Assessment of River Water Quality Using Macroinvertebrate Organisms as Pollution Indicators of Tamirabarani River Basin, Tamil Nadu, India

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***Abstract*- River monitoring study was conducted to assess the current water quality status employing macrobenthic organisms as pollution indicators at 12 sampling stations of the perennial river Tamirabarani during March to December 2008. The river is the main source for potable water supply, irrigation, domestic uses, industrial processes etc., to the two districts namely Tirunelveli and Thotthukudi with the population of more than 42,96,261 people. Based on the physicochemical study, the river water quality deteriorates mainly due to organic contaminants which was measured through high BOD, COD and TKN content of the water samples and due to high discharge of domestic discharges, sewage wastes, open defecation, livestock discharges all along the river course. A sum of 3372 macrobenthic individuals comprising of 58 families were collected during the study. The macrobenthic abundance (97 numbers) was perceived at Pabanasam (T1) during March and June; less (36 numbers) assemblage was observed at Thiruppudaimaruthur (T4). The Family Biotic Index level indicates excellent quality at 10.42% of the sampling stations, very good quality at 6.25% stations, good quality at 25% stations, fair quality at 20.83% stations, fairly poor quality at 16.67% stations and poor quality of water at 20.83% of the stations; EPT and EPT/C Index shows uneven distribution of pollution sensitive and pollution tolerant organisms throughout the river system. ASPT and BMWP score of the study showed the water quality from excellent to poor. At present the perennial river is under threat of anthropogenic disturbances during festival periods especially at upstream areas, Tirunelveli city and suburban reaches due to higher pilgrimage and various religious and rituals practices.**

Keywords*- *Tamirabarani River; Water Quality Assessment; Biomonitoring; Pollution Indicator Organisms; Biological Indices

I. INTRODUCTION

Rivers are dynamic system possessing large, temporal and spatial disparity in water quality. This can be the result of inherent variability and because of the episodic pollution events. Most ancient civilizations grew along the banks of rivers, even today millions of people all over the world live on the banks of rivers and depend on them for their survival [1]. The exertion of modern industrialization, urbanization and development activities increases the environmental pollution consequently. However, most of the research study aims to predict the pollution sources from where it exactly arise; a combination of chemical and biological method constitutes the best approach of monitoring studies for indicating water quality [2]. There are many biological indicators viz., diatoms [3], algae [4], fishes [5], water birds [6], leeches [7], among which the most commonly used have been benthic macroinvertebrates [8-15]. Norris and Thoms [16] suggest that the effects on biota are usually the final point of environmental degradation and pollution of rivers and thus are an important indication of ecosystem health.

The main objective of the present study was to assess the current pollution status of the perennial river Tamirabarani using benthic macroinvertebrate organisms as pollution indicators, since the river receives plenty of organic constituents all along the flow by means of sewage, agricultural runoff, industrial discharges and human in-stream and bank activities [17-25]. Benthos represents an extremely diverse group of aquatic animals, and a large number of species possess a wide range of responses to stressors such as organic pollutants, sediments, and toxicants. Benthos are one of the best biological indicators of water quality monitoring [26], their presence or absence provides a reliable picture of the river ecosystem. Macroinvertebrate organism forms an integral part of an aquatic environment with ecological and economic importance as they maintain various levels of interaction between the community and the environment [13]. Benthos are important bioindicators because of their limited locomotory abilities, their attachment to solid substrates, and their relatively long life cycles. Thus, these organisms are well suited for monitoring water quality in flowing water [27]. The macro benthic population is highly influenced by physicochemical changes, availability of the substratum, food and predation and certain types of human activities [28]. The density of benthic-invertebrate also fluctuates widely with seasonal changes too [29].

II. MATERIALS AND METHODS

A. Study Area

The perennial river Tamirabarani (Plate 1) originates at the Periya Pothigai hill with an altitude of 1725 m above MSL at the eastern slopes of Western Ghats in Tirunelveli district of Tamil Nadu, and it traverses a length of 125 km passing through Tirunelveli and Thoothukudi districts before its convergence with the Bay of Bengal at Punnakayal region. This great river is

fed by both southwest and northeast monsoons; the river is seen with full spate twice a year if the monsoons do not fail. The main river drains with its large network of springs with the catchment area of about 4400 sq.km. Since all its main tributaries are arising from the Western Ghats, the river is prone to heavy flood especially during the northeast monsoon period. The river is the only perennial source for the potable water supply, irrigational activities, industrial processes etc., to both the major district people with the population of more than 42,96,261.

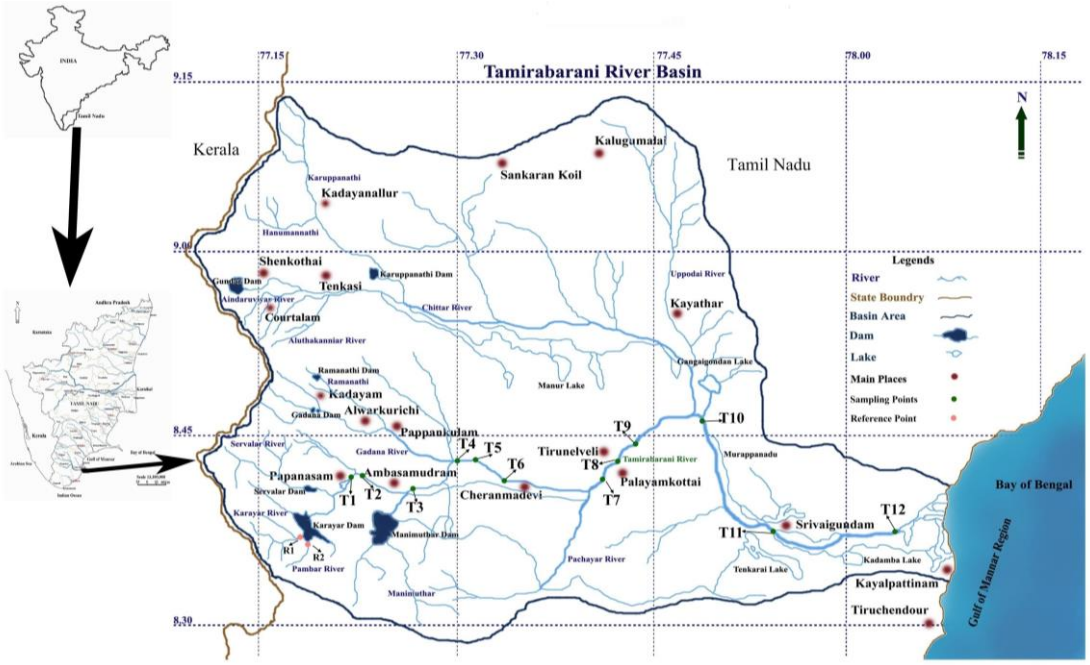

Plate 1 Study area and sampling stations of river Tamirabarani

B. Selection of Sampling Points

Twelve sampling points (T1-T12; Plate 1; Table 1) were selected for the present study based on the habitat assessment through river habitat walk [30]. Sampling points were chosen based on the site specific activities (agricultural, huge gathering points, sewage mixing, open defecation, sand dredging, garbage dumping), tributary entry points and with the basis of the advice from the pollution control board experts. Reference point is selected based on the pristine nature of the location (without human disturbances, before the reach of plains and reserved forest premises). Samples were collected from each station for every quarterly period (March, June, September and December months of the year 2008) separately for chemical, biological and biomonitoring studies.

TABLE 1 GEOGRAPHICAL POSITIONS OF THE SAMPLING SITES OF RIVER TAMIRABARANI

Site ID	Locations	Latitude	Longitude
Reference	Upstream area of Karayar Reservoir	8 °37'27"N	77 °18'44"E
Reference	Upstream area of Karayar Reservoir	8 °37'38"N	77 °18'34"E
T1	Pabanasam	8 °42'39"N	77 °22'2"E
T2	V.K.Puram	8 °42'25"N	77 °22'56"E
T3	Ambasamudram	8 °41'38"N	77 °27'43"E
T4	Thiruppudaimaruthur	8 °43'41"N	77 °29'45"E
T5	Mukkudal	8 °43'57"N	77 °30'48"E
T6	Cheranmahadevi - Suburban	8 °42'4"N	77 °33'56"E
T7	Kurukkuthurai - Suburban	8 °42'37"N	77 °41'49"E
T8	Tirunelveli - Kokkirakulam	8 °43'38"N	77 °42'49"E
T9	Tirunelveli - Vannarappettai	8 °44'21"N	77 °43'6"E
T10	Seevalapperi - Suburban	8 °46'53"N	77 °48'36"E
T11	Srivaigundam	8 °37'35"N	77 °54'44"E
T12	Aattur	8 °37'35"N	78 °4'8"E

C. Physicochemical Study

Water samples were collected in 5-L sterile plastic containers from each sampling station. Determinations like pH, electrical conductivity, temperature, velocity, discharge, turbidity and DO fixing were carried out *in-situ*. Digital handy multi parameter (Eutech Instruments, US) was used to determine pH, temperature, turbidity and EC. The chemical parameters like dissolved oxygen, nitrate, nitrite, sulphate, phosphate, total kjeldahl nitrogen, ammonia, chemical oxygen demand, biological

oxygen demand, total and faecal coliform were analyzed with the adaptation of standard methodologies (Table 2) [31]. The water quality levels were compared with water quality guidelines and quality criteria levels prescribed by the World Health Organization [32] and Central Pollution Control Board [33] India. Pearson correlation (two-tailed) and descriptive statistics were calculated to identify the relationship between physicochemical parameters and biotic indices to summarise the results using SPSS package 15.

TABLE 2 PHYSICOCHEMICAL PARAMETERS SELECTED FOR THE STUDY AND THE METHODS OF ANALYSIS

S.No	Parameter	Methods of analysis	Units of Measurement
Physicochemical			
1.	Velocity (Velo)	Float	m/sec
2.	Discharge (Disch)	Calculation of Area followed by Velocity	m^3/sec
3.	Temperature (Temp)	Thermometer & Electrometric	˚C
4.	Electrical Conductivity (EC)	Electrometric	µS/cm
5.	Turbidity (TDY)	Turbidometric	NTU
6.	pH	Electrometric	
7.	Dissolved Oxygen (DO)	Modified Winkler's	mg/L
8.	BOD	5 days incubation at 20ºC followed by titration	mg/L
9.	COD	Closed reflux	mg/L
10.	Ammonia (NH_4N)	Titration by H_2SO_4	mg/L
11.	Total kjeldahl nitrogen (TKN)	Titration by H_2SO_4	mg/L
12.	Sulphate (SO_4)	Turbidity	mg/L
13.	Nitrate (NO_3)	Ultraviolet screening	mg/L
14.	Nitrite (NO_2)	Spectrophotometric	mg/L
15.	Phosphate (PO_4)	Spectrophotometric	mg/L
Biological			
16.	Total coliform (TC)	Multiple tube fermentation technique	MPN/100ml
17.	Faecal coliform (FC)		

D. Biomonitoring Study

Macroinvertebrate samples were collected using a three-minute single-habitat kick sampling method [34] formulated by Environmental Protection Agency and based on a methodology manual [35].

A 100 m reach representative of the characteristics of the stream was selected for the sampling. Each type of habitats within the 100 m reach was (i.e., turbulent water flow over stretches of shallow, cobble substrate) chosen for the collection of macroinvertebrate organisms. The samples were collected using mesh of 500 µm, 1 m kick net. Large debris was picked up and rinsed for inspecting the presence of organisms; the organisms found were placed into the sample container with the use of fine brushes and forceps. The kicks collected from different riffles and the cobble substrates were merged and the homogeneous sample was preserved with 90% ethanol. Three replicate samples were taken at each site. Random sub-sampling technique was used to isolate the organisms from the original composite from each site. The family level identification of macrobenthic organisms was carried out using the key factors given by [36-38].

E. Calculation of Biological Indices

The biological indices were deliberated by using the following standard methods; Family Biotic Index (FBI) [39], Ephemeroptera, Plecoptera and Tricoptera (EPT) index score and EPT to Chironomidae ratio (EPT/C) [34], Average Score Per Taxon (ASPT) score and Biological Monitoring Working Party (BMWP) score [40]. The sampling stretches were classified into seven classes based on FBI score levels [39], six classes based on the ASPT score level [41] and four categories based on BMWP score levels [2] for the present study.

III. RESULTS

A. Physicochemical Characteristics of River Tamirabarani

The present study results (Table 3) reveal that the water temperature was ranged between 23.2-32˚C; the results showed significant relationship with NH_4-N, NO_3, COD, TC and FC during the study. Velocity and the discharge level were high during the months of March and December due to the release of water from the upper reservoir for irrigational and hydroelectric generation activities during early March and because of high precipitation during the northeast monsoon period which increases the incidence of high discharge level. Water pH ranges between 7.1-8.38 and the results showed significant relationship with discharge, EC, DO, NH_4-N, NO_2, NO_3, BOD, TKN and SO_4 at the levels of $p<0.01$ and $p<0.05$. EC level of the river water varies between 38.63-535.36 µS/cm and showed considerable correlation with pH, DO, NH_4-N, NO_2, NO_3, BOD, TKN and SO_4. The DO concentration ranged within 4.8-8.1 mg/l throughout the river stretch; higher DO levels were recorded during rainy periods; this may be due to high diffusion rate because of high turbulence and precipitation. High turbidity level was noticed during the early northeast monsoon period (September) as 13.37 NTU; higher runoff from adjoining

bank, rural and urban areas may increase the level of turbidity in the running water. Absence of NH_4-N was noticed during the monsoon period due to high velocity and dilution rate; the maximum concentration measured was 0.224 mg/l at station S8 (Tirunelveli - Kokkirakulam) during the months of March and June. The presence of NH_4-N in the river system may be due to the excretory products of animals and due to the decomposition of plants and other organic inputs from direct sewage entry at upstream suburban reaches. Nitrite content of the river was recorded between 0.00-0.30 mg/l and the mean level was 0.015 mg/l during the study. Nitrate content of the river water showed significant correlation with most of the physicochemical variables during the study and it measured between 0.2-0.81 mg/l and the average level was 0.346 mg/l. Phosphate level of the water samples showed significant relationship with TDY, NH_4-N, NO_3 and SO_4. Organic constituents like COD, BOD and TKN levels of the river water were recorded within the range of 2-14 mg/l, 0.2-6.9 and 0.6-0.84 mg/l respectively during the study. Sulphate level was measured between 0.99-18.58 mg/l and the average level was 6.104 mg/l during the study; correlation study showed significant relationship with most of the measured variables. Maximum of TC and FC levels were recorded at stations T8 (Tirunelveli - Kokkirakulam) (900 counts/100 ml) and T9 (Tirunelveli - Vannarapettai) (110 counts/100 ml) respectively. Higher incidence of TC and FC may be due to the direct intrusion of raw sewage from Tirunelveli city and suburban areas, open defecation along the river bank areas, higher cattle wadding and dumping of garbage wastes into the main river channel and adjoining bank areas. Even though the river was prone to high level of pollution threat the physicochemical variables were meeting the national (CPCB) and international (WHO) quality criteria standards except BOD (6.9mg/l) at station T12 (Aattur) during March, TC (900MPN/100ml) at stations T8 (Tirunelveli - Kokkirakulam) and FC (110 MPN/100ml) at S9 (Tirunelveli - Vannarapettai) during September. The results revealed that the dilution rate of pollutants was high throughout the entire river stretch because of the higher level of discharge throughout the year. Since the southwest (June-September) and northeast (October-December) monsoons increase the incidence of rain and successive watershed in the catchment areas. The average rainfall of the river basin area is 1082 mm (northeast 565 mm; southwest 233 and summer and winter 284 mm) with the annual average temperature of 25.5 ℃ - 34.4 ℃ (20.9 ℃ min, 39 ℃ max).

TABLE 3 DESCRIPTIVE SUMMARY OF PHYSICOCHEMICAL VARIABLES OF RIVER TAMIRABARANI

		N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
	Unit	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic
Temp	˚C	48	8.80	23.20	32	27.796	2.1995	4.838
Velo	m/sec	48	1.38	0.00	1.38	0.373	0.26	0.066
Disch	m^3/sec	48	40.77	0.00	40.77	21.112	11.88	141.036
pH		48	1.28	7.10	8.38	7.775	0.34	0.118
EC	µS/cm	48	496.73	38.63	535.36	193.449	129.80	16848.235
DO	mg/l	48	3.30	4.80	8.10	6.357	0.84	0.705
TDY	NTU	48	13.07	0.30	13.37	3.150	3.09	9.550
NH_4N	mg/l	48	0.22	0.00	0.22	0.064	0.067	0.005
NO_2	mg/l	48	0.30	0.00	0.30	0.015	0.04	0.002
NO_3	mg/l	48	0.79	0.02	0.81	0.346	0.21	0.046
PO_4	mg/l	48	3.29	0.00	3.29	1.122	0.93	0.862
COD	mg/l	48	12	2	14	5.854	3.281	10.766
BOD	mg/l	48	6.70	0.20	6.90	2.166	1.281	1.641
TKN	mg/l	48	0.78	0.06	0.84	0.443	0.2145	0.046
SO_4	mg/l	48	17.59	0.99	18.58	6.104	4.19	17.573
TC	MPN Count/100ml	48	896	4	900	80.458	136.57	18651.445
FC	MPN Count/100ml	48	108	2	110	16.438	21.872	478.379

B. Biomonitoring Results of River Tamirabarani

Habitat assessment results during the study were summarised in Table 5 on the basis of watershed features, riparian vegetation, in-stream features and substratum. Less availability of the precise habitat like cobble substratum at stations (V.K.Puram) T2 to T6 (Cheranmahadevi), Tirunelveli - Kokkirakulam (T8), (Seevalapperi) T10, (Srivaigundam) T11 and (Aattur) T12 alters the level of macro-invertebrate organism richness within the course of flow during the study. The substratum of the sampling station T8 (Tirunelveli - Kokkirakulam) was entirely covered with calcareous rocky material. Most of the insect groups were sheltered at the river side weeds and aquatic plants throughout the study.

Altogether, 58 different families were recorded, for a total number of 3372 individuals (Table 6) and total number of organisms observed during the study was graphically presented in Fig. 1. Reference points do not have the pollution tolerant organisms like Chironomidae, Oligochaeta etc., during the study because of its pristine nature and the place was within the reserved forest area without any human disturbances. The community composition and the pollution level at each location were evaluated through the application of the above-mentioned five indexes and the descriptive summary of various biotic index score level is presented in Table 7. These index levels provide the exact quality of the water at that particular place due to various activities over a period of time. Correlation study also reveals that most of the physicochemical variables also showed direct impact on the assemblage of macrobenthic organisms during the study (Table 4).

TABLE 4 CORRELATION MATRIX BETWEEN PHYSICOCHEMICAL VARIABLES AND VARIOUS BIOTIC INDICES OF RIVER TAMIRABARANI

		FBI	EPT	EPTC	ASPT	BMWP
Temp	r	.507(**)	-.420(**)	-.294	-.305(*)	-.337(*)
	p	.000	.003	.053	.035	.019
Velo	r	-.202	.159	.031	.160	.334(*)
	p	.169	.280	.842	.277	.020
Disch	r	.002	-.100	.021	-.018	.156
	p	.992	.500	.894	.905	.289
pH	r	.263	-.316(*)	.005	-.272	-.192
	p	.071	.029	.973	.061	.192
EC	r	.475(**)	-.406(**)	-.176	-.538(**)	-.432(**)
	p	.001	.004	.253	.000	.002
DO	r	-.290(*)	.332(*)	.067	.362(*)	.175
	p	.046	.021	.665	.012	.235
TDY	r	.162	-.123	-.140	-.239	-.192
	p	.272	.406	.364	.102	.192
NH_4N	r	.528(**)	-.363(*)	-.244	-.403(**)	-.518(**)
	p	.000	.011	.110	.005	.000
NO_2	r	.115	-.093	-.113	-.091	-.013
	p	.435	.531	.466	.538	.928
NO_3	r	.213	-.218	-.024	-.386(**)	-.195
	p	.146	.137	.878	.007	.184
PO_4	r	.208	-.037	-.305(*)	-.327(*)	-.179
	p	.156	.804	.044	.023	.223
COD	r	.299(*)	-.254	-.177	-.174	-.233
	p	.039	.082	.250	.236	.112
BOD	r	.352(*)	-.324(*)	-.169	-.514(**)	-.343(*)
	p	.014	.025	.273	.000	.017
TKN	r	.416(**)	-.361(*)	-.148	-.544(**)	-.372(**)
	p	.003	.012	.337	.000	.009
SO_4	r	.360(*)	-.312(*)	-.140	-.495(**)	-.299(*)
	p	.012	.031	.364	.000	.039
TC	r	.393(**)	-.209	-.295	-.224	-.389(**)
	p	.006	.153	.052	.126	.006
FC	r	.416(**)	-.185	-.387(**)	-.229	-.431(**)
	p	.003	.207	.009	.117	.002

Cells shows the Pearson correlation coefficient (r) and significance (p) level at the 0.01 level (**) and 0.05 level (*) (two tailed) (n = 48 samples)

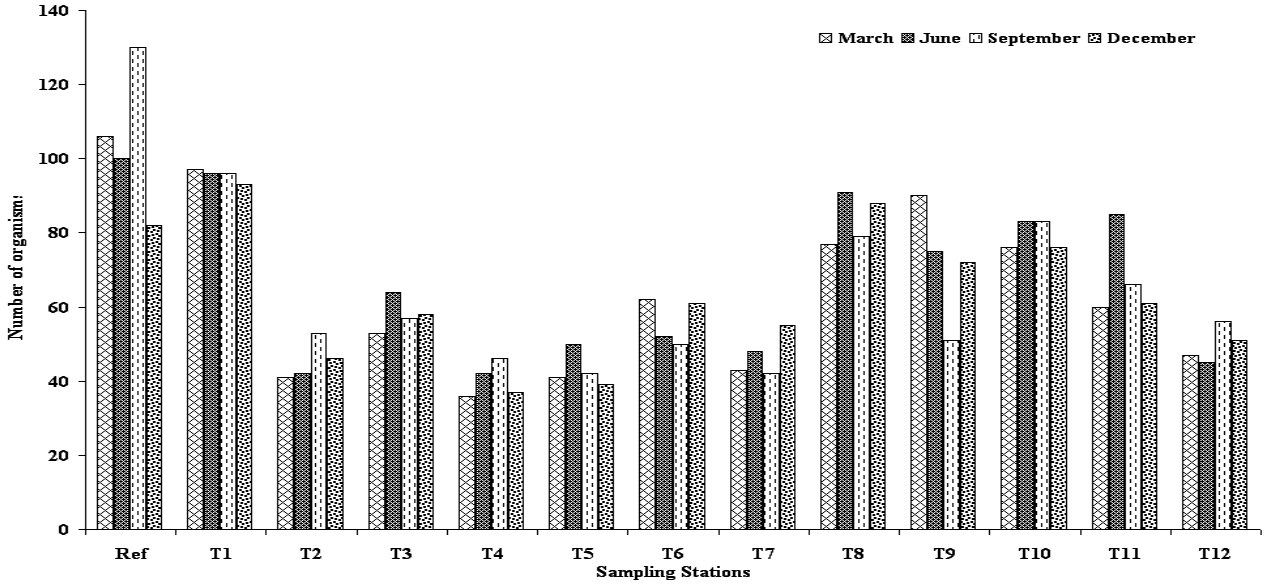

Fig. 1 Total number of organisms recorded during the study

TABLE 5 PHYSICAL CHARACTERIZATION OF SAMPLING LOCATIONS OF PERENNIAL RIVER TAMIRABARANI

Stations	Watershed Features		Riparian Vegetation	In-stream Features				Substratum		
	Nature & Land use	Bank erosion	Structure	Canopy cover	Physical alterations	Mean width	Type	Cobble	Rock	Sand
T1	Agricultural, Tourism, Devotional, Residential, Infiltration wells (PWD)	None	Trees (D), Grass, Shrubs, Irrigational	Slight	Check dam at upstream	64	Riffle	51 %	9 %	40 %
T2	Agricultural, Residential, Industrial	None	Shrubs (D), Trees, Irrigational	None	Check dam at upstream	88	Riffle, Pool	-	1 %	99 %
T3	Township area, Agricultural, Residential, Small workshops, Devotional	Slight	Shrubs, Weeds (D), Irrigational (D)	None	Check dam at upstream	97	Riffle, Pool	1 %	2 %	97 %
T4	Agricultural, Devotional, Infiltration wells (PWD), Brick works	Moderate	Irrigational, Trees (M), Shrubs	None	None	121	Riffle	-	-	100 %
T5	Agricultural, Devotional, Infiltration wells (PWD), Tourism	Moderate	Irrigational (D), Trees, Shrubs (M)	None	Islands	78	Riffle	-	-	100 %
T6	Agricultural, Industrial, Devotional	Slight	Trees (D), Shrubs, Irrigational, Weeds	Slight	Islands, Construction work	61	Riffle	-	-	100 %
T7	Urban (sub urban), Residential, Agricultural, Devotional	None	Shrubs (D), Barren lands, Weeds	None	None	82.4	Riffle	6 %	32 %	62 %
T8	Urban (District Headquarters), Residential, Industrial, Devotional,	None	Shrubs (D), Weeds	None	None	78	Riffle, Pool	-	100 %	-
T9	Urban (District Headquarters), Residential, Industrial, Agricultural	None	Shrubs (D), Weeds Irrigational	None	None	67	Riffle	19 %	29 %	52 %
T10	Agricultural, Devotional, Infiltration wells (PWD)	None	Weeds (D), Shrubs (D), Irrigational	None	River bridge alters flow	101	Riffle	-	-	100 %
T11	Township, Agricultural, Residential, Devotional, Tourism	None	Shrubs, Weeds (D) Irrigational, Trees,	None	Check dam	153	Riffle, Pool	2 %	-	98 %
T12	Township, Residential, Agricultural	None	Shrubs (D), Weeds	None	None	128	Run, Pool	-	-	100 %
Reference	Reserved forest	None	Trees (D)	Good	None	42	Riffle	78%	10%	12%
Reference	Reserved forest	None	Trees (D)	Full	None	31	Riffle	73%	21%	6%

D - Dominance; M- Moderate

TABLE 6 LIST OF OBSERVED MACROINVERTEBRATE ORGANISMS (FAMILY LEVEL) AT VARIOUS LOCATIONS OF RIVER TAMIRABARANI

Order	Family	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	R1	R2	Order	Family	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	R1	R2
Ephemeroptera	Baetidae	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	Diptera	Culicidae			✓		✓	✓		✓	✓					
	Ephemeridae	✓	✓			✓	✓							✓	✓		Tipulidae		✓	✓				✓	✓	✓	✓		✓		
	Heptageniidae	✓				✓	✓							✓	✓		Simuliidae	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓		
	Leptophlebiidae	✓												✓	✓		Ceratopogonidae		✓	✓	✓	✓	✓	✓	✓	✓				✓	✓
	Potomanthidae	✓												✓			Chironomidae		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
	Ephemerellidae	✓	✓	✓	✓	✓	✓							✓	✓	Crustacea	Palemonidae			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
	Caenidae	✓												✓	✓		Potamonautidae			✓			✓	✓	✓	✓	✓				
Plecoptera	Perlidae	✓	✓	✓	✓	✓	✓			✓	✓	✓		✓	✓	Odonata	Aeshnidae	✓	✓			✓	✓								
Trichoptera	Polycentropodidae	✓	✓				✓							✓			Lestidae		✓		✓	✓						✓			
	Rhyacophilidae	✓	✓		✓	✓	✓				✓	✓			✓		Libellulidae	✓		✓	✓	✓	✓					✓	✓		
	Hydroptilidae		✓	✓	✓	✓	✓				✓			✓	✓		Corduliidae	✓													
	Hydropsychidae		✓									✓		✓	✓		Calopterygidae										✓		✓		
	Philopotamidae	✓	✓	✓	✓	✓	✓							✓	✓		Coenagrionidae			✓				✓	✓	✓	✓	✓	✓		

	Sericostomatidae	✓	✓		✓		✓						✓	✓	Gastropoda	Viviparidae		✓							✓				
	Lepidostomatidae	✓	✓	✓		✓	✓						✓	✓		Bithyniidae						✓		✓		✓	✓			
	Glossosomatidae	✓											✓	✓		Planorbidae						✓			✓	✓	✓	✓		
	Calamoceratidae	✓		✓		✓										Lymnaeidae							✓	✓	✓	✓	✓	✓		
Hemiptera	Corixidae			✓	✓	✓	✓			✓	✓	✓				Unionidae							✓	✓		✓				
	Gerridae	✓	✓			✓	✓									Physidae				✓						✓	✓	✓		
	Nepidae (ranatra)					✓	✓			✓						Valvatidae				✓	✓			✓		✓		✓		
	Pleidae			✓				✓				✓				Ancylidae										✓	✓			
	Hydrometridae	✓		✓							✓					Hydrobiidae			✓	✓	✓		✓	✓		✓				
	Veliidae															Thiaridae		✓								✓	✓			
	Belastomatidae														Coleoptera	Gyrinidae	✓	✓		✓		✓				✓				
	Naucoridae															Dytiscidae		✓	✓		✓	✓	✓			✓		✓		
Lepidoptera	Pyralidae	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			Hydrophilidae	✓	✓		✓	✓	✓	✓		✓	✓	✓		✓	✓
Megaloptera	Sialidae	✓	✓	✓	✓					✓	✓	✓				Dryopidae														
Hirudinidae	Hirudidae	✓	✓													Psephenidae			✓			✓		✓	✓	✓				
Oligochaetae	Oligochaetae		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			Elmidae														

R1&R2-Refernce Points

TABLE 7 DESCRIPTIVE SUMMARY OF VARIOUS BIOTIC INDEX SCORE LEVELS OF RIVER TAMIRABARANI

Biotic Index	Station	N	Mean	Stdev	SE	Min	Max
FBI	T1	4	2.97	0.147	0.074	2.76	3.1
	T2	4	4.05	0.445	0.223	3.39	4.36
	T3	4	5.65	0.264	0.132	5.31	5.95
	T4	4	4.39	0.485	0.242	3.81	4.98
	T5	4	4.33	0.220	0.110	4.1	4.62
	T6	4	4.76	0.024	0.012	4.72	4.77
	T7	4	6.39	0.372	0.186	6.05	6.91
	T8	4	6.76	0.187	0.094	6.53	6.98
	T9	4	6.48	0.205	0.103	6.23	6.71
	T10	4	5.5	0.264	0.132	5.17	5.76
	T11	4	5.39	0.234	0.117	5.09	5.62
	T12	4	6.52	0.372	0.186	5.98	6.82
	Total	48	5.27	1.173	0.169	2.76	6.98
EPT	T1	4	78.25	3.202	1.601	75	81
	T2	4	19.25	4.573	2.287	16	26
	T3	4	6.75	3.403	1.702	4	11
	T4	4	16.75	3.403	1.702	12	20
	T5	4	13.25	2.754	1.377	10	16
	T6	4	13	2.449	1.225	10	16
	T7	4	1.25	0.957	0.479	0	2
	T8	4	0	0.000	0.000	0	0
	T9	4	3	1.155	0.577	2	4

	T10	4	10	4.082	2.041	7	16
	T11	4	11.75	1.708	0.854	10	14
	T12	4	0.25	0.500	0.250	0	1
	Total	48	14.46	20.571	2.969	0	81
EPT/C	T1	0	.	.	.	.	.
	T2	4	14	9.626	4.813	4	26
	T3	4	0.92	0.506	0.253	0.5	1.6
	T4	4	11.68	7.536	3.768	1.71	18
	T5	4	9.38	5.406	2.703	2.5	15
	T6	4	6.08	1.965	0.982	3.33	8
	T7	4	0.19	0.139	0.069	0	0.33
	T8	4	0.00	0.000	0.000	0	0
	T9	4	0.22	0.121	0.060	0.13	0.4
	T10	4	3.53	3.154	1.577	1.29	8
	T11	4	8.63	2.926	1.463	5.5	12
	T12	4	0.03	0.050	0.025	0	0.1
	Total	44	4.97	6.285	0.947	0	26
ASPT	T1	4	6.77	0.28	0.14	6.47	7.15
	T2	4	6.09	0.25	0.13	5.85	6.40
	T3	4	4.95	0.34	0.17	4.45	5.18
	T4	4	5.71	0.08	0.04	5.59	5.79
	T5	4	5.73	0.16	0.08	5.61	5.97
	T6	4	5.67	0.44	0.22	5.17	6.23
	T7	4	4.43	0.32	0.16	3.99	4.75
	T8	4	3.85	0.45	0.22	3.24	4.29
	T9	4	4.64	0.27	0.14	4.33	4.97
	T10	4	4.72	1.10	0.55	3.10	5.54
	T11	4	4.66	0.58	0.29	3.81	5.06
	T12	4	4.05	0.19	0.10	3.88	4.33
	Total	48	5.11	0.94	0.14	3.10	7.15
BMWP	T1	4	162.08	11.18	5.59	148.90	174.00
	T2	4	149.00	9.95	4.97	136.10	159.90
	T3	4	121.43	15.24	7.62	106.70	138.70
	T4	4	141.30	9.83	4.92	131.50	150.40
	T5	4	160.45	10.66	5.33	147.90	173.10
	T6	4	161.70	14.84	7.42	144.70	180.70
	T7	4	78.60	19.70	9.85	63.40	107.10
	T8	4	62.48	12.11	6.05	47.90	77.20
	T9	4	78.43	5.95	2.98	69.60	82.20
	T10	4	143.98	31.59	15.80	102.20	177.40
	T11	4	114.08	15.08	7.54	95.30	130.00
	T12	4	62.93	8.91	4.46	54.30	71.90
	Total	48	119.70	40.35	5.82	47.90	180.70

The family biotic index (Fig. 2) level discloses excellent quality at 10% of the sampling stations, very good quality at 6% stations, good quality at 25% stations, fair quality at 21% stations, fairly poor quality at 17% stations and poor quality of water was recorded at 21% of the sampling stations. Sampling station T1 (Pabanasam) showed similar result with the reference point; represented excellent quality whereas remaining stations showed water quality from very good to poor during the study. Pollution sensitivity group (EPT) organism was perceived at station T1 (Pabanasam) and its absence was noticed at stations T7 (Kurukkuthurai), T8 (Tirunelveli - Kokkirakulam) and T12 (Aathur) during various phases of the study. The EPT index score (Fig. 3) revealed maximum score level at station T1 whereas remaining stations showed less score level, and the results showed similarities between station T1 (Pabanasam) and reference point during the study. The EPT and Chironomidae ratio (Fig. 4) of the present study indicates that uneven distribution of the organisms at all stations. An even distribution of individuals of EPTC groups reflects good biotic condition while higher presence of Chironomids (T7 - Kurukkuthurai) alone indicates environmental stress because of its high tolerant nature. It may be due to the higher inflow of raw sewage, urban runoff and disposal of domestic wastes from adjoining urban and suburban areas directly reach the main stream flow. Absence of Chironomid organisms in station T1 (Pabanasam) and reference points indicates that the EPT/C ratio of zero during the study. The ASPT score level (Fig. 5) of the present study showed the water quality from excellent to poor during the study. Based on the results the water quality of the sampling stations was classified as excellent at 14% stations, very good at 27% stations, good at 17% stations, both moderate and moderately poor quality at 12% stations and the remaining 17% stations showed poor quality during the study. BMWP score level (Fig. 6) of the present study reveals excellent quality at 29% stations, very good quality at 37% stations, moderate quality at 31% stations and fair quality at 2% of the sampling stations.

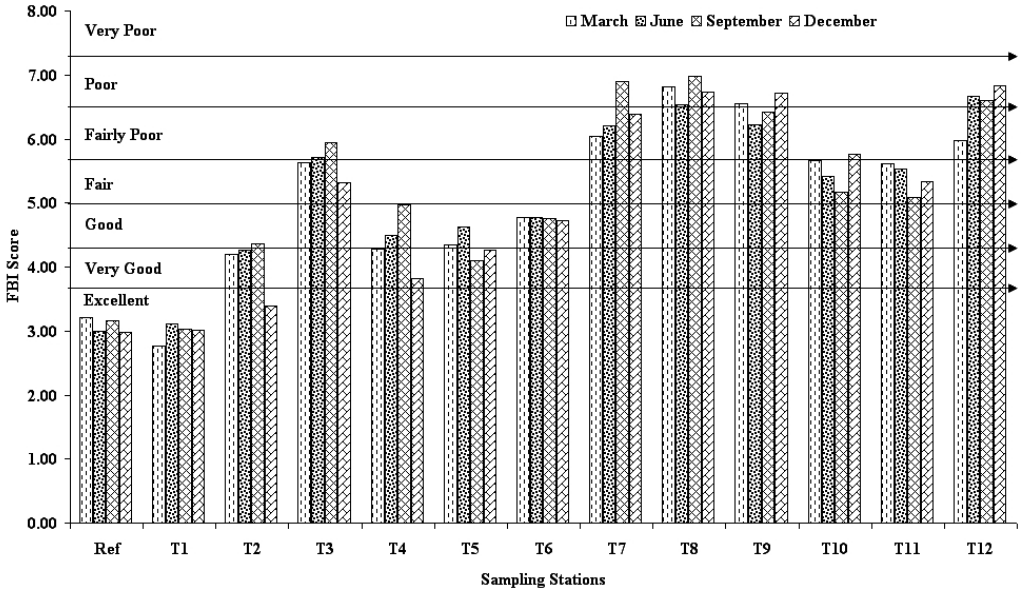

Fig. 2 Variations in the family biotic index level of river Tamirabarani

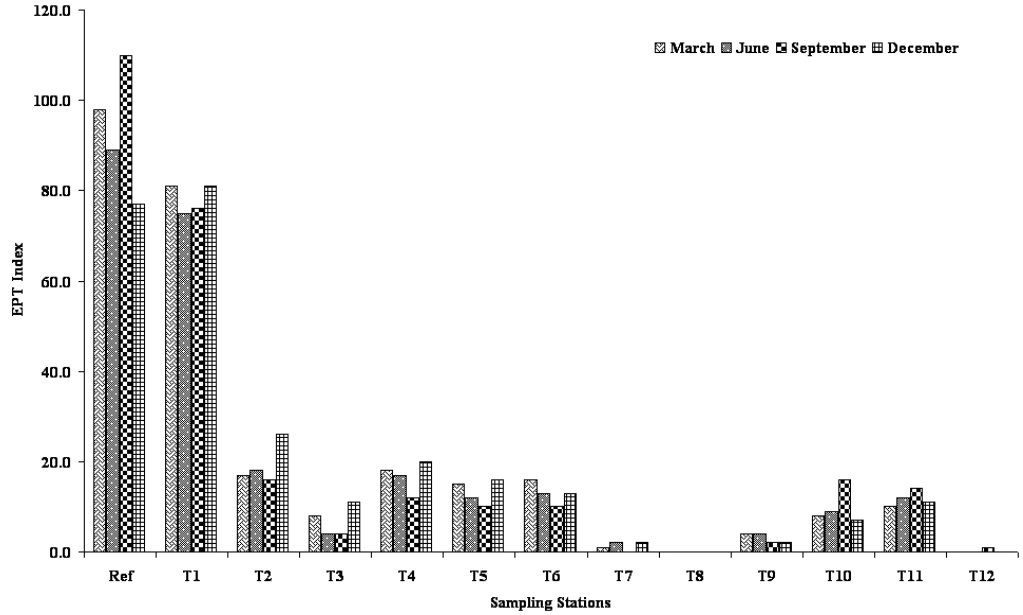

Fig. 3 Variations in the EPT index score level of river Tamirabarani

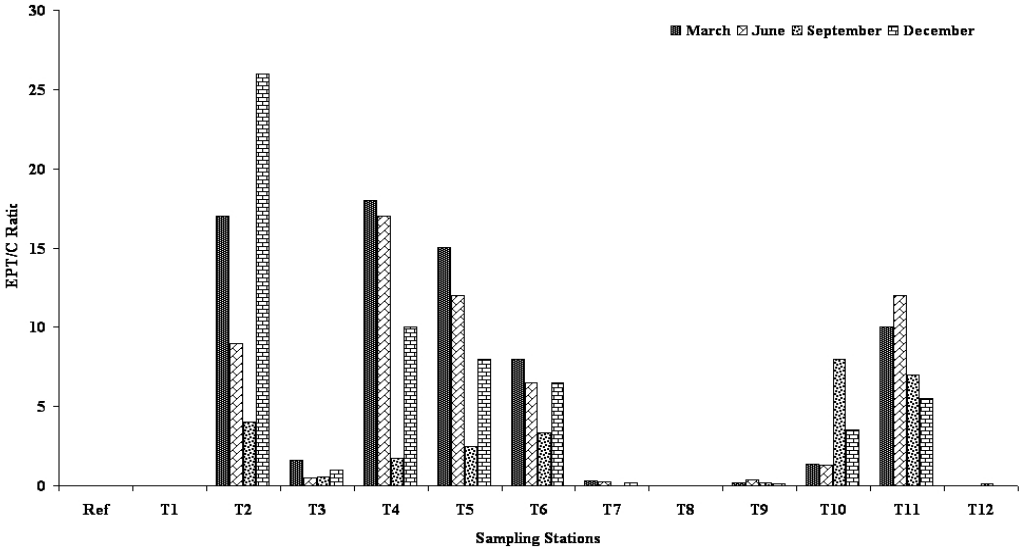

Fig. 4 Variations in the EPT/C ratio of river Tamirabarani

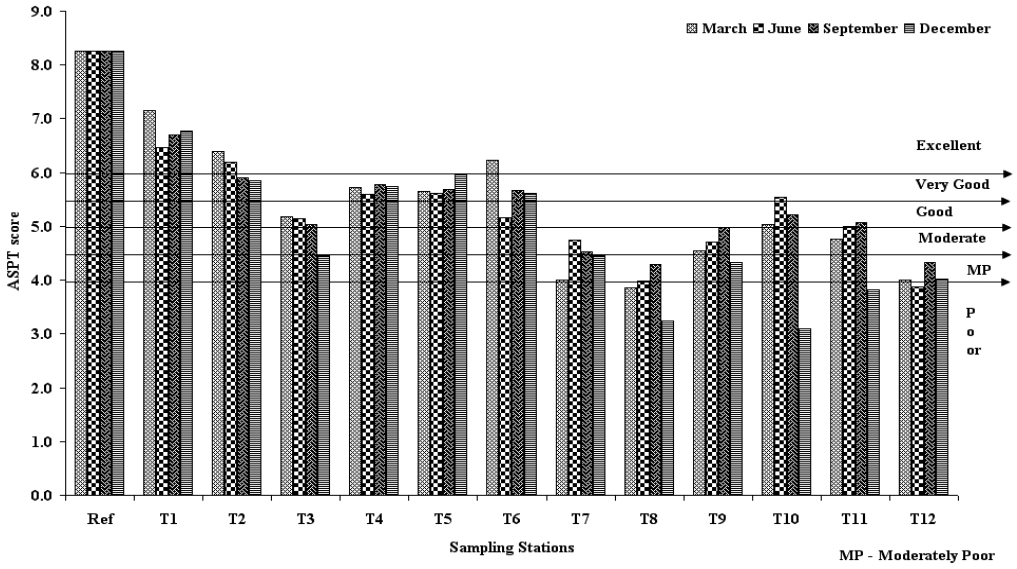

Fig. 5 Variations in the ASPT score level of river Tamirabarani

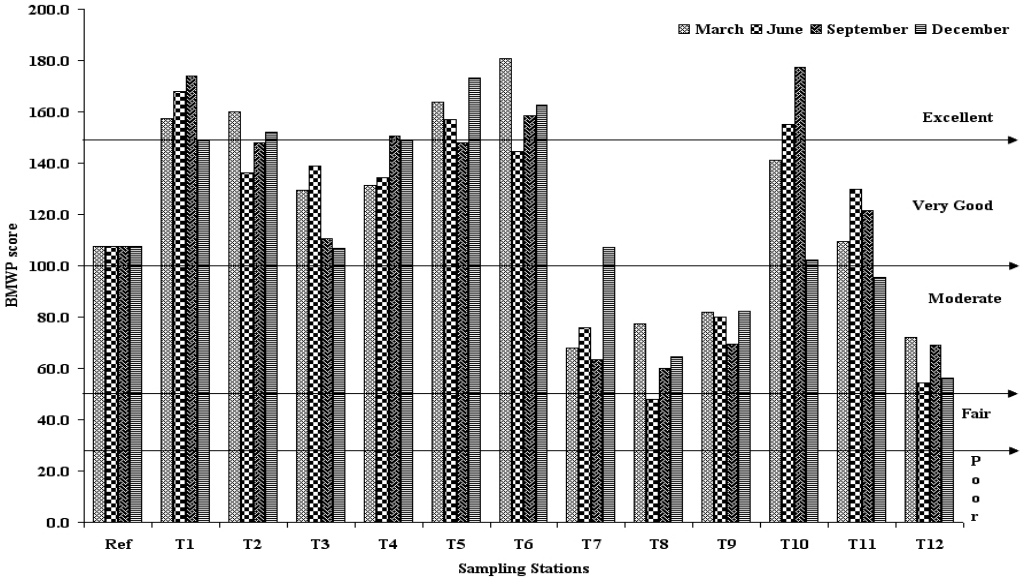

Fig. 6 Variations in the BMWP score level of river Tamirabarani

IV. DISCUSSION

The present study describes that physicochemical variables moderately influence the occurrence of organisms at the downstream areas because most of the physicochemical variables showed increased levels at downstream reaches than the upstream areas and type of substratum and consequently less availability of precise substratum also alters organism richness. Washed-out of aquatic plants during high flow periods also decreases the organism richness because bank-side or marginal zone provides refuges during periods of disturbance [42-43]. High oscillations of water velocity have a negative impact for the egg laying and hatching, as well as for survival of larvae [44]. Present results acknowledge the definition of Sandin and Hering [45] which stated organic pollution as an increase in organic components (increased BOD and nutrients) which decrease the DO content; BOD and nutrients are known to be the environmental indicators of organic enrichment [46]. BOD, TC and FC levels were exceeded during the study period at stations like T12 (Aathur), T8 (Tirunelveli - Kokkirakulam) and T9 (Tirunelveli - Vannarappettai) which is due to higher intrusion of raw sewage at upstream suburban areas and the bank activities like open defecation, disposal of domestic debris and various instream activities by the local residents. Flood occurrence during monsoon period diluted the pollutant rate and washed away all stagnant waste material which was already dumped within the river premises; which directly increased the level of organic enrichment and the formation of NH_4-N and various forms of chemical combinations during decomposition by microbial populations.

The occurrence and distribution of the benthic macroinvertebrates in aquatic ecosystems depend on innumerable factors such as: hydrological characteristics [47], substrate type [48], availability of habitats [49], physical and chemical characteristics of the water [50-51], nutrient [52], riparian vegetation removal [53], intrusion of various residues through human activities [54] and biological interactions [55]. The present study results also clearly indicate that higher rate of human activities, intrusion of raw sewage, dumping of garbage wastes, open defecation, agricultural runoff, substrate type, less availability of habitat washout of plants etc., alter the occurrence of macrobenthic organism and increase the incidence of organic content and coliform organisms in the river ecosystem. The same results were denoted by the previous studies viz., [56-59]. Religious rituals at stations T1, T2, T4, T5, T6, T7, T10 and T11 which also alters the level of organisms particularly in the downstream reaches due to higher incidence of organic material input and various recreational activities by the pilgrimage and devotees from various parts of the two districts.

The results of this study do not fully confirm the literature data of [56, 58], according to them higher densities of macro fauna are noted on stony rather than on sandy bottom whereas the present study results showed macro fauna richness on sandy as well as stony substratum because most of the sampling stations like T2 (V.K.Puram) to T6 (Cheranmahadevi), T10 (Seevalapperi), T11 (Srivaigundam) and T12 (Aathur) were entirely enclosed with sandy substratum rather than stony bottom. Biotic indexes are one of several types of measures that are routinely used in biological monitoring in temperate streams and offer interesting possibilities to assess the environmental quality of rivers. The Family level Biotic Index is a synthetic index used in field assessment of organic pollution [60]. Present results also showed poor quality of water at stations T7 (Kurukkuthurai), T8 (Tirunelveli - Kokkirakulam), T9 (Tirunelveli - Vannarappettai) and T12 (Aathur) through Family level Biotic Index calculation. According to [61] the major aquatic insect taxa of Ephemeroptera, Plecoptera, and Trichoptera complexes are absent in the Tamirabarani River. In contrast during the present study; the river Tamirabarani and its tributaries recorded with the presence of pollution sensitive taxas (EPT). The present study results confess the previous study by [62]; [63], who found abundance and species richness of Ephemeroptera, Plecoptera, and Trichoptera complexes in the Tamirabarani River basin of Courtallam hills and Shenbagadevi falls. High values of EPT index scores are indicative for good water quality, and the low values are a signal for the water quality deterioration [64]. ASPT score and BMWP score system of the present study also showed the water quality of excellent to poor and fair.

EPT/C ratio of the present results showed imbalanced community structure at stations T1 (Pabanasam), T2 (V.K.Puram), T4 (Thiruppudaimaruthur) to T12 (Aathur) of the river system because a community with even distribution of pollution sensitive organism and pollution tolerant organisms considered being good biotic condition [34] whereas the uneven distribution of the Ephemeroptera, Plecoptera, Tricoptera and Chironomidae in the river stretch also reveals the same in quality of excellent to poor due to various in-stream and river bank activities.

Higher intrusion of raw domestic sewer system from Tirunelveli city and suburban areas reaches the river flow between the stations T6 (Cheranmahadevi) and T10 (Seevalapperi) which contributes higher organic content [20] thus reduces the level of EPT families and increases the abundance of Chironomids and Oligochaeta in successive locations up to T8 (Tirunelveli - Kokkirakulam) (Figs. 3 and 4). Likewise less flow at riverside areas, open defecation, cattle grazing, laundry activities, waste disposal also increase the pollutant load when the river reaches the city province. Present results showed similarities with the findings of [65] which stated that increase in nutrients and organic matter produced elevated densities of the Oligochaeta, but when the disturbance also involved changes in the physical habitat or enhancements in toxic substances, the abundance decreased significantly to values even lower than those of non-impacted environments.

Presence of higher order families like Ephemeroptera, Plecoptera and Tricoptera in reference locations is almost absent in the stations like T7 (Kurukkuthurai) and T8 (Tirunelveli - Kokkirakulam) which represent the higher pollutant level and the organisms are more vulnerable to the pollutant stress whereas their presence is recorded in downstream reaches of locations T9 (Tirunelveli - Vannarappettai) to T12 (Aathur); the discontinuity in the presence of organisms denotes the level of pollution over a period of time [64, 50, 51].

V. CONCLUSION

It can be concluded from the results of this present study the water quality of the river Tamirabarani is presently safe from physicochemical point of view at the headwater region and upstream areas whereas at downstream areas the quality was unsupported for direct consumption. Moreover, occurrence of coliforms throughout the entire river stretches worsens the quality. Biological monitoring study results reveal excellent to poor quality of water throughout the entire stretch. There is a slight fluctuation between the biotic index score levels; may be due to the inadequate habitat and substratum at most of the studied stretches. Fluctuations in the physicochemical variables may due to the seasonal variations and fluctuations in the discharge level. The present study concludes that combination of physicochemical and biological measures gives exact condition of the Tamirabarani river system.

In spite of all this human harassment, the aquatic community was indicative of clean-water conditions at head water regions because of the high abundance of pollution sensitive species. This translated into the high scores for the FBI, EPT index, ASPT and BMWP index systems. Downstream areas after station T3 (Ambasamudram) indicate up to poor quality of water through organic contamination during various phases whereas, higher discharge throughout the year increases the dilution which inturn decreases the pollutant concentration during the course of its flow. Physicochemical approach of the present study provides a snapshot of the river at the time of sampling but in contrast biomonitoring study and biotic indices provide an indication of the long-term changes of the river system. The study showed that using macroinvertebrates in water quality assessment provides positive and promising results because they show noticeable sensitivity to environmental changes hence, the study concludes that the macroinvertebrate organisms were good biological indicators of pollution in lotic environments.

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