

## Assessment of Water Quality Parameters and Aquatic Insect Assemblages in Dalvoy Lake, Mysore District, Karnataka, India

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### Abstract

Water is an indispensable natural resource vital for the survival of all life forms. It contributes significantly to the country's economic prosperity and general well-being. As a result, understanding the status of water bodies is crucial to assure their long-term use. A study on water quality parameters and aquatic insect community was therefore carried on the surface waters of Dalvoy Lake which is spread over an area of 133.43 acres and having a length of 2.2 km. Monthly water samples were collected using one-litre labeled plastic containers from three locations between the hours of 8 a.m. and 10 a.m. Water quality analysis was conducted following standard methods and compared to drinking water specifications. The dissolved oxygen content, total hardness, conductivity, total dissolved solids, and turbidity exceeded the permissible limits. Aquatic insects were collected from the same locations and preserved in 4% formalin. A total of 15 species of aquatic insects belonging to four orders, Hemiptera, Coleoptera, Diptera, and Ephemeroptera, were identified in this study. The Hemiptera was shown to be the largest group comprising of 8 species; 4 species of Diptera; 2 species of Coleoptera and a lone species of Ephemeroptera. The computation of aquatic insect dominance status using Engelmann's Scale revealed *Diplonychusrusticus*, *Anisops* sp., *Enithares* sp., *Chironomous* sp. and *Culex* sp. as dominant. Biodiversity metrics like the Shannon Index (1.4-2.11) and the evenness index (0.50-0.66) reflect the agitation of the system. Based on the results of the water quality index (163.67) and aquatic insect assemblage, it is evident that the water in Dalvoy Lake is deteriorated and is unfit for domestic usage. The study also indicated the abundance of two genera *Chironomous* and *Culex* of the Diptera order which are the index of water pollution. Thus, the present study calls for urgent and strict vigilance and continuous monitoring of this perennial water body for conservation and sustainable management.



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## Introduction

Freshwater resources are of great importance to man and other organisms of the environment for sustenance of life and maintaining the balance in the nature.<sup>1</sup> About one-third of the world's fresh water requirement is met by naturally occurring surface waters in rivers, streams, lakes, and ponds.<sup>2</sup> Due to the limited availability of freshwater on earth, it has become imperative to assess its quality as much of the world's freshwater resources are becoming deteriorated by the influence of anthropogenic activities.<sup>3</sup> According to The Millennium Ecosystem Assessment report, freshwater ecosystems are suspected to have the highest number of species threatened with extinction as a result of climate change.<sup>4</sup>

Countries across the globe are facing the challenge of managing the increasing risks and adverse effects of temperature change and urbanization. Among the various freshwater habitats, ponds, reservoirs and lakes in urbanized areas are significantly affected by anthropogenic activity.<sup>5</sup> Urbanization alone puts greater pressure on freshwater resources as more people reside in confined landscapes by converting the natural terrain into water-impermeable lands, diminishing accessible freshwater resources.<sup>6</sup> The watershed of the lakes in urban setup thus tend to emphasize the environmental problems affecting the metropolitan areas, by collecting and accumulating large amount of nutrients and pollutants.<sup>7</sup>

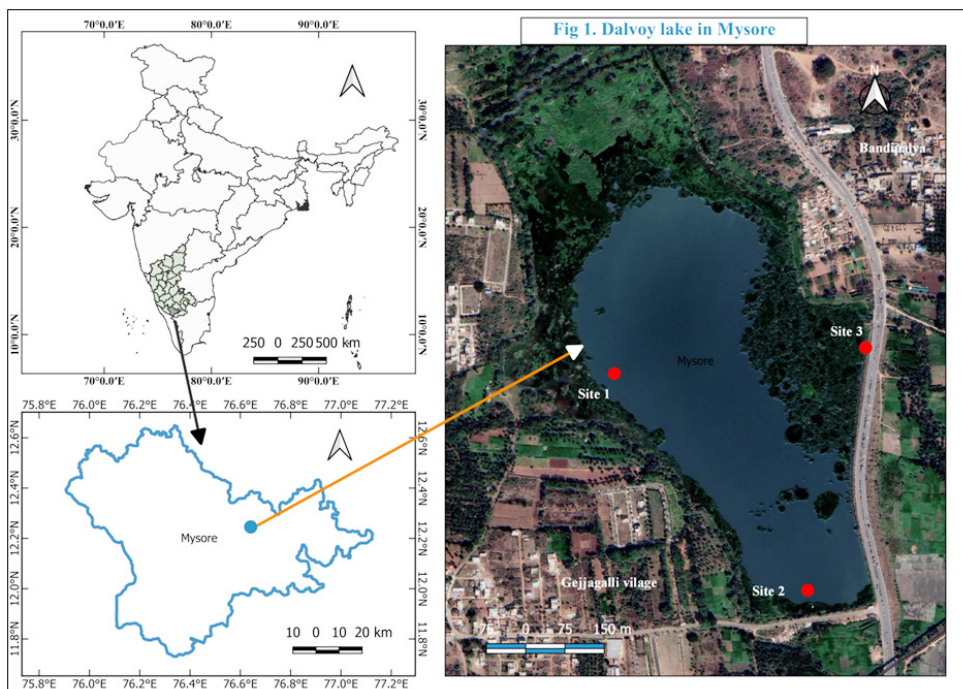
Water quality monitoring assists in identifying and managing pollution conditions, as well as ensuring the effectiveness of management programmes.<sup>8</sup> The use of physico-chemical characteristics and aquatic macro invertebrates are popularly considered worldwide for monitoring the health status of aquatic ecosystems. Among fresh water macro invertebrates aquatic insects are the most numerous and diverse. As they spend all or significant part of their life cycle in the water, they can serve as valuable indicators of the health of water bodies.<sup>9</sup> Different aquatic insect species have different habitat requirements and pollution tolerance. The presence of tolerant species or absence of sensitive taxa can be used to assess the quality of water.<sup>10</sup> Several investigations have been conducted to explore the use of aquatic insects as bio-monitoring tools for assessing water quality.<sup>11,12,13</sup>

Mysore is a well-known tourist destination in India, located at the foot of the Chamundi Hills in the southern state of Karnataka. The city is adorned with many small and medium-sized lakes. Among the popular lakes are Kukkarahalli Lake, Devanoor Lake, Lingambudi Lake, Dalvoy Lake, and Karanji Lake.<sup>14</sup> Several water bodies in and around Mysore have been subjected to various forms of environmental degradation as a consequence of rapid population growth, increasing industrialization, and urban sprawl.<sup>15</sup> The water quality parameters of some of these lakes have been investigated by several workers.<sup>16,17</sup> Studies on the population dynamics of rotifers and the water quality index (WQI) of four major lakes in Mysore city revealed that the rotifers at Dalvoy Lake were stressed, and the lake had a high WQI.<sup>18</sup> In another study abundance of zooplanktons, as well as the physico-chemical characteristics of the same lake, was investigated, and it was shown that the abundance of zooplanktons was unusually high indicating the pollution status of the water body.<sup>19</sup> Most of the studies at Dalvoy were restricted only to the planktons. Studies pertaining to macro-invertebrates diversity in the lake water were lacking. Therefore, in line with this significant lacuna, the present study is designed to thoroughly investigate the composition of aquatic insects and the physico-chemical properties of Dalvoy Lake. In addition, various biotic indices from aquatic insect assemblage and water quality index (WQI) from physico-chemical variables will be computed to determine the overall health of the water body.

## Materials and Methods

### Study Area

Dalvoy Lake is located 5 km south of Mysore district, Karnataka state India (76°65'72.29" E latitude, 12°25'17.81" N, longitude and 707.1m amsl). The water spread area of lake is 133.43 acres and having a length of 2.2 km. The lake is bordered by three villages viz., Gejjagalli, Kuppalur, and Bandipalya, and is located close to the Mysore Nanjangud road. The lake is heavily infested with water hyacinth, *Eichhorniacrassipes* (Mart.) along with *Pistiastratiotes*, *Lemna minor* and *Wolffiaglobosa*. The lake's primary water source includes rain, sewage, and surface runoff from adjoining urban settings (Figure 1).



**Fig.1: Geographical location of the study area showing the sampling sites**

**Water Sample Collection and Physico-Chemical Analysis**

For studying the physico-chemical parameters of water, monthly sampling was done at Dalvoy Lake between 8.00 am to 10.00 am, for a period of one year (from October 2017 to September 2018). Water samples were collected using 1 liter labeled plastic containers from three sampling sites by keeping in view the accessibility and the location of inlet and outlet. The surface water temperature and pH were recorded in the field, with a hand held mercury thermometer and Hanna HI98107 pH meter, respectively. Analysis of different physico-chemical variables like electrical conductivity, salinity, turbidity, total dissolved solids, dissolved oxygen, free carbon dioxide, total alkalinity, calcium, total hardness, nitrate, phosphate, sulphate, chloride, biological oxygen demand (BOD) and chemical oxygen demand (COD) were carried out in the laboratory as per standard methods.<sup>20,21</sup> Variations in the physicochemical properties of water were recorded and compared with Bureau of Indian Standards (BIS)<sup>22</sup> and Indian Council of Medical Research (ICMR) specifications for potable water.<sup>23</sup> The pollution status was determined using water quality index (WQI). For the computation of WQI, the 'weighted arithmetic index method'<sup>24</sup> was

implemented. The overall WQI was calculated using the equation:

$$WQI = \frac{\sum Q_n W_n}{\sum W_n}$$

Where,  $Q_n$  and  $W_n$  indicate the quality rating and unit weight of  $n^{th}$  water quality parameter, respectively. The  $Q_n$  is computed using the following formulae:

$$Q_n = \left[ \frac{(V_n - V_i)}{(S_n - V_i)} \right] \times 100$$

Where,  $V_n$  and  $S_n$  represent the observed value and standard value of the  $n^{th}$  water quality parameter, respectively.

$V_i$  indicates the ideal value, which is 0 for all parameters, except for pH and DO which are 7.0 and 14.6 mg/l respectively.

The Unit weight ( $W_n$ ) is determined following the equation:

$$W_n = K / S_n$$

Where,  $K$  is the proportionality constant, which is computed following equation:

$$K = \frac{1}{\sum \left[ \frac{1}{S_{ij}} \right]}$$

The computed WQI can be used to assess the overall health of the lake by comparing it with the WQI scale (Table 1).

**Table 1: Water quality index scale<sup>24,25</sup>**

WQI	Rating
0-25	Excellent water quality
26-50	Good water quality
51-75	Poor water quality
76-100	Very poor water quality
100 and above	Unsuitable for drinking

**Collection and Identification Aquatic Insects**

Aquatic insects were collected at each sampling site using a circular pond net (Opening 30×30 cm<sup>2</sup>, mesh size 500 μm). The collection was done by disturbing the substrate of littoral zone and dragging the net for one minute across the vegetation. A sample is made up of three such drags.<sup>10,26,27</sup> The aquatic insects were sorted in white trays and were then preserved in 4% formalin at the sampling sites. Insects were identified at the laboratory to the possible lowest taxonomical level with help of a stereo zoom microscope (Labomed CZM4) following the standard keys.<sup>28,29,30,31</sup>

**Statistical Analysis**

Descriptive statistics for all water quality parameters such as mean ( $\bar{x}$ ) and standard deviation (S.D.) were calculated using Microsoft Excel. The PAST software was used to calculate diversity indices like Shannon, Evenness, Margalef and Berger-Parker index. The Pearson correlation coefficient analysis between different environmental variables and the density of aquatic insects was performed using SPSS (version 16) software. The CANOCO v.4.5 software was used to perform Canonical Correspondence Analysis (CCA) to determine the association between aquatic insect taxa and abiotic factors in different seasons. To understand the impact of water quality on aquatic insects community two biotic indices viz., Biological Monitoring Working Party (BMWP) scores and Average Score Per Taxon (ASPT) were computed using family level biotic scores based on their pollution tolerance.<sup>32</sup>

**Results**

**Physicochemical Properties of Water**

Season wise grouped data of water quality variables of Dalvoy Lake from October 2017 to September 2018 are given in Table 2. Most of the physico-chemical (Water quality) variables studied in this investigation showed significant differences across the seasons. Except, water temperature (27.18 - 30.21°C), pH (7.51 – 7.84), calcium (51.3 – 55.30 mg/L) and phosphate (2.38 – 2.9 mg/L) concentrations revealed no significant seasonal changes (Table. 2). The surface water conductivity showed clear cut seasonal variations with less (1008.58μS/cm) during monsoon (July to October), moderate (1192.5μS/cm) in post monsoon (November to February) and more (1270. 83μS/cm) during pre- monsoon (March to June). The turbidity of water was significantly higher(22.31 NTU) in post-monsoon season when compared to pre monsoon (16.44 NTU) and monsoon (15.16 NTU) seasons. Similarly, during the monsoon season, the total dissolved solids were significantly lower (486.08 mg/L) than in the pre-monsoon (668.33 mg/L) and post-monsoon (660 mg/L) seasons. Likewise, the Free CO<sub>2</sub> concentration showed significant variations among seasons with 27.26mg/L during monsoon, 44.56mg/L in post monsoon and 58.10mg/L in pre monsoon. The DO concentration was higher during the post monsoon (4.16 mg/ L) season than during the monsoon (3.96 mg/ L) and pre monsoon (2.49 mg/ L) seasons. The total hardness assessed showed seasonal differences, with Monsoon (267.83mg/L) being much lower than pre-monsoon and post-monsoon seasons (333.33mg/L), which was similar in both seasons. Total alkalinity recorded among seasons ranged between (204.33 – 238.08 mg/L). The high Total alkalinity value (238.08 mg/L) was measured during Monsoon period. The seasonal variation in Chemical Oxygen Demand (COD) ranged between (39.48 - 51.4 mg/L). Further, less COD (39.48mg/L) was reported during post-monsoon and maximum COD value (51.4 mg/L) during monsoon. There were no significant seasonal differences in the Biological Oxygen Demand (BOD). The BOD values (4.58 mg/L) during post monsoon and (6.42 mg/L) in pre-monsoon were the lowest and highest measured values respectively. The surface water Nitrate concentration was comparatively more (12.55 mg/L)

during monsoon, when compare to pre monsoon (7.79 mg/L) and post monsoon (8.91 mg/L) seasons. The sulphate concentration showed seasonal differences with less (33.52 mg/L) in the monsoon, moderate (43.85 mg/L) in the pre-monsoon and more (54.32 mg/L) in the post-monsoon. The concentration of chloride among different seasons revealed that the monsoon had a lower concentration (114.7 mg/L) than the pre monsoon (136.72 mg/L) and post monsoon (140.64 mg/L) seasons (Table. 2).

**Table 2: Physicochemical characteristics of Lake water in different seasons**

Parameters	Post monsoon	Pre monsoon	Monsoon	Annual $\bar{x} \pm SD$
Water temp. (°C)	27.18 ± 2.25	30.21 ± 1.06	28.62 ± 1.32	28.67 ± 1.52
pH	7.71 ± 0.16	7.51 ± 0.09	7.84 ± 0.40	7.69 ± 0.16
Cond(µS/cm)	1192.5 ± 92.23	1270.83 ± 72.74	1008.58 ± 139.52	1157.3 ± 134.62
Turb.(NTU)	22.31 ± 13.19	16.44 ± 14.09	15.16 ± 9.17	17.97 ± 3.82
TDS (mg/L)	660 ± 71.91	668.33 ± 29.63	486.08 ± 66.68	604.81 ± 102.90
Free CO <sub>2</sub> (mg/L)	44.56 ± 1.95	58.1 ± 17.15	27.26 ± 6.31	43.31 ± 15.45
DO (mg/L)	4.16 ± 0.81	2.49 ± 1.34	3.96 ± 0.22	3.54 ± 0.91
Ca <sup>2+</sup> (mg/L)	55.30 ± 5.11	53.74 ± 2.79	51.3 ± 6.92	53.45 ± 2.02
TH (mg/L)	333.33 ± 10.26	328.16 ± 22.50	267.83 ± 42.51	309.78 ± 36.42
TA (mg/L)	204.75 ± 35.10	204.33 ± 53.60	238.08 ± 59.51	215.72 ± 19.37
COD (mg/L)	39.48 ± 17.50	48.91 ± 21.99	51.4 ± 15.08	46.6 ± 6.29
BOD (mg/L)	4.58 ± 1.23	6.42 ± 3.23	6.02 ± 1.52	5.67 ± 0.97
NO <sub>3</sub> <sup>-</sup> (mg/L)	8.91 ± 3.69	7.79 ± 2.73	12.55 ± 7.32	9.75 ± 2.49
PO <sub>4</sub> <sup>3-</sup> (mg/L)	2.9 ± 1.30	2.38 ± 1.22	2.792 ± 0.10	2.71 ± 0.30
SO <sub>4</sub> <sup>2-</sup> (mg/L)	54.32 ± 19.77	43.85 ± 19.78	33.52 ± 4.93	43.89 ± 10.40
Cl <sup>-</sup> (mg/L)	140.64 ± 5.54	136.72 ± 12.44	114.7 ± 12.51	130.68 ± 13.98

Note: Cond-Conductivity, Turb- Turbidity, TDS total dissolved solids, Free CO<sub>2</sub> Carbon dioxide, DO- Dissolved oxygen, Ca<sup>2+</sup> - Calcium, TH total hardness, TA total alkalinity, COD chemical oxygen demand, BOD biological oxygen demand, NO<sub>3</sub><sup>-</sup> - Nitrate, PO<sub>4</sub><sup>3-</sup> - Phosphate, SO<sub>4</sub><sup>2-</sup> - Sulphate, Cl<sup>-</sup> - Chloride.

**Table 3: Drinking water standards and recommended agencies with unit weight (W<sub>n</sub>)**

Parameters	Water quality standards (S <sub>n</sub> )	Recommended agency	Unit weight (W <sub>n</sub> )
pH	6.5-8.5	ICMR/ BIS	0.1514
Conductivity	300	BIS	0.0043
TDS	500	ICMR/ BIS	0.0026
DO	5	ICMR/ BIS	0.2573
Calcium	75	ICMR/ BIS	0.0172
Hardness	300	ICMR/ BIS	0.0043
TA	200	BIS	0.0064
BOD	5	ICMR	0.2573
Nitrate	45	BIS	0.0286
Sulphate	200	BIS	0.0064
Chloride	250	ICMR/ BIS	0.0051
Turbidity	5	BIS	0.2573
		ΣW <sub>n</sub> =	1.00

\* All the parameter units are expressed in mg/L; except pH, conductivity (µS/cm) and turbidity (NTU)

**Table 4: Season wise summary of WQI in Dalvoy Lake**

Seasons	WQI	WQS
Post-monsoon	179.02	Unsuitable
Pre-monsoon	160.83	Unsuitable
Monsoon	151.17	Unsuitable
Overall WQI	163.67	Unsuitable

**Water Quality Index (WQI)**

In accordance with the conventional methods of calculating WQI, the first step is to estimate the

unit weightfor each parameter to a common scale. The unit weight and standard values for selected parameter as per BIS and ICMR standards used for calculating the WQI is given in Table 3. The WQI scores of the surface water samples of Dalvoy Lake for all the 3 seasons are shown in Table 4. The findings revealed that water quality of Dalvoy Lakein all seasons fall under unsuitable category (WQI > 100). The highest value of WQI was seen during post-monsoon (179.02), followed by pre monsoon (WQI = 160.83) and lowest was during monsoon (151.17).

**Table 5: Significant Pearson’s correlations between physico-chemical variables and aquatic insect density in Dalvoy Lake, Mysore**

Variables	r	Variables	r
Free CO2 vs Conductivity	.660*	Insect density vs Free CO2	.618*
Free CO2 vs TDS	.674*	Density vs Chloride	.618*
Free CO2 vs Total hardness	.660*	TDS vs Conductivity	.922**
Total hardness vs Calcium	.602*	Total hardness vs Conductivity	.845**
Phosphate vs Dissolve oxygen	.622*	Total hardness vs TDS	.889**
Sulphate vs Calcium	.662*	BOD vs COD	.923**
Chloride vs Free CO2	.707*	Chloride vs TDS	.899**
Insect density vs COD	-.775**	Chloride vsConductivity	.865**
Insect density vs BOD	-.833**	Total hardness vs Chloride	.920**

\*\*significant at p <0.01 level (2 tailed); \* significant atp < 0.05 level (2 tailed).

**Pearson Correlation (Two- Tailed)**

The results of significant correlations calculated between various physico-chemical parameters and aquatic insect density are shown in Table 5.The physico-chemical (water quality) variables studied, showed weak correlations with density of aquatic insects except free carbon dioxide, chloride, biological oxygen demand and chemical oxygen demand. FCO2 showed a positive correlation with aquatic insect density (0.618, P < 0.05). Similarly, chloride showed a positive correlation with aquatic insect density (0.618, P <0.05).There was a negative correlation between aquatic insect density and biological oxygen demand (-0.833, P 0.01) and chemical oxygen demand (-0.755, P 0.01), respectively.Further, the correlations among water quality variables (Table 5) revealed that the FCO2 having positive correlations of lesser significant with other water quality variables such as, conductivity, TDS, total hardness and

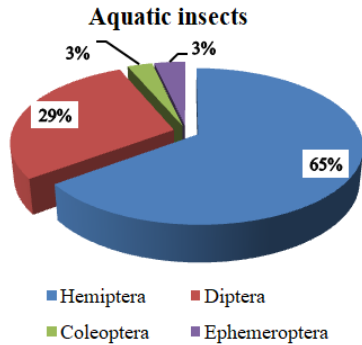
chloride. A similar positive correlation was noticed between total hardness and calcium, phosphate and dissolved oxygen, sulphate and calcium. Further, more significant correlations were noticed between TDS and conductivity, total hardness and conductivity, total hardness and TDS, and between BOD and COD. Similarly, chloride showed significant correlations with TDS, Conductivity and Total Hardness.

**Composition and Distribution of Aquatic Insects**

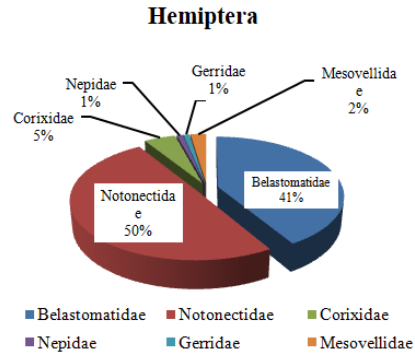
In the present investigation 15 species of aquatic insects were identified and recorded. Thesebelonged to 4 orders – Hemiptera, Coleoptera, Diptera and Ephemeroptera. The species composition of different orders of insects revealed that, the largest group noticed was Hemiptera comprising of 8 species, followed by 4 species of Diptera, 2 species of Coleoptera, and a lone species of Ephemeroptera (Table 6). The Order Hemiptera

was the dominant, most diverse and abundant group when compared to remaining Insect groups studied. Hemiptera accounted for 64.88% of the total insect fauna (Fig. 2). In the current investigation, the order Hemiptera was represented by 6 families (Fig.3) viz. Notonectidae (32.23%), Belastomatidae (26.89%), Corixidae (3.05%), Mesovellidae (1.53%), Nepidae (0.59%) and Gerridae (0.59%).

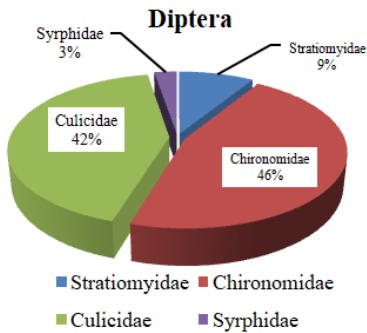
The second largest group was Diptera with 4 families (Fig.4) Chironomidae (13.15%), Culicidae (12.21%), Stratiomyidae (2.54%) and Syrphidae (0.76%). Coleoptera was represented by 2 families (Fig.5) Hydrophilidae (1.70%) and Dytiscidae (1.19%). Ephemeroptera was least represented with only one family Baetidae (3.56%).



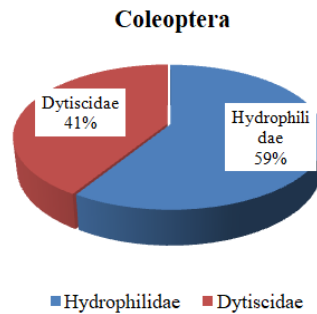
**Fig. 2: Relative abundance of aquatic insect orders**



**Fig. 3: Relative abundance of Hemipteran families**



**Fig. 4: Relative abundance of Dipteran families**



**Fig. 5: Relative abundance of Coleopteran families**

Season wise distribution of aquatic insects revealed that, all families and orders of aquatic insects recorded in this study were present during post-monsoon season. Further, the Belastomatidae and Notonectidae of order Hemiptera; Chironomidae, Culicidae and Stratiomyidae of order Diptera and Dytiscidae of order Coleoptera are common across all the seasons. A lower family variation was found during pre-monsoon with only 8 families representing three orders (Table 6).

The abundance of different taxa of aquatic insects and their relative abundance and dominance status calculated based on Engelmann's scale<sup>33</sup> in the surface waters of Dalvoy Lake are given in

Table 7. The species *Diplonychusrusticus*, *Anisops* sp. and *Enithares* sp. of order Hemiptera and *Chironomus* sp. and *Culex* sp. of order Diptera (Relative abundance (RA%) range 12.21 - 26.89%) are the most abundant and dominant species. The *Baetis* sp. of order Ephemeroptera was the only subdominant (RA=3.56%) species reported. However, *Sigara* sp. and *Mesovilia* sp. of order Hemiptera; *Hydroglyphus* sp. and *Berosus* sp. of order Coleoptera and *Stratiomys* sp. of order Diptera were reported as recedent species (RA% range 1.19 - 3.05%). The *Ranatrafilliformes*, *Laccotrephes* sp. *Limnogonus* sp. *Eristalis* sp. (RA% range 0.25 - 0.76%) were reported in subrecedent category (Table 7).

**Table 6: Seasonal variation of aquatic insects during studied period in Dalvoy Lake**

Family	Taxa Species	Post monsoon	Pre monsoon	Monsoon
<b>Hemiptera</b>				
Belastomatidae	<i>Diplonychusrusticus</i>	+	+	+
Notonectidae	<i>Anisops sp.</i>	+	+	+
	<i>Enithares sp.</i>	+	+	+
Corixidae	<i>Sigara sp.</i>	+	-	+
Nepidae	<i>Ranatrafiliformes</i>	+	-	-
	<i>Laccotrephes sp.</i>	+	-	-
Gerridae	<i>Limnogonus sp.</i>	+	+	-
Mesovellidae	<i>Mesovilia sp.</i>	+	-	+
<b>Coleoptera</b>				
Hydrophilidae	<i>Hydroglyphus sp.</i>	+	-	-
Dytiscidae	<i>Berosus sp.</i>	+	+	+
<b>Diptera</b>				
Stratiomyidae	<i>Stratiomys sp.</i>	+	+	+
Chironomidae	<i>Chironomous sp.</i>	+	+	+
Culicidae	<i>Culex sp.</i>	+	+	+
Syrphidae	<i>Eristalis sp.</i>	+	-	+
<b>Ephemeroptera</b>				
Baetidae	<i>Baetis sp.</i>	+	-	+

+ = Present; - =Absent

**Table 7: Relative abundance and dominance status of aquatic insects in Dalvoy Lake**

Taxa Species	Abundance	Relative abundance (RA)%	Status
<i>Diplonychusrusticus</i>	317	26.89	Dominant
<i>Anisops sp.</i>	218	18.49	Dominant
<i>Enithares sp.</i>	162	13.74	Dominant
<i>Sigara sp.</i>	36	3.05	Recedent
<i>Ranatrafiliformes</i>	3	0.25	Subrecedent
<i>Laccotrephes sp.</i>	4	0.34	Subrecedent
<i>Limnogonus sp.</i>	7	0.59	Subrecedent
<i>Mesovilia sp.</i>	18	1.53	Recedent
<i>Hydroglyphus sp.</i>	20	1.70	Recedent
<i>Berosus sp.</i>	14	1.19	Recedent
<i>Stratiomys sp.</i>	30	2.54	Recedent
<i>Chironomous sp.</i>	155	13.15	Dominant
<i>Culex sp.</i>	144	12.21	Dominant
<i>Eristalis sp.</i>	9	0.76	Subrecedent
<i>Baetis sp.</i>	42	3.56	Subdominant

Relative abundance < 1% = Sub-recedent; 1.1-3.1% = Recedent; 3.2-10 % = Sub-dominant; 10.1-31.6 % = Dominant; > 31.7% = Eudominant<sup>33</sup>



**Table 8: Seasonal variation in the diversity indices and Biomonitoring Scores of Dalvay Lake**

Seasons	Shannon_H'	Evenness_e^H/S	Margalef	Berger-Parker	BMWP	ASPT
Post monsoon	2.111	0.5505	2.227	0.2565	57	4.4
Pre monsoon	1.392	0.5029	1.166	0.4469	32	4.6
Monsoon	1.991	0.6659	1.83	0.2542	42	4.2

Scores of BMWP reflecting water quality: 0-16=Very Poor; 17-50=Moderate; 51-100=Good; 101-150=High; 151+=very high. ASPT score: >6=Good water quality, 5-6=Doubtful water quality, 4-5=probable moderate pollution, <4= Intense pollution<sup>32</sup>

Seasonal variation in the diversity indices score based on insect assemblages calculated is shown in the Table 8. The Shannon index (H') value measured in different seasons ranged from 1.392 to 2.111. These seasonal variation in Evenness value (e^H/S) revealed small differences, the minimum value of 0.5505 was recorded in post-monsoon, and maximum value 0.6659 in monsoon. The value of Margalef's index showed significant variation with maximum value seen in post-monsoon (2.227) and minimum in pre-monsoon (1.166). Seasonal differences in the Berger Parker dominance index were also seen, with the highest score (0.4469) observed in the pre-monsoon season, compared to the post-monsoon (0.2565) and monsoon (0.2542) seasons.

**BMWP and ASPT**

The Biological Monitoring Working Party (BMWP) score is an index that uses macro-invertebrates as biological indicators to evaluate biological water quality.<sup>34</sup> The BMWP score is calculated by adding the scores of individual families present, where the score values of each family reflect their pollution tolerance. A high score indicates the presence of families that are sensitive to pollution, and a low score indicates families that are tolerant of pollution.<sup>35</sup> The average score per Taxon (ASPT) is determined by dividing BMWP score with total number of families present.<sup>32</sup> In the present investigation, the result obtained from the BMWP index revealed that, the water quality was moderate (score 32) during Pre-monsoon and in Monsoon (score 42). Whereas, the BMWP index during Post-monsoon was 57 which is at border for good water quality (50-100). However, the ASPT score was similar among the seasons studied (range 4.2 – 4.6) indicates probably moderate water quality in the surface waters of Dalvay Lake (Table 8).

**Canonical Correspondence Analysis (CCA)**

The association between aquatic insect taxa and water quality variables for first the two axes in Dalvay Lake are shown in Table. 9. CCA showed the following eigenvalues: axis I- 0.182, axis II- 0.076. The species and environmental correlation coefficient for both the axis I and axis II was 1.00, which indicates a significant association between aquatic insect community and environment parameters. The cumulative variance for axis I and axis II was 70.5 % for species data and 100 % for species-environment relationships, respectively.

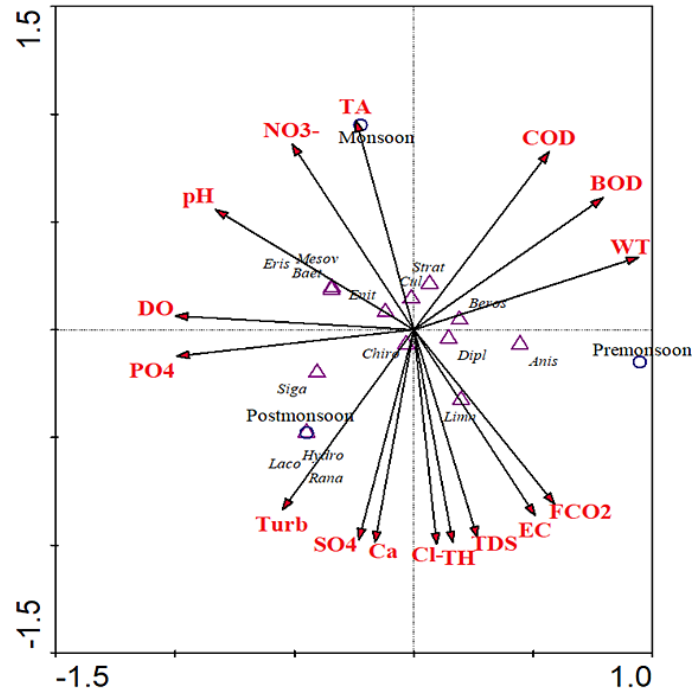
**Table 9: Summary of Canonical correspondence analysis between aquatic insect species and environmental variables for the first 2 axes in Dalvay Lake**

	Axis 1	Axis 2
Eigenvalues	0.182	0.076
Species-environment correlations	1.000	1.000
Cumulative percentage variance:		
Of species data	70.5	100
Of species-environment relation	70.5	100
Sum of all eigenvalues	0.259	
Sum of all canonical eigenvalues	0.259	

**Discussion**

**Environmental Factors**

The seasonal variations in the mean values of selected physico-chemical (Water quality) parameters (Table 2) revealed that some of the Physico-chemical variables viz., Dissolved oxygen, BOD, Conductivity, TDS, Total hardness, Turbidity and Total alkalinity in the present investigation were beyond the minimum permissible limits of BIS and ICMR standards.



**Fig. 6: CCA triplot illustrating association among different species of aquatic insects (triangle), water quality parameters and seasons (Circle). *Dipl* = *Diplonychus* sp., *Anis* = *Anisops* sp., *Enit* = *Enithares* sp., *Siga* = *Sigara* sp., *Rana* = *Ranatra* sp., *Laco* = *Laccotrepes* sp., *Limn* = *Limnogonus* sp., *Meso* = *Mesovilia* sp., *Hydr* = *Hydroglyphus* sp., *Beros* = *Bersous* sp., *Strt* = *Stratiomys* sp., *Chiro* = *Chironomous* sp., *Cul* = *Culex* sp., *Eris* = *Eristalis* sp., *Baet* = *Baetis* sp.**

Temperature is the major physical factor which affects physicochemical and biological characteristics of water. The increase in water temperature not only accelerates chemical reactions but also reduces gas solubility and thereby intensifies the taste and odour of water.<sup>36,37</sup> In the present investigation the mean water temperature did not show much significant seasonal variations, except a slight increase in temperature was found during pre-monsoon (30.21°C) which could be attributable to increased solar radiation, clear skies, and low water levels.<sup>38</sup> The pH of the water was slightly alkaline throughout the sampling period, which agrees with the results of earlier workers<sup>39</sup> and was found to be within the acceptable range of drinking water standards. Electrical conductivity is a function of dissolved solids and it was strongly correlated with total dissolved solids during the study. Moreover, the measured conductivity levels and TDS were significantly higher in all seasons. The maximum values for conductivity (1270.83 S/cm) and TDS (668.33 mg/L) were observed during the pre-monsoon season, which

corresponds with a reduction in water levels which is known to cause an increase in concentration of dissolved solids. Similar trend was observed in earlier studies on Dalvoy Lake.<sup>15,17</sup> The high concentration of total dissolved solids is known to increase the water colour, which leads to increased temperature and decrease the rate of photosynthesis.<sup>40</sup>

The mean turbidity value was higher than the permissible limit (5 NTU) according to the BIS standards. Turbidity is inversely proportional to water transparency which is caused by suspended particles and organic matter, planktons and other microscopic organisms.<sup>41</sup> Turbidity is regarded as a significant limiting factor in the biological productivity of water bodies.<sup>42</sup>

The FCO<sub>2</sub> concentration was high throughout the study period and ranged from 27.26 – 58.10 mg/L, which can attribute to increased respiration. Further, FCO<sub>2</sub> exhibited a strong positive association with aquatic insect density, which could be due

to increased respiration by a large number of insects.<sup>43</sup> Determination of dissolved oxygen (DO) concentration is a fundamental part of water quality assessment. The DO was maximum in the post-monsoon season (4.16 mg/L), which is due to the greater solubility of oxygen at lower temperature, while the lowest was observed in the pre-monsoon season (2.49mg/l) due to high temperatures.<sup>44</sup> Further in this study a negative correlation between water temperature and DO ( $r = -0.459$ ) was noticed. The depletion of DO can also be attributed to pollution, respiration and decomposition of decaying sediment.<sup>45</sup>

Calcium is a major divalent ion that is necessary for shell development, bone growth, and plant precipitation in freshwater bodies.<sup>46</sup> The highest concentration of Calcium was measured during the post-monsoon season (55.30 mg/L) which was within the acceptable limits of BIS. The total hardness of water is also an important water quality parameter for its intended application in domestic or agricultural purposes.<sup>47</sup> The maximum and minimum value of hardness was observed during post-monsoon (333.33 mg/L) and monsoon (267.83 mg/L). There was a strong positive association between total hardness, conductivity and total dissolved solids, which was in accordance with earlier reports.<sup>17</sup>

Alkalinity refers to water's ability to neutralize acids. Water becomes alkaline when carbonates, bicarbonates, and hydroxides are present.<sup>17</sup> The total alkalinity of the water sample was slightly higher than the permissible limit (< 200 mg/L) according to BIS standard. The higher value of biological oxygen demand (BOD) attained during summer (6.42 mg/L) was in contrast to DO value. Moreover, BOD values correlated with COD, which is consistent with previous study<sup>15</sup> and is linked to increased loads of residential sewage.<sup>48</sup> A low BOD/COD value indicate good water quality, whereas a high BOD/COD value indicates polluted water which harms aquatic life.<sup>49</sup> This is supported by a negative correlation of BOD and COD with aquatic insect density.

Nitrate is among the most stable forms of nitrogen and plays key role in growth of plankton and primary production. High concentrations of nitrate are generally the result of human activities like agriculture, disposal of organic and domestic sewage and industrial wastes.<sup>50</sup> In the present

study, the concentration of nitrate falls within the normal limits according to BIS standards. The concentration of phosphate during the study period ranged between 2.38 – 2.97 mg/L. A steady input even low level of nitrates and phosphates to an aquatic water body can considerably enhance algae growth.<sup>51</sup> The mean sulphate values was also within the acceptable limit according to ICMR standards (< 200 mg/L). Sulphate levels in water can be increased by sewage and industrial wastes, as well as biological oxidation of reduced sulphur species.<sup>15</sup> The concentration of chloride was within the acceptable limit of less than 250 mg/L. The general increase in chloride in lakes is likely corresponding to pollution from domestic sewage and agricultural wastes.<sup>52</sup> The positive correlation of chloride with conductivity and total hardness can be attributed to the increase in salinity of the water.<sup>53</sup>

The WQI helps in transforming complex data sets into numeric expressions and present the status of water quality as a single number.<sup>54</sup> The degradation of water quality was significantly higher in post-monsoon season (WQI- 179.02) and was almost similar in pre-monsoon (WQI- 160.83) and in monsoon season (151.17). The finding suggests that water quality is deteriorated throughout the year and is unsafe for human usage. The poor water quality can be ascribed to the excessive inflow of sewage waste and runoff from nearby urban settings.<sup>17</sup>

### Biotic Factors

Aquatic insects are generally considered as the dominant macro-invertebrates in freshwater ecosystems. Several studies have shown that the structure and composition of biotic community changes with water quality which is often reflected in their distribution, diversity and abundance pattern of species.<sup>55, 56, 57</sup> The species diversity and percentage composition of various insect orders collected from Dalvay Lake is shown in Fig.2. The Hemiptera had the highest number of species represented by 8 genera, accounting for 65% of the total insects collected (table 6). Belastomatidae and Notonectidae were the most abundant family among Hemiptera which together accounted 91% of the family (Fig. 4). The dominance of the order Hemiptera is mainly because of its ability to use atmospheric oxygen through various respiratory devices (plastron, siphon etc.) thus they do not rely on DO in water.<sup>58</sup> This is further evidenced in CCA analysis, where *Laccotrephes* sp.,

*Sigarasp.*, *Ranatrafiliformes* were associated with turbidity and low dissolved oxygen, suggesting their less dependency on DO.<sup>59</sup> Similar reports as to the dominance of Hemiptera in freshwater lakes are noted in several studies.<sup>5, 60, 61</sup> The major Coleopteran was contributed by the families Hydrophilidae and Dytiscidae, represented by the genus *Hydroglyphus* and *Berosus* respectively. Studies have shown that Dytiscidae family generally inhabits submerged macrophytes, while the Hydrophilidae which are water scavengers occur in shallow water zones of the lake and feed on detritus and decaying organic matter.<sup>28</sup> In the present study the heavy infestation of lake by *Eichhorniacrassipes* support these families. Diptera constituted second major order and was contributed by 4 major families representing Chironomidae, Culicidae, Stratiomyidae and Syrphidae (Fig. 3). The genus *Chironomous* of Chironomidae and *Culex* sp. of Culicidae were regarded as dominant as per Engelmann's scale.<sup>33</sup> The members of these families tend to dominate heavily polluted water bodies. The high abundance of Chironomidae generally reveals environmental stress from anthropogenic activities. It is for this reason the larvae of the *Chironomous* genus are used as bio-indicators of pollution in many studies.<sup>62, 63, 64</sup> The order Ephemeroptera was represented by only one genus *Baetis* (family: Baetidae) which is reported to be tolerant to organic pollution.<sup>65</sup>

The CCA ordination diagram showed that both environmental variables and aquatic insect assemblages were homogeneously scattered (Fig.6). The correlation coefficient between sites and environmental variables is shown by the Eigen values associated with each axis.<sup>66</sup> An Eigen value closer to 1 suggests a higher magnitude of connectivity among sites and environmental factors.<sup>67</sup> In the present investigation, the correspondence was examined between seasons and variables, thus the total Eigen value of 0.26 suggests a low to medium level of correlation between species and season. The CCA ordination graph distinctly separated the seasons as per the aquatic insect community structure. During pre-monsoon, *Berosus* sp. *Diplonychusrusticus* and *Anisops* sp. showed dependence on water temperature and FCO<sub>2</sub>. In postmonsoon season *Laccotrephe* sp., *Sigarasp.*, *Ranatrafiliformes*, *Hydroglyphus* sp. revealed strong dependence on concentration of phosphate and

turbidity. Again in monsoon most of the species showed dependence on concentration of nitrate and total alkalinity.

The data on assemblage of aquatic insects in different seasons showed a high abundance during the Post monsoon season as compared to other two seasons. This is supported by a high Shannon index value of 2.111 in post monsoon season. The diversity index between 01 - 03 indicates moderate pollution.<sup>68</sup> The low Shannon (H') value (1.392) was recorded during pre-monsoon season which is justified by the maximum Berger – Parker Index (0.4469) indicating that the system was occupied by dominant species (Hemiptera) in that season. Several studies have found a large abundance of aquatic insects during the post-monsoon season, with similar findings.<sup>69, 70</sup> The low evenness value throughout the study indicates relatively even distribution of aquatic insects.<sup>71</sup> The value of Margalef index ranged between 1.83 - 2.227, which indicates moderate pollution.<sup>72</sup> These results are corroborated with the values of biotic indices BMWP (score 17-50) and ASPT (scores 4.2-4.6) suggesting moderate pollution by degradable organic matter.<sup>73</sup>

### Conclusion

The results of the present analysis revealed that Dalvoy Lake is highly polluted, as evidenced by WQI and biological indices that indicate agitation of the system. Elevated levels of various water quality parameters like conductivity, TDS, total hardness, turbidity, and BOD throughout the year suggest a steady inflow of domestic and industrial waste. The study on the composition of aquatic insects revealed the abundance of Hemiptera and Diptera across all seasons. The high abundance of pollution-tolerant genera *Chironomous* and *Culex* of the order Diptera during the study period suggests high organic contamination. This is supplemented by the low diversity value (H') along with low BMWP and ASPT scores. From the investigation, it can be said that the lake ecosystem is adversely affected and calls for stringent measures to control the indiscriminate dumping of municipal waste, industrial effluents as well as other pollutants into the lake water. Further, a long-term monitoring program and strict vigilance are needed for conservation and sustainable management of this perennial water body.

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### Conflict of Interest

The author(s) declares no conflict of interest.

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