feb.	1.6	1.9	1.34	4.85
24	<i>I. obscura</i> (L.) Gawl.	76	29	Aug.-Sept.	1.2	1.1	1.17	3.45
L.	Scrophulariaceae 7.89%							
25	<i>Bacopa monnieri</i> (L.) Pennel	56	67	Jan.-Dec.	1.4	1.6	1.13	4.08
26	<i>Limnophila indica</i> (L.) Druce.	56	30	July-Dec.	1	0.8	1.05	2.84
27	<i>L. heterophylla</i> (Roxb.) Benth.	54	41	Aug.-Jan.	1.1	0.7	1.44	3.24
M.	Lentibulariaceae 5.39%							
28	<i>Utricularia scandens</i> Benj.	73	25	July-Nov.	1.1	0.9	1.33	3.27
29	<i>U. stellaris</i> L.f.	38	32	Mar.-Nov.	0.8	0.8	0.77	2.30
N.	Amaranthaceae 5.37%							
30	<i>Alternanthera philoxeroides</i> L.	11	59	Oct.-Feb.	0.8	0.6	0.95	2.34
31	<i>A. sessilis</i> L.	37	30	Jan.-Dec.	0.7	0.6	0.88	2.23
O.	Polygonaceae 10.64%							
32	<i>Polygonum barbatum</i> L.	24	70	Oct.-Mar.	1	0.9	1.15	3.10
33	<i>P. hydropiper</i> L.	18	58	Oct.-Mar.	0.8	1	0.71	2.52
34	<i>P. orientale</i> L.	72	26	Apr.-Sept.	1.1	1.2	0.94	3.24
35	<i>Rumex nepalensis</i> Spreng.	57	30	Apr.-July	1	1	0.91	2.86
P.	Podostemaceae 2.75%							
36	<i>Podostemum subulatum</i> Gardn.	69	10	Jun.-Oct.	0.9	0.7	1.01	2.62
Q.	Ceratophyllaceae 5.97%							
37	<i>Ceratophyllum demersum</i> L.	40	51	Jan.-June	1	0.8	1.18	3.02
38	<i>C. tuberculatum</i> Cham.	30	73	Jan.-Mar.	1.1	0.9	1.33	3.42

Abbreviations: Dicot Macrophytes recorded in five different Sites. **RD-** Relative Density, **RA-** Relative Abundance, **RF-**Relative Frequency, **IVI** = Importance Value Index.

Table 6: Monocot diversity and Pteridophyte diversity collected from five different sites with IVI % index (among the monocot and pteridophytes plants) in an Oxbow lake, Dhir beel. A to K represents monocot family; L to O represents Pteridophytes family.

Sl. No.	Species	Summer	Winter	Reproductive Phase	RD%	RF%	RA%	IVI %
A.	Hydrocharitaceae 15%	No. of Individuals per year (Means) collected						
1	<i>Hydrilla verticillata</i> (Lf.) Royle.	36	60	Oct.-Mar.	1.1	0.9	1.17	3.17
2	<i>Hydrocharis dubia</i> (Bl.) Baker	45	15	Mar.-Nov.	0.7	0.8	0.55	1.99
3	<i>Blyxa aubertii</i> Rich.	21	88	Jan.-Nov.	1.2	1.2	1.20	3.58
4	<i>B. echinosperma</i> (Clarke) Hook	34	46	Jan.-Nov.	0.9	0.7	1.15	2.70
5	<i>Ottelia alismoides</i> (L.) Pers.	53	20	Aug.-Nov.	0.8	0.8	0.79	2.40
6	<i>Vallisneria spiralis</i> L.	80	39	Mar.-Nov.	1.3	1.4	1.19	3.92
B.	Pontederiaceae 5%							
7	<i>Eichhornia crassipes</i> Solms.	74	117	Jan.-Dec.	2.1	2.5	1.76	6.34
8	<i>Monochoria hastata</i> L.	48	26	Feb.-Nov.	0.8	0.6	1.00	2.47
C.	Commelinaceae 7.5%							
9	<i>Commelina benghalensis</i> L.	51	38	Jan.-May	1	1.1	0.83	2.95
10	<i>Floscopa scandens</i> Lour.	46	97	Jan.-June	1.6	1.4	1.75	4.72
11	<i>Murdannia nudiflora</i> L.	68	34	July-Jan.	1.1	0.9	1.33	3.39
D.	Araceae 7.5%							
12	<i>Alocasia fonicata</i> (Roxb.) Schott.	65	30	May-Sept.	1.1	0.7	1.48	3.25
13	<i>Colocassia esculenta</i> L.	99	25	May-Sept.	1.4	1.1	1.71	4.15
14	<i>Pistia stratiotes</i> L.	122	38	June-Sept.	1.8	2.1	1.47	5.31
E.	Lemnaceae 10%							
15	<i>Lemna perpusilla</i> Torr.	156	10	May-Aug.	1.8	2.2	1.51	5.52
16	<i>Spirodella punctata</i> (Meyer) Thom.	105	6	May-Aug.	1.2	1.2	1.24	3.65
17	<i>S. polyrhiza</i> L. Sch.	36	70	Jan.-May	1.2	1.1	1.26	3.49
18	<i>Wolffia globosa</i> Roxb. Griff.	71	20	June-Sept.	1	1	0.95	2.99
F.	Alismataceae 5%							
19	<i>Sagittaria sagittifolia</i> L.	40	89	Feb.-Apr.	1.4	1.6	1.23	4.26
20	<i>Alisma plantago</i> aquatica L.	57	34	Feb.-Apr.	1	0.8	1.24	3.04
G.	Najadaceae 2.5%							
21	<i>Najas minor</i> Al.	46	101	Jan.-Dec.	1.6	1.5	1.75	4.85
H.	Potamogetonaceae 7.5%							
22	<i>Potamogeton crispus</i> L.	122	38	Mar.-Dec.	1.8	1.5	2.01	5.30
23	<i>P. nodosus</i> Poir.	112	50	Mar.-Dec.	1.8	1.3	2.33	5.47
24	<i>P. octandrus</i> Poir.	47	50	Jan.-Dec.	1.1	0.9	1.18	3.20
I.	Eriocaulaceae 2.5%							
25	<i>Eriocaulon setaceum</i> L.	102	10	June-Aug.	1.2	1.1	1.34	3.69

J.	Cyperaceae 12.5%							
26	<i>Cyperus compressus</i> L.	123	50	July-Nov.	1.9	2.2	1.61	5.73
27	<i>C. iria</i> L.	78	67	Aug.-Dec.	1.6	1.8	1.39	4.79
28	<i>C. pilosus</i> Vahl, Enum	85	40	July-Dec.	1.4	1.5	1.24	4.12
29	<i>C. rotundus</i> L.	101	43	Mar.-Nov.	1.6	1.8	1.40	4.75
30	<i>Eleocharis congesta</i> D. Don.	74	38	Sept.-Dec.	1.2	1	1.54	3.75
K.	Poaceae 25%							
31	<i>Arundo donax</i> L.	59	80	Aug.-Jan.	1.5	1.7	1.33	4.59
32	<i>Eragrostis unioides</i> (Retz) Nees.	30	87	July-Mar.	1.3	1.3	1.22	3.85
33	<i>Hygroryza aristata</i> Nees.	20	81	Sept.-Mar.	1.1	1.2	1.01	3.33
34	<i>Ischane globosa</i> (Thun.) Ktze.	54	40	Jan.-Dec.	1	1.1	0.94	3.10
35	<i>Leersia hexandra</i> Swartz.	42	38	Jan.-Dec.	0.9	0.8	0.95	2.63
36	<i>Oryza rufipogon</i> Griffith, Notul	30	54	Oct.-Jan.	0.9	1	0.87	2.76
37	<i>Pseudoraphis brunoniana</i> Griffith	40	46	Jul.-Sept.	1	0.7	1.23	2.89
38	<i>Phragmites karka</i> (Retz.) Trin	36	66	Sept.-Jan.	1.1	1	1.20	3.36
39	<i>Setaria glauca</i> Beauv	58	44	Mar.-Nov.	1.1	0.9	1.30	3.38
40	<i>Saccharum spontaneum</i> L.	83	29	Sept.-Dec.	1.2	1.1	1.37	3.70
L.	Equisetaceae 40%							
1	<i>Equisetum diffusum</i> D. Don	70	112	Dec.-Mar.	2	2.4	1.64	6.13
M.	Marsiliaceae 20%							
2	<i>Marsilea quadrifolia</i> L.	106	50	May-Sept.	1.7	2	1.45	5.17
N.	Azollaceae 25%							
3	<i>Azolla pinnata</i> R. Br	108	57	Mar.-Nov.	1.8	2	1.58	5.46
O.	Salviniaceae 15%							
4	<i>Salvinia natans</i> (L.) All.	116	31	May-Sept.	1.6	1.8	1.41	4.86

Abbreviations: **RD-** Relative Density, **RA-** Relative Abundance, **RF-**Relative Frequency, **IVI** = Importance Value Index.

Table 7. Diversity Indices at five different sampling site(s) of total Macrophytes in an Oxbow lake, Dhir Beel, Assam, India during the study period of 2016 to 2019. Lower and Upper data presenting the range of the alpha diversity measure in each site (PAST V4 analysis).

Unbiased Alpha diversity	Site - I		Site-II		Site-III		Site-IV		Site-V	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
Individuals	1021	1021	924	924	814	814	1234	1234	1435	1435
Dominance_D	0.01	0.06	0.01	0.08	0.01	0.06	0.01	0.03	0.01	0.03
Simpson_1-D	0.22	0.31	0.14	0.34	0.16	0.49	0.45	0.82	0.39	0.79
Shannon_H	2.11	2.44	2.25	2.59	2.53	2.81	3.84	5.79	3.91	5.63
Evenness_e^H/S	0.62	0.69	0.61	0.68	0.61	0.67	0.51	0.91	0.66	0.98
Menhinick	0.47	0.50	0.30	0.49	3.34	0.46	0.36	0.59	0.42	0.62
Margalef	3.94	5.58	4.41	6.29	5.24	7.28	5.67	7.94	5.91	7.88
Fisher_alpha	14.56	59.85	17.12	80.34	20.87	76.01	23.41	93.51	25.39	79.45
Berger-Parker	0.10	0.19	0.08	0.21	0.06	0.16	0.16	0.25	0.09	0.45

4. DISCUSSION AND CONCLUSION

The Physico-chemical records of the lake water presented differences in terms of seasons and sample collection sites(s) have been able to earn the support of Das and Sharma (2024). Air temperature and water temperature as Das *et al.* (2021) suggested are one of the controlling factors, that alters the functions of the aquatic system and diversity of macrophytes (Rameshkumar *et al.*, 2019). The pH of the lake, which regulates the acidic or basic characters of lake water (Jalal and Sanal Kumar, 2013) were within the range value of 6.9-6.1, possibly managed by the HCO_3^- in maintaining a narrow range at acidic state (Table 2a). That the pH range 5.34-8.67 might be within the acceptable limit for the maintenance of an ecosystem (Bala and Mukherjee, 2010), (Rameshkumar *et al.* 2019, Ljevanak-Masic *et al.*, 2020). Salinity (2.14 ppt. in winter) attributes to the biodiversity particularly the abundance of phytoplanktons (Sridhar *et al.*, 2006). Waterbody with higher pH of 8.4 supported less macrophyte against the present value of pH (6.1-6.9; Table 2a, Site-IV in winter) could draw certain debate (Germ *et al.* 2021). Svitok *et al.* (2016) findings showed that the effects of pH related to the physiological traits of macrophytes are capable of using only CO_2 , scarce in winter with pH 8.3. Wetzel (1983) described that lower temperature should have higher DO% level but in case of Dhir beel higher DO% is in the summer season might be due to flood water during monsoon which results in aeration of water (Das and Sharma, 2024).

In this study, the distribution, abundance, and diversity of macrophytes were positively correlated with pH and dissolved oxygen (Ondiba *et al.*, 2018), as well as conductivity (Dorotovicova, 2013). Enhanced conductivity (Table 2a) at Site-I could be evaluated as an integration of several factors, which might be the reflection of human activities (Epele *et al.*, 2018). This study also presented a positive correlation between the water temperature, pH and DO with that monocot species like *Lemna perpusilla*, *Azolla pinnata*, *Cyperus compressus* during summer. During winter, Ca^{2+} and Zn concentrations increase across all sites, likely due to weather pattern changes, snowmelt runoff, or other environmental factors. Winter decreases Mg^{2+} and Na^+ concentrations at Site-V, possibly due to shifts in environmental conditions affecting ion availability. Site-III exhibits higher N_2 levels, possibly from agricultural activities, urban runoff, or localized pollution sources. Site-I experiences NO_3^- level fluctuations throughout seasons, suggesting influences from agriculture, weather, or other factors. PO_4^{3-} concentrations are elevated solely at Site-V, possibly due to agricultural runoff, industrial discharge, or geological processes. Cl^- and SO_4^{2-} concentrations are consistently higher across all sites, possibly from industrial activities, road salt, or geological processes. Site-III maintains elevated HCO_3^- levels in winter, likely due to groundwater recharge, carbonate rock weathering, or other local influences (Table 2b).

The present search has shown that the ratio value of the biochemical parameters of water (Table 3) might provide certain stoichiometric inferences, through such type of evaluation has been very rare. Yet, the $\text{NO}_3^- : \text{PO}_4^{3-}$ stood at winter at 0.5 suggestive of enhanced value to phosphorous by way of macrophyte degradation in soil, needs further characterization. Application of N:P ratio was applied to identify the threshold of nutrient limitation of a wetland (Koerselman and Meuleman, 1996; Aerts and Chapin, 2000). The acidic nature of this lake water might be due to the decomposition of

organic matter in winter produced CO₂ and Carbonic acid, which reduce the pH (Kumar *et al.*, 2017). The study area notably the Site-I received the runoff from the surrounding area during the rainy season and agricultural runoff from the field activities might be a source of pollution.

The beel despite of being contaminated by the agricultural runoff yet has not been able to show its adverse effect. Since, many of the species like *Lemna minor*, *Myriophyllum aquaticum*, *Spirodela oligorrhiza*, *Elodea canadensis*, *P. australis*, *Nymphaea lotus*, *T. latifolia*, have been shown to have significant potential for removing agrochemicals, principally through bioaccumulation or metabolism (Gomes *et al.*, 2019; Dhir *et al.*, 2020).

The monocot diversity (40 species) and pteridophytes with 4 family (Table 4) in this beel has been significant from the IVI analysis (Table 6). Presence of pteridophytes (such as *Salvinia*, *Azolla*) are the useful angiosperms appeared to be useful in the maintenance of ecosystem of a given wetland (Brix, 1997). The main anions present in the beel water are Cl⁻, SO₄²⁻, PO₄³⁻ and NO₃⁻ activate the cations Ca²⁺, Mg²⁺, Na⁺, K⁺ and Zn (Nickanorov and Brazhnikova, 1989). The domination of Ca²⁺ in the lake water might be due to low mineralized water. Moreover, SO₄²⁻ content in the beel water is limited due to high quantity of Ca²⁺. The diversity of the macrophyte species in this Oxbow lake might be due to their high tolerance of water fluctuation (Saha *et al.*, 2022) and water current (Yakoob *et al.*, 2021). Monocots are playing a great role in the wetland diversity and its ecological characteristics. To date there are more records of monocot aquatic species than that of dicot since the forma has shown a much more adaptability as evident in this study (Table 5 and 6).

Analysis of the diversity index of the macrophytes has been depicted in the Table 7. Habitat-wise analysis diversity indices of the macrophytes in five different Sites showed that the Site-I, II and III in their upper range of dominance (0.06 and 0.08) respectively might be dominated by only few species. Value for Shannon diversity index was at the highest of 5.79 and 5.63 at Site-IV and V signifies the stable environmental conditions. Margalef index ranged between 5.58 (Site-I) to 7.91 (Site-II) in its upper limit (Table 7) showed macrophyte variation depending upon the number of species and used for site comparison (Kocatas, 1992) and only considered the species richness which is independent to that of sample. The low diversity in the Site-I, II, III might be prescribed for Shannon (1949), Margalef (1968) and Menhinick (1964) indices, had been considered as an attribution of species numbers and environmental degradation except the family Onagraceae and Convolvulaceae of emergent aquatic macrophyte as well Scrophulariaceae which could be supported by the work of Ravera (2001). The Fisher-alpha could be seen as species richness compared to Simpson Index (Simpson, 1949), that is a measure of evenness ($r=0.637$, $P\leq 0.05$). The lowest value of Fisher-Alpha (Fisher *et al.* 1943) was at 14.56 (Site-I) against the upper value of 93.51 (Site-IV) indicated the species richness against spatial and temporal distribution pattern (Rosenzweig, 2003). Moreover, the index like Berger-Parker (1970) was at the upper limit of 0.45 (Site-IV) (Table 7). Further, the Simpson diversity index stand below 1.0 i.e. at 0.79 in all the Sites indicating the range variation between 0.14 to 0.82 at the maximal side. The Evenness index of this study presented the highest value at 0.98 in the Site-V reflecting the close relationship of the two indices (0.617, $P\leq 0.05$). The high value of Simpson index has been suggestive of high diversity value (0.6 to 0.9, Table 12),

while the community index stress conditions presented a low diversity (Dash, 2003). The Site-II and III showed minimum value at 0.14 and 0.16 and the maximum value 0.34 and 0.49 respectively indicating the anthropogenic interference (Shah and Pandit, 2013).

Diversity analysis of the total macrophytes indicated that the Fisher alpha is the only diversity index which indicated spatial and temporal distribution pattern of a group of species (Rosenzweig, 1995) like Poaceae and least sensitivity to rare species (could not be detected in this Oxbow lake, Dhir beel) also supported by Magurran (1988). Fisher alpha could well be seen as the measure of species richness compared to Simpson index which is reflected as the measure of evenness ($r=0.91$ and 0.98 in the Site-IV and V; $P=0.05$, could be supported by the work of Gonzalez *et al.* 2010). Unlike that of Menhinick index it is independent to that of sample size. However, various indices followed in this study like Margalef and Berger Parker, independent to those of sample size demonstrated higher value in the undisturbed Site-IV and V, a very sensitive test towards sensitive sample size and abundance of the study, could well be supported by the work of Shah and Pandit (2013), in terms of diversity indices. Overall comparison with results of species richness, perhaps it could be derived that rare-species affects habitat diversity a little and consequently frequent species drive within and between habitat forms of macrophyte diversity in the Oxbow lake, Dhir beel could well be supported by the work of Lukacs *et al.* (2015).

In general, the Site-IV and V that was exposed to minimal anthropogenic impact enriched with rich diversity and macrophyte abundance. The emergent macrophytes (Monocot-Poaceae) were dominant in terms of species diversity, while free floating macrophyte (*P. stratiotes* and *A. nilotica*) were dominant in abundance. Biotic and abiotic factors lead to significant variations in distribution, diversity in abundance of aquatic macrophytes. Good physical condition and presence of macrophytes stand that provide a conducive environment, increases the nutrient loading for the macrophyte species. Therefore, the human interference enhances the nutrient quantity in Site-I and II, however, the Site-III contaminated from the Brick field must be regulated. The study has emphasized on the impact of assessing of the macrophytes diversity (Biodiversity) in an Oxbow lake to understand upon the variation in the community composition. These findings might be relevant for long term conservation and management allowing the most threatened habitat to be protected (Dudgeon *et al.*, 2006; Sun *et al.*, 2022). Thus, this Oxbow lake, the Dhir beel can be protected for future to retain the quality of the aquatic ecosystem on managing and regulating its biotic components for continuity of life on its water.

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