Environment and Ecology 37 (2) : 567—575, April—June 2019
Website: environmentandecology.com ISSN 0970-0420

Seasonal Variation in Physico-Chemical Parameters of Headwater Tributaries of River Alaknanda in Garhwal Himalaya Region of Uttarakhand (India)

Pranav Singh, Navneet Swami, Musharaf Gul, Jitendra Singh Rana, Manju Prakash Gusain, Om Prakash Gusain

Received 6 December 2018; Accepted 11 January 2019; Published on 1 February 2019

Abstract The information regarding physical and chemical nature of running water ecosystem is most important as they get changes with climate, topography, hydrology and the presence of other water systems near it especially in the high mountain region. The distribution of the biotic fauna is very much dependent upon the physical and chemical nature in riverine ecosystem. The present study envisaged to observe the seasonal variation in physico-chemical parameters of 3 major headwater tributaries of River Alaknanda in Garhwal Himalaya (Uttarakhand). Water samples were collected from River Saraswati at Mana, Dhauli Ganga at Vishnuprayag and Birahi Ganga at Birahi between 1040 m to 3150 m asl during 3 seasons (summer, monsoon and autumn) at Saraswati and 5 seasons (spring, summer, monsoon, autumn and winter) at Dhauli Ganga and Birahi Ganga. The physico-chemical variables significantly varied during the different seasons between the selected river systems. Analysis of variance and principal component analysis reveals that among the selected physico-chemical variables the water temperature, velocity, conductivity, pH, total alkalinity and nitrate concentration were the most significant variables which show significant seasonal variation between the 3 headwater tributaries of River Alaknanda.

Keywords Physico-chemical parameters, Seasonal variation, Headwater tributaries, Garhwal Himalaya.

Introduction

It is very truthful fact that survival of living organisms depends on water and we need freshwater to live. As the rivers carry only 0.01% of total volumes of inland water on earth, we rely heavily on it for our water demands. The river ecosystem includes its hydrology, channel structure, habitat types, solutes and sediments and the biota. The abiotic factors of a running water ecosystem are those physical and chemical variables which influence the abundance and distribution of the other key factors known as biotic factors. The water flow conditions, substrate and temperature are the most critical factors in fluvial environment. The climatic conditions, riparian vegetation, geology and terrain place are the components

Pranav Singh, Navneet Swami, Musharaf Gul, Jitendra Singh Rana*, Manju Prakash Gusain, Om Prakash Gusain
Freshwater Biology Unit, Department of Zoology & Biotechnology, Hemvati Nandan Bahuguna Garhwal University, Srinagar (Garhwal) 246174, Uttarakhand, India
e-mail : ranajitendra14@gmail.com
*Corresponding author

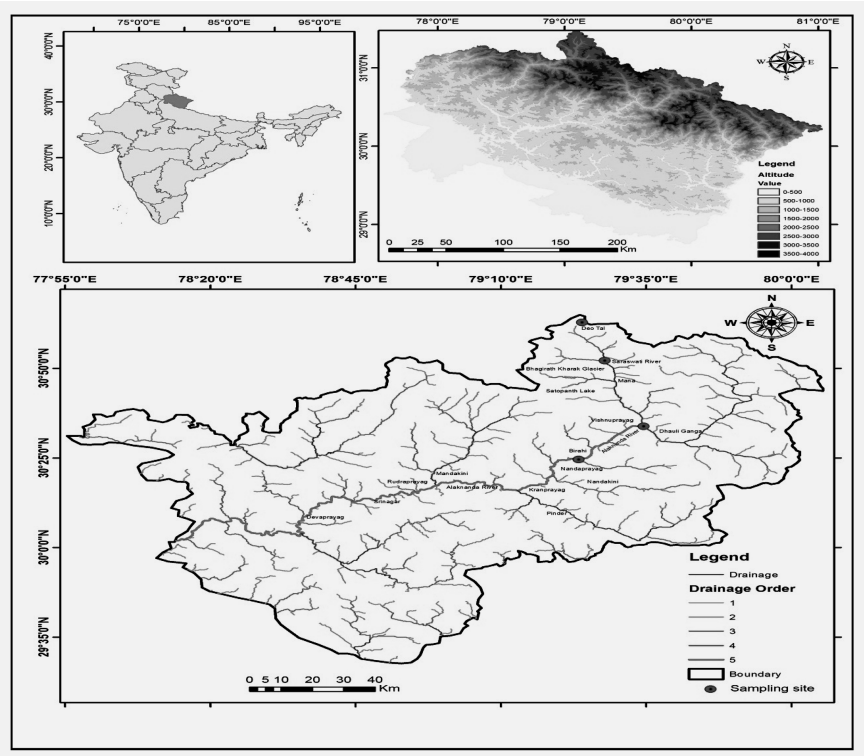

Fig. 1. Location map of the sampling sites at 3 headwater tributaries of River Alaknanda.

that have major impact on hydraulic conditions of lotic ecosystems which further affects the substrate composition and the nutrient recycling process of the watershed (Dodds and Whiles 2002).

Spatial and temporal variability of water source contributions makes rivers in mountain region distinct from other running water systems (Smith et al. 2001). The timing and volume of bulk melt water production (Hannah and Gurnell 2001), along with inputs of groundwater from springs, seeps and upwellings (Ward et al. 1999) generate distinct patterns of stream discharge, water temperature, hydrochemistry, electrical conductivity, turbidity and suspended sediment concentration over annual, seasonal and diurnal time scales (Hannah et al. 2007). There is lack of substantial information on abiotic factors (physical and chemical) variables in headwater tributaries of River Alaknanda. The present study investigated the seasonal variation in physico-chemical parameters of 3 headwater tributaries of River Alaknanda namely Saraswati, Dhauli Ganga and Birahi Ganga in Garhwal region of Uttarakhand.

Materials and Methods

Study area

River Alaknanda is one of the parent streams of River Ganga, originating from the Satopanth and the Bhagirathi Kharak glaciers at an altitude of 3641 m asl (approx) in the Garhwal Himalayan region of Uttarakhand (India). The present study area extends near a stretch of 89 km (approx) from Mana to Birahi, which includes major 3 major headwater tributaries of River Alaknanda (Fig. 1). River Saraswati (SR) which originates from Deo Tal joins the River Alaknanda at Mana ($30^0$46´14´´ N,$79^0$29´40´´ E, 3150 m asl). River Dhauli Ganga (DG) joins the River Alaknanda at Vishnuprayag ($30^0$33´44´´ N, $79^0$34´35´´ E, 1445

Table 1. Range of the physico-chemical parameters at 3 different tributaries during March 2014–February 2016.

Physico-chemical parameters		Saraswati (SR)	Dhauli ganga (DG)	Birahi Ganga (BG)
Water temperature (^{0}C)	Min	5.00 (Jun, Jul, Sep)	7.00 (Jan, Feb)	10.00 (Dec, Jan, Feb)
	Max	6.50 (Jun)	14.50 (Jun)	17.70 (Sep)
Velocity (m s^{-1})	Min	0.70 (May)	0.60 (Mar, Jul)	0.33 (Mar)
	Max	0.85 (Jul)	2.40 (Mar, Jul)	0.90 (Jul, Aug)
Discharge (m^3s^{-1})	Min	3.08 (May)	2.34 (Mar)	0.99 (Mar)
	Max	10.63 (Jul)	47.23 (Jul)	13.68 (Jul)
Turbidity (NTU)	Min	5.00 (May, Jun, Oct)	7.00 (Feb)	7.00 (Jan, Feb)
	Max	51.00 (Aug)	150.00 (Aug)	165.00 (Aug)
Conductivity (S cm^{-1})	Min	32.00 (May)	40.00 (Feb)	60.00 (Jan, Feb)
	Max	42.00 (Aug)	70.00 (Jul)	90.00 (Jul)
pH	Min	6.76 (May)	7.30 (Mar, Nov, Dec)	7.40 (Jan)
	Max	7.70 (Jun)	7.90 (Jul)	8.22 (Jun)
Dissolved oxygen (mg l^{-1})	Min	9.80 (Oct)	9.80 (Aug)	8.80 (Oct)
	Max	10.80 (Jun)	11.40 (Dec-Feb)	10.80 (Mar-May)
Free CO_2 (mg l^{-1})	Min	0.44 (Oct)	0.44 (Jul, Aug)	0.88 (Jul-Oct)
	Max	0.88 (Jul, Aug)	1.98 (Mar)	2.64 (Dec)
Total alkalinity (mg l^{-2})	Min	40.00 (May, Jul)	35.00 (Jul)	90.00 (Aug)
	Max	75.00 (Oct)	115.00 (Dec)	170 (Dec)
Phosphate PO^{3-} (mg l^{-1})	Min	0.01 (Aug-Oct)	0.02 (Oct)	0.02 (Jan, Feb)
	Max	0.06 (May, Jul)	0.37 (Mar)	0.10 (Jun-Aug)
Nitrate No- (mg l^{-1})	Min	0.005 (Oct)	0.006 (Sep)	0.025 (Dec)
	Max	0.014 (May, Jun)	0.05 (Mar, Apr)	0.097 (Apr)
Total dissolved solid (g l^{-1})	Min	0.06 (Sep)	0.05 (Dec, Feb)	0.04 (Feb)
	Max	0.13 (Jul)	0.18 (Jul)	0.21 (Aug)

m asl) and River Birahi Ganga (BG) originating from the peaks of Trishul and Nandaghunti joins the River Alaknanda at Birahi (30^{0}24´29´´N, 79^{0}23´16´´ E, 1040 m asl).

Physico-chemical sampling

Selected physico-chemical parameters namely water temperature, velocity, discharge, turbidity, conductivity, pH, dissolved oxygen, free carbon dioxide, total alkalinity, phosphate, nitrate and total dissolved solids were measured and analyzed at all the sampling sites of 3 headwater tributaries of River Alaknanda during the period of 2 years from March 2014 to February 2016 by following the standard methods outlined in Welch (2003), Golterman (1969), Trivedy and Goel (1984) and APHA (2005).

Data analysis

The range and mean of selected physico-chemical parameters from different seasons were calculated by MS Excel. Analysis of variance (ANOVA) was performed to analyse the variation in selected variables between the different tributaries using SPSS 20. The relationship between different seasons from different tributaries was analyzed by performing the cluster analysis using PAST 1.73 (Hammer et al. 2007). Principal component analysis (PCA) was performed to analyse the relationship between physico-chemical variables and different seasons using PAST 1.73.

Results and Discussion

Seasonal variation in physico-chemical parameters

The physical and chemical nature of the running water bodies such as rivers and stream is majorly influenced by land uses, types of landscape and other water bodies present adjacent to it. Thus, to detect the various changes in physico-chemical nature of water, seasonal data was recorded at different headwater tributaries namely, Saraswati (SR), Dhauli Ganga (DG) and Birahi Ganga (BG) of River Alaknanda.

The water temperature ranged between 5.00^{0}C (SR) to 17.70^{0}C (BG) during the study period (Table 1). Seasonally, it varied between 5.10 ± 14^{0}C (Mon-

Table 2. Seasonal variation in the physico-chemical parameters recorded at River Saraswati during March 2014-February 2016 (Mean ± SD).

Physico-chemical parameters	Saraswati (SR) I year Summer	Monsoon	Autumn	II year Summer	Monsoon	Autumn
Water temperature (^{0}C)	5.25 ± 0.35	5.10 ± 0.14	5.30 ± 0.42	6.25 ± 0.35	5.35 ± 0.49	5.55 ± 0.07
Velocity (m s^{-1})	0.73 ± 0.04	0.83 ± 0.04	0.78 ± 0.04	0.74 ± 0.02	0.83 ± 0.04	0.76 ± 0.01
Discharge (m^3 s^{-1})	4.43 ± 1.91	6.94 ± 0.76	5.72 ± 0.29	4.87 ± 2.40	9.27 ± 1.91	5.06 ± 0.47
Turbidity (NTU)	5.00 ± 0.00	45.00 ± 7.07	5.50 ± 0.71	5.00 ± 0.00	46.50 ± 6.36	5.50 ± 0.71
Conductivity (S cm^{-1})	36.00 ± 1.41	38.50 ± 4.95	41.00 ± 1.41	33.50 ± 2.12	40.00 ± 2.83	41.00 ± 1.42
pH	6.93 ± 0.24	7.05 ± 0.21	7.20 ± 0.14	7.23 ± 0.66	7.15 ± 0.35	7.25 ± 0.03
Dissolved oxygen (mg l^{-1})	10.70 ± 0.14	10.60 ± 0.00	10.10 ± 0.42	10.70 ± 0.14	10.50 ± 0.14	10.50 ± 0.14
Free CO_2 (mg l^{-1})	0.66 ± 0.00	0.66 ± 0.00	0.55 ± 0.16	0.66 ± 0.00	0.88 ± 0.00	0.55 ± 0.16
Total alkalinity (mg l^{-1})	42.50 ± 3.54	42.50 ± 3.54	60.00 ± 21.21	42.50 ± 3.54	55.00 ± 7.07	60.00 ± 21.21
Phosphate (mg l^{-1})	0.05 ± 0.00	0.04 ±0.02	0.02 ± 0.01	0.06 ± 0.01	0.04 ± 0.04	0.01 ± 0.00
Nitrate (mg l^{-1})	0.014 ± 0.000	0.009 ± 0.003	0.006 ± 0.001	0.012 ± 0.000	0.010 ± 0.002	0.006 ± 0.001
Total dissolved solids (g l^{-1})	0.11 ± 0.00	0.09 ± 0.04	0.07 ± 0.01	0.12 ± 0.00	0.10 ± 0.04	0.08 ± 0.01

soon) at SR and 16.63 ± 0.75^{0}C (Summer) at BG during the first year and 5.35 ± 0.49^{0}C (Monsoon) to 16.88 ± 0.63^{0}C (Summer) at SR and BG respectively, during the second year of study period (Tables 2—4). The altitudinal difference between the sites supposed to account for variation in water temperature. Seasonal changes in water temperature follow the seasonal trends in air temperature (Allan and Castillo 2007).

The mean velocity ranged between 0.33 m s^{-1} (BG) to 2.40 m s^{-1} (DG) during the study period (Table 1). Seasonally, it varied between 0.43 ± 0.08 m s^{-1} (Spring) at BG and 1.53 ± 0.72 m s^{-1} (Monsoon) at DG during the first year and 0.45 ± 0.08 m s^{-1} (Spring) at BG to 1.58 ± 0.79 m s^{-1} (Monsoon) at DG during the second year of study period (Tables 2—4). The discharge of water ranged between 0.99 m^3 s^{-1} (BG) to 47.23 m^3 s^{-1} (DG) during the study period (Table 1). Seasonally, it varied between 1.81 ± 0.75 m^3 s^{-1} (Spring) at BG and 23.91 ± 12.13 m^3s^{-1} (Monsoon) at DG during the first year and 2.29 ±0.97 m^3 s^{-1} (Spring) to 27.38 ± 16.28 m^3 s^{-1} (Monsoon) at BG and DG respectively, during the second year of study period (Tables 2—4). The velocity and discharge were highest in monsoon with rising temperature and rain at sites (Rana et al. 2016).

Table 3. Seasonal variation in the physico-chemical parameters recorded at River Dhauli Ganga during March 2014-February 2016 (Mean ± SD).

Physico-chemical parameters	Dhauli Ganga (DG) I year Spring	Summer	Monsoon	Autumn	Winter
Water temperature (^{0}C)	10.70 ± 0.68	13.38 ± 1.11	12.35 ± 1.08	11.65 ± 1.06	8.43 ± 1.55
Velocity (m s^{-1})	0.90 ± 0.26	1.45 ± 0.70	1.53 ± 0.72	1.13 ± 0.38	0.86 ± 0.21
Discharge (m^2 s^{-1})	4.60 ± 1.84	12.22 ± 6.98	23.91 ± 12.13	13.88 ± 5.06	7.30 ± 2.95
Turbidity (NTU)	9.43 ± 1.18	36.63 ± 2.93	137.25 ± 5.74	61.55 ± 2.58	9.28 ± 1.70
Conductivity (S cm^{-1})	50.00 ± 0.00	57.50 ± 2.89	65.00 ± 0.00	52.50 ± 2.89	45.00 ± 3.78
pH	7.46 ± 0.18	7.65 ± 0.13	7.55 ± 0.15	7.44 ± 0.10	7.44 ± 0.13
Dissolved oxygen (mg l^{-1})	10.70 ± 0.42	10.45 ± 0.30	10.20 ± 0.37	10.30 ± 0.12	10.93 ± 0.41
Free CO_2 (mg l^{-1})	1.60 ± 0.33	1.10 ± 0.00	0.66 ± 0.25	1.10 ± 0.25	1.61 ± 0.23
Total alkalinity (mg l^{-1})	87.50 ± 6.45	81.25 ± 2.50	40.00 ± 4.08	68.75 ± 27.50	103.13 ± 8.84
Phosphate (mg l^{-1})	0.27 ± 0.05	0.15 ± 0.07	0.09 ± 0.01	0.05 ± 0.01	0.05 ± 0.01
Nitrate (mg l^{-1})	0.040 ± 0.000	0.018 ± 0.003	0.012 ± 0.004	0.010 ± 0.002	0.024 ± 0.006
Total dissolved solids (g l^{-1})	0.12 ± 0.01	0.14 ± 0.02	0.17 ± 0.01	0.09 ± 0.01	0.07 ± 0.01

Table 3. Continued.

Physico-chemical parameters	Dhauli Ganga (DG) II year Spring	Summer	Monsoon	Autuma	Winter
Water temperature (^{0}C)	10.85 ± 0.73	14.00 ± 0.41	13.25 ±0.29	12.05 ± 0.76	8.79 ± 1.56
Velocity (m s^{-1})	0.83 ± 0.26	1.45 ± 0.70	1.58 ± 0.79	1.08 ± 0.34	0.82 ± 0.21
Discharge (m^3 s^{-1})	4.31 ± 1.89	13.41 ± 9.38	27.38 ± 16.28	13.40 ± 4.77	7.16 ± 3.43
Turbidity (NTU)	9.00 ± 0.00	39.00 ± 3.46	142.00 ± 7.62	59.00 ± 3.56	9.19 ± 1.41
Conductivity (S cm^{-1})	52.50 ± 2.89	58.75 ± 4.79	66.25 ± 2.50	56.25 ± 2.50	46.88 ± 3.72
pH	7.51± 0.17	7.73 ± 0.16	7.67 ± 0.20	7.48 ± 0.11	7.54 ± 0.16
Dissolved oxygen (mg l^{-1})	10.75 ± 0.34	10.50 ± 0.26	10.25 ± 0.34	10.40 ± 0.00	10.90 ± 0.43
Free CO_2 (mg l^{-1})	1.49 ± 0.33	1.16 ± 0.11	0.72 ± 0.21	0.99 ± 0.13	1.57 ± 0.27
Total alkalinity (mg l^{-1})	92.50 ± 6.45	81.25 ± 2.50	43.75 ± 4.79	65.00 ± 23.45	102.50 ± 8.02
Phosphate (mg l^{-1})	0.31 ± 0.06	0.17 ± 0.09	0.09 ± 0.01	0.05 ± 0.02	0.05 ± 0.01
Nitrate (mg l^{-1})	0.048 ± 0.005	0.020 ± 0.004	0.012 ±0.004	0.010 ± 0.004	0.023 ± 0.006
Total dissolved solids (g l^{-1})	0.13 ± 0.01	0.15 ± 0.03	0.17 ± 0.01	0.09 ± 0.01	0.07 ± 0.01

The turbidity of water ranged between 5.00 NTU (SR) to 165.00 NTU (BG) during the study period (Table 1).Seasonally, it varied between 5.00 ± 0.00 NTU (Summer) at SR and 157.75 ± 5.25 NTU (Monsoon) at BG during the first year and 5.00 ± 0.00 NTU (Summer) at SR to 155.25 ± 3.59 NTU (Monsoon) at BG during the second year of study period (Tables 2–4). However, Bundi (2010), Milner et al. (2010) suggested the raise in turbidity during ice melting period.

The conductivity of water ranged between 32.00S cm^{-1} (SR) to 90.00S cm^{-1} (BG) during the study period (Table 1). Seasonally, it varied between 36.00 ± 1.41S cm^{-1} (Summer) at SR and 82.50 ± 2.89S cm^{-1} (Monsoon) at BG during the first year and 33.50 ± 2.12S cm^{-1} (Summer) at SR and 85.00 ± 4.08S cm^{-1} (Monsoon) at BG during the second year of study period (Tables 2–4). Conductivity follows the trends of decrease with the increase in altitude (Kasangaki et al. 2008).

The pH of water ranged between 6.60 (BG) to 7.90 (DG & BG) during the study period (Table 1). Seasonally, it varied between 6.93 ± 0.24 (Summer) at SR and 7.65 ± 0.06 (Summer) at BG during the first year and 7.15 ±0.35 (Monsoon) at SR and 7.73 ±0.16 (Summer) at DG during the second year of study peri-

Table 4. Seasonal variation in the physico-chemical parameters recorded at River Birahi Ganga during March 2014-February 2016 (Mean ± SD).

Physico-chemical parameters	Birahi Ganga (BG) I year Spring	Summer	Monsoon	Autumn	Winter
Water temperature (^{0}C)	13.05 ± 0.10	16.63 ± 0.75	15.60 ± 0.71	16.43 ± 0.94	11.50 ± 2.30
Velocity (m s^{-1})	0.43 ± 0.08	0.68 ± 0.13	0.82 ± 0.09	0.70 ± 0.00	0.51 ± 0.10
Discharge (m^3 s^{-1})	1.81 ± 0.75	5.76 ± 2.92	10.30 ± 2.63	7.14 ± 0.84	2.99 ± 1.49
Turbidity (NTU)	8.50 ± 0.58	55.50 ± 9.54	157.75 ±5.25	64.50 ± 7.59	9.25 ± 1.98
Conductivity (S cm^{-1})	67.50 ± 2.89	73.25 ± 3.95	82.50 ± 2.89	72.50 ± 2.89	62.50 ± 2.67
pH	7.84 ± 0.05	8.12 ± 0.04	8.02 ± 0.10	7.78 ± 0.03	7.50 ± 0.06
Dissolved oxygen (mg l^{-1})	10.60 ± 0.23	10.30 ± 0.35	9.95 ± 0.25	9.35 ± 0.55	9.63 ± 0.48
Free CO_2 (mg l^{-1})	1.21 ± 0.13	1.10 ± 0.00	0.88 ± 0.00	0.88 ± 0.00	1.87 ± 0.51
Total alkalinity (mg l^{-1})	110.00 ± 11.55	115.00 ± 5.77	92.50 ± 2.89	127.50 ± 20.21	151.25 ± 22.80
Phosphate (mg l^{-1})	0.08 ± 0.01	0.09 ± 0.01	0.10 ± 0.00	0.07 ± 0.01	0.04 ± 0.02
Nitrate (mg l^{-1})	0.091 ± 0.001	0.077 ± 0.020	0.043 ± 0.001	0.034 ± 0.002	0.028 ± 0.002
Total dissolved solids (g l^{-1})	0.16 ± 0.01	0.17 ± 0.01	0.19 ± 0.00	0.12 ± 0.01	0.07 ± 0.01

Table 4. Continued.

Physico-chemical parameters	Birahi Ganga (BG) II year				
	Spring	Summer	Monsoon	Autumn	Winter
Water temperature (^{0}C)	13.80 ± 0.36	16.88 ± 0.63	15.63 ± 0.48	15.25 ± 0.29	12.24 ± 1.49
Velocity (m s^{-1})	0.45 ± 0.08	0.66 ± 0.18	0.78 ± 0.09	0.67 ± 0.02	0.53 ± 0.08
Discharge (M^3 s^{-1})	2.29 ± 0.97	5.31 ± 2.59	10.35 ± 2.70	6.85 ± 1.04	3.19 ± 1.58
Turbidity (NTU)	8.75 ± 0.29	57.25 ± 7.54	155.25 ± 3.59	62.75 ± 10.08	9.00 ± 1.51
Conductivity (S cm^{-1})	68.75 ± 2.50	75.00 ± 5.77	85.00 ± 4.08	72.50 ± 2.89	63.75 ± 4.43
pH	7.81 ± 0.03	8.18 ± 0.04	8.07 ± 0.15	7.81 ± 0.04	7.55 ± 0.07
Dissolved oxygen (mg l^{-1})	10.70 ± 0.17	10.25 ± 0.25	9.95 ± 0.10	9.35 ± 0.55	9.60 ± 0.43
Free CO_2 (mg l^{-1})	1.32 ± 0.00	1.16 ± 0.11	0.99 ± 0.13	0.94 ± 0.11	1.98 ± 0.41
Total alkalinity (mg l^{-1})	115.00 ± 10.00	105.00 ± 5.77	95.00 ± 5.77	116.25 ± 19.74	161.88 ± 8.43
Phosphate (mg l^{-1})	0.09 ± 0.01	0.09 ± 0.01	0.10 ± 0.01	0.08 ± 0.01	0.04 ± 0.01
Nitrate (mg l^{-1})	0.096 ± 0.001	0.087 ± 0.012	0.053 ± 0.003	0.040 ± 0.004	0.031 ± 0.004
Total dissolved solids (g l^{-1})	0.17 ± 0.01	0.17 ± 0.01	0.19 ± 0.02	0.14 ± 0.03	0.08 ± 0.03

od (Tables–2–4). Lepori et al. (2003) mentioned that in early snow melting period the release of acid anions leads to decrease in the pH of the mountain stream.

The dissolved oxygen of water ranged between 8.80 mg l^{-1} (BG) to 11.40 mg l^{-1} (DG) during the study period (Table 1). Seasonally, it varied between 9.35 ± 0.55 mg l^{-1} (Autumn) at BG and 10.93 ± 0.41 mg l^{-1} (Winter) at DG during the first year and 9.35 ± 0.55 mg l^{-1} (Autumn) at BG and 10.90 ± 0.43 mg l^{-1} (Winter) at DG during the second year of study period (Tables 2–4). At DG, along with dissolved oxygen, the flow and discharge of water were also recorded highest. Welch (2003) suggested that major source of dissolved oxygen are atmospheric oxygen through the exposed water surface.

The free CO_2 of water ranged between 0.44 mg l^{-1} (SR & DG) to 2.64 mg l^{-1} (BG) during the study period (Table 1). Seasonally, it varied between 0.55 ± 0.16 mg l^{-1} (Autumn) at SR and 1.87 ± 0.51 mg l^{-1} (Winter) at BG during the first year and 0.55 ± 0.16 mg l^{-1} (Autumn) at SR and 1.98 ± 0.41 mg l^{-1} (Winter at BG during the second year of study period (Tables 2–4). Steingruber and Colombo (2010) also suggested the low concentration of dissolved organic carbon for carbonate poor streams of mountain regions.

The total alkalinity of water ranged between 35.00 mg l^{-1} (DG) to 170.00 mg l^{-1} (BG) during the study period (Table 1). Seasonally, it varied between 40.00 ± 4.08 mg l^{-1} (Monsoon) at DG and 151.25 ± 22.80 mg l^{-1} (Winter) at BG during the first year and 42.50 ± 3.54 mg l^{-1} (Summer) at SR and 161.88 ± 8.43 mg l^{-1} (Winter) at BG during the second year of study period (Tables 2–4).

The phosphate concentration of water ranged between 0.01 mg l^{-1}(SR) to 0.37 mg l^{-1} (DG) during the study period (Table 1). Seasonally, it varied between 0.02 ± 0.01 mg l^{-1}(Autumn) at SR and 0.27 ± 0.05 mg l^{-1} (Spring) at DG during the first year and 0.01 ± 0.00 mg l^{-1} (Autumn) at SR and 0.31 ± 0.06 mg l^{-1} (Spring) at DG during the second year of study period (Tables 2–4). The nitrate concentration of water ranged between0.005 mg l^{-1} (SR) to 0.097 mg l^{-1} (BG) during the study period (Table 1). Seasonally, it varied between 0.006 ± 0.001 mg l^{-1} (Autumn) at SR and 0.091 ± 0.001 mg l^{-1} (Spring) at BG during the first year and 0.006 ± 0.001 mg l^{-1} (Autumn) at SR and 0.096 ± 0.001 mg l^{-1} (Spring) at BG during the second year of study period (Tables 2–4). The high decomposition rates of leaves in aquatic body explain the increased concentration of nitrate to some extent. During spring, the pre-monsoon rain may have lead to increased concentration of phosphate and nitrate (Rana et al. 2016).

The total dissolved solids ranged between 0.04 g l^{-1} to 0.21 g l^{-1} at BG during the study period (Table 1). Seasonally, it varied from 0.07 ±0.01 g l^{-1} (Autumn at SR and Winter at DG and BG) to 0.19 ± 0.00 g l^{-1}

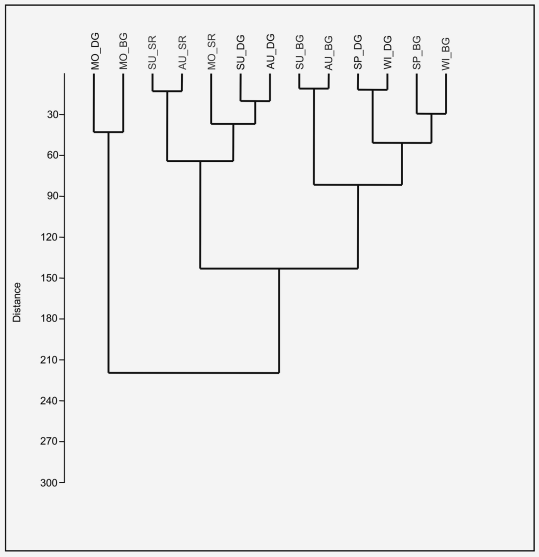

Fig. 2. Cluster analysis based on physico-chemical parameters in different seasons at 3 headwater tributaries of River Alaknanda.

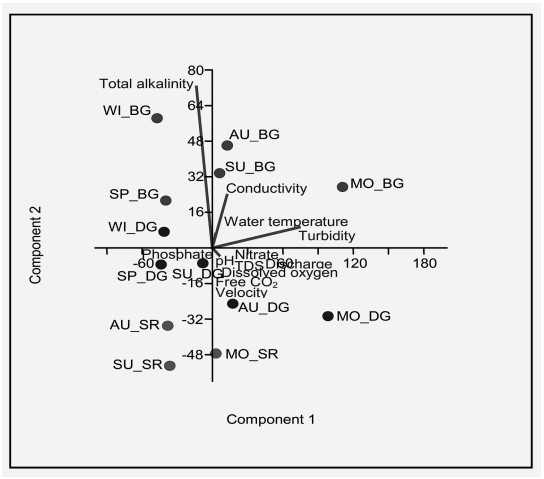

Fig. 3. Ordination plot of principal component analysis (PCA) of different seasons and physico-chemical variables.

(Monsoon) at BG during the first year and 0.07 ± 0.01g l^{-1} (Winter) at DG and 0.19 ± 0.02 g l^{-1} (Monsoon) at BG during the second year of study period (Tables 2–4). The total dissolved solids wete highest during the monsoon season. Glaciers are the major sources of transported sediments in streams (Smith et al. 2001). Rana et al. (2016) suggested that increase in discharge of water in monsoon leads to increase in the amount of suspended solids which raise the concentration of total dissolved solids.

The physico-chemical parameters from 3 tributaries of River Alaknanda were subjected to ANOVA which showed significant variation ($p < 0.05$) in 6 variables in 2 years of study period which includes water temperature, velocity, conductivity, pH, total alkalinity and nitrate concentration (Tables 5 and 6).

Cluster analysis produces 2 major clads of seasons of 3 different water systems based on physico-chemical variables (Fig. 2). The first clad comprises of monsoon season of Rivers Dhauli Ganga and Birahi Ganga, as there were more similarity in discharge than River Saraswati. The second major clad further gets divided into 2 subclads, the first subclad includes the summer, autumn and monsoon seasons of River Saraswati along with summer and autumn seasons of River Dhauli Ganga. The second subclad shows that spring and winter seasons of River Birahi Ganga were distant from summer and autumn seasons and more similar with spring and winter of River Dhauli Ganga with low water temperature and turbidity. In the 2 major clads spring and winter seasons were more distantly related with monsoon seasons of Dhauli Ganga and Birahi Ganga as there is mark decrease in water temperature, turbidity and total dissolved solids.

Table 5. Analysis of variance (ANOVA) for physico-chemical parameters between the 3 different sites during March 2014-February 2015.

Physico-chemical parameters	Degree of freedom	F	Significance
Water temperature (^{0}C)	2.00	24.057	**0.000**
Velocity (m s^{-1})	2.00	8.092	**0.008**
Discharge (m^3 s^{-1})	2.00	2.590	0.124
Turbidity (NTU)	2.00	0.598	0.569
Conductivity (S cm^{-1})	2.00	22.960	**0.000**
pH	2.00	19.757	**0.000**
Dissolved oxygen (mg l^{-1})	2.00	2.785	0.109
Free CO_2 (mg l^{-1})	2.00	2.946	0.099
Total alkalinity (mg l^{-1})	2.00	11.779	**0.002**
Phosphate (mg l^{-1})	2.00	1.944	0.194
Nitrate (mg l^{-1})	2.00	6.299	**0.017**
Total dissolved solids (g l^{-1})	2.00	1.588	0.252

Table 6. Analysis of variance (ANOVA) for physico-chemical parameters between the 3 different sites during March 2015-February 2016.

Physico-chemical parameters	Degree of freedom	F	Significance
Water temperature (^{0}C)	2.00	25.497	0.000
Velocity (m s^{-1})	2.00	6.581	0.015
Discharge (m^3 s^{-1})	2.00	2.192	0.162
Turbidity (NTU)	2.00	0.571	0.583
Conductivity (S cm^{-1})	2.00	23.523	0.000
pH	2.00	14.434	0.001
Dissolved oxygen (mg l^{-1})	2.00	3.760	0.061
Free CO_2 (mg l^{-1})	2.00	2.712	0.115
Total alkalinity (mg l^{-1})	2.00	9.154	0.006
Phosphate (mg l^{-1})	2.00	1.806	0.214
Nitrate (mg l^{-1})	2.00	7.330	0.011
Total dissolved solids (g l^{-1})	2.00	1.642	0.242

Principal component analysis (PCA) shows distinct allocation of seasonal variation in physico-chemical parameters from 3 different tributaries. The first 2 components are responsible for 98.98% of variation in the analyzed physico-chemical parameters at Eigen value 2685.86 and 1289.72 respectively. In PCA biplot, the variables at upper right end include conductivity which corresponds with summer and water temperature along with turbidity which corresponds to the monsoon season. Brown et al. (2006) also suggested the large annual fluctuation in water temperature of glacier fed streams. The total alkalinity was plotted on upper left end and corresponds with the winter season. At lower right end, variables such as pH, dissolved oxygen, nitrate, phosphate, free CO_2, discharge, velocity and total dissolved solids were plotted which correspond with the autumn and monsoon seasons (Fig. 3). Increase in discharge and velocity in monsoon season might leads to increase in total dissolved solids (Smith et al. 2001, Rana et al. 2016).

The present study on the physico-chemical parameters of 3 headwater tributaries namely River Saraswati, River Dhauli Ganga and River Birahi Ganga of River Alaknanda in Garhwal Himalaya concludes that there were distinct seasonal variations in the physico-chemical variables at different selected water systems. Analysis of variance (ANOVA) and principal component analysis (PCA) also reveals the 98.98% of seasonal variation in selected variables. Water temperature, velocity, conductivity, pH, total alkalinity and nitrate concentration were predicted as important variables in the studied 3 headwater tributaries of River Alaknanda. In future, the present finding on the hydrology of headwater tributaries of mountain river system will certainly aid in assessing not only the climate change on high altitude lotic ecosystem but also increases the understanding of impact of tributaries on main river channel.

Acknowledgement

The first author (Pranav Singh) is thankful to UGC for financial assistance in the form of UGC-BSR Fellowship. We are thankful to the Head, Department of Zoology and Biotechnology, Hemvati Nandan Bahuguna Garhwal University (Uttarakhand) for providing necessary facilities for the present work.

References

Allan JD, Castillo MM (2007) Stream ecology : Structure and function of running waters. Springer, New York.

American Public Health Association, American Water Works Association, Water Pollution Control Federation and Water Environment Federation (2005) Standard methods for the examination of water and wastewater. 21st edn. USA: American Public Health Association.

Brown LE, Hannah DM, Milner AM (2006) Thermal variability and stream flow permanency in an Alpine river system. River Res Appl 22 : 493—501.

Bundi U (2010) Alpine waters: The Handbook of Environmental Chemistry. Springer- Verlag Berlin, Heidelberg 6 : In press.

Dodds WK, Whiles MT (2002) Freshwater ecology. 2nd edn. Academic Press Publication, USA.

Golterman HL (1969) Methods for chemical analysis of fresh aters. International Biological Program Handbook No. 8, Blackwell, Oxford.

Hammer Q, Harper DAT, Ryan P (2007) PAST paleontological statistical software package for education and data analysis, Version 1.73. Palaeontol Electron 4 : 9.

Hannah DM, Brown LE, Milner AM, Gurnell AM, McGregor GR, Petts GE, Smith BP, Snook DL (2007) Integrating climate-hydrology-ecology for Alpine river systems. Aquat Conserv 17 : 636—656.

Hannah DM, Gurnell AM (2001) A conceptual, linear reservoir runoff model to investigate melt season changes in cirque glacier hydrology. J Hydrol 246 : 123—141.

Kasangaki A, Lauren JC, Balirwa DJ (2008) Land use and the ecology of benthic macroinvertebrate assemblages of high - altitude rainforest streams in Uganda. Freshwater Biol 53 : 681—697.

Lepori F, Barbieri A, Ormerod SJ (2003) Effects of episodic acidification on macroinvertebrate assemblages in Swiss

Alpine streams. Freshwater Biol 48 : 1873—1885.
Milner AM, Brittain JE, Brown LE, Hannah DM (2010) Water sources and habitat of Alpine streams. In : Bundi U (ed). Alpine waters. Handbook of Environmental Chemistry, Springer, Heidelberg 6 : In press.
Rana JS, Semalty B, Gusain MP, Gusain OP (2016) Seasonal variation in physico-chemical parameters of a glacier-fed river at high montane site. Int J Water Res 6 : 26—31.
Smith BP, Hannah DM, Gurnell AM, Petts GE (2001) A hydro-geomorphological context for ecological research on Alpine glacial rivers. Freshwater Biol 46 : 1579—1596.
Steingruber SM, Colombo L (2010) Effect of acid deposition on chemistry and biology of high Alpine lakes. In : Bundi U (ed). Alpine waters: Handbook of Environmental Chemistry, Springer, Heidelberg 6 : In press.
Trivedy RK, Goel PK (1984) Chemical and biological methods for water pollution studies. Environmental Publications. Karad, India.
Ward JV, Tockner K, Edwards PJ, Kollmann J, Bretschko G, Gurnell AM, Petts GE, Rossaro B (1999) A reference river system for the Alps : The Fiume Tagliamento. River Res Appl 15 : 63—75.
Welch PS (2003) Limnology. Narendra Publishing House. New Delhi, India.