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Seasonal Limnological Variation and Macro Benthic Diversity of River Yamuna at Kalsi Dehradun of Uttarakhand

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Abstract: River Yamuna is a glacier fed river in Dehradun district of Uttarakhand (India). The seasonal variation of River Yamuna at Kalsi was studied for a period of one year. In the present study various physico-chemical parameters *i.e.*, temperature, transparency, velocity, turbidity, conductivity, TS, TDS, TSS, pH, total alkalinity, total hardness, calcium, magnesium, Chloride, Free CO_2, DO, BOD, COD, phosphate, nitrate, sodium and potassium were analyzed for various seasons; summer, monsoon, winter from the period of August 2010 to July 2011 in surface water of river Yamuna including macro benthic diversity. The present study revealed that the physico-chemical parameters showed a great seasonal variation and turbidity and Total Solids were found to be highest in Monsoon period which had a strong impact on other physico-chemical factors of river. 27 genera belonging to seven orders of macro vertebrates were found which include Ephemeroptera, Diptera, Coleoptera, Hemiptera, Plecoptera, Odonata and Trichoptera indicating good quality of water in River Yamuna at Kalsi. Many genera were seasonally and monthly absent at different times in the river; however the overall diversity was found to be maximum in winter and summer. Correlation between the hydrological attributes showed good relationship and Transparency, dissolved oxygen and pH were found to be most important variables in shaping benthic faunal assemblage.

Key words: Kalsi · Macro vertebrates · Physico-chemical · Seasonal · River Yamuna

INTRODUCTION

Fresh water resources are most precious to earth as they are the basic ingredient to life. Water is the commonest fluid in nature. Water is also a vital resource for agriculture, manufacturing and other human activities [1]. Water quality parameters provides current information about the concentration of various solutes at a given place and time [2]. These parameters provide the basis for judging the suitability of water for its designated uses and to improve existing conditions. The Yamuna sometimes called Jamuna or Jumna is the largest tributary of the Ganges (Ganga) in northern India. It is perennial in nature as it receives all the three types of water inputs *i.e.*, snowmelt runoff, rainfall runoff and groundwater [3]. However, the three components vary in space and time. The extent of human activities that influence the environment particularly the freshwater has increased dramatically during the past few decades [4, 5]. The scale of socio-economic activities, urbanizations, industrial operations and agricultural production has a widespread impact on water resources [6]. Over the last century, riverine ecosystems have suffered from intense human intervention resulting in habitat loss and degradation and as a consequence, the aquatic diversity has become the main victim particularly in rivers where heavy demand is placed on freshwater [7]. Aquatic insects have a significant role in an aquatic ecosystem, as they are the important organisms dwelling at the secondary trophic level of the ecosystem. The type and distribution of

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benthic invertebrates have also been widely used as an indicator of water quality and ecological disturbances. The macrozoobenthic population is very sensitive to any environmental perturbation and is highly influenced by environmental change. Distribution, density and biomass of benthic organisms depend upon the physico-chemical characteristics of the water, the nature of the sediments or substratum, biological complexes such as food, predation and other factors. The macroinvertebrate community has been considered as an indicator of stream ecology [8]. Freshwater macrovertebrates are one of the most threatened taxonomic groups [9] because of their high sensitivity to the quantitative and qualitative alteration of aquatic habits [10-12]. Being an important part of food chain, today the diversity and associated habitat management is a great challenge [13]. Conservation measures to mitigate the impact of the pressures have largely been slow and inadequate and as a result many of the species are declining rapidly. The present study was conducted to monitor seasonal Physico-chemical variation and Macrobenthic diversity of River Yamuna at Kalsi in Dehradun district of Uttarakhand.

Study Area: Dehradun or Doon Valley is the capital city of the State of Uttarakhand in North India. It is surrounded by the Himalayas in the north, Shivalik Hills in the south, the River Ganges in the east and the River Yamuna in the west. It is located between 29°58 'and 31°2' 30 "north latitude and 77°34 '45" and 78°18' 30 "east longitude. The River Yamuna originates from the Yamunotri Glacier at a height 6,387 mtrs., on the south western slopes of Banderpooch peak (38°59’ N 78°27’E) in the Mussoorie range of Lower Himalayas at an elevation of about 6320 meter above mean sea level in Uttarkashi district of Uttaranchal. It travels a total length of 1,376 kilometers (855 mi) and has a drainage system of 366,223 km^2, 40.2% of the entire Ganges Basin, before merging with the Ganges at Triveni Sangam, Allahabad, the site for the Kumbha Mela every twelve years. Kalsi is a small town near Dehradun in Uttarakhand and is a dream destination in the Doon valley. Picturesquely located at the confluence of the Tons River, Asan River and the River Yamuna, it is situated by the Chakrata foothills in Jaunsar-Bawar region. Surrounded by beautiful hills and greenery all around, Kalsi sits by the banks of river Yamuna. The River is beyond doubt the most striking attraction moving by in a frenzy after meeting up with Tons and Asan River.

MATERIALS AND METHODS

The present study was conducted on River Yamuna at Kalsi by taking water samples at different sites. The study was carried out for a time period of one year from August 2010-July 2011 on monthly basis. Seasonal relation was later found to know the effect of different environmental conditions on river water and benthic fauna. Water samples were collected every month early in the morning in sterilized sampling bottles and were analysed for twenty two important physical and chemical Parameters. Few physico-chemical parameters like Temperature (°C), Transparency (cm), Velocity (m/s), pH, Free CO_2 (mg/l) and Dissolved Oxygen (mg/l) were performed on spot and other parameters like Turbidity (JTU), Electric conductivity (μmho/cm), Total Solids (mg/l), TDS (mg/l), TSS (mg/l), Total Alkalinity (mg/l), Total Hardness (mg/l), Calcium (mg/l), Magnesium (mg/l), Chloride (mg/l), BOD (mg/l), COD (mg/l), Phosphate (mg/l), Nitrate (mg/l), Sodium (mg/l) and Potassium (mg/l) were analysed in laboratory by following the methodology of APHA [14]. Khanna and Bhutiani [15]. Trivedi and Goel [16]. Wetzel and Likens [17]. Temperature, Transparency, Velocity was measured by using Celsius thermometer (0–110°C), Secchi disc and flow meter. Turbidity, Conductivity and pH were measured by using Jackson Turbidity unit, Conductivity meter and digital pH meter. Total Solids TDS, TSS were measured by volumetric analysis. Total Alkalinity, Total Hardness, Calcium, Magnesium, Chloride, Free CO_2, DO BOD and COD were analysed by titration method. Phosphate and Nitrate were analysed by using UV-VIS Spectrophotometer and Sodium and Potassium by Flame photometer. Macrobenthos were collected from the shallow bottom region of the river and preserved in 4% formaline and their quantitative estimation was based on numerical counting, i.e., units per square meter (ind. m^{-2}). The qualitative analysis of the benthic fauna samples were made with the help of [18-28].

RESULTS AND DISCUSSION

The physico-Chemical parameter (Avg.± SD) values obtained in different seasons of River Yamuna at Kalsi are given in Table 1. The maximum temperature (18.75± 0.95°C) was recorded during the Monsoon period whereas the minimum Temperature was recorded in winter (14.5±1.29 °C) The WHO does not recommend any limit

Table 1: Showing average (Mean ± S.D) seasonal variation in physico-chemical parameters of River Yamuna at Kalsi for the year August 2010-July 2011

Parameters	Monsoon Avg. ±S.D	Winter Avg. ±S.D	Summer Avg. ±S.D
Temperature °C	18.75± 0.95	14.5±1.29	18.5±2.08
Transparency cm	3.85±2.51	46.5±13.65	36.05±19.80
Velocity m/s	2.20±0.52	0.86±0.29	1.33±0.26
Turbidity JTU	800±177.95	41.25±11.08	168.75±254.17
Conductivity μmhocm^{-1}	0.140±0.02	0.263±0.02	0.240±0.02
T.S mg/l	825±170.78	350±57.73	450±129.09
TDS mg/l	325±95.74	175±50.0	200±81.64
TSS mg/l	500±81.64	175±50.0	250±100
pH	8.07±0.09	8.35±0.23	8.4±0.29
Total alkalinity mg/l	143±33.25	143.25±27.06	182.25±3.77
Total Hardness mg/l	75.5±12.50	95±2.16	83.25±2.06
Calcium mg/l	28.63±9.07	40.87±9.61	46.59±2.56
Magnesium mg/l	11.43±1.29	13.2±2.39	9.55±1.00
Chloride mg/l	37.08±3.73	26.80±4.80	28.55±3.72
Free CO_2 mg/l	1.3±0.17	0.87±0.16	1.32±0.09
D.O mg/l	10.46±0.94	12.61±0.19	10.58±0.78
B.O.D mg/l	2.81±0.32	2.19±0.10	2.79±0.38
C.O.D mg/l	5.25±0.80	3.40±0.07	5.15±0.81
Phosphates mg/l	0.60±0.05	0.48±0.06	0.57±0.04
Nitrates mg/l	0.44±0.10	0.46±0.05	0.58±0.10
Sodium mg/l	0.27±0.01	0.34±0.02	0.25±0.02
Potassium mg/l	0.35±0.03	0.37±0.03	0.39±0.06

values, however a temperature higher them 15°C facilitates the development of microorganisms and in the same time intensifies the organoleptical parameters such as odors and taste and activates the chemical reactions. From the results obtained, it is noticed that the pH lies between 8.07±0.09 to 8.4±0.29. According to the potability standards of natural water the pH varies usually between 7.2 and 7.6 and hence increase is noticed in the pH (pH= 8.4) which can result from the dissolution of calcium and magnesium existing from the mountain region which indicates that water is slightly alkaline in nature. Conductivity did not show a significant seasonal variation and ranged between 0.140±0.02 µmhocm^{-1} to 0.263±0.02 µmhocm^{-1}. Higher conductivity values were measured in winter and minimum in monsoon indicating the significant influence of the river inflow. Seasonal fluctuations in the values of TDS of the river were recorded. These were maximum in summer and monsoon and minimum in winter. This pattern of fluctuations in TDS is in conformity with those of Gurumayum *et al*. [29]. However, Rajurkar *et al*. [30] have reported minimum values of TDS during post monsoon. The Total solids and Total suspended solids concentration presented a significant spatial and seasonal variation with higher values measured in Monsoon. This is due to high discharge in this season bringing soil and other sediments and resulting in turbidity which was recorded maximum in monsoon and minimum in winter which was because of rains bringing the sediments from the adjoining areas and due to turbulent flow which stirred up the non living matter like silt and sand at the bottom of the river. High values of turbidity have also been reported during rainy season in other rivers like Vamura [31] and river Ganga [32]. In river Panchnada, higher turbidity values during summer have been reported by Narayan and Chauhan [33].

A marked difference in the seasonal values of transparency, total dissolved solids (TDS) and velocity was also noticed. Transparency of the river was poor during monsoon, but it considerably improved during winter and summer months. TDS and velocity showed a similar trend of seasonal fluctuation. The concentration of dissolved oxygen (DO) showed a variation of 10.46±0.94 mg/l to 12.61±0.19 mg/l and free CO_2 ranged from 0.87±0.16 mg/l in winter to 1.32±0.09 mg/l in summer. Relatively higher values of free CO_2 were observed during late summer, i.e., May–June 2011. These could be explained on the basis of high summer temperature which accelerated the process of decay of organic matter and respiratory activities of organisms, resulting in the addition of large quantities of CO_2 to the water. The results of the present findings are in conformity with the finding of Nath and Srivastava [34] (2001) and Gurumayum *et al*. [29] who have also reported higher values of free CO_2 during summer and monsoon months. However, Das *et al*. [35] have reported low values of free CO_2 during monsoon in river Brahmaputra. An increase in DO content was observed in winter and remained almost stable for three to four months however it changes as the temperature starts increasing during the summer and a further change in monsoon. The variation of DO seasonally is a function of physico-chemical properties of water, which alter its solubility [36] and also as a result of imbalance between the process of photosynthesis, degradation of organic matter and reaeration [37]. A gradual decrease in the BOD values was observed in all the three seasons. The biochemical oxygen demand levels indicate low concentrations of biodegradable organic matter, high oxygen consumption by heterotrophic organisms and a high rate of organic matter remineralization. The values ranged from 2.19±0.10 to 2.81±0.32 mg/l, lowest and highest being observed during winter and monsoon respectively. The lower BOD contents could be due to lower pollution load and low organic matter in the river water at Kalsi during the winter season. Maximum value of BOD was observed during late summer (May–June 2011). This may be attributed to higher rate of decomposition of organic matter at higher temperature. Similar results were observed by Sanap *et al*. [38]. Relatively higher values of BOD were recorded during monsoon (July–August 2011). Minimum value of BOD was observed during winter (December 2010–January 2011). This was because of a decrease in temperature and dilution in the concentration of dissolved organic matter. Total alkalinity values in the present study ranged between 143.0 ±33.25 mg/l and 182.25±3.77 mg/l. The highest concentration of alkalinity was recorded in summer. Higher values of total alkalinity might be due to the presence of excess of CO_2 produced in summer as a result of decomposition processes. Similar observations were recorded by Singh [39]. Whenever there is increase in dissolved oxygen levels, there is definite increase in alkalinity. Agarwal and Thapliyal [40] also obtained maximum alkalinity during winter months in Bhilangana. According to Moyle [41] water bodies having total alkalinity above 50mg/l can be considered productive.

The water samples recorded a low level of total hardness (75.5±12.50 mg/l to 95±2.16 mg/L). The total hardness has no known adverse effects on human health and the recorded values were well below the guideline value for drinking purpose (400 mg/L). Primarily, the calcium and magnesium present are responsible for the hardness of the water. The desirable limit for calcium in water is (75 mg/L) and the maximum permissible limit is (200 mg/L) and for magnesium these values are 30 and 100 mg/L respectively. In the present investigation, we have observed that the values for calcium were 28.63±9.07 mg/l to 46.59±2.56 mg/L and those for magnesium, 9.55±1.00 mg/l to 13.2±2.39 mg/L. Similar findings are reported by Sedemekar and Angadi [42].

The presence of chloride in water was not in excess amounts which mean water was desirable. Its origin is mainly from mineral weathering of bed rocks as well as from anthropogenic source. In the present investigation, the concentrations of chloride were 26.80±4.80 mg/l to 37.08±3.73 mg/L respectively. The desirable limit of chloride is 250mg/L and the maximum permissible limit is 400 mg/L. The concentration of chloride was thus lower than the desirable and permissible limit and water was mostly used for drinking and other domestic purposes. In the present investigation, average phosphate values were 0.60±0.05 mg/l in monsoon, 0.48±0.06 mg/l in winter and 0.57±0.04 mg/l in summer. Little variations in phosphate content were recorded in all the three seasons whereas a great variation was found monthly. Phosphates showed lower values, but there was a definite increase in phosphate concentration in summer months. These results are in conformity with Khanna *et al*. [4]. Phosphate is the key nutrient in the productivity of water [43]. In general, the concentration decreased in the monsoon months due to accumulation of rainwater. There are various sources of phosphates to the river water, such as firm rock deposit, runoff from surface catchments and interaction between the water and sediment from dead plant and animal remains at the bottom of the river. Phosphate is considered to be the most significant among the nutrients responsible for growth of aquatic life. According to Dixit *et al*. [44], atmospheric input, as well, may account for a significant proportion of the influx of nutrients to the river water.

Average nitrate values of River Yamuna are given in the Table 1 and seasonal variations do not showed a great change. Nitrates entering aquatic system arise from a variety of sources which are mostly contributing to aquatic pollution. The important source of nitrates is the domestic runoff and decomposition of organic matter and domestic sewage. The values obtained during the present study indicated low pollution and absence of waste water. According to Ganapathi [45], the non-polluted tropical waters are generally deficient in nitrates, but the factors like discharge of sewage, runoff and nitrogen fixation may increase nitrates concentration in water bodies. Sodium and potassium are the monovalent cations commonly present in water. These ions do not produce hardness to water. However, significantly high amounts of these ions in water create problem in its taste as well as make the water unsuitable for irrigation purpose. In the present study, the concentration of sodium and potassium was well below the permissible limits as given in Table 1.

Table 2: Showing Pearson correlation coefficient between Physico-chemical parameters of River Yamuna at Kalsi from August 2010-July 2011

	Temp.	Trans- parency	Velocity	Turbidity	EC	TS	TDS	TSS	pH	Total Alkalinity	Total Hardness	Ca	Mg	Cl	Free CO_2	DO	BOD	COD	PO_4	NO_3	Na	K
Temp.	1																					
Transparency	-0.72	1																				
Vel.	0.80	-0.99	1																			
Turbidity	0.66	-0.99	0.98	1																		
EC	-0.68	0.99	-0.98	-0.99	1																	
TS	0.70	-0.99	0.98	0.99	-0.99	1																
TDS	0.66	-0.99	0.98	0.99	-0.99	0.99	1															
TSS	0.71	-0.99	0.99	0.99	-0.99	0.99	0.99	1														
pH	-0.42	0.92	-0.88	-0.95	0.94	-0.94	-0.95	-0.93	1													
T Alk	0.44	0.28	-0.17	-0.36	0.34	-0.32	-0.36	-0.30	0.62	1												
T Hd	-0.93	0.91	-0.95	-0.88	0.89	-0.90	-0.88	-0.91	0.70	-0.11	1											
Ca	-0.25	0.85	-0.78	-0.88	0.88	-0.86	-0.89	-0.85	0.98	0.74	0.57	1										
Mg	-0.82	0.21	-0.32	-0.13	0.15	-0.18	-0.13	-0.20	-0.15	-0.87	0.58	-0.32	1									
Cl	0.67	-0.99	0.98	0.99	-0.99	0.99	0.99	0.99	-0.95	-0.36	-0.88	-0.88	-0.14	1								
Free Co_2	0.99	-0.66	0.74	0.59	-0.61	0.63	0.59	0.64	-0.33	0.52	-0.90	-0.16	-0.87	0.60	1							
DO	-0.99	0.72	-0.79	-0.66	0.68	-0.69	-0.66	-0.71	0.41	-0.45	0.93	0.25	0.83	-0.66	-0.99	1						
BOD	0.99	-0.70	0.78	0.65	-0.66	0.68	0.65	0.69	-0.39	0.47	-0.92	-0.23	-0.84	0.65	0.99	-0.99	1					
COD	0.99	-0.72	0.79	0.66	-0.68	0.69	0.66	0.71	-0.41	0.45	-0.93	-0.25	-0.83	0.66	0.99	-0.99	0.99	1				
Po_4	0.98	-0.84	0.89	0.79	-0.80	0.82	0.79	0.83	-0.58	0.27	-0.98	-0.43	-0.70	0.79	0.96	-0.98	0.97	0.98	1			
No_3	0.33	0.40	-0.29	-0.47	0.46	-0.43	-0.47	-0.42	0.71	0.99	0.01	0.82	-0.80	-0.47	0.41	-0.33	0.35	0.33	0.14	1		
Na	-0.96	0.52	-0.61	-0.45	0.46	-0.48	-0.44	-0.50	0.16	-0.66	0.81	-0.006	0.94	-0.45	-0.98	0.96	-0.97	-0.96	-0.89	-0.56	1	
K	-0.05	0.72	-0.63	-0.77	0.76	-0.74	-0.77	-0.73	0.92	0.86	0.39	0.97	-0.51	-0.77	0.03	0.04	-0.02	-0.04	-0.24	0.92	-0.21	1

All Values are significant at 0.05 and 0.001

Relationship Among Hydrological Attributes: The statistical correlation data among the hydrological attributes is presented in Table 2 and the data on the correlation between the diversity of total aquatic insects in the river Yamuna at Kalsi is presented in Table 4. Temperature and Velocity was highly intercorrelated. Turbidity was negatively correlated with transparency (r = -0.99, p > 0.001). Conductivity was positively correlated with transparency (r = 0.00, p > 0.001). Total Solids were positively correlated with Turbidity (r = 0.99, p > 0.001). TDS and TSS were highly positively correlated with Turbidity and Total Solids. pH showed an inverse relationship with Temperature (r = -0.42, p < 0.05). Total Alkalinity was positively correlated with Temperature, Transparency but showed an inverse relationship with TS, TDS and TSS. Total Hardness was positively correlated with Conductivity (r = 0.89, p > 0.001) but negatively correlated with velocity (r = -0.95, p > 0.001). Calcium and Magnesium was positively correlated with Total Hardness (r = 0.57, p> 0.05) and (r = 0.58, p > 0.05) but showed an inverse relationship with TSS (r = -0.85, p >0.001) and (r = -0.20, p < 0.05). Chloride showed a negative relationship with Conductivity (r = -0.99, p > 0.001). Free Co_2 was positively correlated with Temperature (r = 0.99, p > 0.001) but negatively correlated with pH (r = -0.33, p < 0.05). DO showed an inverse relationship with Temperature and Free CO_2 but positive relationship with pH and Transparency (r = 0.41, p < 0.05) and (r = 0.72, p > 0.05). BOD and COD showed inverse relationship with DO (r = -0.99, p > 0.001) and (r = -0.99, p > 0.001), but showed positive relationship with Temperature and Free CO_2. Phosphate was negatively correlated with pH (r = -0.58, p > 0.05) but positively correlated with Total Alkalinity (r = 0.27, p < 0.05). Nitrate showed an inverse relationship with Turbidity (r = -0.47, p < 0.05) but was positively correlated with Phosphate (r = 0.14, p < 0.05). Sodium and Potassium was positively correlated with Conductivity and Total Hardness but negatively correlated with Phosphate (r = -0.89, p > 0.001) and (r = -0.24, p < 0.05).

Macrovertebrate Diversity and Their Relationship with Hydrological Attributes: Benthic aquatic insects are sensitive indicators of environmental changes in streams because they express long term changes in water and habitat quality rather than instantaneous conditions [46]. Physicochemical variables, such as water temperature, dissolved oxygen, discharge, nutrients and substrate, influence community structure and function of aquatic insects [47]. Invertebrate communities are also good indicators of water quality conditions [48]. The total density of benthic macroinvertebrate fauna exhibited a generally increasing trend from winter to monsoon (Table 3); however, it varied significantly from taxa to taxa. Macroinvertebrates were mostly contributed by the immature stages (nymphs) of aquatic insects. These nymphs belonged to the orders of Ephemeroptera (mayflies), Plecoptera (stone flies), Trichoptera

Table 3: Average (Mean ± SD Values) seasonal spatial qualitative and quantitative distribution of Macroinvertebrates (ind.m^{-2}) in River Yamuna at Kalsi from August 2010 to July 2011

Macrobenthos	Monsoon	Winter	Summer
Ephemeroptera			
Ephemera	1.25 ±2.50	30.0±4.24	7.25±7.36
Baetis	6.75±7.32	37.25±7.88	19.0±12.49
Caenis	5.0±6.0	32.0±6.05	11.25±13.5
Leptophlebia	6.5±11.09	42.50±10.84	17.5±15.35
Cleon	0.75±1.50	9.75±10.50	7.75±12.97
Heptagenia	6.75±8.30	30.25±6.29	17.25±11.14
Total	27.0±35.84	181.5±42.01	80.0±69.92
Diptera			
Dixa	1.75±2.36	19.25±7.36	13.5±13.17
Chironomous	8.75±6.39	28.25±8.22	10.75±10.78
Simulium	1.0±2.0	10.50±7.41	7.50±10.53
Antoch	0.50±1.0	14.75±6.89	7.50±7.14
Bibiocephala	1.25±1.89	13.75±6.39	4.50±4.43
Total	13.25±13.07	86.50±34.34	43.75±44.93
Coleoptera			
Laccobius	1.0±2.0	11.0±2.82	3.75±2.98
Hydraticus	1.0±1.41	11.25±3.40	2.75±3.40
Hydrophilus	3.50±3.41	21.5±6.19	6.25±6.13
Dryops	0.75±1.50	13.5±4.65	2.50±3.31
Total	6.25±6.50	57.25±14.26	15.25±14.81
Hemiptera			
Micronecta	1.25±2.50	14.25±7.32	6.50±5.44
Heleoceris	5.0±4.39	16.5±4.93	3.75±3.86
Gerris	1.0±2.0	2.5±3.0	0.0±0.0
Total	7.25±8.34	33.25±13.93	10.25±9.25
Plecoptera			
Perla	5.0±5.83	25.75±8.99	9.75±5.56
Isoperla	3.25±6.5	23.75±4.78	8.0±3.91
Capnia	0.25±0.50	10.25±4.11	2.75±3.40
Total	8.50±11.35	59.75±15.15	20.50±12.71
Odonata			
Corixa	0.75±1.50	12.25±4.11	4.75±3.77
Agrion	0.0±0.0	5.25±5.12	2.50±3.31
Matrona	0.25±0.25	12.0±9.27	2.0±2.82
Total	1.0±1.41	29.5±17.71	9.25±9.63
Trichoptera			
Hydrosyche	6.75±6.94	28.25±6.18	10.50±5.0
Glossoma	2.75±3.40	17.25±4.11	3.75±2.98
Hydroptila	0.0±0.0	11.0±5.35	1.25±2.50
Total	9.50±9.88	56.5±15.19	15.50±10.08

Table 4: Showing Pearson correlation coefficient (r) between Physico-chemical parameters and Macro benthic diversity of River Yamuna at Kalsi from August 2010-July 2011

	Tempe-rature	Trans-parency	Velocity	Turbidity	Condu-ctivity	T.S	TDS	TSS	pH	Total Alkalinity	Total Hardness	Calcium	Mag-nesium	Free CO_2	D.O	B.O.D	C.O.D	Chlo-ride	Phos-phates	Nit--rates	Sod-ium	Pota-ssium
Ephemeroptera	-0.95	0.89	-0.94	-0.85	0.86	-0.88	-0.85	-0.89	0.66	-0.17	0.99	0.52	0.63	-0.92	0.95	-0.95	-0.95	-0.85	-0.98	-0.05	0.86	0.37
Diptera	-0.93	0.92	-0.96	-0.90	0.90	-0.91	-0.89	-0.92	0.72	-0.09	0.99	0.59	0.56	-0.89	0.93	-0.92	-0.92	-0.89	-0.97	0.02	0.81	0.45
Coleoptera	-0.99	0.80	-0.86	-0.75	0.76	-0.78	-0.75	-0.79	0.52	-0.34	0.97	0.36	0.76	-0.97	0.99	-0.99	-0.99	-0.75	-0.99	-0.23	0.93	0.20
Hemiptera	-0.99	0.76	-0.83	-0.71	0.72	-0.74	-0.71	-0.75	0.47	-0.40	0.95	0.31	0.79	-0.98	0.99	-0.99	-0.99	-0.71	-0.99	-0.29	0.95	0.14
Plecoptera	-0.98	0.83	-0.89	-0.79	0.80	-0.81	-0.79	-0.83	0.57	-0.28	0.98	0.42	0.72	-0.96	0.98	-0.98	-0.98	-0.78	-0.99	-0.17	0.91	0.26
Odonata	-0.97	0.86	-0.92	-0.82	0.83	-0.85	-0.82	-0.86	0.62	-0.23	0.99	0.47	0.67	-0.94	0.97	-0.96	-0.97	-0.82	-0.99	-0.11	0.88	0.32
Trichoptera	-0.99	0.77	-0.84	-0.72	0.73	-0.75	-0.72	-0.76	0.48	-0.39	0.95	0.32	0.79	-0.98	0.99	-0.99	-0.99	-0.71	-0.99	-0.28	0.95	0.16

All Values are significant at 0.05 and 0.001

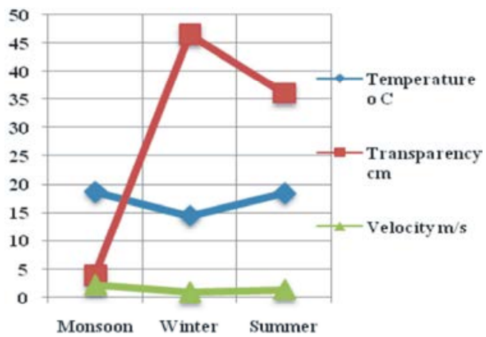

Fig. 1: Showing average seasonal variation in Temp., Transparency and velocity River Yamuna at Kalsi

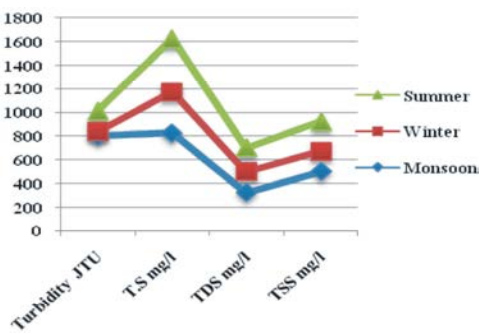

Fig. 2: Showing average seasonal variation in Turbidity, TS, TDS and TSS in River Yamuna at Kalsi

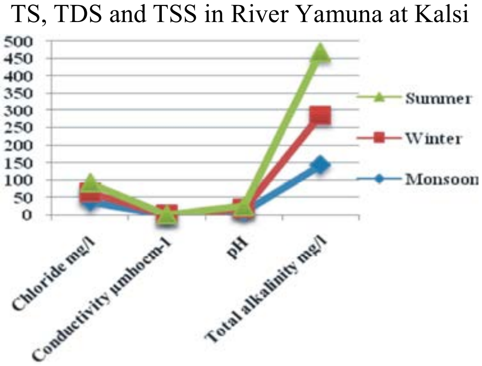

Fig. 3: Showing average seasonal variation in pH, Total alkalinity, Chloride and Conductivity in River Yamuna at Kalsi

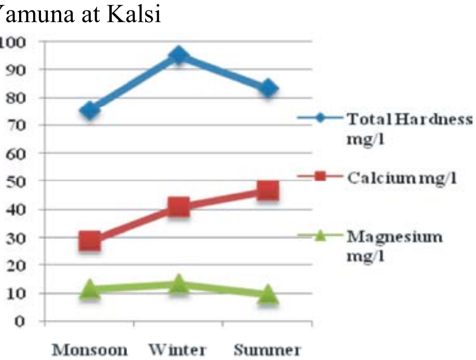

Fig. 4: Showing average seasonal variation in Total hardness, Calcium and Magnesium in River Yamuna at Kalsi

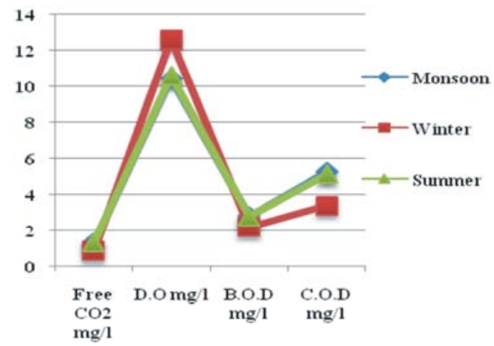

Fig. 5: Showing average seasonal variation in DO, Free CO_2, BOD and COD in in River Yamuna at Kalsi

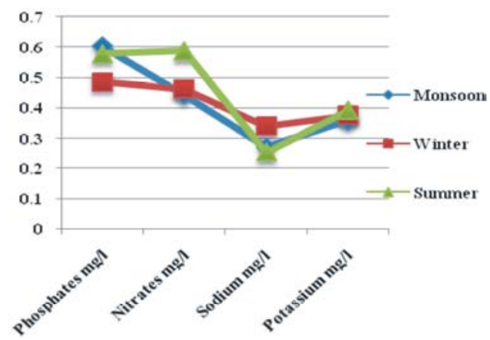

Fig. 6: Showing average seasonal variation in Phosphate, Nitrate, Potassium and Sodium River Yamuna at Kalsi

(caddis flies), Diptera, Coleoptera, Hemiptera, Odonata. The densities of macro invertebrates in all the seasons are presented in Tables 3. A total of 7 macro invertebrates taxa including 27 genera were recorded from the river Yamuna. These were represented by Ephemeroptera (114%), Diptera (57%), Coleoptera (28%), Hemiptera 922%), Plecoptera (35%), Odonata (12%) and Trichoptera (32%). The density of macro invertebrates was found to be maximum in winter (504.25 ind•m^{-2}) (Table 3) and minimum (72.75 ind•m^{-2}) in monsoon. Ephemeroptera were dominated by six genera and was represented by *Ephemera*, *Baetis*, *Caenis*, *Leptophlebia*, *Cleon* and *Heptagenia*. Members of Ephemeroptera were found to be the most dominant community in the fluvial system of River Yamuna. The density of Ephemeropterans was found to be maximum (181.5 ind•m^{-2}) in winter and minimum (27 ind•m^{-2}) in monsoon. Diptera was found to be second most abundant component among all the macroinvertebrates dwelling in the river. It was represented by *Dixa, Chironomous, Simulium, Antoch* and *Bibiocephala.* The Diptera was found maximum in winter (86.50 ind•m^{-2}) and minimum in monsoon (13.25 ind•m^{-2}) The Coleoptera was represented by *Laccobius, Hydraticus, Hydrophilus and Dryops.*

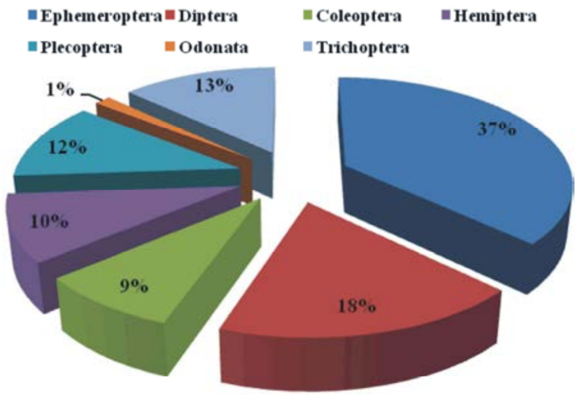

Fig. 7: Monsoon.

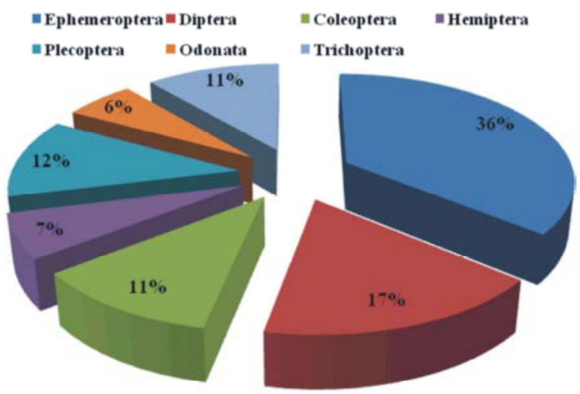

Fig. 8: Winter

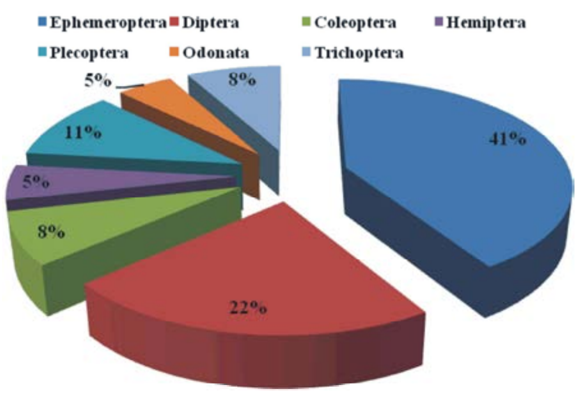

Fig. 9: Summer

Fig. 7,8,9:Showing average seasonal (Monsoon,Winter and Summer) Macrobentic diversity of River Yamuna at Kalsi from August 2010 to July 2011.

The Coleoptera ranged from (57.25 ind•m^{-2} to 6.25 ind•m^{-2}) and was found maximum in winter. The Hemiptera was dominated by *Micronecta, Heleoceris and Gerris* whereas Plecoptera was represented by *Perla, Isoperla and Capnia.* However the density of Plecoptera was found maximum than Hemiptera. The Odonata and Trichoptera were represented by *Corixa, Agrion, Matrona* and *Hydrosyche, Glossoma, Hydroptila*. The Trichoptera was found maximum in winter (56.5 ind•m^{-2}) whereas Odonata ranged from (29.5 ind•m^{-2} to 1.0 ind•m^{-2}). A thorough perusal of the above data revealed that the maximum abundance of macroinvertebrates was recorded in winter and minimum in monsoon. So the sequence of abundance of macroinvertebrates in River Yamuna was winter > Summer >Monsoon.

Most aquatic habitats, particularly free flowing water streams and waters with acceptable water quality and Physico-chemical conditions support diverse macroinvertebrate communities in which there is a reasonably balanced distribution of species among the total number of individuals present. Such communities respond to changing habitats and water quality by variations in community structure (invertebrate abundance and composition) [49]). However, many habitats, especially disturbed ones, are dominated by few species. Several factors were known to influence the distribution of aquatic macroinvertebrates, but the important factors likely to affect the diversity and abundance in an aquatic ecosystem, are water temperature, water velocity, transparency and turbidity [50]. Stanford and Ward [51] also suggested that water flow, temperature and substrates are the major factors determining the composition and abundance of benthic invertebrates. Every species is restricted in its distribution to a certain range of latitude and altitude under a certain temperature range. Lekmkuhl [52] studied the influence of water temperature variations on a benthic community. The high abundance of macroinvertebrates during winter may be explained as due to relatively low velocity of water current, high dissolved oxygen, high transparency and low turbidity of water. The macroinvertebrate density declined in the monsoon season. The reason for this may be low dissolved oxygen content due to high turbidity which may be the cause of less penetration of light and low phototosynthetic activity, thus a disturbance in food chain which result in low benthic diversity. The average macrobenthic density showed an inverse relationship with Temperature, Velocity and Turbidity but was positively correlated with transparency. Benthic invertebrates are particularly sensitive to different water velocities and bed sediment/stability [53, 54]. High flow events have been identified in many studies to greatly reduce the biomass and change the species composition of invertebrates in aquatic ecosystems. Many aquatic populations living in the harsh environment of unpredictable flow suffer high mortality from physiological stress.Similar results were also found during the study on the river Chandrabhaga [55]. Maximum abundance of macro-invertebrates was found during winter season (November - February) in the river Yamuna, which may be due to increased growth efficiency of insects during this period in addition to hydrological attributes. The macrobenthic density was negatively correlated with TS, TDS and TDS but positively correlated with pH. The abundance of benthic macro-invertebrates dwelling in the Yamuna River was found to be increasing from October to May and then gradually decreases from June. The increase during October to May may be due to low turbidity, increased transparency, low water velocity and high dissolved oxygen. The abundance of macro-invertebrates in the Yamuna River was found to be at the minimum during the monsoon season (July– September). This can be explained by high turbidity, high total dissolved solids, high water velocity and low dissolved oxygen during the monsoon season. Emergence of insects from the Yamuna River may also be one of the possible reasons for the decrease in abundance during the monsoon season [56]. The bentic fauna diversity was found to be positively correlated with Total Hardness, Calcium and magnesium but was negatively correlated with Total Alkalinity. The macrovertebrate density was positively correlated with Dissolved Oxygen. Nelson *et al*. [57] have also shown that dissolved oxygen has a strong influence on macro-invertebrate community structure. They opined that the higher dissolved oxygen level in open water habitats is necessary for substantive growth of macro-invertebrate populations [58].

CONCLUSION

The diversity of macro-invertebrates in the river Yamuna in different seasons was found to be in the order winter> summer > monsoon. The annual mean macro-invertebrate diversity was found to be highest in winter and minimum in monsoon. The abundance of macro invertebrates was also found to be highest winter in the present study on the Yamuna River in Doon Valley. This variation may be due to the variations in phytoplankton composition as well the hydrological attributes prevailing in all the three seasons. It may be inferred from the above discussion that the nature of the physico-chemical environmental parameters dominate the river which influence the diversity of aquatic benthos. Overall the conditions of River Yamuna at Kalsi are still justifiable however if not monitored continuously and if proper management strategies were not followed, the day will not be far when the River Yamuna in Uttarakhand will be facing the challenge of being the symbol of purity.

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