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Anthropogenic Pressure- A Potential threat to Biodiversity. An Evidence from Macroinvertebrate Community of Dal Lake, Kashmir, India

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ABSTRACT

A survey was conducted to assess the macroinvertebrate community and water quality of the Dal Lake of Kashmir in relation to anthropogenic pressure on the lake. Macroinvertebrates were collected by D-frame net and Ekman's dredge. Physico-chemical analysis of water was performed by following methods of the American public health association. During the survey, 28 macroinvertebrate taxa were recorded, representing phylum Annelida (8 taxa), Arthropoda (13 taxa), and Mollusca (7 taxa). The mean population density of macroinvertebrates was estimated at 6376 ind./m2. The annelids were found dominant (2524 ind./m2) followed by arthropods (2411 ind./m2) and mollusks (1441 ind./m2). Mean value of Biological indices was computed 2.41 (Shannon's index), 0.89 (Simpson's index), 1.55 (Margalef's index), and 0.17 (Pielou evenness index).

Water quality assessment revealed eutrophic, alkaline, highly productive, hard water type, and the organically polluted nature of lake waters. Water quality, sewage influx, organic wastes, agricultural wastes, and macrophytes were observed as the influential factors in determining the patterns in diversity, distribution, and composition of the macroinvertebrate community in the lake. Anthropogenic pressure at lake catchments was observed as a major force behind the current ecological conditions of the lake. The study concludes that the lake is under anthropogenic and pollution stress and urges for immediate restoration measures.

Keywords: Macroinvertebrates, diversity, water quality, urbanization, pollution

INTRODUCTION

Water bodies have always been recognized as the backbone of the economic and domestic affairs of any country or region. Besides, these aquatic ecosystems have been recognized as hot spots of biodiversity (Gudoo, 2019). Rich biodiversity is probably crucial to the normal functioning of an aquatic ecosystem in fluctuating environments (Zavaleta et al., 2010; Cao et al., 2018). However, currently, biological diversity is declining at a faster rate than observed ever before: as a result of habitat demolition and annexation of unfamiliar taxa resulted by undesirable anthropogenic actions on aquatic ecosystems (Sala et al., 2000; Havel et al, 2015, Cao et al., 2018), particularly the fall in pollution sensitive taxa, uncommon taxa, and keystone taxa due to advancing pollution level in water bodies (Purvis et al., 2000; Berg et al., 2015; Cao et al., 2018). The extinction of crucial species not only results in biodiversity loss but also upsets the overall patterns in composition, distribution, and structure of ecological communities and thus affects the resilience and stability of an aquatic ecosystem (Fahrig, 2003; Foley et al., 2005; Mouillot et al., 2013; Wang & Loreau, 2014). Among the diverse aquatic biota inhabiting aquatic ecosystems, invertebrates occupy a unique position from an ecological point of view (Kotpal, 2018-2019) and play an active role in maintaining the structure, function, and integrity of aquatic ecosystems (Gore et al., 2001; Sandin & Solimini, 2009; Cao et al., 2018). Invertebrates play a vital role in nutrient cycling like Carbon, Nitrogen, and Sulfur cycling (Cross et al., 2005). They also serve as food for fishes (Sharma & Gandhi, 2012). They have been categorized as excellent biological indicators and are employed in the biomonitoring of water bodies (Johnson, 1993). It is quite unfortunate that despite having such ecologically significant biodiversity, water bodies are under constant threat of over-exploitation. Degradation of habitat has been recognized as a major hazard to macroinvertebrate diversity and their assemblies (Sala et al., 2000; Feld et al., 2014; Havel et al., 2015). Habitat destruction results in abrupt alteration of habitat quality from a species-rich state to a species-poor state (Muradian, 2001). The urbanization pressure associated with increasing sedimentation, the release of domestic sewage, and the dumping of solid wastes into the water have severely disturbed water bodies' ecology (Baur & Pringle, 2000; Paul & Meyer, 2001). The continuous increase in the influx of nitrogen and phosphorous-rich fertilizers and other wastes have resulted in the eutrophication of water bodies (Burton et al., 1977).

Multiple approaches have been employed from time to time for assessing the conditions of water bodies. On a lighter note, the classical approach, which mostly relies on physico-chemical analysis, is commonly used for the assessment of aquatic ecological conditions. Although this approach is still in use, it seems insufficient on broader perspective to study the overall aquatic ecology (Karr, 1995).

Currently, in addition to the physico-chemical approach, the biological approach (biomonitoring or bio-assessment) relies on the application of living organisms to assess the status of water bodies (Tate & Heiny, 1995). Among various living organisms, macroinvertebrates are recognized as model organisms that can be employed in the biomonitoring process (Duda et al., 1982; Johnson, 1993) either through their taxonomic or functional approach because of their ability to respond to any slight change to aquatic conditions.

The Taxonomic approach includes their diversity, distribution, and population density which are greatly determined by the abiotic factors of an aquatic ecosystem (Habib & Yousuf, 2015). The Functional approach includes their role in the food web and energy flow (Cummin et al., 2005). Any alteration in invertebrate community structure indicates the cumulative ecological effects of various natural and anthropogenic activities. These invertebrate communities are sensitive to shifts in food resources and ultimately generate shifts in the trophic structure of the lake (Schneider & Sager, 2007). They are considered as the most ideal and most familiar targets to investigate the impact of urbanization and other anthropogenic activities on a water body (Duda et al., 1982). The benthic macroinvertebrate community of a particular aquatic habitat is crucial in determining the pollution status of a water body, and it is, therefore, an important criterion for the ecological classification of lakes (Malik & Ali, 2012). Application of macroinvertebrates in the biomonitoring approach of an aquatic ecosystem might have few difficulties. Despite these difficulties, many scientific studies have documented their efficiency and validity in evaluating the impact of undesirable anthropogenic activities on an aquatic ecosystem.

OBJECTIVES OF THE STUDY

The current study was undertaken to assess the macroinvertebrate community and water quality of Dal Lake in Kashmir to provide comprehensive information about the current ecological status of the lake. The factors affecting the patterns in diversity, distribution, and composition of macroinvertebrate community in the lake were also studied. Further, the impact of anthropogenic pressure on water quality and macroinvertebrate fauna of the lake was also assessed.

MATERIALS AND METHODS

Study area

Dal Lake - a high altitude urban lake of fluviatile basis is situated in the North-East of Srinagar city of Kashmir at an altitude of 1886 meter above sea level. It is located between the geographical coordinates of 34o 6’ -34o 10’ North latitude and 74o 8’ -74o 9’ East longitude at the foot of the Zabarwan mountains. This stunning lake ecosystem has a tectonic origin. It is fenced by several mountain ranges, including the Mahadev mountain range on its East, Kohi Suleiman on its South, and Hari Parbat hill on its West. The overall catchment area of the Dal Lake is about 317 km2. It is said that the Dal is nourished up by several underground springs, but Telbal Nallah- a perennial; stream from the Northern side of the lake serves as the chief source of water for Dal Lake. It transports water from high altitude Marsar Lake and the bulk of sewage and sediment load from the Tebal area into the lake.

In addition to the Telbal stream, Peshpawnala, Shalimarnala, Merakhshanala, and Harshikul are other small streams that supply water to the Dal Lake. The major water outlets of the lake are Pokhribal nallah and Dalgate. A small canal locally known as “Nalla Amir Khan” links Dal Lake with Khushalsar Lake through Nigeen and serves as an additional outflow channel. The lake is multi basined comprising of four basins: Hazratbal basin, which is located on the Northern side of the lake and is under gradual siltation due to sediment load brought into the lake by Telbal nallah; Bod-Dal basin, which is located on the Western side of the lake; Gagribal basin, which is located between the Dalgate exit and

Nehru Park, mainly used for holding shikaras and houseboats; and the Nigeen basin, which is the deepest of all the four basins. Since the past few decades, Dal Lake has undergone severe eutrophication as a result of the influx of huge quantities of municipal sewage, domestic sewage, and agricultural wastes into the lake. The Dal Lake is deprived of its ecological, aesthetic, and recreational worth as a consequence of its deteriorated water quality and dull appearance (Yousuf & Shah, 1988; Mukhtar & Chisti, 2013; Shah, 2012; Khan et al., 2013; Najar & Bashir, 2013; Dar et al., 2016).

Description of sampling sites in Dal Lake:

Site-D1. This site is located on the Eastern side of the lake at its exit (dalgate). Sparsely distributed vegetation at the littorals of this site mainly comprises *Myriophyllum spicatum* L, *Potamogeton pectinatus*, *P. luecens* L, and *P. crispus* L, *Ceratophylum damersum* L, and *Hydrilla verticillata* (Lf) Royle. Further, this site also possesses a sandy and gravelly bottom.

Site-D2. This site is situated on the Western side of the lake in the BOD dal basin. Macrophytic vegetation at this site comprises *Myriophyllum spicatum* L, *M. verticillatum*, *Potamogeton leucens* L, *P. natans*, *Najas gramine,* and *N. major*, *Nelumbo nucifera*, *Nymphoides peltatum*, *Trapa natans*, and *Typha angustata*.

Site-D3. This site is located on the Northern side of the lake near the point where Telbal nallah enters into the part of Dal Lake locally known as Hazratbal basin. This site is characterized by macrophytic vegetation of *Ceratophylum damersum* L, *Myriophyllum spicatum* L, *Myriophyllum verticillatum* L, *Utricularia flexuosa*, and *Typha angustata.*

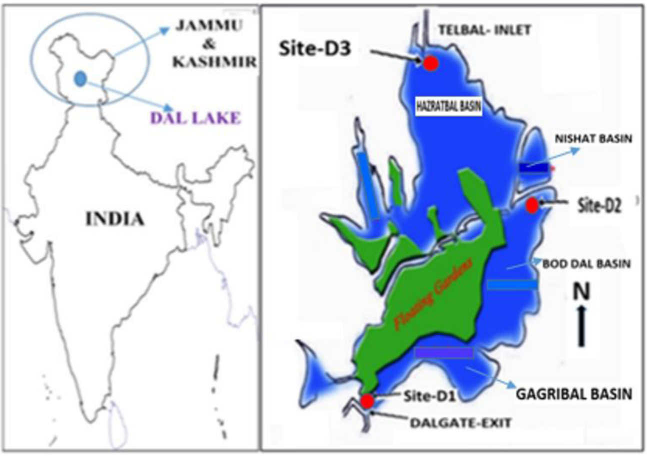


Figure 1. Location of Dal Lake in Kashmir, India and location of sampling sites in Dal Lake.

Collection of water samples

During the two-year study period (March 2016 to February 2018), water samples were collected monthly during the early morning hours in iodine-washed polyethylene plastic bottles. Water quality analysis was carried out according to the standard protocols of the American public health association (APHA), 2004. Air and water temperature, transparency, depth, dissolved oxygen (DO), pH, and free carbon dioxide were estimated on the spot during sample collection. Electrical conductivity, total dissolved solids (TDS), total alkalinity, total hardness, chlorides, nitrates, biological oxygen demand (BOD), ammonia, and iron were estimated in the laboratory.

Collection and preservation of macroinvertebrates

Macroinvertebrates sampling was executed on a monthly basis from March 2016 to February 2018 by employing D-Frame net (mesh width 0.5 mm) and Ekman, s Dredge each with an area of 15×15 cm2. D-frame net sweeps in a forward direction were performed to collect the macroinvertebrates residing in the water column present between bottom and surface (Hoffsten & Malmqvist, 2000; Kovalenko et al., 2014) while as, Ekman, s Dredge was employed to collect benthic samples (Fishar and William, 2006). At each site, the sample was taken in triplicate and then pooled together. The samples were properly mixed with water and were sieved through a sieve net (mesh width 250 μm) to get rid of fine mud particles (Kovalenko et al., 2014). The organisms retained in the sieve were sorted out manually using forceps and brushes and were preserved in clean plastic bottles filled with 4% formalin and 70% alcohol, depending upon the kind of organisms to be preserved. The soft-bodied organisms were preserved in 70% alcohol while the shelled organisms like mollusks in 4% formalin (Borror et al., 1976).

Qualitative and quantitative study of macroinvertebrates:

For qualitative analysis, preserved samples of macroinvertebrates were identified to the lowest possible taxonomic level according to standard taxonomic works of Edmondson (1959), Pennak (1978), and Adoni (1985). For quantitative analysis, macroinvertebrates were counted individually species-wise. The density of macroinvertebrate fauna was calculated by using the formula:

N= (O÷A×S) x 10,000 (Welch, 1948)

Where,

N = no. of macroinvertebrate organisms/m2.

O = no. of organisms counted.

A = area of sampler in square meter

S = no. of samples taken at each site.

Application of Biodiversity indices

The biological indices employed during present study include:

Shannon-wiener diversity index (H). This biodiversity index was proposed by Shannon in 1948 (Turkmen and Kazanci, 2010) It is calculated by the formula given below.

$$H= -\sum_{I=1}^{S} pi \times \ln pi$$

Where,

H = Shannon-wiener index

Pi = proportion of individuals in species i

Where, pi = ni/N

(ni is the number of individuals found in species i and N is the total number of individuals in a community)

S = number of species encountered

∑ = sum from species i to species s

ln = natural logarithm

Simpson's diversity index (1-D). Simpson prosed this biodiversity index in 1949 (Turkmen & Kazanci, 2010). It is calculated by the formula given below.

$$1\text{-}D = 1-\sum n (n-1) \div N (N-1)$$

Where,

1-D = Simpson's index

n = number of individuals of each species

N = total number of individuals of all species

Margalef's richness index. Margalef's richness index was derived by Margalef in 1958 (Gamito, 2010) and was calculated by the formula given below.

$D = (S-1) \div \text{Ln}(N)$
Where,
D = Margalef's diversity index
S = number of species
N = total number of individuals in sample

Pielou Evenness Index. This index was derived from Shannon diversity index by Pielou in 1966. The values of this index ranges from 0 – 1. The value closer to 1 indicates equal distribution of individuals (Turkmen and Kazanci, 2010).

$E = H / H'max$
Where,
E = Species Evenness
H = Shannon-Wiener diversity index
$H'max = \text{Ln}(S)$
S = number of species recorded

RESULTS AND DISCUSSION

Physico-Chemical Analysis of Dal Lake

Temperature

During the present investigation, the air temperature ranged from 3.1 0C in December 2016 at site D1 to 23.4 0C in August 2017 at site D3 with an average value of 13.07 ± 7.7 0C. The water temperature fluctuated from 2.0 0C in January 2018 at site D1 to 21.7 0C in August 2017 at site D2 with a mean value of 11.27 ± 7.40 0C. The fluctuations in air and water temperature followed a seasonal climatic pattern. It was found maximum during the summer and minimum during the winter season throughout the study period, which may be attributed to high intensity and longer bright sunlight duration during summers and vice-versa (Zuber, 2007; Sawhney, 2008).

Depth

The depth fluctuated from 1.40 m in July 2016 at site D3 to 2.70 m in April 2017 at site D1 with a mean depth of 2.07 ± 0.25 m. The maximum depth in the Dal Lake was observed during winters as compared to summers, which may be ascribed to higher precipitation, increased flow of glacial waters into the lake and low rate of evaporation during winters and vice-versa, as also opined by Sawhney (2008) and Ahanger (2014).

Transparency

The transparency ranged from 0.93 m in August 2017 at site D3 to 1.5 m in January 2017 at site D1 with an average value of 1.10 ± 0.12 m. Transparency was recorded maximum during winters as compared to summers. Winter maxima may be ascribed to less turbidity in waters due to the presence of low suspended organic matter which settles down to the bottom because of the slow movement of water during winters and vice-versa (Shinde et al., 2010), while as summer minima may be attributed to higher silt loading and increasing rate of discharge of domestic and municipal sewage in the lake during summers that coincide with findings of Singh (2004), Ayoade et al. (2006), Jayabhaye et al. (2008).

pH

The water pH ranged from 7.3 in January 2017 at site D3 to 8.9 in August 2017 at site D3 with an average value of 8.07 ± 0.48. The observed variations in pH follow the seasonal trends. It was found higher in the summer season and lower during the winter season, attributed to enhanced photosynthesis at high temperature, prolonged photoperiod during summers, and vice-versa (Egborge, 1994; Akthar et al., 2015). The pH also depicted the alkaliphilous nature of lake water under the present study (Venkateshwarlu, 1983), which may be attributed to the bulk of sewage discharge from immediate catchments into the lake (Umerfaruq & Solanki, 2015).

Dissolved oxygen

Dissolved oxygen was observed to fluctuate from 3.7 mg L-1 in August 2016 at site D3 to 7.8 mg L-1 in January 2018 at site D1, with a mean value of 6.13 ± 1.39 mg L-1. The higher dissolved oxygen was recorded during winter, spring, and rainy season attributed to low temperature and high transparency (Ali et al., 2015), decreased consumption rate of oxygen by decomposers to decompose organic matter (Ahanger, 2014) during winters, enhanced aeration during rainfall

(Ayoade et al., 2006), and increased photosynthetic process during spring (Baig et al., 2010). On the other hand, low dissolved oxygen was recorded during the summer season, ascribed to high temperature (Ibrahim et al., 2006), increased consumption rate of oxygen by decomposers to bring decomposition of organic matter (Arimoro et al., 2007), and enhanced biological processes (Olomukoro, 2008).

Free carbon dioxide

Free carbon dioxide ranged between 7.7 mg L-1 in April 2016 at site D1 to 26 mg L-1 in January 2018 at site D3, with a mean value of 14.48 ± 6.64 mg L-1. It was found higher in winters ascribed to low pH (Wetzel, 2001), less macrophytic growth at low temperature (Zuber, 2007), and reduced solubility of carbon dioxide in water at low temperature (Akhar et al., 2015). Meanwhile, while as lower free carbon dioxide was recorded in spring and summers attributed to enhanced photosynthesis (Aura et al., 2011), abundant macrophytic growth (Akthar et al., 2015). The free carbon dioxide content also revealed the hard water type nature of lakes under the present study (Reid & Wood, 1976).

Electrical conductivity

Electrical conductivity fluctuated from 260 µScm-1 in January 2017 at site D1 and 379 µS cm-1 in August 2017 at site D3 with an average value of 307.57 ± 27.35 µSm-1. The observed variations in electrical conductivity clearly followed the seasonal trends. It was found higher in the summer season and lower during winter and spring season, attributed to the emission of nutrients due to which decomposition of organic matter in the lake waters, increasing organic and inorganic loading in lakes from immediate catchments during summers and vice-versa during winters. Spring minima is a result from the absorption of nutrients by macrophytes (Ahangar, 2014; Sushil et al., 2014; Akthar et al., 2015). The conductivity also depicted eutrophic nature of lakes under present study (Olsen, 1950; Dunn, 1954).

Total alkalinity

Total alkalinity fluctuated from 192 mg L-1 in May 2017 at site D1 to 299 mg L-1 in January 2018 at site D3 with a mean value of 239.25 ± 27.35 mg L-1. The observed values for total alkalinity were found to reveal an increasing trend from the summer to winter months. High total alkalinity during summers is attributed to the higher evaporation rate associated with elevated temperature (Naik, 2015), an increase in algal growth, and a higher decomposition rate (Chapman, 1992). The low total alkalinity during spring and early summers may be attributed to the absorption of nutrients at a higher rate by macrophytes and phytoplanktons to attain their maximum growth. The alkalinity also reflected the nutrient-rich and productive nature of the lake (Spence, 1964., Sugunan, 1989).

Total hardness

Total hardness fluctuated from 157 mg L-1 in July 2016 at site D1 to 302 mg L-1 in January 2018 at site D3 with a mean value of 214.77 ± 48.79 mg L-1. The higher values for total hardness were recorded during the winters, while lower values were recorded during spring and summer. Winter maxima of total hardness is attributed to less macrophytic and algal growth due to low temperature and increased solubility of ions at low temperature, as also reported by Otsuki and Wetzel (1972). Spring and summers minima of total hardness may be attributed to the utilization of carbonates and bicarbonates by phytoplanktons as a source of carbon and reduced solubility of calcium ions at the higher temperatures as also noted in earlier findings of Bhat et al. (2012) and Ahangar (2014). The total hardness also revealed the hard water type nature of the lake (Sawyer, 1960).

Chlorides

Chlorides fluctuated from 13.9 mg L-1 in February 2017 at site D1 to 26 mg L-1 in August 2017 at site D3, with a mean value of 19.68 ± 4.18 mg L-1. The chloride values were found higher during summers and precipitation as compared to the winter season. Summer maxima is attributed to elevated temperature (Korai et al., 2008), increased organic matter loading, mainly animal wastes (Mahananda et al., 2010), and increased rate of sewage influx into these lakes from immediate catchments (Ahanger, 2014). Winter chloride minima is attributed to decreased water temperature (Dalpatia, 1998) and dilution of water by winter rains (Okeola et al., 2010). The high chloride content depicted the organically polluted nature of Anchar Lake (Ohle, 1934). Jeelani and Kaur (2014) depicted organic pollution in Dal Lake. Bashir et al. (2017) and Tehseen et al. (2018) depicted the organically polluted type nature of Anchar Lake in their respective studies.

Total phosphorous

The total phosphorous content was observed to fluctuate from 294 µg L-1 in April 2016 at site D1 to 419 µg L-1 in August 2016 at site D3, with a mean value of 365.09 ± 34.23 µg L-1. The higher values for total phosphorous were registered during summers and precipitation, and lower values were obtained during winters and spring. The summer total phosphorous maxima may be attributed to increased agriculture runoff, the input of domestic, municipal sewage (Gasim et al., 2006), and elevated decomposition rate, as also observed by Patra et al. (2010), Shinde et al. (2010), and Edokpayi et al. (2010). The winter and spring total phosphorus minima may be attributed to low decomposition rate, low temperature, and increased phosphorous utilization by macrophytes, which grow vigorously during spring and summers leading to a decrease in phosphorous towards winters. The total phosphorous content revealed the eutrophic nature of lakes being study (Vollenweider, 1968). Naik et al. (2015) revealed the eutrophic nature of Manasbal Lake in their respective studies. Ahanger (2014), Bashir et al. (2017), and Tehseen et al. (2018) depicted the eutrophic nature of Anchar Lake in their respective studies.

Nitrates

The nitrates fluctuated from 288 µg L-1 in January 2017 at site D1 to 418 µg L-1 in July 2017 at site D3 with a mean value of 348.81 ± 44.07 µg L-1. The higher concentration of nitrates was registered during summers and rainy seasons, while the minimum concentration of nitrates was found during winters and spring. Summer maxima are attributed to agricultural waste input (Gochhait, 1991), an increased rate of decomposition (Naik, 2015), rotting of macrophytes at high temperature (Zuber, 2007). Winter and spring minima of nitrates may be attributed to low decomposition rate, low temperature, and increased utilization of nitrates by macrophytes, which grow vigorously during spring and summers that lead to a decrease in nitrate content towards winters. The high nitrate content revealed the eutrophic nature of the lake under study as per the classification of lakes on the basis of the nitrate content by Vollenweider, 1968.

Total dissolved solids (TDS)

TDS fluctuated between 187 mg L-1 in January 2017 at site D1 and from 187mg L-1 in January 2017 at D1 and 348 mg L-1 in August 2017 at site D3, with an average value of 273.81 ± 50.52 mg L-1. The higher TDS were registered during summers and rainy season as a result of increased input of wastes into lakes and emission of minerals due to elevated decomposition rate at a higher temperature during summers, increase rate of surface runoff, and leaching of substances from rocks into the lake during precipitation, while as lower TDS were observed during winters may be attributed to reduced waste input from immediate catchments and absorption of salts and other ions by phytoplanktons and macrophytes of lakes to attain maximum growth during spring and summers, which ultimately lead to decreased TDS towards winters. The results obtained are in agreement with the earlier findings reported by Korai et al. (2008), Singh et al. (2010), and Ahanger (2014).

Biological oxygen demand

BOD values were observed to fluctuate from 3.0 mg L-1 in January 2017 at site D1 to 5.9 mg L-1 in July 2017 at site D3 with a mean value of 4.67 ± 0.71 mg L-1. It was observed that the biochemical oxygen demand showed a gradual increase from winters to summers. Summers BOD maxima may be attributed to a higher temperature, which increases microbial activity and rate of decomposition (Singh et al., 2002), agricultural runoff (Sachidanandmurthy & Yajurvedi, 2006), low dissolved oxygen, elevated organic matter loading (Sawhney, 2008). The lower BOD values recorded during winters may be attributed to low temperature associated with low decomposition rate, high dissolved oxygen, and decreased microbial activity (Sachidanandamurthy & Yajurvedi, 2004).

Ammonia

The ammonia content was observed to fluctuate from 0.07 mg L-1 in July 2016 at site D1 to 0.31 mg L-1 in January 2018 at site D3 with a mean value of 0.16 ± 0.05 mg L-1. The higher values for ammonia were obtained during winters, while lower values were recorded during summers. The higher values of ammonia content during winters may be attributed to less macrophytic growth to consume ammonia. The lower values of ammonia recorded during spring and summer are attributed to the photosynthetic incorporation of ammonia by autotrophs to attain their maximum growth. The results are in agreement with the findings of Naik et al. (2015).

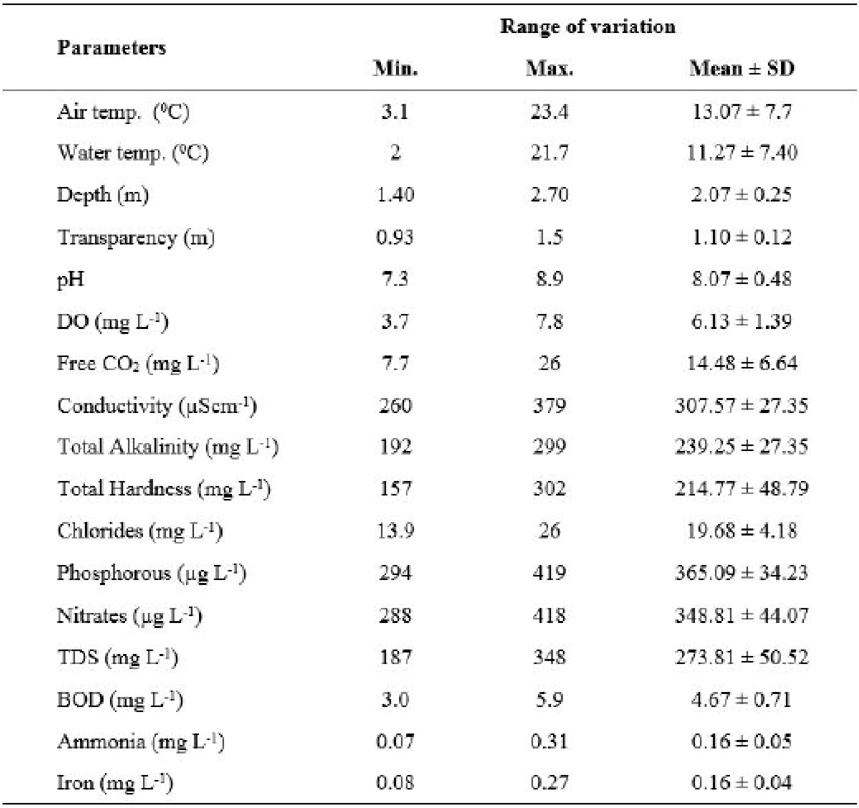
Iron

Iron content was observed to fluctuate from 0.08 mg L-1 I in February 2017 at site D1 to 0.27 mg L-1 in August 2017 at site D3 with a mean value of 0.16 ± 0.04 mg L-1. The iron content in lake waters followed a seasonal trend with lower concentration during winters and higher concentration during summers, attributed to high organic loading into these lakes during summers and vice-versa. According to Jumppanen (1976), a decline in oxygen could be the reason for elevated iron content in water bodies during summers.

The physico-chemical analysis of Dal Lake is summarized in Table 1.

Table 1

Physicochemical report on Dal Lake



Parameters	**Range of variation**		
	Min.	**Max.**	**Mean ± SD**
Air temp. (^{0}C)	3.1	23.4	13.07 ± 7.7
Water temp. (^{0}C)	2	21.7	11.27 ± 7.40
Depth (m)	1.40	2.70	2.07 ± 0.25
Transparency (m)	0.93	1.5	1.10 ± 0.12
pH	7.3	8.9	8.07 ± 0.48
DO (mg L^{-1})	3.7	7.8	6.13 ± 1.39
Free CO_2 (mg L^{-1})	7.7	26	14.48 ± 6.64
Conductivity (μScm^{-1})	260	379	307.57 ± 27.35
Total Alkalinity (mg L^{-1})	192	299	239.25 ± 27.35
Total Hardness (mg L^{-1})	157	302	214.77 ± 48.79
Chlorides (mg L^{-1})	13.9	26	19.68 ± 4.18
Phosphorous (μg L^{-1})	294	419	365.09 ± 34.23
Nitrates (μg L^{-1})	288	418	348.81 ± 44.07
TDS (mg L^{-1})	187	348	273.81 ± 50.52
BOD (mg L^{-1})	3.0	5.9	4.67 ± 0.71
Ammonia (mg L^{-1})	0.07	0.31	0.16 ± 0.05
Iron (mg L^{-1})	0.08	0.27	0.16 ± 0.04

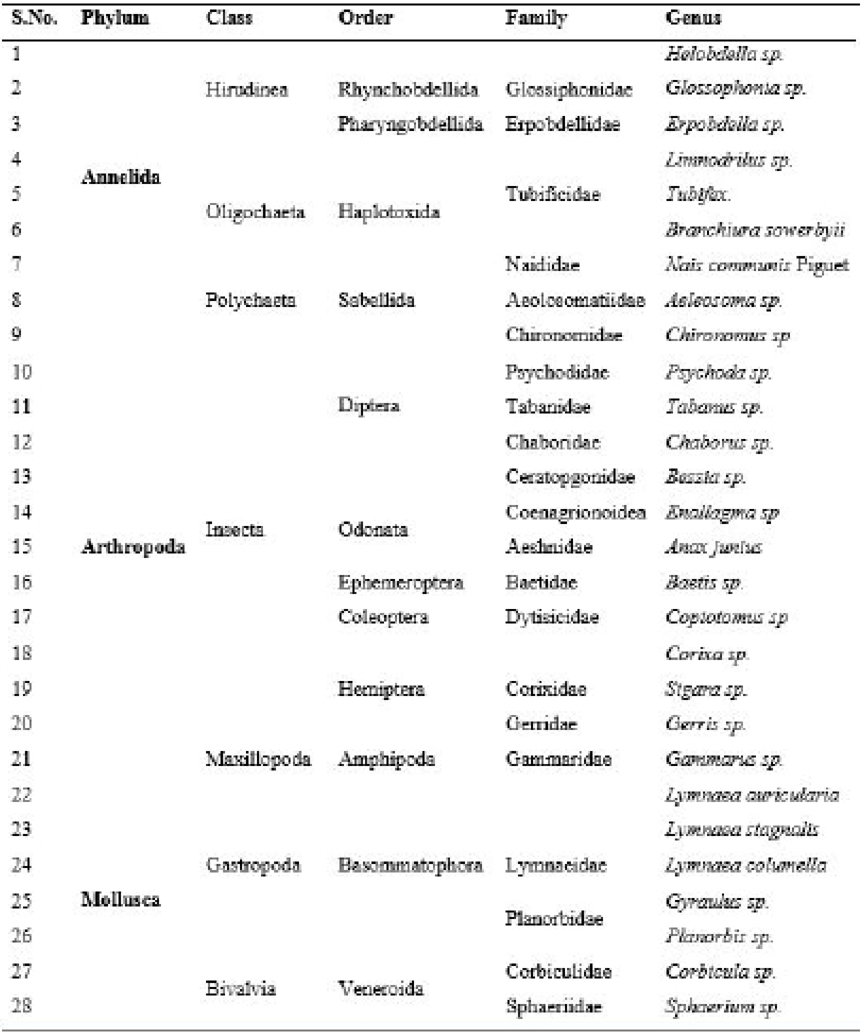
Diversity of Macroinvertebrate in Dal Lake

During the present study stretched from March 2016 to February 2018, a total of 28 macroinvertebrate taxa belonging to three major phyla viz Annelida, Arthropoda, and Mollusca, were recorded from three different study sites of Dal Lake. The recorded macroinvertebrate taxa belong to seven classes, twelve orders, and twenty-one families of, which twelve families belong to Arthropoda, four to Annelida, and five to Mollusca.

The systematic list of macroinvertebrates recorded from Dal Lake is given in Table 2

Table 2

The systematic list of macroinvertebrates in Dal Lake



S.No.	Phylum	Class	Order	Family	Genus
1	**Annelida**	Hirudinea	Rhynchobdellida	Glossiphonidae	*Helobdella sp.*
2					*Glossophonia sp.*
3			Pharyngobdellida	Erpobdellidae	*Erpobdella sp.*
4		Oligochaeta	Haplotoxida	Tubificidae	*Limnodrilus sp.*
5					*Tubifex.*
6					*Branchiura sowerbyii*
7				Naididae	*Nais communis* Piguet
8		Polychaeta	Sabellida	Aeolosomatiidae	*Aeleosoma sp.*
9	**Arthropoda**	Insecta	Diptera	Chironomidae	*Chironomus sp*
10				Psychodidae	*Psychoda sp.*
11				Tabanidae	*Tabanus sp.*
12				Chaboridae	*Chaborus sp.*
13				Ceratopgonidae	*Bezzia sp.*
14			Odonata	Coenagrionoidea	*Enallagma sp*
15				Aeshnidae	*Anax junius*
16			Ephemeroptera	Baetidae	*Baetis sp.*
17			Coleoptera	Dytisicidae	*Coptotomus sp*
18			Hemiptera	Corixidae	*Corixa sp.*
19					*Sigara sp.*
20				Gerridae	*Gerris sp.*
21		Maxillopoda	Amphipoda	Gammaridae	*Gammarus sp.*
22	**Mollusca**	Gastropoda	Basommatophora	Lymnaeidae	*Lymnaea auricularia*
23					*Lymnaea stagnalis*
24					*Lymnaea columella*
25				Planorbidae	*Gyraulus sp.*
26					*Planorbis sp.*
27		Bivalvia	Veneroida	Corbiculidae	*Corbicula sp.*
28				Sphaeriidae	*Sphaerium sp.*

The species composition of macroinvertebrates recorded from three investigated sites of Dal Lake is given in Table 3.

Table 3

Species Composition of macroinvertebrates at different study sites of Dal Lake

S. No.	Taxa	Site-D1	Site-D2	Site-D3
1	*Helobdella sp.*	+	-	+
2	*Glossophonia sp.*	+	-	+
3	*Erpobdella octoculata*	-	+	+
4	*Limnodrilus hoffmeistri*	-	+	+
5	*Tubifex*	-	+	+
6	*Branchiura sowerbyii*	-	+	-
7	*Nais communis*	-	+	+
8	*Aeleosoma sp.*	-	+	+
9	*Chironomus sp.*	-	+	+
10	*Psychoda sp.*	+	-	-
11	*Tabanus sp.*	+	-	-
12	*Chaborus sp.*	-	+	+
13	*Bezzia sp.*	+	-	-
14	*Enallagma sp.*	+	+	+
15	*Anax junius*	+	-	-
16	*Baetis sp.*	+	-	-
17	*Coptotomus sp.*	+	+	-
18	*Corixa sp.*	+	+	-
19	*Sigara sp.*	+	-	-
20	*Gerris sp.*	+	+	-
21	*Gammarus sp.*	+	+	+
22	*Lymnaea auricularia*	+	-	+
23	*Lymnaea stagnalis*	-	-	+
24	*Lymnaea columella*	-	+	-
25	*Gyraulus sp.*	+	-	-
26	*Planorbis sp.*	-	-	+
27	*Corbicula sp.*	+	+	-
28	*Sphaerium sp.*	+	-	-

Population density of macroinvertebrates in Dal Lake

At site-D1:- During the entire course of study, the total population density of macroinvertebrate fauna at site D1 was estimated at 4720 ind/m2 (Table-4) with a minimum population density of 60 ind./m2 in December 2016, January and October 2017, and January 2018 and maximum population density of 404 ind/m2 in July 2016 (fig. 1). The relative contribution of arthropods was 55%, with 2615 ind/m2. The relative contribution of mollusks was 38%, with 1790 ind/m2. The relative contribution of annelids was estimated to be 7% with 315 ind/m2 (Fig. 2).

At site-D2:- The total population density of macroinvertebrate fauna at site D2 was 6466 ind./m2 (Table-4) with a minimum population density of 74 ind./m2 in January 2017 and 2018 and a maximum density of 592 in June 2016 and July 2016 (fig. 1). The relative contribution of annelids was 45%, with 2927 ind/m2. The relative contribution of arthropods was estimated to be 37%, with 2394 ind/m2. The relative contribution of mollusks was estimated to be 18 with 1145 ind./m2 (Fig. 3).

At site-D3:- The total population density of macroinvertebrate fauna at site D3 was 7914 ind/m2 (Table-1), with a minimum population density of 75 ind./m2 in December 2017 and a maximum density of 824 ind./m2 in June 2016 (Fig. 1). The relative contribution of annelids was estimated to be 54.51%, with 4329 ind./m2. The relative contribution of arthropods was estimated to be 28.01%, with 2224 ind/m2. The relative contribution of mollusks was estimated to be 17.48%, with 1388 ind./m2 (Fig. 4).

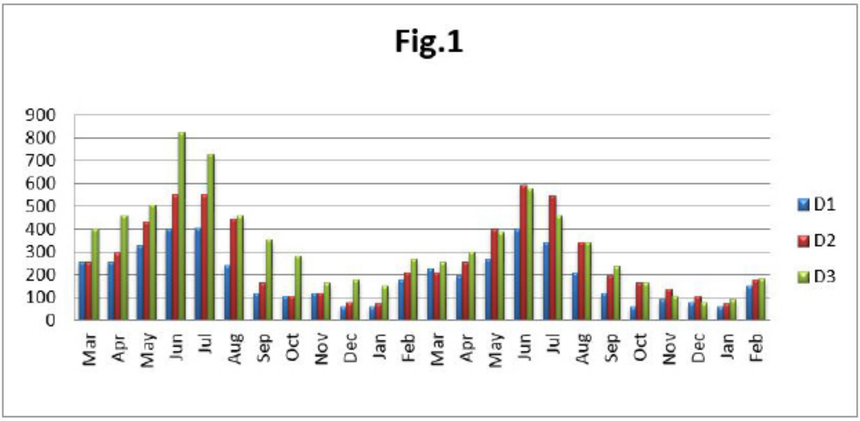


Figure 1. Monthly fluctuation in population density (ind./m2) of macroinvertebrates in Dal Lake (March 2016 - February 2018).

Fig.2

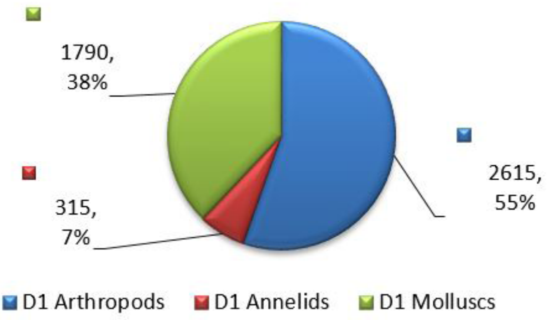


Figure 2. Total population density (ind. /m2) and percent contribution of Arthropods, Annelids, and Mollusks at Site- D1 in Dal Lake (March 2016 - February 2018).

Fig.3

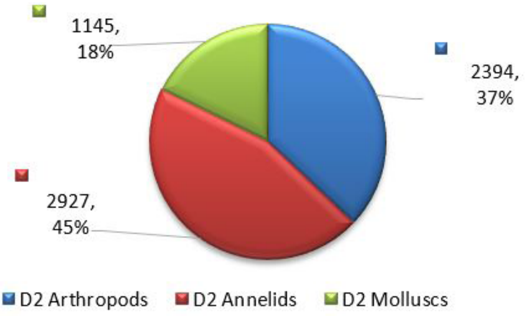


Figure 3. Total population density (ind. /m2) and percent contribution of Arthropods, Annelids, and Mollusks at Site- D2 in Dal Lake (March 2016 - February 2018).

Fig.4

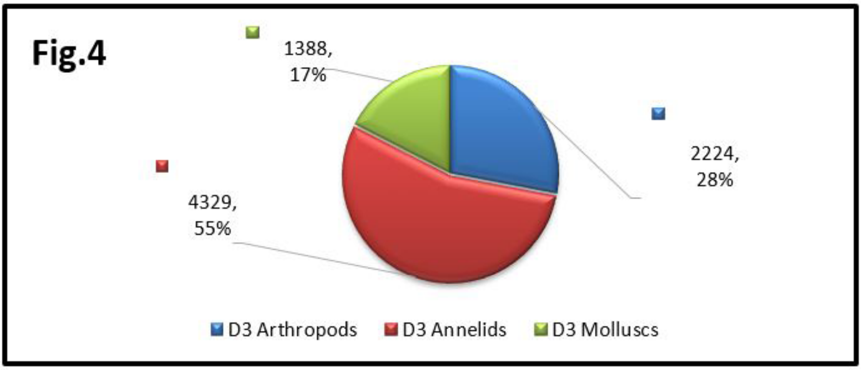


Figure 4. Total population density (ind. /m2) and percent contribution of Arthropods, Annelids, and Mollusks at Site- D3 in Dal Lake (March 2016 - February 2018).

Mean population density (ind./m2) in Dal Lake

A total of 19127 individuals of macroinvertebrates were recorded from Dal Lake, out of which arthropods comprised 7233 individuals, annelids comprised of 7571 individuals, and mollusks comprised of 4323 individuals. The mean population density of macroinvertebrate fauna in Dal Lake was estimated at approximately 6376 ind./m2. The annelids were found to be dominant over arthropods and mollusks. The percent contribution of annelids was computed at 39.58 %, with a mean population density of approximately 2524 ind./m2. The percent contribution of arthropods was estimated at 37.82 %, with a mean population density of 2411 ind./m2. The percent contribution of mollusks was estimated at 22.60 %, with a mean population density of 1441 ind./m2 (Table-4). The order of dominance in population density of macroinvertebrate fauna in Dal Lake was Annelids > Arthropods > Mollusks.

Table 4

Mean population density (ind./m2) and Percent contribution of different macroinvertebrate phyla in Dal Lake

Phylum	**Site-D1 (ind./m2)**	**Site-D2 (ind./m2)**	**Site-D3 (ind./m2)**	**Tot. no. of individuals**	**Mean Pop.density (ind./m2)**	**% contribution**
Arthropoda	2615	2394	2224	7233	2411.00	37.82
Annelida	315	2927	4329	7571	2523.67	39.58
Mollusca	1790	1145	1388	4323	1441.00	22.60
Total	4720	6466	7941	19127	6375.67	

Diversity, richness and evenness of macroinvertebrates in Dal Lake

Biological indices applied to the recorded macroinvertebrate fauna in Dal Lake exhibited a marked variation at different study sites during the investigation period. Shannon-wiener diversity index (H) was computed 2.55, 2.41, and 2.29 at sites D1, D2, & D3, with a mean value of 2.41. Simpson's diversity index (1-D) was computed 0.91, 0.89, and 0.87 at sites D1, D2, & D3, with a mean value of 0.89. Margalef"s richness index (D) was computed 1.73, 1.54, and 1.38 at sites D1, D2, & D3, with a mean value of 1.55. Pielou evenness (H/Ln (S) was computed 0.17, 0.17, and 0.18 at sites D1, D2 & D3, with a mean value of 0.17 (Fig. 5).

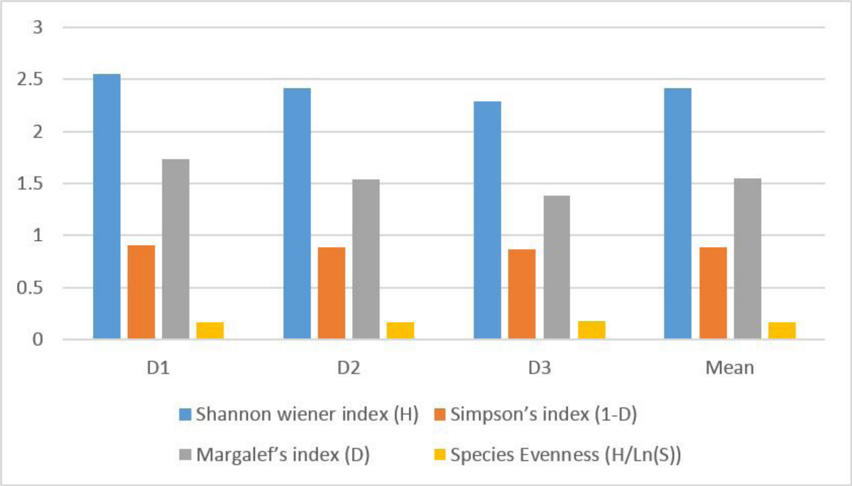


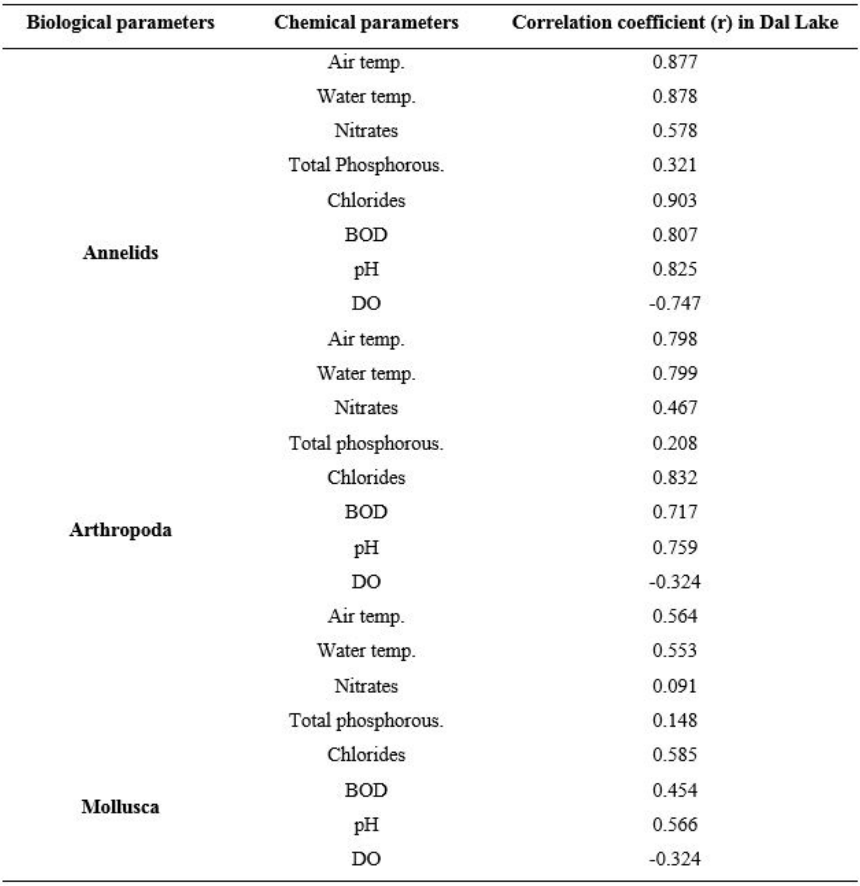
Figure 5. Diversity, Richness & Evenness of macroinvertebrates in Dal Lake.

Pearson's Correlation test between physico-chemical and biological parameters

Pearson's correlation test revealed a significant positive correlation of annelids, arthropods, and mollusks, with temperature, chlorides, BOD, and pH. Annelids revealed a significantly negative correlation with dissolved oxygen (Table-5).

Table 5

Pearson's Correlation test between physico-chemical and biological parameters



Biological parameters	Chemical parameters	Correlation coefficient (r) in Dal Lake
Annelids	Air temp.	0.877
	Water temp.	0.878
	Nitrates	0.578
	Total Phosphorous.	0.321
	Chlorides	0.903
	BOD	0.807
	pH	0.825
	DO	-0.747
Arthropoda	Air temp.	0.798
	Water temp.	0.799
	Nitrates	0.467
	Total phosphorous.	0.208
	Chlorides	0.832
	BOD	0.717
	pH	0.759
	DO	-0.324
Mollusca	Air temp.	0.564
	Water temp.	0.553
	Nitrates	0.091
	Total phosphorous.	0.148
	Chlorides	0.585
	BOD	0.454
	pH	0.566
	DO	-0.324

The patterns in macroinvertebrate diversity, distribution, and composition in an aquatic ecosystem are influenced by a number of factors, including biotic and abiotic factors, interspecific and intraspecific interactions among macroinvertebrates like competition and predation, water quality, sediment and substratum type, and trophic status (Jonasson, 1996; Walker, 1998; Kownacki et al., 2000; Ngodhe et al., 2014). Habitat destruction, as a result of undesirable anthropogenic activities, is globally emerging as a major cause behind biodiversity loss and malfunctioning of the aquatic ecosystems (Cao et al., 2018). During the current study, a diverse spectrum of macroinvertebrate fauna was recorded from the Dal Lake, ascribed to its lentic nature (Pamplin et al., 2006; Petrovici et al., 2010). It has an abundant macrophytic growth that offers a great array of microhabitats, food, protection from predators and right breeding locations to macroinvertebrates (Tolonen et al., 2003; Yaqoob et al., 2008; Petrovici et al., 2010; Elipek et al., 2010), and decomposed organic matter which provide a favorable bottom for the growth of certain specific macroinvertebrate fauna especially detritivores taxa like *Chironomus larva*, *Tubifex tubifex*, etc. (Yaqoob et al., 2008; Elipek et al., 2010).

Macroinvertebrate density is positively related to habitat complexity and macrophytic density, especially with highly dissected leaves, e.g., *Hydrilla verticillata* (Thorp et al., 1997); *Myriophyllum spicatum* (Lillie and Budd, 1992); *Trapa natans* (Strayer et al., 2003); *Ceratophyllum* sp (Bogut et al., 2007). Barreto (1999) reported that complex habitats experience less stress and provide more protection against predators and physical disturbances, thus tends to increase biological diversity. However, as compared to earlier studies, the macroinvertebrate reveals a noticeable decline ascribed to habitat destruction as a result of increasing urbanization pressure and many anthropogenic activities like mechanical harvesting of aquatic plants, recreational activities like bathing, washing, sewage loading, waste dumping, etc. (Dinakaran & Aabalagan, 2007). The extinction of rare taxa because of habitat damage is responsible for major and abrupt disturbances in normal ecosystem function and alteration in its biotic community structure (Mouillot et al., 2013). Mechanical harvesting of macrophytes greatly reduces the abundance of invertebrate fauna as aquatic plants are critical for retaining variability in density and abundance of invertebrates (Beckett et al., 1992). Habib (2013) reported that the macrophytic condensed regions reflect a higher density of macroinvertebrates as compared to lake zones, which have been deprived of macrophytic cover by employing mechanical harvesters. Similar results were achieved by Mushtaq et al. (2014) in their study. Excessive sedimentation due to advancing urbanization prevents penetration of sunlight to greater depths and interferes with crucial life processes like nutrition and reproduction of benthic organisms, including benthic macroinvertebrates (Mangun, 1989). The increasing metal influx in water bodies from urban areas drops the abundance and changes the structure of the macroinvertebrate community in an aquatic ecosystem (Gundacker, 2000).

Further, in addition to the above-mentioned factor, the quality also influences the patterns in diversity, distribution, and species composition of the macroinvertebrate community (Ngodhe et al., 2014). The lower values of species diversity and richness indices at site-D3 may be attributed to maximum anthropogenic pressure (Olomukoro, 2008) and poor water quality (Erimoro et al., 2007) as compared to site-D1 and D2. Gong and Xie (2000) observed a decline in the diversity of macroinvertebrates with increasing trophic status in their respective study on Donghu Lake of China. Pearson's correlation test revealed that, in general, macroinvertebrates, especially pollution tolerant taxa are positively and significantly correlated to temperature, BOD, chlorides, and pH. However, annelids revealed a significant negative correlation to dissolved oxygen (0.747). The results are in line with the findings of Milbrink, 1978. Custodio et al. (2018) observed a positive and highly significant correlation of temperature, total phosphorous, and BOD with macroinvertebrates while working on Andean wetlands of the Junin region, Peru. Higher BOD, high chloride content, and low dissolved oxygen content reflect organic pollution, which favors the growth of organic pollution tolerant macroinvertebrates. Hepp (2002) reported that DO concentration less than 4 mg L-1 is sufficient to cause loss of numerous invertebrate taxa not adjusted to hypoxic environments near sediment. Shimabukuro and Henry (2011) also observed a positive correlation of Chironomidae with pH. Certain species, mostly *Limnodrilus hoffmeisteri*, *Tubifex tubifex*, *Glossophonia* sp., *Chironomus genus*, *Psychoda* sp., *Chaboru*s sp., *Anax junius*., *planorbis*, and *Lymnaea* species, were found to increase their numerical strength in the habitat enriched with high organic nutrient loading. The abundance of these species indicates the organic pollution and eutrophication, as also reported by Timm et al. (2001), Khan et al. (2007), Yaqoob et al. (2008), and König et al. (2008) in their respective findings. Strixino and Trivinho-strixino (1980) reported that water bodies with average depth (approximately 3 m) retain high temperatures and favor the propagation of Chironomidae and Chaboridae. However, Shimabukuro and Henry (2011) observed the negative influence of high water temperature on Chironomidae. It has been reported that certain species like Sigara species require typical habitat requirements that are not available in Dal Lake due to its polluted nature, which could be the possible reason behind the rare occurrence of this species in Dal Lake. This observation is also in line with the findings of Yaqoob et al. (2008). Organic enhancement results in the vanishing of pollution-sensitive taxa like EPT, thus drop rivalry for resources and favor the propagation of pollution tolerant organisms. Ngodhe et al. (2014) observed that high-temperature, low DO, and high BOD negatively influenced macroinvertebrate diversity, dominance, and richness in Yenga and Mauna Dams and ascribed his findings to the fact that at high temperature rate of decomposition of organic matter increases, BOD increases, and DO decreases. As a result, competition for available resources takes place among macroinvertebrates in which pollution tolerant taxa are favored and pollution sensitive taxa are eliminated. Bio-indices are employed in evaluating the aquatic ecological conditions.

Higher values of biological indices reflect better water quality and minimum stress water bodies (Ngodhe et al., 2014). Shannon diversity index value above 3 indicates balanced and stable habitat with clean water and values between 1.00 to 3.00 indicates moderately stable and polluted habitat and values between 0 to 1.00 indicates unstable and degraded habitat victim heavy pollution (Willhm & Dorris, 1966; Turkmen & Kazanci, 2010) and thus, as per this criterion, Dal Lake can be categorized as a moderately unstable and polluted water body. Cairns et al. (1971) hold the opinion that vigorous water bodies generally reflect high species diversity. But, little numbers of individuals per species, and unhealthy water bodies reflect less diversity, but a large number of individuals per species. Somasheker and Ramaswamy (1984) related higher richness index value with healthy conditions of the water body. Ghosh and Biswas (2015) related low values of diversity indices with pollution and increasing anthropogenic pressure on lakes.

During the current study, the peak values of the population density of macroinvertebrates were observed during summers as compared to winters. Summer maxima of macroinvertebrate diversity and density may be attributed to high temperature (Ibanez et al., 2002), elevated rate of organic matter decay, and decomposition (Pamplin et al., 2006., Elipek et al., 2010) and less depth (Arab et al., 2004; Shimabukuro & Henry, 2011), death and decay of macrophytes rendering suitable bottom for benthic macroinvertebrates to flourish (Dutta & Malhotra, 1986) and to dense macrophytic growth, which provides food, shelter, suitable breeding sites to macroinvertebrates (Kouame et al., 2011). The sharp decrease in density of macroinvertebrate fauna during winters may be attributed to winter precipitation coupled with enhanced loading of suspended solids causing dislodgement of macroinvertebrate fauna due to instability created in the bottom substrate (George et al., 2010) and higher depth (Arab et al., 2004).

Chironomus larva and *Tubifex* species have been recognized as detritus feeders and important components of detritus food chain in eutrophic water bodies (Yaqoob et al., 2008; Cao et al., 2018). This supports the present finding the organic detritus-rich bottom sediment favors the abundance of these pollution indicator species. A decline in the numerical strength of Chironomidae during winters can also be ascribed to increasing transparency, which increases the chances of visualization of chironomidae by predators like fishes, as also opined by Leech and Johnsen (2009).

CONCLUSIONS

The ecological survey of Dal Lake shows that there has been a continuous rise in alkalinity, pH, total hardness, conductivity, chlorides, nitrates, total phosphorous, and BOD of lake waters, while as a continuous fall in transparency, depth, and DO is persisting in Dal lake which has deteriorated the water quality of the lake, rendered the lake extremely polluted, eutrophicated, and ecologically unstable. Dal Lake, which is globally recognized as the jewel in the crown of Kashmir, and most attractive tourist destination is gradually losing the natural beauty and precious biological diversity as a result of increasing pollution. Since a respectable diversity of macroinvertebrate fauna was observed in the lake, but the abundance of organic pollution tolerant macroinvertebrate taxa like *Tubifex sp*., *Limnodrilus sp*., and *Chironomus* larva and the tremendous decline or disappearance of pollution sensitive taxa (EPT) in Dal Lake clearly witnesses the organic pollution and eutrophication in the lake because of growing anthropogenic and urbanization pressure. Constantly increasing anthropogenic pressure, including the influx of sewage, solid waste dumping, the influx of agricultural wastes, organic matter loading, and illegal encroachments at the lake peripheries are the main causes behind the devastation of Dal Lake. Further, macrophytic dense regions witnessed more diverse macroinvertebrate fauna as compared to less macrophytic dense regions. Periodic removal of macrophytes by mechanical harvesters could be another important factor contributing to biodiversity loss in Dal Lake.

RECOMMENDATIONS

Though Dal Lake is a victim of severe pollution, there is some scope for ecorestoration of this lake. The study recommends immediate restoration measures to protect the lakes from further deterioration, including the installation of highly efficient sewage treatment plants at lake inlets, prevention of illegal encroachments at lake peripheries, mass awareness programs, plantation on lake shorelines, and above all, there is an utmost need for proper coordination between forest ecology and environment department and housing and urban development department towards the protection of Dal Lake

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