Influence of nutrient enrichment chemistry on species richness and IVI index of aquatic macrophytes: substantiation by Diversity Indices

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Abstract

The water quality of Bandh Baretha an important freshwater dam is getting impacted by increase in nutrient content due anthropogenic activities conducted nearby. However, studies have not been conducted on how the nutrient chemistry is impacting the water body and the influence of the same on the divergent macrophyte population of this water body. For ascertaining this influence both water and macrophyte samples were collected seasonally from July 2021- April 2022, from three selected sites of the dam. The macrophytes importance value index (IVI), Carlson's Trophic State Index (CTSI), Pearson's Correlation Matrix and Diversity indices were calculated to substantiate the findings. The study found that as nutrients in the lake increased, so did the growth of invasive macrophytes, whose leaves frequently covered the lake's surface leading to degradation of water quality. The increase in the nutrient content is alarming and the authorities and local bodies must work out measures limiting the degradation of the water body.

1. Introduction

Fresh water resources have always been essential for maintaining life and building civilizations. Freshwater reservoirs throughout the world are in danger due to a combination of new and enduring challenges. Water quality is reduced as a result of population explosion leading to enhanced land use practices which pollute waterways with poisonous compounds and excessive nutrients [1,2,3]. A number of investigations have been conducted on the physico-chemical quality of various water bodies to estimate the pollution level and nutrient load in wetland ecosystems throughout the world [4-13] The vital role of macrophytes in the water column is extensive because they play a significant role to the ecosystem's structure, function, and variety, maintain the food chain, and provide habitat for invertebrates and fish [14,15]. Eutrophication is recognized as a type of pollution of water brought on by humans that occasionally results in an aquatic environmental catastrophe and pose threat to the health of the human race and the animal population alike [16,17]. Four stages have been identified for the various phases and their trophic characteristics: oligotrophic/ultra-oligotrophic, mesotrophic or meso-eutrophic, eutrophic, and hyper-eutrophic [18]. The large accumulation of phosphorus in the water bodies, which is supplied by agricultural land, promotes the eutrophication process [19 - 23].

It is essential to understand the contribution of nutrient chemistry on the seasonal fluctuations in macrophyte diversity and density and ascertain the trophic status of water bodies. With its location in the western portion of the Aravalli mountains and characteristics of a rolling plateau with rounded hills and forest, Eastern Rajasthan is a significant physiographic unit in the state of Rajasthan [24]. The study was conducted on a Dam situated in Eastern Rajasthan to determine the nutrient chemistry of the dam water which influence the macrophyte density and diversity. Further, according to their maximal biomass, the species richness of submerged, floating, and rooted macrophytes was calculated. Along with evenness and dominance indices, the important value index (IVI) of the macrophytes calculated.

2. Materials and methods

2.1.Study area

The three sampling locations were selected at the Dam known as Bandh Baretha. The Dam is situated on the Kakund River and is spread across 36 kms. The region exhibits semi-arid climatic conditions. The nutrient chemistry is influenced by anthropogenic activities which is mainly agriculture. The nutrient content is mainly due to runoff from the neighboring agricultural fields.

2.2. Sampling and analysis

2.2.1. Water sample collection and analysis

The water samples from the three sampling locations were collected in July, October, and December 2021 and April 2022. Water samples were collected at the depth of 0.3-0.5 m. Water temperature (℃), Secchi depth and Dissolved Oxygen (DO) were measured on site. 2 liters of water from each sites was mixed with 2% nitric acid stored and carried to lab at 4℃. All physico-chemical parameters of water were analyzed according to standard methods described by American Public Health Association 2012 [25].

2.2.2. Macrophytes sampling, analysis and diversity of macrophytes

Sampling was done four times for a period of July 2021 to April 2022. Quantitative and analysis of diversity of macrophytes was carried at the three sampling stations. Macrophytes were identified by using dominant taxonomic characteristics. The macrophytes present near the shoreline were handpicked and those deep in water were collected by boat. The macrophytes of the waterbody were identified by visual estimation [26- 30]. Floating quadrant of 1m × 1m was used for counting the number of species of macrophytes and number of macrophytes. For the estimation of dominant species of macrophytes importance value index (IVI) used. IVI was calculated for the each individual species after calculating relative density, frequency and dominance. Following formulas were used for the calculations:

$$Importance\ value = Relative\ frequency + Relative\ density + Relative\ dominance$$

Where,

Relative frequency = number of occurrences of one genus as a percentage of the total number of occurrences of all genera,

Relative density = number of individuals of one genus as a percentage of the total number of individuals of all genera,

Relative dominance = Total area coverage (by visual estimation) of one genus as a percentage of the total area coverage of all genera.

2.3. Carlson’s Trophic State Index (CTSI)

A widely used method for describing the trophic condition or health status of a lake is Carlson's Trophic State Index (CTSI). Chlorophyll a (Chl-a), Secchi disc depth (SD), and total phosphorus (TP) are the three variables that Carlson's trophic status index primarily uses to measure algal biomass. Secchi disck was used to measure the secchi depth, disk has 20 cm diameter. The reading was recorded at the deepest point in the lake where the disk was clearly visible when it was lowered. The lakes are categorized as oligotrophic (low productive), mesotrophic (moderately productive), and eutrophic (very productive) based on the values of the Carlson trophic state index. The Table.1 shows the range of the Carlson's trophic state index values and categorization of water.

The formula used for the calculation of CTSI [31] given below:

TSI (Chl-a) = 9.81 ln Chl-a (µg/l) + 30.6

TSI (SD) = 60 – 14.41 ln SD (m)

TSI (TP) = 14.42 ln TP (µg/l) + 4.15

Where TSI = Trophic state index

ln = Natural logarithm

SD = Secchi depth

TP = Total phosphorus

Carlson’s trophic state index (CTSI) = [TSI(Chl-a) + TSI(SD) + TSI(TP)]/3.

Table 1 Classification of water on the basis of trophic state index [32].

S.no.	CTSI value	Trophic state	Characteristics of trophic state
1	TSI <30	Oligotrophic	Clear water containing oxygen throughout of the year in upper basin
2	TSI 30-40	Mesotrophic	Water continues to grow aquatic macrophytes, which can cause hypoxia in some shallow water and cause some lakes to become eutrophic in the summer.
3	TSI 40-50	Mesotrophic	Water is moderately clean, but the risk of oxygen depletion rises throughout the summer, and the presence of macrophytes and algae can cause choking condition.
4	TSI 50-60	Eutrophic	Lower classical eutrophic limit, lower transparency
5	TSI 60-70	Eutrophic	Due to excessive growth of macrophytes, blue-green algae and algal scum level of DO decrease
6	TSI 70-80	Hyper eutrophic	Excessive growth of algal bloom throughout of the summer and cyanotoxins algae may be present.
7	TSI >80	Hyper eutrophic	With increasing cyanotoxin algae growth of algal scum become dominant which increases fish mortality, and macrophytes become less in number

2.4. Data processing and analysis

The Carlson's Trophic state index (CTSI) of Dam water was calculated on the basis of Chl-a, SD, TP [33]. Pearson correlation analysis also computed among the physico-chemical parameters of Dam water. The statistical mean with standard deviation of all physico-chemical attributes of water sampled from all three sampling locations of the Dam (table 2).

Table 2: Physico-chemical parameters

Months	July 2021			October 2021			December 2021			April 2022		
Parameters	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
Temp	30.67±0.58	29.67±0.85	29.33±0.85	25±1.00	24.33±0.85	24.67±0.85	10.33±0.85	10.67±0.85	10±1.00	26±1.00	26.33±0.85	27.67±0.85
pH	6.2±0.1	6.13±0.0	6.17±0.0	7.3±0.1	7.1±0.09	6.87±0.0	7.57±0.0	7.37±0.0	7.33±0.0	6.87±0.0	6.77±0.1	6.63±0.1

		6	6			6	6	6	6	6	5	5
SD	0.31±0.01	1.37±0.01	1.53±0.02	0.46±0.02	1.36±0.01	1.62±0.01	0.73±0.01	1.32±0.03	1.78±0.01	0.96±0.02	1.45±0.02	1.83±0.02
TDS	820.67±10.12	455±4.58	410±9.17	797±2.65	534±3.61	567±4.36	761.33±1.53	307.67±2.52	391.33±3.21	478.33±12.58	527±45.04	447±27.73
EC	1560.33±10.2	1469±17.78	1462±37.59	1473.67±42.15	1357.33±10.79	1321.33±17.04	1273±22.61	1118.33±24.01	1238.67±26.02	1455.67±41.53	1493±55.67	1392.67±5.13
DO	1.87±0.06	5.2±00	5.5±0.1	2.4±0.1	6.87±0.06	6.73±0.15	3.47±0.06	10.17±0.15	11.2±0.2	4.67±0.06	12±0.5	9.7±0.26
BOD	109.33±0.58	75±00	75±1.00	102±1.00	68±1.00	67.33±2.08	97±2.00	62.33±2.08	69.67±0.58	59.33±1.15	70.67±0.58	50±1.00
TH	231±1.00	305±5.00	173.67±3.21	163.67±3.51	177.67±2.52	162±2.65	222.33±3.21	162.67±2.52	106.67±3.21	459±2.65	414±4.58	339±4.58
Alk	1372±10.82	1319.67±44.00	1350.67±35.80	1057.67±34.12	1167.67±16.44	1138.33±24.79	1039±6.56	1279.67±13.06	1232.33±45.54	1174.33±12.66	1174.67±26.41	1171.67±16.56
Nitrate	413±2.65	363.33±5.69	318.33±3.05	382.33±2.09	219±6.24	202.33±1.15	369±1.00	222.67±1.53	221.67±3.79	237.37±3.07	243.2±2.71	247.07±5.18
Nitrite	201.67±1.15	154.33±2.08	132.33±1.53	134.33±2.08	105.33±0.58	113.67±2.08	237.33±2.08	157±1.00	120±7.94	109.67±1.53	165.67±2.08	120.33±0.58
TP	31.47±0.02	20.01±0.01	16.41±0.04	26.03±0.02	19.28±0.03	15.09±0.01	29.15±0.04	19.28±0.07	13.6±0.01	24.94±0.05	17.47±0.02	12.35±0.01
Chl-a	6.21±0.02	5.02±0.01	3.81±0.01	5.33±0.06	3.65±0.01	3.2±0.01	6.03±0.02	4.96±0.12	3.00±0.01	4.98±0.01	3.82±0.15	2.93±0.05

3. Results and discussion

3.1. Main physico-chemical characteristics of dam water along with its trophic state

3.1.1. Stie 1: The water quality at site 1st differed noticeably from site 2nd in that site three's pH, TDS, and EC were comparably lower than site 1st, but site 3rd DO was comparatively greater. Higher chlorophyll a content at site 3rd indicates that algal biomass is higher at site 3rd. According to CTSI's assessment, the site's overall trophic condition is eutrophic (Table 3, Fig.1). *Eichhornia crassipes*, as well as rooted and emergent macrophytes, completely covered the site, which may help with phytoremediation by first removing nutrients from the site [34]. This could have assisted in reducing the lake's trophic status from eutrophic to mesotrophic. Aquatic macrophytes that are invasive and have nutrient enrichment outside of their natural region, like *Eichhornia crassipes*, spread swiftly when introduced under those conditions. This species' exceptional potential for rapid growth has led to its domination in the aquatic ecosystem's trophic structure [35].

3.1.2. Site 2: Site 2nd showed low pH, TDS, DO as compared to permissible limit. Anthropogenic activities from different sources of pollution affect the water quality of Dam. CTSI of the site 2nd was found to be mesotrophic shown in table 4 and Fig.2.

3.1.3. **Site 3:** Site 3rd is undisturbed area therefore its water quality was better than other two sites. CTSI of this site was found to be mesotrophic as shown in table 5 and Fig.3.

Table 3 Trophic state index of Site 1st

Months	Chl-a (µg/l)	TSI	SD (m)	TSI	TP (µg/l)	TSI
J 21	6.21	48.51	0.31	76.88	31.48	53.88
	6.19	48.48	0.32	76.42	31.45	53.87
	6.22	48.53	0.30	77.35	31.49	53.88
O 21	5.30	46.96	0.45	71.51	26.05	51.16
	5.30	49.96	0.46	71.19	26.02	51.13
	5.40	47.14	0.48	70.58	26.01	51.12
D 21	6.05	48.26	0.73	64.53	29.18	52.79
	6.01	48.19	0.72	64.73	29.11	52.75
	6.02	48.21	0.73	64.53	29.16	52.78
A 22	4.97	46.32	0.98	60.29	24.90	50.51
	5.00	46.39	0.95	60.74	25.00	50.56
	4.98	46.35	0.96	60.59	24.92	50.51
Average		47.77		68.28		52.07

$\text{CTSI}_{\text{site 1st}}$ = [TSI (Chl-a) + TSI (SD) + TSI (TP)]/3

= [47.77 + 68.28 + 52.07]/3

= 56.04 (Eutrophic)

Fig. 1 Three main variables of trophic state index of site 1st

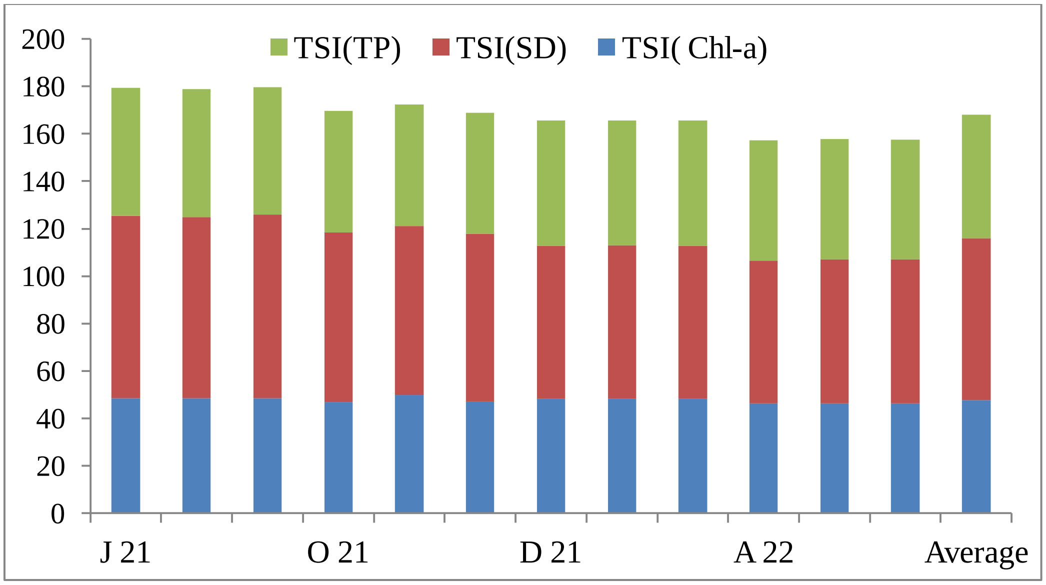


Table 4 Trophic state index of site 2^{nd}

Months	Chl-a (µg/l)	TSI	SD (m)	TSI	TP (µg/l)	TSI
J 21	5.01	46.41	1.36	55.57	20.01	47.36
	5.03	46.45	1.38	55.36	20.01	47.36
	5.01	46.41	1.36	55.57	20.02	47.36
O 21	3.65	43.30	1.36	55.57	19.29	46.82
	3.64	43.27	1.36	55.57	19.25	46.79
	3.65	43.30	1.35	55.68	19.31	46.84
D 21	4.89	46.17	1.3	56.22	19.27	46.81
	4.88	46.15	1.31	56.11	19.36	46.88
	5.1	46.58	1.35	55.68	19.22	46.77
A 22	3.65	43.301	1.43	54.85	17.47	45.39
	3.94	44.05	1.45	54.65	17.45	45.38
	3.86	43.85	1.46	54.55	17.49	45.41
Average		44.93		55.44		46.60

$CTSI_{\text{site 2nd}}$ = [TSI (Chl-a) + TSI (SD) + TSI (TP)]/3
= [44.93 + 55.44 + 46.60]/3
= 48.99 (Mesotrophic)

Fig.2 Three main variables of trophic state index of site 2^{nd}

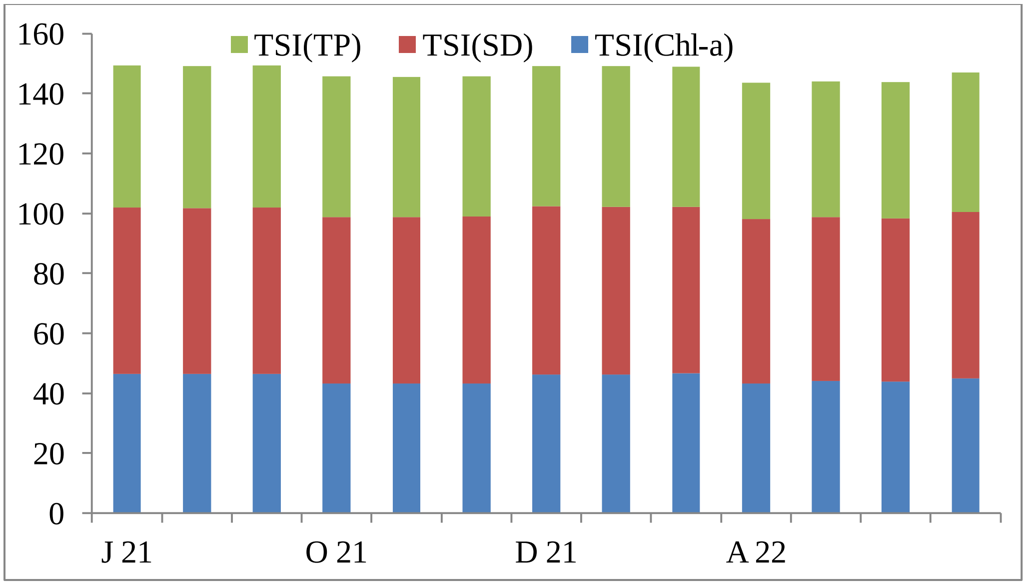


Table 5 Trophic state index of site 3rd

Months	Chl-a (µg/l)	TSI	SD (m)	TSI	TP (µg/l)	TSI
J 21	3.82	43.75	1.55	53.68	16.46	44.54
	3.81	43.72	1.52	53.97	16.38	44.47
	3.81	43.72	1.51	54.06	16.39	44.478
O 21	3.19	41.98	1.61	53.14	15.1	43.30
	3.21	42.04	1.63	52.96	15.09	43.29
	3.2	42.01	1.62	53.05	15.09	43.29
D 21	3.01	41.41	1.78	51.69	13.6	41.79
	3	41.38	1.77	51.77	13.61	41.80
	3	41.38	1.79	51.61	13.59	41.78
A 22	2.99	41.34	1.85	51.14	12.35	40.40
	2.91	41.08	1.81	51.45	12.34	40.39
	2.9	41.04	1.83	51.29	12.36	40.41
Average		42.07		52.48		42.49

CTSI $_{\text{site 2nd}}$ = [TSI (Chl-a) + TSI (SD) + TSI (TP)]/3

= [42.07+ 52.48 + 42.49]/3

= 45.68 (Mesotrophic)

Fig.3 Three main variables of trophic state index of site 3rd

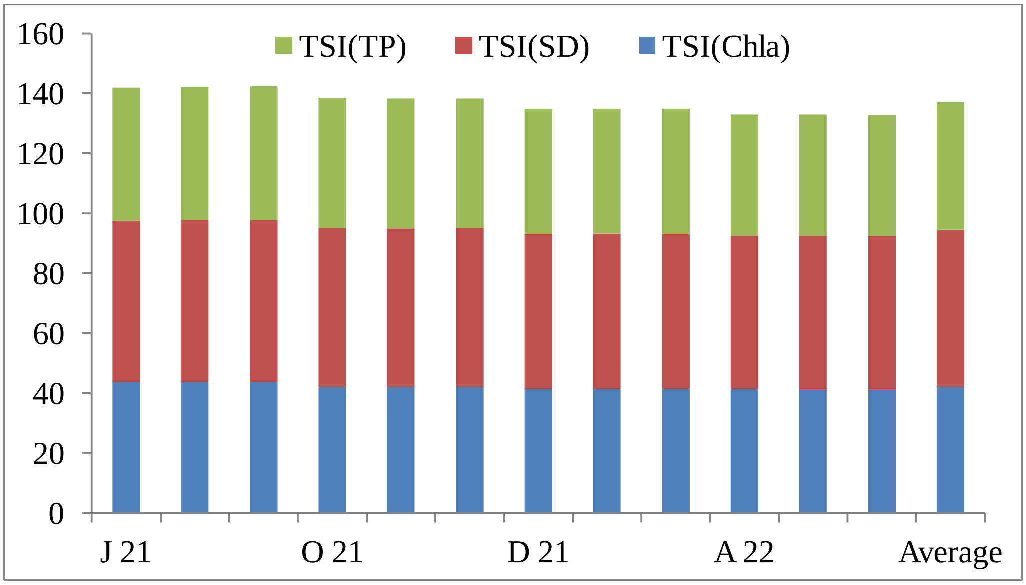
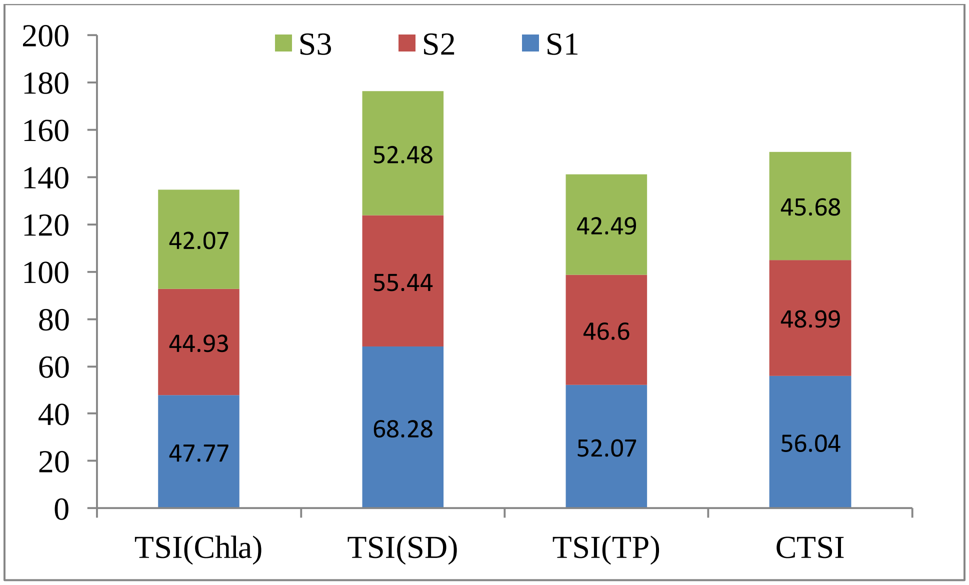


Fig.4 Comparative TSI of the selected three sampling sites



3.2. Statistical analysis in the physico-chemical attributes of selected sites

The five physico-chemical parameters of the dam water, SD, TP, Chl-a, DO, and BOD, responsible for determination of trophic condition, were determined using Pearson's correlation coefficients (Table 6).

At site 1, the correlation coefficients between SD and TP, Chl-a, and DO were all significantly inversely linked with each other. SD and BOD have an inverse correlation. Significantly positive correlations between TP and Chl-a, negative correlations between TP and SD and DO, and positive correlations between TP and BOD were all found.

Site 2nd showed the positive correlation between SD, DO and BOD. TP showed positive correlation with Chl-a and BOD. However, SD showed negatively correlation with TP and Chl-a a. TP also showed the negative correlation with DO. Chl-a negatively correlated with DO and BOD. And DO also show negatively correlation with BOD.

Site 3rd showed positively correlation of SD with DO. TP with BOD and Chl-a. Chl-a also positively correlated with BOD. SD negative correlated with TP, Chl-a and BOD. TP was negatively correlated with DO. DO also show negatively correlation with TP and BOD.

Table 6 Correlation Matrix for different sampling sites

Correlation at Site 1

		SD	TP	Chla	DO	BOD
SD	Pearson Correlation	1	-.658*	-.623*	.994**	-.206
	Sig. (2-tailed)		.020	.030	.000	.520
	N	12	12	12	12	12
TP	Pearson Correlation	-.658*	1	.975**	-.657*	.057
	Sig. (2-tailed)	.020		.000	.020	.861
	N	12	12	12	12	12
Chla	Pearson Correlation	-.623*	.975**	1	-.640*	.153
	Sig. (2-tailed)	.030	.000		.025	.635
	N	12	12	12	12	12
DO	Pearson Correlation	.994**	-.657*	-.640*	1	-.264
	Sig. (2-tailed)	.000	.020	.025		.406
	N	12	12	12	12	12
BOD	Pearson Correlation	-.206	.057	.153	-.264	1
	Sig. (2-tailed)	.520	.861	.635	.406	
	N	12	12	12	12	12

Correlation at Site 2

		SD	TP	Chla	DO	BOD
SD	Pearson Correlation	1	-.771**	-.496	.435	.531
	Sig. (2-tailed)		.003	.101	.158	.075
	N	12	12	12	12	12
TP	Pearson Correlation	-.771**	1	.610*	-.862**	.075
	Sig. (2-tailed)	.003		.035	.000	.816
	N	12	12	12	12	12
Chla	Pearson Correlation	-.496	.610*	1	-.274	-.011
	Sig. (2-tailed)	.101	.035		.390	.972
	N	12	12	12	12	12
DO	Pearson Correlation	.435	-.862**	-.274	1	-.465
	Sig. (2-tailed)	.158	.000	.390		.128
	N	12	12	12	12	12
BOD	Pearson Correlation	.531	.075	-.011	-.465	1
	Sig. (2-tailed)	.075	.816	.972	.128	
	N	12	12	12	12	12

Correlation at Site 3

		SD	TP	Chla	DO	BOD
SD	Pearson Correlation	1	-.982**	-.908**	.915**	-.755**
	Sig. (2-tailed)		.000	.000	.000	.004
	N	12	12	12	12	12

TP	Pearson Correlation	-.982**	1	.914**	-.854**	.846**
	Sig. (2-tailed)	.000		.000	.000	.001
	N	12	12	12	12	12
Chla	Pearson Correlation	-.908**	.914**	1	-.841**	.696*
	Sig. (2-tailed)	.000	.000		.001	.012
	N	12	12	12	12	12
DO	Pearson Correlation	.915**	-.854**	-.841**	1	-.452
	Sig. (2-tailed)	.000	.000	.001		.141
	N	12	12	12	12	12
BOD	Pearson Correlation	-.755**	.846**	.696*	-.452	1
	Sig. (2-tailed)	.004	.001	.012	.141	
	N	12	12	12	12	12

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

3.3. Macrophytes of Baretha Dam

At the study area, 11 macrophytes were observed which included 4 submerged, 5 floating and 2 rooted emergent macrophytes. The dominant macrophyte at site 1st was *Eichhornia crassipes*, and at site 2nd *Hydrilla verticillata* and at site 3rd *Najas minor* was dominant macrophyte species. The dominance was calculated by importance value index (IVI). Macrophytes' diversity was maximum at site 3rd (CTSI = 45.68) in comparison to other sites, indicating that the water was moderately clean. Due to anthropogenic activities trophic state of site 1st (CTSI = 56.04) have highest density of *Eichhornia crassipes* which was evidenced by the lower transparency, risk of oxygen depletion [35].

3.4. Macrophytic diversity indices

The density and diversity of aquatic macrophytes are impacted by changes in land use as well as other stresses, such as urban development, eutrophication, macroeconomic activity, and the spread of exotic invasive species [36,37]. Simpson's diversity index of site 3rd (0.208) was relatively lower than site 1st (0.23) and site 2nd (0.249) as shown in table 7 and Fig. 5. This indicates that macrophytic diversity increases with decreasing anthropogenic activities and trophic state of the dam. Comparation of CTSI of dam water is shown in Fig. 4. The species richness of submerged macrophytes significantly decreased with rising TP, but the species richness of floating-leaved macrophytes significantly increased. A significant change in trophic status was seen as TP increased. The Shannon-Wiener index of macrophytic species ranged from 1.601 to 1.813. The site with the lowest TP, site 3, had the highest Shannon-Wiener index (1.813), whereas the one with the highest TP, site 1, had the lowest Shannon-Wiener index (1.601). Pielou's evenness index of the dam water ranged from 0.208 to 0.249 having maximum Pielou's evenness at site 2nd and minimum at site 3rd. With lower nutrient loading, the species evenness was found to be decrease. Margalef's diversity index ranged from 1.04 to 1.17. Maximum Margalef's diversity was found at site 3rd and minimum at site 2nd. This examination of diversity makes it abundantly evident that human-induced activities and TP, which determines trophic condition and is a key factor, both have an impact on the macrophytic variety of the lake. The several diversity indices calculated for different sampling sites are shown in table 7.

Fig. 5 Showing comparative picture of macrophytic diversity indices of the sampling sites

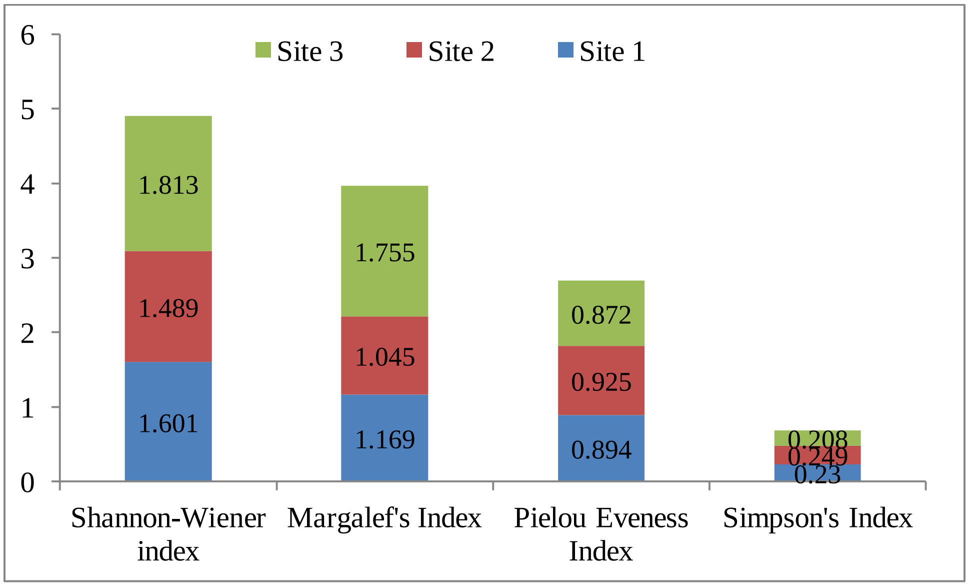


Table 7 Diversity index estimated for different sampling sites

Sampling sites	Site 1	Site 2	Site 3
Shannon-Wiener index	1.601	1.489	1.813
Margalef's Index	1.169	1.045	1.755
Pielou's Eveness Index	0.894	0.925	0.872

Simpson's Index	0.23	0.249	0.208

Under varied anthropogenic disturbance levels, the Dam exhibits a range of physico-chemical characteristics of water as well as dominance, the composition, and variety of macrophytes. *Eichhornia crassipes, Potamogeton cripus, Typha angustifolia*, and *Trapa natas* are examples of exotic invasive aquatic weeds that thrive in tropical nations because of the unique eco-hydrological conditions, nutrient-rich runoff, and changes in the watershed land use brought on by human activity [38-41]. The *Eichhornia crassipes* species is the most troublesome free-floating macrophyte whose harmful effects are extensive in aquatic ecosystem. Furthermore, the greater number of exotic invasive species has an effect the native macrophytic diversity of the Dam [35]. The higher nutrient levels have a significant negative impact on submerged macrophytes. Declining natural biodiversity is a result of increased pollution and anthropogenic intervention, as well as the invasion of floating macrophytes.

The species richness of the floated-leaved and submerged macrophytes is significantly affected by total phosphorous (TP), a critical factor determining trophic status [42]. In this study, mesotrophic (TSI = 45.68) site 3rd shows highest species diversity and richness then eutrophic site 1st. According to multiple additional researches, a rise in TP causes an increase in the trophic status of lakes, which leads to eutrophication and decrease in species diversity [43]. Low TP is found to enhance the number of submerged and free-floating macrophytes in lakes, which improves habitat variability and hence species diversity. Submerged macrophytes may occupy a large area in mesotrophic lakes, and their presence has a significant influence on overall structural complexity [44,45] .

4. Conclusion

The variations in the hydro-chemical characteristics of Bandh Baretha (Dam) located in Eastern Rajasthan, India was studied. The study revealed the influence of nutrient chemistry on the macrophyte density and diversity. The dominant macrophytes were estimated using the IVI index which were *Eichhornia crassipes, Hydrilla verticillata* and *Najas minor*. To have a better understanding of the nutrient influences the trophic status of the water body was also estimated. A Pearson's correlation matrix also substantiated the findings. The various diversity indices also established that the trophic status which is influenced by nutrient content is the driving factor impacting the macrophyte heterogeneity of the study area. The higher nutrient content indicated the degradation of the water body and it is advised that authorities and local bodies must come together to formulate policies for the sustenance of this freshwater ecosystem.

5. References

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