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BIOMONITORING FOR POLLUTION ASSESSMENT: A CASE STUDY IN VELI-AKKULAM AND VELLAYANI LAKES, SOUTH WEST COAST OF KERALA

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Abstract: In the context of an ecological approach of assessing pollution in lakes, biomonitoring render a strategic method for estimating ecosystem health. Rapid bioassessment method using benthic macroinvertebrates as ecological indicators was successfully applied in two study lakes, Veli-Akkulam and Vellayani lake of Kerala. The lakes were surveyed for a period of two years for recording physicochemical variables of water and estimating the diversity of benthic macroinvertebrates and biotic indices. The spatial and temporal variability in macroinvertebrate communities and water quality showed noticeable ecological degradation in Veli-Akkulam lake. The taxonomic groups recorded from Veli-Akkulam lake included Nematoda, Oligochaeta, Mollusca and Diptera. Conversely in Vellayani lake the majority of the invertebrate taxa were dominated by aquatic insects of the order Ephemeroptera, Trichoptera, Odonata, Hemiptera, Coleoptera. The pollution index HFBI values in Vellayani lake ranged from 3.35 to 4.33, while in Veli-Akkulam lake it ranged from 6.63 to 8.25, indicating very poor water quality conditions in the latter. The percentage EPT taxa and BMWP score showed distinct variation between Veli-Akkulam and Vellayani lakes, with highest biological monitoring working party score recorded at Vellayani lake, substantiated by the presence of pollution intolerant taxa such as Ephemeroptera and Trichoptera. Very low BMWP score values recorded at Veli-Akkulam lake stations reflected the presence of pollution tolerant taxa particularly Oligocheates and many of the dipteran insects with 24 genera under 15 families. The present paper discusses the reasons for ecological degradation of the Veli-Akkulam lake and effectiveness of macroinvertebrates as bioindicators in pollution monitoring studies.

Key words: Bioassessment, Macroinvertebrates, HFBI, EPT, BMWP, bioindicators

INTRODUCTION

In aquatic ecosystems, the biodiversity has received less attention during the last decades and these have been rigorously affected by anthropogenic pressures which resulted in gradual and alarming depletion of aquatic communities. The fundamental constraint for biodiversity conservation is the lack of knowledge about its high diversity and hotspot assessments in the tropics (Barbosa and Callisto, 2000). Biomonitoring has been widely used to assess the environmental impact of pollutant discharges with the use of biological variables to survey the environment properly (Gerhardt, 2000; Sharma and Sharma, 2010). A well balanced monitoring programme includes physical, chemical and biological measurements (Hynes, 1960; Hawkes, 1979; Reynold and Zarull, 1989). Generally, biomonitoring programme involves the use of indicator species or indicator communities, and the presence or absence of these reflects environmental conditions.

Bioassessment is a widely accepted technique for monitoring aquatic health in streams, lakes, and wetlands throughout the world. It is now recognized as an elementary tool for sustainable management of the world's freshwater resources (Jafari and Foroutan, 2007). However, the fast degradation of these ecosystems brings forth the urgent need for biodiversity and demands its management surveys. Biological communities can serve as integrators of the dynamic physicochemical changes and are considered indicators of environmental conditions. The macroinvertebrate community characteristics such as diversity and richness are often used as indicators of the degree of pollution of bodies of water and gives an alternative way of physicochemical information (Arimoro *et al.*, 2007; Silva *et al.*, 2009). Thus, biological monitoring using macroinvertebrates are based on the assumption that with increasing pollution, change will occur in the community assemblage of species present. Macroinvertebrates are often ubiquitous, can be extremely productive and abundant, and are good indicators of environmental conditions, toxic contamination and also perform important ecosystem functions. It is widely accepted that benthic macroinvertebrates play a major role in the evaluation of environmental quality of aquatic ecosystems and reflects the combined effects of various stresses influencing water quality in time and space (Stewart *et al.* 2000; Timms, 2006). In south India, a lot of works concerned with the diversity and distribution of aquatic macroinvertebrates were documented (Sharma and Rai, 1991; Sivaramakrishnan *et al.* 1995, 1996, 2000; Thirumalai, 1999; Anbalagan *et al.,* 2004; Subramanian and Sivaramakrishnan, 2005; Balachandran and Ramachandra, 2010. The spatial and temporal variation in diversity and distribution patterns of benthic macroinvertebrates was studied in Veli and Kadinamkulam lakes of Kerala (Latha and Thanga, 2010).

The main objective of the present study was to use the diversity and abundance of macroinvertebrates and reliable macroinvertebrate based biotic indices (BMWP, HFBI and % Ephemeroptera taxa) as indicators of water quality in both Veli-Akkulam and Vellayani lake in order to characterize the lake ecosystem health. The spatial and temporal variation in physical and chemical water quality parameters was seasonally analyzed and the results were further compared between both the lakes to study the degree of pollution.

MATERIAL AND METHODS

Study Area

Located in northwest of Thiruvananthapuram district (08°30´– 08°31´ N and 76°52´–76°53´ E), Veli-Akkulam is a small inland brackish water lake in the southwest coast of Kerala (1 km long and 0.3 km broad), and has no permanent connection with the Lakshadweep Sea (Fig. 1). The lake was seriously affected by anthropogenic pressures due to industrial waste discharge, municipal waste disposal, tourism activities, developmental activities, dredging and eutrophication (Nair *et al.,* 1998). Sampling took place for two years from October 2008 to September 2010 at six different sites of Veli-Akkulam lake- Veli Bar mouth (station 1), Veli Boat club (station 2), Veli Parvathy Puthen Ar (station 3), Akkulam bridge (station 4), Akkulam Boat club (station 5) and Akkulam Kannammoola canal (station 6). The study was also conducted in Vellayani Lake (reference site) the second largest freshwater lake of Kerala, which is located in the outskirts of Thiruvananthapuram city (8"24’09" - 8"26’30" N; 76°59’08"-76°59’47" E) and has a water spread area of 450 ha (Fig. 2). The length of the lake is about 3.15 km and its maximum width is about 1000 m; depth of the lake varies from 2 to 6 m. In order to compare Veli-Akkulam lake the reference site at Vazhavila of Vellayani was selected. For this biomonitoring study the sample was taken from both reference site (Vellayani lake) and test site (Veli-Akkulam lake).

Sampling and analysis

Standard analysis of water quality parameters such as pH, water temperature, electrical conductivity, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), nitrate, nitrite, phosphate were performed following the methodologies of APHA (2005).

Macroinvertebrates were sampled following the methodology of Rapid Bioassessment Protocol (Barbour *et al.,* 1999). Aquatic macroinvertebrates was collected from 10 meter reach of each station of Veli-Akkulam and Vellayani lakes using D-frame dip net and kick net. A total of 10 jabs and 10 kicks were taken randomly from each site. Sorting was performed at the site itself and the collected sample was transferred into a white pan for a closer observation with a magnifying glass, and picked not less than 200 organisms using forceps and brushes, picked out as many different types as possible and then preserved in 95% Ethyl alcohol and brought to the laboratory for further taxonomic analysis. The collections of sediment benthic macroinvertebrates were done using a Van Veen grab following the standard methodology of APHA (2005). The sediment sample was sieved through 40 mm and 100 mm sieves and taken in large white trays. Small proportions of the sediment was taken in white trays and carefully checked under a microscope and watch glass to pick the stained organisms using fine brushes of varying sizes, forceps, needles etc. The group wise

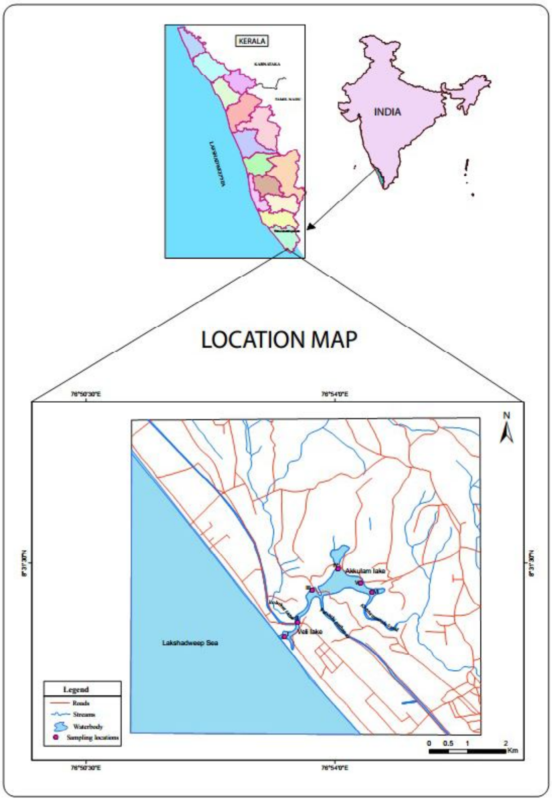

Fig. 1. Location map showing study sites of Veli-Akkulam lake

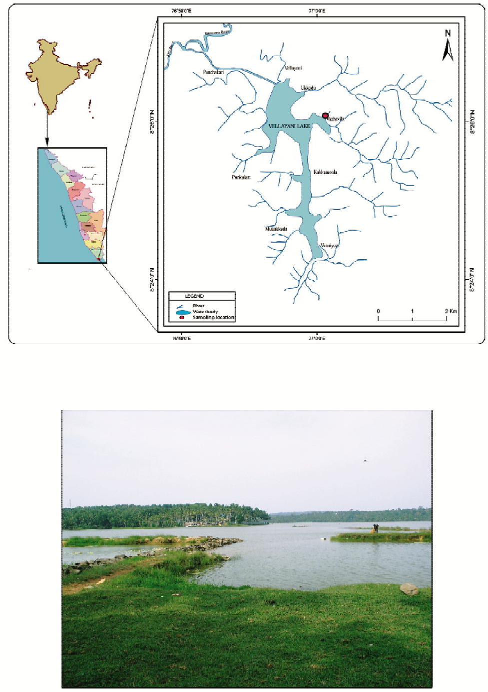

Fig. 2. Location map showing study site of Vellayani lake

sorted sediment organisms were preserved in 70% ethanol and kept for further taxonomic resolution. The collected samples were examined under a dissection or stereozoom microscope (4X and above) and identified using standard taxonomic keys. The identification of aquatic macroinvertebrates was done following the keys and manuals (Needham, 1957; Pennak, 1989; Edmondson, 1993; Subramanian and Sivaramakrishnan, 2007).

Statistical analysis of physicochemical parameters was performed using SPSS 20. For macroinvertebrate community various diversity indices such as total species number (S), total number of individuals (N), Margalef's index (d), Shannon Wiener diversity (H'), Pielou's evenness index (J') and Simpson index were estimated using PRIMER 6 software. Pollution tolerance index such as Hilsenhoff's family biotic index (Hilsenhoff, 1988) were calculated based on the family level tolerance value of all the macroinvertebrate taxa using its standard formula;

$$FBI= \Sigma [(xi)\ (ti)] / n$$

Where x_i =number of individuals within a taxon; t_i = tolerance value of a taxon and n = total number of organisms in the sample

Biotic index such as percentage Ephemeroptera, Plecoptera and Trichoptera taxa (% EPT) and Biological Monitoring Working Party (BMWP) score were estimated for all the samples for two years. Biological Monitoring Working Party (BMWP) score was calculated based on the standard scores attributed to different invertebrate families, according to their degree of intolerance against organic pollution (Armitage *et al.*, 1993).

Table 1. Seasonal values of physicochemical parameters of Veli-Akkulam and Vellayani lakes during the study period (mean ±SD)

Stations	Season	Temperature	pH	Conductivity	DO	BOD	COD	Nitrate	Nitrite	Phosphate
Station 1	Pre monsoon	28.5±0.7	7.26±0.5	5089.67±5281	3.4±0.9	5.0108±1.2	35.2683±2.6	0.22±0.1	0.25±0.1	1.06±0.9
	Monsoon	27.3±1.1	6.8±0.4	15509.5±14983.2	3.97±0.5	6.298±1.1	33.0025±5.3	0.26±0.1	0.27±0.1	1.7±1.1
	Post monsoon	27.25±1.1	7.21±0.5	5043.3±5299.8	3.14±0.8	5.6163±1.1	23.0138±7.4	0.23±0.2	0.37±0.4	0.49±0.5
Station 2	Pre monsoon	30.75±1.3	7.49±0.5	2376.17±701.3	3.34±0.5	6.2908±1.2	39.375±4.4	0.21±0.1	0.23±0.1	1.21±1.2
	Monsoon	28.21±1.3	7.15±0.4	2575.5±1503.3	3.27±0.7	6.399±1.2	38.1±5.4	0.27±0.1	0.43±0.2	2.05±1.9
	Post monsoon	28.91±1.4	7.2±0.2	1747.28±1861.6	2.98±0.9	6.175±1.5	27.6813±6.0	0.17±0.1	0.32±0.3	0.68±0.7
Station 3	Pre monsoon	29±0.5	7.54±0.4	1266.67±546.1	2.41±0.8	6.9175±1.0	48.2083±12.6	0.25±0.1	0.12±0.1	1.75±1.7
	Monsoon	28.5±0.7	6.85±0.3	8090.63±9434.8	2.99±0.7	7.4885±0.9	53.156±12.4	0.25±0.1	0.33±0.3	2.95±1.6
	Post monsoon	29.13±1.6	7.31±0.4	1784.08±2693.8	2.9±1.2	7.1269±1.0	35.8487±6.5	0.21±0.2	0.31±0.3	0.97±1.4
Station 4	Pre monsoon	27.58±1.8	7.24±0.5	517.07±277.4	1.39±0.5	13.5133±5.2	47.2583±5.0	0.15±0.1	0.14±0.1	1.74±1.8
	Monsoon	26.45±1.1	6.93±0.3	323.2±185	1.1±0.3	19.2105±10.2	56.705±7.2	0.26±0.1	0.32±0.2	3.83±1.1
	Post monsoon	26±1.2	7.05±0.4	1031.8±1694.9	1.42±0.5	14.8956±10.4	44.7625±8.1	0.18±0.2	0.45±0.4	1.56±1.5
Station 5	Pre monsoon	28.33±0.9	7.11±0.2	62.67±13.7	0.25±0.1	18.6333±7.3	54.7833±4.1	0.18±0.1	0.18±0.1	5.49±1.6
	Monsoon	27.6±1.2	6.82±0.2	55.22±9.1	0.32±0.2	22.06±8.9	61.186±7.4	0.27±0.1	0.23±0.1	5.88±1.8
	Post monsoon	27.5±1.4	6.89±0.4	59.8±20.1	0.29±0.2	14.9569±7.1	52.8875±7.0	0.16±0.2	0.22±0.2	4.23±1.8
Station 6	Pre monsoon	28.25±2.0	7.09±0.2	187±151.3	0.37±0.3	25.7833±6.3	60.3417±4.6	0.2±0.1	0.18±0.1	3.65±2.6
	Monsoon	28.15±1.2	6.88±0.2	48.29±11	0.62±0.3	23.4±7.3	71.139±14.2	0.32±0.1	0.3±0.2	5.08±1.5
	Post monsoon	28.19±2.1	6.89±0.4	117.78±94.6	0.45±0.2	25.1612±7.4	61.1687±3.4	0.19±0.2	0.24±0.3	4.41±3.1
Station 7	Pre monsoon	31.28±0.7	7.06±0.3	139.02±36.1	7.03±0.6	2.2533±0.9	5.9067±0.7	0.07±0.0	0.05±0	0.2±0.1
	Monsoon	30.35±0.4	6.88±0.2	146.87±59.2	7.65±0.3	1.576±0.4	5.356±1.1	0.02±0.0	0.02±0	0.23±0.1
	Post monsoon	29.5±0.7	6.98±0.2	123.63±31.2	6±0.7	2.9175±0.5	5.583±0.6	0.04±0.0	0.04±0	0.05±0

RESULTS AND DISCUSSION

Physicochemical Parameters

The water temperature ranged from 24°C to 33°C during the study period. Mean temperature of Veli-Akkulam and Vellayani lake is shown in Table 1. The highest warm temperature during pre-monsoon months might be due to the clear sky and more solar radiation than the other months. The highest mean water temperature of Vellayani lake during the present study substantiates the findings of Sandhya (2003). In the present investigation, pH of lake water remains acidic to alkaline ranged from 6.01 to 8.87. In Veli-Akkulam lake the maximum mean water pH observed at station 3 (7.53) during pre-monsoon may be due to the discharge of sewage and domestic wastes being dumped through the river Parvathy Puthen Ar which connects Veli lake in its north. Minimum pH values of Vellayani lake water varied from 6.79 to 7.06 in the present investigation. Radhika *et al.* (2004) also observed similar trend in pH gradient between the seasons of waters in Vellayani lake. The electrical conductivity ranged from 24 µS/cm to 45967 µS/cm during the study period. In Veli-Akkulam lake maximum mean electrical conductivity observed at station 1, Veli bar mouth (15509.5 µS/cm and 20656.31 µS/cm) was due to the intrusion of saline water. Lowest mean electrical conductivity was observed at station 6 (48 µS/cm and 47 µS/cm) during the monsoon season. Reduction in pH at Akkulam lake region may be due to the degradation of organic matter by microbial activity, release of organic acids and anoxic conditions prevailed there. In Vellayani lake the mean conductivity values of water ranged from 116.48 µS/cm to 146.87 µS/cm. Similar observations agrees with the studies done in Vellayani lake (Sandhya, 2003). Mean DO content during the study period varied from 0.078 mg/l (station 6) to 3.97 mg/l (station 1) whereas in Vellayani lake it ranged from 6.0 mg/l to 7.68 mg/l indicated prominent oxygen variation at both Veli-Akkulam and Vellayani lakes, clearly depicting the ecological integrity of the lake. In Veli-Akkulam lake dissolved oxygen was highest at the downstream stations of Veli region and was lowest towards the upstream Akkulam stations. Lowest DO concentration at stations 5 and 6 of Akkulam lake revealed heavy eutrophication, sedimentation and pollution as a result of dumping of hospital wastes, sewages, domestic wastes etc. In the present investigation BOD of water ranged from 1.24 mg/l (station 7) to 36.85 mg/l (station 5). In Veli-Akkulam lake maximum mean BOD was recorded at station 6 and minimum at station 1 even though their values were beyond the acceptable tolerance limit of 6 mg/l (CPCB, 2008). BOD above 6 mg/l in a water body is considered polluted. In Vellayani lake lowest BOD values during all seasons (1.57 mg/l to 2.91 mg/l) indicated its good water quality conditions. COD varied from 3.82 mg/l (station 7) to 96.50 mg/l (station 6). During the study period highest COD values were noted at station 6 during monsoon season whereas lowest COD values were obtained at station 1 during post-monsoon season. Similar highest COD values were reported in lake water of Nagpur city, India (Puri *et al.*, 2010). COD content of Vellayani lake showed more or less equal distribution in almost all seasons and was significantly varied with Veli-Akkulam lake spatially and temporarily. The nutrient nitrate ranged from 0.01 µg/ml to 1.37 µg/ml during the study period with highest at station 2 and lowest at station 7 revealed varied distribution of nitrate in two lakes. In Veli-Akkulam lake highest mean nitrate concentration recorded at station 6 during monsoon attributed to the freshwater discharge from Kannammoola canal and may possibly be due to nitrate enrichment by means of regeneration from sediment or through organic matter decomposition. When comparing with Veli-Akkulam, Vellayani recorded very low values during this study that confirmed less organic wastes input and their subsequent decomposition. In Veli-Akkulam spatial trend in nitrite strongly exhibited wider fluctuations and it too varied seasonally. In the present investigation maximum mean concentration of nitrite at station 4 during post-monsoon season was due to the freshwater influx receiving organic inputs. Highest nitrite (0.793 µg/ml) at station 2 during monsoon season was due to the continuous replenishment of freshwater influx at this site. Low nitrite values recorded at lake Vellayani might be due to the growth of algal flora which consumes ammonia nitrogen as soon as it is formed (Radhika *et al.*, 2004). Phosphate concentration in the present investigation showed clear fluctuations separating Veli-Akkulam and Vellayani lakes with regard to pollution influence. Highest mean phosphate recorded at station 5 (5.88 mg/l and 5.45 mg/l) during monsoon might be due to heavy sewage loads, agricultural wastes, hospital wastes. Very high values recorded at upper reaches of Akkulam lake region were probably due to high rate of phosphate in freshwater input carrying solid wastes, detergents, resultant oxygen depletion due to the death and decay of organic matter, regeneration from sediment particulate matter and from suspended sediments. Sharma and Sarang (2004) reported that the increased phosphate concentration was mainly due to flood washing and mixing of fertilizers from nearby agricultural lands.

Structure and Composition of Macroinvertebrates

A total of 246 species were recorded during the study period from both Veli-Akkulam and Vellayani lakes. A total of 32,895 individuals of macroinvertebrates representing 172 taxa classified under 11 classes, 22 orders, 91 families were recorded from 6 different stations of Veli-Akkulam lake. In Vellayani lake a total of 2760 individuals comprising 153 taxa of macroinvertebrates classified under 13 classes, 25 orders and 78 families were recorded. The relative richness of macroinvertebrates was generally consistent between two lakes as shown in Fig. 3. The dominant class was Polycheates in station 1 whereas in station 2 and 3 it was dominated by Oligocheates. But in Akkulam lake stations 4, 5 and 6 the dominant taxa was contributed by dipteran insects. Similar findings of relatively high species richness of dipteran insects were reported in Kadinamkulam lake (Latha and Thanga, 2010). In Vellayani lake, there was an equidistribution of macroinvertebrate fauna with abundance of pollution sensitive taxa of orders Ephemeroptera and Trichoptera. Here the dipteran taxa were very less owing to the good water quality conditions of the lake.

Benthic Macroinvertebrate Diversity in Veli-Akkulam And Vellayani Lakes

Many of the lentic habitats support diverse macroinvertebrates communities which respond to habitat and water quality alterations thereby exhibit variations in community structure. On the other hand, many habitats, especially disturbed ones, are dominated by few species and are of less diverse due to one factor or other. The diversity of macroinvertebrates of Veli-Akkulam and Vellayani lakes are shown in Table 2. The macroinvertebrate communities respond to changing habitats and water quality by variations in community structure (Sharma *et al.,* 2004). Shannon diversity showed highest value at station 7 during monsoon and lowest at station 6 during pre-monsoon season. Simpson diversity was found maximum at station 7 and minimum at station 5 during monsoon season. Margalef’s species richness was found to be high at station 7 during monsoon and minimum at station 6 during pre-monsoon. Pielou’s evenness index was high at station 2 (pre-monsoon) and low at station 6 (post-monsoon). Stations 5 and 6 at Veli-Akkulam lake showed very low diversity and richness that might be due to heavy organic pollution particularly eutrophication.

Benthic Macroinvertebrate Hilsenhoff’s Family Biotic Index for Evaluation of Pollution

The spatial trend of Hilsenhoff’s family based biotic index is shown (Fig. 4). Family Biotic Index values at stations 1, 2, 3, 4, 5 and 6 were considerably high for all the three seasons indicating poor water quality conditions. This was due to deterioration of water quality as a result of industrial effluents, sewages, solid wastes, agricultural wastes and eutrophication. But in Vellayani lake the biotic index value was consistently low for all the three seasons during the sampling period indicating excellent water quality conditions of the lake. Henne *et al.* (2002) showed that Hilsenhoff’s family biotic index can able to separate polluted from relatively unpolluted water quality conditions.

The biotic index such as percentage Ephemeroptera, Plecoptera and Trichoptera taxa (% EPT) and Biological Monitoring Working Party (BMWP) score for both the Veli-Akkulam and Vellayani lakes are represented in Fig. 5. The BMWP score of Veli-Akkulam lake ranged from 38.6 to 61 whereas in Vellayani lake the score was 129. BMWP score values for individual families reflect their pollution tolerance. That is, pollution intolerant families that have high BMWP scores, while pollution tolerant families have low scores (Sivaramakrishnan, 1992).

Simply, BMWP score increases with an increase in abundance of pollution sensitive taxa. In the case of percentage occurrence of EPT taxa, EPT taxa were negligible present in Veli stations 1 and 2 and Akkulam station 4, but it was high at Vellayani lake indicating better water quality conditions. In Veli-Akkulam lake, lower percentage of EPT taxa (<1) along with dominance of tolerant taxa indicates severe environmental degradation.

In the present study the biomonitoring based on macroinvertebrate community played a significant role in assessing the environmental status of Veli-Akkulam and Vellayani lakes. This study provided detailed evidence of severe degradation in water quality in Veli-Akkulam lake through a thorough evaluation of both physico-chemical and biological quality. Shannon and Simpson diversity of macroinvertebrate was rich in Vellayani lake when compared to Veli-Akkulam lake. The lowest diversity in Veli-Akkulam lake was due to the abundance of pollution tolerant groups such as dipteran insects and Oligocheates in Veli-Akkulam lake. Macroinvertebrate community in upstream region of Akkulam lake was dominated by highly tolerant diptera insects represented by 15 families and 24 genera. The important families recorded were Tipulidae, Culicidae, Psychodidae, Ptychopteridae, Simulidae, Ceratopogonidae, Chironomidae, Stratiomyidae, Tabanidae, Empididae, Syrphidae, Sciomyzidae, Ephydridae, Muscidae and Sarcophagidae; taxa recorded were *Tipula* sp., *Aedes* sp., *Anopheles* sp., *Culex* sp., *Culiseta* sp., *Mansonia* sp., *Tripteroides* sp., *Psychoda* sp., *un identified* sp. (Ptychopteridae), *Simulium* sp., *Bezzia* sp., *Chironomus* sp., *Odontomyia* sp., *Oplodontha* sp., *Oxycera* sp., *Stratiomys* sp., *Chrysops* sp., *Tabanus* sp., *Empis* sp., *Eristalis* sp., *Sepedon* sp, *Brachydeutera* sp, *un identified* sp. (muscidae), *un identified* sp. (sarcophagidae) respectively. The downstream Veli region was dominated by Oligocheates under the families Naididae and Tubificidae represented by a total of 13 taxa. The taxa representing under family Naididae and Tubificidae were *Aulophorus carteri*, *Aulophorus furcatus*, *Dero dorsalis*, *Dero nivea*, *Dero zeylanica*, *Pristina proboscidea*, *Pristina longiseta longiseta*, *Branchiodrilus* sp., *Stylaria fossularis*, *Nais communis*, *Tubifex tubifex*, *Scyllis* sp. and *Limnodrilus* sp respectively. However, in Vellayani lake the sensitive EPT taxa was represented by the families Caenidae and Baetidae under order Ephemeroptera with species *Caenis* sp., *Baetis* sp., *Centroptilum* sp. and *Cloeon* sp. respectively whereas the order Trichoptera was represented by the families Philopotamidae, Polycentropodidae, Hydropsychidae, Odontoceridae and Leptoceridae.

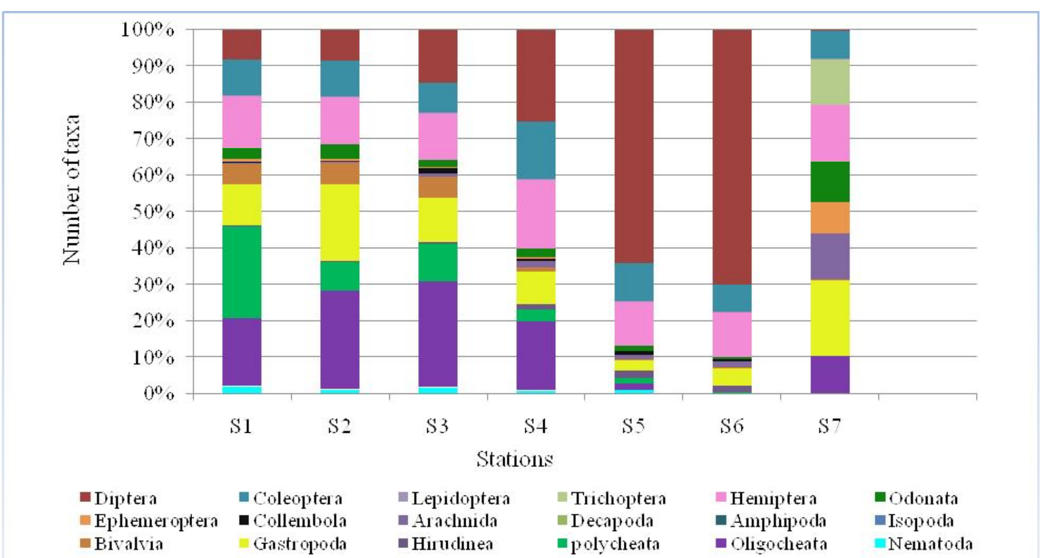

Fig. 3. Relative percentage contribution of various taxonomic classes of macroinvertebrates in Veli-Akkulam and Vellayani lake

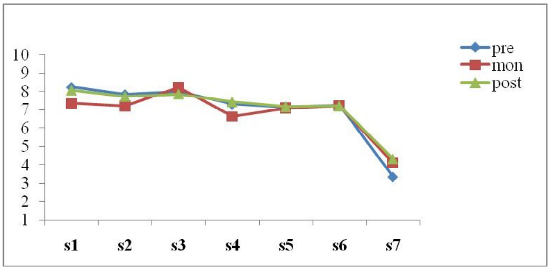

Fig. 4. Spatial variations in Hilsenhoff Family Biotic Index of Veli-Akkulam lake (stations 1, 2, 3, 4, 5 and 6) and Vellayani lake (station 7)

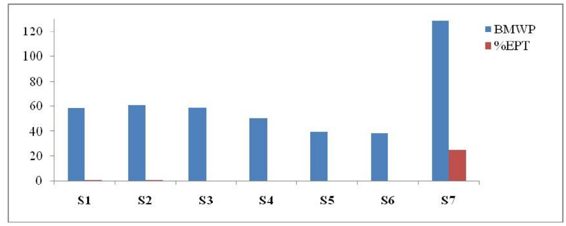

Fig. 5. Contribution of percentage EPT taxa and BMWP score for Veli-Akkulam lake (stations 1, 2, 3, 4, 5 and 6) and reference site, Vellayani lake (station 7)

Table 2. Diversity indices of Benthic Macroinvertebrates of Veli-Akkulam and Vellayani lake during the study period (October 2008 to September 2010)

Stations	Seasons	S	N	d	J’	H’ (loge)	1-Lambda’
Station1	Pre-monsoon	99	298.3	17.198	0.7	2.4	0.73
	Monsoon	108	216.2	15.903	0.74	2.7	0.75
	Post-monsoon	97	204.7	16.949	0.73	2.8	0.69
Station 2	Pre-monsoon	107	274.7	15.876	0.75	2.6	0.77
	Monsoon	112	235.9	16.317	0.75	2.7	0.77
	Post-monsoon	118	294	16.107	0.73	2.6	0.74
Station 3	Pre-monsoon	105	252	17.542	0.72	2.7	0.69
	Monsoon	109	272.4	15.261	0.72	2.5	0.7
	Post-monsoon	74	236.5	16.828	0.6	2.6	0.77
Station 4	Pre-monsoon	82	196.2	15.344	0.74	2.5	0.68
	Monsoon	89	156.5	17.415	0.73	2.6	0.65
	Post-monsoon	98	184.4	14.375	0.6	2.4	0.66
Station 5	Pre-monsoon	62	153.3	12.121	0.61	2.3	0.65
	Monsoon	65	165.5	12.527	0.66	2.3	0.6
	Post-monsoon	83	173.1	13.91	0.64	2.3	0.61
Station 6	Pre-monsoon	61	173.7	11.634	0.62	2.2	0.64
	Monsoon	67	177.4	12.745	0.61	2.3	0.62
	Post-monsoon	78	176.5	14.884	0.61	2.4	0.61
Station 7	Pre-monsoon	128	323.8	18.718	0.84	3.5	0.93
	Monsoon	130	356.8	21.405	0.82	3.6	0.94
	Post-monsoon	123	336.4	19.131	0.83	3.5	0.92

S = total taxa; N = number of species; d = Margalef’s species richness index; J’ = Pielou’s evenness index; H’(loge) = Shannon-Wiener diversity index; 1-Lambda’ = Simpson diversity index

The taxa recorded were *Chimarra* sp., *Polycentropus* sp., *Hydropsyche* sp. and *Leptocerus* sp. respectively. Low values of DO and high values of BOD, COD, phosphate in Akkulam upstream region significantly indicated severe eutrophic status of Veli-Akkulam lake due to the discharges of hospital wastes, sewages, agricultural wastes, sedimentation and eutrophication. The macroinvertebrate communities of Veli downstream were occupied predominantly by highly tolerant Oligocheates and Polycheates. However, highest species diversity of macroinvertebrates in Vellayani lake indicates better water quality conditions when compared to Veli-Akkulam lake. Moreover, macroinvertebrate indices of water quality such as BMWP score, percentage EPT (% EPT) and Hilsenhoff's family biotic index could remarkably distinguish the water quality conditions of two lakes thereby confirmed oligotrophic conditions in Vellayani lake and severely eutrophic status in Veli-Akkulam lake.

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