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Temporal assessment using WQI of River Henwal, a Tributary of River Ganga in Himalayan Region

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Abstract

Limnological study plays a vital role in determining the seasonal water quality in terms of the physico-chemical parameters, heavy metals, the density, diversity and occurrence of planktons at four different sites of an aquatic ecosystem. The present study is conducted to assess the relationship between physicochemical parameters and different groups of plankton through statistical approaches to assess the quality of Henwal river. Different kind of indices (CPI, Simpson's diversity index (D), Shannon-Weaver index (H) and Taxon Evenness (E) are used to depict the water quality of Henwal river. CPI was used by considering eleven physicochemical parameters and eight heavy metals. The range of CPI was found to be 2.07-8.83 (CPI > 2), which is an indication of severely polluted water of Henwal river. Control site was slightly polluted but moderately in monsoon as CPI 1.61-3.24. Jajal shows the highest CPI values which indicates that it is severely polluted. Nagni had the highest diversity index (D = 4.69, H = 1.58) of the four sites in the monsoon season and the Khadi had the lowest diversity index (D = 3.84, H = 1.48) in the winter season.

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Introduction

In India, 14 major river systems shares about 83% of the drainage basin. The Himalayas are the source of freshwater rivers so they can be called "the cradle of major rivers" that supports the life of many ecosystems(Matta, Gagan, 2010; Cherian and Matta, 2010; Prachi, *et al*., 2011; Singh, *et al*., 2011). The Himalayan Rivers receive about 20-30 % of their water from melted snow during the summer and monsoon seasons and are also important in a geopolitically context which has been realized and attracted the attention of country's planners towards the developmental activities of this mountain region (Matta, *et al*., 2015c; Matta, *et al*., 2015d; Matta, *et al*., 2016; Matta and Gjyli, 2016).

Garhwal region in Uttarakhand state lying between the latitude of 29° 26' - 31° 28' N and longitude 77° 99' - 80° 6' E with an area of 30,000 km (approx) has vast source of fresh water bodies are present in the form of rivers, rivulets, tributaries, and springs, fulfilling the freshwater requirement of the population (Khanna and Matta, 2009; Singh, *et al*., 2010; Matta, *et al*., 2011; Tewari, *et al*., 2010). Along with a large number of snow-fed rivers and streams such as Alaknanda, Bhagirathi, Mandakini Dhauliganga, Pindar and Ganga River, there are so many springs fed rivers such as Bhilangna, Nayar, Gular, Song, Suswa, Henwal and hundreds of rivulets (Matta, *et al*., 2014; Matta and Kumar, 2015; Matta, Gagan, 2015a; Matta, *et al*., 2015a; Matta, Gagan, 2015b; Matta, *et al*., 2015b).

River Henwal is spring fed river. It originates from Kaddukhal (Near Surkanda Devi Temple, Chamba, Uttaranchal) and its length is near about 38 kilometers. This river can be divided into three different ecological sections, *viz.*, the upper, the middle and the lower section. River substratum is stony, rocky and pebbly and finally, it is sandy, when it meets the River Ganga (Bhadauriya, *et al*., 2011; Matta, Gagan, 2014a; Matta, Gagan, 2014b). Due to the great variation in the velocity and temperature of the water, the biodiversity may also vary.

The present study is to assess the influence of anthropogenic activities on water quality in terms of limnological characters of spring fed River Henwal, a tributary of River Ganga. Henwal River is originating from Surkanda hills (2900 msl) in the greater Himalayas and merges into River Ganga at Shivpuri. The present study has been carried out by considering the importance of aquatic ecosystems of Himalayas with special reference to Garhwal region.

Materials and Method

Study Area

The present study has been carried out in Chamba, Distt. Tehri Garhwal to examine pollution status of River Henwal, located in newly carved state of Uttarakhand. Chamba is situated at a junction of roads connecting Mussoorie and Rishikesh with the Tehri Dam reservoir and New Tehri. Its nearby tourist places are Dhanaulti, Surkanda Devi Temple, Ranichauri, New Tehri, and Kanatal, halfway between Chamba and Dhanaulti. About 50 km from Mussoorie, the small hill town of Chamba, Uttaranchal, is another of those destinations yet unknown to most tourists and therefore unspoilt and fresh like a daisy for the lucky few who venture out seeking new places to explore and enjoy. Chamba is situated at an altitude of 1600m above sea level with coordinates 30.21°N

78.23°E. There are pleasant forests of pine and deodar trees, with some good views.

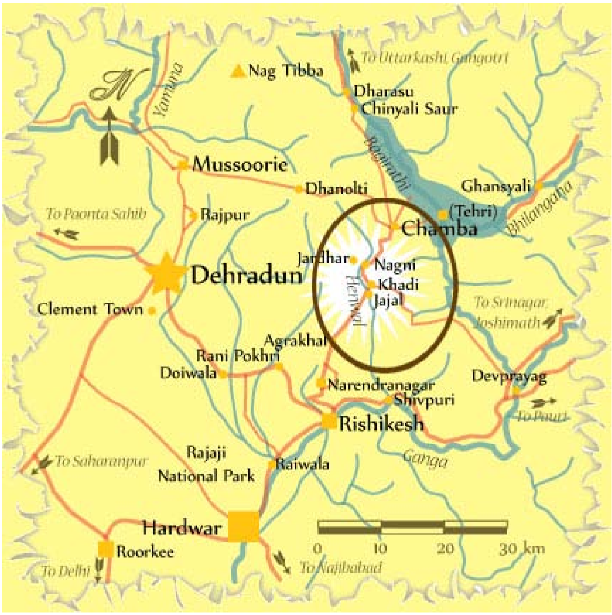

Fig. 1: Map showing sampling location on River Henwal

During course study period physico-chemical parameters of River Henwal were studied. Water samples were taken from three different sites of Henwal River *i.e.* from Nagni, Jajal and Kharee (Fig. 1). This river is the tributary of Holy River Ganga proving water for irrigation, domestic and for other purposes. Due to number of uses, comprehensive river water quality monitoring program is becoming a necessity in order to safeguard public health and to protect the valuable and vulnerable fresh water resources (Kannel *et al*. 2007 and Singh, 2010).

Samples collection and analysis

Water samples were collected seasonally during 2011 to 2012. Samples were collected using a clean plastic bucket, transferred to clean plastic bottles and transported to the laboratory on ice and stored in a deep freezer (-20°C) till analysis. Samples were collected in triplicate from each site and average value for each parameter was reported. The physical parameters like pH, Temperature, DO, Transparency, Velocity, and Free CO_2 are recorded on the spot and other chemical parameters are recorded in the Laboratory which were determined using standard methods (Khanna *et al*., 2011; APHA, 2012).

Statistical Analysis

All the data obtained subjected to statistical analysis. In statistical analysis, a correlation developed between parameters by using Karl Pearsons's coefficient of correlation for data analysis of River Henwal water to measure the variations between Site I and Site II parameters. MS Excel, 2007 was used to measure the Mean and Standard deviation (SD) of the data. For other statistical analysis like correlation Minitab 16 was used.

Comprehensive pollution index (CPI): This CPI has been applied to classify the water quality status by many of the research findings (Zhao, Y. *et al.*, 2012). It is evaluated by the following equations as:

$$PI = \frac{\text{Measured concentration of individual parameter}}{\text{Standard permissible concentration of parameter}} \quad (1)$$

$$CPI = \frac{1}{n}\sum_{i=0}^{n} PI \quad (2)$$

Where PI is the pollution index of individual water quality parameter considered, n is the number of parameters and CPI is a comprehensive pollution index. The standard permissible concentrations of each parameter considered in the study were obtained from the norms of the Indian government for a general discharge of environmental pollutant (CPCB; 2011, EPA; 1986, BIS; 2012, WHO; 2011). CPI ranges from 0 to 2 which classify water quality as: ≤0.20 is Clean; 0.21–0.40 is Sub-clean; 0.41–1.00 is slightly polluted; 1.01–2.0 is moderately polluted; ≥2.01 is severely polluted.

Simpson's diversity index (D):

The Simpson's diversity index (D) is calculated using the following equation:

$$D = 1/\sum (P(i))^2$$

where p(i) is the fraction of the total sample made up by the species,

$$p(i) = n(i)/N$$

where n(i) is the number of the individuals and N is total number of all species

Shannon-Weaver index (H):

This is widely used method of calculating biotic diversity in aquatic and terrestrial ecosystems and is expressed as:

$$H = -\sum P(i) \ln P(i)$$

where p(i) is the fraction of the total sample made up by the species,

$$p(i) = n(i)/N$$

where n(i) is the number of the individuals and N is total number of all species

Taxon Evenness

This is relative distribution of individuals among taxonomic groups within a community) and is expressed as:

$$E = H/\ln(R)$$

Where E= Taxon Evenness, R is the Taxon Richness defined as total no. of distinct taxa in a population.

Result and Discussion

The result from the seasonal variation in physicochemical, heavy metal and plankton analysis of river Henwal indicated the quality status of water. The values of water may be affected in a variety of ways by pollution. Variations in physicochemical and heavy metal properties of River Henwal in summer, winter and monsoon seasons at control site, Nagni, Khadi and Jajal sampling sites are appended in Table 1-4. CPI was used to depict the seasonal and site wise water quality in Table 5 and through graphical representation in Fig. 3. Plankton composition is represented in Table 6-9 and different diversity indices were used for groups of zooplankton.

Velocity has an impact on the DO levels in a river stream. Water velocity of river Henwal was within the range of 0.63m/s in summer to 1.11m/s in monsoon at Jajal. This was due to climatic conditions in which water level and its velocity started increasing from winter season onwards due to melting of snow at the place of origin of the river. Joshi *et al.*, (2009) also reported the maximum velocity 2.18 m/s of the Ganga at Haridwar was recorded in monsoon season and the minimum velocity 0.39m/s were observed in winter season

Seasonally change in temperatures observed in this study shows a gradually increase from autumn to summer and starts slightly decrease in monsoon season at all sampling location throughout the study period. The average range of temperature is 13^0C to 28^0C throughout the study period. Water temperature is an important parameter which influences the chemical process such as dissolutionprecipitation, adsorption – desorption, oxidation – reduction and physiology of biotic community in an aquatic habitat (Aken, 2008). Highest temperature was recorded during the summer and lowest was in winter season on all the sites of Henwal river (Table. 1-4).

The average value of conductivity was within the range of 97.69 siemen/cm in winter at control site to 125.76 siemen/cm in autumn at control site.

Turbidity of water is an important parameter, which influences the light penetration inside water and thus affects the aquatic life (Verma and Saksena, 2010; Tambekar *et al.,* 2013). River water was turbid with the average range of 21.84 JTU in autumn at Jajal to 365.95 JTU in monsoon season at Khadi.

In the present study maximum range of TS (411.15-510.15 mgl^{-1}) was recorded in monsoon as compared with summer and winter seasons (Table 1-4). Higher values of TS (510.15 mgl^{-1}) was observed in monsoon season at Jajal as compared to other sites. Matta and Kumar, 2015 reported maximum range of TS (351.00-1039.00 mg/l) in the Ganga river water at Haridwar.

Dissolved oxygen (DO) is an important indicator to depict the water quality of any aquatic system and helps to support a well balanced aquatic life. The DO concentration showed remarkable seasonal variations with the range of 7.1 mg L^{-1} in summer at Nagni to 10.4 mg L^{-1} in winters at control site and Nagni also. Dissolved oxygen concentration was registered high during the winter season followed by autumn, monsoon and summer period (Table. 1-4).

CO_2 is very important factor in existence of plants and microorganisms. It is produced due to respiration of aquatic organisms. In the present study highest concentration range of free CO_2 (0.4-1.8 mgl^{-1}) were recorded in summer season and lowest concentration was (0.1-0.9 mgl^{-1}) in winters on all sites. Kumar *et. al.*, 2014 reported higher concentration of Free CO_2 (1.58-4.29 mgl^{-1}) in kali river Pithoragarh district of Uttarakhand, India. Lower concentration of Free CO_2 was recorded in winter and higher in monsoon seasons.

In the present study the range of acidity was higher (39.79-57.22 mgl^{-1}) during winter and lower (27.54-56.82 mgl^{-1}) in autumn season at all sites recorded. Yadav and Srivastava (2011) reported maximum acidity (68.92mgl^{-1}) in Ganga river water at different sites of Ghazipur, (Uttar Pradesh) India. They reported values of acidity were seasonally high in summer followed by rainy and winter season.

The maximum range of total alkalinity (172-213 mg/l) during winter season and minimum range was (115-164.5 mg/l) recorded during monsoon season. This is due to dilution of acids present into river water during rainy season.

During the present study the maximum range of Total hardness was (138-226 mgl^{-1}) during the summer and minimum TH was (121-198 mgl^{-1}) in autumn season recorded at all four sites. In other terms of hardness (Ca^{2+} and Mg^{2+}), highest range of Ca^{2+} and Mg^{2+} (33.61-42.15 mg/l) and (14.85-27.12 mg/l) was recorded in autumn season and lower range (21.2-35.14 mg/l) and (11.89-23.84 mg/l) in winter season.

Cl affects freshwater organisms and plants by varying reproduction rates, increasing species mortality, and changing the characteristics of the entire local ecosystem. Low to moderate concentrations of both chloride and sulfate ions add palatability to water (Matta *et al.*, 2015). During the present study the maximum range of Cl^- was (7.87-12.67 mgl^{-1}) during the autumn and minimum TH was (6.10-7.92 mgl^{-1}) in winter season recorded at all four sites.

Phosphate concentration in river waters of Henwal was noticed in the range of 0.29 mg L^{-1} in winters to 0.92 mg L^{-1} in summer at Jajal.

Phytoplankton

In all sampling locations three groups of phytoplankton, diatoms, green algae and blue green algae were recorded throughout the study period. Blue-green algae were the most dominant of all the groups of phytoplankton. There was seasonally variation in their occurrence and followed no specific trend. This seasonal variation in phytoplankton's number may be due to change in temperature and nutrient access and light. Other factors such as zooplankton grazing and water column also affect phytoplankton diversity (Carstensen *et al*., 2007). Their average number get reduced in summer season due to high temperature as we move to control site (987.05) to Jajal (544.26). Several researchers have proposed temperature as a vital factor responsible for the growth of algae (Ramkrishnaiah and Sarkar, 1982; Verma and Datta Munshi, 1987; Kaushik *et al.*, 1991; Bohra and Kumar, 1999). Wisharad and Mehrotra (1988) reported that proliferation of phytoplankton from winter to summer could be attributed to progressively increasing water temperature and photoperiod. Tiwari and Nair (1998) and Senthil kumar *et al*. (2002) supported the dominance of diatoms near coastal waters in west coast of India.

Muhammad *et al*. (2005) and Tas and Gonulol (2007) have suggested spatial differences in distribution of blue green algae which may occur due to high organic pollution load leading to nutrient rich condition.

Zooplankton:

In this river the five major groups of zooplankton were identified. Those are Protozoa, Rotifer, Cladocera, Copepod and Ostracods shown in (Table-8, 11, 14 and 17). Among the five groups Protozoa are dominant species in the river Henwal at all four sites during the study period. Their average number get increased in autumn season (286.23) at control site to Jajal (326.49). The sequence of zooplankton groups at control site found in order of protozoan> rotifers > cladocera> copepod> ostracoda. Group Diversity indices for control site during study period also demonstrated values of Group Richness, Evenness, Shannon-Weiner Index and Simpson Index respectively (Table 8, 11, 14 and 17).

Nagni had the highest diversity index (D = 4.69, H = 1.58) of the four sites in the monsoon season and the Khadi had the lowest diversity index (D = 3.84, H = 1.48) in the winter season. Group richness (R) is 5. The Shannon-Wiener (H) and Simpson (D) indices can be used to indicate water quality as follows: H > 3 (or D > 6) indicates clean water, 3 > H > 2 (or 6≥ D ≥ 3) indicates slight contamination, 2 > H > 1 (or 3≥ D ≥ 2) indicates moderate contamination and 1 > H > 0 (or D < 2) indicates heavy contamination. According to these indicators, the water quality of the Henwal river slightly to moderately contaminated. These results are consistent with phytoplankton and comprehensive trophic state indices (TSIc). Xie *et al*. (1996) showed that the species diversities of copepods and rotifers responded differently to water nutrient levels; when the levels changed from nutrient-moderate to nutrient-rich, the species diversity decreased (*i.e*., nutrient enrichment decreased zooplankton diversity). Because contamination-resistant species in nutrient-rich water can become dominant, the growth of other species can be inhibited, which can decrease diversity. However, many researchers warn against using the zooplankton diversity index as a measure of water quality and have indicated the drawbacks of using the Shannon-Wiener (H) and Simpson (d) indices to calculate zooplankton diversity (Hu C. Y., 2000; Li, G. G. and Yu, Z. M., 2002; Gilbert, J. J., 1988).

Season	Water velocity (m/sec)	Water temperature(°C)	Conductivity (Siemens/cm)	Turbidity (JTU)	Total solids (mg/l)	Phosphates (mg/l)
Autumn	1.03±0.02	19.00±0.25	125.76±0.03	235.17±2.65	339.17±6.35	0.31 ± 0.14
Winters	0.84±0.14	13.00±0.26	107.27±0.02	85.48±4.32	108.15±0.21	0.64 ±0.15
Summer	0.65±0.19	23.0±1.05	119.77±0.08	82.72±7.81	164.90±1.46	0.70 ± 0.15
Monsoon	0.99±0.02	24.0±2.08	124.98±0.11	295.76±162.00	411.15±32.51	0.37 ±0.11

Season	DO (mg/l)	Free CO_2 (mg/l)	Acidity (mg/l)	Total Alkalinity (mg/l)	Total Hardness (mg/l)	Ca Hardness (mg/l)	Mg Hardness (mg/l)	Chlorides (mg/l)
Autumn	9.4±0.24	0.5±0.00	37.73±0.21	183.0±5.68	163.0±0.00	33.61±2.40	19.20±0.29	12.67±0.05
Winters	10.4±0.17	0.4±0.00	39.79±0.13	208.0±1.40	175.0±1.05	31.78±0.05	23.84±0.16	7.54±1.00
Summer	7.1±0.16	1.5±0.13	46.00±1.68	172.0±2.16	138.0±0.05	21.96±8.01	14.85±0.24	7.92±0.06
Monsoon	8.7±0.12	0.6±0.00	42.51±0.05	164.5±6.91	189.0±0.04	29.15±0.50	22.74±0.15	6.10±0.18

Season	Zn (mg/l)	Pb (mg/l)	Mn (mg/l)	Fe (mg/l)	Cu (mg/l)	Al (mg/l)	Cd (mg/l)	Mg (mg/l)
Autumn	0.14 ± 0.18	2.45 ± 1.314	0.567 ± 0.4	0.34 ± 0.455	0.288 ± 0.03	0.75 ± 0.42	0.036 ± 0.27	22.42 ±31.6
Winters	0.72 ± 0.92	0.08 ± 0.659	0.007 ± 0.41	1.168 ± 0.464	0.167 ± 0.04	0.76 ± 0.45	0.031 ± 0.26	1.89 ± 1.72
Summer	1.51 ± 1.77	0.01 ± 0.303	0.269 ± 0.37	0.544 ± 0.486	5.251 ± 0.04	0.77 ± 0.46	0.029 ± 0.3	9.78 ± 8.63
Monsoon	6.96 ± 8.19	1.38 ± 0.639	0.5 ± 0.36	0.572 ± 0.471	0.411 ± 0.04	0.8 ± 0.42	0.031 ± 0.28	34.95 ±29.6

Table 1: Seasonal physico-chemical and heavy metal observation at Control site

Season	Water velocity (m/sec)	Water temperature (°C)	Conductivity (Siemens/cm)	Turbidity (JTU)	Total solids (mg/l)	Phosphates (mg/l)
Autumn	0.98±0.04	17.5±0.05	106.10±0.00	134.42±2.52	188.97±62.50	0.43±0.12
Winters	0.64±0.00	14.0±0.01	101.59±0.03	29.40±0.04	79.84±0.18	0.69±0.17
Summer	0.79±0.00	26.0±0.06	124.28±0.01	184.61±8.55	189.40±0.52	0.82±0.20
Monsoon	1.05±0.05	22.5±0.60	123.98±0.52	332.45±22.46	486.79±2015	0.52 ± 0.11

Season	DO (mg/l)	Free CO_2 (mg/l)	Acidity (mg/l)	Total Alkalinity (mg/l)	Total Hardness (mg/l)	Ca Hardness (mg/l)	Mg Hardness (mg/l)	Chlorides (mg/l)
Autumn	9.7±0.07	0.2±0.10	29.52±0.02	187.0±1.47	187.0±1.25	40.50±0.12	17.36±0.05	8.31±2.54
Winters	9.3±0.05	0.1±0.15	54.29±2.52	198.0±8.97	151.0±0.05	34.80±0.03	20.56±0.15	8.94±0.02
Summer	7.6±0.17	0.9±0.10	45.52±0.17	212.0±0.00	226.0±3.56	27.50±0.22	25.64±0.58	6.79±0.15
Monsoon	8.2±0.30	0.4±0.00	32.54±0.23	134.0±0.37	191.0±8.26	40.63±1.85	23.54±0.26	6.54±2.50

Season	Zn (mg/l)	Pb (mg/l)	Mn (mg/l)	Fe (mg/l)	Cu (mg/l)	Al (mg/l)	Cd (mg/l)	Mg (mg/l)

Autumn	1.27 ± 0.66	0.56 ± 0.267	1.482 ± 0.35	0.329 ± 0.421	0.007 ± 0.03	0.83 ± 0.38	0.004 ± 0.24	1.27 ± 1.51
Winters	10 ± 10.8	1.15 ± 6.047	1.505 ± 0.34	5.413 ± 0.393	0.254 ± 0.03	0.54 ± 0.34	0.016 ± 0.32	1.23 ± 1.47
Summer	30.7 ± 33.6	1.27 ± 0.396	1.499 ± 0.43	1.52 ± 0.425	0.58 ± 0.03	0.58 ± 0.4	0.016 ± 0.29	4.94 ± 3.7
Monsoon	2.38 ± 0.34	4.27 ± 0.09	3.63 ± 0.45	1.33 ± 0.01	1.79 ± 0.63	2.63 ± 0.36	2.15 ± 0.58	0.87 ± 0.13

Table 2: Seasonal physico-chemical and heavy metal observation at Nagni

Season	Water velocity (m/sec)	Water temperature (°C)	Conductivity (Siemens/cm)	Turbidity (JTU)	Total solids (mg/l)	Phosphates (mg/l)
Autumn	0.92±1.25	17.0±0.00	108.76±1.64	99.67±3.86	227.10±0.15	0.40 ±0.14
Winters	0.71±1.15	16.00±0.00	97.69±0.01	25.36±2.06	69.94±0.36	0.60 ± 0.19
Summer	0.79±1.13	28.50±0.05	122.64±0.00	235.49±14.64	206.47±0.18	0.86 ± 0.16
Monsoon	1.07±1.66	24.00±2.12	125.13±0.60	365.95±30.25	479.49±0.12	0.38 ± 0.09

Season	DO (mg/l)	Free CO_2 (mg/l)	Acidity (mg/l)	Total Alkalinity (mg/l)	Total Hardness (mg/l)	Ca Hardness (mg/l)	Mg Hardness (mg/l)	Chlorides (mg/l)
Autumn	9.3±2.14	0.7±0.00	27.54±0.06	192.0±7.36	198.0±0.16	40.12±0.04	17.12±0.15	9.13±1.62
Winters	10.4±0.00	0.1±0.01	57.22±0.32	192.0±2.15	158.0±1.19	35.14±6.17	20.37±0.02	8.80±0.16
Summer	8.4±1.64	0.4±0.00	55.27±0.25	210.0±0.12	212.0±1.00	21.91±6.10	27.12±0.22	6.98±1.62
Monsoon	8.9±0.17	0.7±0.00	43.90±0.16	115.0±0.85	159.0±0.90	34.87±3.31	20.95±1.07	8.32±0.17

Season	Zn (mg/l)	Pb (mg/l)	Mn (mg/l)	Fe (mg/l)	Cu (mg/l)	Al (mg/l)	Cd (mg/l)	Mg (mg/l)
Autumn	2.22 ± 0.02	0.41 ± 0.564	3.57 ± 0.5	1.323 ± 0.075	1.317 ± 0.14	1.93 ± 0.51	0.202 ± 0.51	0.88 ± 0.18
Winters	0 ± 0	0.70 ± 1.531	5.316 ± 1.99	0.038 ± 0.358	27.53 ± 0.03	0.66 ± 0.36	0.247 ± 0.36	1.9 ± 0.57
Summer	0.36 ± 0.25	0.97 ± 0.469	9.23 ± 0.31	0.842 ± 0.36	0.15 ± 0.03	0.65 ± 0.36	0.217 ± 0.32	0.42 ± 0.05
Monsoon	1.29 ± 0.74	9.79 ± 1.94	13.51 ± 0.43	1.858 ± 0.404	0.375 ± 0.03	0.67 ± 0.36	0.24 ± 0.23	0.69 ± 0.72

Table 3: Seasonal physico-chemical and heavy metal observation at Khadi

Season	Water velocity (m/sec)	Water temperature (°C)	Conductivity (Siemens/cm)	Turbidity (JTU)	Total solids (mg/l)	Phosphates (mg/l)
Autumn	0.67±0.02	17.5±0.15	99.92±0.01	21.84±0.02	59.71±0.35	0.47 ± 0.12
Winters	0.69±0.05	20.5±1.26	110.37±0.05	34.78±0.08	97.18±1.86	0.29±0.15
Summer	0.63±0.05	23.0±2.00	116.75±0.00	84.21±6.32	138.73±0.28	0.92 ±0.19
Monsoon	1.11±0.03	19.0±1.92	120.10±0.10	331.76±13.72	510.15±0.08	0.54 ± 0.10

Season	DO (mg/l)	Free CO_2 (mg/l)	Acidity (mg/l)	Total Alkalinity (mg/l)	Total Hardness (mg/l)	Ca Hardness (mg/l)	Mg Hardness (mg/l)	Chlorides (mg/l)
Autumn	9.3±0.02	0.2±0.12	56.82±0.02	203.0±1.68	121.0±0.21	42.15±0.10	17.95±0.73	7.87±0.90
Winters	8.9±0.20	0.9±0.05	45.97±0.30	163.0±0.24	131.0±8.20	21.20±0.05	11.89±0.24	8.46±2.00
Summer	7.4±0.05	1.8±1.02	50.22±0.14	213.0±10.25	218.0±0.11	26.40±0.21	23.46±0.58	6.10±0.10
Monsoon	8.3±0.06	0.6±0.00	39.27±0.20	149.0±0.35	209.0±0.16	34.43±0.58	23.37±0.14	7.92±0.32

Season	Zn (mg/l)	Pb (mg/l)	Mn (mg/l)	Fe (mg/l)	Cu (mg/l)	Al (mg/l)	Cd (mg/l)	Mg (mg/l)
Autumn	2.3 ± 0.09	3.97 ± 0.497	0.225 ± 0.24	3.55 ± 4.91	1.622 ± 0.5	1.91 ± 0.63	0.035 ± 0.33	5.38 ± 7.54
Winters	2.27 ± 0.13	0.36 ± 0.607	0.02 ± 0.03	22.61±12.71	0.008 ± 0.37	11.81 ± 0.416	0.26 ± 0.03	0.7 ± 0.38
Summer	2.28 ± 0.12	3.59 ± 0.611	0.3 ± 0.47	4.82 ± 0.905	0.001 ± 0.35	0.193 ± 0.442	0.625 ± 0.03	0.78 ± 0.4
Monsoon	4.027 ± 0.84	1.329 ± 0.084	0.56 ± 0.86	18.36 ± 7.01	1.318 ± 0.41	0.016 ± 0.437	0.274 ± 0.03	0.75 ± 0.41

Table 4: Seasonal physico-chemical and heavy metal observation at Jajal

Sampling sites	CPI (Autumn)	CPI (Winters)	CPI (Summer)	CPI (Monsoon)	Polluted
Control	1.84	1.61	1.76	3.24	Moderately but Severely in monsoon
Nagni	2.07	3.03	3.54	4.55	Severely
Khadi	3.62	5.01	5.63	6.35	Severely
Jajal	2.15	6.64	8.83	5.47	Severely

Table 5: Water pollution at each sampling location

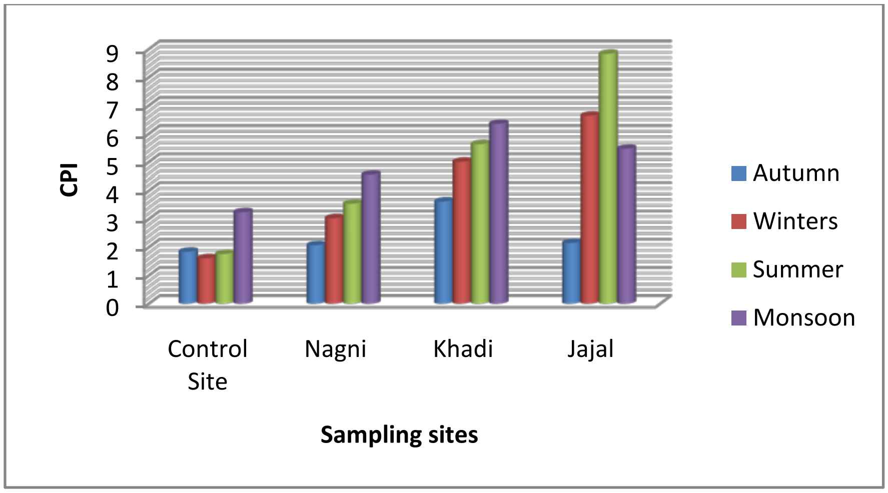

Fig. 2: Variation of CPI during autumn, winter, summer and monsoon season

Water Pollution Assessment

The CPI values are represented in table 5 and the graphical presentation in Fig. 2 clearly indicates that the river water was severely polluted at all four sites during the study period *i.e.* 2.07-8.83. Only on the Khadi location the river water was moderately polluted in autumn, winter and summer season as the CPI value falls beyond the range 1.01-2.0 but get severely polluted in the monsoon season as CPI value rise to 3.24. The seasonal variation in water quality is clearly illustrated by CPI plot, which shows increasing pollution index at control site and Jajal during study period. Highest value was calculated at Nagni in summer season. According to this Khadi is less polluted as compared to other sites.

Season	Phytoplankton	Zooplankton	Plankton
Autumn	1003.41±1.43	286.23±4.77	1289.64±6.20
Winters	939.18±2.63	317.49±3.27	1256.67±5.90
Summer	987.05±3.96	280.03±5.5	1267.08±9.46
Monsoon	487.20±5.32	240.14±5.69	727.34±11.01

Table 6: Quantitative Analysis of the Plankton of the Henwal River at Control site

Season	Total Phytoplankton/ Liter of water	Total Diatoms / Litre of water	Total green algae/ Litre of water	Total Blue green algae/ Litre of water
Autumn	1003.41±1.43	255.11±0.29	399.81±0.15	348.49±0.99
Winters	939.18±2.63	236.46±1.12	299.90±0.39	402.82±1.12
Summer	987.05±3.96	274.19±1.21	294.49±1.39	418.37±1.36
Monsoon	487.20±5.32	108.51±2.83	169.75±1.24	208.94±1.25

Table 7: Number of different Group among the Phytoplankton of the Henwal River

Season	***Protozoa***	***Rotifera***	***Cladocera***	*Copepod*	***Ostracods***	D	H	E
Autumn	86.28±0.37	55.57±1.21	76.86±1.08	30.50±0.57	37.02±1.54	4.37	1.54	0.43
Winters	131.05±0.13	50.33±0.50	60.28±0.21	41.27±1.21	34.56±1.22	3.84	1.48	0.39
Summer	86.18±1.23	62.45±0.32	51.73±1.02	52.17±1.16	27.50±1.77	4.49	1.55	0.44
Monsoon	72.27±1.65	53.48±1.14	50.29±0.91	37.14±0.43	26.96±1.56	4.53	1.56	0.44

Table 8: Number of Different Genera among Zooplankton in the Henwal River

Season	Phytoplankton	Zooplankton	Plankton
Autumn	866.01±1.43	302.78±5.46	1168.79±6.89
Winters	945.59±2.63	305.49±5.81	1251.08±8.44
Summer	932.27±3.96	290.03±5.04	1222.30±9.00
Monsoon	628.52±5.32	266.89±5.76	895.41±11.08

Table 9: Quantitative Analysis of the Plankton of the Henwal River at Nagni

Season	Total Phytoplankton/ Liter of water	Total Diatoms / Litre of water	Total green algae/ Litre of water	Total Blue green algae/ Litre of water
Autumn	866.01±1.43	250.97±0.29	268.92±0.15	346.12±0.99
Winters	945.59±2.63	229.36±1.12	296.47±0.39	419.76±1.12
Summer	932.27±3.96	242.13±1.21	290.17±1.39	399.97±1.36
Monsoon	628.52±5.32	177.37±2.83	165.70±1.24	285.45±1.25

Table 10: Number of different Group among the Phytoplankton of the Henwal River

Season	***Protozoa***	***Rotifera***	***Cladocera***	*Copepod*	***Ostracods***	D	H	E
Autumn	89.28±1.37	57.57±1.24	75.86±1.18	39.50±0.53	40.57±1.14	4.53	1.56	0.44
Winters	111.05±1.13	59.33±0.53	61.28±1.21	45.27±1.71	28.56±1.23	4.15	1.51	0.41
Summer	89.18±1.24	60.45±0.31	57.73±1.09	54.17±1.12	28.50±1.28	4.50	1.55	0.44
Monsoon	74.27±1.25	56.48±1.04	59.29±0.31	38.14±1.40	38.71±1.76	4.69	1.58	0.46

Table 11: Number of Different Genera among Zooplankton in the Henwal River

Season	Phytoplankton	Zooplankton	Plankton
Autumn	864.29±2.24	323.20±4.92	1187.49±7.16
Winters	889.01±1.16	306.35±3.28	1195.36±4.44
Summer	633.78±1.69	276.56±3.75	910.34±5.44
Monsoon	594.98±1.41	282.55±6.08	877.53±7.94

Table 12: Quantitative Analysis of the Plankton of the Henwal River at Khadi

Season	Total Phytoplankton/ Liter of water	Total Diatoms / Litre of water	Total green algae/ Litre of water	Total Blue green algae/ Litre of water
Autumn	864.29±2.24	209.05±0.11	256.52±1.11	309.43±1.02
Winters	889.01±1.16	211.34±0.21	279.29±0.68	398.38±0.27
Summer	633.78±1.69	189.33±0.28	168.05±0.51	276.4±0.90
Monsoon	594.98±1.41	179.28±0.42	168.61±0.70	247.09±0.29

Table 13: Number of different Group among the Phytoplankton of the Henwal River

Season	***Protozoa***	***Rotifera***	***Cladocera***	*Copepod*	***Ostracods***	D	H	E
Autumn	89.39±0.89	82.35±0.25	72.08±1.01	47.71±1.01	31.67±1.76	4.49	1.55	0.44
Winters	97.95±0.23	62.26±0.34	76.28±0.85	35.27±0.85	34.59±1.01	4.32	1.53	0.43
Summer	61.25±1.11	66.08±0.02	72.16±0.52	49.78±1.02	27.29±1.08	4.62	1.56	0.44
Monsoon	88.58±0.28	63.98±1.86	57.84±1.19	41.07±0.82	31.08±1.22	4.45	1.55	0.44

Table 14: Number of Different Genera among Zooplankton in the Henwal River

Season	Phytoplankton	Zooplankton	Plankton
Autumn	863.70±3.05	326.49±5.39	1190.19±8.44
Winters	1022.36±1.17	300.58±5.2	1322.94±6.37
Summer	544.26±3.20	273.66±5.02	817.92±8.22
Monsoon	527.09±1.94	264.64±6.58	791.73±8.52

Table 15: Quantitative Analysis of the Plankton of the Henwal River at Jajal at Control site

Season	Total Phytoplankton/ Liter of water	Total Diatoms / Litre of water	Total green algae/ Litre of water	Total Blue green algae/ Litre of water
Autumn	863.70±3.05	289.52±0.42	254.19±1.31	319.99±1.32
Winters	1022.36±1.17	231.37±0.23	299.18±0.69	491.81±0.89
Summer	544.26±3.20	139.29±0.37	198.49±1.61	206.48±1.22
Monsoon	527.09±1.94	133.18±0.37	168.15±0.56	225.76±1.01

Table 16: Number of different Group among the Phytoplankton of the Henwal River

Season	*Protozoa*	*Rotifera*	*Cladocera*	*Copepod*	*Ostracods*	D	H	E
Autumn	89.88±0.59	83.15±0.35	73.05±1.51	46.72±1.21	33.69±1.73	4.51	1.55	0.44
Winters	98.28±1.25	60.26±0.44	71.26±0.75	39.26±1.35	31.52±1.41	4.32	1.53	0.43
Summer	67.51±0.88	60.02±0.42	78.14±1.52	42.79±1.02	25.20±1.18	4.48	1.55	0.44
Monsoon	55.12±0.83	65.58±1.37	64.27±1.75	56.20±0.72	23.47±1.31	4.61	1.56	0.44

Table 17: Number of Different Genera among Zooplankton in the Henwal River

	Water velocity	*Temperature*	*Conductivity*	*Turbidity*	*TS*	*DO*	*Free CO2*	*Acidity*	*Total Alkalinity*	*Total Hardness*	*Ca Hardness*	*Mg Hardness*	*Chlorides*	*Phosphates*	*Zn*	*Pb*	*Mn*	*Fe*	*Cu*	*Al*	*Cd*	*Mg*
Water velocity	1																					
Temperature	0.249525485	1																				
Conductivity	0.648027452	-0.3755446	1																			
Turbidity	0.989930426	0.38317449	0.55497062	1																		
TS	0.971207851	0.18648805	0.78197831	0.949543	1																	
DO	0.752298561	0.76681391	0.29998907	0.824294	0.760048	1																
Free CO2	-0.673845752	-0.4773412	0.08815285	-0.72284	-0.48201	-0.51367	1															
Acidity	-0.725055781	0.41722076	-0.65361502	-0.63588	-0.6694	-0.09188	0.494296	1														
Total Alkalinity	-0.298946363	-0.9604246	0.17199601	-0.42012	-0.30039	-0.84706	0.312472	-0.43104	1													
Total Hardness	0.345871606	0.41596534	-0.4209589	0.404537	0.114176	0.222062	-0.92436	-0.3068	-0.177227949	1												
Ca Hardness	0.180632559	0.2849401	-0.51703416	0.22919	-0.05887	0.020875	-0.83504	-0.26788	-0.021947373	0.979045551	1											
Mg Hardness	0.754135128	0.44417614	0.02835467	0.793532	0.578218	0.559233	-0.99314	-0.5666	-0.303924785	0.876451975	0.77391731	1										
Chlorides	0.683383437	0.23932547	0.78256204	0.674625	0.827559	0.757469	0.000961	-0.2303	-0.46672501	-0.374743309	-0.55056627	0.097347939	1									
Phosphates	-0.049554968	0.15207405	-0.63988435	-0.0091	-0.28542	-0.20783	-0.67664	-0.15895	0.126918473	0.90122616	0.96994896	0.599199588	-0.73694	1								
Zn	0.13567173	-0.3985114	-0.12586677	0.085971	-0.04692	-0.40945	-0.53818	-0.64354	0.608200122	0.66823695	0.75576695	0.515972091	-0.58164	0.7879548	1							
Pb	-0.623562182	0.58917566	-0.9039346	-0.50685	-0.68238	-0.04794	0.081189	0.884469	-0.479034892	0.168741252	0.21132833	-0.18264251	-0.47336	0.29949791	-0.30399	1						
Mn	0.424530482	0.97883475	-0.26933327	0.548391	0.340673	0.83494	-0.63051	0.223096	-0.928406207	0.528002638	0.38085396	0.609539566	0.292419	0.21567066	-0.26972	0.440472	1					
Fe	-0.999777133	-0.2684199	-0.64115915	-0.99233	-0.97169	-0.76602	0.674666	0.710394	0.318933081	-0.34553105	-0.17790038	-0.75437882	-0.69038	0.05401661	-0.1199	0.609483	-0.4414	1				
Cu	0.400813906	0.96023958	-0.11615946	0.518024	0.38984	0.894718	-0.4044	0.326347	-0.99332837	0.245092141	0.07912105	0.402381216	0.499864	-0.0895921	-0.54046	0.401855	0.951865	-0.41988	1			
Al	-0.999683819	-0.2281911	-0.66640072	-0.98633	-0.975	-0.74233	0.658451	0.734648	0.282106082	-0.327564666	-0.16346251	-0.74071982	-0.69052	0.06533973	-0.13458	0.641966	-0.40357	0.999129	-0.38394	1		
Cd	-0.881831164	-0.2078974	-0.82437826	-0.86349	-0.96613	-0.78622	0.276113	0.503545	0.380241747	0.111433394	0.2925183	-0.37831944	-0.94425	0.50979287	0.291688	0.625613	-0.323	0.885123	-0.44796	0.88761	1	
Mg	0.386357397	-0.5323974	0.95241638	0.280464	0.564097	0.083431	0.383457	-0.48171	0.300504287	-0.660159796	-0.71455703	-0.27408157	0.693844	-0.7741243	-0.23701	-0.83217	-0.47697	-0.37875	-0.27517	-0.40852	-0.65763	1

Table 18: Karl Pearson's correlation matrix of physico-chemical parameters and plankton for control site during study period

Correlation

The Karl Pearson's correlation matrix was developed between physic-chemical parameters and biotic factors/plankton to gain the basic knowledge of tropic status of river water and shown in Table 18. The distribution of plankton is correlated with temperature, DO, Alkalinity, Hardness, Chlorides and phosphate. According to Cabecadas and Brogueira (1987), the growth and photosynthesis of algae are influenced by the pH and alkalinity of water. Highly Positive correlation was observed between phytoplankton and DO total alkalinity, acidity, hardness and chloride, in the present study. Agarwal *et al.* (1990) developed a relationship between nutrients and algal growth. Pandy *et al.* (1995) showed a positive correlation between pH, dissolved oxygen, bicarbonate, phosphate and transparency. They reported a positive correlation between pH, dissolved oxygen and transparency and chlorophyceae. Bhat and Pandit (2005) found a close relationship between physico-chemical characters of water and growth and abundance of phytoplanktons. They observed high growth of phytoplanktons during summer and a very low growth during winter. In the present study high growth was observed during autumn and winter months and it was low during summer. According to Bhat and Pandit (2005), higher transparency and temperature associated with low water levels seem to be conducive factors of maximum phytoplankton density. Kumar and Bohra (2005) showed a significant positive correlation between phytoplanktons and pH in Raja Dighi pond, Jharkhand. Khare (2005) found a marked and significant correlation among plankton density and temperature, DO, phosphate and nitrate. Hulyal and Kaliwal (2008) showed a significant relation between biotic and abiotic factors. They revealed a positive relationship between cyanophyceae with dissolved oxygen, nitrate, phosphate and negative correlation with pH, chloride, rainfall and humidity. Lashkar and Gupta (2009) observed a highly significant positive correlation between phytoplankton density and transparency ($p<0.01$) and significant positive correlation with total hardness.

Synudeen Sahib (2011) observed a close relationship between turbidity and velocity and plankton biomass. A rise in turbidity, during summer and rainfall, leads to silting, disturbances of normal O_2 and CO_2 exchange, consequently an inhibition of photosynthesis of the phytoplanktons. During winter DO reaches the peak and free CO_2 remains less while a reverse situation occurred in the rainy season. The results indicate that fall in DO and rise in free CO_2 during rainy season could be ascribed to retarded photosynthetic activity of the phytoplanktons or decreased concentration of O2 being consumed by the organic matter in turbid state of water during low phytoplankton density. In the present study no significant correlation was found between turbidity and phytoplankton. The positive correlation of DO with plankton indicates the role of phytoplankton in contributing DO and of zooplankton's occurrence due to sufficient DO level. Moreover, highest DO concentration was observed during post-monsoon period because of maximum occurrence of the phytoplankton density (Morgan *et al*., 2006). With the progression of winter, DO raised to its peak value, and it might be due to high rate of photosynthesis by phytoplankton population that forms the major source of DO (Sharma and Rathore, 2000).

Kumar and Babu (2013) found the correlation regression coefficient (r) is high (upto 0.979) between Conductivity and DS, TA and TH for hand pump and surface water whereas it was low (0.750) for tap water. Correlation regression coefficient (r) was high (0.975) for surface water between Turbidity and suspended solids.

Conclusion

The present study summarizes the seasonal fluctuations of various physico-chemical parameters, heavy metals and plankton diversity in the waters of the Henwal river as exploratory statistical data output. The high load of DO total alkalinity, acidity, hardness and chloride during the study period contributes to the growth of plankton community which is evident from the correlation analysis. The highest and abundance of the phytoplankton in water environment could encourage accumulation of micocystins and neurotoxin in the water, passing through the food chain could pose significant threat to public health. Eutrophication, heavy metal toxicity and other pollution problems make this study so important to be done. For this reason a limonological study was done by considering different biotic and abiotic factors. The influx of domestic and sewage waste into the river, could be expected the plankton may be pollution tolerant and hence indicators species like algae.

In the present study, the CPI was evaluated to be 2.07-8.83 (CPI > 2), which is an indication of severely polluted water of Henwal river. The highest diversity index (D = 4.69, H = 1.58) of the four sites in the monsoon season and the lowest diversity index (D = 3.84, H = 1.48) in the winter season. The overall study provides a good outline on the prevailing polluted condition of the river ecosystem.

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