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Monitoring aquatic macroinvertebrates as indicators for assessing the health of lakes in Bangalore, Karnataka

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Abstract

Lakes, important ecosystems of great value to humans are prone to pollution from autochthonous and allochthonous sources; the latter include various anthropogenic stresses that disturb the complex interactions and self purification capacity of aquatic ecosystems. The physical and chemical factors influencing aquatic ecosystems decide as well their biological diversity, of which the macroinvertebrates are the focus of this study. The diversity and abundance of aquatic macroinvertebrates might vary at the inlets and outlets of urban lakes depending upon the pollution levels and purification capacity of the lake ecosystems as such. The current study, carried out in 17 spatially well distributed lakes in around Bangalore city explores macroinvertebrate diversity and abundance at the inlets and outlets of these lakes, in relation to physico-chemical parameters of the water. The samples were collected from the inlets and outlets of the lakes concerned and macro-invertebrate diversity studied. The results of one way ANOVA pointed out that no significant differences ($P < 0.05$) were found between the macroinvertebrate communities of inlets and outlets of all the lakes studied, indicating high degree of pollution beyond the self cleansing powers of the lakes. The first axis of principle component analysis accounted for 25.69 % of the overall variance and was most heavily weighted on the variables pH, total hardness, dissolved oxygen, and nitrate. Canonical component analysis ordination for 27 aquatic genera in 17 lakes with 14 environmental variables show that phosphate, nitrate and pH played more decisive roles in the macroinvertebrate diversity and assemblage of Bangalore lakes.

Keywords: Lake biodiversity, Macroinvertebrate, ecosystem, functional feeding group, environmental parameters

Introduction

Lakes are fragile ecosystems which while contributing to suitable climatic conditions for life on the earth also meet vital needs of humans in many ways. These fragile ecosystems function as kidneys of the landscape through the uptake of nutrients from their surroundings. They are sources of water for agriculture, drinking, domestic use and livestock rearing (Ramachandra, 2009a). Close to human habitations the lakes make the air cooler in hot summer months. Their very presence renders aesthetic beauty to the landscape and promotes tourism and recreation. While supporting inland fisheries, the lakes especially their edges, overgrown with marsh grasses and other herbage furnish fodder for livestock. Large lakes support water transport energy, help in stabilizing local climate. They recharge ground water and channalise water flow to prevent water logging and flooding. They act as important crucibles for aquatic biodiversity of which the macro-invertebrates play a critical role in ecosystem balance by facilitating flow of energy and matter through food web and constitute an important trophic level in the aquatic ecosystem. (Verneaux *et al.*, 2004 and Ramachandra ,2009b).

Macroinvertebrate composition, abundance and distribution are influenced by water quality. Most of urban lakes of India have been polluted due to unplanned urbanisation by organic matter from both point source (industries and domestic), non-point source pollution (agri and storm water runoff) and autochthonous sources (mainly planktons) directly influencing the light penetration and affecting the production efficiencies in lakes (Zutchi *et al.*, 2008 and Ramachandra, 2009). Anthropogenic stresses are disturbing complex fragile interactions and self-cleansing or treatment capability of aquatic eco-systems. These influence aquatic macroinvertebrates as reflected in their assemblages and species compositions. If the inflows of pollutants are below the lake's self cleaning capacity, then impacts get attenuated in the lakes as evidenced by improved water quality at outlets compared to inlets. However, in most urban lakes, levels of pollution have crossed the threshold resulting in eutrophic status.

The distribution and diversity of macro-invertebrates are interrelated to water quality, evident from the rising richness of macroinvertebrates in tune with levels of organic pollution. Their relative abundance has been used to make inferences about pollution loads (Azrina *et al.*, 2006). Presence and absence of dominant species and the degree of community assemblages reflect pollution levels making macro-invertebrates good bioindicators. Bhattacharya (2000), Khan and Ghosh (2001), Saha *et al.* (2007) and Jana *et al.* (2009), documented the diversity and ecology of lake ecosystems in north and north-east regions of India. Benjamin *et al.* (1996) reported the causal factors for fish mortality in Bangalore lakes. Earlier studies focusing on wetland restoration and conservation (Ramachandra and Ahalya, 2001 and Ramachandra, 2009 a,b), physicochemical analysis and role of phytoplankton (Roselene and Paneerselvam, 2008) and macroinvertebrate diversity and water quality of nine lakes of Bangalore (Balachandran and Ramachandra, 2010), reveal diversity, health of lake ecosystem and conservation related issues. The assemblage and abundance of aquatic macroinvertebrates varies in inlet and outlets depending upon the nutrient availability in urban stressed lakes (Richardson and Mackay, 1991) and there are very few studies supporting this model. In this context, the present study examines the macro invertebrate diversity and abundance in inlet and outlets along with environmental parameters of selected lakes in and around the Bangalore city to explore the possibility of using macro invertebrates as surrogates for environmental conditions.

Materials and Methods

Study area: Bangalore is the capital of Karnataka state and it is located in the heart of south Deccan of Peninsular India (12 58 ' N and 77 35 ' E and at about 920 m above the mean sea level). The climate of the locality is having agreeable temperature ranging from the lowest, 11.4°C (January) to 36.2°C (May). It experiences two rainy seasons from June to September (south west monsoon) and from October to November (north east monsoon). The present study has been carried out in 17 lakes located in three major watersheds of Bangalore - Vrishabavarthy, Koramangla-Challagatta and Hebbal Valley watersheds (Fig.-1). Lakes chosen in and around Bangalore city are Anchepalya, Lakkenahalli, Yellamma, Varthur, Abbigere, Kommagondanahalli, Malsandra, Valley School, Nellakondoddi, Vaderahalli, Begur, Hulimavu, Madivala, Rayasandra, Bommasandra, Muthanallur and Hennagara.

Method: Samples of macroinvertebrates were collected at each sampling site using a 'D' frame hand net (frame 30 ×30 cm, mesh size 300 μm) disturbing the substrate of littoral zone for 3 minutes covering 1 m^2 area with different substrate. Hand picking method was also used in some conditions. The collected macroinvertebrates samples were preserved in 70% ethanol. Organisms were hand-sorted under a stereoscopic microscope, identified with the help of identification manual and literatures (Dudgeon, 1999; Merrit and Cummins, 1994; Subramanian and Sivaramakrishnan, 2005 and 2007). Taxa were assigned to a trophic category based on Merrit and Cummins (1994) and Morse *et al.* (1994). The physico-chemical parameters like temperature, pH, turbidity dissolved oxygen (DO), free carbon dioxide, etc. were measured at the sampling sites, while other parameters like total hardness, chloride, total alkalinity, chemical oxygen demand (COD), nitrate, phosphate, sodium and potassium were measured in laboratory using standard protocols (APHA, 1998).

Data analysis: Species diversity indices such as Shannon-Weiner, Simpson's, Pielou evenness, and Margaleg were computed to understand a particular biotic community (Chakrabarty and Das, 2006). Shannon-Weiner diversity index helps in species relative abundance, Simpson's diversity index weighs towards the abundance of the most common species. Pielou evenness index is used for the degree to which the abundances are equal among the species present in a sample or community. Margalef index is having a good discriminating ability and is sensitive to sample size. It is a measure of the number of species present for a given number of individuals. Cluster analysis of Jaccard index of similarity was used to compare both inlet and outlet of 17 lakes based on presence and absence data of macroinvertebrates. ANOVA (one-way analysis of variance) was used to find significant differences between inlets and outlets of each lake. Environmental parameter data ($\log(x+1)$) were transformed and used for principal component analysis (PCA). PCA was applied to relate the relationship between different study sites and physico-chemical variables. Canonical correspondence analysis (CCA) is a multivariate analysis to explain the relationships between macroinvertebrate species assemblages and their environment. It is used as a preliminary analysis for determining whether particular variable influence species diversity and abundance or not. Calculations were done using package PAST version 2.04.

Results and discussion

Community analysis of macroinvertebrates: A total of 2010 individuals of aquatic macroinvertebrates belonging to 27 genera, 25 families, 10 orders and three phyla were identified from 36 (both inlet and outlet) sampling sites in 17 lakes of Bangalore. Diversity of macroinvertebrate with the functional feeding groups is listed out in the table - 2. Shannon diversity and Simpson's diversity indices were higher in Bommasandra, and lower in Yellamma (1.81, 0.79 and 0.35, 0.20) inlet respectively. Species richness (Margalegf) was lower in Yellamma inlet (0.46) and higher in Malsandra inlet (2.18). Evenness was higher in Nellakondoddi (0.97) and lower in Malsandra (0.56) inlets (Table - 3).

Totally 26 genera of macroinvertebrates were found in the outlets, except *Gabbia* sp., belonging to the Bithynidae families, which was exclusively found at inlets. Genera like *Caenis* sp., *Gerris* sp., *Orectochilus* sp., *Hirudinid* sp., *Bellamya* sp. were not found in any of the inlets but were present in the outlets. Hemiptera was the major group present in inlets, which contained species like *Micronecta* sp., *Diplonychus* sp., *Nychia* sp., *Naucoris* sp., *Ranatra* sp., *Laccotrephes* sp. *Plea* sp., followed by *Cloeon* sp. of the order Ephemeroptera. Odanata, Diptera and Decapoda constituted >40% of total macroinvertebrate richness in inlets and other groups were < 40%. The most abundant groups were *Micronecta* sp. (34.61%) *Chironominus* sp (19.84%), *Cloeon* sp. (18.72), and whereas *Bellamya* sp. (0.04%) Gabbia sp. (0.04%) and *Caenis* sp (0.09%) were found very less while remaining groups of macroinvertebrates were moderately present.

Table - 1a. Physico-chemical parameters of inlets and outlets of different urban lakes in Banalgore.

S.No	Places	Code	pH	DO	TU	CO_2	COD	BOD	Al
1.	Anchinapalaya	AP(in)	8.4	0	77.1	0	197.33	54.86	660
		AP(o)	8.01	9.1	60.6	161.9	144	56.89	500
2.	Lakkenahalli	LH(in)	7.41	5.53	7.66	158.4	154.67	40.63	420
		LH(o)	7.45	0	4.4	3.52	176	37.93	180
3.	Yellamma	YM(in)	7.7	0	44.4	7.04	64	74.5	420
		YM(o)	7.73	2.6	48.9	9.152	101.33	68.4	560
4.	Varthur	VR(in)	7.92	0	36.6	172.5	153.33	30.48	360
		VR(o1)	7.53	2	86.9	14.08	133.33	37.25	380
		VR(o2)	7.66	0.7	86.2	7.744	140	10.16	380
5.	Abbigere	AB(in)	7.66	5.2	34.2	80.96	186.67	37.25	360
		AB(o)	8.33	4.6	38.1	17.95	240	50.79	190
6.	Kommagondana-halli	KH(i)	8.05	3.9	124	0	474.67	57.57	400
		KH(o)	8.31	9.8	41.9	0	106.67	50.79	400
7.	Malsandra	MS(in)	9.05	9.76	58.4	0	442.67	71.11	260
		MS(o)	8.97	8.3	52.7	70.4	480	44.02	220
8.	Valley school	VS(i)	9.05	6.2	19.3	0	248	12.87	510
		VS(o)	8.7	8.13	14.6	88	232	10.16	500
9.	Nellalondoddi	ND(in)	9.01	7.2	24.4	22.88	236	12.87	420
		ND(o)	8.05	10.98	22.9	24.64	232	20.32	400
10.	Vaderahalli	VH(i)	8.5	6.2	12.8	0	232	16.93	340
		VH(o)	8.6	7.8	10.6	0	236	28.44	340
11.	Begur	BR(i)	8.01	4.8	14	0	58.67	50.12	240
		BR(o)	7.79	5.9	12	0	42.67	48.76	220
12.	Hulimavu	HU(i)	7.49	3.09	17.4	99.12	53.33	44.7	238
		HU(o)	7.4	4.9	53	99.12	42.67	38.6	256
13.	Madivala	MW(i)	7.91	6.83	26.3	0	74.67	58.24	226
		MW(o)	8.33	11.1	12.3	0	64	52.15	256
14.	Rayasandra	RS(i)	8.4	10.41	17.7	0	42.67	61.63	660
		RS(o)	7.8	4.6	28.1	7	37.33	49.44	660
15.	Bommasandra	BS(i1)	8.5	13.01	67.6	0	138.67	52.82	1180
		BS(i2)	8.5	0	66.6	0	58.67	60.27	1100
		BS(o)	8.6	7.2	57.6	0	64	54.86	1100
16.	Muthanallur	MN(i)	8	7.8	16.1	0	37.33	50.79	560
		MN(o)	7.2	10.1	22.7	0	42.67	53.5	540
17.	Hennagara	HN(i)	7.1	14.31	29.2	0	58.67	39.96	680
		HN(o)	7.2	9.1	24.7	0	37.33	60.95	520

Table - 1b. Physico-chemical parameters of inlets and outlets of different urban lakes in Banalgore.

S.No	Place	Code	T.H	C.H	Cl	Po_4	No_3	Na	K
1	Anchinapalaya	AP(in)	512	424.34	88.04	5.261	0.44	1420	1130
		AP(o)	524	476.38	105.08	2.127	0.59	6564.5	1140
2	Lakkenahalli	LH(in)	564	472.38	105.08	0.091	0.5	287	68
		LH(o)	712	568.45	244.24	0.163	0.23	1875	680
3	Yellamma	YM(in)	524	440.35	107.92	0.511	2.57	--	--
		YM(o)	280	180.14	167.56	2.981	0.39	205.5	65.5
4	Varthur	VR(in)	236	184.15	90.88	2.984	1.74	200	52
		VR(o1)	256	192.15	90.88	3.029	1.57	198.5	45.5
		VR(o2)	236	164.13	82.36	2.422	1.7	198.5	48
5	Abbigere	AB(in)	404	344.27	221.52	0.65	0.23	273	2
		AB(o)	228	184.15	133.48	0.12	0.55	197	39.5
6	Kommagondana-halli	KH(i)	444	392.31	136.32	2.964	3.22	201.5	62
		KH(o)	1292	964.77	130.64	4.178	0.63	316.5	59.5
7	Malsandra	MS(in)	536	316.25	107.92	0.817	0.7	201.5	90.5
		MS(o)	608	432.34	102.24	0.586	2.61	200	61.5
8	Valley school	VS(i)	276	68.05	127.8	-	-	230	7
		VS(o)	252	48.04	19.88	0.26	0.18	179	16.5
9	Nellalondoddi	ND(in)	364	36.03	39.76	0.11	0.02	357.5	18.5
		ND(o)	300	16.01	31.24	0.16	0.18	304.5	15.5
10	Vaderahalli	VH(i)	284	160.13	31.24	0.08	0.36	160.5	15
		VH(o)	276	120.1	31.24	0.04	0.06	1325	16
11	Begur	BR(i)	176	96.08	116.44	0.025	0.57	205	52
		BR(o)	224	96.08	110.76	0.005	0.73	179	48.2
12	Hulimavu	HU(i)	288	172.14	187.44	0.484	0.62	205	36
		HU(o)	292	160.13	184.6	0.269	0.59	198	56
13	Madivala	MW(i)	236	88.07	119.28	0.039	0.62	303	45
		MW(o)	272	92.07	110.76	0.059	0.62	202	59
14	Rayasandra	RS(i)	468	176.14	150.52	0.037	0.23	18.38	0
		RS(o)	404	32.03	269.8	1.187	0.61	18.38	0
15	Bommasandra	BS(i)	480	348.28	335.12	0.265	0.18	22.84	0
		BS(i)	524	260.21	346.48	0.282	0.17	23.39	0
		BS(o)	488	268.21	346.48	0.31	0.19	23.95	0
16	Muthanallur	MN(i)	356	172.14	298.2	0.005	0.15	20.05	0
		MN(o)	404	152.12	306.72	0.031	0.15	18.94	0
17	Hennagara	HN(i)	336	124.1	133.48	0.01	0.12	15.6	0
		HN(o)	312	116.09	127.8	0.063	0.15	13.37	0

Table - 2: Macroinvertebrates diversity with FFG category of urban lakes of Bangalore.

Order / Phylum	Family	Genus	Code	FFG
Ephemeroptera	Baetidae	*Cloeon sp.*	Clo	Collector-gatherer
	Caenidae	*Caenis sp.*	Cae	Scraper
Hemiptera	Corixidae	*Micronecta sp.*	Min	piercer (herbivores)
	Notonectidae	*Nychia sp.*	Nyc	Predators
	Naucoridae	*Naucoris sp.*	Nau	Predators
	Belostomatidae	*Diplonychus*	Dip	Predators
	Pleidae	*plea sp.*	Ple	Predators
	Nepidae	*Laccotrephes sp.*	Lac	Predators
	Nepidae	*Ranatra sp.*	Ran	Predators
	Gerridae	*Gerris sp.*	Ger	Predators
Odanata	Coenagrionidiae	*Paraceriagrion sp.*	Cer	Predators
	Libellulidae	*Crocothemis sp.*	Cro	Predators
Tricoptera	leptoceridae	*Leptocerus sp.*	Lep	Shredders
Coleoptera	Gyrinidae	*Orectochilus sp.*	Ore	Predators
	Gyrinidae	*Gyrinus sp.*	Gyr	Predators
	Curculionidae	*Bagous sp.*	Bag	Shredders
Diptera	Chironomidae	*Chironominus sp.*	Chi	Collector-gatherer
	Culicidae	*Culex sp.*	Cul	Collector-gatherer
Decapoda	Carideae	*Caridina sp.*	Car	-
Annelida	Hirudinea	*Hirudinid sp.*	Hir	Predators
Mollusca	Planorbidae	*Indoplanorbis sp.*	Idp	Scraper
	Planorbidae	*Gyraulus sp.*	Grs	Collector-gatherer
	Physidae	*Physa sp.*	Phy	Collector-gatherer
	Thiaridae	*Melanoides sp.*	Mel	Collector-gatherer
	Viviparidae	*Bellamya sp.*	Bel	Scraper
	Bithynidae	*Gabbia sp.*	Gab	Scraper
	Lymnaidae	*Lymniana sp.*	Lym	Collector-gatherer

Table – 3. Diversity indices of macroinvertebrates in 17 inlets and outlets of different urban lakes of Bangalore

	Taxa		Shannon (H)		Simpson (1-D)		Evenness		Margalef	
	Inlet	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**
AP	**2**	**3**	0.60	0.88	0.41	0.54	0.91	0.80	0.51	0.60
LH	5	**3**	1.16	**0.48**	0.57	**0.24**	0.64	0.54	1.36	**0.59**
YM	**2**	**3**	**0.35**	0.90	**0.20**	0.53	0.71	0.82	**0.46**	0.96
VR1	5	**3**	1.37	1.06	0.69	0.64	0.78	0.96	1.67	1.24
VR2	-	**3**	-	1.08	-	0.65	-	**0.98**	-	1.03
AB	4	**3**	1.12	0.69	0.61	0.40	0.77	0.66	1.25	0.67

KH	6	7	1.28	1.11	0.68	0.52	0.60	0.44	0.84	1.19
MS	**5**	9	1.62	0.84	0.72	0.40	**0.56**	0.46	**2.18**	1.00
VS	4	7	1.29	**1.85**	0.69	**0.83**	0.91	0.90	1.25	2.34
VH	3	5	1.04	1.03	0.63	0.51	0.95	0.56	0.72	1.01
BR	4	3	1.33	0.86	0.72	0.51	0.95	0.79	1.86	0.83
MW	4	5	1.28	1.26	0.69	0.66	0.90	0.71	1.54	1.48
HU	5	**10**	1.42	0.78	0.72	0.32	0.83	**0.22**	1.61	1.41
RS	4	7	1.26	**1.85**	0.69	**0.83**	0.88	0.91	1.04	**2.50**
BS1	**9**	9	1.73	1.40	0.78	0.63	0.63	0.45	1.69	1.59
BS2	**9**	-	**1.81**	-	**0.79**	-	0.68	-	1.90	-
MN	5	4	1.06	1.28	0.54	0.69	0.58	0.90	0.97	1.54
HN	7	5	1.60	1.56	0.76	0.78	0.71	0.95	1.69	1.61
ND	3	7	1.07	1.79	0.64	0.81	**0.97**	0.86	0.83	1.91

Table - 4: Functional Feeding Group (%) of macroinvertebrates in inlets and outlet of 17 lakes of Bangalore.

S.no	Places	Collector (%)		Piercer (%)		Predators(%)		Scraper(%)		Shredders(%)	
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1	AP	71.4	57.1	28.6	0.0	0.0	0.0	0.0	42.9	0.0	0.0
2	LH	70.6	89.3	0.0	0.0	29.4	10.7	0.0	0.0	0.0	0.0
3	YM	0.0	0.0	**88.9**	0.0	11.1	62.5	0.0	37.5	0.0	0.0
4	VR	20.0	0.0	0.0	**40.0**	26.7	0.0	53.3	40.0	0.0	**20.0**
	VR	-	0.0	-	0.0	-	60.0	-	40.0	-	0.0
5	AB	85.7	0.0	0.0	0.0	14.3	33.3	0.0	0.0	0.0	0.0
6	KH	48.3	21.4	6.9	4.5	0.3	3.9	44.5	**70.1**	0.0	0.0
7	MS	81.8	**98.1**	0.0	0.0	9.1	1.9	9.1	0.0	0.0	0.0
8	ND	**96.5**	46.0	0.0	0.0	3.5	40.0	0.0	14.0	0.0	0.0
9	VS	0.0	20.0	0.0	0.0	42.9	**70.0**	42.9	0.0	14.3	10.0
10	VH	83.3	63.6	0.0	0.0	16.7	36.4	0.0	0.0	0.0	0.0
11	BR	55.6	70.0	0.0	0.0	**44.4**	30.0	0.0	38.5	0.0	0.0
12	MW	33.3	53.8	0.0	0.0	16.7	7.7	50.0	9.2	0.0	0.0
13	HU	42.9	89.8	0.0	0.0	14.3	1.0	42.9	25.0	0.0	0.0
14	RS	0.0	25.0	0.0	0.0	30.0	50.0	**70.0**	0.0	0.0	0.0
15	BS	23.5	59.1	0.0	11.4	17.6	26.1	27.9	3.4	**30.9**	0.0
	BS	34.5	-	0.0	-	8.6	-	56.9	-	0.0	-
16	MN	89.4	50.0	0.0	0.0	10.6	0.0	0.0	0.0	0.0	0.0
17	HN	71.4	33.3	0.0	0.0	14.3	66.7	14.3	0.0	0.0	0.0

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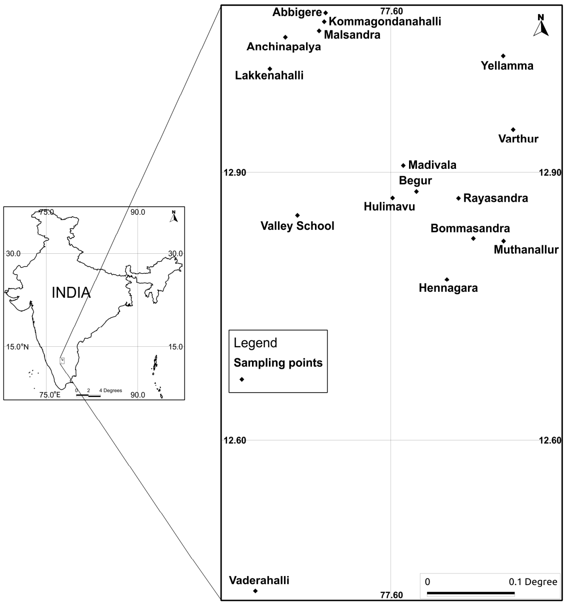

Fig – 1. A map showing location of 17 lakes in an around the Bangalore lakes.

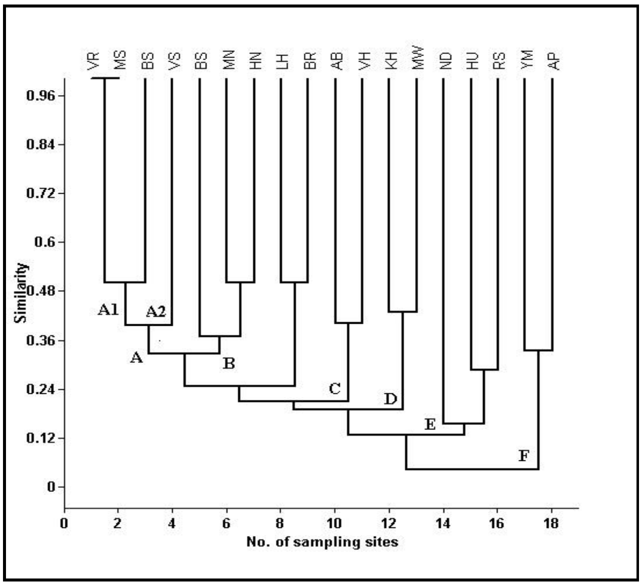

Fig – 2. Cluster analysis of Jaccard index similarity macroinvertebrate present in different urban lakes inlets of Bangalore. For lake codes see Table -1

The result of Jaccard cluster analysis, based on macroinvertebrate presence/absence data, divided lake inlets into six basic clusters (A to F) as given in Fig -2.

The first cluster A is subdivided into two clusters (A1, A2). Two lakes inlets (Varthur and Malsandra) were grouped under sub-cluster A1. The taxa of these two lakes are absolutely very similar. Sub cluster A1 consists of only lake (Valley School) and the common taxa found here were *Cloeon* sp, *Indoplanorbis* sp. and *Ceriagrion* sp. Cluster B consists of three lakes (Bommasandra, Muthanallur and Hennagara); they contained *Cloeon sp*., *Micronecta* sp., and *Ceriagrion* sp. Two lakes (Abbigere and Vaderahalli) were grouped under the cluster C, and the similar taxa found here were like *Cloeon* sp. and *Cardia* sp. Cluster D had two lakes (Kommagondanahalli and Madivala), characterized by the commonness of *Cloeon* sp., *Diplonychus* sp. and *Bagous* sp. Three lakes were grouped under cluster E had *Chironominus* sp. The cluster F (Anchepalya and Yellamma lakes) characterized by *Naucoris* sp. had very less diversity.

Eighteen outlet sites were divided into three basic clusters based on presence and /or absence data (Fig - 3). The cluster B is divided into two subclusters B1 and B2. B1 has two groups, one based on high genera richness (7 to 10) and the second with lesser richness (4 to 7). In this group of lakes the taxa commonly found were *Cloeon* sp., *Micronecta* sp., *Nychia* sp., *Ceriagrion* sp. Subcluster B2 consists of five lakes namely Begur, Lakkenahalli, Valley School, Abbigere and Vaderahalli containing common taxa like *Cloeon* sp., and *Caridina* sp. The cluster A includes 3 lake outlets (Yellamma, Anchepalya and Kommagon- danahalli) with relative less diversity in Yellamma and Anchepalya; these had very similar taxa like *Micronecta* sp., *Bagous* sp. and *Chironominus* sp. Cluster C also contain less diversity in Varthur outlet 2 and Hennagara lakes. The results of one way ANOVA pointed out that no significant differences ($P<0.05$) were found between the macroinvertebrate communities of inlets and outlets of urban lakes of Bangalore.

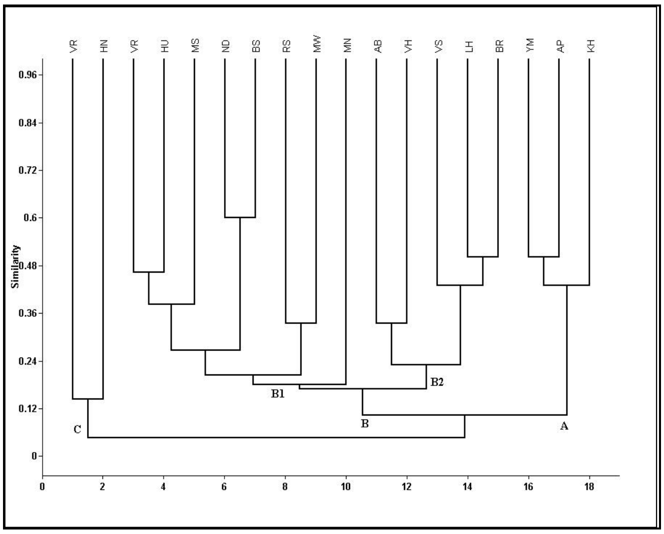

Figure 3: Cluster analysis of Jaccard index similarity macroinvertebrate present in different urban lakes outlets of Bangalore. For lake codes see Table -1.

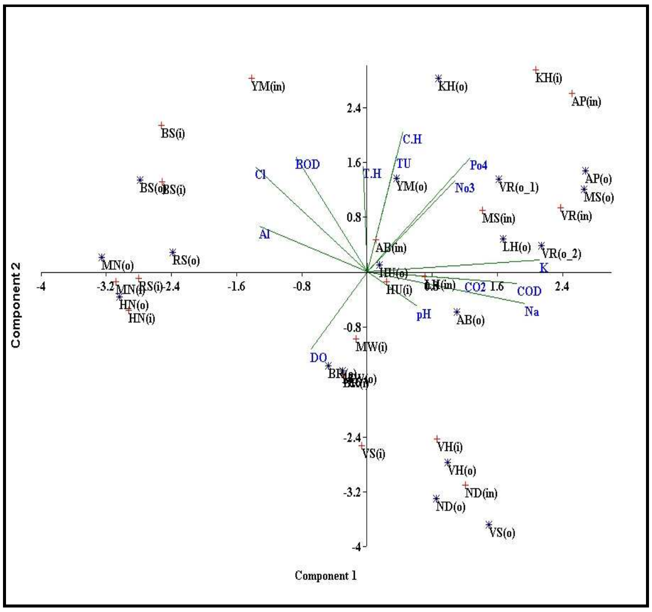

Figure 4: Principle component analysis (PCA) shows that relationship between environmental parameter and different sampling sites of various urban lakes in Bangalore. Details of code are given in the table - 1.

The function feeding group of collectors- gatherer ranged between 0 and 96.5% in inlets of lakes, where as outlets ranged between 0 and 98.1% (Table-4). Six lakes were found to have higher values for outlets than for inlets. The scrapers ranged from 0 to 70% in inlets and outlets of lakes. The piercer- herbivores was recorded ranged between 0 and 88.9% in inlets of lakes, whereas outlets range from 0 to 40%. The predator was recorded ranged between 0 and 44.4% in inlets of lakes, while the outlets ranged between 0 and 70%. The shredder was recorded range between 0 and 30.9% in inlets of lakes, whereas outlets range from 0 to 20%, which are almost consequently absent in lakes except Valley school, Varthur and Bommasandra. The result of trophic categorization showed collector-gatherer and scraper as predominant groups in both regions of inlets and outlets of different lakes in Bangalore. In many studies focused on lake outlets, the predominant invertebrate groups are filter feeders such as simuliidae, net spinning trichoptera and other filter-feeder invertebrates in mountain lakes (Richardson and Mackay, 1991). In this study, collector-gatherer and scrapers were found dominant near outlets due to increased periphyton growth caused by nutrient availability and enhanced light (Gullan and Cranston, 2010). The assemblage of predators was observed high near inlets as they depend on primary consumers like collectors and scrapers as their food source, similar to the earlier reports by Sheldon and Oswood (1977).

Environmental Parameters: In natural waters, the pH is between 6.0 and 8.5. Lower values indicate acid water which could be related to the higher presence of CO_2 and/or higher organic matter content. pH values of all the study sites higher than 7 may indicate alkaline water. The pH ranged between 7.1 and 9.05 in different urban lakes of Bangalore (Table-1). It was higher in Malsandra and Valley School and lower in Hennagara lake. In the study area rain water and surface runoff were found to lower pH. In addition, pH values were significantly affected by mixing of sewage and industrial water. These values were within the permissible

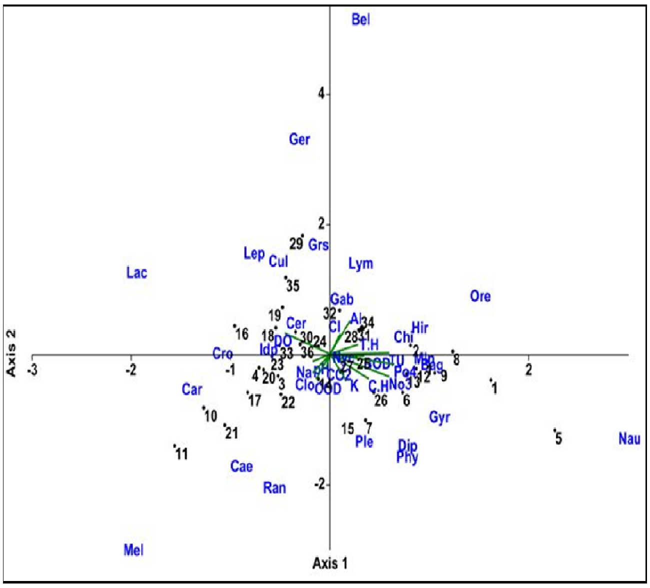

Figure 5: CCA analysis of macroinvertebrates and environmental parameters of seventeen lakes of Bangalore. Details of code are given as table 1 and 2.

limits except in the Malsandra and Valley School lakes. Similar observation was made in Perumal lakes, Cuddalore, by Vijayakumar *et al.* (2010). The higher values of pH recorded in Malsandra could be attributed to increased primary productivity wherein carbonates, sulfates, nitrates and phosphates are converted to hydroxyl ions. Dissolved oxygen (DO) analysis measures the amount of gaseous oxygen (O_2) dissolved in an aqueous solution. The DO was practically absent in Anchepalya, Yellamma, Varthur, Bommasandra lake inlets and Lakkenahalli lake outlets. The dissolved oxygen obviously decreased by the process of eutrophication causing algal death and decomposition. Carpenter *et al.* (1998) state that increased nutrient concentration in the water causes decrease in aquatic oxygen level. These two reasons and the dense growth of floating water weeds like *Eichornia, Pistia, Lemna* and other organisms characterised these study sites. The dense growth of water weeds, covering the surface, blocks atmospheric oxygen reaching into the water body and the absorption of dissolved oxygen by their roots create oxygen depletion in the aquatic ecosystem as a whole. The highest dissolved oxygen values were recorded at Hennagara (14.31 mgL^{-1}); it was believed to be due to the faster flow and more mixing of rain water. Water turbidity affects the amount of light penetration into a lake, which decreases in the presence of suspended material and colour in the water. Suspended material is often associated with phytoplankton biomass and so transparency level can be an indication of the amount of algal growth in the water. Turbidity recorded ranged between 4.4 (Lakkenahalli) to 124 NTU (Kommagondanahalli). WHO (1984) prescribed highest desirable limit 5.0 NTU and maximum permissible limit 25.0 NTU. Turbidity level exceeding 25 NTU in water, affects the aesthetic quality of water significantly. In all the lakes studied turbidity observed was beyond the permissible limit except in Lakkennahalli, Valley School, Vaderahalli and Nellakkondoddi lakes. The hardness of water is not a pollution parameter but indicates water quality. It is defined as the major divalent cations present in water, notably Calcium and Magnesium. It was observed in the range from 176 mgL^{-1} (Begur) to 1292 mgL^{-1} (Kommakondahalli). All the lakes observed were within the permissible limit of 600 mgL^{-1} (BIS, 2004) except in Lakkennahalli, Kommagondahalli and Malsandra outlets which were above this limit. The COD test is indirect measurement of oxygen required to oxidise organic/inorganic matter such as pollutants. High oxygen is required to oxidize the inorganic pollutants at Kommagondanahalli lake (474.64 ppm) and the minimum was required at Hennagara, Bommasandra and Rayasandra lake outlets (37.33 ppm). The values that exceed the permissible limit (40 ppm) indicate the fact that these water bodies were in eutrophic condition. Bio-chemical Oxygen Demand (BOD) is used for assessing the organic load in water body; it has a positive correlation with temperature. On increasing the temperature biochemical oxygen demand also increases. This may be attributed to the photosynthetic activity and abundance of phytoplankton during hot period. The BOD value was recorded range between 10.16mgL^{-1}and 74.5 mgL^{-1}. Almost all the lakes were indicated in eutrophic condition. The higher concentrations of chlorides indicate higher degree of organic pollution (Munawar, 1970). The concentration of chloride fluctuated between 19.28 ppm of Valley School and 346.8 ppm of Bommasandra. In Bommasandra it may be due to high anthropogenic activities (bathing, washing, cattle washing), entry of industrial and domestic sewage etc. Total alkalinity of water is due to the presence of mineral salts present in it. It is primarily caused by the carbonate and bicarbonate ions. Total water alkalinity of the inlets and outlets of 17 lakes fluctuated from 180 -1180 mgL^{-1}. They were within permissible limits except at Anchepalya, Bommasandra, Rayasandra and Hennagara inlets. Bommasandra lake had highest concentration due to the discharge of industrial waste into it. Phosphate occurs in various forms like orthophosphates, condensed phosphates and naturally found phosphates. Their presence in water is due to detergents, from used boiler waters, fertilizers and due to biological processes. They occur as detritus in the bodies of aquatic organisms. Inorganic phosphorus plays a dynamic role in aquatic ecosystems and it is one of the most important nutrients when present in low concentration, but in excess along with nitrates and potassium, cause algal blooms (Ramachandra *et al.*, 2002). The highest value (5.26 mgL^{-1}) of phosphate was recorded at Anchepalya lake, while the minimum value (0.005 mgL^{-1}) was recorded at Begur lake. The physico-chemical parameters of water samples in inlet and outlets of different lakes are listed in table 1. Fourteen abiotic variables were combined in different lakes of Bangalore. A two-dimensional biplot representing PC1 and PC2 is shown in figure 4. The PC1 axis accounted for 25.69 % of the overall variance and was most heavily weighted on the variables pH, total harness, Dissolved oxygen, and Nitrate. These ordinations are positively correlated to physico-chemical parameters (total hardness, nitrate, turbidity, calcium hardness and potassium) with Varthur, Anchepalya, Yellamma, Kommagondanahalli lakes, Malsandra, Lakkenahalli outlets and Hulimavu inlets, whereas negatively correlated with Madivala, Begur, Hennagara and Muthanallur lakes. The second axis accounted for 22.67% of the variance and large contributions was by COD, free carbon dioxide, dissolved oxygen, chloride, BOD, and Alkalinity in which loadings for first two variables was positively correlated with Abbigere, Vadarahalli, Nellakondadotti lakes and Valley School outlets, and negative for the last four variables as with Bommasanda, Rayasandra lakes and Yellamma inlets.. The remaining principal components' axis was accounted in less significant variance.

Macroinvertebrates assemblages in relation to environment: The results of CCA ordination for 26 aquatic genera, 17 lakes (both 18 inlet and 18 outlets) and 14 environmental variables showed that about 22.33%, 16.35%, 12.2%, 11.1% of the variance in species abundance accounted for the first four ordination axes (Fig-5). Eigen values for first four axes were 0.381, 0.279, 0.208, and 0.189. The first and third ordination was related to phosphate, nitrate and turbidity. The total alkalinity, dissolved oxygen, and chloride were in second ordination. Fourth ordination comprised free carbon dioxide, turbidity, nitrate and potassium. Macroinvertebrates and environmental factors ordination showed that the species were highly related to nitrate, phosphate, pH and dissolved oxygen. Macroinvertebrates like *Indoplanorbis* sp. *Ceriagrion* sp., *Leptocerus* sp. *Crocothemis* sp were positively correlated with increasing DO and pH. *Chironominus* sp., *Gyrinus* sp. *Naucoris* sp. *Diplonychus* sp., and *Bellamya* sp. were negatively correlated with increasing DO and pH, but positively correlated with increased chloride, BOD, turbidity, phosphate, nitrate and total hardness. *Plea* sp., *Cloeon* sp., and *Nychia sp.* were positively correlated with COD. *Lymniana (pseudosuccinia* sp.), *Gerris* sp., *Orectohillus* sp., *Chironominus* sp., and *Hirudinid* sp. were positively correlated with increased total alkalinity, total hardness and chloride.

The taxonomic composition 27 genera of macroinvertebrates were obtained out of which, 25 were found in outlets and 21 in inlets. The differences between taxonomic compositions were not significant at inlets and outlets of different lakes. Generally aquatic species are not predominant at inlet sites and most abundant at nearby outlets. This contradiction suggests that certain fundamental physical conditions differ between outlet and non-outlet habitats, or that attributes providing an advantage in one habitat do not operate similarly in another (Richardson and Mackay, 1991). However, the result of one way ANOVA based on the study of eutrophic lakes shows no significant variation between inlets and outlets. This indicate inlet and outlet sites of each lake are polluted to the same extent of pollution level; it means pollution levels have surpassed sustenance of sensitive macroinvertebrate species and self cleansing capability of the lake ecosystem.

Canonical component analysis for understanding the relationships between aquatic macroinvertebrate and environmental factors clearly shows that macro-invertebrates were affected by some environmental factors such as, phosphate, nitrate, alkalinity chloride, biological oxygen demand and turbidity of water column which decide the distribution and abundance of species. Apart from these variables, pH, dissolved oxygen and chemical oxygen demand were important factors. Ward and Stanford (1979) reported that environmental parameters such as water velocity; temperature and substrate are the the major factors determining the composition of macroinvertebrates. Results of the current study reveal that (along with earlier well studied parameters) phosphate, nitrate, turbidity pH and dissolved oxygen are the main factors deciding the macroinvertebrate diversity and abundance in urban lakes. For example dissolved oxygen was conspicuously absent in Anchepalya, Yellamma, Varthur, Bommasandra inlets and Lakkenahalli outlet sites, which affect the diversity and abundance of macroinvertebrates by changes in the physico-chemical properties of water. The dissolved oxygen level decreases with increased environmental stress, while the other environmental variables increase (Gabriels *et al.*, 2010) and affects adversely.

Conclusion

Lakes of Bangalore, as our studies reveal, are in gravely polluted condition due to the following reasons:

1. All the 17 lakes studied had not shown significant changes in their outlet waters, which are as impure as their inlets, since these lakes are challenged beyond their self purification capacities. The ANOVA analysis shows no significant variation between inlet and outlet waters. Our findings clearly show that macro-invertebrates diversity, abundance and trophic categorizations are almost same in both inlet and outlet locality of the urban lakes of Bangalore.

2. Increased input of urban sewage and other urban wastes have raised the nutrient concentrations of these lake waters creating eutrophic conditions.

3. Important environmental parameters like phosphate, nitrate, alkalinity, chloride, biological oxygen demand and turbidity, the harmonious balance of which are decisive in the upkeep of pristine aquatic ecosystems, were in an utter state of disorder, as indicated also by the existing macroinvertebrate diversity in these lakes.

4. The abundant presence of macroinvertebrate indicators of water pollution, such as *Micronecta* sp., and

Chironominus sp., in the outlet waters also is indicative of the failure of the self purification capabilities of these lakes studied.

5. The dense growth of floating water weeds, especially *Eichhornia, Pistia, Lemna* etc., along with several other tall dicot herbs, grasses and sedges that grow along the shallow parts of the lakes, have caused depleted oxygen levels in many weeds.

6. The entry of industrial pollutants in Bangalore lakes have been documented in many earlier studies also (Ramachandra *et al*., 2000; Lokeshwari and Chandrappa, 2006; Ramachandra and Solanki, 2007 and Alakananda *et al.*, 2011).

In brief it may be stated Bangalore and suburbs had a glorious past as regards the number of lakes and quality of their waters were concerned. Many of these lakes have already vanished under urbanization and many remaining ones are in precarious state. Water bodies being the lifelines of humanity utmost care need to exercise in protecting the lakes of Bangalore from encroachments and their water quality needs to be improved steadily through appropriate management interventions, specific to each lake.

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