Original Article

Biomonitoring Macrophytes Diversity and Abundance for Rating Aquatic Health of an Oxbow Lakeecosystem in Ganga River Basin

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ABSTRACT

Objective: Evaluation of the biological community of a water body provides sensitive and cost effective means of assessing its water quality. Aquatic macrophytes diversity and its role in understanding the oxbow lake ecosystem dynamics have tremendous significance. The study is aimed for quantitative biomonitoring the ecological quality through macrophytes diversity.

Methods: A survey of macrophytes communities of freshwater Chhariganga oxbow lake of West Bengal in eastern India along with analysis of diversity indices, dominance trends with importance value index (IVI) and composition trends was carried out.

Results: Estimating annual average IVI values, we found that emergent (154.91±12.59) were dominant, followed by the free-floating (78.22±25.12), submerged (37.78±11.82) and rooted floating-leaved genus (29.09±13.84). Among emergent, *Cynodon sp* was the most dominant during pre monsoon and post monsoon and *Ipomoea sp* during monsoon. Among the free-floating genus, *Eichhornia sp* was highly dominant throughout the year while *Lemna sp* topped the group during pre monsoon. Among the submerged genus, *Hydrilla sp* was observed to be the most dominant genus throughout the year. Among rooted floating-leaved *Nymphaea sp* was highly dominant during monsoon and post monsoon and *Brasenia sp* during pre monsoon. Highest values of density (120no/m^2), average area coverage (69.34%) and average wet biomass (1816.72 g/m^2) were observed during post monsoon while lowest values of density (27no/m^2), average area coverage (38.95%) and average wet biomass (281.78g/m^2) were estimated during the monsoon. We found genus richness values higher during post (44) and pre (36) monsoon and lower in monsoon (22) with mean genus Evenness value of 0.79±0.05. In our study lower average diversity values of Shannon Wiener index (2.74 ±0.36) and Simpson index (0.90±0.04) throughout the year render poor to moderate pollution status to the oxbow lake while presence of certain bio-indicators species like

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Lemna, *Eichhornia*, *Myriophyllum, Potamogeton, Trapa, Marsilea* and *Cyperus* also confirm pollution. Similar pollution status was observed when assessed with rotifer, whole zooplankton and macroinvertebrate diversity indices on the same oxbow lake during the same period. The growth of the macrophytes reveals the lower productive nature of the lake. The Throughout dominance of emergent among other growth forms indicates the slight encroachment of littoral vegetation, reducing the core area of the lake and showing the slow trend of succession towards marsh meadow condition. Lower richness values also do affirm its oligotrophic status.

Conclusion: We find selected lake has much anthropogenic activity and not suitable for fish growth especially during monsoon. So we opine that highest priority must be given to removal of macrophytes especially water hyacinth; and regulation and prevention in jute retting process, intensity and density are needed for its sustainable management and conservation of aquatic environment.

Keywords: Oxbow Lake, Macrophytes, Diversity index, Aquatic health, Biomonitoring.

INTRODUCTION

Aquatic macrophytes are macroscopic forms of aquatic vegetation, including macro algae, mosses, ferns and angiosperms found in aquatic habitat. They have evolved from many diverse groups and often demonstrate extreme plasticity in structure and morphology in relation to changing environmental condition. Aquatic macrophytes in different growth forms represent the most important biotic element of the littoral zone in a lake ecosystem.

Oxbow lakes are often described as "kidneys of the landscape"[31]. They are among the most productive ecosystems of the world, comparable to rain forests and coral reefs. They are potentially rich in aquatic resources, which play a significant role in maintaining biodiversity. They offer habitats suitable to support growth of a variety of aquatic life forms. Oxbow lakes are not only important life support system for the flora and fauna alone but also supply bio resources as well as act as sources of livelihood for the people living in its vicinities. Hydrological conditions of oxbow lakes can directly modify or change chemical and physical properties which in turn, have a direct impact on the biotic response in the oxbow lakes.[23] Due to low gradient in the lower deltaic region, high discharge during monsoon and meandering nature of river Ganga in West Bengal, India, a large numbers of oxbow lakes formed. These are open type oxbow lakes remain connected with the main river either throughout the year or at least a part of the year, thereby allowing the free mixing stagnant and flowing waters. Such oxbow lakes therefore exhibit physico-chemical; and biological characteristics of both lacustrine and riverine ecosystems and support significant fishery in the region as these harbor rich floral and faunal diversity. Most of the oxbow lakes of the Nadia district are degrading due to various anthropogenic activities like encroachment, siltation due to flood, construction of roads, agricultural activities, and excessive growth of water hyacinth. Macrophytes are affected by a variety of abiotic factors, including water and sediment nutrients, underwater light, fetch, and water-level fluctuations. Flood pulses alter macrophytes biomass, productivity, composition, and richness. The growth, propagation and abundance of aquatic and semi aquatic macrophytes along with other hydrophilic terrestrial vegetations during different seasons help enhancement of biodiversity and influence their distribution pattern in the oxbow lake ecosystem.

Aquatic macrophytes diversity and its role in understanding the oxbow lake ecosystem dynamics have tremendous significance. Free-floating and rooted floating leaved species are the most competitive in the aquatic environment for light, and usually are dominant macrophytes communities when nutrient Levels in the water are sufficiently high. Two factors, number of species and importance values (number, biomass, productivity) of individuals, determine the species diversity of a community[36]. Importance Value Index (IVI), a quantitative parameter, is useful, as it provides an overall picture of the density, frequency and cover of a species in relation to community[12]. It is reported that an aquatic plant alters the physico-chemical characteristics of water[28]. Many workers have tried to establish relationship between trophic status of water bodies and aquatic plants[56]. Aquatic communities reflect anthropogenic influence and are very useful to detect and assess human impacts[44].

Evaluation of the biological community of a water body provides a sensitive and cost effective means of assessing water condition. Pollution problem of inland water bodies has attracted the attention of researchers since long. It was opined that aquatic macro vegetation plays important role in maintaining ecological balance by nutrient recycling.[26] It was designated certain aquatic plant species as pollution indicators.[37,53] Seasonal variation was studied in Importance Value Index (IVI), Diversity Indices and Biomass of aquatic macrophytes at Biratnagar and adjoining areas, eastern Nepal[35]. It was undertaken a quantitative investigation of aquatic macrophytes in Beeshazar Tal (Beeshazar Lake) in Nepal[7]. Several studies have been done on macrophytic diversity in different lentic fresh water bodies.[52, 3, 14, 25] Several workers have done significant works on the phyto-sociology of different macrophytes in different freshwater bodies of India[30,46, 16, 2, 15, 5, 34] Quantitative analysis of macrophytes and physico-chemical properties of water were studied[45] of two wetlands of Nalbari district of Assam.

It was studied diversity of freshwater macrophytic vegetation of six rivers of south West Bengal[40]. Though few workers[13] have done ecological studies on hydrophytes of different oxbow lakes of West Bengal, so far no works on quantitative bioassessment of diversity study on aquatic macrophytes and aquatic health of oxbow lake in northern part of Nadia district in particular exist. Hence the objective of the present study is set as survey of the macrophytes communities and analysis of macrophytes with diversity indices to bio-assess the water quality and aquatic health of an oxbow lake in northern part of Nadia district of West Bengal in eastern India. This type of study would hopefully be a reference archive for future studies on assessment of aquatic health in designing a plan for the sustainable management of the oxbow lake in the region.

MATERIAL AND METHODS

Study Area

The Chhariganga oxbow lake, abandoned, fractioned and derived from the river Ganga is located in Nakashipara development block of Nadia district, West Bengal, India. It is situated at 23.5800° N, 88.3500° E, about 90 Km away from Kalyani University Campus, Nadia and nearly 40 km away from the line of Tropic of Cancer towards the north. It is a fresh water and semi open type oxbow lake and receives water from the river Ganga during monsoon through a narrow channel at the North East corner of a loop of the river. The oxbow lake is spread over an area of 145.69 Acres with an annual average depth of 8.5 ft. It also stores rain water. The catchment area of the oxbow lake is nearly 600 hectare (Fig-1).

There are three distinct annual seasons observed in changed climate of this region: the Monsoon (MON) or rainy season generally from July to October, post monsoon (POM) or winter from November to February and the pre monsoon (PRM) or dry season from March to June. There was an occasional inundation of the surrounding banks during the monsoon. The oxbow lake is subjected to all forms of human activities including jute retting during monsoon, agriculture and fishing. It is the only source of irrigation water to the immediate agriculture communities.

Macrophyte sampling, Identification and Analysis

Investigations were made through three seasons for a period of April 2013 to March 2014. We recorded data on macrophytes from a country boat along the entire shoreline. Submerged plants were sampled from the boat with a rake. We applied a random sampling method with the help of a 1m×1m light wooden quadrat. The macrophytes were counted by hand picking. We studied altogether 60 quadrats in the oxbow lake during the year with 20 quadrats in each season. For taxonomic identification we followed the specialized literature[41,4, 17, 18, 50, 27, 24, 11,32] Macrophytes were categorized into four main growth forms. Rooted plants with main photosynthetic parts projecting above the water surface were classified as emergent, rooted plants with leaves floating on the water surface as rooted floating-leaved macrophytes, rooted or floating plants completely or largely submerged as submerged macrophytes, and plants with crown floating on the water surface as free floating macrophytes.

Importance Value Index and Various diversity indices were calculated to obtain various analytical data of the genus by using the following formulas:

Importance Value Index (IVI)

It was calculated by equation[7]:

Importance value = Relative frequency + Relative density + Relative dominance,

where Relative frequency is the number of occurrences of one genus as a percentage of the total number of occurrences of all genera, Relative density is the 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. The maximum importance value for any one genus is 300 (100 + 100 + 100). It is useful, as it provides an overall picture of the density, frequency and cover of a genus in relation to community.

Simpson's Dominance Index (D)

The Simpson's index (D) is calculated using the following equation[49]:

$$D = \frac{\sum_{i=1}^{s} n_i(n_i - 1)}{n(n-1)}$$

Where 'ni' is the proportion of individuals of the i^{th} species in the community. Simpson's index gives relatively little weight to the rare species and more weight to the common species. It weighs towards the abundance of the most common species. It ranges in value from 0 (low diversity) to a maximum of (1-1/s), where s is the number of species. In nature the value of d ranges between 0 and 1. With this, index 0 represents infinite diversity and 1, no diversity. The bigger the (D) value, the smaller the diversity.

Simpson's Diversity Index (1-D)

It represents the probability that two individual organisms randomly selected from a sample will belong to different species. The value of this index also ranges between 0 and 1, the greater the value, the greater the sample diversity.

Shannon-Wiener Index (H')

This is a widely used method of calculating biotic diversity in aquatic and terrestrial ecosystems and is expressed as SWI [47]:

$$H' = \sum_{i=1}^{s} \frac{n_i}{n} \ln \frac{n_i}{n}$$

Where H= index of species diversity s= number of species n_i= proportion of total sample belonging to the i^{th} species. This diversity index helps in calculating species relative abundance. A large H value indicates greater diversity, as influenced by a greater number and/or a more equitable distribution of species. The index values ranges between 0 and 5, where higher index values demonstrates higher diversity, while low index values are considered to indicate pollution. Diversity and anthropogenic disturbances are inversely related to each other. The Shannon index takes account of species richness as well as abundance. It is simply the information entropy of the distribution, treating genus as symbols and their relative population sizes as the probability. The advantage of this index is that it takes into account the number of species and the evenness of the species. The index is increased either by having additional unique species, or by having greater species evenness. Diversity is maximum when all species that made up the community are equally abundant (i.e. have a similar population sizes). The diversity is partly a function of the variety of habitats; the more varied habitats tend to be inhabited by a large number of species than less variable ones. Secondly the older habitats usually contain more species than younger ones.

Evenness Index (E)

This is relative distribution of individuals among taxonomic groups within a community and is expressed[39] as:

E= H'/logS, Where, H' = Shannon – Wiener diversity index, and log S= Natural log of the total number of species (S defined as **Species Richness**) recorded. It is used for the degree to which the abundances are equal among the groups present in a sample or community.

RESULTS AND DISCUSSIONS

We recorded altogether 45 genera of macrophytes in the present investigation (Table-1 & 2). It was found altogether 13 genera of aquatic macrophytes[13] (quite similar to our study) belonging to 10 families and 24 plant species (bank flora) belonging to 16 families. It was also recorded almost similar[33] (49) taxa of macrophytes from Amazonian lakes. In terms of genus number of plant, emergent showed the largest number in our study, followed by submerged, free floating, and rooted floating leaved during the year. The result that emergent outnumbered submerged and floating genus is substantiated[7]. The number of aquatic macrophytes genus was higher during the post (44) and pre (36) monsoon and lower during the monsoon (22) (Table 1). In terms of individual numbers Emergent were the most dominant during the post monsoon while Free floating were dominant rest of the year. We found among the Emergent group, both *Enhydra* sp and *Marsilea sp* were found dominant during POM. Among the free-floating genus, *Wolffia sp* and *Lemna sp* topped the group during PRM while *Wolffia sp* and *Eichhornia* sp. both dominated during monsoon. *Lemna sp* topped the group during POM too. It was applied novel aquatic bioassay[19] with *Lemna minor* (duckweed) to demonstrate the usefulness of a macrophyte bioassay, as a supplement to the standardized algae bioassays for the ecotoxicological assessment of sediments in several German rivers.

The dominance of genus by growth forms on the basis of Importance Value Index (IVI) value is presented in Table 1. Estimating annual average IVI values (Fig-2) we found that emergent were dominant, followed by the free-floating, submerged and rooted floating-leaved genus. After emergent, the next highest IVI values were those of free-floating genus in the PRM and MON, and submerged genus in the POM. The dense growth of free-floating and rooted floating-leaved genus prevented colonization of submerged genus in the PRM and MON[26]. Emergent were the most dominant form throughout the year. Seasonally, emergent's IVI was highest in the post monsoon (POM), followed by pre monsoon (PRM) and monsoon (MON). Among emergent, *Cynodon sp* was the most dominant in the PRM and the POM, and *Ipomoea sp* in the MON. Among the free-floating genus, *Eichhornia sp* was highly dominant throughout the year while *Lemna sp* topped the group during PRM. Quite similar IVI values were found for the macrophytes. [35,45] The largest IVI values for *Eichhornia* sp were found during MON (39.76), followed by the PRM (22.05) and the POM (21.55). Higher growth of *Eichhornia sp* in the MON may be due to invasion through the inflowing water from the river Ganga in to the oxbow lake. Its current dominance may be ascribed to its invasive nature and also its preference for eutrophic water during MON when the oxbow lake accommodates higher organic load due to jute retting. It was concluded[45] that excessive growth of invasive aquatic weed like *Eichhornia crassipes* can be used as bioindicator of water quality of oxbow lakes gradually degrading due to various anthropogenic activities.

In our study, among the submerged genus, *Hydrilla sp* was observed to be the most dominant genus throughout the year. The year-round growth of the genus indicates its ability to adapt in diverse conditions. It was also found[48] this species in a lake area characterized by high silt and organic load. The silt and organic load in our oxbow lake were found to be due to the transportation of silt, organic matter and litter from the catchment area at the time of flooding and due to jute retting during MON. Similar findings regarding *Hydrilla sp* are reported[7]. Among the growth forms, rooted floating-leaved genus were the least dominant in terms of IVI value. *Nymphaea sp* was highly dominant during MON and POM and *Brasenia sp* during PRM.

It was pointed out certain aquatic plants like *Lemna sp*, *Eichhornia sp*, *Myriophyllum sp* and *Potamogeton sp* as pollution indicator[53]. It is also reported *Potamogeton sp, Trapa sp, Marsilea sp* and *Cyperus sp* as pollution indicator[37]. Their presence in the Chhariganga oxbow lake of our study detected pollution significantly during MON and POM which might be attributed to the increase in heavy organic matter of jute retting during later part of monsoon. It was studied[8] Populations of *Myriophyllum alterniflorum* L. as bioindicator of pollution in acidic to neutral rivers in the Limousin region, France. It was studied[10] submerged aquatic plants as environmental indicators of ecological condition in New Zealand lakes. We found *Najas sp* in and around 3% composition of the macrophytes throughout the year. It was observed that eutrophication and acidification of lakes are the main threats to *Najas* in Europe[55].

Table-3 shows seasonal variations in macrophytes density, coverage and wet biomass in Chhariganga Oxbow Lake. Highest values of density (120no/m^2), average area coverage (69.34%) and average wet weight (1816.72 g/m^2) were observed during post monsoon while lowest values of density (27no/m^2), average area coverage (38.95%) and average wet weight (281.78g/m^2) were estimated during the monsoon (Table-3 & 4). Free Floating has the highest (66) and Rooted Floating leaved has the lowest (2) density during pre monsoon while Free Floating has the highest (15) and Submerged has lowest (2) density values during monsoon. During post monsoon emergent has the highest (59) and Rooted Floating leaved has lowest (7) density per square meter of lake water with annual average highest density of Free Floating and lowest that of Rooted Floating leaved macrophytes. Highest annual average wet biomass was observed for Emergent (541.70g/m^2) and lowest for Submerged macrophytes (40.15g/m^2). It was found macro vegetation useful in maintaining ecological balance by deriving nutrients from the water in benthic zone [26].

Macro vegetation in and around a water body plays important role in determining its hydro biological and trophic status. According to a study[1] eutrophic conditions can be generally characterized by increasing number of aquatic plants in water body. The presence of lower numbers of macrophytes in our study lake renders its oligotrophic status. It was highlighted the differences[40] in vegetation patterns in response to different ecological conditions of riverine tracts and during monsoon, due to heavy precipitation, much of river belts became water saturated which was conducive for the plant species to grow and propagate and they opined seasonal flourishing of plant biomass ultimately leads to enrich the soil and water of rivers during post-monsoon months through the process of decomposition. It was found[13] a general relationship between trophic status of a water body and the aquatic plants. They also observed alteration of water quality due to presence of various aquatic plants in three oxbow lakes in Krishnanagar city (88^{0}33'E, 23^{0}24'N) in Nadia district, India.

The growth of the macrophytes reveals the lower productive nature of the lake. The dominance of emergent among other growth forms (as shown by IVI measurements) indicates the encroachment of littoral vegetation, reducing the core area of the lake and showing the trend of succession towards marsh meadow condition. When a lake becomes choked by water hyacinth, the number of birds and other animals in the upper strata of the food chain decreases significantly[43]. Accumulation of silt and detritus from the catchment area and decomposition of macrophytes reduces the water quality as well as the core area of the lake and promotes the encroachment of littoral vegetation, a familiar succession trend as the oxbow lake is transformed into marsh meadow[54]. A sustainable management plan should be formulated and implemented soon if Chhariganga oxbow lake's diverse ecosystem is to be preserved. The highest priority must be given to removal of macrophytes especially water hyacinth.

Genus diversity is a useful parameter for the comparison of communities under the influence of biotic disturbances or to know the state of succession and stability in the community. In terms of average annual genus Richness values, emergent showed the largest number followed by submerged and free floating and rooted floating leaved during the year (Table-5 & Fig-3). The result that emergent outnumbered submerged and floating genus is substantiated[7]. The genus Richness of aquatic macrophytes was higher during the post (44) and pre (36) monsoon and lower during the monsoon (22). In terms of annual average Genus evenness index values, free floating group showed highest value (0.87±0.03) and rooted floating leaved the lowest value (0.66±0.38) while community as a whole showed highest value (0.83) during the POM and lowest (0.74) during PRM in the oxbow lake with low annual average value of 0.79±0.05 (Table-6).

Shannon-Wiener's index of genus diversity (H') was highest for the emergent (2.3± 0.1) followed by the submerged (1.63±0.55), free-floating (1.24±0.22) and rooted floating leaved (0.86±0.52) genus respectively (Table-7). The highest genus diversity index for the entire community was found in the POM (3.14), as compared to the PRM (2.64) and MON (2.45). According to study[42] (cited [9]), lake was classified based on phyotcenotic diversity index (i.e. SWI): Mature lakes >2.0, Ageing lakes 1.5-2.0, ''Old lakes''<1.4. Our SWI results suggest that our selected lake is a mature one based on this classification. Simpson's diversity indices (1-D) The seasonal variation in requirements of the diverse growth forms may cause the variation in the genus diversity. Lowest diversity indices were observed during monsoon as compared to other two seasons of the year for all four growth forms including the community as a whole in the oxbow lake. This might be due to intense anthropogenic pressure like jute retting process that is generally taken place during the monsoon in the lake. Table- 8 shows seasonal variation Simpson index of diversity (1-D) values. It was observed SWI values[7] for Submerged macrophytes 1.527 (summer), 2.020 (winter), 1.325 (spring) and 1.624 ± 0.21(average) which are almost similar to our study and observed higher values for free floating with quite similar average value. They found average SWI value much higher (more than 2 times) for rooted floating leaved macrophytes and more than 38% for the Emergent forms and the community as a whole as compared to our average values. They also reported highest species diversity in the summer, followed by winter and then spring which also has quite similarity with our study. It was found SWI values[29] (1.09-1.94), Evenness (0.5-0.79) and Species richness (40-62) with 2-8 communities and for macrophytes in six different oxbow lakes in Poland which also have quite similarity with our study. It was too observed[35] SWI value (0.50-2.68) higher during winter and lower during rainy season in river and Simpson index of dominance values which have quite similarity with the present study. It was also found quite similar values[38] of species richness (16-33), SWI (0.38-4.63) and Evenness index (0.12-0.82) in oxbow lakes in Poland. It was found diversity indices[45] (1.78-3.45), quite similar like ours, but to be the highest in summer and lowest in winter season in Assam oxbow lakes unlike our study as we found lowest during MON and highest during POM. Their evenness values (0.58-1.03) and Simpson index of dominance (0.02-0.11) almost concur with our results.

The community as a whole shows the lowest Simpson index of diversity values (0.87) during monsoon and highest during post monsoon (0.94). Annual average values shows Rooted Floating leaved macrophytes the lowest (0.49±0.32) and Emergent ones the highest (0.86±0.02). Despite observation[51] that diversity indices based on aquatic macrophytes community structure and composition (unlike macro invertebrate based on taxonomic richness of particular groups) not pertinent tools in assessing domestic pollution of running waters and water quality of river of France, our low diversity values of Shannon-Wiener's index and Simpson's diversity indices (1-D) obviously indicated that the selected lake was polluted and had high anthropogenic activity. The pollution status of the oxbow lake in this study showed a poor to moderate level of pollution load. Similar pollution status was also observed when assessed with rotifer diversity indices[20], with zooplankton diversity indices[21] and with macro invertebrate diversity indices[22] on the same oxbow lake during the same period.

CONCLUSION

In the present study the growth of the macrophytes reveals the lower productive nature of the lake. The Throughout dominance of emergent among other growth forms indicates the slight encroachment of littoral vegetation, reducing the core area of the lake and showing the slow trend of succession towards marsh meadow condition. So by this study we can highlight the detail changes of macrophytes composition in a seasonal frame and also we can correlate these studies in depicting the pollution status of a water body. In the present study lower average diversity values of Shannon Wiener index (2.74 ±0.36) and Simpson index (0.90±0.04) throughout the year render poor to moderate pollution status while presence of certain bio-indicators species like *Lemna*, *Eichhornia*, *Myriophyllum, Potamogeton, Trapa, Marsilea* and *Cyperus* in the lake also confirm pollution. Similar pollution status was observed when assessed with rotifer diversity indices[20], with zooplankton diversity indices[21] and with macroinvertebrate diversity indices[22] on the same oxbow lake during the same period. Lower richness values do affirm its oligotrophic status. We conclude selected lake has anthropogenic activity and not suitable for fish growth during monsoon. So regulation and prevention in jute retting process, intensity and density are needed and the highest priority must be given to removal of macrophytes especially water hyacinth for sustainable management and conservation of aquatic environment.

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Table-1: Seasonal Variations in Macrophytes Importance value Index

SL	Macrophytes name			PRM				MON				POM				Year mean	
	Scientific	Common	Vernacular	RF	RD	RA	IVI	RF	RD	RA	IVI	RF	RD	RA	IVI	IVI	SD
A	Emergent macrophytes																
1	*Typha sp.*	Cattail	Hogla	0.88	0.53	0.74	2.15	2.56	1.65	3.34	7.55	1.24	0.91	1.08	3.24	4.31	2.86
2	*Arundo sp*	Giant Reed		0.88	0.09	0.15	1.11	2.56	0.37	0.64	3.57	1.24	0.21	0.27	1.72	2.14	1.28
3	*Phragmites sp*	common Reeds (cane-like perennial grass)		4.39	1.86	3.27	9.51	5.13	3.30	6.42	14.84	3.73	2.28	3.24	9.25	11.20	3.16
4	*Alternanthera sp*	Alligator Weed	Chhenachi /Chanchi	2.63	0.27	1.04	3.94	5.13	0.55	1.93	7.60	2.48	0.29	0.90	3.68	5.07	2.20
5	*Panicum sp*	Maidencane, Torpedograss		5.26	1.59	3.56	10.42	7.69	3.85	3.85	15.39	3.73	1.58	2.34	7.65	11.15	3.92
6	*Polygonum sp*	Smartweed, Water Pepper	Chemti /dubia , Bekh-unjubaz,Pakur mul, Pani-maricha, Bekhanjubar	0.88	0.13	0.03	1.04	2.56	0.37	0.13	3.06	0.62	0.17	0.04	0.82	1.64	1.23
7	*Hydrochloa sp*	Southern Watergrass		2.63	0.93	4.45	8.01	-	-	-	-	1.86	1.04	3.24	6.15	7.08	1.32
8	*Scirpus sp*	Bulrush, Three-Square	Patpati,Dal/Chhotodal	4.39	2.47	6.53	13.39	-	-	-	-	-	-	-	-	13.39	0.00
9	*Juncus sp*	Soft Rush		-	-	-	-	-	-	-	-	0.62	1.33	0.45	2.40	2.40	0.00
10	*Eleocharis sp*	Spike Rush		7.02	0.75	3.27	11.03	5.13	1.65	2.57	9.34	4.35	0.79	2.16	7.30	9.23	1.87
11	*Carex sp*	Sedges		-	-	-	-	-	-	-	-	0.62	0.71	0.72	2.05	2.05	0.00
12	*Hydrocotyle sp*	Water Pennywort		0.88	0.13	0.45	1.45	-	-	-	-	0.62	0.17	0.36	1.15	1.30	0.22
13	*Cyperus sp*		Gothubi	-	-	-	-	-	-	-	-	4.97	3.40	4.33	12.70	12.70	0.00
14	*Monochoria sp*		Kajal-lata / Nukha	2.63	0.75	2.23	5.61	-	-	-	-	3.73	1.74	2.16	7.63	6.62	1.43
15	*Hygrophila sp*		Kuleykharha	1.75	0.53	1.34	3.62	-	-	-	-	0.62	0.29	0.90	1.81	2.72	1.28
16	*Colocasia sp*		Kochu	4.39	0.49	2.37	7.25	2.56	0.92	5.78	9.26	1.86	0.37	1.80	4.04	6.85	2.63
17	*Centella sp*		Thankuni	0.88	0.09	0.74	1.71	-	-	-	-	0.62	0.17	1.08	1.87	1.79	0.11

18	*Commelina sp*	Karhuli/Kanchira	Kanchira, Jata Kanclira	3.51	2.39	2.37	8.27	5.13	5.49	6.42	17.04	3.11	2.99	1.98	8.08	11.13	5.12
19	*Ipomoea sp*	Water spinach	Kalmee /Dhol Kalmi	6.14	1.63	10.39	18.16	7.69	4.95	8.99	21.62	7.45	2.53	10.46	20.44	20.08	1.76
20	*Sagittaria sp*		Chotokut	7.02	0.53	2.52	10.07	5.13	1.28	7.70	14.11	3.73	0.29	0.90	4.92	9.70	4.61
21	*Cynodon sp*		Durba ghash	10.53	1.86	9.05	21.43	7.69	4.21	5.13	17.04	7.45	3.49	11.72	22.66	20.38	2.95
22	*Enhydra sp*		Helencha	1.75	9.05	2.67	13.48	-	-	-	-	1.86	12.54	3.06	17.46	15.47	2.82
23	*Marsilea sp*			0.88	5.48	2.91	9.26	-	-	-	-	1.24	11.87	3.24	16.36	12.81	5.02
B	**Free Floating macrophytes**																
24	*Salvinia sp*	water moss, Pteridophyta	Jal Fern	0.88	2.39	4.16	7.42	-	-	-	-	0.62	1.08	0.90	2.60	5.01	3.41
25	*Lemna sp*	Duckweed	Khudipana	2.63	20.01	5.34	27.98	-	-	-	-	1.24	11.96	1.26	14.46	21.22	9.56
26	*Wolffia sp*	Watermeal	Guripana	1.75	22.44	3.71	27.90	5.13	26.74	5.78	37.64	0.62	5.48	0.54	6.64	24.06	15.85
27	*Pistia sp*	Water Letttuce	Topa-pana	0.88	5.57	1.04	7.48	2.56	7.51	5.13	15.21	0.62	2.99	0.36	3.97	8.89	5.75
28	*Eichhornia sp*	Water Hyacinth	Kachuripana	6.14	7.60	8.31	22.05	10.26	20.51	8.99	39.76	5.59	8.39	7.57	21.55	27.78	10.37
C	**Rooted Floating leaved macrophytes**																
29	*Trapa sp*	Jal Singara	Pani-phal/water singara	0.88	0.04	0.74	1.66	-	-	-	-	0.62	0.04	0.45	1.11	1.39	0.39
30	*Ludwigia sp, Jussiaea sp*	Water Primrose	Kesara-dam / Murhilata	0.88	0.04	0.45	1.37	-	-	-	-	1.24	0.17	0.90	2.31	1.84	0.67
31	*Nymphoides sp*	Banana Lily, Floating Heart	Panchuli,Chandmalla	-	-	-	-	5.13	3.30	3.85	12.28	3.73	1.74	5.05	10.52	11.40	1.24
32	*Nymphaea sp*	White Water Lily, Fragrant Water Lily	Rakto kamal, Saluk/Shapla / Salook	-	-	-	-	5.13	3.85	6.42	15.39	6.21	1.58	6.31	14.10	14.75	0.92
33	*Brasenia sp*	Water Shield, Dollar Bonnet	Jal Shild	4.39	1.41	4.30	10.10	2.56	2.20	5.52	10.28	2.48	1.87	3.79	8.14	9.51	1.19
D	**Submerged macrophytes**																
34	*Ceratophyllum*	Coontail	Jhanji,	0.88	1.02	0.74	2.64	-	-	-	-	1.24	1.45	1.08	3.78	3.21	0.81

			Sheoyala														
35	*Vallisneria sp*	Eelgrass	Pata-jhangi	0.88	0.53	0.89	2.30	-	-	-	-	1.86	1.16	1.80	4.83	3.56	1.79
36	*Elodea sp*	Elodea		-	-	-	-	-	-	-	-	1.86	0.75	1.08	3.69	3.69	0.00
37	*Cabomba sp*	Fanwort		-	-	-	-	-	-	-	-	2.48	1.66	2.88	7.03	7.03	0.00
38	*Hydrilla sp*	Hydrilla	Kaschra, Jhanji/Jal-Khangi	2.63	3.18	4.75	10.56	2.56	3.30	4.36	10.23	1.86	2.99	2.70	7.56	9.45	1.65
39	*Myriophyllum sp*	Eurasian Milfoil		-	-	-	-	-	-	-	-	1.24	2.37	1.44	5.05	5.05	0.00
40	*Chara sp*	Muskgrass (Chlorophyta) Algae		1.75	0.31	0.30	2.36	-	-	-	-	1.86	0.50	0.45	2.81	2.59	0.32
41	*Potamogeton sp*	Pondweed (Spermatophyta)		-	-	-	-	2.56	1.28	2.57	6.41	2.48	0.50	0.72	3.70	5.06	1.92
42	*Ruppia sp*	Widgeon Grass		0.88	0.13	0.30	1.31	-	-	-	-	1.24	0.21	0.45	1.90	1.60	0.42
43	*Najas sp*	Southern Naiad, Bushy Pondweed		2.63	3.00	4.16	9.79	2.56	2.56	3.21	8.34	1.24	2.74	2.52	6.51	8.21	1.65
44	*Ottelia sp*	Otteli	Parmi-Kala	1.75	0.04	0.30	2.10	2.56	0.18	1.28	4.03	0.62	0.08	0.36	1.06	2.40	1.51
45	*Aponogeton sp*			0.88	0.75	0.45	2.07	-	-	-	-	1.24	1.16	0.90	3.31	2.69	0.87

PRM=Pre monsoon, MON=Monsoon, POM=Post monsoon, RF=Relative Frequency, RD=Relative Density, RA=Relative abundance, IVI=Importance Value Index, SD=Standard deviation,

Table- 2: Seasonal variation in compositions of Macrophytes

SL		PRM		MON		POM		YEAR	
Emergent macrophytes									
1	*Typha sp.*	12	0.53	9	1.65	22	0.91	14	0.82
2	*Arundo sp*	2	0.09	2	0.37	5	0.21	3	0.17
3	*Phragmites sp*	42	1.86	18	3.30	55	2.28	38	2.20
4	*Alternanthera sp*	6	0.27	3	0.55	7	0.29	5	0.31
5	*Panicum sp*	36	1.59	21	3.85	38	1.58	32	1.82
6	*Polygonum sp*	3	0.13	2	0.37	4	0.17	3	0.17
7	*Hydrochloa sp*	21	0.93		0.00	25	1.04	23	1.32
8	*Scirpus sp*	56	2.47	-	-	-	-	56	3.22
9	*Juncus sp*	-	-	-	-	32	1.33	32	1.84
10	*Eleocharis sp*	17	0.75	9	1.65	19	0.79	15	0.86
11	*Carex sp*	-	-	-	-	17	0.71	17	0.98
12	*Hydrocotyle sp*	3	0.13	-	-	4	0.17	4	0.20
13	*Cyperus sp*	-	-	-	-	82	3.40	82	4.71
14	*Monochoria sp*	17	0.75	-	-	42	1.74	30	1.70
15	*Hygrophila sp*	12	0.53	-	-	7	0.29	10	0.55
16	*Colocasia sp*	11	0.49	5	0.92	9	0.37	8	0.48
17	*Centella sp*	2	0.09	-	-	4	0.17	3	0.17
18	*Commelina sp*	54	2.39	30	5.49	72	2.99	52	2.99
19	*Ipomoea sp*	37	1.63	27	4.95	61	2.53	42	2.39
20	*Sagittaria sp*	12	0.53	7	1.28	7	0.29	9	0.50
21	*Cynodon sp*	42	1.86	23	4.21	84	3.49	50	2.85
22	*Enhydra sp*	205	9.05	-	-	302	12.54	254	14.57
23	*Marsilea sp*	124	5.48	-	-	286	11.87	205	11.78
Total Emergent macrophytes		714	31.54	156	28.57	1184	49.15	685	39.35
Free Floating macrophytes									
24	*Salvinia sp*	54	2.39	-	-	26	1.08	40	2.30
25	*Lemna sp*	453	20.01	-	-	288	11.96	371	21.29
26	*Wolffia sp*	508	22.44	146	26.74	132	5.48	262	15.06
27	*Pistia sp*	126	5.57	41	7.51	72	2.99	80	4.58
28	*Eichhornia sp*	172	7.60	112	20.51	202	8.39	162	9.31
Total Free Floating macrophytes		1313	57.99	299	54.76	720	29.89	777	44.67
Rooted floating leaved									
29	*Trapa sp*	1	0.04	-	-	1	0.04	1	0.06
30	*Ludwigia sp, Jussiaea sp*	1	0.04	-	-	4	0.17	3	0.14
31	*Nymphoides sp*	-	-	18	3.30	42	1.74	30	1.72
32	*Nymphaea sp*	-	-	21	3.85	38	1.58	30	1.70
33	*Brasenia sp.*	32	1.41	12	2.20	45	1.87	30	1.70

Total Rooted floating leaved		34	1.50	51	9.34	130	5.40	72	4.12
Total Floating macrophytes		1347	59.50	350	64.10	850	35.28	849	48.79
Submerged macrophytes									
34	*Ceratophyllum sp*	23	1.02	-	-	35	1.45	29	1.67
35	*Vallisneria sp*	12	0.53	-	-	28	1.16	20	1.15
36	*Elodea sp*	-	-	-	-	18	0.75	18	1.03
37	*Cabomba sp*	-	-		0.00	40	1.66	40	2.30
38	*Hydrilla sp*	72	3.18	18	3.30	72	2.99	54	3.10
39	*Myriophyllum sp*	-	-	-	-	57	2.37	57	3.28
40	*Chara sp*	7	0.31	-	-	12	0.50	10	0.55
41	*Potamogeton sp*	-	-	7	1.28	12	0.50	10	0.55
42	*Ruppia sp*	3	0.13	-	-	5	0.21	4	0.23
43	*Najas sp*	68	3.00	14	2.56	66	2.74	49	2.84
44	*Ottelia sp*	1	0.04	1	0.18	2	0.08	1	0.08
45	*Aponogeton sp*	17	0.75	-	-	28	1.16	23	1.29
Total Submerged macrophytes		203	8.97	40	7.33	375	15.57	206	11.84
Whole macrophytes community		2264	100.00	546	100.00	2409	100.00	1740	100.00

PRM=Pre monsoon, MON=Monsoon, POM=Post monsoon

Table-3: Seasonal Variations in Macrophytes wet Biomass and coverage

MCROPHYTES	UNIT	PRM	MON	POM	Year mean	SD
Emergent	gm^{-2}	153.33	59.11	1412.67	541.70	±755.75
Free Floating	gm^{-2}	217.39	147.77	119.14	161.43	±50.53
Rooted Floating leaved	gm^{-2}	30.88	60.94	201.32	97.71	±90.98
Submerged	gm^{-2}	22.89	13.96	83.60	40.15	±37.89
Average wet weight	gm^{-2}	424.49	281.80	1816.72	841.00	±848.01
Average lake area coverage	%	42.11	38.95	69.34	50.13	±16.71

PRM=Pre monsoon, MON=Monsoon, POM=Post monsoon

Table- 4: Seasonal variation in Average Density values

Growth forms (no/m^2)	PRM	MON	POM	Year mean	SD
Emergent	36	8	59	34	±26
Free Floating	66	15	36	39	±25
Rooted Floating leaved	2	3	7	4	±3
Total Floating	67	18	43	42	±25
Submerged	10	2	19	10	±8
community as a whole	113	27	120	87	±52

PRM=Pre monsoon, MON=Monsoon, POM=Post monsoon

Table- 5: Seasonal variation in Genus Richness

Growth forms	PRM	MON	POM	Average	SD
Emergent	20	12	22	18	±5
Free Floating	5	3	5	4	±1
Rooted Floating leaved	3	3	5	4	±1
Submerged	8	4	12	8	±4
community as a whole	36	22	44	34	±11

PRM=Pre monsoon, MON=Monsoon, POM=Post monsoon

Table- 6: Seasonal variation in Evenness Index (E)

Growth forms	PRM	MON	POM	Average	SD
Emergent	0.79	0.88	0.76	0.81	±0.06
Free Floating	0.84	0.90	0.86	0.87	±0.03
Rooted Floating leaved	0.24	0.98	0.77	0.66	±0.38
Submerged	0.75	0.81	0.89	0.82	±0.07
community as a whole	0.74	0.79	0.83	0.79	±0.05

PRM=Pre monsoon, MON=Monsoon, POM=Post monsoon

Table- 7: Seasonal variation in Shannon-Wiener's index (H')

Growth forms	PRM	MON	POM	Average	SD
Emergent	2.37	2.19	2.35	2.30	±0.10
Free Floating	1.36	0.99	1.38	1.24	±0.22
Rooted Floating leaved	0.26	1.07	1.24	0.86	±0.52
Submerged	1.56	1.12	2.21	1.63	±0.55
community as a whole	2.64	2.45	3.14	2.74	±0.36

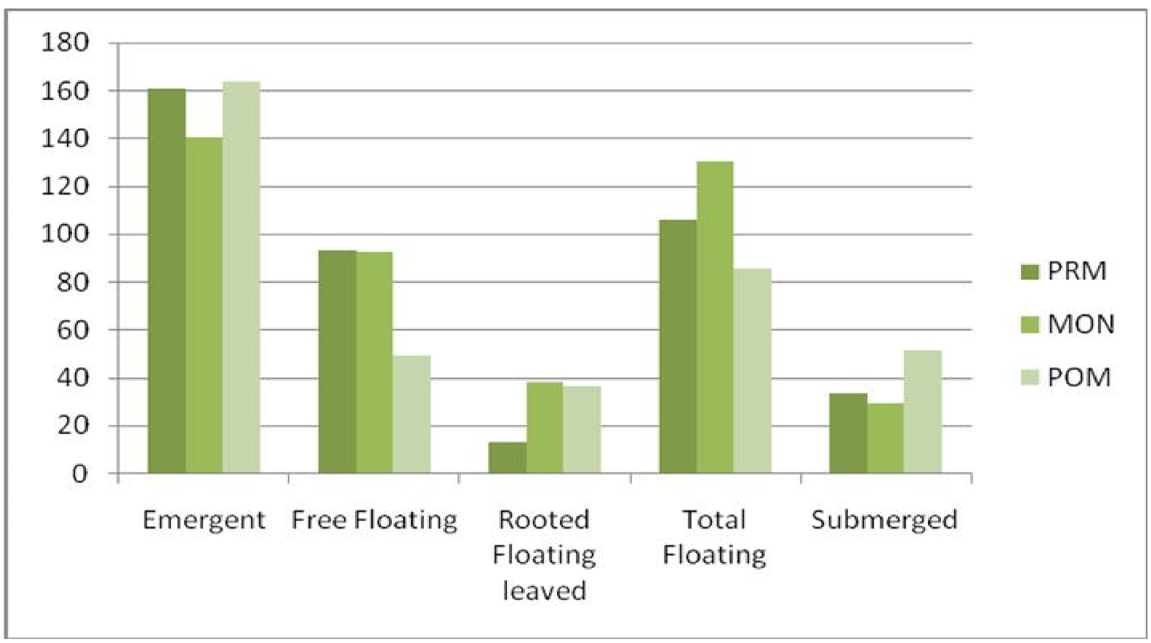
PRM=Pre monsoon, MON=Monsoon, POM=Post monsoon

Table- 8: Seasonal variation in Simpson index of Diversity (1-D)

Growth forms	PRM	MON	POM	Year Average	SD
Emergent	0.86	0.88	0.85	0.86	±0.02
Free Floating	0.70	0.60	0.72	0.67	±0.06
Rooted Floating leaved	0.12	0.66	0.69	0.49	±0.32
Submerged	0.74	0.66	0.88	0.76	±0.11
community as a whole	0.88	0.87	0.94	0.90	±0.04

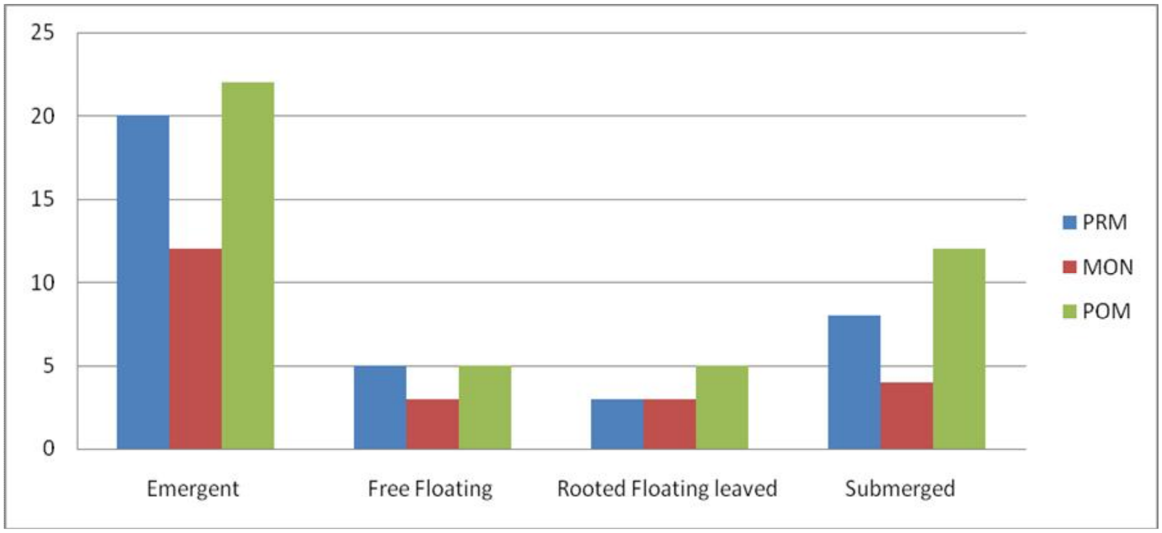
PRM=Pre monsoon, MON=Monsoon, POM=Post monsoon

Fig-1: Showing map of study area



PRM=Pre monsoon, MON=Monsoon, POM=Post monsoon

Fig-2: Seasonal variations in average Importance Value Index



PRM=Pre monsoon, MON=Monsoon, POM=Post monsoon

Fig-3: Seasonal variations in Occurrence of Number of macrophytes Genera