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# Water quality and function of Mandakini River ecosystem of Central Himalaya

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**Key words:** Plankton, Periphyton, Macro invertebrates, PCA, CCA.

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## Abstract

Mandakini river is one of the important sources of drinking water for the rural and urban population of Rudraprayag district (Uttarakhand). It also harbours a variety of flora and fauna. A major flash flood occurred during June 16-17, 2013 which resulted into mass mortality of aquatic flora, fauna in addition to huge loss of human life and property. The main aim of this study is to evaluate the quality of water, function of river ecosystem and reestablishment of aquatic communities after this major ecodisaster. 13 physico-chemical parameters and some biological parameters forming the river ecosystem were analysed for the period of two years. A rich floral and faunal diversity encompassing 35 genera of phytoplankton, 47 genera of periphyton, 18 species of macrophytes, 8 genera of zooplankton, 38 genera of macroinvertebrates and 19 species of fish were recorded from the Mandakini river. Principal Component Analysis (PCA) and Canonical Correspondence Analysis (CCA) revealed total alkalinity water temperature, water velocity, turbidity, nitrates, phosphates dissolved oxygen and free carbon dioxide to be the most important physico-chemical parameters playing their role in ecosystem function. The range of physico-chemical parameters did not exceed the limit set by WHO and FAO for drinking water which also proved its suitability for aquatic biota and human consumption. The river ecosystem recovered, aquatic communities re-established themselves and ecosystem started functioning normal some months after the major flash flood.

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## Introduction

Quality of the water is important for harbouring a good spectrum of aquatic biota. The river water fulfils various human needs and provides ecosystem for aquatic life. Concentration of various solutes at a given time and place is reflected in water quality. Water quality parameters can provide the information regarding the suitability of water for its designated uses and to improve current conditions (Ali *et al.*, 2004).

Structural and functional components of a river can give a broad and clear image of a healthy ecosystem. Functional component assess the function provided by ecosystem and structural component assess what live in ecosystem (Young *et al.*, 2003). The use of structural measurements like water quality, the composition of stream invertebrate communities, biomass of fish, algae and macrophytes were traditionally used for judging the health and integrity of river ecosystems (Boulton, 1999).

Natural ecosystem includes communities with multiple trophic levels; species loss from any trophic level can affect ecosystem function (Duffy *et al.*, 2007). The aquatic organism needs adequate nutrients and healthy environment to thrive. The health of an aquatic ecosystem depends upon the physical, chemical and biological characteristics of the water body. At optimum level of physico-chemical parameters the highest productivity occurs (Kamal *et al.*, 2007). Biotic communities can be divided functionally into plant producers, the consumers that feed on producers and the decomposers (Naeem *et al.*, 1999).

Flooding in the Himalayan rivers results from natural or anthropogenic activities or climatologic events like intense rainfall. It poses multiple risks to human health (Tunstall *et al.*, 2006). The rivers originating from Himalaya are frequently exposed to flash flood during monsoon. Major flash flood during 16-17 June 2013 has been disastrous resulting into big loss of human, aquatic life and property (settlement near bank of river). The substratum was completely washed out and all levels of the ecosystem were affected. However, every ecosystem has inherent capacity to recover. The present study is a maiden attempt to access the status of the biodiversity, reestablishment of the aquatic communities and function of river ecosystem of Mandakini after major flash flood (Kedarnath disaster).

## Materials and methods

*Study area*

The Mandakini basin lies between latitudes 30°17'-30°49' N and longitudes 78°49'-79°32' E with the elevation ranges from 620 to 6940 m. a.s.l. River Mandakini originates from the terminal moraines of Chaurabari Glacier (3895 m a.s.l.) and meets with Alaknandariver at Rudraprayag. The total stretch of river from Kedarnath to Rudraprayag is of about 72 km. Three sampling sites, $S_1$, $S_2$ and $S_3$ were selected at Kund (998m. a.s.l.), Agustyamuni (760m a.s.l.), and near its confluence with Alaknanda River at Rudraprayag (620 m. a.s.l.), respectively (Fig. 1).

*Sampling*

*Physico-chemical parameters*

Monthly samples of water were collected from January 2014 to December, 2015 for analyzing the physico-chemical parameters of the river. Temperature, dissolved oxygen (DO), water velocity and transparency were estimated at the site and other physico-chemical factors were analyzed in the laboratory by standard methods outlined in Welch, 1952; Golterman *et al.*, 1969; Wetzel and Likens, 1991; APHA (2005). Air temperature and water temperature were measured by Centigrade thermometer. pH was measured using pH meter (Model- Systronics µ pH system 361). Conductivity meter (Model APX185) was used to measure the conductivity of river water. Turbidity of river water was measured by Turbidity meter (Model-5D1M). Total hardness was measured by EDTA titration. Total alkalinity was determined using Phenolphthalein and Methyl orange titration. Dissolved oxygen was measured by Winkler's method. Free $CO_2$ of river water was measured by Sodium hydroxide and Phenolphthalein indicator.

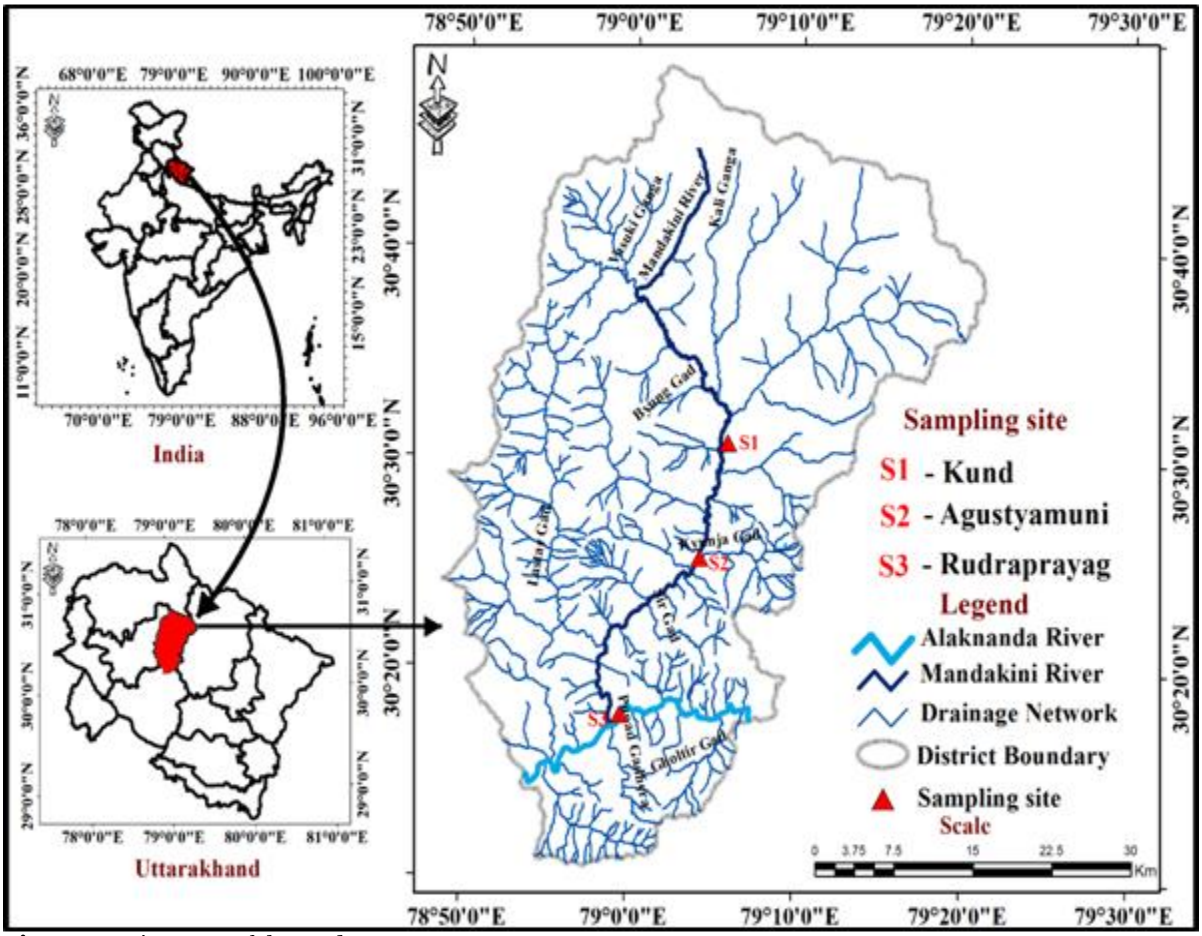


**Fig. 1.** Location map of the study area.

Phosphate was measured by Molybdenum-blue method using Spectrophotometer and nitrate was measured by Phenol-disulphonic acid method using Spectrophotometer.

*Biotic parameters*

The plankton (phytoplankton and zooplankton) collection was done by filtering 10 litters of river water through plankton net (20 µm mesh size) at each sampling site.

The samples for periphyton were collected by scraping 2-3 square centimetre surface area of the stones that were submerged in the running water and preserved in 4% formalin in sampling jars. The identification of plankton and periphyton was done to the lowest recognizable taxonomic level usually genera with the help of keys by APHA, 2005; Ward and Whipple, 1992; Wetzel, 1979; Needham and Needham, 1980.Macrophysics that could not be identified in the field were collected for later identification at the laboratory. The species were identified with the help of subject specialists and key by Gaur (1999).

The macro invertebrates colonizing the substrate were collected by lifting the substrate from a quadrate of 30 $cm^2$ area at the depth of 5-25 cm and sample was collected in sampling jar.

The qualitative analyses of macro invertebrates were done with the help of identification keys by Usinger, 1950; Ward and Whipple, 1992; Needham and Needham, 1980; Eduington and Hildrew, 1995; Tonapi, 1980; Macan, 1979 *etc*.

The fishes of the river were sampled by cast net, local traditional fishing device (long string with nylon loops), gill nets *etc*. with the help of local fishermen. The identification was done with the help of Day, 1878; Jhingran and Sehgal, 1978; Jhingran, 1982.

*Statistical analysis*

Statistical analyses of data was carried out with the help of data analysis tool pack available in MS Excel, SPSS Statistics 20 and statistical software PAST version 2.10.

## Results

*Physico-chemical parameters*

Air and water temperature ranges were found well within WHO permissible limit (Table 1). Seasonally, average air and water temperatures were recorded highest (26.92 °C, 18.71 °C, ) during monsoon and lowest (16.5 °C, 12.17 °C) during winter. (Fig. 2). Current velocity was found to be maximum (0.61 m $sec^{-1}$) during monsoon and minimum (0.43 m $sec^{-1}$) during summer (Fig. 2). Transparency was lowest in monsoon (Table 1).

**Table 1.** Monthly variations in physico-chemical parameters of the Mandakini river during the study period.

| Parameters | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Mean ±SD | WHO | FAO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AT (°C) | 12.33 ±1.53 | 17.67 ±1.53 | 22.83 ±1.04 | 26.00 ±0.87 | 26.83 ±1.26 | 27.50 ±2.00 | 27.67 ±1.61 | 25.83 ±1.76 | 26.67 ±1.61 | 22.17 ±1.76 | 17.83 ±0.76 | 13.67 ±1.26 | 22.25 ±5.54 | <40 | - |
| WT (°C) | 9.83 ±1.44 | 12.67 ±1.53 | 14.33 ±1.53 | 16.17 ±1.15 | 16.50 ±1.50 | 17.33 ±2.02 | 19.67 ±1.53 | 18.83 ±2.25 | 19.00 ±1.80 | 15.50 ±1.32 | 13.33 ±1.26 | 10.00 ±1.00 | 15.26 ±3.32 | <40 | - |
| VL (m $sec^{-1}$) | 0.33 ±0.02 | 0.41 ±0.05 | 0.41 ±0.07 | 0.47 ±0.00 | 0.44 ±0.03 | 0.51 ±0.08 | 0.78 ±0.06 | 0.60 ±0.03 | 0.54 ±0.04 | 0.50 ±0.04 | 0.47 ±0.02 | 0.47 ±0.04 | 0.49 ±0.11 | - | - |
| TR (m) | 0.36 ±0.00 | 0.31 ±0.02 | 0.33 ±0.02 | 0.34 ±0.01 | 0.35 ±0.02 | 0.22 ±0.03 | 0.11 ±0.01 | 0.21 ±0.03 | 0.27 ±0.01 | 0.34 ±0.03 | 0.37 ±0.02 | 0.39 ±0.01 | 0.30 ±0.08 | - | - |
| TA (mg $l^{-1}$) | 70.00 ±2.50 | 68.75 ±2.50 | 57.75 ±4.13 | 54.50 ±2.60 | 46.92 ±4.16 | 38.00 ±2.29 | 36.17 ±2.25 | 52.42 ±2.24 | 50.33 ±2.02 | 56.00 ±3.04 | 63.50 ±5.41 | 82.67 ±5.01 | 56.42 ±13.40 | 120.00 | - |
| TH (mg $l^{-1}$) | 48.17 ±3.55 | 51.67 ±2.31 | 41.83 ±1.04 | 36.67 ±0.29 | 32.33 ±1.53 | 33.17 ±3.01 | 33.33 ±1.44 | 39.67 ±1.44 | 34.83 ±1.61 | 43.50 ±1.80 | 42.00 ±2.00 | 50.17 ±2.84 | 40.61 ±6.80 | 300.00 | - |
| DO (mg $l^{-1}$) | 9.91 ±0.15 | 9.62 ±0.17 | 8.98 ±0.32 | 9.33 ±0.08 | 9.09 ±0.12 | 8.90 ±0.08 | 8.87 ±0.05 | 9.02 ±0.17 | 9.09 ±0.12 | 9.02 ±0.03 | 9.49 ±0.06 | 10.03 ±0.00 | 9.28 ±0.40 | 5.0-7.0 | >4.0 |
| $FCO_2$ (mg $l^{-1}$) | 2.01 ±0.11 | 2.20 ±0.09 | 2.20 ±0.19 | 2.73 ±0.01 | 1.91 ±0.25 | 2.02 ±0.13 | 2.16 ±0.13 | 2.54 ±0.11 | 2.31 ±0.00 | 2.09 ±0.22 | 2.18 ±0.14 | 2.09 ±0.22 | 2.20 ±0.23 | - | - |
| pH | 7.63 ±0.05 | 7.56 ±0.07 | 7.34 ±0.11 | 7.44 ±0.06 | 7.46 ±0.02 | 7.36 ±0.05 | 7.32 ±0.13 | 7.19 ±0 | 7.17 ±0.03 | 7.20 ±0.02 | 7.14 ±0.07 | 7.26 ±0.08 | 7.34 ±0.16 | 6.5-8.5 | 6.0-8.5 |
| PHO (mg $l^{-1}$) | 0.082 0.0007 | 0.081 ±0.0007 | 0.081 ±0.0005 | 0.077 ±0.000 | 0.080 ±0.001 | 0.082 ±0.0009 | 0.102 ±0.007 | 0.088 ±0.008 | 0.083 ±0.0004 | 0.081 ±0.0008 | 0.083 0.002 | 0.084 ±0.001 | 0.084 ±0.006 | 0.10 | 2.00 |
| NIT (mg $l^{-1}$) | 0.011 ±0.0002 | 0.012 ±0.0003 | 0.012 ±0.0001 | 0.012 ±0.0003 | 0.012 ±0.0005 | 0.018 ±0.0008 | 0.020 ±0.0014 | 0.018 ±0.0003 | 0.013 ±0.0006 | 0.012 ±0.0007 | 0.012 ±0.0007 | 0.012 ±0.0006 | 0.014 ±0.003 | 45.00 | 50.00 |
| TUR (NTU) | 0.17 ±0.29 | 1.00 ±0.00 | 2.17 ±0.58 | 1.67 ±0.58 | 6.00 ±0.50 | 157.50 ±4.82 | 185.33 ±4.48 | 57.00 ±3.00 | 8.83 ±0.29 | 3.83 ±0.58 | 2.00 ±0.50 | 0.67 ±0.29 | 35.51 ±65.65 | 5.00 | - |
| CON (µS $cm^{-1}$) | 118.00 ±1.32 | 122.17 ±3.79 | 144.67 ±5.75 | 150.70 ±1.56 | 135.12 ±10.19 | 103.10 ±5.43 | 82.07 ±11.38 | 87.00 ±11.44 | 99.50 ±14.91 | 108.88 ±8.31 | 116.17 ±6.45 | 122.33 ±1.76 | 115.81 ±21.22 | 750.00 | 3000.0 |

Acronyms: AT- Air Temperature, WT-Water Temperature, TR-Transparency, VL-Velocity, TA-Total Alkalinity, TH-Total Hardness, DO- Dissolved Oxygen, $FCO_2$-Free Carbon Dioxide, pH-pH, PHO-Phosphates, NIT-Nitrates, TUR-Turbidity, CON-Conductivity, WHO-World Health Organisation, FAO-Food and Agriculture Organisation.

Total alkalinity value was recorded within the WHO permissible limit (120 mg $l^{-1}$) in the Mandakini river (Table 1). Total hardness was maximum (45.96 mg $l^{-1}$) in winter and minimum (35.25 mg $l^{-1}$) in monsoon. Total hardness value was well below the WHO highest permissible limit (300 mg $l^{-1}$) for drinking water (Table 1). Dissolved oxygen was recorded highest (9.61 $mgl^{-1}$) during winter and lowest (8.97 $mgl^{-1}$) during monsoon. Dissolved oxygen value was noticed to be high to the WHO (5.0-7.0 mg $l^{-1}$) and FAO (>4.0 mg $l^{-1}$) permissible limit. Average free carbon dioxide fluctuated between 1.91±0.25 and 2.73±0.01 $mgl^{-1}$ (Table 1). Average pH of river water fluctuated between 7.14±0.07 to 7.63±0.05 which was also within permissible limit of WHO and FAO for drinking water (Table 1).Phosphate range (0.077±0.000 to 0.102±0.007 mg $l^{-1}$) was found well below the WHO (0.1 mg $l^{-1}$) and FAO (2 mg $l^{-1}$) highest permissible limit for drinking water. Nitrate (NIT) was observed maximum (0.0173 mg $l^{-1}$) during monsoon and minimum (0.0118 mg $l^{-1}$) during summer. Nitrate values (0.011±0.0002 to 0.020±0.0014 mg $l^{-1}$) were also noticed well below the WHO and FAO highest permissible limit for drinking water. Highest turbidity of Mandakini water during monsoon (185.33±4.48 NTU) exceeded the WHO permissible limit (5 NTU).

**Table 2.**Floral Diversity of Mandakiniriver (Uttarakhand).

| Genera | | | |
|---|---|---|---|
| Phytoplankton | *Cosmarium* | *Caloneis* | Cyanophyceae |
| Bacilariophyceae | *Closterium* | *Frustula* | *Phormidium* |
| *Nitzschia* | *Desmidium* | *Epithemia* | *Oscilatoria* |
| *Navicula* | *Stegeocolonium* | *Eunotia* | *Anabaena* |
| *Cymbella* | *Micrasterias* | *Diploneis* | *Merismapodia* |
| *Amphora* | Cyanophyceae | *Diatoma* | *Spirulina* |
| *Fragilaria* | *Phormidium* | *Meridion* | Macrophytes |
| *Diatoma* | *Oscilatoria* | *Gomphonema* | *Solenumnigrum* |
| *Pinnularia* | *Anabaena* | *Gyrosigma* | *Euqesitum* sp. |
| *Gomphonema* | *Spirulina* | *Encyonema* | *Polygonum* sp. |
| *Rhopalodia* | *Merismapodia* | *Fragilariforma* | *Polygonum amplexicaule* |
| *Tabilaria* | Periphyton | *Surirella* | *Persicaria* sp. |
| *Cocconeis* | Bacillariophyceae | *Actinella* | *Ageratum conyzoides* |
| *Synedra* | *Nitzschia* | *Rhoicosphenia* | *Spilanthes calva* |
| *Encyonema* | *Navicula* | *Gomphoneis* | *Gynura nepalensis* |
| *Fragilariforma* | *Cymbella* | *Reimeria* | *Parthenium hysterophorus* |
| *Achnanthidium* | *Amphora* | *Neidium* | *Gynura cusimbua* |
| *Surrirella* | *Synedra* | *Cyclotella* | *Gnaphalium* sp. |
| *Gyrosigma* | *Achnanthidium* | Chlorophyceae | *Chenopodium album* |
| *Cyclotella* | *Tabellaria* | *Closterium* | *Scopariadulcis* |
| *Caloneis* | *Cocconeis* | *Ulothrix* | *Cannabis sativa* |
| *Rhoicosphenia* | *Stauroneis* | *Stigeoclonium* | *Nepeta*sp. |
| *Denticulla* | *Hantzschia* | *Hydrodictyon* | *Ocimum basilicum* |
| Chlorophyceae | *Pinnularia* | *Chlorococcus* | *Galinosoga* sp. |
| *Ulothrix* | *Denticula* | *Spirogyra* | *Bidens bipinnata* |
| *Hydrodictyon* | *Peronia* | *Micrasterias* | |
| *Spirogyra* | *Rhopalodia* | *Desmidium* | |
| *Chlorococcus* | *Fragilaria* | *Cosmarium* | |

Seasonally conductivity was recorded highest (138.95 µS $cm^{-1}$) during summer and lowest (92.92 µS $cm^{-1}$) during monsoon season. Average conductivity (82.07±11.38 to 150.70±1.56 µS $cm^{-1}$) was also found within the WHO and FAO highest permissible limit for drinking water (Table 1).

*Principal Component Analysis (PCA)*

PC 1 explained 79.729 of variation in the parameters with eigen value of 10.3648. PC 2 explained 20.3648 of variation in the parameters with eigen value of 2.63523. PC1 mainly represents parameters like total alkalinity, water temperature, nitrate, water velocity, air temperature, phosphate, turbidity dissolved oxygen, and free carbon dioxide. PC2 mainly represents parameters like conductivity, total hardness and transparency. Site 1 ($S_1$) was most influenced by water velocity. Site 2 ($S_2$) was influenced by conductivity, total hardness, pH, phosphate and nitrate.

However, total alkalinity, water temperature, air temperature, turbidity and free carbon dioxide were prevalent at $S_3$ (Fig. 3).

**Table 3.** Faunal diversity of the Mandakini river (Uttarakhand).

| Genera | | | |
|---|---|---|---|
| Zooplankton | *Leptophlebia* | Coleoptera | *Schizothorax plagiostomus* |
| Protozoa | Diptera | *Psephenus* | *Schizo thoraichthys progastus* |
| *Tetrahymina* | *Pedicia* | *Helichus* | *Tor chilinoides* |
| *Loxodes* | *Chironomus* | *Laccophilus* | *Tor putitora* |
| Rotifera | *Dixa* | *Heterelmis* | *Crossocheilus latius* |
| *Notholca* | *Antocha* | *Promoresia* | *Barilius bendelisis* |
| *Asplanchna* | *Bibiocephala* | *Gyrinus* | *Bariliusbarna* |
| *Branchionus* | *Simulium* | Lepidoptera | *Barilius vagra* |
| *Dipleuchlanispropatula* | *Blepharicera* | *Paragyractis* | *Garra gotyla gotyla* |
| *Lepidella* | *Tabanus* | Plecoptera | *Garralamta* |
| Copepoda | *Hemerodormia* | *Isoperla* | Cobitidae |
| *Cyclops* | *Limnophora* | *Perlinella* | *Noemacheilus multifasciatus* |
| Macroinvertebrate | *Metriochemus* | *Paraperla* | *Noemacheilus denisonii* |
| Ephmeroptera | Trichoptera | Odonata | *Noemacheilus rupicola* |
| *Ephemerella.* | *Leptocella* | *Ophiogomphus* | *Noemacheilus montanus* |
| *Baetis* | *Glossosoma* | *Argia* | *Noemacheilus zonatus* |
| *Caenis* | *Hydroptila* | Nematoda | Family: Sisoridae |
| *Heptagenia* | *Hydropsyche* | Fish | *Pseud echeneis sulcatus* |
| *Rhithrogena* | *Philopotamus* | Cypriniforms | *Glyptothorax madraspatanum* |
| *Cloeon* | *Dicosmoecus* | Cyprinidae | *Glyptothorax pectinopterus* |
| *Centroptilum* | *Limnephilus* | *Schizothorax richardsonii* | |

*Biotic parameters*

Phytoplankton were represented by 35 genera belonging to three classes, Bacillariophyceae (21 genera), Chlorophyceae (9 genera) and Cyanophyceae (5 genera) and 18 families (Table 2).

The density of phytoplankton ranged from 31.86 to 498.50 cells $l^{-1}$ at $S_1$, 38.68 to 459.40 cells $l^{-1}$ at $S_2$ and 26.78 to 449.20 cells $l^{-1}$ at $S_3$.

The average density of phytoplankton of Mandakini river was calculated to be 249.13±132.12 cells $l^{-1}$, 248.42±123.91 cells $l^{-1}$ and 243.40±120.20 cells $l^{-1}$ at $S_1$, $S_2$ and $S_3$respectively during the study period (Table 4).

Periphyton were represented by 47 genera belonging to 19 families and three classes, Bacillariophyceae, Chlorophyceae and Cyanophyceae with 33, 9 and 5 genera respectively (Table 2).

The density of periphyton ranged from 73.50 to 3300.00 cells $cm^{-1}$ at $S_1$, 81.00 to 4998.00 cells $cm^{-1}$ at $S_2$ and 76.50 to 4277.30 cells $cm^{-1}$ at $S_3$. Average density was computed to be 1297.43±901.88cells $cm^{-1}$, 1692.10±1271.36 cells $cm^{-1}$ and 1435.11±1134.96 cells $cm^{-1}$ at $S_1$, $S_2$ and $S_3$, respectively during the study(Table 4). Macrophytes were sparely distributed only in some months and represented by 18 species belonging to 16 genera at all the three sampling sites (Table 2).Zooplankton commonly were represented by 8 genera belonging to three major groups Protozoa (2 genera), Rotifera (5 genera) and Copepoda (1genus) and 5 families (Table 3, Fig. 4).

Zooplankton were found in a very low quantity (2.55 to 8.09 ind. $l^{-1}$) in Mandakini river. Average density of zooplankton of study area was computed to be 3.68±1.30 ind. $l^{-1}$, 4.59±1.28ind. $l^{-1}$ and 5.68±2.34 ind. $l^{-1}$at $S_1$, $S_2$ and $S_3$ respectively during the study (Table 4).

**Table 4.** Biotic density of the Mandakini river at three sampling sites ($S_1$, $S_2$ and $S_3$).

| Sites | | Phytoplankton (cells $l^{-1}$) | Periphyton (cells $cm^{-2}$) | Zooplankton (ind. $l^{-1}$) | Macroinvertebrates (ind. $m^{-2}$) |
|---|---|---|---|---|---|
| $S_1$ | Range | 31.86 - 498.50 | 73.50-3300.00 | 2.55 - 5.10 | 11.10 - 759.90 |
| | Mean±SD | 249.13±132.12 | 1297.43±901.88 | 3.68±1.30 | 355.86±223.16 |
| $S_2$ | Range | 38.68 - 459.40 | 81.00 - 4998.00 | 3.41 to 6.78 | 13.32 - 1108.90 |
| | Mean±SD | 248.42±123.91 | 1692.10±1271.36 | 4.59±1.28 | 378.11±256.77 |
| $S_3$ | Range | 26.78 - 449.20 | 76.50 - 4277.30 | 3.41 to 8.09 | 8.00 - 731.10 |
| | Mean±SD | 243.40±120.20 | 1435.11±1134.96 | 5.68±2.34 | 318.51±227.79 |

Macro invertebrates were represented by 38 genera of classInsecta belonging to 7 orders encompassing Ephemeroptera (8 genera), Diptera (11 genera), Trichoptera (7 genera), Coleoptera (6 genera), Lepidoptera (1genus), Plecoptera (3 genera), Odonata (2 genera) and a Nematode genus (Table 3).

The average density of the macroinvertebrates ranged from 318.51±227.79 ind. $m^{-2}$ to 378.11±256.77 ind. $m^{-2}$ among all the three sampling sites(Table 4). Fish were represented by 19 species belonging to 9 genera and three families Cyprinidae (6 genera, 11 species), Cobitidae (1 genus, 5 species) and Sisoridae (2 genera, 3 species) (Table 3).

*Canonical Corresponding Analysis (CCA)*

CCA was useful to observe the effect of physico-chemical parameters on abundance of biotic components. Axis 1 explained 76.11% of variation in the biotic abundance with eigenvalue of 0.013535 and Axis 2 explained 23.89% of variation in the biotic abundance with eigenvalue of 0.0042481. Nitrate, phosphate, pH, total alkalinity, total hardness, conductivity and water temperature were of the primary importance and favoured the growth and abundance of phytoplankton/periphyton families (Naviculaceae, Cymbellaceae, Coscinodiscaceae, Ulotrichasceae, Desmidaceae, Zygnemataceae, Leptophlebiidae, Tipulidae, Elmidae) and macroinvertebrate families (Philopotamidae, Ephemerellidae, Hydrophsychidea). Water velocity was favourable for the growth and abundance of families like Chlorococcaceae, Oscillatoriaceae, Zygnemataceae, Nostocaceae, Epithemiaceae of periphyton and Baetidae, Hydrophsychidea, Heptageniidae, Leptoceridae, Simuliidae and Pyralidae of macroinvertebrates. Dissolved oxygen and transparency were positively correlated and favoured growth and abundance of some families of periphyton like, Zygnemataceae, Hydroptilidae, Blepharoceridae, Dixidae, Glossosomatidae and Leptoceridae. Air temperature, turbidity and free carbon dioxide were highly correlated and favoured the biotic families like Coscinodiscaceae, Eunotiaceae, Psephenidae, Caenidae, Asplanchidae and Brachionidae (Fig. 4).

## Discussion

*Physico-chemical Parameters*

Physico-chemical parameters can influence the river ecosystem function. Some of the parameters play a vital role determining the structure and function of river ecosystem. Temperature is one of the important physical parameters to influence the chemical and biological quality of aquatic ecosystem. The fluctuation of temperature usually depends on the season, geographic location, sampling time and content of effluents entering the stream (Dallas and Day, 2004). Highest temperature during the monsoon season followed by summer and winter season in the Mandakini river reflects the respective climatic conditions during the period. Suravi *et al.*, 2013 also observed the same trend in the Pungli river in Bangladesh.

Transparency of water usually varies with the combined effect of colour and turbidity and measures the light penetrating through the water body

(Ramachandran and Solanki, 2007). Highest transparency during winter season may be due to stable ecosystem as a result of settlement of SPM. It was also noticed in Chandrabhaga River, Maharashtra by Watkar and Barbate (2015). Water velocity is most important parameter and affects the river water quality. High velocity may result into increased turbidity and enhance corrosion rate in the water distribution system consequently declining water quality (Shamsaei *et al.*, 2013). Highest water velocity incorporating high silt content was noticed in monsoon resulting into poor or turbid water quality not fit for drinking in the Mandakini river. However, in rest of the season the water was fit for human consumption. Similar results were also observed in spring fed Kosi River at Almora by Selakoti and Rao (2015).

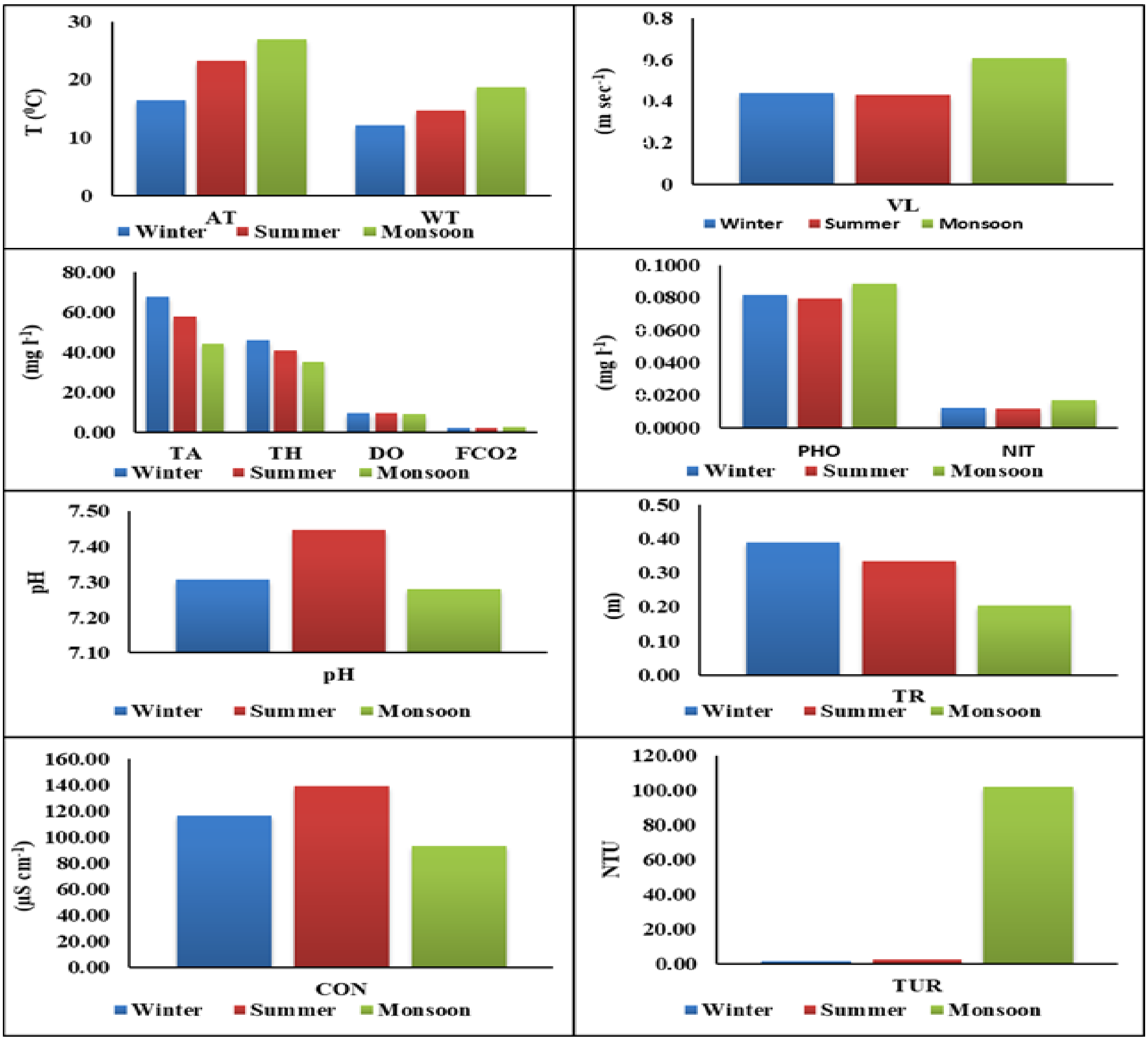


**Fig. 2.** Seasonal variations in physico-chemical parameters of Mandakini river.

Acronyms: AT-Air Temperature, WT-Water Temperature, TR-Transparency, VL-Velocity, TA-Total Alkalinity, TH-Total Hardness, DO-Dissolved Oxygen, $FCO_2$-Free Carbon Dioxide, pH-pH, PHO-Phosphates, NIT-Nitrates, TUR-Turbidity, CON-Conductivity.

Dissolved oxygen (DO) is also important parameter for survival of aquatic organism and good indicator of water quality. Dissolve oxygen was found maximum during winter and minimum during monsoon in the present study. Higher DO during winter may be due to clear water consequently good photosynthesis activity of aquatic flora. However, in monsoon high turbidity of water hinders the photosynthesis and water is also loaded by the particulate matter, chemicals and pollutants. Similar findings were also observed by other researchers (Khinchi *et al.*, 2011; Selakoti and Rao, 2015). Dissolved oxygen shows significant negative correlation with water temperature indicating decrease in solubility of gases when temperature increases. Inverse relationship between DO and free $CO_2$ is also evident from the present study. Maximum carbon dioxide was found during summer and monsoon due to increased rate of degradation while minimum during winter.

pH is also an important ecological parameter because most of the metabolic activities of biota depend upon pH. The acceptable range of drinking water pH is 6.5-8.5 (ABD, 1994) which is also suitable for aquatic life. The pH of Mandakini river was slightly alkaline throughout the year which also proves its suitability for human consumption as well as for biota. pH being function of $CO_2$ was found highest during summer season followed by winter and monsoon season. Similar finding were also reported in river Ganga at Allahabad by Raghuvanshi *et al.* (2014).

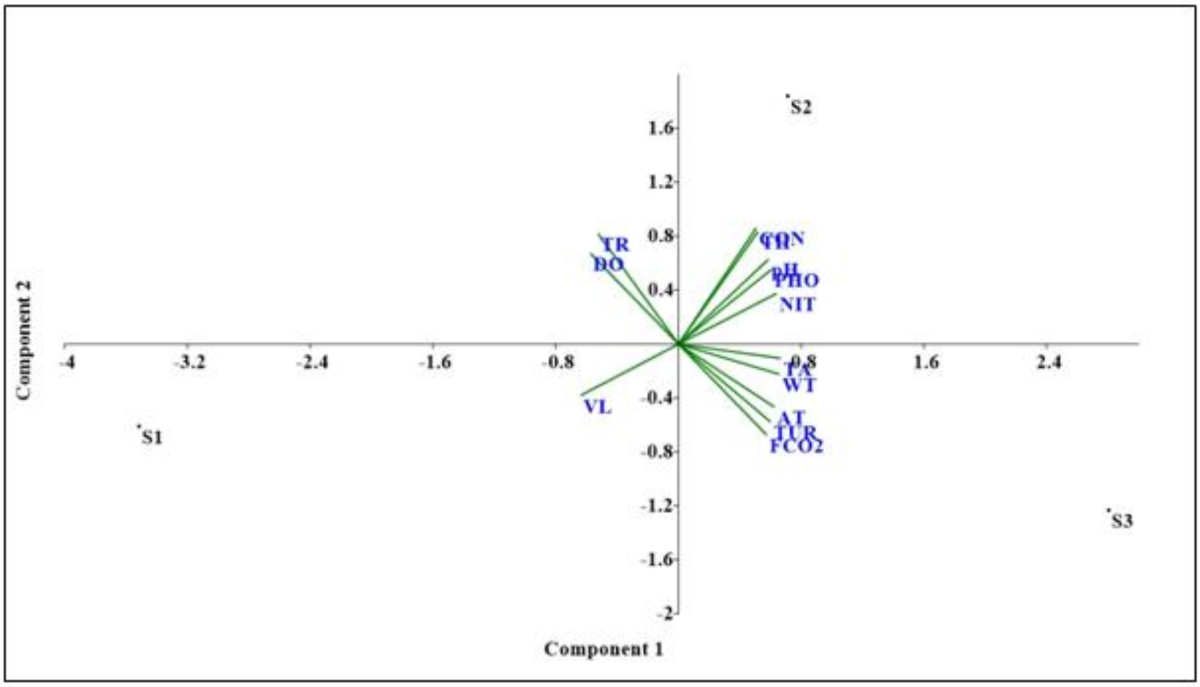


**Fig. 3.**Principal Component Analysis (PCA) showing physico-chemical parameters prevailing at different sampling sites in the Mandakini river.

Acronyms: $S_1$-Kund, $S_2$-Agustyamuni, $S_3$-Rudraprayag, AT-Air Temperature, WT-Water Temperature, TR-Transparency, VL-Velocity, TA-Total Alkalinity, TH-Total Hardness, DO-Dissolved Oxygen, $FCO_2$-Free Carbon Dioxide, pH-pH, PHO-Phosphates, NIT-Nitrates, TUR-Turbidity, CON-Conductivity.

The total alkalinity is contributed by hydroxide, carbonates and bi-carbonates compounds of Ca, Mg, Na and K. Seasonally, the values were highest during winter season and lowest during monsoon season which may be due to increased volume of water during monsoon. Temperature of water also had a highly significant negative correlation with total alkalinity which also proves the relation of being highest in winter. Similar finding was also observed by Gangwar *et al.*, 2012; Gupte and Shaikh, 2013; Selakoti and Rao, 2015. Total hardness, the important parameter of water quality is due to the presence of bicarbonate, sulphate, chloride, and nitrates of Ca and Mg (Kumar *etal.*,2010).

The total hardness of Mandakini water was found maximum during winter season and minimum during monsoon due to higher concentration of bicarbonates, carbonates and other salts in winter.

Phosphate is the most important nutrient for the growth of phytoplankton and periphyton. In the present study, phosphate was present in maximum quantity during monsoon season and minimum during summer season. High value of phosphate during monsoon is also attributed to high rainfall and runoff adding more nutrients to the water body. Nitrate is an indicator of level of micronutrients in aquatic ecosystem which favours growth of aquatic flora. Seasonally, it was highest during monsoon and lowest during summer in the Mandakini river. Nitrate was recorded highest in monsoon season due to catchment runoff and erosion of river bank subsequently adding more nitrate to the water. Similar pattern of nitrate fluctuation was also noticed by many researchers (Gohram, 1961; Rajashekhar, 2007; Pawar and Shembekar, 2012; Lianthuamluaia *et al.*, 2013).

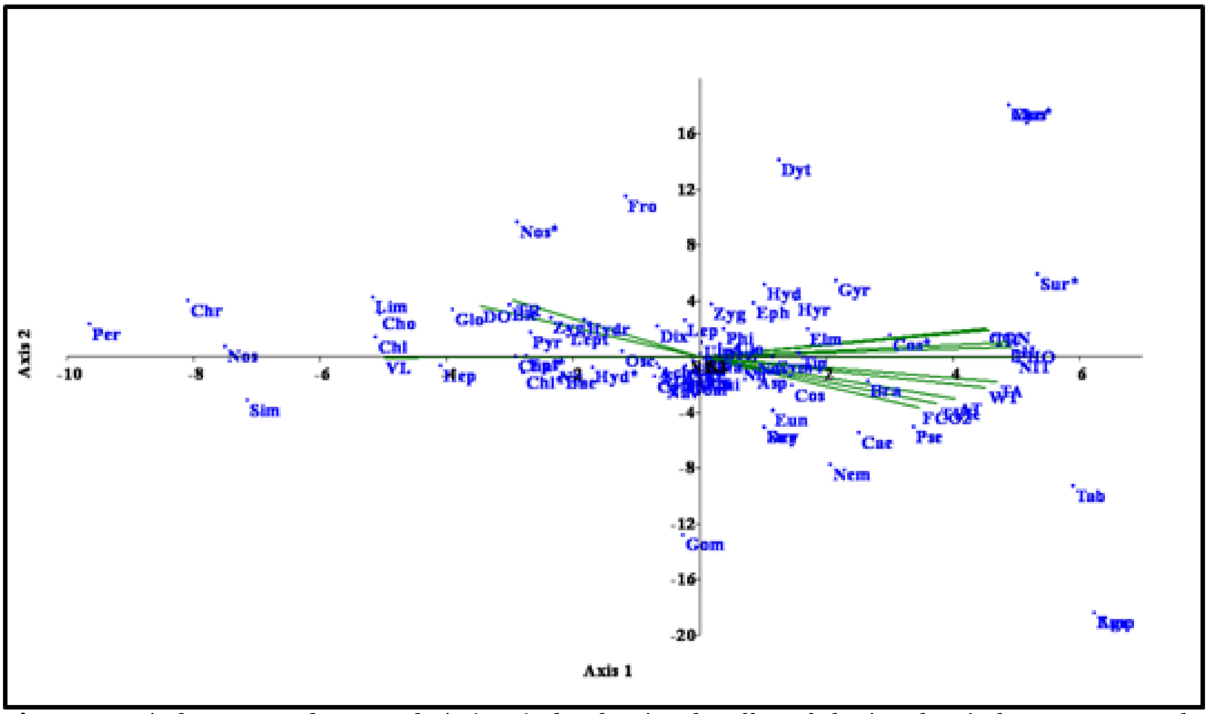


**Fig. 4.**Canonical Correspondence Analysis (CCA) plot showing the effect of physico-chemical parameters on the abundance of biotic communities in the Mandakini river of Uttarakhand.

Acronyms:Physico-chemical parameters: AT-Air Temperature, WT-Water Temperature, TR-Transparency, VL-Velocity, TA-Total Alkalinity, TH-Total Hardness, DO-Dissolved Oxygen, $FCO_2$-Free Carbon Dioxide, pH-pH, PHO-Phosphates, NIT-Nitrates, TUR-Turbidity, CON-Conductivity, Phytoplankton: Fra*-Fragilariaceae, Nav*-Naviculaceae, Cym*-Cymbellaceae, Ach*-Achnanthaceae, Gom*-Gomphonemaceae, Epi*- Epithemiaceae, Nit*-Nitzschiaceae, Sur*-Surirellaceae, Cos*-Coscinodiscaceae, Chl*-Chlorococcaceae, Hyd*-Hydrodictyaceae, Des*-Desmidiaceae, Zyg*-Zygnemataceae, Ulo*-Ulotrichasceae, Cha*-Chaetophoraceae, Osc*-Oscillatoriaceae, Nos*-Nostocaceae, Chr*-Chroococcaceae, Periphyton: Fra-Fragilariaceae, Nav-Naviculaceae, Cym-Cymbellaceae, Ach-Achnanthaceae, Gom-Gomphonemaceae, Epi*-Epithemiaceae, Eun-Eunotiaceae Nit-Nitzschiaceae, Sur-Surirellaceae, Cos-Coscinodiscaceae, Chl-Chlorococcaceae, Hyd-Hydrodictyaceae, Des-Desmidiaceae, Zyg-Zygnemataceae, Ulo-Ulotrichasceae, Cha-Chaetophoraceae, Osc-Oscillatoriaceae, Nos-Nostocaceae, Chr-Chroococcaceae, Macroinvertebrates: Eph- Ephemerellidae, Bae-Baetidae, Cae-Caenidae, Hep-Heptageniidae, Lep-Leptophlebiidae, Chi-Chironomidae, Sim-Simuliidae, Dix-Dixidae, Tab-Tabanidae, Tip-Tipulidae, Ble-Blepharoceridae, Emp-Empididae, Mus-Musidae, Glo-Glossosomatidae, Hyr-Hydrophsychidea, Hydr-Hydroptilidae, Lept-Leptoceridae, Phi-Philopotamidae, Lim-Limnephilidae, Pse-Psephenidae, Elm-Elmidae, Dyt-Dytiscidae, Dry-Dryopidae, Gyr-Gyrinidae, Cho-Chloroperlidae, Per-Perlidae, Pyr-Pyralidae, Gom-Gomphidae, Agr-Agrionidae, Nem-Nematoda, Zooplankton: Fro-Frontoniidae, Lox-Loxodidae, Bra-Brachionidae, Asp-Asplanchidae, Cyc-Cyclopidae.

Turbidity measures the amount of light scattered and absorbed by the materials suspended in river water (Jasmin Lena and Maneemegalai, 2015). In the present study, turbidity was found to be highest at $S_3$ during monsoon may be due to more influx of rainwater from surrounding area. Highest turbidity in monsoon season in the Mandakini river is due to high rainfall, and increasing runoff carrying more particles to the water body Shivashankar and Venkataramana (2015) also observed it in the Bhadra River of Karnataka. During monsoon season silt, clay and other suspended materials contribute to the high turbidity, while low value during summer and winter is the results of settlement of silt, clay and other suspended material. Conductivity is the ability of a substance to convey an electrical current. Conductivity increases in direct proportion to dissolved ion concentration (Boyd, 2000). High value of conductivity during summer season is evident due to more ion concentration in summer in the present study. Similar finding was observed in Varahanadhi River by Jasmin Lena and Maneemegalai (2015).

Mandakini river is an important drinking water sources for rural and urban population of Rudraprayag district (Uttarakhand). Physico-chemical parameters recorded from the Mandakini river do not exceed the limits prescribed by WHO (World Health Organization) and FAO (Food and Agriculture Organization) for drinking water. The physico-chemical parameters of the Mandakini river were of good quality for aquatic biota and human consumption except in monsoon season.

The importance of physico-chemical parameters of Mandakini river was analysed by Principal Component Analysis (PCA). A principal component provides information on the most meaningful parameters in the data as well as facilitates data reduction as reported by Helena *et al.* (2000) and Shrestha and Kazama (2007). PCA reduced thirteen physico-chemical parameters into nine most important parameters affecting biota and river water quality. Total alkalinity, water temperature, nitrate, water velocity, air temperature, phosphate, turbidity, dissolved oxygen and free carbon dioxide were noticed to be most important parameters playing their role in ecosystem function. Remaining physico-chemical parameters were less significant in the present study.

*Biotic parameters*

The collective life activities of flora and fauna such as growing, feeding, moving, excreting waste, etc. and their effects on physico-chemical conditions of their environment are reflected by ecosystem functioning (Naeem *et al.*, 1999). A rich floral (phytoplankton, periphyton and macrophytes) and faunal (zooplankton, macroinvertebrates and fish) diversity was found in the Mandakini river some months after a major flash flood. Aquatic diversity severely depressed after the extreme flash flood recovered after approximately 1 year was also observed by Mundahl and Hunt (2011).

The biota of Mandakini river was divided into functional groups based on their trophic status (place in food web like producers, consumers, predators and decomposers). The first trophic level contains primary producers such as phytoplankton, periphyton and macrophytes used solar energy to produce organic compounds (food) by photosynthesis. Primary productivity is dependent upon temperature, carbon dioxide and some essentials nutrients like nitrates and phosphates. Class Bacillariophyceae (Diatoms) was the dominant group in the Mandakini river and major food source for some aquatic fauna. Periphyton density of Mandakini river was observed maximum at $S_2$ during the two-years of study which can be attributed to the higher diversity of substrate (cobble, pebble, boulder gravel and sand) at $S_2$.

Consumers like zooplankton and macroinvertebrates constitute the secondary trophic level. Macroinvertebrates form functional feeding groups like scrapers/grazers, shredders, collectors-gatherers, filterers, and playing important role in nutrient cycling and trophic interaction. The dominant functional feeding groups were the scrapers/ grazers (*Glossosoma*) and Collectors- gatherer (*Baetis,* *Heptagenia and Chironomus*) due to the supply of abundant fine particles of organic matter and attached algae in Mandakini river of Uttarakhand. Macroinvertebrate density was observed maximum at $S_2$ in the Mandakini river may be due to less physical disturbance and suitable composition of substratum for macroinvertebrates. Zooplankton population an important part of aquatic food chain is sensitive to environment changes. Zooplankton density was very low at all the three sampling sites in Mandakini river due to high water velocity. De Ruyter Van Steveninck *et al.*(1992) also reported the importance of water velocity in composition and abundance of zooplankton in the lotic water ecosystems.

The third trophic level contains the secondary consumer (fish). Fishes of Mandakiniriver (Garhwal Himalaya) were classified according to their feeding habits such as herbivores, carnivores and omnivores (Badola, 1979). Some species *Tor chilinoides, Tor putitora, Barilius bendelesis, Bariliusvagra, Bariliusbarna, Pseudo echeneis sulcatus* are omnivorous and feed on algae, macroinvertebrates and zooplankton. *Schizothorax richardsonii, Schizothorax plagiostomus, Garralamta, Garra gotyla gotyla* and *Crossocheilus latius* are herbivores and feed on periphyton and phytoplankton. Carnivorous fishes in the Mandakini river like *Pseudo echeneis sulcatus, Glyptothorax madraspatanum* and *Glyptothorax pectinopterus* feed on mainly aquatic insect larvae and nymph were tertiary consumers.

Canonical Corresponding Analysis (CCA) reflects the effect of physico-chemical parameters on the abundance of biotic components in the Mandakini river. The length of line indicates the importance of variables and shows positive and negative correlations with axis (Abrants *et al.*, 2006 and Liu *et al.*, 2010). Nitrate, velocity, phosphate, pH, total alkalinity, total hardness, conductivity and water temperature were most important parameters and affect the abundance of biotic components. However, transparency, dissolved oxygen, free carbon dioxide and turbidity were of secondary importantance and effect the abundance of biotic components. No significant difference was found between physico-chemical parameters and abundance of biotic components among sites ($S_1$, $S_2$ and $S_3$) in the Mandakini river.

Flash floods destroy every trophic level of the river ecosystem of Himalaya. However, the rivers of Himalaya are flood adapted systems and the biodiversity lost due to floods recovers after few months consequently all the trophic levels of the river ecosystem reestablish and a healthy ecosystem starts functioning again.

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