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IMPACT OF SEASONAL CHANGES IN FRESHWATER PHYTOPLANKTON AND ZOOPLANKTON BIODIVERSITY AT VALANKULAM LAKE, COIMBATORE DISTRICT, TAMIL NADU, INDIA

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ABSTRACT. The plankton communities are important source of food for the aquatic organisms, and if any undesirable changes in aquatic environment may affect plankton diversity and density. Therefore, assessment of planktonic communities in the freshwater ecosystems is essential because they serve as bio-indicators of water quality parameters. Hence, the present research was focused to evaluate the freshwater phytoplankton and zooplankton diversity and their abundance in Valankulam Lake (Lat. 10.59° N and Long. 76.57° E), at Coimbatore city, Tamil Nadu, India. Results from the study revealed that a total of 77 species of phytoplankton and zooplankton were recorded, under 37 families and 46 genera. In addition to that, a total of 43 phytoplankton species were recorded under 25 families and 30 genera, (which includes; 15 species of Cyanophyceae, 17 species of Chlorophyceae, 08 species of Bacillariophyceae, 03 species of Euglenophyceae). and a total of 34 species of zooplankton were recorded under 12 families and 17 genera, (which includes 13 species of Rotifera, 09 species of Cladocera, 08 species of Copepoda and 04 species of Ostracoda). The maximum plankton diversity was observed during the monsoon season and the minimum in the summer season. Results from study revealed the ecological status of the lake is categorized as moderately polluted due to the presence of municipal waste and industrial discharges into the lake water. Therefore, the assessment of planktonic communities in water bodies will be useful to monitor and maintain the water quality parameters and wealth of aquatic biota in the aquatic ecosystem.

Keywords: plankton; species composition; community structure; water quality.

INTRODUCTION

Water is a prime abiotic factor that supports life and major components in the natural environment. Any undesirable changes in the hydrographical profile can influence the life of aquatic biota, where different species of flora and fauna can show great variations in environmental ecosystem (Dey *et al.*, 2021; Pinheiro *et al.*, 2021). The aquatic ecosystems can be divided into types namely, freshwater and marine water ecosystems. The total availability of freshwater on the earth is hardly gently 0.3 to 0.5 % and they are very essential to aquatic biota and to the human beings (Maltby *et al.*, 2011). The rivers, lakes, ponds, pools, estuaries, streams, and wetlands considered to be a part of freshwater ecosystems. Freshwater bodies provide valuable ecosystem services, such as drinking, irrigation purposes, and also they provide support to the production recreation to aesthetics (Alan Yeakley *et al.*, 2016). The continuous monitoring of freshwater bodies is essential, to maintain the health and wealth of aquatic organisms. Nowadays aquatic stress is increasing due to various anthropogenic activities like the dumping of municipal waste, mixing of veterinary antibiotics, the release of sewage sludge, and industrial effluents into freshwater bodies. Moreover, deteriorate surface water can also impair the basic use freshwater bodies and they may cause pollution by releasing toxic substances into surface water which significantly affect the water quality (Li *et al.*, 2019; Onyemesili *et al.*, 2022).

The pollutant may be derivative from the point or non-point sources into the water bodies. Point source of pollution can be identified as originating from only one location in their environments such as the release of industrial effluents, spillage, urban sewage treatment plants and municipal waste (Beckers *et al.*, 2018; Anju *et al.*, 2010). Non-point source of pollution can be identified as originating from different locations in the environment and they are generally afforded from more diffuse sources like urban storm runoff, agriculture waste, eutrophication, and, etc., (Xue *et al.*, 2019). These types of pollution (Point and Non-Point) will release substances that can alter the inherent hydrographical profile and biological properties in aquatic ecosystems (Ossai *et al.*, 2020; Nilsson and Renöfält, 2008). Therefore, continuous monitoring of water quality is essential for controlling surface water pollution in aquatic ecosystems. In addition, plankton density and diversity are used to assess the status of aquatic pollution in the past few decades, because they are highly sensitive to small changes in the aquatic environment and have short life spans (Ghosh and Biswas, 2015). Hence, plankton diversity and density are considered to be important ecological parameters. The composition of each and every species will be represented morphologically as well as taxonomically different. A strong relationship exists between phytoplankton and zooplankton species, and these both are mainly filter feeders, and raptorial predators in aquatic ecosystems (Gołdyn and Kowalczewska-Madura, 2008).

Phytoplankton species will respond quickly to environmental changes and are very good bio-indicators of water quality at any type of water body in aquatic ecosystems and they used in the understanding pattern of lentic water bodies (Qureshi and Dube, 2022; Yusuf, 2020; Gökçe, 2016; Mohan and Priyadarshinee, 2023). The diversity, density, appearance, disappearance, and distribution pattern depend upon the biotic factors in aquatic ecosystems.

The basic trophic level of phytoplankton is followed by the next level of zooplankton (Frederiksen *et al.*, 2006). The population density of zooplankton species is mainly influenced by the hydrographical characteristics of lake water. They play important role in the bio-monitoring process to assess the status of pollution in water bodies, especially Rotifer species are used as a bio-monitoring agent in all aquatic ecosystems (Xiong *et al.*, 2020; Panikkar *et al.*, 2022). In the past few decades, the bio-monitoring program has become an essential part, because water bodies are facing tremendous pollution due to various anthropogenic activities in their surrounding environment.

Therefore, assessment of plankton diversity and density in aquatic ecosystems is essential for the aquatic organisms. Hence, the present study was focused to evaluate the seasonal impact of seasonal in freshwater phytoplankton and zooplankton at Valankulam Lake, Coimbatore city, Tamil Nadu, India. In addition, Valankulam Lake has provided a habitat for various flora and fauna.

MATERIALS AND METHODS

Description of the Study Area

The Valankulam Lake located in Coimbatore city, Tamil Nadu, India, (Lat. 10.59° N and Long. 76.57° E) is fed by canals derived from Noyyal River.

The Valankulam Lake located upstream in the north (*Figure 1*).

This lake also receives drainage water from various sources like, industrial runoff, agricultural waste, and other anthropogenic activities. And it has an inlet connection with Ukkadam Lake. Valankulam Lake water is spread over an area of 64.75 ha with average depth of 4.5 Mtrs, a storage capacity of 27.88 Mcft, and a catchment area of 479.27 ha. The major activities carried out here are fishing by local fishermen.

Physico-chemical characteristics of lake water

The surface water samples were collected by using coracle bottles, during the early morning hours between 5.00 AM to 7.00 AM, once in a fortnight and period of nine months from September-2021 to May-2022 at five different sites and pooled to check the on-field physico-chemical parameters, such as water temperature, P^H, salinity, dissolved oxygen, total dissolved solids, electrical conductivity, phosphate, chloride, total alkalinity, total hardness, calcium hardness, nitrate and ammonia by using “µP Based Water & Soil Analysis Kit” (Model 1160).

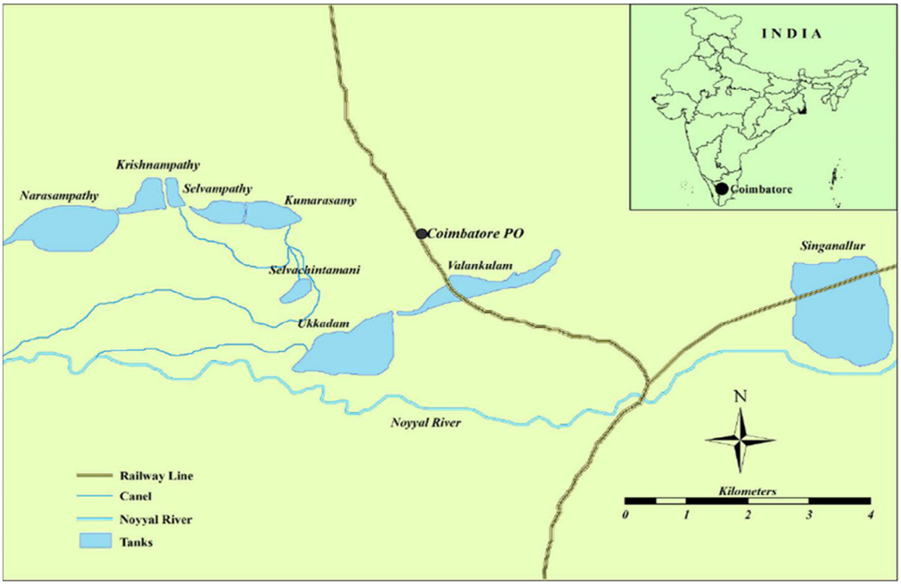

Figure 1 - Study area - Valankulam Lake, Coimbatore city, Tamil Nadu, India

Qualitative and quantitative analyses of plankton

The phytoplankton and zooplankton samples were collected by using Towing-Henson's standard plankton net (25 µm for phytoplankton and 150 µm mesh for zooplankton) by towing horizontally at surface of lake water at five different sites. The quantitative analysis of plankton species, was performed by filtering 100 litters of water through plankton net made up blotting silk (25 µm and 150 µm) using a 10 litter capacity plastic container. Immediately after filtering out the water, plankton biomass were transferred to specimen bottles containing 4 % of neutralized formalin and subjected to microscopic analysis. The sample (1 ml) was taken with a wide-mouthed pipette and placed into the counting chamber of the Sedgwick Rafter. After allowing it to settle for some time, they were counted. Each group was countered at least 5 times, and the average values were noted. The total number of plankton species present in 1 liter of water sample was calculated by using method of Santhanam *et al.*, 1989.

Identification of phytoplankton and zooplankton species

The phytoplankton and zooplankton species were identified by referring to the standard manuals, textbooks, and monographs (Venkataraman, 1939; Iyengar and Venkataraman, 1951; Adoni *et al.*, 1985; Agarker *et al.*, 1994; Battish, 1992; Reddy, 1994; Anand, 1989; Sheil, 1995; Murugan *et al.*, 1998; Altaff, 2004; Manickam *et al.*, 2019a, 2019b). The taxonomic identification was completed under the compound light microscope at a magnification of 40 X to 100 X and they were photomicrographed by using, Inverted Biological Microscope (Model Number INVERSO 3000 (TC-100) CETI) attached to the camera (Model IS 300).

Statistical analyses of phytoplankton and zooplankton species

Species diversity index (H') was calculated using Shannon and Weaner's formula (1949); H1 =pi ∑ log2 pi, I = 1s, Where, H1 ◊ species diversity in bits of information per individual, pi - ni / N (proportion of the sample belonging to the species), ni ◊ Number of individual in all the sample; Species Richness (SR) was calculated as described by Gleason (1922); D = 1 - C, Where, C = ∑ pi2 , pi - ni/N, ni – N/S, N ◊ Total number of individuals, S ◊ Number of species in the collection; Evenness index (J1) was calculated by using the formula of Pielous (1966); J1 = H1 /log2 s, Where, H1 = species diversity in bits of information per individual, S = Number of species. Shannon and Weaner's species diversity index (H1), Species Richness (SR), and Evenness index (J) were analysed using the PAST (Palaeontological Statistics), software (ver. 2.02).

RESULTS

Physico-chemical characteristics of lake water

The average values of hydrographical characteristics of lake water depicted in *Table 1*. During the study period, all the parameters were found to be higher in the summer season, whereas lower in the monsoon season. Moreover, the Dissolved oxygen, Total dissolved solids and ammonia were found to be higher in the monsoon season, whereas lower in the summer season.

Morphologically identifiedphytoplankton species

Totally 43 species of phytoplankton were recorded under 25 families and 30 genera, which include 15 species of Cyanophyceae, 17 species of Chlorophyceae, 8 species of Bacillariophyceae: and 3 species of Euglenophyceae as seen in *Table 2*.

Table 1- Physico-chemical characteristics of the Valankulam Lake, Coimbatore city, Tamil Nadu

Parameters	Monsoon (2021)	P. Monsoon (2022)	Summer (2022)
Water temperature (°C)	$24.26±0.96^{a}$	$26.99±0.42^{b}$	$29.88±0.49^{c}$
pH	$7.06±0.25^{a}$	$7.20±0.35^{b}$	$8.93±0.40^{c}$
Salinity (ppt)	$107.92±0.06^{a}$	$104.15±0.22^{b}$	$132.48±0.20^{c}$
DO (mg/l^{-1})	$8.31±0.50^{c}$	$7.79±0.14^{b}$	$6.21±0.29^{a}$
TDS (mg/l^{-1})	$109.21±24.06^{b}$	$108.28±15.20^{ab}$	$104.34±24.06^{a}$
EC ($\mu S\ cm^{-1}$)	$193.42±0.16^{a}$	$200.03±0.24^{b}$	$209.35±0.29^{c}$
Phosphate (mg/l^{-1})	$33.14±0.28^{a}$	$34.24±0.09^{b}$	$35.75±1.27^{bc}$
Chlorides (mg/l^{-1})	$2.65±0.45^{a}$	$2.98±0.70^{b}$	$3.69±0.51^{c}$
Total alkalinity (mg/l^{-1})	$120.80±7.04^{a}$	$128.23±9.10^{b}$	$134.36±8.86^{c}$
Total hardness (mg/l^{-1})	$6.97±0.57^{a}$	$7.40±0.73^{b}$	$8.30±0.80^{c}$
Calcium hardness (mg/l^{-1})	$68.05±1.05^{a}$	$71.43±2.44^{b}$	$77.37±3.59^{c}$
Nitrate (mg/l^{-1})	$22.42±1.27^{a}$	$23.50±1.80^{ab}$	$24.83±1.69^{bc}$
Ammonia (mg/l^{-1})	$2.53±0.80^{c}$	$2.45±0.68^{b}$	$2.13±0.01^{a}$

DO, dissolved oxygen; **TDS**, total dissolved solids; **EC**, electrical conductivity. Each season value is overall average of mean ± SD (n=15; 5 sites × 3 seasons). Mean values within the same row but having different superscript are significantly different (P<0.05).

Table 2 - List of phytoplankton species recorded in the Valankulam Lake

Group	Family	Genus	Species	M. soon. (2021)	P.Ms. (2022)	Sum. (2022)
Cyanophyceae (15 species)	Aphanizomenonaceae	*Aphanizomenon*	*Aphanizomenon flosaquae*	-	+	+
		Cylindrospermopsis	*Cylindrospermopsis raciborskii*	+	-	+
		Nodularia	*Nodularia spumigena*	+	+	-
	Chroococcaceae	*Chroococcus*	*Chroococcus indicus*	+	-	+
			Chroococcus turgidus	+	+	+
	Merismopediaceae	*Merismopedia*	*Merismopedia glauca*	+	+	+
			Merismopedia punctata	+	+	-
	Microcystaceae	*Microcystis*	*Microcystis aeruginosa*	+	+	-
	Osillatoriaceae	*Oscillatoria*	*Oscillatoria subbrevis*	+	-	-
			Oscillatoria tenuis	+	+	-
	Phormidiaceae	*Phormidium*	*Phormidium granulatum*	+	+	+
			Phormidium pristleyi	-	+	+
	Pseudanabaenaceae	*Pseudanabaena*	*Psseudanabaena limneica*	+	-	+
	Nostocaceae	*Nostoc*	*Nostoc carneum*	+	+	+
	Spirulinaceae	*Spirulina*	*Spirulina laxissima*	+	+	-
Chlorophyceae (17 species)	Desmidiaceae	*Actinotaenium*	*Actinotaenium cucurbitinum*	+	-	+
	Chlorellaceae	*Chlorella*	*Chlorella vulgaris*	-	+	-
	Desmidiaceae	*Closterium*	*Closterium acherianum*	+	-	+
			Closterium acutum	-	+	+
			Closterium venus	+	-	+
	Scenedesmaceae	*Coelastrum*	*Coelastrum proboscideum*	+	+	-
			Coelastrum microporum	-	+	+
		Scenedesmus	*Scenedesmus dimorphus*	+	-	+
			Scenedesmus longus	+	+	-
			Scenedesmus quadricauda	+	-	+
		Crucigenia	*Crucigenia lauterbornii*	+	+	-
			Crucigenia tetrapedia	+	+	-
	Coccomyxaceae	*Dispora*	*Dispora crucigenioides*	+	-	+
	Mesotaeniaceae	*Spirotaenia*	*Spirotaenia condensata*	+	+	+
	Zygnemataceae	*Spirogyra*	*Spirogyra hyalina*	+	+	-
	Scenedesmaceae	*Staturastrum*	*Staturastrum armatus*	+	+	-
		Tetrastrum	*Tetrastrum hetracanthum*	+	-	+
Bacillariophyceae (8 species)	Cocconeidaceae	*Cocconeis*	*Cocconeis placentula*	+	+	+
	Gomphonemataceae	*Gomphonema*	*Gomphonema lanceolatum*	+	-	+
	Fragilariaceae	*Fragilaria*	*Fragilaria capucina*	-	+	-
	Naviculaceae	*Navicula*	*Navicula cuspidata*	+	+	+
			Navicula radiosa	+	+	-
			Navicula subrynchocephala	+	+	+
	Fragilariaceae	*Synedra*	*Synedra ulna*	+	+	+
	Tabellariaceae	*Tabellaria*	*Tabellaria fenestrata*	+	+	-
Euglenophyceae (3 species)	Euglenaceae	*Euglena*	*Euglena acus*	+	-	+
			Euglena gracilis	+	+	-
	Phacaceae	*Phacus*	*Phacus longicauda*	+	+	+
Total	**25**	**30**	**43**	**37**	**30**	**26**

*M. soon: Monsoon; P. Ms: Post Monsoon; Sum: Summer

Population density with percentage composition of phytoplankton species

The population density was recorded in the range of 2130 - 3188 Ind./L at Valankulam Lake during September-2021 to May-2022. The total density of population during monsoon time is 3188 Ind/L, during post monsoon 2530 Ind/L and in summer 2130 Ind/L it means that the maximum population density was noticed during the monsoon followed by post-monsoon and summer (*Table 3*). In the present observation, phytoplankton percentage composition shows that the holds the Cyanophyceae was most abundant in Valankulam Lake. The seasonal wise variations of phytoplankton species values were depicted in *Figure 2*.

The groups Cyanophyceae were found in predominant in monsoon, followed by post monsoon and summer season with (35.07%) followed by species of Chlorophyceae (29.47%), Bacillariophyceae (25.46%) and Euglenophyceae with (10%) in *Figure 3*.

Table 3 - Phytoplankton density with percentage composition in the Valankulam Lake, Coimbatore city, Tamil Nadu

Phytoplankton groups	Monsoon (2021)	P. Monsoon (2022)	Summer (2022)	Total (Ind./L) & %
Cyanophyceae	1087±42[a]	867±29[b]	798±32[c]	2752 (35.07%)
Chlorophyceae	916±30[a]	746±34[b]	651±27[bc]	2313 (29.47%)
Bacillariophyceae	798±31[a]	698±26[ab]	502±25[c]	1998 (25.46%)
Euglenophyceae	387±32[a]	219±28[ab]	179±16[bc]	785 (10%)
Total	**3188**	**2530**	**2130**	**7848**

Each season value is overall average of mean ± SD (n=15; 5 sites × 3 seasons). Mean values within the same row but having different superscript are significantly different (P<0.05).

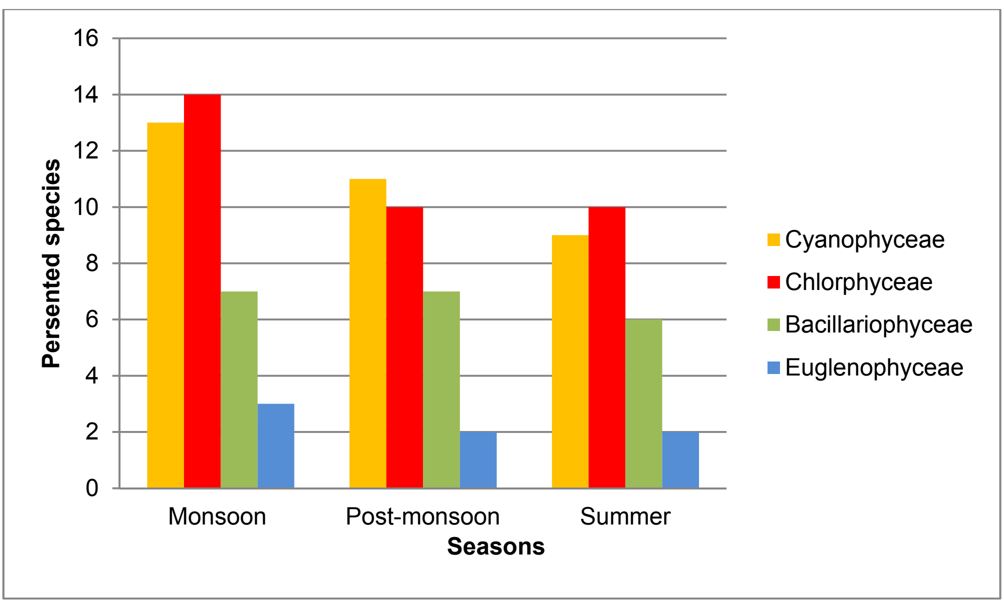

Figure 2- Seasonal wise variations of phytoplankton species in Valankulam Lake

Diversity indices of phytoplankton species

The calculated seasonal diversity indices, such as Simpson's species dominance (D), Shannon-Wiener's diversity (H), Buzas and Gibson's evenness (e^H/S) and Margalef's (R1) species richness for each group of phytoplankton species recorded at Valankulam Lake is presented in (*Table 4*). In overall diversity index for D was recorded in the order of, Cyanophyceae > Chlorophyceae > Bacillariophyceae > Euglenophyceae (0.162, 0.154, 0.144 and 0.137, respectively).

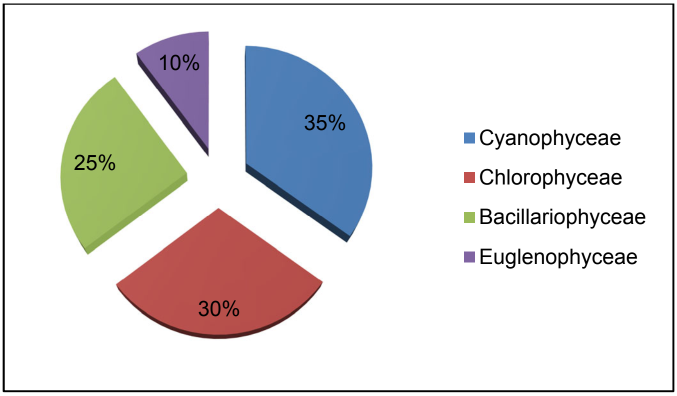

Figure 3 - Percentage composition of different groups of phytoplankton recorded in the Valankulam Lake

Table 4 - Species diversity indices of phytoplankton in the Valankulam Lake, Coimbatore city, Tamil Nadu

Phytoplankton groups	Diversity indices	Monsoon (2021)	P. Monsoon (2022)	Summer (2022)
Cyanophyceae (15 Species)	Dominance (D)	0.162±0.007[a]	0.154±0.005[b]	0.146±0.009[c]
	Shannon (H)	1.983±0.040[a]	1.967±0.041[b]	1.991±0.038[c]
	Evenness_e^H/S	0.981±0.024[a]	0.978±0.024[b]	0.971±0.028[bc]
	Margalef (R1)	0.821±0.047[a]	0.829±0.042[ab]	0.831±0.045[bc]
Chlorophyceae (17 Species)	Dominance (D)	0.154±0.006[a]	0.144±0.008[b]	0.130±0.006[c]
	Shannon (H)	1.963±0.042[a]	1.956±0.043[b]	1.973±0.042[c]
	Evenness_e^H/S	0.974±0.023[a]	0.970±0.021[ab]	0.967±0.027[bc]
	Margalef (R1)	0.812±0.045[bc]	0.817±0.042[a]	0.820±0.046[a]
Bacillariophyceae (8 Species)	Dominance (D)	0.144±0.004[a]	0.136±0.006[b]	0.127±0.008[c]
	Shannon (H)	1.954±0.040[a]	1.948±0.038[ab]	1.969±0.032[c]
	Evenness_e^H/S	0.968±0.020[a]	0.961±0.017[ab]	0.957±0.022[b]
	Margalef (R1)	0.815±0.040[a]	0.811±0.037[ab]	0.807±0.040[b]
Euglenophyceae (3 Species)	Dominance (D)	0.137±0.004[a]	0.126±0.006[b]	0.112±0.008[c]
	Shannon (H)	1.926±0.040[a]	1.914±0.038[b]	1.929±0.032[c]
	Evenness_e^H/S	0.952±0.020[a]	0.912±0.017[b]	0.895±0.022[c]
	Margalef (R1)	0.727±0.040[c]	0.734±0.037[b]	0.805±0.040[a]

Each season value is overall average of mean ± SD (n=15; 5 sites × 3 seasons). Mean values within the same row but having different superscript are significantly different (P<0.05).

The overall diversity index for H was recorded in the order of, Cyanophyceae > Chlorophyceae > Bacillariophyceae > Euglenophyceae (1.991, 1.973, 1.969 and 1.929, respectively). The diversity value for evenness was observed in the order of, Cyanophyceae > Chlorophyceae > Bacillariophyceae > Euglenophyceae (0.981, 1.974, 1.968 and 0.952, respectively). The R1 was observed in the order of, Cyanophyceae > Chlorophyceae > Bacillariophyceae > Euglenophyceae (0.831, 0.820, 0.815 and 0.805, respectively). Simpson's species dominance (D), and Buzas and Gibson's evenness (e^H/S) was higher in monsoon and lower in summer season. Shannon-Wiener's diversity (H), and Margalef's (R1) was higher in summer and lower in monsoon season.

Morphologically identified zooplankton species

Totally 34 species of zooplankton was recorded under 12 families and 17 genera, which include 13 species of Rotifer, 9 species of Cladocera, 8 species of Copepoda, and 4 species of Ostrocoda as shown in *Table 5*.

Population density with percentage composition of zooplankton species

The population density was recorded in the range of 3,828 - 4,815 Ind./L at Valankulam Lake during September-2021 to May-2022. The total density of population during monsoon time is 4815 Ind./L, during post monsoon 4274 Ind./L and in summer 3828 Ind./L it means that the maximum population density was noticed during the monsoon followed by post-monsoon and summer (*Table 6*). The seasonal wise variations of zooplankton species depicted in *Figure 4*.

In the present observation, zooplankton percentage composition shows that the rotifer were most abundant in Valankulam Lake. The groups Rotifera were (33.36%) followed by species of Cladocera (24.80%), Copepoda (22.44%) and Ostrocoda with (19.40%) in *Figure 5*.

Diversity indices of zooplankton species

The calculated seasonal diversity indices, such as Simpson's species dominance (D), Shannon-Wiener's diversity (H), Buzas and Gibson's evenness (e^H/S) and Margalef's (R1) species richness for each group of zooplankton species recorded at Valankulam Lake is presented in (*Table 7*). In overall diversity index for D was recorded in the order of, Rotifera > Cladocera > Copepoda > Ostrocoda (0.165, 0.160, 0.153 and 0.142, respectively). The overall diversity index for H was recorded in the order of, Rotifera > Cladocera > Copepoda > Ostrocoda (1.977, 1.967, 1.965 and 1.861, respectively). The diversity value for evenness was observed in the order of, Rotifer > Cladocerans > Copepoda > Ostrocoda (0.988, 0.980, 0.978 and 0.862, respectively). The R1 was observed in the order of, Rotifera > Cladocera > Copepoda > Ostrocoda (0.837, 0.831, 0.828 and 0.717, respectively). Simpson's species dominance (D), and Buzas and Gibson's evenness (e^H/S) was higher in monsoon and lower in summer season. Shannon-Wiener's diversity (H), and Margalef's (R1) was higher in summer and lower in monsoon season.

Table 5 - List of zooplankton species recorded in the Valankulam Lake

Group	Family	Genus	Species	M.soon (2021)	P.Ms. (2022)	Sum. (2022)
Rotifera (13 species)	Asplanchnidae	*Asplanchna*	*Asplanchna brightwelli*	+	+	-
			Asplanchna girodi	+	-	+
			Asplanchna intermedia	+	+	-
	Brachionidae	*Brachionus*	*Brachionus angularis*	-	+	+
			Brachionus calyciflorus	+	+	+
			Brachionus caudatus personatus	-	+	+
			Brachionus diversicornis	+	-	+
			Brachionus falcatus	+	+	-
			Brachionus forficula	+	+	-
			Brachionus plicatilis	+	+	+
			Brachionus quadridentatus	+	-	+
			Brachionus rotundiformis	-	+	-
	Filinidae	*Filinia*	*Filinia longiseta*	+	-	+
	Philodinidae	*Philodina*	*Philodina acuticornis*	-	+	+
Cladocera (9 species)	Bosminidae	*Bosmina*	*Bosmina longirostris*	+	+	-
	Daphnidae	*Ceriodaphnia*	*Ceriodaphnia reticulate*	+	+	-
		Diaphanosoma	*Diaphanosoma excisum*	+	-	+
			Diaphanosoma sarsi	+	+	+
	Moinidae	*Moina*	*Moina brachiata*	+	+	-
			Moina macrocopa	+	+	+
			Moina micrura	+	-	+
	Macrothricidae	*Macrothrix*	*Macrothrix goeldii*	-	+	+
			Macrothrix spinosa	+	+	-
Copepoda (8 species)	Diaptomidae	*Heliodiaptomus*	*Heliodiaptomus viduus*	+	+	+
	Cyclopoidae	*Eucyclops*	*Eucyclops speratus*	+	-	+
		Mesocyclops	*Mesocyclops leuckarti*	+	+	+
	Diaptomidae	*Thermocyclops*	*Thermocyclops consimilis*	+	+	-
			Thermocyclopsdecipiens	+	+	-
			Thermocyclops hyalinus	+	+	+
			Thermocyclops inversus	+	+	-
		Tropocyclops	*Tropocyclops confinis*	+	+	+
Ostracoda (4 species)	Cyprididae	*Cypris*	*Cypris bispinosa*	+	-	+
			Cypris decaryi	+	+	+
		Cypretta	*Cypretta fontinalis*	+	+	+
		Cyprinotus	*Cyprinotus nudus*	+	+	+
Total	**12**	**17**	**34**	**30**	**27**	**23**

Table 6 - Zooplankton density with percentage composition in the Valankulam Lake, Coimbatore city, Tamil Nadu

Zooplankton groups	Monsoon (2021)	P. Monsoon (2022)	Summer (2022)	Total (Ind./L) & %
Rotifera	1,590±43[a]	1,432±39[b]	1,287±41[c]	4,309 (33.36%)
Cladocera	1,158±36[a]	1,067±42[ab]	978±38[c]	3,203 (24.80%)
Copepoda	1,089±37[a]	956±32[ab]	853±31[b]	2,898 (22.44%)
Ostrocoda	978±27[a]	819±32[ab]	710±33[bc]	2,507 (19.40%)
Total	**4,815**	**4,274**	**3,828**	**12,917**

Each season value is overall average of mean ± SD (n=15; 5 sites × 3 seasons). Mean values within the same row but having different superscript are significantly different (P<0.05)

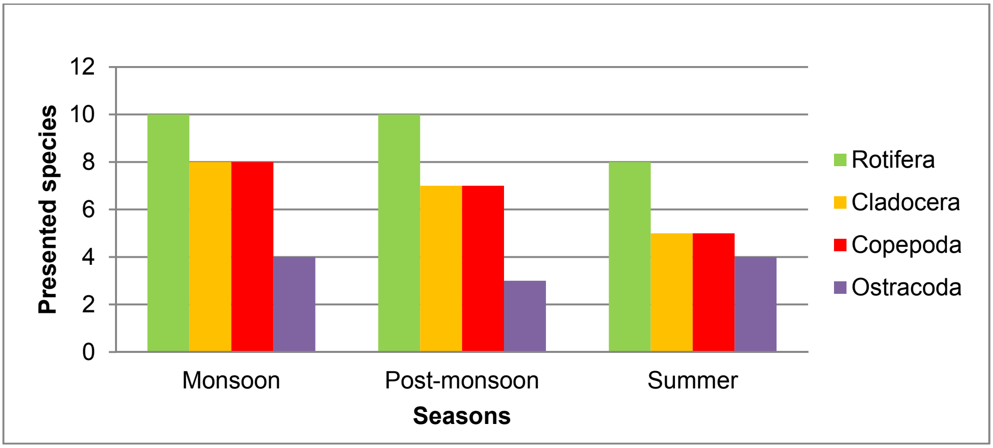

Figure 4- Seasonal wise variations of zooplankton species in Valankulam Lake

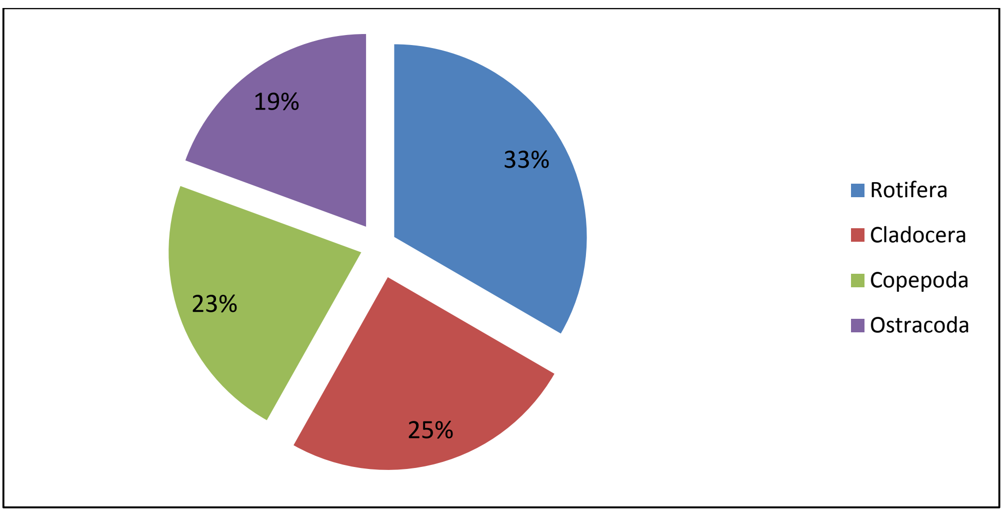

Figure 5 - Percentage composition of different groups of zooplankton recorded in the Valankulam Lake

Table 7 - Species diversity indices of phytoplankton in the Valankulam Lake

Zooplankton Groups	Diversity Indices	Monsoon (2021)	P. Monsoon (2022)	Summer (2022)
Rotifera (13 Species)	Dominance (D)	0.165±0.009[a]	0.157±0.004[b]	0.149±0.008[c]
	Shannon (H)	1.969±0.042[a]	1.960±0.038[ab]	1.977±0.038[c]
	Evenness_e^H/S	0.988±0.026[a]	0.979±0.023[ab]	0.973±0.025[bc]
	Margalef (R1)	0.835±0.048[a]	0.832±0.045[ab]	0.837±0.041[bc]
Cladocera (9 Species)	Dominance (D)	0.160±0.004[a]	0.153±0.007[b]	0.142±0.009[c]
	Shannon (H)	1.963±0.040[a]	1.957±0.032[ab]	1.967±0.035[c]
	Evenness_e^H/S	0.980±0.025[a]	0.971±0.024[ab]	0.964±0.021[bc]
	Margalef (R1)	0.818±0.037[bc]	0.824±0.041[ab]	0.831±0.042[a]
Copepoda (8 Species)	Dominance (D)	0.153±0.006[a]	0.147±0.008[b]	0.140±0.008[c]
	Shannon (H)	1.960±0.038[a]	1.954±0.030[ab]	1.965±0.034[c]
	Evenness_e^H/S	0.978±0.022[a]	0.968±0.025[ab]	0.961±0.023[bc]
	Margalef (R1)	0.815±0.032[bc]	0.821±0.038[ab]	0.828±0.040[a]
Ostrocoda (4 Species)	Dominance (D)	0.142±0.005[a]	0.135±0.009[b]	0.131±0.008[c]
	Shannon (H)	1.854±0.031[a]	1.847±0.035[b]	1.861±0.036[c]
	Evenness_e^H/S	0.862±0.021[a]	0.857±0.029[ab]	0.852±0.026[bc]
	Margalef (R1)	0.704±0.031[bc]	0.711±0.034[ab]	0.717±0.045[a]

Each season value is overall average of mean ± SD (n=15; 5 sites × 3 seasons). Mean values within the same row but having different superscript are significantly different (P<0.05).

DISCUSSION

A notable aspect of the present study was focused on the impact of seasonal variation in freshwater phytoplankton and zooplankton species at Valankulam Lake based on the prevailing hydrographical characteristics in the aquatic environment. If any moderate fluctuation in the biological density of water bodies, the hydrographical characteristics, and biological circumstances must be taken into consideration immediately. The hydrographical characteristics play a crucial role in species diversity and their community structure in the aquatic environment (Sharma *et al.*, 2016). The water temperature plays important role in physiological activities and their life process such as feeding, reproduction, movements, density, and diversity of the organisms are greatly influenced by the high temperature in water bodies. Moreover, the maintenance of water temperature is essential for aquatic biota, there is a significant similarity between water temperature and atmospheric temperature in the environment. The temperature mainly depends upon the intensity of solar radiation, evaporation, and freshwater influx (Ma *et al.*, 2019). The results from the study revealed, the water temperature increased during the summer season and decreased during the monsoon season respectively. P^H is the most important index of alkalinity and acidity. The rise of P^H levels in aquatic ecosystems indicates that increased level of pollution in water bodies (Jeyaraj *et al.*, 2016; Zhou *et al.*, 2008), due to the erosion of carbonated rocks, and higher evaporation, will definitely affects the aquatic organisms. In the present study, the P^H level was increased during in summer season due to the higher level of pollution, and the occurrence of blooms in the aquatic environment, and the P^H level was decreased during the monsoon season due to the heavy dilution of water. Salinity is the most important parameter for living aquatic organisms and helps to determine the biological process in the aquatic environment. In the present investigation, high-level salinity was found in summer and lows in the monsoon season. The salinity level increases due to high evaporation of water and low precipitation in aquatic ecosystems. When the salinity level increase, at the same time P^H level will also increase, because salinity induce the hydrogen ions in water surfaces. In aquatic ecosystems DO level varies according to their trophic levels. A DO fluctuate seasonally or daily with variations due to the consumption of DO owing by the respiration of aquatic organisms and mainly influenced by atmospheric temperature, decomposition of organic matter, and occurrence of various chemical reactions in the aquatic environment (Bhateria and Jain, 2016; Omer, 2019). Sewage from the surrounding areas that flows down, anthropogenic activities, and agricultural runoff will reduce the DO level in aquatic ecosystems (Sasakova *et al.*, 2018). The maximum level of DO was noticed during the monsoon season and the minimum level was noticed during the summer season respectively. The total dissolved solids will represent a total concentration of soluble salts in given water samples that may be organic or inorganic but precisely total dissolved solids are mainly composed of carbonates, sulfate, calcium, phosphate, nitrate, and potassium (Chebet *et al.*, 2020). The TDS content was increased during the monsoon and lower in the summer respectively. A high level of TDS content in Valankulam Lake might be attributed due to the higher amount of industrial effluents, municipal waste, and sewage sludge adjoining the Valankulam Lake. Electrical conductivity will decide the pollution status of the water bodies. In the present study, a maximum level of EC was noticed during the summer and a minimum in monsoon respectively. Total alkalinity represents a chemical property that accelerates and neutralizes the acidic nature of the water bodies and hardness shows the presence of total polyvalent captions in the water and they will mostly be divalent cations, known to be calcium and magnesium. A high level of alkalinity in water bodies has a bitter taste and is harmful to the irrigation process, can damage soil properties, and affects the life of aquatic communities (Ma *et al.*, 2020; Patil *et al.*, 2012). In the present study, the total alkalinity and hardness level was higher in summer and lower in the monsoon season. The calcium is essential for all aquatic organisms, and they are present due to the dissolution of gypsum and calcareous rock within aquatic ecosystems (Ayoob and Gupta, 2006; Anim-Gyampo *et al.*, 2018). In the present study, the maximum level of calcium was found in summer and the minimum in monsoon season respectively. Nitrate, phosphate, and chlorides are the most important nutrient, which is generally found in a higher level of organic polluted water bodies. Nitrate and phosphate are good indicators of eutrophication in aquatic ecosystems, and chloride is one of the important water quality parameters, to assess water pollution in water bodies. The Nitrate, phosphate, and chlorides enter the lake via different sources like municipal waste, agricultural runoff, and other anthropogenic activities (Isiuku and Enyoh, 2020; Mushatq *et al.*, 2013). The nitrate, phosphate, and chloride values indicate that Valankulam Lake is loaded with a higher amount of organic matter with various substances (Halder and Islam, 2015) and ammonia plays important role in the nitrogen cycle of aquatic ecosystems. Moreover, higher amounts of ammonia were found in the monsoon season and lower in the summer season. In the present study, all the parameters are found to be higher in summer and lower in monsoon and except for DO, TDS, and ammonia. The Valankulam Lake has been experiencing great pressure from human activities that alter the hydrographical profile and biological process. Therefore, conservation and management of the lake environment are necessary to classify according to the paved certain standard platform for other biologists to work on these primary producers and consumers of aquatic ecosystems (Pan *et al.*, 2014). Freshwater lakes are facing tremendous ecological stress due to various anthropogenic activities in the environment and lead to in the extinction of some species in the aquatic environment.

Plankton (phytoplankton and zooplankton) are unique organisms which present in the aquatic environment. The distribution patterns of planktonic communities are strongly correlated with environmental factors, and can be used to assess the pollution status of water bodies (Jiang *et al.*, 2014; Nandan and Sajeevan, 2018). The freshwater phytoplankton diversity and their population density are highly influenced by the interaction of some hydrographical and biological factors acting simultaneously to maintain health and wealth of aquatic ecosystems (Mohan and Priyadarshinee, 2022). In the present findings, a total of 43 species of phytoplankton was recorded under 25 families and 30 genera, which include 15 species of Cyanophyceae, 17 species of Chlorophyceae, 08 species of Bacillariophyceae, and 03 species of Euglenophyceae in Valankulam Lake. In the percentage compositions of phytoplankton species, Cyanophyceae were found to be the predominant group at 35.07% followed by Chlorophyceae at 29.47%, Bacillariophyceae at 25.46%, and Euglenophyceae at 10%. Cyanophyceae are the major group of freshwater algae and can produce cyano-toxins. The Cyanobacterial toxins are considered to be important because of their spreading tropical to the temperate environment and they are highly correlated with the global warming phenomena. The present study shows that there are certain members of species in the Cyanophyceae and Chlorophyceae which are tolerant of organic pollution and resist the stress caused by pollutants (Rajagopal *et al.*, 2010; Annalakshmi and Amsath, 2012). However, *Phormidium*, *Oscillatoria, Spirillum, Cylindrospermopsis,* and *Merisomopedia* in Cyanophyceae and *Chlorella, Closterium, Tetrastrum* and *Scenedesmus* in chlorophyceae were found to be dominant genera in Valankulam Lake. These species are mainly used as bio-indicator (bio-monitoring agents) of water quality in aquatic ecosystems (Xue *et al.*, 2018; Sarwade and Kamble, 2014). *Gomphonema, Fragilaria,* and *Navicula* in Bacillariophyceae and *Euglena* in Euglenophyceae are dominant genera in

Valankulam Lake. *Oscillatoria*, *Scendesmus*, and *Navicula sp* are mainly found in organic-rich water bodies. Moreover, *Phacus, Fragilaria capucina, Navicula radiosa,* and *Navicula subryn chocephala* were found in highly polluted water bodies and they correlated with the intensity of pollution (Bhat *et al*., 2015). Freshwater phytoplankton communities have numerous environmental functions related to the recycling of nutrients and the enormous increase in the numbers of some species (*Cylindrospermopsis raciborskii*; *Oscillatoria tenuis*) has made the water unfit for drinking and any other purpose (Khan *et al*., 2011). Blooms producing Cyanobacterial species like *Cylindrospermopsis raciborskii, Aphanizomenon flosaquae, Nostoc corneum,* and *Microcystis aeruginosa* are affects the water ecosystems due to the releasing of Cyanotoxins substances. The cyanobacterial blooms will impair the physico-chemical characteristics (Merel, *et al*., 2013). Therefore, chlorination is best method to treat drinking water, for removing the cyanobacterial blooms. In the past few years, Indian freshwater lakes are facing various anthropogenic activities due to rising pollution from rapid industrialization, urbanization, high human population, and human exploitation. Therefore, conservation freshwater bodies are very important for the purpose of future. Coimbatore city may future aggravate the level of pollution due to Urbanization and industrial revolution.

Crustacean zooplankton is an essential aquatic organism, occurring abundantly in all types of aquatic habits, and has an important role in energy transfer at the base of aquatic ecosystems. They hold the center position in the aquatic food chain. Zooplankton not only forms an integral part of the lentic community but also contributes a significant role in biological productivity in the aquatic ecosystem (Le Loc'h *et al*., 2008; Xu and Zhang, 2012; Mohan and Priyadarshinee, 2022). The zooplankton community often exhibits rapid changes to hydrographical characteristics in the aquatic environment (Hsu *et al*., 2008). In the present findings, a total of 34 species of zooplankton was recorded under 12 families and 17 genera, which include 13 species of rotifer, 09 species of Cladocerans, 08 species of Copepods, and 04 species of Ostracoda in Valankulam Lake. In the percentage composition of zooplankton species, rotifers were found to be the predominant group at 33.36% followed by Cladocerans at 24.80%, Copepods at 22.44%, and Ostracoda at 19.40%. The rotifer species were found to be predominant in municipal and industrial discharges water, and they play important role in energy flow and nutrient cycling, according to more than 50% of the zooplankton production in some freshwater ecosystem (Kaur *et al*., 2018; Singh *et al*., 2021). In the present study, among the four major groups of zooplankton species; Rotifera was found to be predominant, which are the good bio-indicators of eutrophication in water bodies. Continuous measures must be taken to reduce water pollution by regulating human activities and other anthropogenic activities in the watershed area (Verma and Prakash, 2020; Shen *et al*., 2021). Among the zooplankton species, *Asplanchna brightwelli,* *Asplanchna girodi, Brachionus calyciflorus*, *B. diversicornis, B. rotundiformis*, and *B. falcatus*, in rotifer, *Diaphanosoma, Moina macrocopa*, and *Moina brachiata* in cladoceran *Thermocyclops consimilis*, *T. decipiens*, *T. hyalinus, Tropocyclops confinis,* and *Heliodiaptomus viduus* in Copepoda and *Cypretta fontinalis,* and *Cypris decaryi* in Ostracoda were dominantly recorded zooplankton species in Valankulam Lake and the presence has been recorded in both eutrophic and oligotrophic lakes reported by Vadadi Fülöp *et al*., (2008); Makino *et al*., (2020) and Kalpana *et al*. (2017). The copepods species contain an important link in the aquatic food web, and they are in the intermediate trophic level among bacteria, algae, and protozoa. The presents of *cyclopoids* suggest that preponderance in higher trophic level of water, and good bio-indicators of high turbidity due to the suspended solids (Balakrishna *et al*., 2013; da Conceicao *et al*., 2021). The quantitative and qualitative assessment of the planktonic community in aquatic ecosystems is essential to explain the status of water quality and biological productivity. Hence, the present study gives the seasonal-wise distribution of diversity among the phytoplankton and zooplankton from the given area which can be useful as data to identify one of the biological aspects. A relationship between plankton communities and hydrographical profile (phytoplankton, zooplankton, diversity, temperature, p^H, alkalinity, hardness, nitrates, and phosphates) by calculating Dominance (D), Shannon (H'), Evenness e^H/S, Margalef (R1) to analyses their interrelationships (Imran *et al*., 2014; Perumal *et al*., 2009). In the present study, Simpson's species dominance (D), and Buzas and Gibson's evenness (e^H/S) was higher in monsoon and lower in summer season. Shannon-Wiener's diversity (H), and Margalef's (R1) was higher in summer and lower in monsoon season. The higher value of Shannon (H') indices and the population of plankton communities are found higher in the summer season and lower in the monsoon season (Panwar and Malik, 2016; Malik *et al*., 2020; Nandy and Mandal, 2020). The Evenness indices are relatively higher in the monsoon season (Offem *et al*., 2011) and lower in summer season, R1 indices are higher in summer season and lower in monsoon season, and this species abundance indicated the stable environmental conditions in Valankulam Lake. The analyses of species composition and community structure of phytoplankton and zooplankton species are very important because there are ecologically important organisms in aquatic ecosystems. The plankton population is affected by the impact of seasonal variations and they show a different pattern in different months.

CONCLUSIONS

The increase in industrialization, urbanization, human population, and global warming-induce latitudinal shifts in climate zones resulting in a hydrological regime that has serious implications for aquatic organisms including phytoplankton zooplankton species. Results from this study revealed hydrographical characteristics, plankton diversity, and population density are more useful tools to assess the lake ecosystem. The hydrographical characteristics of Valankulam Lake are almost suitable for all aquatic forms. The analysis of diversity indices from September-2021 to May-2022 indicated that Valankulam Lake had a richness of phytoplankton and zooplankton species. The maximum plankton diversity was observed during the monsoon and the minimum diversity was observed during in summer season. Totally 78 species of plankton were recorded, under 39 families and 47 genera, which includes 44 species of phytoplankton and 34 species of zooplankton. However, hydrographical characteristics of Valankulam Lake, are categorized as moderately polluted. It is understood that affected by various anthropogenic activities such as entry of agricultural runoff (insecticides and pesticides) from surrounding agricultural fields, dumping of municipal waste, and mixing of sewage sludge into the lake, and seems that the major cause is eutrophication. Among the phytoplankton and zooplankton species, Cyanophyceae and Rotifera were found to be predominant groups, and they may serve as good bio-indicators of eutrophication. Continuous measures must be taken to minimize pollution in water bodies by regulating human activities in the watershed area. Moreover, Valankulam Lake has more potential for fish resources. Further, water quality and quantity in this lake should be maintained by the desilting process. The present study concluded that strict vigilance and general awareness are required so that proper conservation of water can be done, which supports a rich biodiversity of flora and fauna in their surrounding environment.

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