Article

Biodiversity and abundance of aquatic insects in two freshwater lakes of Mysore district, Karnataka, India

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Abstract

A study on aquatic insects biodiversity and abundance along with physicochemical parameters of two lentic water bodies (Varuna and Dalvoy) of Mysore district was carried out on monthly basis from October 2018 to March 2019. A total of 31 species belonging to 19 families and 6 orders were recorded during the study period. At order level, Coleoptera showed maximum relative abundance (57%) followed by Hemiptera (13%) in Varuna Lake, while in Dalvoy Lake, the order Hemiptera (66%) was most abundant, followed by Coleoptera (16%). Computation of dominant status of different species of aquatic insects in lakes based on Engelmann's scale revealed that *Canthydrus laetabilis* and *Gyrinus distinctus,* from the order Coleoptera, were dominant in Varuna Lake, while two Hemipteran species, *Diplonychus rusticus* and *Anisops* sp., were dominant in Dalvoy Lake. The highest Shannon diversity index (2.803) and evenness values (0.66) were recorded in Varuna Lake, which was slightly greater than Dalvoy Lake (2.028 and 0.45). Similarly, the Biological Working Party Score (BMWP) and Average Score Per Taxon (ASPT) values were 80 and 5.33 in Varuna Lake and 53 and 4.08 in Dalvoy Lake. This indicates Varuna Lake is less polluted and has higher species diversity than Dalvoy Lake. In terms of the physico-chemical properties of water, a significant difference was noted in electrical conductivity, total dissolved solids, free carbon dioxide, dissolved oxygen, total alkalinity, hardness, nitrate, sulphate, and chloride concentrations between Dalvoy Lake and Varuna Lake. The results of physicochemical analysis and diversity indices suggest stressed and disturbed water quality conditions at Dalvoy Lake.

Keywords aquatic insects; abundance; bio indicator; diversity; water quality.

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1 Introduction

Water is the lifeblood of the planet and the glue that holds all living things together. The availability of water both in terms of quality and quantity is essential for the existence of living world. Freshwater ecosystems comprise only one percent of the earth's surface, yet they are critical to human societies as they provide food, medicine, and other necessities, as well as a home for many animals (Strayerand Dudgeon, 2010). Due to rapid unplanned urbanization, industrialization, and agricultural activities, water supplies have been depleted, making the need for water in all forms of life, from bacteria to humans, a huge concern today (Satterthwaite et al., 2010). Among various freshwater ecosystems, urban ponds, reservoirs, and lakes are the most affected (Dalal and Gupta, 2014). Ponds and lakes are commonly used to regulate the movement of storm water in an urban setting. This method, which produces heavily regulated wetlands, is known as "sustainable drainage systems" and is required by construction codes in a number of nations. Due to the lack of an alternate stormwater treatment system and impermeable urban surfaces (e.g., asphalt roads and parking lots, and cement sidewalks), urban lakes may receive all the surface water runoff in their watersheds, where it stays until it evaporates, soaks into the ground, is pumped to another place, or overflows into another lake (Wolf, 1996). Studies on these delicate ecosystems have revealed that despite significant variance in community structure, these wetlands can offer a remarkable level of variation to a regional species pool, particularly in cases when other habitats are scarce (Mitsch and Gosselink, 2000; Werritty, 2006; Hamer et al., 2012; Moore and Hunt, 2012; Hassall, 2014).

Aquatic biodiversity is characterized by a wide range of genetic diversity and species composition, the preservation of which is important for the sustainability of any lotic or lentic ecosystem (Singh and Sharma, 1998). Aquatic insects are the most diverse group of organisms found in almost every type of aquatic ecosystem on the planet, including lakes, rivers, seawater, salty pools, and even leaking pools of raw petroleum (Chainey, 2004). Despite comprising only 3% to 5% of all insect species, aquatic insects are taxonomically diverse (Dijkstra et al., 2014). They play a significant ecological role in maintaining the proper functioning of freshwater ecosystems, where they are a vital part of food webs and nutrient cycling (Bouchard, 2004). In addition to being crucial food web components, aquatic insects also serve as good indicators of anthropogenic impact on freshwater habitats (Hadicke et al., 2017). Several species are particularly susceptible to pollution, while others can thrive in waters that have been severely contaminated (Merritt and Cummins, 2008). As a result, aquatic insects are commonly utilized for freshwater ecosystem monitoring due to their abundance and responsiveness to changes in their environment (Aduand Oyeniyi, 2019). Three insect orders Ephemeroptera, Plecoptera and Trichoptera are proven to be most sensitive to the natural and anthropogenic disturbances, and are used extensively in aquatic insect biomonitoring programs (Bonada et al., 2006; Jacobus et al., 2019).

Freshwater ecosystems are more susceptible to biodiversity loss than terrestrial habitats, possibly as a consequence of the overwhelming biodiversity seen in inland waters (Sala et al., 2000). These habitats are typically threatened by five major factors: invasive species, habitat deterioration, water pollution, overexploitation, and flow alteration (Dudgeon et al., 2006). The environmental pollution of water resources is increased due to uncontrolled population growth, urbanization, industrialization, excessive use of fertilizers and pesticides in agriculture and other man-made activities. A number of water quality parameters, including temperature, turbidity, nutrients, hardness, alkalinity, dissolved oxygen, etc., determine the growth of living organisms in a body of water. Consequently, water quality evaluation requires the measurement of physico-chemical, biological, and microbiological characteristics that indicate the biotic and abiotic condition of the ecosystem (Smitha, 2013; Verma et al., 2012). Several studies have been conducted in different ponds and lakes of Mysore district, which have focused primarily on the assessment of physico-chemical parameters and diversity of planktons (Jalilzadeh et al., 2007; Padmanabha and Belagali, 2007; Sudeep et al., 2008; Savitha and Yamakanamardi, 2012; Udayashankara et al., 2013; Deepthi and Yamakanamardi, 2014; Jayalakshmi, 2019). However, no comprehensive work has been done on the diversity of aquatic insects in lakes of Mysore district. Therefore, the present study was carried out to investigate the diversity, distribution and abundance of aquatic insects in relation to water quality in two freshwater urban lakes (Varuna and Dalvoy) of Mysore district, Karnataka.

2 Materials and Methods

2.1 Study area

The study was carried out for six months from October, 2018 to March, 2019, in two perennial lakes, Varuna (76°74'58.72" E and 12°27'50.31" N) and Dalvoy (76°65'72.29" E and 12°25'17.81" N) (Fig. 1). Varuna Lake is located on the city outskirts, adjacent to the Mysore-Trichy national highway and surrounded by Varuna, Chikkalii, and Varokodu villages. The lake is a popular destination for water sports offered by Outback Adventure Sports. It has diverse aquatic vegetation such as *Hydrilla, Nymphaea, Ceratophyllum, Vallisneria, Typha*, etc., and supports many bird species like spot-billed pelicans, cattle egrets, spot-billed ducks, painted storks, grey-headed swamphens, waterhens, and sandpipers. Dalvoy Lake is situated in the southern part of the city, close to Ooty Road. The lake is relatively more agitated as it receives municipal wastewater from the adjacent residential areas. The lake is covered with floating aquatic plants such as *Eichornia*, *Lemna*, and *Pistia*.

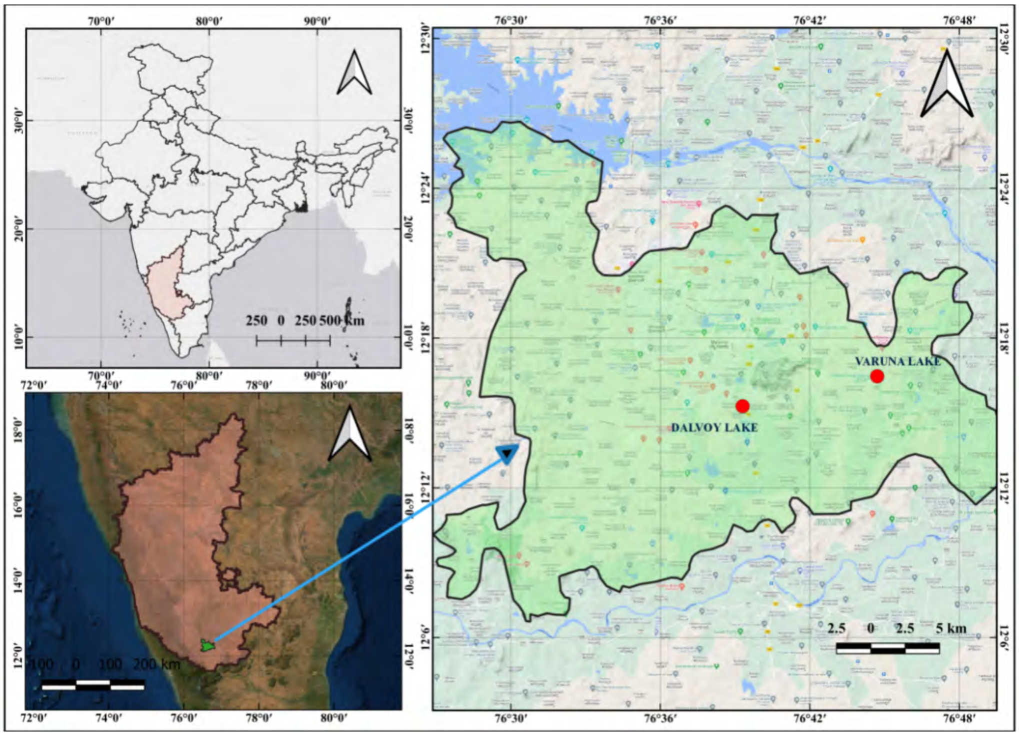

Fig. 1 Geographical location of the study area.

2.2 Methodology

Water and insect samples were collected monthly from three sites in each lake. Water temperature and pH were measured onsite using a mercury bulb thermometer and a pH meter (Hannah make. Physico-chemical parameters such as conductivity, turbidity, total dissolved solids (TDS), total alkalinity (TA), total hardness, calcium, dissolved oxygen (DO), free carbon dioxide, chemical oxygen demand (COD), biological oxygen demand (BOD), chloride, nitrate, sulfate, and phosphate were analyzed in the laboratory following standard methods (APHA, 2005; Trivediand Goel, 1986). The results were compared with the prescribed limits for potable water given by the Bureau of Indian Standards (BIS, 2012) and the Indian Council of Medical Research (ICMR, 1975). Aquatic insects were collected by disturbing the vegetation and dragging a circular pond net around the vegetation for one minute. Three such drags were counted as a sample (Macan and Maudsley, 1968; Brittain, 1974; Subramanian and Sivaramakrishnan, 2007a; Dalal and Gupta, 2016). Collected insects were immediately sorted and preserved in a 4% formalin solution. They were identified using a Labomed stereozoom microscope following standard keys (Khan and Ghosh, 2001; Nieser, 2002; Subramanian and Sivaramakrishnan, 2007b; Merritt and Cummins, 2008; Gosh and Hegde, 2013; Jaiswal, 2013; Jehamalar and Chandra, 2013; Thirumalai, 2013; Sundar et al., 2014; Holzenthal, 2015; Basu et al., 2016; Miller and Bergsten, 2016; Prommi, 2016; Bird et al., 2017; Bezděk and Hájek, 2017; Basu et al., 2018; Saha and Gupta, 2018). Data processing was done using Microsoft excel 2010 (Microsoft corporation) and diversity indices were worked using PAST software.

3 Results

3.1 Water quality parameters

Mean values of selected physicochemical parameters of water quality of Varuna and Dalvoy Lake are presented in Table 1. The study revealed that water temperature and pH in both the lakes did not show much variation. Majority of water quality variables recorded from Varuna Lake were within the permissible limits of BIS and ICMR standards for potable water. The range of several physicochemical variables of Dalvoy Lake such as, Electrical Conductivity (EC), Total dissolved solids (TDS), Turbidity, Free carbon-dioxide (FCO_2), Calcium, Hardness, Total alkalinity (TA), Chemical Oxygen Demand (COD), Biological oxygen demand (BOD), Nitrate, Phosphate, Sulphate and Chloride were higher than Varuna Lake. The mean concentration of EC, TDS, Turbidity and Hardness of Dalvoy Lake were beyond than the permissible limits of water quality standards. In Varuna Lake correlation coefficient analysis revealed a significant positive relationship of WT with pH and Sulphate. The pH of Varuna Lake also showed positive relationship with Hardness, COD and Sulphate. A significant negative correlation of nitrate with Hardness, COD and BOD was observed in Varuna Lake. In Dalvoy Lake strong positive relationship was observed between EC and TDS, Calcium and Nitrate, COD and Chloride and BOD. A significant negative relationship was observed between Turbidity and Sulphate, FCO_2 and Calcium, Sulphate and Chloride in Dalvoy Lake.

3.2 Aquatic insect composition and abundance

A total of 31 species from 19 families representing 6 orders were collected and identified during the investigation. The composition and relative abundance of aquatic insects in Varuna and Dalvoy Lakes are shown in Table 2 and Table 3 respectively. The significant correlation between physicochemical variables, taxa richness and density of insect are shown in Table 4. Fig. 2 and Fig. 3 shows the relative abundance of aquatic insect orders recorded from Varuna and Dalvoy Lake during the study period. The pattern of variation in various diversity indices such as Shannon-Weiner Diversity index (H´), Evenness index (J´), Margalef index and Berger-Parker index of dominance and biomonitoring scores (BMWP and ASPT) of Varuna and Dalvoy Lakes are shown in Table 5 and Table 6, respectively. Table 2 lists the 25 species of aquatic insects recorded in Varuna Lake across 6 orders and 15 families (Dytiscidae, Noteridae, Hydrophilidae, Gyrinidae, Belostomatidae, Naucoridae, Micronectidae, Notonectidae, Pleidae, Nephidae, Chironomidae, Libellulidae, Coenagrionidae, Baetidae and Leptoceridae. In Dalvoy Lake 17 species from 4 orders, 13 families (Dytiscidae, Noteridae, Hydrophilidae, Belostomatidae, Micronectidae, Notonectidae, Mesoveliidae, Pleidae, Culicidae, Chironomidae, Stratiomyidae, Syrphidae and Baetidae) were recorded (Table 3) during the study period. In Varuna Lake *Canthydrus laetabilis* and *Gyrinus distinctus* from the order Coleoptera were marked as dominant species (Table 2) according to Engelmann’s scale of dominance (1973). In contrast, *Diplonychus* *rusticus* and *Anisops* sp. from order Hemiptera were marked as dominant in Dalvoy Lake (Table 3). The most abundant order in Varuna Lake was Coleoptera (Fig. 2) while the order Hemiptera was most abundant in Dalvoy Lake (Fig. 3). Values of the Shannon-Weiner diversity index (H), evenness index (J) and Margalef index were found higher in Varuna Lake than in Dalvoy Lake, while the Berger-Parker index of dominance (d) was found higher in Dalvoy Lake (Table 5).

Table 1 Range and mean values of physicochemical variables of surface waters of Varuna and Dalvoy Lake.

Parameters	Varuna Lake		Dalvoy Lake		Drinking water standard
	Range	Mean ± SD	Range	Mean ± SD	BIS/ ICMR limit
WT (^oC)	27.07-30.50	27.96 ± 1.28	26.50-30.47	28.3 ± 1.50	NA
pH	7.03-7.83	7.38 ± 0.32	7.33-7.77	7.54 ± 0.19	6.5 - 8.5
EC (µS cm^{-1})	226.00-346.00	290.00 ± 41.33	1051.33-1243.33	1151.72 ± 64.47	< 300 µS cm^{-1}
TDS (mg L^{-1})	120.67-157.67	143.00 ± 12.72	522.00-596.67	565.1 ± 28.18	< 500 mg L^{-1}
Turbidity (NTU)	1.20-3.37	2.02 ± 0.99	3.20-22.93	10.6 ± 7.60	< 5 NTU
DO (mg L^{-1})	4.53-5.63	5.04 ± 0.45	0.90-4.40	3.33 ± 1.29	≥ 5.0 mg L^{-1}
FCO2 (mg L^{-1})	0.00-10.93	5.31 ± 4.50	27.13-48.40	37.99 ± 7.68	NA
Calcium (mg L^{-1})	14.33-27.53	20.56 ± 4.50	44.00-61.00	50.6 ± 6.09	< 75 mg L^{-1}
Hardness (mg L^{-1})	84.33-112.67	98.78 ± 10.49	277.67-333.67	308.5 ± 20.57	< 300 mg L^{-1}
TA (mg L^{-1})	61.33-94.00	83.06 ± 11.86	172.67-233.33	202.61 ± 26.65	< 200 mg L^{-1}
COD (mg L^{-1})	12.40-43.67	26.24 ± 11.63	37.94-65.13	54.37 ± 9.34	NA
BOD (mg L^{-1})	1.30-4.10	2.64 ± 1.08	4.40-7.50	6.12 ± 1.11	< 5 mg L^{-1}
Nitrate (mg L^{-1})	0.47-3.97	1.81 ± 1.47	12.07-25.33	17.85 ± 4.69	< 45 mg L^{-1}
Phosphate (mg L^{-1})	-	< 0.1	0.33-3.20	1.81 ± 1.18	NA
Sulphate (mg L^{-1})	4.83-6.87	5.59 ± 0.77	19.20-29.60	23.2 ± 3.89	< 200 mg L^{-1}
Chloride (mg L^{-1})	28.33-35.97	32.86 ± 2.78	121.33-137.00	131.89 ± 5.71	< 250 mg L^{-1}

WT- Water Temperature, **EC**- Electrical Conductivity, **TDS** – Total Dissolved Solids, **DO**- Dissolved oxygen, **FCO2**– Free carbon dioxide, **TA**– Total Alkalinity, **COD**– Chemical Oxygen Demand, **BOD** – Biological Oxygen Demand, **NA**– Not Available.

Table 2 Composition and relative abundance (RA) of aquatic insects in Varuna Lake.

Sl. No	Order	Insect taxa	RA%	Dominance status
1	Coleoptera	*Laccophilus anticatus* (Sharp, 1890)	3.59	Subdominant
2		*Laccophilus flexuosus* (Aube, 1838)	2.99	Recedent
3		*Hydroglyphus flamulatus* (Sharp, 1882)	2.69	Recedent
4		*Canthydrus laetabilis* (Walker, 1858)	11.98	**Dominant**
5		*Canthydrus luctuosus* (Aube, 1838)	4.79	Subdominant
6		*Hyphydrus* sp. (Illiger, 1802)	1.20	Recedent
7		*Berosus indicus* (Motschulsky, 1861)	1.20	Recedent
8		*Amphiops* sp. (Erichson, 1843)	2.40	Recedent
9		*Sternolophus rufipes* (Fabricius, 1792)	1.20	Recedent
10		*Laccobius* sp. (Erichson, 1837)	2.40	Recedent

11		*Helochares* sp. (Mulsant, 1844)	4.19	Subdominant
12		*Gyrinus distinctus* (Aube, 1836)	18.56	**Dominant**
13	**Hemiptera**	*Diplonychus rusticus* (Fabricius, 1781)	3.89	Subdominant
14		*Heleocoris* sp. (Mulsant, 1844)	2.40	Recedent
15		*Micronecta siva* (Kirkaldy, 1897)	0.60	Subrecedent
16		*M. scutellaris* (Stal, 1858)	0.60	Subrecedent
17		*Anisops* sp. (Spinola, 1840)	1.80	Recedent
18		*Paraplea frontalis* (Fieber, 1844)	1.20	Recedent
19		*Ranatra filiformis* (Fabricius, 1790)	2.40	Recedent
20	**Diptera**	*Chironomus* sp. (Meigen, 1803)	1.20	Recedent
21	**Odonata**	*Diplocodes* sp. (Kirby, 1889)	1.20	Recedent
22		*Ishcnura* sp. (Charpentier, 1840)	6.59	Subdominant
23	**Ephemeroptera**	*Cloeon* sp. (Leach, 1815)	1.80	Recedent
24		*Baetis* sp. (Leach, 1815)	9.58	Subdominant
25	**Trichoptera**	*Triplectides* sp. (Kolenati, 1859)	9.58	Subdominant

RA < 1 = Subrecedent; 1.1-3.1 = Recedent; 3.2-10 = Subdominant; 10.1-31.6 = Dominant; > 31.7% = Eudominant.

Table 3 Composition and relative abundance (RA) of aquatic insects in Dalvoy Lake.

Sl. No	Order	Insect taxa	RA%	Dominance status
1	**Coleoptera**	*Laccophilus flexuosus* (Aube, 1838)	2.67	Recedent
2		*Hydroglyphus flammulatus* (Sharp, 1882)	4.76	Subdominant
3		*Canthydrus laetabilis* (Walker, 1858)	0.38	Subrecedent
4		*Berosus indicus* (Motschulsky, 1861)	1.52	Recedent
5		*Amphiops* sp. (Erichson, 1843)	6.10	Subdominant
6		*Helochares* sp. (Mulsant, 1844)	0.38	Subrecedent
7	**Hemiptera**	*Diplonychus rusticus* (Fabricius, 1781)	31.05	**Dominant**
8		*Micronecta haliploides* (Horvath, 1904)	0.76	Subrecedent
9		*M. scutellaris* (Stal, 1858)	3.43	Subdominant
10		*Anisops* sp. (Spinola, 1840)	29.33	**Dominant**
11		*Mesovilia horvathi* (Lundblad, 1933)	0.76	Subrecedent
12		*Paraplea liturata* (Fieber, 1844)	0.76	Subrecedent
13	**Diptera**	*Culex* sp. (Linnaeus, 1758)	7.62	Subdominant
14		*Chironomus* sp. (Meigen, 1803)	3.43	Subdominant
15		*Stratiomys* sp. (Geoffroy, 1762)	3.62	Subdominant
16		*Eristalis* sp. (Latreille, 1804)	0.38	Subrecedent
17	**Ephemeroptera**	*Cloeon* sp. (Leach, 1815)	3.05	Recedent

RA < 1 = Subrecedent; 1.1-3.1 = Recedent; 3.2-10 = Subdominant; 10.1-31.6 = Dominant; > 31.7% = Eudominant.

Table 4 Significant Pearson's correlations among physicochemical variables of water and taxa richness in Varuna and Dalvoy Lakes.

Varuna Lake		Dalvoy Lake	
Variables	***r* value**	**Variables**	***r* value**
DO vsTaxa Richness	0.829*	DO vs Taxa richness	0.925**
BOD vs Taxa Richness	-0.862*	ECvs TDS	0.950**
WT vs pH	0.812*	Turbidity vs Sulphate	-0.869*
WT vs Sulphate	0.891*	FCO_2 vs Calcium	-0.975***
pH vs Hardness	0.897*	FCO_2 vs Nitrate	-0.973**
pH vs COD	0.815*	Calcium vs Nitrate	0.932**
pH vs Sulphate	0.911*	COD vs BOD	0.973**
ECvs TDS	0.986***	COD vs Chloride	0.828*
TDS vs Total Alkalinity	0.819*	Sulphate vs Chloride	-0.919**
Turbidity vs Calcium	0.868*		
Calciumvs Total Alkalinity	0.855*		
Hardness vs Nitrate	-0.935**		
COD vs Nitrate	-0.864*		
BOD vs Nitrate	-0.844*		

* $p< .05$, ** $p < .01$, *** $p < .001$. DO – Dissolved oxygen; FCO_2- Free Carbon-dioxide; EC-Electrical conductivity; TDS-Total dissolved solids; COD-Chemical oxygen demand; BOD- Biological oxygen demand.

Table 5 Diversity indices of aquatic insects in Varuna and Dalvoy Lakes.

Indices	Varuna Lake	Dalvoy Lake
Taxa richness	25	17
Individuals	334	525
Shannon- Weiner index	2.803	2.028
Evenness index	0.66	0.4469
Margalef index	4.13	2.555
Berger-Parker index	0.1856	0.3105

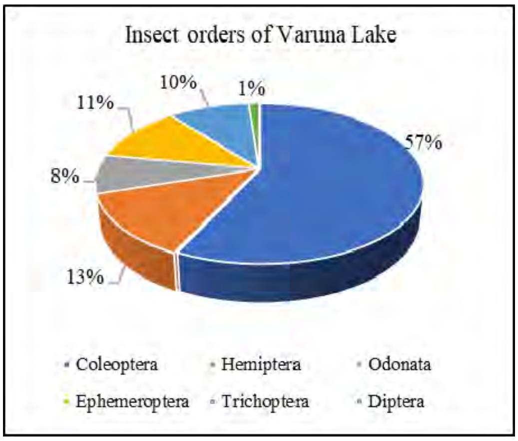

Fig. 2 Relative abundance of aquatic insect orders in VL.

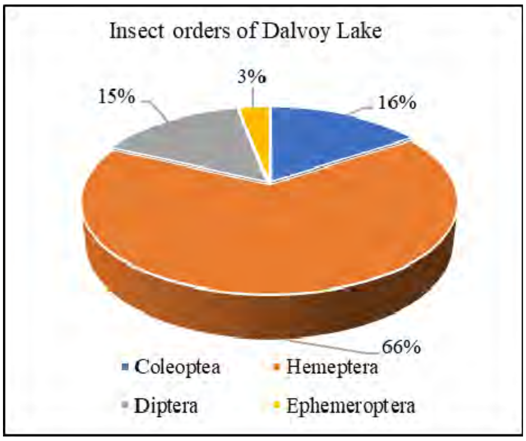

Fig. 3 Relative abundance of aquatic insect orders in DL.

3.3 BMWP and ASPT

The biological assessment of the lakes was done by computing the Biological Monitoring Working Party (BMWP) score and the Average Score Per Taxon (ASPT. The BMWP score is obtained by summing the individual scores of all families present, where the score values of each family reflect their pollution tolerance (Table 6). A higher BMWP score is considered to reflect better water quality by having more pollution-intolerant families, while a lower score suggests pollution-tolerant families. The Average Score Per Taxon (ASPT) is obtained by dividing the BMWP by the number of families represented in the sample. It shows the average tolerance score of all taxa within the community (Armitage et al., 1983; Hynes, 1998; Mandavillae, 2002; Paisley et al., 2014). The BMWP score of 80 and the ASPT rating of 5.33 indicate that the water is of good quality with minor pollution at Varuna Lake. Dalvoy Lake was found to be moderately impacted by pollution with a BMWP score of 53 and an ASPT value of 4.08 (Mandavillae, 2002).

Table 6 BMWP score and ASPT values obtained from families recorded at Varuna and Dalvoy Lakes.

Varuna Lake		Dalvoy Lake	
Families	**Tolerance score**	**Families**	**Tolerance score**
Dytiscidae	5	Dytiscidae	5
Hydrophilidae	5	Hydrophilidae	5
Noteridae	5	Noteridae	5
Gyrinidae	5	Belostomatidae	5
Belostomatidae	5	Micronectidae	5
Micronectidae	5	Notonectidae	5
Naucoridae	5	Mesoveliidae	5
Notonectidae	5	Pleidae	5
Pleidae	5	Culicidae	2
Nepidae	5	Chironomidae	2
Chironomidae	2	Stratiomyidae	4
Libellulidae	8	Syrphidae	1
Coenagrionidae	6	Baetidae	4
Baetidae	4		
Leptoceridae	10		
Total (BMWP)	80	Total (BMWP)	53
ASPT score	5.33	ASPT score	4.08

Lake water quality bases on BMWP score: > 100 Very good (Class I); 71-100 Good (Class II); 41-70 Moderate (Class III); 11-40 Poor (Class IV); 0-10 Very poor (Class V) (Mandaville, 2002; Kazanci et al., 2013).

4 Discussion

The physicochemical water parameters of Varuna and Dalvoy Lakes were significantly different, except for water temperature and pH. The chemical and biological properties of surface water are both affected by temperature. There was little temperature fluctuation in the Varuna and Dalvoy Lakes in the current study. The concentration of dissolved oxygen is one of the most important indicators of water quality and a key determinant of the distribution of aquatic insect groups (Wahizatul et al., 2011). There was a strong positive correlation between DO and taxa richness in both the lakes highlighting the importance of DO in species composition. The main sources of dissolved oxygen in the aquatic environment are atmospheric air and photosynthesis, which rely on its solubility and temperature. Breakdown by aerobic bacteria, respiration, and decomposition of dead decaying sediments reduces dissolved oxygen concentrations in aquatic environments (Gupta and Gupta, 2006). In the present investigation, the DO concentration in Dalvoy Lake was significantly lower than in Varuna Lake. Dalvoy Lake receives a substantial amount of sewage waste, which raises the water's biological oxygen demand. This is also demonstrated by the greater concentrations of CO_2, BOD, and COD in Dalvoy Lake compared to Varuna. BOD at Varuna Lake correlated negatively with taxa richness, indicating the prevalence of pollution intolerant species. The electrical conductivity (EC) and total dissolved solids (TDS) were significantly higher in Dalvoy Lake (1151.72 S/cm and 565.1 mg/L) which were well above the desirable limit of water quality standards. An increase in electrical conductivity could be caused by bacteria that break down and mineralize matter quickly or by bottom sediments that release nutrients (Egborge, 1994).

While physicochemical measurements are useful for identifying the effects of pollution on water quality, changes in the trophic conditions of water also affect the organization of the biological community, including species pattern, distribution, and diversity (Fouzia and Amir, 2013). A change in habitat conditions can affect the type of species present in the ecosystem. Since insects have the ability to migrate, they can readily move from unfavourable habitats to favourable ones. Thus, the type of species present in a habitat reflects the condition of the waterbody (Medina et al., 2007). The findings of current study showed that the aquatic insect fauna of Varuna and Dalvoy Lake is consisted of six orders namely: Coleoptera, Hemiptera, Diptera, Odonata, Ephemeroptera and Trichoptera. A total of 31 species were collected and identified out of which 11 species were recorded from both the lakes (*Laccophilus flexuosus, Hydroglyphus flamulatus, Canthydrus laetabilis, Berosus indicus, Amphiops* sp., *Diplonychus rusticus, Helochares* sp., *Micronecta scutellaris*, *Chironomous* sp., and *Cloeon* sp.), indicating their wide distribution and adaptability to diverse habitats. In both lakes, two orders, Hemiptera and Coleoptera, accounted for the greatest number of species. The higher abundance of the order Hemiptera in Dalvoy Lake (66%) may be explained by the fact that aquatic and semi-aquatic hemipterans do not rely greatly on DO in the water due to their ability to use atmospheric oxygen via respiratory apparatus (Thorpe, 1950; Wells et al., 1981). This is also reflected in Engelmann’s scale of dominance where two Hemipteran species *Diplonychus rusticus* and *Anisops* sp. marked as dominant (Table 3) At Varuna Lake, Coleoptera was the most abundant order (57%) with 12 species in four families (Hydrophilidae, Dytiscidae, Noucoridae, and Gyrinidae). At family level, Hydrophilidae dominated the collection with the maximum number of species, followed by Dytiscidae. Studies have shown that the Dytiscidae insects generally prefer the leaves of submerged aquatic vegetation as hideouts due to their predatory nature. On the other hand, aquatic Hydrophilidae are mainly phytophagous and live-in shallower parts of water with lots of macrophytes where they feed on debris, algae, and dead plants (Khan and Ghosh, 2001; Nilsson and Soderberg, 1996; Bloechl et al., 2010). The Varuna Lake supports diverse aquatic vegetation, floating and submerged, providing an ideal habitat for both immature and adult insects of Dytiscidae and Hydrophilidae. The existence of luxuriant aquatic vegetation, which is important for shelters, oviposition sites, and food sources, is correlated with a greater diversity and abundance of insects in lentic waterbodies (Korkeamäki and Suhonen, 2002). The order Diptera was represented by four species at Dalvoy Lake (*Culex* sp., *Chironomus* sp., *Stratiomys* sp., and *Eristalis* sp.). Dipteran members are known to tolerate a wide range of water quality parameters, including nutrient enrichment, extreme pH, ion concentrations, and water stagnation, with *Chironomus* sp. and *Eristalis* sp. in particular being able to survive in low DO conditions. The presence of these pollution-tolerant species can serve as an indicator of poor water quality (Helson et al., 2006; Rydzanicz et al., 2016; Jindal et al., 2020). In contrary, a sole pollution intolerant taxon was observed in Varuna Lake, belonging to the order Trichoptera. The *Triplectides* sp. (Fam: Leptoceridae) was marked as subdominant in terms of Engelmann's scale of dominance (Engelmann, 1973). Studies have shown that gill-breathing aquatic insects, such as caddisflies and mayflies, are negatively impacted by conditions such as low dissolved oxygen levels in the water resulting from organic pollution. As a result, the abundance of caddisflies and mayflies is an indicator of good water quality (Barbour, 1999; Houghtona, 2004; Prommi et al., 2014; Stoyanova et al., 2014; Thamsenanupap et al., 2021).

In the present investigation, different diversity indices demonstrated distinct patterns. Highest Shannon diversity index (H′) was recorded at Varuna Lake (2.803) and lowest was observed at Dalvoy Lake (2.028). A Shannon diversity index of less than 1 indicates extremely polluted water, whereas 1-3 suggests moderate pollution, and greater than 4 indicates clean water (Wilhm and Dorris, 1968). An Evenness value of 1 indicates equal distribution of individuals (Turkmen and Kazanci, 2010). The Evenness value (J′) of Varuna Lake was 0.66 which was close to 1 suggesting equal distribution of individuals. This is also confirmed by the lowest Berger-Parker index of dominance at Varuna Lake (0.1856). The Margalef diversity index of Varuna Lake and Dalvoy Lake was 4.13 and 2.55, respectively. Margalef's water quality index values greater than 3 indicate clean conditions, values less than 1 indicate severe pollution, and intermediate values indicate moderate pollution (Lenat et al., 1980). The Margalef Diversity Index value of Varuna Lake was found to be greater than 3, indicating a clean condition, while Dalvoy had 2.555, which is a sign of moderate pollution. This is substantiated by a higher BMWP score, which was 80 in Varuna Lake and 54 in Dalvoy Lake (Table 6). A BMWP score of 100 or higher indicates that the environment is unaffected (Class I), 71-100 indicates that the environment is clean but slightly polluted (Class II), 41-60 indicates that the environment is moderately impacted (Class III), and less than 40 indicates that the environment is poor or polluted (Class IV) (Mandaville, 2002; Kazanci et al., 2013). Similarly, the ASPT value also indicates water quality. A score of 6 or more implies very good quality, a score of less than 4 indicates poor quality, and an intermediate value implies moderate quality (Armitage et al., 1983; Hynes, 1998; Mandaville, 2002). In the present investigation, the ASPT value of Varuna Lake was 5.33 and that of Dalvoy was 4.08, suggesting moderate quality.

5 Conclusions

The current study provides baseline data on the water quality status of Varuna and Dalvoy Lakes and further emphasizes the significance of water quality in determining the composition and abundance of aquatic insects. The prevalence of pollution-tolerant species of aquatic insects (*Chironomus* sp. and *Eristalis* sp.) at Dalvoy Lake suggested poor water quality, which was also supported by the low BMWP and ASPT scores, indicating moderate pollution. The Shannon Diversity index (2.80) demonstrated that Varuna Lake had a greater diversity of aquatic insects. In addition, the presence of pollution-sensitive taxa (Trichoptera: Leptoceridae) and a BMWP score of more than 80 (Class II) indicate good water quality conditions. Monitoring the change in species composition and distribution of aquatic insects in response to environmental changes could provide valuable data for analyzing the effects of pollution and habitat degradation on aquatic ecosystems and could aid in the proper management of urban lakes by the municipal government.

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References

Adu BW, Oyeniyi EA. 2019. Water quality parameters and aquatic insect diversity in Aahoo stream, southwestern Nigeria. The Journal of Basic and Applied Zoology, 80(1): 15

APHA. 2005. Standard Methods for the Examination of Water and Wastewater (21st Ed). American Water Works Association, Washington DC, USA

Armitage PD, Moss D, Wright JF, Furse MT. 1983. The performance of a new biological water quality score system based on macroinvertebrates over a wide range of unpolluted running-water sites. Water Research, 17(3): 333-347

Balian E, Harrison I, Butchart S, Chambers P, Cordeiro J, Cumberlidge N, de Moor F, Gascon C, James H, Kalkman V, van Dijk PP, Yeo D. 2010. Chapter 2. Diversity of Species in Freshwater Systems: In: Freshwater – the Essence of Life. 50-89, Conservation International and Cemex Conservation Book Series, Eds. Earth in Focus Editions, China

Balian EV, Segers H, Martens K, Lévéque C. 2008. The freshwater animal diversity assessment: an overview of the results. Hydrobilogia, 595: 627-637

Barbour MT. 1999. Rapid Bioassessment Protocols For Use In Wadable Streams and Rivers: Periphyton, Benthic Macroinvertebrates and Fish. US Environmental Protection Agency, Office of Water, USA

Basu S, Chandra K, Subramanian KA, Saha GK. 2018. Water bugs (Insecta: Hemiptera: Heteroptera) of Himalayan and sub-Himalayan regions of West Bengal, India. Journal of Threatened Taxa, 10(12): 12619-12714

Basu S, Subramanian KA, Saha GK. 2016. Aquatic and semi-aquatic Heteroptera (Insecta: Hemiptera) of Terai-Dooars Region of West Bengal, India. Halteres, 7: 120-135

Bezděk J, Hájek J. 2017. Insect biodiversity of the Socotra Archipelago–underlined and counted. Acta Entomologica Musei Nationalis Pragae, 57(3): 1-39

Bird MS, Bilton DT, Perissinotto R. 2017. Diversity and distribution of polyphagan water beetles (Coleoptera) in the Lake St Lucia system, South Africa. ZooKeys, (656): 51

BIS. 2012. Specifications for Drinking Water- Indian Standard: IS 10500. Bureau of Indian Standards, New Delhi, India

Bloechl A, Koenemann S, Philippi B, Melber A. 2010. Abundance, diversity and succession of aquatic Coleoptera and Heteroptera in a cluster of artificial ponds in the North German Lowlands.Limnologica-Ecology and Management of Inland Waters, 40(3): 215-225

Bonada N, Prat N, Resh VH, Statzner B. 2006. Developments in aquatic insect biomonitoring: a comparative analysis of recent approaches. Annual Review of Entomology, 51(1): 495-523

Bouchard RW, Ferrington LC, Karius ML. 2004. Guide to aquatic invertebrates of the Upper Midwest. Water Resources Center, Univsersity of Minnesota, St. Paul, USA

Brittain JE. 1974. Studies on the lentic Ephemeroptera and Plecoptera of Southern Norway. Norsk Entomologisk Tidsskrif, 21: 135-151

Chainey J. 2004. Freshwater invertebrates of the Malaysian region. Insecta: Diptera, Tabanidae. Malaysia

Dalal A, GuptaS. 2014. Aquatic insect diversity in two temple ponds of Silchar, Assam, NE India and their conservation values. Knowledge and Management of Aquatic Ecosystems, 415: 09

Deepthi S, Yamakanamardi SM. 2014. Abundance of cladoceran zooplankton in Varuna, Madappa and Giribettethe lakes of mysore, Karnataka state, india. International Journal of Science, 3(3): 885-900

Dijkstra KDB, Monaghan MT, Pauls SU. 2014. Freshwater biodiversity and insect diversification. Annual Review of Entomology, 59: 143

Dudgeon D, Arthington AH, Gessner MO, Kawabata Z, Knowler DJ, Lévêque C, Naiman RJ, Prieur-Richard

AH, Soto D, Stiassny ML, Sullivan CA. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Eeviews of the Cambridge Philosophical Society, 81(2): 163-182

Egborge ABM. 1994. Water pollution in Nigeria: Biodiversity and chemistry of Warri River. 27-59, Ben-Miller Books Nigeria Ltd, Nigeria

Engelmann HD. 1973. Untersuchungenzur Erfassungpredozoogenerkomponentenimdefinierten.Okosystem. Forschungen.Staatl. Mus. Naturkde, Gorlitz, 23

Fouzia I, Amir K. 2013. Aquatic biodiversity as an ecological indicator for water quality criteria of River Yamuna in Doon Valley, Uttarakhand, India. World Journal of Fish and Marine Sciences, 5(3): 322-334

Ghosh SK, Hegde VD. 2013. On a collection of aquatic beetles (Order: Coleoptera: Gyrinidae, Dytiscidae and Hydrophilidae) of Renuka Wildlife Sanctuary, Himachal Pradesh, India. Records of the Zoological Survey of India, 113(2): 61-67

Gupta SK, Gupta PC. 2006. General and Applied Technology (Fish and Fisheries). S. Chand and Company, New Delhi, India

Haedicke CW, Redei D, Kment P. 2017. The diversity of feeding habits recorded for water boatmen (Heteroptera: Corixoidea) world-wide with implications for evaluating information on the diet of aquatic insects. EJE, 114(1): 147-159

Hamer AJ, Smith PJ, McDonnell MJ. 2012. The importance of habitat design and aquatic connectivity in amphibian use of urban stormwater retention ponds.Urban Ecosystems, 15(2): 451-471

Hammer Ø, Harper DA., Ryan PD. 2001. PAST: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica, 4(1): 9

Hassal C. 2014. The ecology and biodiversity of urban ponds. Water, 1(2): 187-206

Helson JE, Williams DD, Turner D. 2006. Larval chironomid community organization in four tropical rivers: human impacts and longitudinal zonation. Hydrobiologia, 559(1): 413-431

Holzenthal R W, Thomson RE, Ríos-Touma B. 2015. Order Trichoptera. In: Thorp and Covich's Freshwater Invertebrates. 965-1002, Academic Press, USA

Houghtona DC. 2004. Utility of caddisflies (Insecta: Trichoptera) as indicators of habitat disturbance in Minnesota. Journal of Freshwater Ecology, 19(1): 97-108

Hynes KE. 1998. Benthic macroinvertebrates diversity and Biotic indices for monitoring of 5 urbanizing lakes within the Halifax regional municipality (HRM): Nova Scotia, Canada. Soil and Water Conservation Society of Metro Halifax, Canada

ICMR. 1975. Manual of Standards of Quality For Drinking Water Supplies. New Delhi, India

Jacobus LM, Macadam CR, Sartori M. 2019. Mayflies (Ephemeroptera) and their contribution to ecosystem services. Insects, 10(6): 1-26

Jaiswal, D. 2013. Aquatic Insects of Lakes in and around Hyderbad (Hempitera and Coleoptera. Records of the Zoological Survey of India, Occasional Paper Number, 350: 1-51

Jalilzadeh AK, Yamakanamardi SM, Altaff K. 2007. Abundance of zooplankton in three contrasting lakes of Mysore city, Karnataka state, India. In: Proceedings of Taal2007: The 12th World Lake Conference (Vol). 469

Jayalakshmi B, Abhilasha J, Amruthesh KN. 2019. Physico-chemical investigations of Major Lakes of Thattekere, Hunsur, Karnataka. “Environment & We” an International Journal of Science & Technology, 14(1): 65-75

Jehamalar EE, Chandra K. 2013. On a collection of aquatic and semi-aquatic bugs (Hemiptera: Heteroptera) from Chhattisgarh, India. Records of the Zoological Survey of India, 113(1): 183-195

Jindal R, Singh D, Chandel VC. 2020. Checklist of macroinvertebrates of Binwa a western Himalayan hill stream and their role as bioindicator. Plant Archives, 20(1): 2674-2677

Kazanci N, Türkmen G, Ekingen P, Başören Ö. 2013. Preparation of a biotic index (Yeşilırmak-BMWP) for water quality monitoring of Yeşilırmak River (Turkey) by using benthic macroinvertebrates. Review of Hydrobiology, 6(1)

Khan DR, Ghosh LK. 2001. Faunal diversity of aquatic insects in freshwater wetlands of South Eastern West Bengal. Zoological Survey of India, India

Khan KA, Ghosh LK. 2001. Faunal Diversity of Aquatic Insects in Freshwater Wetlands of South Eastern West Bengnl. Zoological Survey of India, Occ. Paper No. 194: 1-104

Korkeamäki E, Suhonen J. 2002. Distribution and habitat specialization of species affect local extinction in dragonfly Odonata populations. Ecography, 25(4): 459-465.

Lenat DR, Smock LA, Penrose DL. 1980. Use of benthic macroinvertebrates as indicators of environmental quality. In: Biological Monitoring for Environmental Effects (Douglass LW, ed). 97-114, Lexington Books, Toronto, Canada

Macan TT, Maudsley R. 1968. The insects of the stony substratum of windermere. Transaction Society of the British Entomology, 18: 1-18

Mandaville SM. 2002. Benthic macroinvertebrates in freshwaters: taxa tolerance values, metrics, and protocols. Soil and Water Conservation Society of Metro Halifax. 21-38, Nova Scotia, Canada

Medina MH, Correa JA, Barata C. 2007. Micro-evolution due to pollution: possible consequences for ecosystem responses to toxic stress. Chemosphere, 67(11): 2105-2114

Merritt RW, Cummins KW. 2008. An Introduction To The Aquatic Insects of North America. Kendall Hunt, Iowa, USA

Miller KB, Bergsten J. 2016. Diving Beetles of The World: Systematics and Biology of The Dytiscidae. Johns Hopkins University Press, USA

Mitsch WJ, Gosselink JG. 2000. The value of wetlands: importance of scale and landscape setting. Ecological Economics, 35(1): 25-33

Moore TL, Hunt WF. 2012. Ecosystem service provision by stormwater wetlands and ponds–a means for evaluation? Water Research, 46(20): 6811-6823

Nieser N. 2002. Guide to aquatic Heteroptera of Singapore and Peninsula Malaysia. IV. Corixoidea. Raffles Bulletin of Zoology, 50(1): 263-274

Nilsson AN, Söderberg H. 1996. Abundance and species richness patterns of diving beetles (Coleoptera, Dytiscidae) from exposed and protected sites in 98 northern Swedish lakes. Hydrobiologia, 321(1): 83-88

Padmanabha B. 2011. Diversity of macroinvertebrates as a tool to assess aquatic pollution in lentic ecosystems. Nature, Environment and Pollution Technology, 10(1): 69-71

Padmanabha B, Belagali SL. 2007. Diversity indices of rotifers for the assessment of pollution in the lakes of Mysore city, India. Pollution Research, 26(1): 63

Polhemus JT, Polhemus DA. 2007. Global diversity of true bugs (Heteroptera; Insecta) in freshwater.In Freshwater Animal Diversity Assessment. 379-39, Springer, Dordrecht, Netherlands

Prommi TO. 2016. Descriptions of larvae of four species of Hydropsyche (Hydropsychidae: Trichoptera) from Thailand. Zootaxa, 4158(4): 577-591

Prommi TO, Laudee P, Chareonviriyaphap T. 2014. Biodiversity of adult Trichoptera and water quality variables in streams, northern Thailand. APCBEE Procedia, 10: 292-298

Reid AJ, Carlson AK, Creed IF, Eliason EJ, Gell PA, Johnson PT, Cooke SJ. 2019. Emerging threats and persistent conservation challenges for freshwater biodiversity. Biological Reviews, 94(3): 849-873

Revenga C, Kura Y. 2003. Status and Trends of Biodiversity of Inland Water Ecosystems. Technical Series No. 11. Secretariat of the Convention on Biological Diversity, Montreal, Canada

Rydzanicz K, Jawień P, Lonc E, Modelska M. 2016. Assessment of productivity of Culex spp. larvae (Diptera: Culicidae) in urban storm water catch basin system in Wrocław (SW) Poland. Parasitology Research, 115(4): 1711-1720

Saha A, Gupta S. 2018. Aquatic and semi aquatic Hemiptera community of Sonebeel, the largest wetland of Assam, northeastern India. Journal of Threatened Taxa, 10(13): 12792-12799

Sala OE, Chapin FS, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke LF, Jackson RB, Kinzig A, Leemans R, Lodge DM, Mooney HA, Oesterheld M, Poff NL, Sykes MT, Walker BH, Walker M, Wall DH. 2000. Global biodiversity scenarios for the year 2100. Science, 287(5459): 1770-1774

Satterthwaite D, McGranahan G, Tacoli C. 2010. Urbanization and its implications for food and farming.Philosophical transactions of the royal society B: biological sciences, 365(1554): 2809-2820

Savitha N, Yamakanamardi SM. 2012. Studies on abundance of zooplanktons in lakes of Mysore, India. Journal of Environmental Biology, 33(6): 1079

Sharma RC, Bhanot G, Singh D. 2004. Aquatic macroinvertebrate diversity in Nanda Devi Biosphere Reserve, India. Environmentalist, 24(4): 211-221

Singh D, Sharma RC. 1998. Biodiversity, ecological status and conservation priority of the fish of the River Alaknanda, a parent stream of the River Ganges (India). Aquatic Conservation: Marine and Freshwater Ecosystems, 8(6): 761-772

Smitha. 2013. Physico-chemical analysis of the freshwater at River Kapila, Nanjangudu Industrial Area, Mysore, India.International Research Journal of Environment Sciences 2: 59-65

Stoyanova T, Vidinova Y, Yaneva I, Tyufekchieva V, Parvanov D, Traykov I, Bogoev V. 2014. Ephemeroptera, Plecoptera and Trichoptera as indicators for ecological quality of the Luda Reka River, Southwest Bulgaria. Acta Zoologica Bulgarica, 66(2): 255-260.

Strayer DL, Dudgeon D. 2010. Freshwater biodiversity conservation: recent progress and future challenges. Journal of the North American Benthological Society, 29(1): 344-358

Subramanian KA, Ksivaramakrishnan KG. 2007a. Aquatic Insects for Biomonitoring Fresh Water Ecosystems: A Methodology Manual. Ashoka Trust for Ecology and Environment, Bangalore, India

Subramanian, K. A., &Sivaramakrishnan, K. G. 2007b. Aquatic Insects of India-A Field Guide. Ashoka Trust for Ecology and Environment, Bangalore, India

Sudeep BM, Srikantaswamy S, Hosmani SP. 2008. The study of phytoplankton dynamics in two lakes of Mysore, Karnataka state, India. Nature Environment and Pollution Technology, 7(4): 697-702

Sundar S, Sites RW, Arunachalam M. 2014. Descriptions of immature stages of three species of Laccocorinae (Hemiptera: Heteroptera: Naucoridae) from India. Annals of the Entomological Society of America, 107(6): 1056-1065

Thamsenanupap P, Seetapan K, Prommi T. 2021. Caddisflies (Trichoptera, Insecta) as bioindicator of water quality assessment in a small stream in northern Thailand. Sains Malaysiana, 50(3): 655-665

Thirumalai G. 2013. Insecta: Hemiptera (aquatic and semi-aquatic. Fauna of Karnataka. In: Fauna of Karnataka, India. State Fauna Series. Zoological Survey of India, 133-162

Trivedy RK, Goel PK. 1986. Chemical and Biological Methods For Water Pollution Studies. Environ Publ, India

Turkmen G, Kazanci N. 2010. Applications of various biodiversity indices to benthic macroinvertebrate assemblages in streams of a national park in Turkey. Rev. Hydrobiology, 3: 111-125

Udayashankara TH, Anitha KG, Rao S, Shifa A, Shuheb M. 2013. Study of water quality and dynamic analysis of phytoplanktons in four fresh water lakes of Mysore, India. International Journal of Innovative Research in Science, Engineering and Technology, 2(7): 2600-2609

Verma PU, Purohit AR, Patel NJ. 2012. Pollution status of Chandlodia Lake located in Ahmedabad Gujarat. International Journal of Engineering Research and Applications 2: 1600-1610

Werritty A. 2006. Sustainable flood management: oxymoron or new paradigm? Area, 38(1): 16-23

Wilhm JL, Dorris TC. 1968. Biological parameters for water quality criteria. Bioscience, 477-481

Wolf CF. 1996. Aquatic macroinvertebrate diversity and water quality of urban lakes. Doctoral Dissertation. Texas Tech University, USA