Spatial and temporal pattern of zooplankton assemblage in response to Limnological factors of river, Yamuna

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Abstract-Zooplankton plays a key role in maintaining aquatic ecosystem quality and is closely related with the community structure. During the present investigation, the zooplankton samples were collected from the three different sampling stations of River Yamuna for a period of one year from April 2012 to March 2013. The physico-chemical parameters of water such as temperature, transparency, velocity, turbidity, conductivity, pH, total alkalinity, total hardness, calcium, magnesium, dissolved oxygen, biological oxygen demand, phosphate and nitrate. The temperature ranged from 17.0±2.59 ^{o}C to 18.58±2.90^{o}C and pH showed slightly alkaline nature. Sampling station, I registered a maximum dissolved oxygen concentration of 11.41±0.775 mg/l and minimum nutrient concentration. A total of 29 genera of zooplankton belonged to four different taxonomic groups were identified. Among these 10 genera belonged to protozoa, 11 genera belonged to rotifera, 6 genera belonged to copepod and 2 genera belonged to ostracoda. The zooplankton density was highest at sampling site I with maximum number of individuals belonging to all the four group. Rotifera formed the dominant group followed protozoa, copepoda and ostracoda. *Daphnia, Asplanchna* and *Paramecium* was reported with highest number of individuals during the entire study period. The total zooplanktonic richness generally indicated favorable environmental conditions and these were characterized by tolerant of widely fluctuating environmental conditions. Pearson correlation coefficient and Shannon- Weiner diversity index (H’) was calculated.

Key words: Aquatic, Community, Shannon-Weiner, Taxonomic, Yamuna, Zooplankton

Introduction

Rivers are important zones for biodiversity but they are exposed to widely fluctuating environmental conditions with periodic changes in inundation, temperature and water quality. Furthermore, they are often exposed to high levels of human disturbances. Despite these stresses, rivers often support valuable fisheries, provide excellent natural resources for different activities and contributing to regional aquatic diversity. The hydro-zoological communities are particularly important component of river ecosystem. Assessing the diversity of these communities by estimating species abundances/occurrences in valued rivers is one way by which aquatic populations can be compared between sites and be used to help monitor ecosystem quality. Within a particular river, the species composition of aquatic communities is closely linked with seasonal and hydrologic cycles. Many species of zooplankton and aquatic invertebrates can however tolerate changing conditions by both physiological and life cycles adaptations. Rivers are very important ecosystems because they are ecologically and biologically rich and zooplankton is a critical ecological component (Gliwicz, 1999; Hart, 2004). The spatial and temporal dynamics of zooplankton communities are influenced by a variety of physical, chemical and biological factors, whose relative role in structuring zooplankton assemblages and controlling seasonal dynamics may vary within or between biological systems (Hunter and Price, 1992). In general, both biotic and abiotic factors define the microhabitat boundaries for zooplankton by partitioning the environment and minimizing competitive interactions. Further, these are highly susceptible to physical and chemical changes in their environment due to their small size and permeable integument (Nogrady et al. 1993). The various factors that influence the dynamics of natural zooplankton populations are: temperature, oxygen concentration, light intensity and pH. The physical, chemical and biological conditions prevailing in river Yamuna have been studied by Rai (1974 b), De Zwart (1991) and Kaur (1996), Prasad and Singh (2003), Khanna and Fouzia Ishaq (2012); Fouzia Ishaq and Amir Khan (2013). A large number of studies covering a wide variety of ecosystems and organisms suggest that species richness tends to vary strongly with ecosystem production and habitat heterogenicity (Rosenzweig, 1995). This is particularly so with freshwater fauna (zooplankton), which plays a key role in preservation and maintenance of ecological balance and its basic study is wanting and is absolutely necessary. The present investigation attempts to analyze the spatial and temporal pattern of zooplankton assemblage in response to limnological factors of Instream ecosystem of River Yamuna.

Material and Methods

Study area

River Yamuna is a perennial Himalayan river which originated from Yamunotri glacier in the banderpoonch peak of lower Himalayas in Uttarkashi district of Uttarakhand India at an elevation of 6,387 m (20,955 ft) located geographically 38°59′N 78°27′E latitude and 38.983°N 78.45°E longitude and travels a total length of 1376 Km. The catchment area of river Yamuna is 366,220 Km^2 out of which 74,208 Km^2 lies in Uttarakhand.

Dehradun is capital of Uttarakhand famous for its beauty, basmati rice, litchi and also a centre of various research institutes as well. It is bounded in the north by the higher range of lesser Himalaya and in the south by the younger Shivalik ranges. Geographically the Doon valley (Dehradun) lies between latitude 29° 55’N and 38° 30’N, longitude 77° 35’E and 78° 20’E covering an area of about 3,088 sq. km, with a population of 12, 82,143 (as per 2001 census) (Chauhan, 2008).

Study sites

The study was carried out on river Yamuna from April 2012 to March 2013 to assess the spatial and temporal pattern of zooplankton assemblage in response to limnological factors. The sampling sites; Site I Kalsi (S-I), Site II Dakpathar (S-II) and Site III Asan lake (S-III) were selected on 50 Km stretch of river Yamuna.

Site I: Kalsi is a small town approximately 56 kilometers from Dehradun in Uttarakhand and is a dream destination in the Doon valley. The place is just ideal for such recreational activities like kayaking, parasailing and fishing and also witnesses the glory of King Ashoka. Picturesquely it is located at the bank of River Yamuna and surrounded by beautiful hills and greenery all around. The River is beyond doubt the most striking attraction moving by in a frenzy after meeting up with Tons and Asan Rivers. In this stretch of river only anthropogenic activities were seen and domestic waste from residential areas is the main stress on the river.

Site II: Dakpathar is newly developed recreation centre of Garhwal Mandal Vikas Nigam and is about 45 Kms from Dehradun, located at the foothills of Shivaliks. It is a beautiful tourist spot in the western Doon Valley and one of the major attractions of the place is hydel power station which is located on the downstream of the dakpathar barrage. Its sheer size and dimension would awestruck from every angle you see it. Strategically positioned near the banks of mighty River Yamuna, it is naturally exotic surrounded with forests and bejeweled with lush green lawns and gardens. Thus the site being a tourist resort, the wastes from tourist activities is deteriorating the quality of water.

Site III: The Asan Reservoir is a small man-made wetland of ca. 4 sq km area, located 40 km west of Dehradun, in Doon valley on Dehradun-Paonta road. Geographically it is situated between latitude 30º 24’-30º 28’ N and longitude 77º 40’-77º 44’ E, near the confluence of the two perennial rivers, river Asan and Yamuna. The barrage is 287.5 m long, the river bed being 389.4 m above sea level, with minimum and maximum water levels respectively at 402.4 m and 403.3 m. The asan reservoir attracts 53 species of water birds of which 19 are winter migrants from Eurasia. During winter months 90% of the water bird population comprises the following 11 migratory species, namely Brahminy Duck, Pintail, Red Crested Pochard, Gadwall, Common Pochard, Mallard, Coot, Wigeon, Common Teal, Tufted Duck, Shoveller. The birds listed as globally threatened species and in the IUCN Red Data Book have been observed at Asan. The site is mostly influenced by tourism and people from different far flung areas visit the place leaving behind lot of waste. The activities like skiing, boating, rowing, kayaking, canoeing etc are stressful for the reservoir.

Sampling strategy

Water samples collected for the purpose of estimation of various parameters were brought to the laboratory and subjected to analysis immediately as far as possible. Standards Methods for Estimation of Water and Wastewater 20th edition, 1998 were referred for estimation of parameters viz., temperature, transparency, velocity, turbidity, conductivity, pH, total alkalinity, total hardness, calcium, magnesium, dissolved oxygen, biological oxygen demand, phosphate and nitrate. The data collected was subjected to standard deviation, and correlation coefficient for the comparison between sites.

For qualitative and quantitative analysis of zooplankton, collections were made by using cone shaped plankton net made up of nylon bolting silk plankton net (No. 25 mesh size 50 μ) attached with collection tube at the base of net. The net was hauled for a distance of 10 m collected samples were transferred to labeled vial bottles containing 4% formalin. The volume of filtered sample was calculated by multiplying the area of mouth of the net by the depth of the river (i.e., the length through which the net was towed). After sedimentation, 100 ml of sample is subjected to centrifugation and used for further investigation. Counting the protozoa, rotifera, copepoda and ostracoda was carried out using a Sedgewick Rafter cell (Needham and Needham, 1962). Zooplankton diversity was calculated using the Shannon Weiner index, which has moderate sensitivity to the sample number (Magurran, 1988).

Shannon Weiner index

$$H' = \sum_{i=1}^{S} Pi \log 2\, pi$$

Where,

S = Total number of species

$Pi = n_i/N$ = proportion of individuals of the total sample belonging to the *i*th species

n_i = Number of individuals (N) belonging to the ith species

N = Total number of individuals of all the species

Results

Physico-chemical factors

Table-1 presented the values recorded for physico-chemical variables in the samplings stations carried out during the study period. The mean variation in the surface water temperature of the three stations is presented in table 1. The temperature ranged between the lowest values of 17.0±2.59 ºC obtained from station-I and the highest of 18.58±2.90 ºC obtained from station-III and showed no substantial differences between the sampling sites. The temperature in Asan lake (S-III) was higher than that reported for other two sites that may be due to the fact of standing condition of water and activities of tourism and recreation where as at sampling station, lower temperature is on account of the high altitude location as well as less sources of pollution from surrounding areas. Kolo and Yisa, (2000) reported higher temperature in Suka lake and Adam et al. (1990) reported low temperature at high altitude rivers. Secchi's disc transparency was the highest at S-I with a mean value of 42.62±26.82 cm and S-I recorded the least Secchi's disc transparency value with a mean of 20.32±9.24 cm (table 1). The transparency was found positively and significantly correlated with temperature ($P<0.05$). The maximum transparency may be attributed to increasing depth, low pollution load and minimum transparency may be attributed to minimum depth as well as pollution load and increased concentration of suspended solid and other materials that Results in low light penetration and less transparency. Ali et al. (2000) reported similar Results in Ravi and Chenab rivers in Pakistan. The velocity of the river ranged from lowest of 0.405±0.104 m/s at

S-I to the highest of 2.57±0.32 m/s at S-II (table 1). Sampling site III was significantly different from other stations and velocity was significant at ($p < 0.01$). The highest mean water current observed in station II may be due to regulation from the dam site and the release from this station Resultsing in a constant flow of water. A factor of potential limnological significance is water movement within the barrage produced by discharge from the upstream and the release downstream (station II). The actual effects of the current on the chemistry and the biota of the water are not known, but one may speculate that significant water movement through the surface of the river may prevent development of anoxic conditions and thereby preclude release of sediment bound nutrients. Similar observations have been recorded by Dobriyal (1985) and Nautiyal (1990) in the snow fed rivers of Garhwal Himalayas. The velocity was higher in River Yamuna during summer and monsoon months as it is a glacier fed river Resultsing in more and more water due to melting of ice and snow and also heavy rainfall Results in maximum runoff hence increasing its velocity. Values for turbidity marked spatial variation from lowest of 213.79±329.78 JTU at sampling station-I to 264.58±311.51 JTU at sampling station-III. Turbidity showed positive significant relation with temperature and transparency ($p< 0.05$). The high turbidity may be due to the factors contributing which include soil erosion, elevated nutrient inputs and an abundance of bottom feeders that stir up sediments as well as heavy rainfall in monsoon period (Schlesinger, 1991). As water becomes more turbid, less sunlight is able to penetrate its surface, therefore the amount of photosynthesis that can decrease. This Results in a decrease in the amount of oxygen produced by aquatic plants. This also limits the amount of dissolved oxygen water can hold (Merritts, 1998). The quality may not, however, have adverse effect on the aquatic organisms in the river. The mean conductivity value was highest at sampling station-I 0.210±0.030 µmhocm^{-1}to 0.150±0.010 µmhocm^{-1} at sampling site-III. Conductivity showed significant relation with temperature and velocity ($p< 0.05$). Compared with the Results of Taheruzzaman and Kushari, (1995) the conductivity of River Yamuna was low. Low ionic content in natural waters is generally attributed to slow chemical weathering in the catchments (Blakaret al. 1990). Moreover, apart from slightly random spatial and yearly fluctuations; water of this river does not express definite seasonal trends in conductivity value. Occasional fluctuations in conductivity at a particular season during the study period were quite normal as in all natural systems and were due to differences in the rate of local in flow.

The surface water pH fluctuated between lowest of 8.03±0.293 at sampling site-I to highest of 8.28±0.17 at sampling site-III (table 1). No acidic pH was reported during the study and alkaline pH was recorded at all the sampling sites. The variation in pH was significant throughout the study at all the stations ($p< 0.05$). Kaul and Handoo, (1980) found that increased surface pH in water bodies is due to increased metabolic activities of autotrophs, because in general they utilize the CO_2 and liberate O_2thus reducing H^+ ion concentration . The same authors are also of the opinion that in the bottom of water bodies, liberation of acids from decomposing organic matter under lowO_2 concentration Results in low pH. A pH range of 6 to 8.5 is normal according to the United States Public Health Association (De, 1999). When compared to all these standards, pH observed in river Yamuna in general was within the safe limits. The highest total alkalinity was recorded at station I (187.33±23.97 mg/l) followed by 181.08±20.71 mg/l at station- III. The lowest mean value of 162.0±16.85 mg/l was recorded at sampling station-II, which was not significantly different from stations I and III. The higher alkalinity might be due to increase in atmospheric temperature and the consequent increase in the photosynthetic process in summer. In pure natural waters alkalinity is mostly due to dissolved CO_2 or bicarbonate ions and it represents the main carbon source for assimilation during photosynthesis (Ansa Asare, 1992). Total hardness, calcium was reported lowest at sampling station-II and highest at sampling station –I. whereas magnesium was reported in higher concentration of 11.94±1.74 mg/l at site-II and lowest of 11.18±4.24 at site –I. Total hardness also showed significant relation with turbidity and pH ($p<0.01$) and transparency and total alkalinity ($p<0.05$). Higher total hardness at sampling site I may be due to presence of salts in the catchment area and may be attributed to presence of high calcium and magnesium levels. Khanna et al. (2012) observed the similar trend of hardness in River Yamuna and Tons. The source of Ca and Mg in natural waters is basically leaching from Ca rich mineral rocks such as lime stone or mineralization of organic matter by the bacteria. Therefore, Ca in natural waters differs according to difference in geographic regions or anthropogenic impact (Jain et al. 2002). Dissolved oxygen fluctuated between lowest of 10.70±0.412 mg/l at sampling station-I and the highest mean of 11.41±0.775 mg/L recorded from sampling station- I (Table-1). Dissolved oxygen was found significantly correlated with temperature, velocity and pH ($P<0.05$). The cause of maximum DO may be due to the reduced rate of decomposition by decreased microbial activity at low temperature in winter season (Prasad and Singh, 2003). Depletion of oxygen may occur in summer due to increase in temperature as well. The oxygen cycle in water involves a rapid decrease during summer at a steady increase through autumn till maximum content is reached in winter, following the well known solubility of gases (Kaul and Handoo, 1980). The low temperature and high speed of water flow increase dissolved oxygen in upstream and high temperature with low speed of water flow decrease dissolved oxygen in downstream. So the fast moving water and colder water contain higher dissolved oxygen than slow or stagnant water and warmer water. Chopra et al., (1994) also got the same Results and have revealed that low temperature in winter season increases the oxygen retaining capacity of water and solubility of oxygen in water. There was no significant variation between the values of biochemical oxygen demand (BOD) recorded for all stations. The mean values varied between lowest of 2.87±0.490 mg/l at sampling station-I and highest of 3.35±0.318 mg/l at sampling station-III (table 1). However, there was significant difference ($P < 0.01$) between the values recorded for all stations. BOD increases as the bio-degradable organic content increases in waters. The higher BOD recorded in station III could probably be due to organic matter degradation which utilized oxygen within the river. According to Kolo and Yisa (2000) organic matter in the form of increased decomposition of domestic sewage can increase the BOD. The highest BOD may be due to addition of high organic content leading to lower oxygen concentration indicating deoxygenation rate due to higher biological decomposition of organic matter. The mean values of phosphate recorded varied between 0.569±0.152 mg/l at sampling site- I to 0.659±0.080mg/l in sampling station- III. Phosphate showed significant correlation ($P < 0.05$) with temperature, turbidity, pH and total hardness. Phosphate is the nutrient considered to be the critical limiting nutrient, causing eutrophication of fresh water systems (Rabalais, 2002). It is a major nutrient that triggers eutrophication and required by algae in small quantities (Bandela, et al. 1999). Each Phosphate ion promotes the incorporation of seven molecules of N and 40 molecules of CO_2 in algae (Wetzel, 2001). Phosphate enters surface water from human-generated wastes and land run off; domestic waste contains approximately 1.6 kg per person, per year of which 64 % is from synthetic detergents (Kataria, et al. 1995). P additions to landscape enter water via waste water effluents and soil erosions, and also from detergents. Therefore, Phosphate in large quantities in water is an indication of pollution through sewage and industrial waste. In instances where phosphate is a growth limiting nutrient, the change in its concentration can cause the stimulation or inhibition in the growth of photosynthetic aquatic micro and macro organisms such as phytoplankton and green bacteria (APHA, 1998).The highest mean value for nitrate was 1.525±0.1 46mg/l at sampling site-III, while the lowest mean value of 0.532±0.082 mg/l was recorded at sampling site- I. Nitrate showed significant correlation of ($P< 0.05$) with temperature, conductivity, pH and dissolved oxygen (table 2). No significant difference occurred between the years of study in nitrate and phosphate concentrations. The most important source of NO_3 in waters is biological oxidation of nitrogenous organic matter of both autochthonous and allochthonous origin, which include domestic sewage, Agricultural run-off and effluents from industries (Saxena, 1998). NO_3 concen-tration depends on geochemical conditions such as degree of use of agricultural fertilizers and industrial discharges of nitrogenous compounds (Kataria, et al. 1995). The increased concentration of nitrate in river at sampling site- I may be due to domestic activities and agricultural runoff. High Levels of both phosphate and nitrate can lead to eutrophication, which increases algae growth and ultimately reduces dissolved oxygen levels in the water (Murdoch, et al. 2001).

Table-1 Mean values of physico-chemical parameters at three sampling stations (S-I, S-II and S-III) of river Yamuna

Parameters	S-I	S-II	S-III	Avg. ± S.D
Temperature ^{o}C	17.0±2.59	17.83±2.20	18.58±2.90	**17.80±0.790**
Transparency Cm	20.32±9.24	40.90±20.94	42.62±26.82	**34.61±12.408**
Velocity m/s	1.84±0.51	2.57±0.32	0.405±0.104	**1.60±1.101**

Turbidity JTU	213.79±329.78	249.16±351.67	264.58±311.51	**242.51±26.04**
Conductivity µmhocm^{-1}	0.210±0.030	0.208±0.041	0.150±0.010	**0.189±0.034**
pH	8.03±0.293	8.13±0.30	8.28±0.17	**8.14±0.125**
Total alkalinity mg/l	187.33±23.97	162.0±16.85	181.08±20.71	**176.80±13.195**
Total Hardness mg/l	103.16±20.30	96.50±13.71	98.91±18.46	**99.52±3.372**
Calcium mg/l	57.32±8.32	47.54±9.44	52.23±12.49	**52.36±4.891**
Magnesium mg/l	11.18±4.24	11.94±1.74	11.38±2.00	**11.5±0.39**
Dissolved Oxygen mg/l	11.41±0.775	11.35±0.705	10.70±0.412	**11.15±0.393**
B.O.D mg/l	2.87±0.490	3.21±0.497	3.35±0.318	**3.14±0.246**
Phosphates mg/l	0.569±0.152	0.637±0.086	0.659±0.080	**0.621±0.0469**
Nitrates mg/l	0.532±0.082	0.544±0.061	1.525±0.146	**0.867±0.5699**

Table 2: Pearson correlation coefficient between physico-chemical parameters of river Yamuna

	Temperature	**Transparency**	**Velocity**	**Turbidity**	**Conductivity**	**pH**	**Total alkalinity**	**Total Hardness**	**Calcium**	**Magnesium**	**D.O**	**B.O.D**	**Phosphates**	**Nitrates**
Temperature	1													
Transparency	0.91*	1												
Velocity	-0.63	-0.25	1											
Turbidity	0.98*	0.97*	-0.47	1										
Conductivity	-0.87*	-0.58	0.93*	-0.75	1									
pH	0.99*	0.84*	-0.73	0.94*	-0.92*	1								
Total alkalinity	-0.27	-0.63	-0.58	-0.44	-0.25	-0.12	1							
Total Hardness	-0.65	-0.90*	-0.18	-0.78	0.18	-0.53	0.90*	1						
Calcium	-0.55	-0.84*	-0.31	-0.69	0.05	-0.41	0.95*	0.99*	1					
Magnesium	0.28	0.65	0.56	0.46	0.23	0.14	-0.99*	-0.91*	-0.90*	1				

D.O	-0.89*	-0.62	0.91*	-0.78	0.99*	-0.94*	-0.20	0.23	0.10	0.19	1			
B.O.D	0.97*	0.97*	-0.46	0.99*	-0.74	0.93*	-0.45	-0.79	-0.71	0.47	-0.77	1		
Phosphates	0.96*	0.98*	-0.41	0.99*	-0.71	0.92*	-0.50	-0.82*	-0.74	0.52	-0.74	0.99*	1	
Nitrates	0.85*	0.56	-0.94*	0.74	-0.99*	0.92*	0.27	-0.16	-0.03	-0.3	-0.99*	0.73	0.69	1

Significant at p < 0.05 and 0.01*

Zooplankton composition and diversity

Zooplankton is rarely important in rivers because they cannot maintain positive net growth rates in the face of downstream losses. These communities are highly sensitive to environmental variation. As a Results, changes in their abundance, species diversity, or community composition can provide important indications of environmental change or disturbance. Zooplankton species inhabiting freshwater habitats offer an excellent model system to study spatial interactions.

The composition and occurrence of zooplankton recorded at various stations showed significant variations and fluctuations during the study period (Table 3). Twenty nine genera of zooplankton were identified from the river. They belong to Protozoa (10 genera), Rotifera (11 genera), Copepoda (6 genera) and Ostracoda (2 genera). The qualitative analysis of zooplankton in river Yamuna revealed that the Protozoan's were represented by *Actinophrys*, *Actinosphaerium*, *Euglena*, *Paramecium*, *Peridinium*, *Campenella*, *Epistylis*, *Vorticella*, *Arcella* and *Diffugia*. The total zooplankton that belonged to protozoa was recorded maximum at sampling station –III (178.25±63.0 Ind. /m^2) and minimum at sampling station-II (141.92±56.28Ind. /m^2). Among these genera *Paramecium* was reported with highest number of individuals ranging from 14.58±7.37 Ind. /m^2 at S- I to 25.58±12.65 Ind. /m^2 at S-III and *Epistyl is* was reported with minimum number of individuals ranging from 8.16±4.28 Ind. /m^2 at S-II to 13.25±5.86 Ind. /m^2 at S-III. However the higher number of individuals that belonged to protozoa was recorded from sampling station-III during the period of investigation. Protozoa showed a negative correlation with velocity, conductivity and dissolved oxygen ($p<0.05$) (table 4) but showed a positive significant relation with all other parameters ($p< 0.01$). The Rotifera was represented by *Keratella*, *Nolthoca*, *Rotaria*, *Testudinella*, *Ascomorpha*, *Polyarthra*, *Philodina*, *Asplanchna*, *Pompholix*, *Brachionus* and *Trichocera*. The total zooplankton that belonged to Rotifera was recorded maximum at sampling station –III (197.5±66.19 Ind. /m^2) and minimum at sampling station-II (163.5±62.55 Ind. /m^2). Among these genera *Testudinella* was reported with highest number of individuals ranging from 12.75±8.28 Ind. /m^2 at S- II to 24.0±9.70 Ind. /m^2 at S-I and *Trichocera* was reported with minimum number of individuals ranging from 9.16±5.11 Ind. /m^2 at S-I to 15.25±6.34 Ind. /m^2 at S-III. However Rotifera was dominating the river Yamuna with maximum diversity and density at all the three sampling stations. The number of genera as well as number of individuals belonging to each genus was highest in case of Rotifera. Rotifera also showed a positive significant relation with temperature, transparency, pH and nutrients ($p<0.01$) and negative correlation with conductivity and velocity ($p<0.05$) (Table 4). The Copepoda was represented by *Cyclops, Diaptomus, Daphnia, Bosmina, Helobdella* and *Nauplius* andthe Ostracoda was represented by *Cypris* and *Stenocypris*. Among Copepoda the maximum number of individuals was reported from sampling station-III (116.25±34.02 Ind. /m^2)and minimum number was recorded from sampling station –I (92.5±36.57 Ind. /m^2). *Daphnia*was reported with highest number of individuals and *Bosmina* with lowest number of individuals during the study period among Copepoda at all the three sampling stations. Ostracoda was found with maximum number at S-III (30.25±10.63 Ind. /m^2) and minimum number at S-I (19.5±5.91 Ind. /m^2). *Cypris* was observed with highest number of individuals and *Stenocypris* with lowest number of individuals throughout the study period. Copepoda and Ostracoda was positively significantly correlated with temperature, transparency, pH and nitrates ($p<0.05$).

Table-3 Mean values of zooplankton at S-I, S-II and S-III of river Yamuna

Zooplankton	S-I	S-II	S-III
Protozoa			
Actinophrys	14.66±5.51	19.16±7.37	16.50±5.55
Actinosphaerium	11.75±4.59	14.41±7.14	14.83±6.20
Euglena	16.91±8.57	14.08±5.69	23.41±8.35
Paramecium	14.58±7.37	15.66±8.51	25.58±12.65
Peridinium	17.83±8.67	11.41±6.11	18.66±5.21
Campenella	12.0±6.84	17.08±8.77	18.0±5.83
Epistylis	11.0±6.98	8.16±4.28	13.25±5.86
Vorticella	15.0±6.0	13.5±6.38	14.75±7.35
Arcella	19.25±9.57	13.91±5.99	17.33±7.03
Diffugia	18.33±8.01	14.5±5.79	15.91±7.77
Total	151.33±61.92	141.92±56.28	178.25±63.0
Rotifera			
Keratella	14.75±6.06	19.0±7.08	17.75±6.98
Nolthoca	15.91±8.44	11.5±5.50	16.0±5.41
Rotatoria	16.08±7.02	15.66±7.79	19.0±6.41
Testudinella	24.0±9.70	12.75±8.28	13.33±5.43
Ascomorpha	13.83±7.96	17.58±6.03	21.58±9.48
Polyarthra	17.66±9.03	14.25±6.64	23.25±9.69
Philodina	17.5±9.84	17.25±7.43	18.16±6.42
Asplanchna	19.58±9.07	12.75±8.09	25.75±8.74
Pompholix	15.66±7.11	16.41±7.56	10.33±4.83
Brachionus	11.41±6.99	15.75±5.49	17.08±7.39
Trichocera	9.16±5.11	10.58±4.99	15.25±6.34
Total	175.58±71.76	163.5±62.55	197.5±66.19
Copepoda			
Cyclops	21.0±10.98	13.16±5.95	19.58±6.25
Diaptomus	17.08±8.08	14.58±6.28	20.5±6.97
Daphnia	16.25±5.77	23.66±8.60	24.33±9.90
Bosmina	12.66±7.22	14.75±6.73	16.0±5.20
Helobdella	11.33±7.48	18.25±5.73	12.25±4.86
Nauplius	14.16±5.28	12.66±5.85	23.58±7.52
Total	92.5±36.57	97.08±32.74	116.25±34.02
Ostracoda			
Cypris	8.25±4.02	11.33±5.66	16.33±4.77
Stenocypris	11.25±3.25	8.66±4.61	13.91±7.02
Total	19.5±5.91	20.0±9.76	30.25±10.63

Table-4 Pearson correlation coefficient between zooplankton andphysico-chemical parameters

	Temperature	Transparency	Velocity	Turbidity	Conductivity	pH	Total alkalinity	Total Hardness	Calcium	Magnesium	D.O	B.O.D	Phosphates	Nitrates
Protozoa	0.69	0.33	-0.99*	0.54	-0.96*	0.79	0.51	0.09	0.22	-0.49	-0.94*	0.53	0.48	0.96*
Rotifera	0.61	0.23	-0.99*	0.45	-0.92*	0.72	0.59	0.19	0.32	-0.58	-0.90*	0.43	0.39	0.93*
Copepoda	0.93*	0.70	-0.86*	0.85*	-0.98*	0.97*	0.10	-0.33	-0.20	-0.08	-0.99*	0.83*	0.80*	0.98*
Ostracoda	0.87*	0.59	-0.92*	0.76	-0.99*	0.93*	0.24	-0.19	-0.06	-0.22	-0.99*	0.75	0.71	0.99*

Significant at p < 0.05 and 0.01*

Zooplankton abundanceand distribution

The abundance and richness of zooplankton is presented in (table 5). The zooplankton was more prevalent during the rains and winter season while their population declined during the dry season. The three stations showed similar genera composition. The only difference was in their abundance and distribution within the sampling stations. Among all the genera *Daphnia* was recorded with maximum abundance (21.41±4.48 Ind. /m^2) followed by *Asplanchna*. Qualitatively the zooplankton fauna of each sampling site was dominated by rotifera followed by protozoa, copepods and ostracoda following the order *rotifer* > *protozoa* > *copepod* > *ostracoda*. The rotifers constitute the largest group of zooplankton recorded at all the sites during the study period. During the study period, Shannon–Wiener diversity was relatively high and ranged from 0.2234 to 1.8551(table 5). Shannon–Wiener diversity index indicated that a more even or equitable distribution among species tends to increase diversity and did not showed significant variation between the sampling stations. Twenty-nine genera of zooplankton belonging to 4 groups were recorded. The percentage occurrences of these genera are presented in table 5. The genera with highest percentage among four groups were *Paramecium* (11.83 %), *Asplanchna* (10.82%), *Daphnia* (21%) and *Cypris* (51.48%). The genera with lowest percentage occurrence among all the four groups was Epistylis (6.87%). The genera belonging to Copepoda was reported with highest percentage occurrence during the study period. Accordingly, Rotifer taxa representing different genera recorded their maximum densities at different sites and as such kept the rotifer diversity relatively high throughout the year.

Table-5 Diversity richness, abundance and distribution of zooplankton

	Avg.± S.D	Shannon-Weiner Index (H')	% of zooplankton in each genera
Protozoa			
Actinophrys	16.77±2.26	0.5386	10.66
Actinosphaerium	13.66±1.67	0.3573	8.69
Euglena	18.13±4.78	0.6295	11.53
Paramecium	18.60±6.06	0.6626	11.83
Peridinium	15.96±3.96	0.4878	10.15
Campenella	15.69±3.23	0.4715	9.98
Epistylis	10.80±2.55	0.2234	6.87
Vorticella	14.41±0.80	0.3977	9.16

Arcella	16.83±2.70	0.5425	10.70
Diffugia	16.24±1.93	0.5051	10.33
Rotifera			
Keratella	17.16±2.18	0.4955	9.59
Nolthoca	14.47±2.57	0.3523	8.09
Rotatoria	16.91±1.81	0.4812	9.45
Testudinella	16.69±6.33	0.4688	9.33
Ascomorpha	17.66±3.87	0.5249	9.87
Polyarthra	18.38±4.54	0.5685	10.27
Philodina	17.63±0.47	0.5231	9.85
Asplanchna	19.36±6.50	0.6308	10.82
Pompholix	14.13±3.31	0.3360	7.90
Brachionus	14.74±2.96	0.3556	8.24
Trichocera	11.66±3.18	0.2288	6.51
Copepoda			
Cyclops	17.91±4.17	0.9472	17.56
Diaptomus	17.38±2.97	0.8919	17.04
Daphnia	21.41±4.48	1.3536	21.00
Bosmina	14.47±1.68	0.6183	14.19
Helobdella	13.94±3.75	0.5738	13.67
Nauplius	16.80±5.91	0.8334	16.48
Ostracoda			
Cypris	11.97±4.07	1.8551	51.48
Stenocypris	11.27±2.62	1.6445	48.47

Discussion

In the present study temperature fluctuations in water were influenced considerably by air temperature, humidity and solar radiation. The higher concentration of pH was observed during summer season could be attributed to enhanced rate of evaporation coupled with human interference are partly to enhance photosynthetic activity. The higher values of transparency were recorded during summer season, which may be due to increased solar radiation and thus, considerably good standing crop of zooplankton productivity. The Yamuna river water was in moderate hard water conditions, which in turn useful for the higher productivity. The zooplankton of Yamuna river consists of Protozoa, Rotifers, Copepoda and Ostracoda; a total 29 genera were recorded from the river Yamuna during the present study. There was a distinct seasonal fluctuations and composition of the zooplankton in the river Yamuna with productive (October to March), retardation (June to August) and recovery (September onwards) periods. The total zooplankton population was dominated by rotifera followed by Protozoa, copepoda and ostracoda respectively. Among rotifera*Asplanchna*, *Polyarthra* and *Ascomorpha* were dominated in the present in the present investigation of rotifers. The composition of rotifera population showed higher population during monsoon and summer, while lower population observed in the month of August. This perhaps may be due to influence of copious quantity of rainwater and turbidity, which gets drained into the river. Ostracoda occupied fourth position of zooplankton and represented very low population diversity compared to other groups. The densities of various zooplankton were in the order of rotifera> protozoa > copepod > ostracoda. The Results indicated that the maximum number of genera occurred during winter season than summer and monsoon season which also reported by Abdus et al (1995), Kumar (2001). The less number of genera might be attributed to the less nutrients in the river which consequently Results in less productivity or might be due to the depletion of important limnological. The reduction in the number of genera may be due to predation, variation in the pH of water is always associated with the genera (species) composition of zooplankton inhibiting among them (Jhingran 1982). In winter, it is biotic interaction operating through feeding pressure rather than water quality it seems to affect the zooplankton diversity and density particularly the stocked fish species play an important role in harvesting species of copepoda and ostracoda, thereby reducing their predatory pressure on other groups. The rotifers and protozoa were higher in winter can be linked to favorable temperature and availability of abundant food in the form of bacteria, nano plankton and suspended detritus (Edmondson, 1965). Wetzel (2001) reported that maximum diversity of freshwater ecosystems occurs where the terrestrial wetland-littoral interface regions are strongly coupled to open waters of lakes and river channels. The waters of the river Yamuna represent such a habitat and hence support diverse biotic communities in general and rotifers in particular, although the total number of species is less than half that expected in eutrophic lakes (Dumont and Segers, 1996). In addition, seasonal flushing of these low-lying areas by the river plays a crucial role in maintaining high zooplankton diversity, as these lentic ecosystems provide refuge to the resting eggs carried by the river from its headwaters.

In addition, the rotifer taxocoenos is had a tropical character, with an abundance of 'tropic centered' genera such as *Lecane* and *Brachionus*. This is supported by the presence of fewer species of 'temperate-centered' brachionid genera such as *Keratella* and a restricted occurrence of the cold-water genera *Notholca*. These observations are in concurrence with reports by Sharma and Michael (1980) and Sharma (1998) with regard to Indian rotifer fauna. During the one-year cycle, the rotifer density reached maxima during spring–early summer and minima during winter. In earlier studies on river Yamuna, the zooplankton density was found to be maximum during summer (Rai, 1974b: Kaur, 1996). This difference could reflect the different ecological conditions prevailing in the backwaters. A number of investigators (Pontin and Shiel, 1995; Duggan et al. 1998) also observed that macrophytes in aquatic ecosystems provide a rich variety of microhabitats for a diverse zooplankton fauna. In general, high densities of zooplankton reflect the availability of a wide range of natural sestonic food particles, which zooplankton may consume (Dumont, 1977; Gulati, 1990). Various investigators reported that the rapid increase in zooplankton numbers may be attributed to their intrinsic high fecundity supported by favorable food and environmental conditions (Dumont, 1977; Lynch, 1979; Gulati, 1999). Thus, the presence of favourable physical–chemical characteristics (e.g., temperature, nutrients and pH) as also relative abundance of diatoms were possibly responsible for promoting the growth of zooplankton densities during this study (Michaloudi et al. 1997). Hofmann (1977) suggested that temperature (a conditional factor) and oxygen (a material factor) are the main but not the only determinative factors which influence the occurrence and diversity of zooplankton. De Zwart (1991) and Kaur (1996) observed dominance of zooplankton with low species diversity in the segments of the Yamuna having high levels of BOD and COD. In comparison, the present study sites recorded highly diverse zooplankton fauna with relatively low BOD and COD values.

The zooplankton genera found in the river Yamuna agrees with the observations of Rocha et al. (1999) about zooplankton assemblages in rivers. The rotifer was noted to be main and first dominating group of total zooplankton during the entire study. The present study has also revealed that rotifer densities depend on the quantitative changes of organic decaying materials and temperature the same view was given by Alfred, et al. (1973). The zooplankton assemblage in river Yamuna was attributed to several biotic and abiotic factors interacting together. These include temperature, transparency, nutrients, food availability and river morphometry. Monthly and seasonal variation in zooplankton was significant in river Yamuna. The seasonal, monthly and altitudinal variation of zooplankton in the river Yamuna was related with temperature and dissolved oxygen which favors the survival of zooplankton in water. In summer and winter zooplankton showed a rise in their population but the zooplankton volume and population was low in monsoon due to high temperature, high turbidity, high solids, high conductivity and low DO. Similar Results were obtained by Nath and Srivastava, (2001) in river Narmada and Pathani and Mahar, (2006) in some lotic systems of Himalayas in Uttarakhand. The velocity of water, and transparency of water in different spots were studied and it was found that the number and quality of zooplankton were higher in low altitude than the high altitude. On the Other hand the velocity of water was very high in monsoon due to which plankton population was found low in river Yamuna. Zooplankton advective losses are especially great in rivers having high velocities (Pace et al. 1990), Most of the zooplankton encountered in the study area appears to be normal inhabitants of river Yamuna and increase in primary production (phytoplankton) tends to be the reason for increased zooplankton number and biomass. The species composition of zooplankton with dominance of rotifers was observed in river Yamuna. Arora and Mehra, (2003) also observed richness and dominance of rotifers among zooplankton in Yamuna river. Rotifers were numerically dominant in the lower zone and most of genera had a high frequency of occurrence in samples. In the present investigation, the observation clearly revealed that zooplankton represents a sensitive indicator of pollution and the maximum zooplankton density in winter and minimum in monsoon season may be due to water temperature, water velocity, and turbidity been lower in winter months and these provide favorable environment for the growth of zooplankton. This has been confirmed by Sinha et al. (2000) and Valecha and Bhatnagar, (1998).

Our study suggests that physical and chemical factors largely influence the spatial and temporal dynamics of the zooplankton populations in the waters of the Yamuna. However, an additional investigation of some top-down factors and on the influence of competitive interactions on the seasonal succession of zooplankton communities is required to reach a definite conclusion.

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Disclaimer Statement

Authors declare that no competing interest exists. The products used for this research are commonly used products in research. There is no conflict of interest between authors and producers of the products.

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