International Journal of
Life Sciences
International Peer Reviewed Open Access Refereed Journal

Int. J. of Life Sciences, 2018; 6 (2):507-516
ISSN:2320-7817(p) | 2320-964X(o)
UGC Approved Journal No 48951

Original Article | Open Access

Periphyton assemblages and diversity in a major flash flood exposed Himalayan river Mandakini of Uttarakhand, India

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ABSTRACT

The rivers of Garhwal Himalaya experience frequent flash floods every year. However, the major flood of June 16-17, 2013 in the Mandakini river was devastating resulting into huge loss of flora including periphyton communities and fauna in addition to human and property loss. Periphyton communities contribute as important primary producers in an aquatic ecosystem. The present study is aimed at to know how the river ecosystem recovers itself and reestablishes the communities. Lack of information on periphyton diversity and ecosystem resilience of Mandakini river after experiencing this major ecodisaster of Kedarnath led to the present study. Glacier fed Perennial river Mandakini originates from Chaurabari glacier above the Kedarnath peaks (6940m. a.s.l.). Monthly samples for physico-chemical parameters and periphyton were collected from three sampling sites, Kund, Agustyamuni and Rudraprayag located at different altitudes on the Mandakini river for the present study. Periphyton belonging to 3 classes, 7 orders, 19 families and 47 genera were recorded from the Mandakini river. The most abundant class Bacillariophyceae (diatoms) (70%) was followed by Cyanophyceae (blue green algae) (19%) and Chlorophyceae (green algae) (11%). The periphyton started increasing after flash floods and attained highest species diversity (H'=3.462±0.240) in winter season, moderate in summer and lowest (H'= 2.482±0.296) in monsoon season. The periphyton communities have short life cycles, reestablished soon after the flood event in monsoon, and achieved high density and diversity in winter due to most favourable environmental conditions. Physico-chemical factors like nitrate, phosphate, pH, velocity, total alkalinity, total hardness, and water temperature were found to be most important factors influencing periphyton density and diversity. However, turbidity, transparency, free CO_2, and dissolved oxygen were of secondary importance in regulating periphyton diversity.

Keywords: Abundance, density, diversity index, CCA, periphyton

Manuscript details:

Received : 31.12.2017
Accepted : 03.03.2018
Published : 26.04.2018

Editor: Dr. Arvind Chavhan

Cite this article as:
Goswami Gunjan and Singh Deepak (2018) Periphyton assemblages and diversity in a major flash flood exposed Himalayan river Mandakini of Uttarakhand, India, *Int. J. of. Life Sciences*, Volume 6(2): 507-516.

Available online on
http://www.ijlsci.in

ISSN: 2320-964X (Online)
ISSN: 2320-7817 (Print)

INTRODUCTION

The periphyton community is the slimy covering that adheres to rocks and other stable substrates in the fresh water ecosystems. They are the dominant primary producers in aquatic ecosystems and serve as an important food source for invertebrates and fishes. Periphyton receive their nutrition from dissolved and suspended matter (Organic matter) in the water body and have capability to purify water by absorption of metals, nutrients and provide important component of the food resource to the food web (Gray 2013). Periphyton have been widely used as a tool for water quality assessment because they have rapid growth, reproduction and short life cycles. Therefore, many researchers used algae as ecological indicator (Siva and John 2002; Bojsen and Jacobsen 2003; Cascallar *et al.* 2003; Azim *et al.* 2006).

Periphyton exhibit high biodiversity within the limited space they inhabit, and their fast growth rate and short life cycle allow them to quickly respond to environmenttal alternations (Pfeiffer Žuna *et al*. 2015). In running water (rivers), the most critical impact on periphyton diversity is flood. Flood is important organizing factor that affects the growth of periphyton by removing or disturbing of communities, and thus creating an opportunity for new individuals to become dominant and some individual to lose. Therefore, physical instability such as substrate movement and rapid changes in hydraulic forces can remove organisms at rates faster than the rates of recruitment (Stanley 2010). According to Agostinho *et al*. 2004 changes in the hydrological regime of river affect the physical and biological environments, constituting one of the serious threats to the biotic integrity of the ecosystem. Environmental changes influence the structure and distribution of the periphyton communities living in the freshwater ecosystem (Gottlieb *et al.* 2006; Luttention and Baisden 2006; Davidson *et al.* 2012; Mihaljevic´ and Žuna Pfeiffer 2012). The purpose of the present study was to observe the reestablishment of the periphyton communities and recovery of Mandakini river ecosystem destroyed by major flash flood during 16-17 June 2013, which resulted into huge loss of flora and fauna of this river ecosystem including human life and property.

METHODOLOGY

The Mandakini basin lies between latitudes $30^0 17'$-$30^0 49'$ N and longitudes $78^0 49'$-$79^0 32'$ E. River Mandakini is a perennial glacier-fed tributary of the river Alaknanda and originates from the terminal moraines of Chaurabari glacier, above the Kedarnath peaks (6940m). One of the snouts is the source of the Mandakini river at 3,865m (12,680ft). The other snout, at 3,835m (12,582ft) drains into the Chaurabari lake. Mandakini river meets with Alaknanda river at Rudraprayag (620m a.s.l.) after covering its course of 72 km. After the preliminary observation of Mandakini River, three sampling sites, S_1, S_2 and S_3 were selected at Kund (998m a.s.l.), Agustyamuni (760m a.s.l.), and Rudraprayag (620 m a.s.l.), respectively (Figure 1).

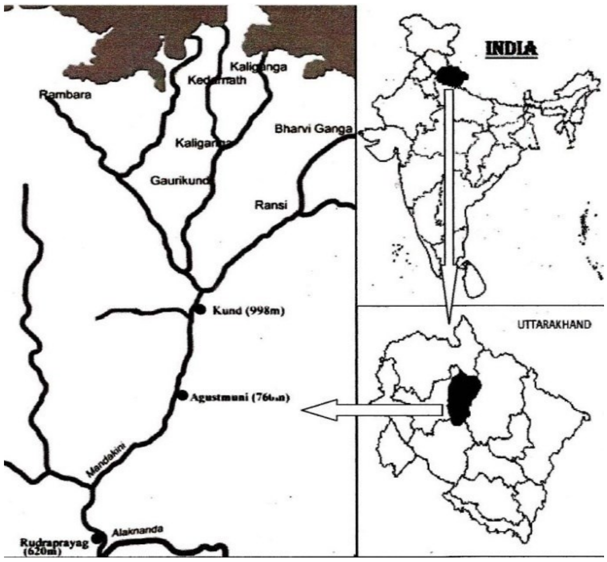

Fig. 1: Location map of the study area.

Sampling for periphyton and physico-chemical parameters of Mandakini river was done every month for two years from January 2014 to December 2015. Air temperature, water temperature, water velocity, transparency, dissolved oxygen and free carbon dioxide were recorded on the spot while other parameters were analyzed at the laboratory. Temperature was measured by Centigrade thermometer. pH meter (Model-Systronics µ pH system 361) was used to measure water pH. Conductivity of water was measured by Conductivity meter (Model APX185). Turbidity was measured by Turbidity meter (Model-5D1M); total hardness was measured by EDTA titration; total alkalinity was measured by Phenolphthalein and Methyl orange titration; dissolved oxygen was measured by Winkler's method; free CO_2 was measured by Sodium hydroxide and Phenolphthalein indicator; phosphate was measured by Spectrophotometer, Molybdenum-blue method and nitrate was measured by Spectrophotometer, Phenol-disulphonic acid method. The physico-chemical parameters of the study area were analysed by standard methods described by Welch

(1952); Golterman *et al*. (1969); Wetzel and Likens (1991); APHA (2005). The periphyton of the river Mandakini were collected by time scraping method following Ward (1974) with the help of sharp knife for each replicate sample. A total of five quadrats were scraped from each sampling site. The bottom of the substratum consisted of cobbles, pebbles, gravels and sand. The samples were collected by scraping 2-3 square centimetre surface area of the stones that were submerged in the running water. Great care was taken to select cobbles that was similar with respect to size, depth and exposure to current and sunlight. These samples preserved in 4% formalin were brought to the laboratory. The volume of the sample was adjusted to 50 ml by adding or removing the preservative solution. The sample was mixed thoroughly and removed 1 ml aliquot with a pipette and transferred to Sedgwick Rafter counting cell. The species were identified with the help of light microscope. 10 replicates of 1 ml were taken and 10 random fields were counted for each replicate. The calculated values were converted to cells/cm^2. Identification of species was done with the help of standard keys (Weitzel 1979; Needham and Needham 1980; Ward and Whipple 1992 and APHA 2005), *etc*. The periphyton classification adopted by Ward and Whipple (1992) was followed in the present study.

Statistical Analysis of data

The statistical analysis of Data was done using data analysis tool pack available in MS Excel and statistical software PAST version 2.10.

Shannon-Wiener species diversity index (H'):

The species diversity index was calculated using the Shannon-Wiener diversity index (Shannon and Wiener 1964) as:

$$H' = -\sum_{i=1}^{s} p_i l_n p_i$$

Where pi, is the proportion of individuals found in the *i*th species. It is estimated as (ni/N), N is total number of individuals in S species.

Species richness index (I_{mg}):

Species richness was computed following (Marglef 1968; Odum 1971) as:

$$I_{mg} = \frac{S-1}{\log_e N} \text{ Or } DMg = \frac{S-1}{I_n N}$$

Where, S = number of species, l_n = $\log_e$; natural Naperian logarithm and N = Total number of individuals.

Concentration of Dominance (C):

Concentration of dominance was computed following (Simpson 1949) as:

$$C = \sum_{i=1}^{s} (p_i)^2$$

RESULTS AND DISCUSSION

Physico-chemical Parameters

Flash floods in the Himalayan rivers caused due to high rainfall in a short period during monsoon leads to high velocity and turbidity of water and removes the substratum altering the river environment. The abundance and diversity of periphyton is largely related to physico-chemical factors. Many factors controlling periphyton community growth include temperature, light penetration, water velocity, nitrate, phosphate, dissolved oxygen, nature of substrate, disturbance, nutrients and invertebrate grazing. The variations in different physico-chemical parameters among all the three sampling sites in the Mandakini river were analysed by one-way ANOVA. No significant variation was recorded in physico-chemical parameters among all the three sampling sites on the Mandakini river (Table 1). Air temperature and water temperature ranged from 10^0C to 31^0C and 8^0C to 22^0C respectively at all the three sampling sites. Water temperature is important parameter and directly related to the growth and distribution of periphyton, which was also reported by Barman *et al*. (2015). Water velocity ranged from 0.20 to 0.89 m sec^{-1} at all three sites with a significant variation (F=13.31, p=0.004) among seasons. High velocity of water negatively affected some of the families of periphyton. Transparency ranged from 0.07 to 0.43 m at all sampling sites. Low water temperature and high light penetration (transparency) act as a driving factor favouring the development of periphyton. The importance of any one factor to algal growth depends upon whether some other factor is in even shorter supply, and these environmental conditions vary by location and season (Allan and Castillo 2007). Total alkalinity ranged from 28.00 to 90.00 mg l^{-1} and total hardness from 26.00 to 56.00 mg l^{-1} in the Mandakini river. These two parameters affected the growth and abundance of periphyton communities. Dissolved oxygen and free carbon dioxide ranged from 8.11 mg l^{-1} to 11.75 mg l^{-1} and 1.54 mg l^{-1} to 3.08 mg l^{-1} respectively at all the sites. No significant variation was noticed among various seasons in the amount of dissolved oxygen (F=2.16, p=0.12) and free carbon dioxide (F=0.82, p=0.46) in the Mandakini river during the study period. Present study shows a strong positive correlation between dissolve oxygen and periphyton diversity in the Mandakini river. Increased dissolved oxygen favoured periphyton diversity in the Mandakini river. pH range (6.80 to 7.79) of the river water is conducive. Phosphate and nitrates ranged from 0.075 mg l^{-1} to 0.111 mg l^{-1} and 0.010 to 0.028 mg l^{-1} respectively in the Mandakini river. These nutrients are important for the growth and metabolism of periphyton. Similar results were obtained by Varadharajan and Soundarapandian (2014).

Turbidity ranged from 0.00 to 196 NTU and conductivity fluctuated between 75.00 to 158.20 μScm^{-1} in the Mandakini river of Uttarakhand. High precipitation in monsoon along with increased runoff leads to the high turbidity of river bodies. Increased water turbidity adversely affects periphyton growth as low light penetration decreases rate of photosynthesis. Significant variations were recorded in the air temperature, water temperature, velocity, transparency, total alkalinity, pH, phosphates, nitrates, turbidity and conductivity among various seasons in the Mandakini river in the present study (Table 1). The variations in the abundance and diversity of periphyton in different seasons may be attributed to the variations in these physico-chemical factors.

Periphyton Assemblages and Diversity:

Periphyton belonging to 3 classes, 7 orders, 19 families and 47 genera were found to occur in the Mandakini river of Uttarakhand during the study period (2014-2015). The periphyton community was represented by three classes Bacillariophyceae with 2 orders, 10 families and 33 genera, Chlorophyceae with 3 orders, 6 families and 9 genera, and Cyanophyceae with 2 orders, 3 families and 5 genera. Abundant genera were *Cymbella*, *Synedra* and *Navicula*. Common genera were *Navicula*, *Amphora*, *Nitzschia*, *Fragilaria*, *Diatoma*, *Cocconeis*, *Achnanthidium*, *Gomphonema*, *Ulothrix*, *Stigeoclonium* and *Oscilatoria* (Table 2). These 47 periphyton taxa play important role in primary production and nutrient cycling in the Mandakini river. Oterler (2016) also reported similar findings in Tundzha river. No significant difference (F=0.198, p=0.82) was found in the density of periphyton among all the three sampling sites in the Mandakini river during the study period. Kruskal-Wallis test applied for individual genus among all the three sampling sites also retained the null hypothesis [Asymptotic significance (2 tailed test) =0.368 p>0.05]. Average density of Bacillariophyceae was recorded to be maximum (2678.88±836.33 cells cm^{-2}) in January and minimum (89.00±24.75 cells cm^{-2}) in July. Average density of Cyanophyceae and Chlorophyceae were recorded to be highest (446.75±92.28 cells cm^{-2}, 249.25±94.40 cells cm^{-2}) in February and lowest (3.75±2.47 cells cm^{-2}, 16.25±17.32 cells cm^{-2}) in monsoon months (Table 3).

Table 1: Physico-chemical parameters of Mandakini river at all sites with one-way ANOVA to assess the variations among sites and seasons.

Factors	Study sites			Sites		Seasons	
	S_1	S_2	S_3	F value	p value	F value	p value
AT (⁰C)	10.00-28.00	11.00-29.00	13.00-31.00	1.46	0.24	65.55	3.85E-08
WT (⁰C)	8.00-18.00	9.00-20.00	11.00-22.00	5.31	0.007	30.4	5.28E-06
VL (m sec^{-1})	0.23-0.80	0.29-0.88	0.20-0.89	0.60	0.55	13.31	0.004
TR (m)	0.10-0.42	0.08-0.43	0.07-0.40	0.049	0.95	34.98	2.25E-06
TA (mg l^{-1})	28.00-80.00	30.00-85.00	32.00-90.00	0.47	0.62	10.12	0.002
TH (mg l^{-1})	26.00-50.00	30.00-54.00	27.00-56.00	0.75	0.47	16.77	1.50E-04
DO (mg l^{-1})	8.50-11.35	8.11-11.55	8.11-11.75	0.025	0.97	2.61	0.12
FCO_2 (mg l^{-1})	1.64-2.86	1.54-3.03	1.54-3.08	1.62	0.20	0.82	0.46
pH	6.80-7.67	7.02-7.79	6.83-7.71	0.50	0.61	5.12	0.02
PHO (mg l^{-1})	0.075-0.106	0.075-0.096	0.076-0.111	0.79	0.46	7.18	0.006
NIT (mg l^{-1})	0.010-0.027	0.010-0.026	0.011-0.028	0.05	0.95	5.17	0.02
TUR (NTU)	0.00-189.00	0.00-186.00	0.00-196.00	0.006	0.99	2201.79	3.03E-19
CON (μS cm^{-1})	78.00-158.00	86.00-158.20	75.00-145.00	0.54	0.59	90.92	4.12E-09

Where, AT, Air Temperature; WT, Water Temperature; VL, Velocity; TR, Transparency; TA, Total Alkalinity; TH, Total Hardness; DO, Dissolved Oxygen; FCO_2, Free Carbon Dioxide; pH, pH; PHO, Phosphate; NIT, Nitrate; TUR- Turbidity; CON, Conductivity.

Table 2: Periphyton diversity of the Mandakini river at all the three sampling sites (S_1, S_2 and S_3).

Genera	S_1	S_2	S_3		S_1	S_2	S_3
Bacillariophyceae				*Encyonema*	+	+	+
Nitzschia	++	++	++	*Flagilariforma*	+	+	+
Navicula	++	++	++	*Surirella*	+	+	+
Cymbella	+++	+++	+++	*Actinella*	+	+	+
Amphora	++	++	++	*Rhoicosphenia*	+	++	++
Synedra	+++	+++	+++	*Gomphoneis*	+	+	+
Achnanthidium	++	++	++	*Reimeria*	+	+	-
Tabellaria	+	+	+	*Neidium*	+	+	+
Cocconeis	++	++	++	*Cyclotella*	+	+	+
Stauroneis	+	+	+	**Chlorophyceae**			
Hantzschia	+	+	+	*Closterium*	+	+	+
Pinnularia	+	+	+	*Ulothrix*	++	++	++
Denticula	+	+	+	*Stigeoclonium*	++	++	++
Peronia	+	+	+	*Hydrodictyon*	+	+	+
Rhopalodia	+	+	+	*Chlorococcus*	+	+	+
Fragilaria	++	++	+	*Spirogyra*	+	++	+
Caloneis	+	+	+	*Micrasterias*	-	+	-
Frustula	+	+	+	*Desmidium*	+	+	+
Epithemia	+	+	+	*Cosmarium*	+	+	+
Eunotia	+	+	+	**Cyanophyceae**			
Diploneis	+	-	+	*Phormidium*	+++	+++	+++
Diatoma	++	++	++	*Oscilatoria*	++	++	++
Meridion	+	+	+	*Anabaena*	+	+	+
Gomphonema	++	++	++	*Merismapodia*	+	+	-
Gyrosigma	+	+	+	*Sprilium*	-	-	+

S_1 = Kund; S_2 = Agustyamuni; S_3 = Rudraprayag; - = Absent; + = Present; ++ = Common; +++ = Abundant

Table 3: Average monthly variations in the density (cells cm^{-2}) of periphyton dwelling in the Mandakini river during January 2014 to December 2015.

Months	BAC	CHL	CYA	Total
January	2678.88±836.33	187.75 ±105.01	374.25 ±261.28	**3240.88**
February	1600.27±306.98	249.25 ±94.40	446.75 ±92.28	**2296.27**
March	1120.02±188.11	111.75 ±33.59	425.75 ±22.27	**1657.52**
April	813.30 ±85.94	217.75 ±119.85	373.00 ±37.48	**1404.05**
May	667.77 ±111.35	123.33 ±64.82	289.25 ±64.70	**1080.35**
June	263.71 ±58.98	16.25 ±17.32	99.25 ±3.89	**379.21**
July	89.00 ±24.75	-	3.75 ±2.47	**92.75**
August	239.50 ±94.75	-	32.75 ±7.42	**272.25**
September	534.25 ±5.30	46.25 ±51.27	327.62 ±74.08	**908.12**
October	1116.82±152.08	67.50 ±91.92	356.00 ±52.33	**1540.32**
November	1942.33±284.49	139.25 ±90.86	355.50 ±45.25	**2437.08**
December	2367.57±819.63	191.75 ±114.20	424.25 ±24.40	**2983.57**
Mean ± SD	**1119.45±858.46**	**112.57 ±87.15**	**292.34 ±156.53**	**1524.36±1046.3**

Where, BAC, Bacillariophyceae, CHL, Chlorophyceae, CYA, Cyanophyceae, -, Absent

Table 4: Variations in abundance of periphyton at three sampling sites (S_1, S_2 and S_3) in the Mandakini river of Uttarakhand.

Class/Order/ Family	**S_1**	**S_2**	**S_3**	**Mean±SD**
Bacillariophyceae				
Pennales				
Fragilariaceae	15926.15	19006.05	18133.95	**17688.72 ±1587.49**
Naviculaceae	4478.75	6951.25	6628.25	**6019.42 ±1344.00**
Cymbellaceae	13795.25	23427.15	21885.75	**19702.72 ±5173.74**
Achnanthaceae	5887.1	6515	7048.5	**6483.53 ±581.34**
Gomphonemaceae	2801.25	2878.95	3384.75	**3021.65 ±316.84**
Epithemiaceae	394.25	445	497.5	**445.58 ±51.63**
Eunotiaceae	255	305	500	**353.33±129.45**
Nitzschiaceae	3257.25	2273.75	2309.75	**2613.58±557.72**
Surirellaceae	30	30	60	**40.00±17.32**
Centrales				
Coscinodiscaceae	57.5	90	112.5	**86.67±27.65**
Total	**46882.5**	**61922.15**	**60560.95**	**56455.20±8318.09**
Chlorophyceae				
Chlorococcales				
Chlorococcaceae	247.5	125	67.5	**146.67±91.94**
Hydrodictyaceae	35	82.5	35	**50.83±27.42**
Zygnematales				
Desmidaceae	242.5	310	275	**275.83±33.76**
Zygnemataceae	2127.5	3690.5	1867.5	**2561.83±986.06**
Ulotricales				
Chaetophoraceae	1312.5	1686	1546	**1514.83±188.69**
Ulotrichasceae	3279.25	5208.75	3974.75	**4154.25±977.19**
Total	**7244.25**	**11102.75**	**7765.75**	**8704.25±2093.46**
Cyanophyceae				
Nostocales				
Oscillatoriaceae	16163	15781.15	13182	**15042.05±1622.13**
Nostocaceae	100	30	15	**48.33±45.37**
Chroococcales				
Chroococcaceae	37.5	15	-	**17.50±18.87**
Total	**16300.5**	**15826.15**	**13197**	**15107.88±1671.78**
Grand total	**70427.25**	**88851.05**	**81523.7**	**80267.33±9275.93**

Overall periphyton density showed increasing trend from monsoon onwards and being highest in winter (3240.88 cells cm^{-2}) indicating reestablishment of communities, medium in summer and lowest (92.75 cells cm^{-2}) in monsoon due to heavy rain and flash floods. Bacillariophyceae contributed maximum (1119.45±858.46 cells cm^{-2}) followed by Cyanophyceae (292.34±156.53 cells cm^{-2}) and Chlorophyceae (112.57±87.15 cells cm^{-2}) towards periphyton density. The high density of periphyton in winter season may be due to low water temperature, high transparency, low water velocity, stable substrate and other favourable factors. Other researchers (Sharma *et al.* 2008; Nautiyal *et al.* 2013; Pfeiffer Žuna *et al.* 2015 and Kumar 2015) have also observed similar findings. Cyanophyceae and Chlorophyceae highest (175.52±68.34 cells m^{-2} and 383.69±70.19 cells cm^{-2}) in summer season and lowest (15.63±21.81 cells $cm^{-2}$and 115.84±146.73 cells cm^{-2}) in monsoon season may be due to increased water temperature and light intensity which relate to its excessive growth and reproduction. Many other researchers (Palmer 1969; Kant and Kachroo 1980; Vass and Zutshi 1979; Van der Grinten *et al.* 2004; Piska and Krishna 2009; Kolayli and Sahin 2009 and Mieczan

2009) have also observed similar findings. Light has been shown to be of major importance for primary productivity (Harris 1980). However, Periphyton (Algae) adjust their pigmentation, cell size and metabolic activity to the prevailing environmental factors (Richardson *et al*. 1983; Falkowski and Laroche 1991).

The abundance of periphyton during the study period was recorded highest (88851.05) at S_2, moderate (81523.7) at S_3 and lowest (70427.25) at S_1 (Table 4) which may be attributed to the higher diversity of substrate (boulder, cobble, pebble, gravel and sand) at S_2 and less heterogeneous substrate at S_1 and S_3 in the present study. Other researchers (Howkins 1984 and Angradi 1996) also reported that the physical complexes in substrate types (boulder, cobbles, pebbles, gravel and sand) generally support more diversity than simple substratum such as sand and wood. Family Cymbellaceae was most abundant (19702.72±5173.74) followed by Fragilariaceae (17688.72±1587.49) and Oscillatoriaceae (15042.05±1622.13). Dominance of families Cymbellaceae and Fragilariaceae among diatoms may be attributed to good concentration of SiO_2 in Himalayan streams enabling them to withstand altering environment conditions in rainy season. Bacillariophyceae (diatoms) contributed maximum (70%) followed by Cyanophyceae (blue green algae) (19%) and Chlorophyceae (green algae) (11%) toward the periphyton diversity (Figure 2).

Some other researchers (Moore 1979; Stevenson 1996; Albay and Aykulu 2002; Acs *et al*. 2004; Rashid and Pandit 2005; Muylaert *et al*. 2009; Moonsyn *et al*. 2009; Chettri and Thapa 2016 and Oterler 2016) also observed dominance of diatoms (Bacillariophyceae) among periphyton. The diatoms are considered as fast and efficient colonizers. Most species have specialized fixation structures to attach to the substratum (Biggs 1996). Periphyton may accumulate rapidly in some gravel bed stream where the invertebrate community has not yet recovered from a catastrophic flood event (Sagar, 1986). The diatoms resist and quickly recover disturbance like flood, drought and unstable substratum. However, no significant difference ($F = -1.932$, $p>0.05$) was found in the abundance of periphyton among all the three sampling sites during the study period in the Mandakini river of Uttarakhand.
The average value of Shannon-Wiener diversity index (H') was computed to be maximum (3.462±0.240) in January (winter month) and minimum (2.482±0.296) in July (monsoon month) (Table 5). Shannon-Wiener diversity index (H') and species diversity index (D) were recorded highest in January (winter month) and lowest in July (monsoon). Similar trend was found for species diversity index (D) being highest (3.499±0.540) in winter month and lowest (1.360±0.294) in monsoon. Highest diversity in winter season may be attributed to the suitable environmental conditions like gentle water flow, stable substrate and high transparency. Low diversity of periphyton during monsoon was due to frequent physical disturbances (flood, high velocity, turbidity and substratum movement) in this Himalayan river ecosystem. Excessive flow of water (flash flood) during monsoon in Mandakini river results into unstable substrate thus affecting periphyton density and diversity.

Table 5: Monthly variations in the Shannon-Wiener diversity (H'), Concentration of dominance and Species diversity index (D) calculated for periphyton of Mandakini river

January	H'	C	D
February	**3.462±0.240**	**0.129±0.034**	3.292±0.037
March	3.445±0.007	0.137±0.001	**3.499±0.540**
April	3.247±0.130	0.163±0.030	2.930±0.368
May	3.190±0.090	0.174±0.009	2.887±0.466
June	3.104±0.056	0.172±0.011	2.594±0.206
July	3.015±0.047	0.170±0.004	2.126±0.223
August	**2.482±0.296**	**0.218±0.037**	**1.360±0.294**
September	2.847±0.260	0.160±0.024	1.376±0.163
October	3.042±0.483	0.182±0.063	2.600±0.354
November	3.194±0.580	0.165±0.080	2.699±0.502
December	3.391±0.288	0.129±0.037	2.697±0.122
January	3.355±0.382	0.144±0.039	2.877±0.538

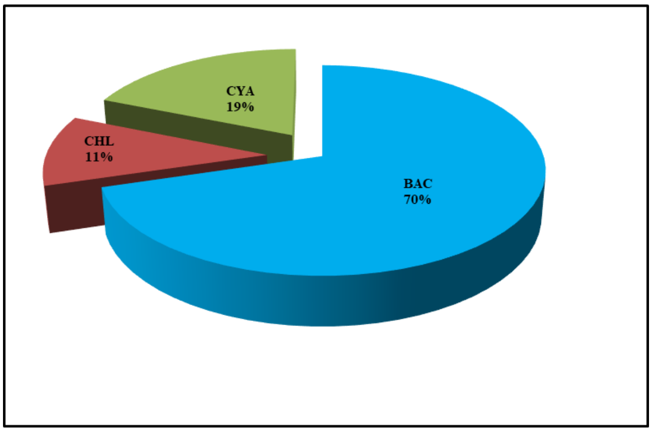

Fig. 2: Percentage composition of periphyton in Mandakini river during the study period.

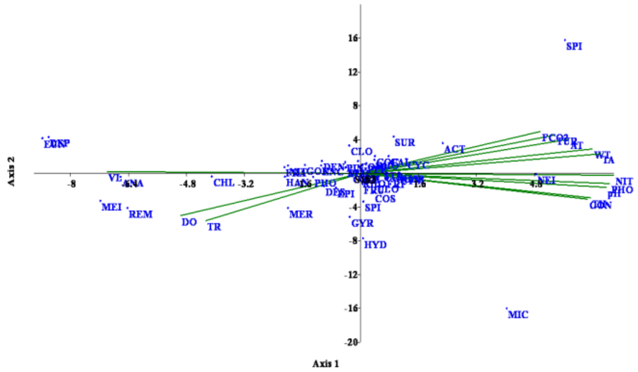

Fig. 3: Canonical Correspondence Analysis (CCA) showing effect of physico-chemical variables on the density and diversity of periphyton in the Mandakini river of Central Himalaya.

However, the periphyton are efficient colonizers having short life cycle hence they are able to recover soon during favourable environment conditions of the water body. The suitable substrate (big boulder, cobble and pebbles) in the Mandakini river bears a high diversity in winter. Other researcher (Sharma et al. 2008) has also reported similar findings of being highest diversity in winter. The value of concentration of dominance (C) was recorded highest (0.218±0.037) in July and lowest (0.129±0.034) in January being reversed to the Shannon-wiener diversity index and species diversity index supporting the diversity results. Increasing diversity index and decreasing concentration of dominance is associated with increasing stability (McNaughton 1967). Canonical correspondence analysis (CCA) was applied to examine the effect of physico-chemical parameters on periphyton abundance during the two years (2014-2015) study. Axis 1 explained 76.1% of variation in the periphyton abundance with eigen value of 0.017685 and Axis 2 explained 23.9% of variation in the periphyton abundance with eigen value of 0.005553. Nitrate, phosphate, pH, total alkalinity, water temperature, conductivity and total hardness were of primary importance and favoured the growth and abundance of *Spirogyra*, *Micrasterias*, *Neidium, Actinella*, *Cyclotella* and *Surirella* while water velocity, dissolved oxygen and transparency negatively affected these genera. Velocity, dissolved oxygen and transparency were positively correlated and favourable for *Eunotia*, *Diploneis*, *Anabaena*, *Merismapodia*, *Reimeria*, *Chlorococcus* and *Meridion.* Sampling sites (S_1, S_2 and S_3) were having almost similar composition of species (Figure 3).

Acronyms: 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, NIT-*Nitzschia*, NAV-*Navicula,* CYM-*Cymbella,* AMP-*Amphora*, SYN-*Synedra*, ACH-*Achnanthidium*, TAB-*Tabellaria*, COC-*Cocconeis*, STA-*Stauroneis*, HAN-*Hantzschia*, PIN-*Pinnularia*, DEN-*Denticula*, PER-*Peronia*, RHO-*Rhopalodia,* FRA-*Fragilaria*, CAL-*Caloneis*, FRU- *Frustula*, EPI-*Epithemia,* EUN-*Eunotia*, DIP-*Diploneis*, DIA-*Diatoma,* MER-*Meridion,* GOM-*Gomphonema,* GYR-*Gyrosigma*, ENC-*Encyonema*, FRF- *Flagilariforma,* SUR-*Surirella*, ACT-*Actinella*, RHO-*Rhoicosphenia*, GON-*Gomphoneis*, REM-*Reimeria*, NEI-*Neidium*, CYC-*Cyclotella,* CLO-*Closterium*, ULO-*Ulothrix*, STI-*Stigeoclonium*, HYD-*Hydrodictyon*, CHL-*Chlorococcus*, SPI-*Spirogyra*, MIC-*Micrasterias*, DES-*Desmidium*, COS-*Cosmarium*, PHO-*Phormidium*, OSC-*Oscilatoria*, ANA- *Anabaena*, MEI-*Merismapodia*, SPR-*Sprilium*

Winter months (November, December and January) were having the maximum (23) number of common species indicating the most favourable environment during the period. However, lowest number (07) of taxa were present during monsoon season (June, July and August) in the Mandakini river which may be attributed to the unfavourable environmental conditions substrate due to heavy rainfall and flash floods during the period.

CONCLUSION

Flash floods in Himalayan rivers like Mandakini is caused due to heavy rainfall in a short period which increases run-off and soil erosion in the hills leading to high turbidity of water bodies and removal of the substratum resulting into destruction of aquatic flora. Periphyton community removed by the flash floods during monsoon recovers soon and reaches to its peak in winter season due to most favorable environmental conditions like stable substrate, high transparency of water and less current velocity forming a healthy ecosystem. Among periphyton, Class Bacillariophyceae contributed maximum (70%) followed by Cyanophyceae (19%) and Chlorophyceae (11%). The myriad of different physico-chemical factors influenced the density and diversity of the periphyton during different months of the year.

Acknowledgement
The first author (GG) is thankful to University Grants Commission, New Delhi for financial support in the form of BSR fellowship.

Conflicts of interest: The authors stated that no conflicts of interest.

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