Manickam et al. The Journal of Basic and Applied Zoology (2018) 79:15
https://doi.org/10.1186/s41936-018-0029-3

The Journal of Basic and Applied Zoology

RESEARCH Open Access

# Impact of seasonal changes in zooplankton biodiversity in Ukkadam Lake, Coimbatore, Tamil Nadu, India, and potential future implications of climate change

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## Abstract

**Background:** Zooplankton biodiversity serves as an ecological indicator of aquatic environment due to their rapid response according to environmental changes. At the present study, impact of seasonal changes on zooplankton biodiversity was conducted in the Ukkadam Lake (Lat 10° 59′ N and Long 76° 57′ E), at Coimbatore city, Tamil Nadu, India.

**Results:** The biodiversity of zooplankton taxa were studied for a period from December 2011 to November 2012 on seasonal basis. During this time period, in total, 28 species of zooplankton were noticed, which includes 9 species of each Rotifera and Cladocera and 5 species of Copepoda and Ostracoda. In this present observation, total abundance of Rotifera was found to be predominant with 35%, followed by Cladocera 29%, Copepoda 29% and Ostracoda 7%. The population density of various group of zooplankton was observed, and it was found to be following order Rotifera > Copepoda > Cladocera > Ostracoda. The high and low population densities were recorded in summer and early monsoon season respectively. This higher zooplankton population density in summer might be due to the temperature acceleration in the Ukkadam Lake.

**Conclusions:** The present study revealed that zooplankton productivity was found to be higher in the Ukkadam Lake when the temperature was increased in summer season. It indicates that the temperature has influence on the zooplankton diversity. Therefore, increased temperature due to global climate change might have influence on the zooplankton production. Assessment of zooplankton biodiversity will be useful to monitor the health (water quality) and wealth (fishery productivity) of this lake system in the near future.

**Keywords:** Global climate change, Biodiversity, Zooplankton, Ukkadam Lake, Cladocera

## Background

Zooplankton biodiversity is one of the important ecological indicators of the aquatic environment. Biodiversity of zooplankton is essential to keep our ecosystem healthy because each species plays a specific role (recycling of nutrients, food for another and maintaining of soil fertility) in the ecosystem and some species may allow natural ecosystem to function in a healthy manner (Jeelani, Kaur, & Kumar, 2008). Zooplankton are crucial elements of freshwater lake ecosystems as they occupy the centre of the aquatic food web and being as an important food for almost all freshwater fish species at some stage in their life history (Lampert & Sommer, 1997). Moreover, zooplankton communities are sensitive to anthropogenic impacts and their study may be useful in the prediction of long-term changes in lake ecosystems, as these communities

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are highly sensitive to environment fluctuations (Ferrara, Vagaggini, & Margaritora, 2002; Jeppesen et al., 2011; Kehayias, Chalkia, & Doulka, 2014; Preston & Rusak, 2010). Changes in zooplankton abundance, species diversity and community composition can indicate the change or disturbance of the environment; it has been reported by several studies that zooplankton can serve as an indicator of changes in trophic dynamics and the ecological state of lakes related to changes in nutrient loading and climate (Caroni & Irvine, 2010; Kehayias et al., 2014). The filtering capacity of zooplankton has significant implications for the eutrophic state of a lake. Zooplankton community structure (species density and species composition) is potentially affected by both "natural" lake water chemistry and lake morphology, and anthropogenic changes in lakes and watersheds (Allen, Whittier, Kaufmann, Larsen, O'Connor, & Hughes, 1999a; Allen, Whittier, Larsen, Kaufmann, O'Connor, & Hughes, 1999b; An, Du, Zhang, Li, & Qi, 2012; Dodson, Arnott, & Cottingham, 2000). A change in the physico-chemical conditions in aquatic systems brings a corresponding change in the relative composition and abundance of organisms thriving in the water; therefore, they can be used as a tool in monitoring aquatic ecosystems, hence, zooplankton have been considered as ecological importance organisms (Jose, Furio, Borja, Gatdula, & Santos, 2015; Smitha, Shivashankar, & Venkataramana, 2013).

The increasing human population in India leads to number of industrialization which creates the problems of disposal of waste water products. An undesirable substance is regularly discharged into the lake water through surface runoff that degrades the water quality. The water quality is defined in terms of the chemical, physical and biological contents of water (Lawson, 2011; Shukla, Preeti, & Singh, 2013). The aspect information of water quality and states of affected living organisms of water bodies are necessary for implementation of any management strategies.

The plankton diversity was mainly important of ecological parameter in freshwater and marine water. The species diversity of each community is composed of taxonomically as well as morphologically different species. Species diversity refers to numbers of different species in the community including both in abundant and rare species. The species diversity is very high in natural communities like tropical and subtropical, whereas it is very low in physically or human-controlled communities. Species diversity has two components: species richness and species evenness. In simple words, species richness refers to different types of species and their numerical strength. Technically, it refers to ratio between different species (S) and total number of species (N). Species evenness refers to a measure which qualifies as to how even species are in terms of their number. The species diversity can be measured by using various diversity indices—the mathematical expressions based on species abundance data. The species diversity can be measured separately either as species richness or evenness or diversity as a whole. In the present study, Ukkadam Lake is a natural habitat lake and slightly attached with north of the river Noyyal, Coimbatore city. The availability and value of freshwater in this lake is important because it provide employment to local fisherman and main source of livelihood of some of very poor community of this area. Hence, current study was undertaken to investigate the impact of seasonal changes in zooplankton biodiversity in the perennial lake at Ukkadam, Coimbatore, Tamil Nadu, India.

## Methods

### Study area

The Ukkadam Lake (Lat 0° 59′ N and Long 76° 57′ E) ecosystem is located in Coimbatore city, Tamil Nadu, India (Fig. 1). This lake water spread over an area of 1.295 $km^2$ (0.500 sq. mi) with average depth of 5.82 m (19.1 ft), and it is filled up when the rains lashed the city. A part of the lake is regularly used for dumping domestic and municipal wastes. The lake is also used for regular fishing by local fishermen.

### Collection and analyses of water samples

The water and plankton samples were collected for a period of 1 year from December 2011 to November 2012 at three different sites. The water samples were taken in sterilized wide-mouth, screw-capped glass bottles. Samples from the lake were collected vertically between 1 and 4 m depth with few meters of distance between samples from surface and bottom using Van Dorn sampler during early morning hours (5.30 am to 6.30 am), transported to the laboratory and subjected to analyses on the same day. Atmospheric and surface water temperature was measured on the spot. pH, salinity, electrical conductivity (EC), total dissolved solids (TDS) and dissolved oxygen (DO) were estimated by using μP Based Water & Soil Analysis Kit (Model-1160).

### Qualitative and quantitative analyses of zooplankton

For qualitative analysis of zooplankton, samples were collected from the lake by towing in zig-zag moving horizontally at a depth of 0.50 to 1.00 m for about 5 to 10 min with a uniform speed of boat using Towing-Henson's standard plankton net (150 μm mesh). For the quantitative analyses of zooplankton, 100 l of water were filtered through plankton net made up of bolting silk (No: 10; mesh size 150 μm) and the plankton biomasses were transferred to the specimen bottles (pre filed with 5% formalin) and subjected to stereo microscopic analysis. The zooplankton was segregated groupwise like Rotifera, Cladocera, Copepoda and Ostracoda. They were separated under a binocular


**Fig. 1** Map showing sampling sites at the Ukkadam Lake, Coimbatore city, Tamil Nadu, India

stereo zoom dissection microscope (Magnus, Japanese Technology) using a fine needle and brush. Individual species of plankton were mounted on microscopic slides on a drop of 20% glycerin after staining with eosin or rose bengal.

### Identification of zooplankton sample

The plankton were identified by referring the standard manuals and textbooks (Altaff, 2004; Battish, 1992; Edmondson, 1959; Murugan, Murugavel, & Kodarkar, 1998; Sharma & Michael, 1987) using a compound microscope and inverted biological microscope (INVERSO 3000 (TC-100) CETI) attached with a camera (Model IS 300). A 1 ml of zooplankton sample was taken with a wide-mouthed pipette and poured into the counting cell of the Sedgewick Rafter and allowed to settle for some time, followed by count was made. The counting process was made in triplicate for each sample of the plankton. Total number of plankton present in 1 l of water sample was calculated using the following formula (Santhanam, Velayutham, & Jegatheesan, 1989): $N = n \times v/V$, where $\boldsymbol{N}$ = total number of plankton per liter of water filtered; $n$ = average number of plankton in 1 ml of plankton sample; $v$ = volume of plankton concentrated (ml); and $v$ = volume of total water filtered (litre).

### Statistical analyses and diversity indices

The data between zooplankton and physico-chemical characteristics were subjected to correlation and linear regression using IBM-SPSS (v20.0). Species diversity index (H) was calculated using Shannon and Weaner's (1949) formula: $H^1 = \text{pi} \sum \log_2 \text{pi}$, I = 1 s, (where, $H^1$ is species diversity in bits per individual (it is the individuals and populations in a community), pi ➔ ni/$N$ (proportion of the sample belonging to the species), ni ➔ number of individual in all the sample; species richness (SR) was calculated as described by Gleason (1922); $D = 1 - C$, where $C = \sum pi^2$, pi – ni/$N$, ni – $N/S$, $N$ ➔ total number of individuals, $S$ ➔ number of species in the collection; evenness index ($J^1$) was calculated by using the formula of Pielous (1966); $J^1 = H^1/\log_2 s$, where $H^1$ = species diversity in bits of information per individual, and $S$ = number of species. Shannon and Weaner's species diversity index (H′), species richness (SR) and evenness index (J) were analysed using the PAST (Palaeontological Statistics), software (ver. 2.02).

## Results

### Physico-chemical parameters

In the present study, the recorded atmospheric and surface water temperature of four different seasons is given in Fig. 2a. The results reviled that the recorded atmospheric and surface water temperature ranged between 23.78 ± 0.87 to 26.94 ± 1.01 °C and 24.61 ± 0.55 to 28.92 ± 0.39 °C respectively. Among four different seasons, monsoon showed the minimum atmospheric and surface water temperature, whereas summer season showed the maximum minimum atmospheric and surface water temperature during the study period. The recorded pH and salinity of lake ranged between 7.34 ± 0.35 to 8.57 ± 0.61 and 0.81 ± 0.09 to 1.02 ± 0.21 mg/l during the study period (Fig. 2b, c). The minimum and maximum level of pH was noticed during monsoon and summer seasons respectively. In context, the minimum and maximum salinity was recorded during the post-monsoon and summer season respectively. The

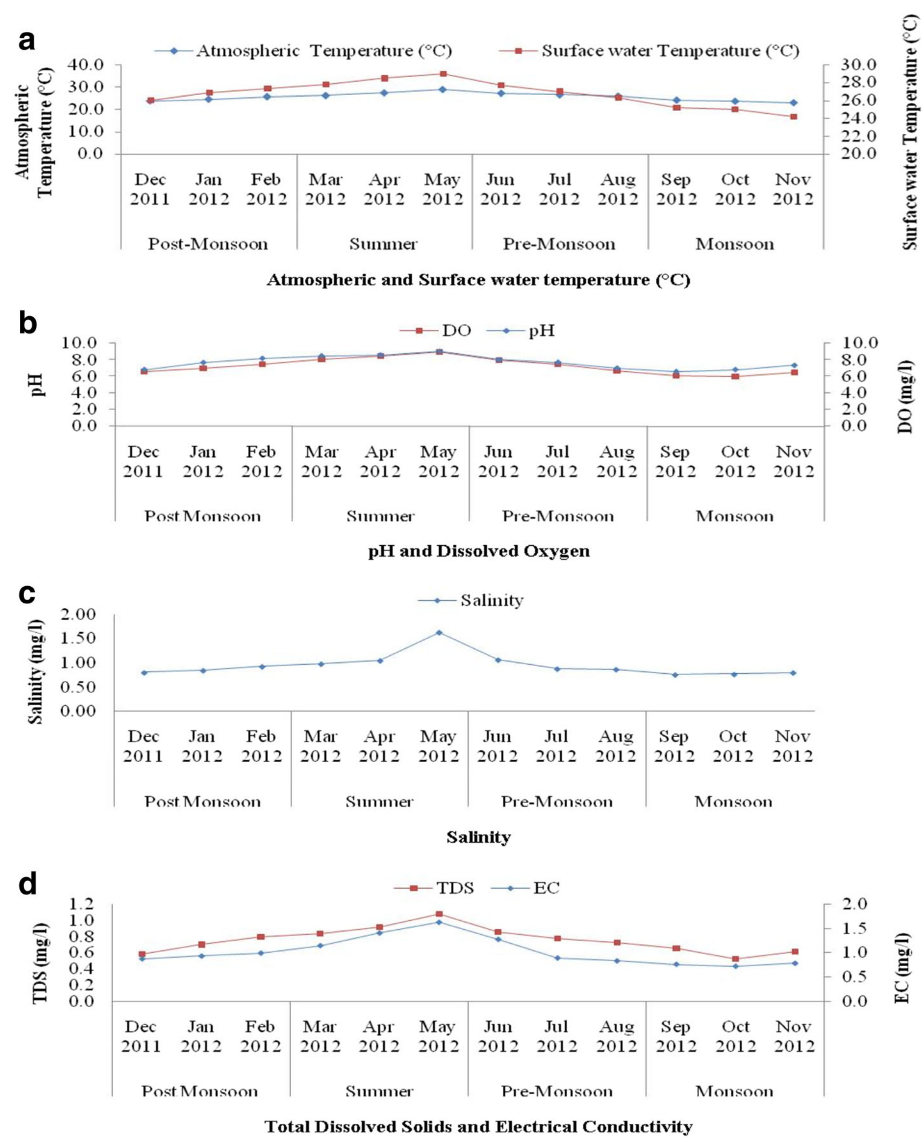


**Fig. 2** Seasonal variations in physico-chemical parameters of the Ukkadam Lake during December 2011–November 2012. **a** Atmospheric and surface water temperature. **b** pH and DO. **c** Salinity. **d** TDS and EC

observed DO, EC and TDS of Ukkadam Lake were varied between 6.18 ± 0.54 to 8.56 ± 0.59 mg/l, 0.79 ± 0.04 to 1.21 ± 0.07 mg/l and 0.66 ± 0.06 and 0.85 ± 0.08 mg/l respectively. All these three parameters were found to be higher in summer season, whereas lower in monsoon season (Fig. 2b–d).

### Zooplankton species composition and species diversity

In total, 28 species of zooplankton were recorded in the Ukkadam Lake which includes 9 species Rotifera (2 families and 3 genera), 9 of Cladocera (4 families and 6 genera), 5 species of each Copepoda (2 families and 4 genera) and Ostracoda (1 family and 5 genera) (Table 1). In the present study, Rotifera holds the top rank in percentage composition with 35%, followed by Copepoda 29%, Cladocera 29% and Ostracoda 7% (Fig. 3). The population density of zooplankton was ranged between 73,085 and 110,900 Ind/$m^3$ (Fig. 4) during the study period. Among the different seasons, the least population density was noticed in monsoon season and extreme population density was noticed in summer season. Among these different zooplankton, Rotifera showed significantly ($p < 0.001$) higher abundance in all seasons (Table 2). The other species like Copepoda and Cladocera were found to be significantly ($p < 0.001$) higher in post-monsoon and pre-monsoon seasons respectively. In context, the significantly lower abundance of Ostracoda was recorded during all seasons.

In the current study, the groupwise species diversity of zooplankton, such as Rotifera, Cladocera, Copepoda and Ostracoda, were ranged between 2.032 to 2.089, 2.067 to 2.133, 1.740 to 1.761, and 1.551 to 1.585, respectively, during the study period (Table 3). Among these, the minimum species diversity was noted during the period of monsoon season, while the maximum was observed in post-monsoon season. While the productivity of zooplankton species were ranged between 1.157 to 1.257,

**Table 1** List of freshwater zooplankton recorded in the Ukkadam Lake during December 2011–November 2012

| Group | Family | Genus | Species |
|---|---|---|---|
| Rotifera | Brachionidae (Ehrenberg, 1838) | *Brachionus* Pallas, 1776 | *Brachionus angularis* Gosse, 1851 |
| | | | *Brachionus calyciflorus* Pallas, 1776 |
| | | | *Brachionus caudatus personatus* Ahlstrom,1940 |
| | | | *Brachionus diversicornis* Daday, 1883 |
| | | | *Brachionus falcatus* Zacharias, 1898 |
| | | | *Brachionus quadridentatus* Hermann, 1783 |
| | | | *Brachionus rubens* Ehrenberg, 1838 |
| | | *Keratella* Bory & Vincent, 1822 | *Keratella tropica* Apstein, 1907 |
| | Asplanchnidae (Harring & Myers, 1933) | *Asplanchna* Gosse, 1850 | *Asplanchna intermedia* Hudson, 1886 |
| Cladocera | Sididae (Baird, 1850) | *Diaphanosoma* Fischer, 1850 | *Diaphanosoma sarsi* Richard, 1895 |
| | Daphnidae (Straus, 1850) | *Daphnia* Muller, 1785 | *Daphnia carinata* king, 1853 |
| | | | *Daphnia magna* Straus, 1820 |
| | | *Ceriodaphnia* Dana, 1853 | *Ceriodaphnia cornuta* Sars, 1853 |
| | | | *Ceriodaphnia reticulate* Jurine, 1820 |
| | Moinidae (Goulden, 1968) | *Moina* Baird, 1850 | *Moina brachiata* Jurine, 1820 |
| | | | *Moina micrura* Kurz, 1874 |
| | | *Moinodaphnia* Herrick, 1887 | *Moinodaphnia macleayi* King, 1853 |
| | Macrothricidae (Norman & Brady, 1867) | *Macrothrix* Baird, 1843 | *Macrothrix goeldii* Richard, 1897 |
| Copepoda (Calanoida) (Cyclopoida) | Diaptomidae (Baird, 1850) | *Heliodiaptomus* Kiefer, 1932 | *Heliodiaptomus viduus* Gurney, 1916 |
| | | *Sinodiaptomus* Kiefer, 1937 | *Sinodiaptomus* (*Rhinediaptomus*) *indicus* Sewell, 1934 |
| | Cyclopoidae (Dana, 1853) | *Mesocyclops* Claus, 1893 | *Mesocyclops hyalinus* Rehberg, 1880 |
| | | | *Mesocyclops leuckarti* Claus, 1857 |
| | | *Thermocyclops* Kiefer, 1927 | *Thermocyclops hyalinus* Rehberg, 1880 |
| Ostracoda | Cyprididae (Baird, 1845) | *Cypris* Muller, 1776 | *Cypris protubera* Muller, 1776 |
| | | *Eucypris* Vavra, 1891 | *Eucypris bispinosa* Victor & Michael, 1975 |
| | | *Cyprinotus* Brady, 1886 | *Cyprinotus nudus* Brady, 1885 |
| | | *Heterocypris* Claus, 1892 | *Heterocypris dentatomarginatus* Baird, 1859 |
| | | *Hemicypris* Sars, 1903 | *Hemicypris anomala* Klie, 1938 |

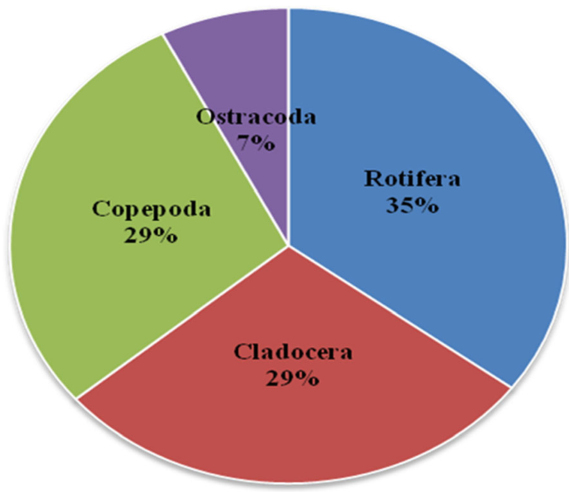


**Fig. 3** Percentage composition of zooplankton recorded in the Ukkadam Lake during December 2011–November 2012

1.177 to 1.321, 0.749 to 0.800, and 0.718 to 0.891 for Rotifera, Cladocera, Copepoda and Ostracoda respectively (Table 3). In general, minimum species richness was recorded during post-monsoon to summer season, whereas maximum was noticed during pre-monsoon to monsoon season. In this study, the observed species evenness of Rotifera, Cladocera, Copepoda and Ostracoda during the study period were ranged between 0.848 to 0.899, 0.878 to 0.938, 0.950 to 0.970, and 0.943 to 0.976 respectively (Table 3). However, the lower evenness was observed during the post-monsoon season and maximum during the pre-monsoon season. Also, the relationship between physico-chemical parameters and zooplankton population density of Ukkadam Lake showed positive correlation (Table 4).

## Discussion

Knowledge on hydrology of any lake is essential for proper utilization. Physico-chemical parameters and nutrient quantity of lake water play a significant role in the distribution patterns and species composition of plankton (Horne & Goldman, 1994; Mahar, Baloch, & Jafri, 2000). In aquatic habitats, environmental factors including various physical properties (gases and solids solubility, light penetration, temperature and density) and chemical properties (salinity, pH, hardness, phosphates and nitrates) of water are very important for growth and dispersal of phytoplankton on which zooplankton depend for their existence. In the current study, the Ukkadam Lake showed significant variation in physico-chemical parameters of water, species composition, population density, species diversity, species evenness and species richness of different zooplankton species. It suggests that physico-chemical parameters of water influenced by different season variations and it led to significant differences in the density, diversity, evenness and richness of zooplankton in the Ukkadam Lake. Surface water temperature is one of the most essential and changeable environmental factors, since it influences the growth and distribution of flora and fauna of lake ecosystem. Also, influence of surface water on limnological phenomenon, such as stratification, solubility of gases, pH, conductivity and planktonic distribution are well known (Singh, Sharma, & Deorani, 1990). A rise from the temperature leads to the fast chemical and biochemical reactions. In the growth and death of microorganisms, the kinetics of the biochemical oxygen demand that is also regulated to some extent by water temperature have also been reported (Khuhawar & Mastoi, 1995).

All metabolic and physiological activity and life processes, such as feeding, reproduction, movements and distribution of aquatic organisms are greatly influenced by water temperature (Bhavan et al., 2015; Manickam, 2015; Manickam, Bhavan, & Santhanam, 2017; Manickam, Bhavan, Santhanam, Chitrarasu, & Ali, 2012; Manickam et al. 2014, 2015. Moreover, this present study provides the evidence that increased fall temperatures trigger dominance of significantly smaller zooplankton species. The rise in temperature speeds up the biochemical reactions and reduces the solubility of gases. Generally, the atmospheric temperature was always found higher than the water temperature (Harney, Dhamani, & Andrew, 2013). In the present study, highest atmospheric and surface temperature was observed in summer and minimum in monsoon; it might be due to shallowness of the Ukkadam Lake. The surface water temperature has shown a tendency to follow closely to the atmospheric temperature; this result agrees with the earlier findings (Malhotra, Dutta, & Suri, 1986; Reid & Wood, 1976; Singhal, Swarn, & Davis, 1985). An increase in solar radiation and concomitant evaporation due to comparatively longer day length may explain gradual increase in both air and water temperatures from April to August. Similarly, a gradual reduction in solar radiation may explain fall in

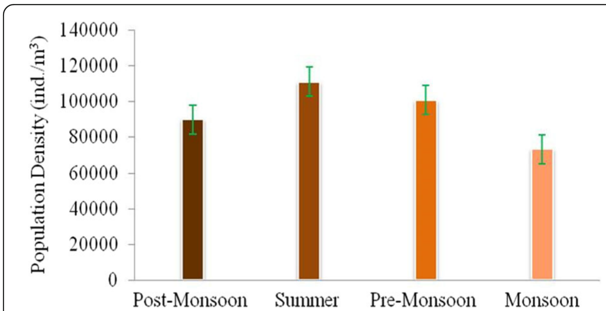


**Fig. 4** Population density of zooplankton recorded in the Ukkadam Lake during December 2011–November 2012

**Table 2** Zooplankton population density during in the Ukkadam Lake during December 2011–November 2012

| Season | Rotifera | Cladocera | Copepoda | Ostracoda | *F* value | *P* - value |
|---|---|---|---|---|---|---|
| Post-monsoon | 6508 ± 75[a] | 5012 ± 39[c] | 5257 ± 26[b] | 1205 ± 29[d] | 5975.37 | 0.000 |
| Summer | 9196 ± 64[a] | 5514 ± 51[b] | 5045 ± 42[c] | 2425 ± 23[d] | 8663.32 | 0.000 |
| Pre-monsoon | 7078 ± 38[a] | 5980 ± 36[b] | 5601 ± 18[c] | 1497 ± 31[d] | 19,149.31 | 0.000 |
| Monsoon | 5243 ± 29[a] | 3863 ± 23[c] | 4685 ± 26[b] | 826 ± 18[d] | 17,520.37 | 0.000 |

$n = 3$; mean ± SD. Different superscript small letters denote significant difference at $p < 0.001$

temperature from October to February (monsoon to post-monsoon) and again it begins to increase March onwards. Also, water temperature is important for calculating the solubility of oxygen and carbon dioxide and bicarbonate and carbonate equilibrium (Harney et al., 2013; Hutchinson, 1957).

The pH is the scale of intensity of acidity and alkalinity of water and measure the concentration of $H^+$ ions. Kataria, Iqbal, and Chandilya (1996) observed the elevated level of pH in the months of May (summer) indicates high rate of photosynthesis in water bodies. In the present study, maximum pH was observed during summer and minimum during pre-monsoon. Jakher and Rawat (2003) reported that the maximum pH with increased photosynthesis during summer due to high temperature resulted in higher consumption of carbon dioxide in the aquatic environment. Similarly, the result of the present study showed maximum pH at summer seasons and minimum at pre-monsoon. In the current study, the significant elevation in salinity during summer indicates that the elevated level of temperature led to high evaporation of water whereas the lower salinity noticed during monsoon months could be attributed to lower temperature and high freshwater input due to rainfall. Salinity might be playing a more indirect role by shaping of zooplankton communities towards salinity tolerant species. In a climate change perspective, these results suggest that changes in the trophic structure of lakes in temperate regions might be expected as a result of the warmer temperature and the potentially associated increases in salinity.

In the present study, elevated level of DO was documented in summer months; it might be due to the increased photosynthesis of phytoplankton. Minimum DO was recorded in monsoon months; it might be due to the utilization DO and decomposition of organic matter and respiration of micro and macroorganisms. In the present study, maximum electrical conductivity was recorded in the summer months and minimum in monsoon months. The changes in conductivity of water followed the same seasonal pattern as that of salinity. The pioneer researchers aggregated with elevated EC in summer month (May, 2012) and minimum in monsoon month (October, 2012) in the freshwater lake ecosystem (Manickam et al., 2015). Further, it has increased and decreased TDS during summer, and post-monsoon and monsoon months due to the decreased inflow and increased inflow (dilution) of water in the respective seasons.

**Table 3** Seasonal variation in zooplankton species diversity in the Ukkadam Lake during December 2011–November 2012

| Zooplankton groups | | Zooplankton species diversity indices (sites 1–3; average value) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Post-monsoon[a] | | | Summer[b] | | | Pre-monsoon[c] | | | Monsoon[d] | | |
| | | Dec 2011 | Jan 2012 | Feb 2012 | Mar 2012 | Apr 2012 | May 2012 | Jun 2012 | Jul 2012 | Aug 2012 | Sep 2012 | Oct 2012 | Nov 2012 |
| Shannon (H) | Rotifera | 2.032 ± 0.037 | | | 2.086 ± 0.016 | | | 2.089 ± 0.014 | | | 2.052 ± 0.022 | | |
| | Cladocera | 2.067 ± 0.027 | | | 2.102 ± 0.008 | | | 2.133 ± 0.010 | | | 2.106 ± 0.023 | | |
| | Copepoda | 1.752 ± 0.008 | | | 1.759 ± 0.006 | | | 1.761 ± 0.005 | | | 1.740 ± 0.015 | | |
| | Ostracoda | 1.551 ± 0.031 | | | 1.581 ± 0.007 | | | 1.585 ± 0.014 | | | 1.563 ± 0.022 | | |
| Evenness | Rotifera | 0.848 ± 0.031 | | | 0.891 ± 0.017 | | | 0.899 ± 0.013 | | | 0.865 ± 0.019 | | |
| | Cladocera | 0.878 ± 0.024 | | | 0.909 ± 0.007 | | | 0.938 ± 0.009 | | | 0.913 ± 0.020 | | |
| | Copepoda | 0.961 ± 0.007 | | | 0.968 ± 0.006 | | | 0.969 ± 0.005 | | | 0.950 ± 0.014 | | |
| | Ostracoda | 0.943 ± 0.029 | | | 0.972 ± 0.007 | | | 0.976 ± 0.013 | | | 0.955 ± 0.022 | | |
| Richness | Rotifera | 1.217 ± 0.027 | | | 1.156 ± 0.024 | | | 1.204 ± 0.024 | | | 1.257 ± 0.016 | | |
| | Cladocera | 1.271 ± 0.045 | | | 1.176 ± 0.030 | | | 1.234 ± 0.032 | | | 1.321 ± 0.025 | | |
| | Copepoda | 0.789 ± 0.016 | | | 0.748 ± 0.019 | | | 0.755 ± 0.078 | | | 0.799 ± 0.011 | | |
| | Ostracoda | 0.831 ± 0.066 | | | 0.717 ± 0.024 | | | 0.788 ± 0.038 | | | 0.891 ± 0.044 | | |

[a]Dec 2011, Jan 2012 and Feb 2012; [b]Mar 2012, Apr 2012 and May 2012; [c]Jun 2012, Jul 2012 and Aug 2012; [d]Sep 2012, Oct 2012 and Nov 2012

**Table 4** The relationship between physico-chemical parameters and zooplankton abundance/population in the Ukkadam Lake during the study period (December 2011–November 2012)

| Physico-chemical parameters vs. zooplankton abundance | 'y'—value (linear type) | R | $R^2$ | Correlation | 'p' values |
|---|---|---|---|---|---|
| Atmospheric temperature | $y = 579.78x - 10,135.73$ | 0.997 | 0.994 | Positive | 0.003 |
| Surface water temperature | $y = 434.490x - 7024.97$ | 0.952 | 0.907 | Positive | 0.048 |
| pH | $y = 1188.315x - 4520.06$ | 0.820 | 0.673 | Positive | 0.180 |
| Salinity | $y = 7137.77x - 1740.56$ | 0.837 | 0.701 | Positive | 0.163 |
| Dissolved oxygen | $y = 800.527x - 1192.43$ | 0.964 | 0.929 | Positive | 0.036 |
| Electrical conductivity | $y = 3907.52x + 932.21$ | 0.861 | 0.742 | Positive | 0.139 |
| Total dissolved solids | $y = 9900.094x - 2815.88$ | 0.996 | 0.992 | Positive | 0.004 |

The pioneer report in highest average value of total dissolved solids might be due to the accumulation of the anthropogenic activity, which hampered the quality of water (Bhavan et al., 2015; Ezhili, Manikanadan, & Ilangovan, 2013; Manickam, 2015; Manickam et al., 2012, 2014, 2015). In the present study, the high level of TDS during summer months suggests that the stagnation of nutrients in the lake led to higher production of zooplankton. In the present observation, 28 species of zooplankton were recorded consisting of 9 species that belong to each Rotifera and Cladocera and 5 species each belongs to Copepoda and Ostracoda. The present result was supported by earlier reports (Bhavan et al., 2015; Dhanasekaran, Bhavan, Manickam, & Kalpana, 2017; Manickam, 2015; Manickam et al., 2012, 2014, 2015). The diversity of zooplankton in the Ukkadam Lake focused on the effect of high temperature. Surface water temperature constrains the life history traits of zooplanktonic organisms by changing metabolic rate and activity level with direct effects on growth and reproduction (Burns, 1969; Goss & Bunting, 1983; Orcutt & Porter 1984). Present findings clearly indicated that the increased temperature due to the discharge of household and industrial waste can enhance the TDS. Hence, it is understood that the increased water temperature along with TDS may positively support the zooplankton population for some instance. The statistical findings showed the positive relationship between physico-chemical characteristics of water and zooplankton population in the Ukkadam Lake. Present results agree with the previous report of Ezhili et al. (2013) who reported that zooplankton were abundant during summer season, whereas minimum in during rainy season in the Ukkadam Lake during year 2003–2004.

In the present study, zooplankton percentage composition of Rotifera was found to be predominant, followed by Copepoda > Cladocera > Ostracoda. These results were similar to earlier observation by Bhavan et al. (2015), Dede and Deshmukh (2015), Manickam et al. (2014, 2015) and Ramakrishna (2014). The distribution and population of density of zooplankton are based on the prevailing physico-chemical parameters of the environment. In the present study, the rotifers were found to be predominant in groups in which they are the indicators of eutrophication and measures must be taken to minimize the water pollution by regulating human activities in watershed area (Manickam, 2015; Manickam et al., 2012, 2014, 2015). The population of zooplankton, such as Rotifera, Cladocera, Copepoda and Ostracoda, did not show any swarming phenomena during the study period. However, peak population was noticed in summer, followed by winter and the lowest numbers were noticed in the monsoon season. The differences in the population of different components were not of significance.

The summer season zooplankton population was found to be higher; it might be attributed to favorable environmental conditions and availability of food (phytoplankton) in the lake ecosystem. Also, rich nutrient loading may support the high phytoplankton production which can ultimately support to zooplankton abundance/population (Manickam et al., 2014). In the present study, overall population density of zooplankton were found be minimum in monsoon season and this might be due to high turbidity, low light intensity, cloudy, sky besides high rain fall. The similar results have also been reported by earlier works (Bhavan et al., 2015; Dede & Deshmukh, 2015; Dhanasekaran et al., 2017; Ezhili et al., 2013; Manickam et al., 2012, 2014, 2015; Patel, Shukla, & Patel, 2013; Thirupathaiah, Sammatha, & Sammaiah, 2011; Watkar & Barbate, 2013). The zooplankton population shows sudden decrease in monsoon months and indicates the fact that the prevailed physico-chemical conditions were not supported for the growth of zooplankton due to the lentic water system. These effects may also be due to over predation of zooplankton by the higher trophic members like planktivorous fishes which regulate the zooplanktonic population in the water body (Poongodi, Bhavan, Vijayan, Kannan, & Karpagam, 2009). The population of zooplankton falls during the monsoon due to dilution of lake by rainfall. The zooplankton population of lake showed an increasing trend during the winter because of favorable environmental conditions which include temperature, dissolved oxygen and the availability of rich nutrients in the form of bacteria, nano-plankton and suspended detritus. The elevated level of zooplankton in winter seasons due to favorable environmental factors has also been reported (Baker, 1979; Edmondson, 1965).

In the present study, higher value of species diversity indicated the health of selected lake ecosystem. Previously, Das (1996) and Manickam et al. (2012) reported higher value of Shannon's index (H′) and the population of zooplankton during summer and lower during monsoon months. High species diversity of zooplankton in the perennial lake indicates least pollution and plays a pivotal role in aquatic ecosystem (Manickam et al., 2015). The diversity of zooplankton species tends to be low in stressed and polluted ecosystem (Bass & Harrel, 1981). In the present study, zooplankton species richness was found to be lower in summer and pre-monsoon summer season, whereas higher in post-monsoon to monsoon. The species equitability (evenness) was relatively high during the rainy season indicating a reduction in the plankton diversity at this period (Adesalu & Nwankwo, 2008).

## Conclusions

The results from this study indicated that the increased level of temperature led to increased water evaporation, followed by rich nutrients and elevated level of zooplankton abundance in the lake during the summer season, whereas zooplankton falls during the monsoon due to dilution of lake by rainfall. Therefore, the present study suggests that the water temperature can positively support the population diversity of zooplankton with the evidence from high degree of positive correlation between temperature, total dissolved solids and plankton density. However, further studies are warranted on the continuous monitoring of this lake ecosystem to know the future impact of climate change on distribution of zooplankton which can help to identify the sensitive and sentinel species to formulate the effective conservation strategies.

### Abbreviations

Am: Ante meridiem; DO: Dissolved oxygen; E: East; EC: Electrical conductivity; Ind: Individual; Lat: Latitude; Long: Longitude; N: North; TSD: Total dissolved solids

### Acknowledgements

The authors are thankful to the Head, Department of Zoology, Bharathiar University, School of Life Sciences, Coimbatore - 46, Tamil Nadu, India, for the necessary laboratory facilities provided. The first author (NM) gratefully acknowledged the SERB, Department of Science and Technology (DST), Govt. of India, New Delhi, for granting National Post-Doctoral Fellowship (DST-SERB, File No. PDF/2016/000738; Date—05.06.2016).

### Funding

The research reported is funded by SERB, Department of Science and Technology (DST), Govt. of India, New Delhi.

### Availability of data and materials

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

### Authors' contributions

The work was framed and executed by NM. PSB and PS supervized the first author. The manuscript edition (calculation and language) was done by RB and TM. VS, AA, GR, RU, and MK served as sample collectors during the experimental period. All authors read and approved the final manuscript.

### Ethics approval

We declare that we do not need an ethics approval regarding our work on the freshwater zooplankton.

### Consent for publication

Not applicable.

### Competing interests

The authors declare that they have no competing interests.

## Publisher's Note



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Received: 18 May 2017 Accepted: 8 February 2018
Published online: 22 February 2018

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