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Ecological Dynamics of Macrophytes in Lentic Water Bodies: A Case Study in Valsad, Gujarat, India

Harvi Patel[1], Susmita Sahoo[2]

[1*] *Department of Botany, Shrimad Rajchandra Vidyapeeth, Dharampur, Valsad, Gujarat, India* - 396051
[2] *Department of Biological and Environmental Sciences, Natubhai V. Patel College of Pure and Applied Sciences (NVPAS), Vallabh Vidyanagar, Anand, Gujarat, India* – 388120.

harviipatel2405@gmail.com

ABSTRACT

We examined the occurrence of macrophyte diversity and its distribution in the selected lakes of Valsad district, Gujarat, India. There were two main objectives, first examine the macrophyte species diversity in the selected lakes using the Shannon-Wiener diversity index, and the second one was to investigate the impact of environmental parameters on the macrophyte diversity. The canonical correspondence analysis (CCA) was utilized to better understand the relationship between macrophyte communities and environmental conditions. The results showed that from the 50 macrophyte species recorded, 30 species were emergent, 06 species were submerged and 14 species were floating and the overall Shannon-Wiener diversity (H') of water bodies ranged from 1.917 to 2.584. As per the Sorenson percentage similarity result, there was 80.3 % of an average similarity was present in macrophytes composition ($p = 0.0039$). The 14 (except phosphate and salinity) out of 16 selected physicochemical variables were statistically significant ($p < 0.05$) and mentioned in the CCA model, which revealed that macrophyte assemblage structure was strongly associated with Physicochemical parameters.

Keywords: aquatic macrophytes, biodiversity, CCA, physicochemical variables, Valsad

INTRODUCTION

The biodiversity of freshwater ecosystems is rapidly dwindling. The majority of the freshwater bodies are endangered, and many have already been degraded because of high population growth, urbanization, increased economic activities, and other developing activities **(CPCB, 2008).** The United Nations Conference on Environment and Development (UNCED) and global conservation organizations, including the RAMSAR convention, have identified wetland biodiversity to be the most threatened biodiversity, and the ecosystems are rapidly degraded across the world **(Davidson et al., 2018).** It is significant to conserve wetlands and their rich biodiversity to define their "*Critical environment capital*" because they are more productive than terrestrial crops (**Nuamah et al., 2020)**. Macrophytes are macroscopic and large aquatic plants that can be visible without the use of a microscope, they include angiosperm, pteridophytes, bryophytes, and a few macroalgae (large algae) **(May, 2007)** and act as a link between the sediment and water **(Bai et al., 2020).** Macrophytes play a crucial role in the aquatic ecosystem because they act as preliminary producer sources in the food chain of the aquatic ecosystem and maintain the proper equilibrium between abiotic and biotic components in the aquatic ecosystem **(Cronk & Fennessy, 2016).** Since the early 1900s, aquatic ecology experts have been interested in studying the distribution of aquatic plants. The distribution of the aquatic macrophyte is dependent on the climatic, edaphic, and hydric characteristics of the environment, and the number of ecological factors affect the associated macrophytes directly or indirectly. **(Rameshkumar et al., 2019)**. The macrophyte distribution with the relation of ecological factors in the lentic ecosystem has been studied in detail in India (e.g. **Odelu (2014); Sankhwal et al. (2015); Patel & Patel (2016); Panchal et al. (2017); Sharma & Singh (2017); Suthar et al. (2019); Charan et al. (2019)).** Water depth, substrate material, nutrient content, light conditions, etc. are elements that influence the establishment of macrophyte communities, furthermore, the presence of water contaminants in the lake ecosystem strongly influences the water physicochemical parameters and the development of macrophyte communities **(Saha et al., 2017).** The variety of macrophyte richness is connected to environmental conditions, which play a key role in macrophyte distribution patterns **(Sarkar et al., 2020)**. The main purpose of this research is to determine the contribution of the pond to the biodiversity of macrophytes in the selected region and the fluctuation of the macrophyte diversity due to the physicochemical parameters.

MATERIALS AND METHODS

Study area

Valsad is the southernmost district of Gujarat state, India, and is situated on the Arabian Sea's coast, the global position is located on 20º 35' 57.246" N and 72º 56' 3.282" E with an average altitude of 42 feet (13 meters) **(SAC, 2011).** The district covers a 3034 sq. km geographic area and a 23116 ha wetland area, which is 0.67 % of the total wetland area **(SAC, 2011).** Valsad has a tropical, wet, and dry climate with little to no rainfall from October to May month and strong to extremely high rainfall from July to September month, when it is directly influenced by the Arabian Sea branch of the South-West monsoon **(Lunagaria et al., 2015)**. The average temperature of this district ranged from 21 ℃ to 35 ℃.

Site selection

For the present investigation, preliminary work was started by visiting various lentic water bodies and lakes in Valsad district, Gujarat, India. Five distinct, natural and perennial standing water bodies were chosen based on pollution run-off entering into the lakes (Segvi Lake, Rakhodiya Lake, Atakpardi Lake, Pardi Lake, and, Gundlav Lake) for the investigation **(Fig:1).** Segvi Lake was designated a clean lake for this inquiry since it carried little or no effluents into the lake. Rakhodiya Lake is located in the middle of the city area and carries a huge volume of household sewage and agricultural run-off from the surrounding area. Atak Pardi Lake carried a large amount of ceramic effluents from nearby areas. Pardi Lake carries a significant amount of home waste and industrial run-off because this lake is situated near the GIDC (Gujarat Industrial Development Corporation) area. Gundlav Lake is located in Gundlav village near the industrial area and carries a huge amount of industrial effluents into the lake. Furthermore, because the selected lakes have several features, they may be easily differentiated using a few fundamental criteria **(Table: 1).**

Macrophyte sampling

The selected lakes of the district were surveyed and sampled, in January 2019. Macrophyte species were collected through quadrate (50 × 50 m^2) using the **Devi (1998)** method. Floras, Gujarat flora **(Shah, 1978),** and Bombay flora **(Cook, 1908)** were examined to establish the identification of the species for their nomenclature and classified based on their growth forms prescribed by **Sculthorpe (1967).** The vegetational data of the macrophytes were quantitatively analyzed for frequency **(Ambasht, 1970)** (Value expressed in terms of a macrophyte per square meter by multiplying an appropriate value.)

Water samples and laboratory procedures

Surface water samples (from the 10 cm surface layer to a depth of over 30 cm) were taken at random from various locations of the lakes in all directions. Following the collection of composite water samples, the collected water was filtered through a 0.45 m pore-size filter and stored in acid-washed plastic bottles with the appropriate precautions. Temperature, dissolved oxygen (DO), total dissolved solids (TDS), conductivity, salinity, and pH were determined on the spot, and the remaining parameter samples were brought to the laboratory as soon as feasible for further analysis using the standard methods recommended by **Trivedy et al. (1987); APHA (2005); Maiti (2011).**

Statistical analysis

We changed the ordinal scale data into ratio-scale data using the mean values before performing any statistical analysis **(Engloner, 2012).** To assess the contribution of the lakes for species diversity, we performed the Shannon-Wiener diversity index, based on species abundance data. The relationship between macrophyte diversity and environmental variables was analyzed using the Kruskal–Wallis Chi-Square test **(Sreekumar et al., 2020),** which was performed using the PAST 4.03 software. Based on macrophyte abundance data and analysis of similarities, ANOSIM has been used to examine the degree of similarity between lakes. Sorenson percentage similarity calculated ANOSIM. To analyze the correlations between species and observed environmental factors, we employed CCA, which shows the correspondence (~influence) of main environmental factors **(Xu et al., 2016).** In this method, the two data sets' relationships may be directly compared. PAST 4.03 software was used to calculate CCA. The analysis was significant overall at $p < 0.05$ (permutation test for CCA) **(Kar et al., 2018).**

RESULTS

Macrophyte diversity

A total of 50 macrophytes were found in five selected lakes of the Valsad district. These macrophytes were classified into three categories, submerged, floating, and emergent, based on their growth forms **(Sculthorpe, 1967)**. Of the total species, 30 species were emergent, 06 species were submerged and 14 species were floating. The lowest submerged species was found at Segvi Lake. Atak pardi lake represents the lowest floating species and highest submerged species. The lowest emergent species was found at Atak pardi lake and Gundlav Lake, besides the highest emergent taxa was found at Segvi lake and Rakhodiya lake **(fig: 2a).** The pattern present in the taxa and Shannon-Wiener diversity was different between macrophyte categories in water bodies. The computation of the Shannon-Weiner diversity index (H') of present macrophytes revealed that during the study period. The high H' was recorded at Pardi Lake (2.547), and Segvi lake (2.522), as compared to 2.236 at Atak pardi lake and 2.206 at Rakhodiya lake, while the lowest H' was recorded at Gundlav lake (1.966) during the study period. Within macrophyte categories, the average H' exhibited comparable values. Emergent species showed high diversity index values within water bodies and submerged species showed low diversity index. H' of submerged species ranged from 0.501 to 1.259; ranged from 0.8839 to 1.816 for floating species and 2.289 to 2.683 found for emergent species. The overall Shannon-Wiener diversity of water bodies ranged from 1.917 to 2.584 **(fig: 2b).** ANOSIM testing similarity (Sorenson percentage similarity) among the examined macrophyte community gave high statistical data (cophen. Corr = 0.81, p = 0.0039), there was 80.3 % of an average similarity was present in macrophytes composition. The ANOSIM results showed significant differences between the species located at selected water bodies, where the lakes of Segvi and Gundlav were highly dissimilar (64.2 %) and the other hand Rakhodiya lake and Gundlav lake were highly similar (89.2 %) at selected water bodies. The Sorenson percentage similarity analysis results clearly illustrated the variations between the selected water bodies

(Fig:3). From the quantitative results, *Pistia stratiotes* L. showed the highest frequency with 55 %, followed by *Hydrilla verticillata* (L. f.) Royle, *Salvinia natans* L. and *Spirodela polyrhiza* (L.) Schleid. (45 %) at Segvi lake. *Eichhornia crassipes* (Mart.) Solms. (60 %), *Azolla pinnata* R. Br. (55 %) and *Ceratophyllum demersum* L. (55 %) showed the highest frequency at Rakhodiya Lake, *Ceratophyllum demersum* L., *Hydrilla verticillata* (L. f.) Royle and *Lemna trisulca* L. showed the highest (45 %) frequency at Atak pardi lake. *Ceratophyllum demersum* L. showed the highest frequency with 50 %, followed by *Hydrilla verticillata* (L. f.) Royle, *Lemna trisulca* L., and *Chara* (45 %) at Pardi Lake, furthermore *Lemna minor* L. and *Spirodela polyrhiza* (L.) Schleid. showed the highest (45 %) frequency at Gundlav Lake **(Table: 2)**

Species–environment relationships

Physicochemical parameters are regarded as one of the most important elements capable of altering the aquatic environment, with significant temporal and geographical variations. The Kruskal-Wallis Chi-Square test was used to analyze the relationship between macrophytes and environmental factors, and the findings were given, with p-values less than 0.05 indicating that there was a substantial relationship present, except for the phosphate (p = 0.840) and salinity (p = 0.29) **(Table: 3).** Rakhodiya lake represents the high turbidity (7.2 ± 2.39 NTU), COD (chemical oxygen demand) (114.6 ± 41.94 mg/L), BOD (biological oxygen demand) (12.5 ± 2.48 mg/L), TDS (total dissolved solids) (769.3± 276.17 mg/L), EC (electric conductivity) (514.9 ± 137.40 ms/cm), salinity (1.1 ± 0.35 ppt), Free CO_2 (37.4 ± 5.54 mg/L), and total hardness (278 ± 96.50 mg/L) furthermore, low DO (dissolved oxygen) (6.8 ± 0.52 mg/L) and potassium (5 ± 4.32 mg/L). Segvi Lake represents the low COD (27.5 ± 37.56 mg/L), and BOD (3.6 ± 3.97 mg/L). Atak pardi lake represent the low pH (7.1 ± 0.11), alkalinity (107 ± 17.13 mg/L), TDS (273.1 ± 220.94 mg/L), EC (378.9 ± 138.90 ms/cm), salinity (0.3 ± 0.20 ppt), Free CO_2 (21.1 ± 5.37 mg/L), total hardness (103 ± 39.32 mg/L), and sodium (14 ± 4.44 mg/L), and also represent the high DO (7.9 ± 0.19 mg/L), nitrate (8.3 ± 0.58 mg/L) and phosphate (0.5 ± 0.04 mg/L). Pardi lake represents the low turbidity (2.5 ± 1.07 NTU) and Gundlav lake represents the high pH (7.9 ± 0.34), alkalinity (289 ± 19.34 mg/L), sodium (43 ± 9.7 mg/L) and potassium (14 ± 1.9 mg/L) with low concentration of nitrate (6.3 ± 1.08 mg/L) and phosphate (0.01 ± 0.04 mg/L)

(Table: 3). The CCA analyses showed the differences between macrophyte diversity and environmental parameters of selected lakes. Based on the macrophyte community, selected lakes were highly overlapping with each other, with a low differentiation of Rakhodiya lake and Pardi Lake along axis 2 and with a high differentiation of Pardi Lake and Segvi lake along axis 2 **(Fig: 4a).** Species communities were similar across all selected lakes. Only a few species appeared in a specific lake. The results of the quantitative data suggested macroalgae *Chara*, angiosperm macrophyte species *Hydrolea zeylanica* (L.) Vahl, *Limnophyton obtusifolium* (L.) Miq, *Nymphoides indicum* (L.) O. Ktze. and *Sagittaria sagittifolia* L. represent only Pardi Lake. *Coldenia procumbens* L. and *Utricularia aurea Lour.* appeared only in Gundlav Lake and Atak Pardi Lake, respectively. *Cyperus difformis* L., *Saccharum spontaneum* L., and *Salvinia natans* L. appeared only in Segvi Lake. The emergent species were spread over the CCA plot but most of the species were observed in the center of the CCA plot whereas most of the submerged species and floating species were observed in the lower part and upper part of the CCA plot, respectively. *Chara* was highly present at Pardi Lake observed lower side in the CCA plot **(Fig: 4a)**. The environment parameters and species diversity had a strong correlation with each other represented in **Figure 4b**. For water physicochemical parameters, the eigenvalues were 0.01976 and 7.47E-06 for axis 1 and axis 2, respectively. Atak Pardi Lake and Rakhodiya Lake represent the shallow depth (4 to 5 m) and Pardi Lake represents the higher depth (7 to 8 m) in the selected water bodies.

DISCUSSION

Macrophyte diversity of selected lakes

This study provided information about the regional macrophyte diversity and their relation with water parameters (physicochemical parameters) in the selected lentic water bodies of the Valsad district, Gujarat, India. Emergent macrophytes are the most common kind of aquatic vegetation (**Kassa et al., 2021)**, out-competing other types due to their capacity to catch sunlight before it reaches the water's surface **(Gebrehiwot et al., 2017),** due to these reasons emergent macrophytes are high, but the submerged and floating species was found to be low, which may be explained by the intermediate - low nutrition condition and because of the amount of urban pollutant present at the lentic water bodies **(Odelu, 2014; Sharma & Singh, 2017).** Shannon-Wiener diversity index indicated huge differences between the floating, submerged, and emergent categories in the lakes. We found the overall H' of water bodies ranged from 1.917 to 2.584. This investigation is similar to those done in other regions of Asia, by **Sarma and Upen, (2014)** (2.70 - 1.77), India; **Sarmah and Debojit (2015)** (2.51- 3.21) in River Subansiri wetland, Assam, India. Based on the macrophyte community, the Shannon-Wiener diversity index indicates the ecological state of water bodies, here we found a high Shannon-Wiener diversity index in Pardi lake and Segvi lake, which means the more diverse species are present in this habitat, which occurred because compared to other water bodies, these lakes carried the less amount of household sewages and industrial pollutant, also this lake covered the large area which also help to dilute the pollutant, similar result was obtained by **Luzuriaga et al., (2005)** and **Conessa et al., (2007).** We also found a high abundance of *Eichhornia crassipes* (Mart.) Solms., *Lemna trisulca* L., and *Wolffia arrhiza* (L.) Wimmer at Rakhodiya Lake due to the high anthropogenic activities. **Schmera and Baur (2011)** support the result we found.

Environmental variables explaining aquatic macrophyte species distribution

The physical parameters of lakes, as well as nutrient concentrations and meteorological circumstances, are reflected in macrophyte communities **(Lougheed et al., 2001; Lukács et al., 2009).** Various environmental factors drive floating, submerged, and emergent macrophyte communities, according to CCA studies of different macrophytes **(Decatanzaro et al., 2009). Figure 4b** shows the statistical variations of the water parameters for the selected lakes. Water temperature is one of the controlling variables that affect the growth and distribution of aquatic flora, which influences species composition and varies with depth **(Jalal & Sanalkumar 2013; Tank & Chippa, 2013).** Due to the high industrial effluents entering the Gundlav lake, the water pH was acidic, which is a critical property of any aquatic ecosystem since all biochemical functions and the retention of physicochemical properties of the water are heavily reliant on it **(Jalal & Sanalkumar 2013).** Here we found less diversity of macrophytes because, at a certain level, greater pH levels can affect aquatic life **(Tank & Chippa, 2013; Verma et al., 2012).** The key physical elements that are directly linked to biodiversity are salinity and electrical conductivity, which function as a limiting factor and limit aquatic species distribution **(Bala & Mukherjee, 2010; Sridhar et al., 2006).** High water conductivity and salinity were caused by the extremely high concentration of sodium bicarbonate present at Rakhodiya Lake from the drainage, which decreased the macrophyte diversity in the lake **(Bala & Mukherjee, 2010; Sridhar et al., 2006).** The components dissolved in water, such as bicarbonate, calcium, magnesium, nitrate, organic ions, phosphate, sodium, and sulphate is known as total dissolved solids, Rakhodiya lake contains high TDS and total hardness, due to urbanization, agricultural fertilizer waste, and household effluents **(Bala & Mukherjee, 2010)**. The volume of oxygen present in a water body is referred to as dissolved oxygen, which influences ecosystem health. By aerial diffusion and as a photosynthetic by-product of macrophytes, oxygen enters in to the water. The degree of contamination in water bodies is indicated by the DO level **(Kotadiya Nikesh, 2014).** DO and BOD are negatively correlated with each other, in our results we found the high BOD and low DO at Rakhodiya Lake due to the excess anthropogenic activity present, which ultimately caused stress for macrophyte species and decreased the diversity. The **BIS, (2012)** recommends a DO of at least 5 mg/l. However, in this study, the dissolved oxygen level was found to be higher than the acceptable level, posing a threat to these wetland ecosystems. Turbidity is caused by phytoplankton, tiny creatures, mud, and other organic substances in a lake, due to the high anthropogenic activities present at Rakhodiya lake the sample water was more turbid **(Bala & Mukherjee, 2010)**, also observed that submerged macrophytes could disappear by high water turbidity present at Rakhodiya lake because of light limitation, results supported by **Ibelings et al. (2007).** The concentration of distribution, diversity, density and productivity of macrophytes are all decreased by eutrophication, due to the high nitrate and phosphate level, similar result was found at Atak pardi lake **(Bala & Mukherjee, 2010)**. The Lake form, as well as lake depth, was also responsible for the poor species diversity in the aquatic ecosystem. In present study, environmental conditions can only be tolerated by a few species such as *Colocasia esculenta* (L.) Schott, *Lemna minor* L., *Spirodela polyrhiza* (L.) Schleid., and *Wolffia arrhizal* L. Wimmer **(Khan et al., 2014).** *Eichhornia crassipes* (Mart.) a highly tolerant macrophyte for polluted wastewater, was the prevalent species observed as floating mats at Rakhodiya lake **(Ting et al., 2018).** Some macrophytes had a limited area of distribution and were specialised to particular water conditions (e.g., species mentioned above). These species were found in the CCA figures' corners and were considered "severe" circumstances (e.g., high salinity, high DO etc.). The majority of macrophytes, were ubiquitous, were found in the centre of CCA figures, and had no special environmental requirements **(Fig: 4a).**

CONCLUSION

The current study contributes to the understanding of aquatic macrophyte diversity and distribution, and its relationship to environmental habitat parameters in the Valsad district of Gujarat, India. Lakes are key aspects of the environment in heavily human-modified areas, such as the Valsad district. Our findings backed up the present study's basic hypothesis on how environmental variables impact macrophyte diversity in lakes using the CCA. The overall variation in biological response variables for a given set of explanatory factors revealed that physicochemical features had a stronger influence on aquatic macrophyte diversity ($p < 0.05$). The research concludes the ecological state of the studied wetland water bodies, as affected by anthropogenic activities, where the maximum environmental parameters were high in Rakhodiya Lake as this site was more polluted than other sites, which creates ecosystem degradation, and biodiversity losses. The study also recommended that to protect macrophytes and the health of aquatic ecosystems, it is essential to address and mitigate pollution sources. Conservation efforts should also focus on restoring and maintaining the health of water bodies to support macrophyte populations and the diverse ecosystems they are a part of.

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Tables & Figures

Table 1: Overview of selected lakes

Code	Lake name	Coordinates	Coverage (perimeter)	Water depth (in meters)	Altitude (in meters)	Pollutant present
SL (Site-1)	Segvi Lake	20º 35' 20.4" N 72º 54' 46.0" E	650.04 m	6 – 7	11 - 12	little or no effluents
RL (Site-2)	Rakhodiya Lake	20º 36' 53.4" N 72º 55' 21.4" E	555.19 m	4 – 5	13 - 14	household sewage & agricultural run-offs
AL (Site-3)	Atakpardi Lake	20º 35' 20.9" N 72º 57' 24.4" E	714.19 m	4 – 5	14 - 15	ceramic effluents
PL (Site-4)	Pardi Lake	20º 30' 35.7" N 72º 57' 11.9" E	2298.25 m	7 – 8	25 - 26	household sewage & industrial run-off
GL (Site-5)	Gundlav Lake	20º 37' 16.8" N 72º 57' 45.3" E	636.35 m	5 – 6	16 - 17	industrial effluents
*In the cell of the table minimum and maximum values are shown						

Table 2: Recorded species, code number, percentage frequency, and macrophyte category in selected water bodies.

		S - 1	S - 2	S - 3	S - 4	S - 5	
NAME	**Code**	**Frequency**					**Categories**
Alternanthera sessilis (L.) Dc.	*A_se*	20	25	25	25	10	emergent
Ammania baccifera L.	*A_ba*		20	15	25		emergent
Ammania multiflora Roxb.	*A_mu*	15	10		15	10	emergent
Azolla pinnata R. Br.	*A_pi*	35	55		30		floating
Bacopa monnieri (L.) Pennell	*B_mo*	20			10		emergent
Bergia ammanniodes Roxb.	*B_am*	20	30	20	5	10	emergent
Ceratophyllum demersum L.	*C_de*	25	55	45	50	30	submerged
Chara sp.	*Cha*				45		submerged
Coldenia procumbens L.	*C_pr*					15	emergent
Colocasia esculenta (L.) Schott	*C_es*		10		30		emergent
Commelina benghalensis L.	*C_be*	25	30	20	25	15	emergent

Commelina diffusa Burm. f.	*C_di*	25	20	10	20	25	emergent
Cyperus alopecuroides Rottb.	*C_al*		15		20	15	emergent
Cyperus articulatus L.	*C_ar*	15	15	20	25	20	emergent
Cyperus compressus L.	*C_co*	20		10			emergent
Cyperus difformis L.	*C_dif*	15					emergent
Cyperus iria L. var. *iria*	*C_ir*	20	10	10	20	10	emergent
Eclipta prostrata (L.) L.	*E_pr*		10	25			emergent
Eichhornia crassipes (Mart.)	*E_cr*		60		35	30	floating
Eragrostis tenella L.	*E_te*	20	20	5			emergent
Grangea maderaspatana (L.) Poir.	*G_ma*	20		10	20		emergent
Heliotropium indicum L.	*H_in*	10	20			10	emergent
Heliotropium ovalifolium Forsk.	*H_ov*	10	10			5	emergent
Heliotropium supinum L.	*H_su*		10			15	emergent
Hydrilla verticillata (L. f.) Royle	*H_ve*	45	45	45	45	40	submerged
Hydrolea zeylanica (L.) Vahl	*H_ze*				10		emergent
Ipomoea aquatica Forsk.	*I_aq*	25	40	30	25	30	floating
Ipomoea fistulosa Mart. ex Choisy	*I_fi*		30	30	5	10	emergent
Leersia hexandra Sw.	*L_he*	10	40	10	10	10	emergent
Lemna minor L.	*L_mi*	30	50		35	45	floating
Lemna trisulca L.	*L_tr*	30	50	45	45	25	floating
Limnophyton obtusifolium (L.)	*L_ob*				35		floating
Ludwigia hyssopifolia L.	*L_hy*		30		20	20	floating
Marselia quadrifolia L.	*M_qu*	20			30		emergent
Nelumbo nucifera Gaertn.	*N_nu*	20		20	10		floating
Nephrolepis exaltata L.	*N_ex*			30		10	emergent
Nymphaea nouchali Willd	*N_no*	20		20	15		floating
Nymphoides indicum (L.) O. Ktze.	*N_in*				15		floating
Oldenlandia corymbosa L.	*O_co*	5	15	20	25	10	emergent
Pistia stratiotes L.	*P_st*	55			20		floating
Polygonum glabrum L.	*P_gl*	25	20	15	20	15	emergent
Pteris vittata L.	*P_vi*			30		20	emergent
Saccharum spontaneum L.	*S_sp*	15					emergent
Sagittaria sagittifolia L.	*S_sa*				25		floating
Salvinia natans L.	*S_na*	45					floating
Spirodela polyrhiza (L.) Schleid.	*S_po*	45	50	40	30	45	floating

Typha angustata Bory & Chaub.	*T_an*	10	25		10		emergent
Utricularia aurea Lour.	*U_au*			15			submerged
Vallisneria spiralis L.	*V_sp*	20	40	30	35	40	submerged
Wolffia arrhiza (L.) Wimmer	*W_ar*		45	25		40	submerged

Table 3: Mean values and standard deviation (±d) of water physicochemical parameters and Kruskal – Wallis test with species.

Physico Chemical Parameters	Site 1	Site 2	Site 3	Site 4	Site 5	Kruskal–Wallis Chi-Square	*P* - value
Turbidity	3.6 ± 2.00	7.2 ± 2.39	3.1 ± 2.46	2.5 ± 1.07	6.3 ± 1.09	15.65	0.011
Temperature	28.0 ± 2.96	32.0 ± 2.19	29 ± 1.67	30 ± 1.14	24.0 ± 1.19	20.27	0.002
pH	7.3 ± 0.33	7.8 ± 0.48	7.1 ± 0.11	7.5 ± 0.23	7.9 ± 0.34	19.94	0
DO	7.4 ± 0.45	6.8 ± 0.52	7.9 ± 0.19	7.5 ± 0.28	6.9 ± 0.43	20.27	0
Alkalinity	134.0 ± 89.20	287 ± 39.39	107 ± 17.13	139 ± 18.48	289 ± 19.34	14.53	0.033
COD	27.5 ± 37.56	114.6 ± 41.94	28.9 ± 24.20	32.4 ± 4.87	34.5 ± 4.6	13.61	0.047
BOD	3.6 ± 3.97	12.5 ± 2.48	3.7 ± 2.45	5.4 ± 1.01	9.8 ± 1.13	15.42	0.002
TDS	317.2 ± 230.91	769.3 ± 276.17	273.1 ± 220.94	378.3 ± 118.13	663.7 ± 130.11	15.57	0.046
EC	417.3 ± 51.82	514.9 ± 137.40	378.9 ± 138.90	405.6 ± 97.15	414.6 ± 148.40	19.45	0.015
Salinity	0.6 ± 0.31	1.1 ± 0.35	0.3 ± 0.20	0.4 ± 0.24	0.7 ± 0.21	9.35	0.29
Free CO_2	24.2 ± 7.32	37.4 ± 5.54	21.1 ± 5.37	22.9 ± 2.76	34.2± 1.76	17.31	0.038
Total Hardness	182 ± 71.78	278 ± 96.50	103 ± 39.32	107 ± 19.76	146 ± 13.26	17.89	0.006
Sodium	20.0 ± 11.90	15 ± 14.32	14 ± 4.44	27 ± 9.09	43 ± 9.7	16.8	0.045
Potassium	6.0 ± 3.56	5 ± 4.32	7 ± 1.14	9 ± 3.67	14 ± 1.9	17.07	0.001
Nitrate	6.4 ± 0.88	7.1 ± 1.14	8.3 ± 0.58	7.9 ± 0.97	6.3 ± 1.08	19.72	0.001

Phosphate	0.06 ± 0.21	0.25 ± 0.09	0.5 ± 0.04	0.4 ± 0.14	0.01 ± 0.04	2.49	0.84

*Different letters in a row have statistical significance at a 0.05 level

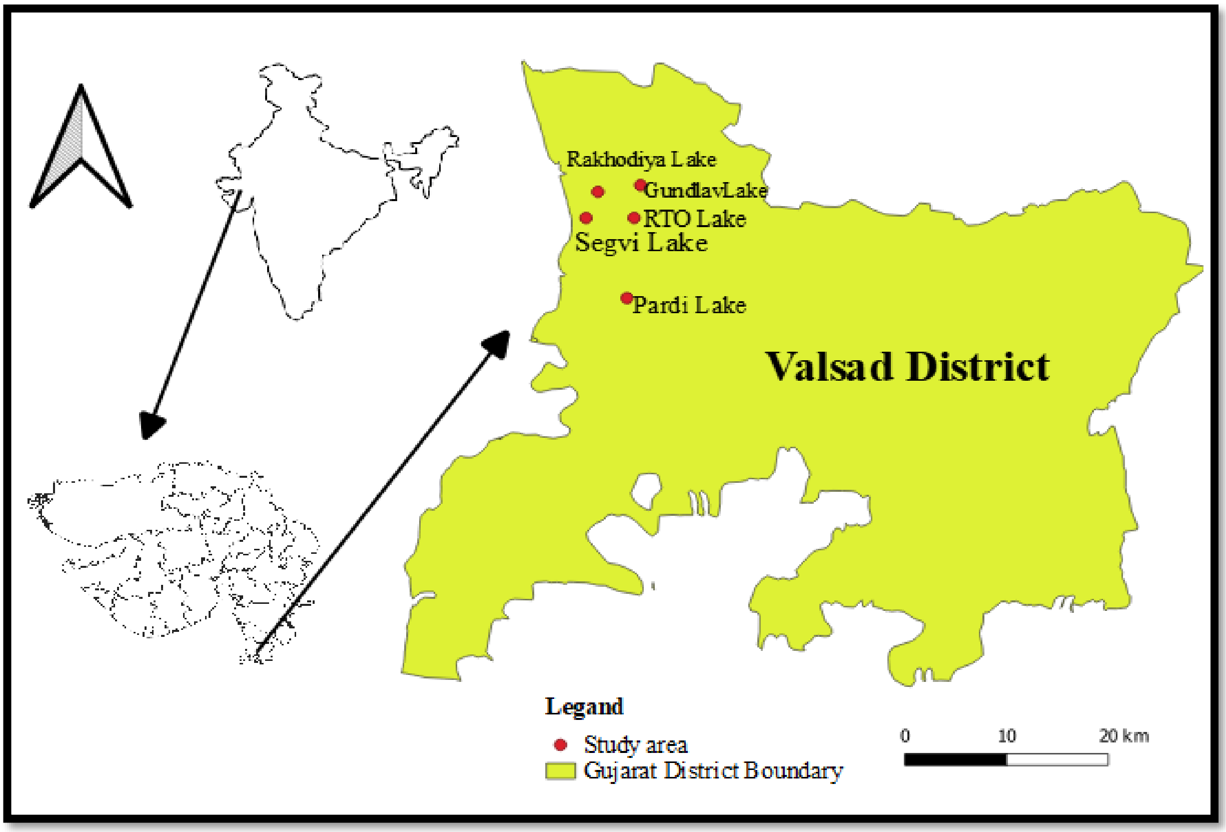
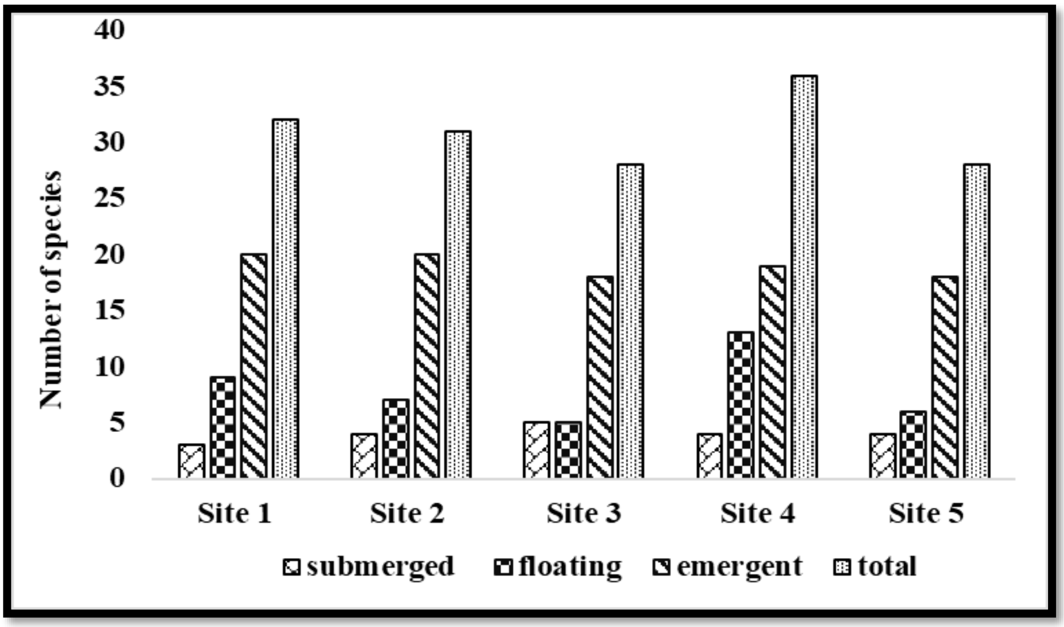


Figure 1: GIS map of selected study sites at Valsad district, Gujarat, India



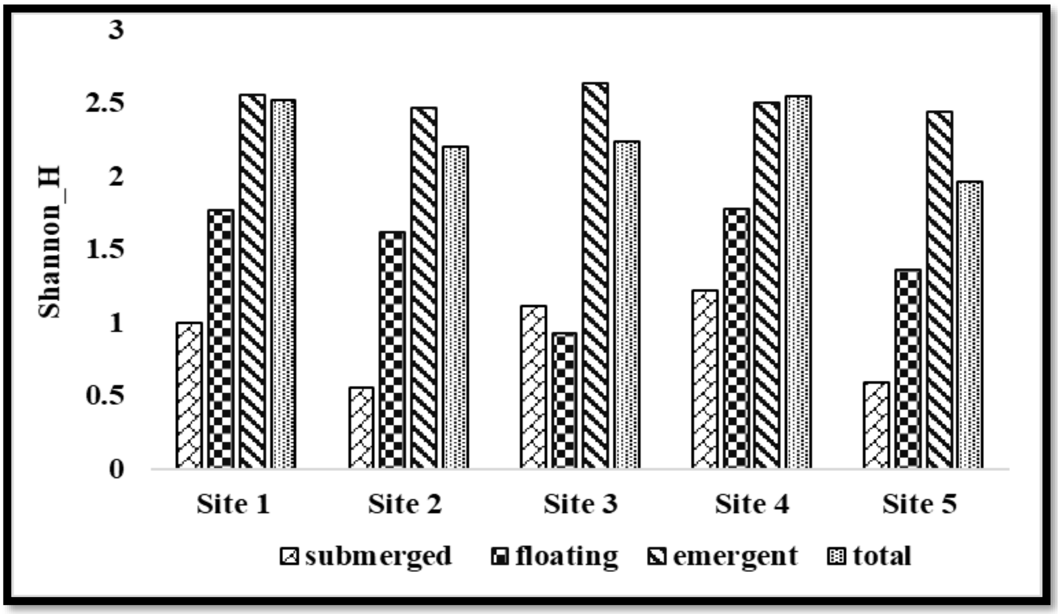


Figure 2: (a) Number of species; (b) Shannon-Wiener diversity index of species at selected water bodies (submerged, floating, emergent, and total species level)

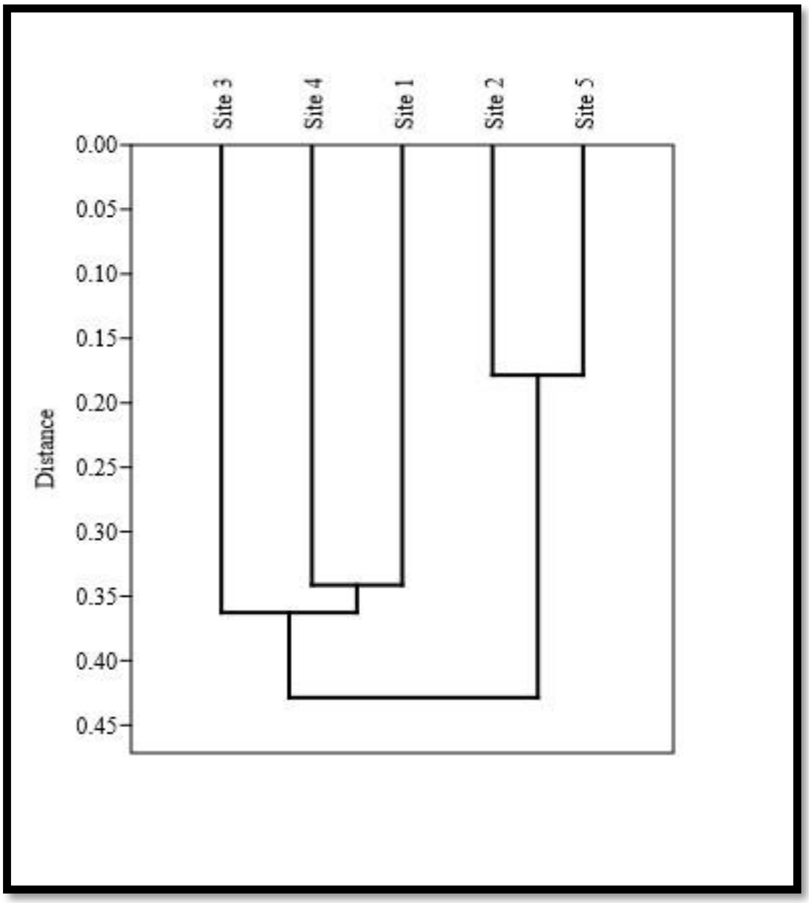
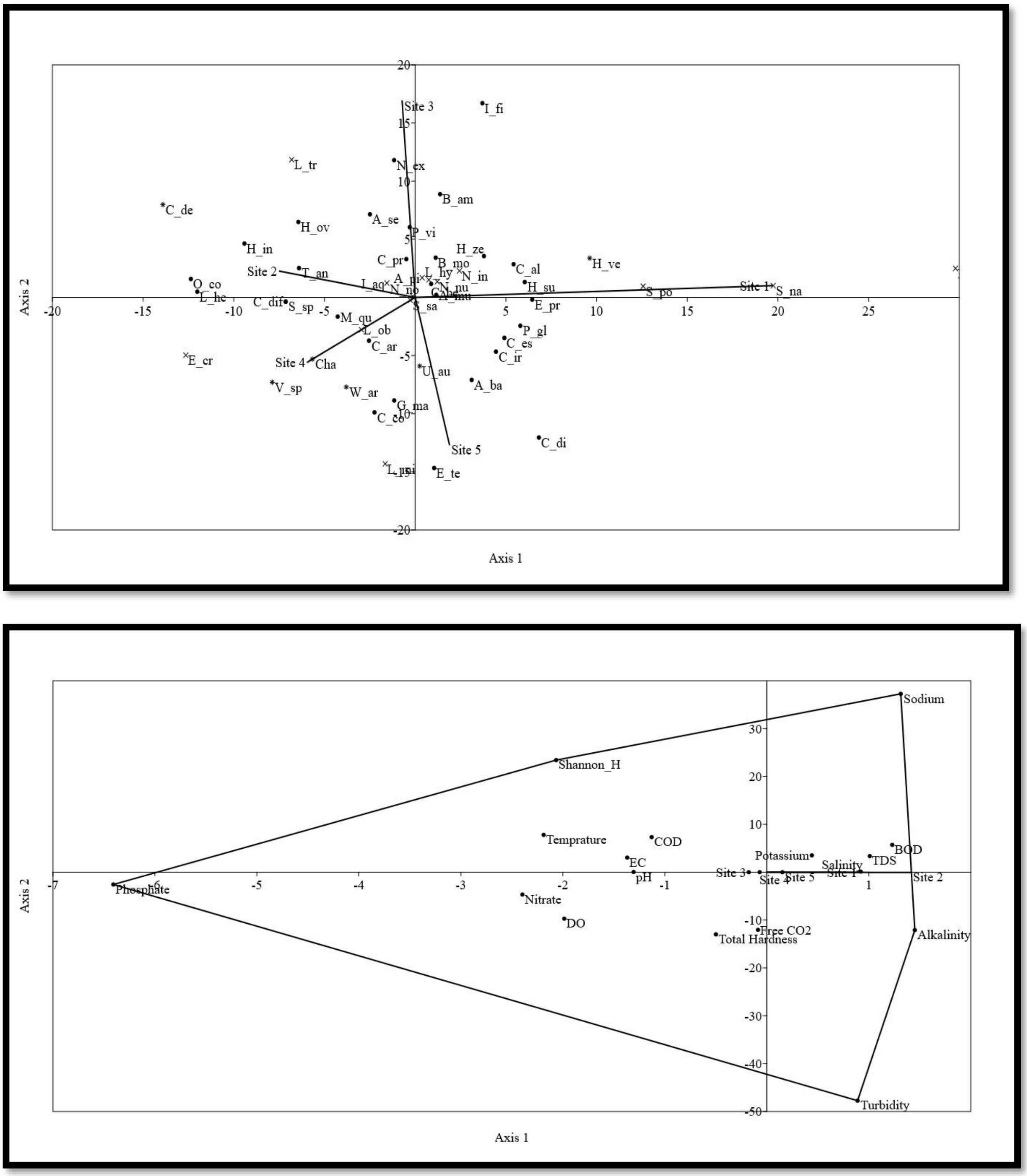


Figure 3: Sorenson percentage similarity of selected water bodies

Figure 4:



Canonical correspondence analysis plot (a) the frequency of 50 recorded species, Natation: submersed (*), floating (×) and emergent (•); (b) the physicochemical parameters in the selected lakes of Valsad district, Gujarat.