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Aquatic Biodiversity as an Ecological Indicators for Water Quality Criteria of River Yamuna in Doon Valley, Uttarakhand, India

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Abstract: During the last few decades there has been an increasing demand for monitoring water quality of many rivers by regular measurements of various water quality variables. River Yamuna in Uttarakhand requires the same qualitative and quantitative aspects of monitoring for predicting the steady state water quality conditions. The present study was carried out for a period of one year on monthly basis from April 2011 to March 2012 for Physico-chemical and biological parameters of the River Yamuna at S1, S2 and S3 in Doon Valley (Dehradun) Uttarakhand India. The influence of Physico-chemical parameters of River Yamuna and its biological diversity revealed that the quality of water has been slightly deteriorated showing a fairly good diversity with Phytoplankton followed by Zooplankton and Macrobenthos (Phytoplankton > Zooplankton > Macrobenthos). Correlation between hydrological attributes and biological diversity was good to some extent; however the conditions of hydrological attributes had a great effect on biotic diversity of River Yamuna. In the present study biological diversity was found highest at S1 and lowest at S2 showing a general and irregular trend from S1 to S3 (S1>S3>S2). The current prevailing condition of physicochemical parameters of River Yamuna and aquatic diversity besides acting as potential bioindicators of trophic status requires the management strategies for the conservation of River Yamuna in Doon Valley.

Key words: Biodiversity · Bioindicators · Correlation · Doon Valley · Hydrological · River Yamuna

INTRODUCTION

India is facing a serious problem of natural resource scarcity, especially that of water in view of population growth and economic development. Water is a prime natural resource, a basic human need and a precious national asset and hence its use needs appropriate planning, development and management. However, studies related to ecology and environment are often perceived as ‘anti-development and detrimental to the overall growth and welfare of human beings and are viewed with suspicion and generally considered as nuisance [1, 2].

The Yamuna sometimes called Jamuna or Jumna is the largest tributary river 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. However, the three components vary in space and time. Therefore, the understanding of different components of water input to the River Yamuna may reveal its behavior at different locations that may be of great use to manage the groundwater as well as the river in a better way [3]. The river gets maximum contribution of snowmelt during the month of May and June. But the main source to this river is precipitation that it receives. The extent of human activities that influence the environment particularly the freshwater has increased dramatically during the past few decades [4]. The scale of socio-economic activities, urbanizations, industrial operations and agricultural production has a widespread impact on water resources. As a result, very complex inter-relationships between socio-economic factors and

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natural hydrological and ecological conditions have developed. There are three main sources of pollution in the River, namely households and municipal disposal sites, soil erosion resulting from deforestation occurring to make way for agriculture along with resulting chemical wash-off from fertilizers, herbicides and pesticides and run-off from commercial activity and industrial sites [5]. Rivers are currently degraded by both natural and anthropogenic activities, which deteriorate their quality and made them as sewage channel and push them to the brink of extinction in the process of unplanned development, giving rise to the need for suitable conservation strategies [6]. Unfortunately, over the years, less attention has been given towards their management. The contaminations altered their functions, affecting the ecological balance. Physicochemical and biological characteristics characterize any water body. The physical and chemical properties of fresh water body are characterized by the climatic, geochemical, geomorphological and pollution conditions. The biota in the surface water is governed entirely by various environmental conditions. The water quality characteristics influence the ability of species live in a given river habitat [6]. Aquatic biodiversity is one of the most essential characteristics of the aquatic ecosystem for maintaining its stability and a means of coping with any environmental change. Phytoplankton plays the role of primary producer in the rivers food chain [7]. They can convert inorganic material, such as nitrate and phosphate, into new organic compounds (e.g., lipids and proteins) through photosynthesis whereas Zooplankton organisms occupy a central position in the food webs of aquatic ecosystem. They do not only form an integral part of the aquatic community but also contribute significantly in the biological productivity of the fresh water ecosystem [8]. The importance of the Zooplankton is well recognized as these have vital part in food chain and play a key role in cycling of organic matter in an aquatic ecosystem [9]. Similarly the macro-invertebrates act as the secondary producers in the aquatic ecosystems. They are an important link in the food web of aquatic ecosystem.

A considerable work has been done on Physico-chemical parameters and aquatic diversity by a large number of limnologists and aquatic biologists in India and other countries [10-22].

The main aim of the present study was to assess the status of aquatic biodiversity in order to know the water quality conditions, to analyze the impact of physicochemical attributes on the biodiversity present in the River Yamuna and recommend suggestive and valuable measures for conservation and sustainability of this riverine ecosystem.

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 m, on the south western slopes of Banderpooch peak (380 59’ N 78027’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 km (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. The head waters of Yamuna river are formed by several melt streams, the chief of then gushing out of the morainic smooth at an altitude of 3250 m, 8 km North West of Yamunotri, hot springs at the latitude 310 2’12” N and longitude 780 26’ 10”. Arising from the source, the river flows through series of curves and rapids for about 120 km to emerge into Indo-Gangetic plains at Dak Pathar in Uttaranchal.

Methodology: The present study was conducted on River Yamuna covering a stretch of approximately 40 km from upstream to downstream. Three sites were selected along the river as shown in Fig. 1. The study was carried out for a time period of one year from April 2011-March 2012 on monthly basis. The study sites were Kalsi (S1), Dakpathar (S2) and Asan Lake (S3). Water samples were collected every month early in the morning in sterilized sampling bottles and were analyzed for twenty two important physical and chemical Parameters. Few physicochemical 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 analyzed in laboratory by following the methodology of APHA [23] Trivedi and Goel [24]

Wetzel and Likens [25]. 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 analyzed by titration method. Phosphate and Nitrate were analyzed by using UV-VIS Spectrophotometer and Sodium and Potassium by Fame photometer.

The plankton collection was made by hauling of water by plankton net (0.1mm mesh size) and preserved in 4% formalin solution. The plankton count was made by Sedgewick rafter cell under the microscope (Model No.CH-20i.). Macrobenthos were collected from the shallow bottom region of the river by using forceps and preserved in 4% formalin and their quantitative estimation was based on numerical counting, i.e., units per square meter (ind. m^{-2}). The qualitative analysis of the plankton and benthic fauna samples were made with the help of [26-38].

Statistical Measurement: Statistical analysis like Standard deviation and Karl Pearson's correlation coefficient (r value) were was carried out with the help of the statistical software SPSS to find the relation between the hydrological attributes and their impact on biological variables.

RESULTS

Physicochemical Parameters of Water: The physico-chemical parameters (Avg. ± SD) values obtained from the three sites of River Yamuna are given in Table 1. From the results the temperature recorded at S1 was minimum (17.91±2.02°C) and at S2 it was found maximum (19.08±2.06°C) showing a great variation fro upstream to downstream. The highest value of velocity was recorded at S2 (2.00±0.55m/s) while the lowest value of velocity was found at S3 (0.415±0.08 m/s). The pH recorded at S2 was maximum (8.22±0.16) and it was found minimum at S1 (8.14±0.12) and S2 (8.1±0.12) showing little variation from each other. Total Alkalinity was found to be highest at S1 (298.75±422.59 mg/l) and it was found minimum at S2 (172.0±16.50 mg/l). The concentration of Dissolved oxygen was found to be maximum at S1 (10.89±0.95 mg/l) and it was found minimum at S2 (10.54±0.41mg/l). Other parameters like Transparency showed a decreasing trend from S1 to S3 while as Conductivity showed an increasing trend from S1 to S3. Turbidity was found to be highest at S2 (291.66±397.28 JTU) and it was found lowest at S3 (267.91±354.2 JTU).Parameters like TS, TDS and TSS was showed an irregular trend at all three sites during the whole year. Total Hardness was found to be highest at S1 (91.33±14.04 mg/l) and lowest at S2 (81.91±9.59 mg/l) and so the calcium and magnesium. Free CO_2 was found to be highest at S3 (1.55±0.22 mg/l) and COD was found lowest at S2 (4.97±0.65mg/l). The parameters like Phosphate, Nitrate, Sodium and Potassium showed an irregular trend and a great variation in their concentration from S1 to S3 during the study period. The variation of different physic-chemical parameters at S1, S2 and S3 are also depicted in Figures 1-7.

Table 1: Physicochemical characteristics (mean value of three sampling sites S1, S2 and S3) of River Yamuna for a year (April 2011-March 2012)

Parameters	S1	S2	S3
Temperature (°C)	17.91±2.02	18.5±2.23	19.08±2.06
Transparency (cm)	19.25±14.66	29.28±22.10	34.84±25.60
Velocity (m/s)	1.60±0.62	2.00±0.55	0.415±0.08
Turbidity (JTU)	285.45±382.51	291.66±397.28	267.91±354.2
Conductivity (μmhocm^{-1})	0.195±0.02	0.183±0.03	0.139±0.01
T.S. (mg/l)	508.33±267.84	625.00±310.79	566.66±274.1
TDS (mg/l)	266.66±149.74	316.66±133.71	300.0±147.7
TSS (mg/l)	241.66±150.50	308.33±202.07	266.66±149.7
pH	8.14±0.12	8.22±0.16	8.1±0.12
Total alkalinity (mg/l)	298.75±422.59	145.75±10.33	172.0±16.50
Total Hardness (mg/l)	91.33±14.04	81.91±9.59	87.58±13.53
Calcium (mg/l)	45.64±4.46	30.59±5.27	30.59±4.21
Magnesium (mg/l)	11.14±2.59	13.90±2.31	13.90±3.90
Chloride (mg/l)	29.84±3.83	36.17±4.39	31.79±2.84
Free CO_2 (mg/l)	1.40±0.14	1.52±0.20	1.55±0.22
DO (mg/l)	10.89±0.95	10.54±0.41	10.55±0.74
BOD (mg/l)	2.87±0.31	2.71±0.21	2.57±0.22
COD (mg/l)	5.15±0.70	4.97±0.65	5.20±0.59
Phosphates (mg/l)	0.559±0.06	0.551±0.07	0.635±0.11
Nitrates (mg/l)	0.516±0.09	0.519±0.04	0.971±0.29
Sodium (mg/l)	0.31±0.07	0.331±0.05	0.392±0.07
Potassium (mg/l)	0.36±0.06	0.376±0.05	0.465±0.08

Phytoplankton, Zooplankton and Macrobenthos Diversity and Density: The phytoplankton inhabited the River Yamuna at S1, S2 and S3 comprises of 35 taxa out of which Chlorophyceae constitutes (15 genera), Bacillariophyceae (14 genera) and Myxophyceae (6 genera). Mean variation of all the three sites is shown in Table 2 and Fig. 8. The diversity of phytoplankton was recorded to be maximum for Bacillariophyceae (850.33±287.70) at S1 followed by Chlorophyceae (232.58±123.32) and Myxophyceae (61.5±47.24). At S2 highest diversity was recorded to be

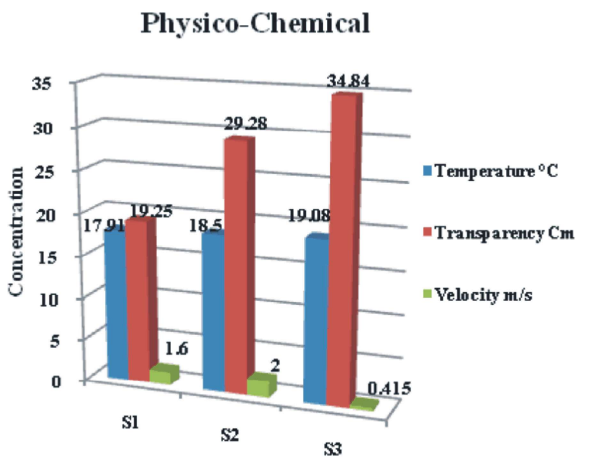

Fig. 1: Showing average variation in Temperature, Transparency and Velocity at S1, S2, S3 of River Yamuna for the year April 2011-March 2012

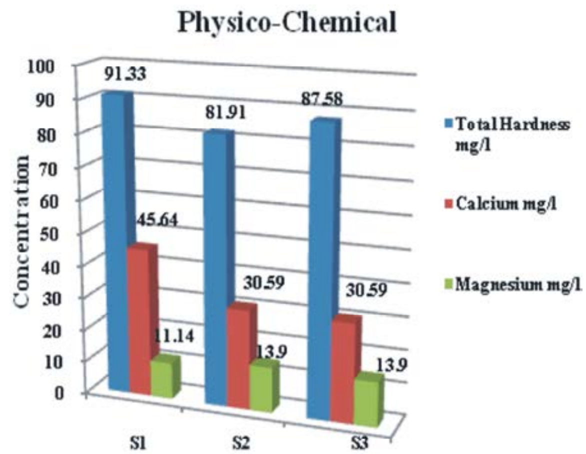

Fig. 4: Showing average variation in Total Hardness, Calcium and Magnesium at S1, S2, S3 of River Yamuna for the year April 2011-March 2012

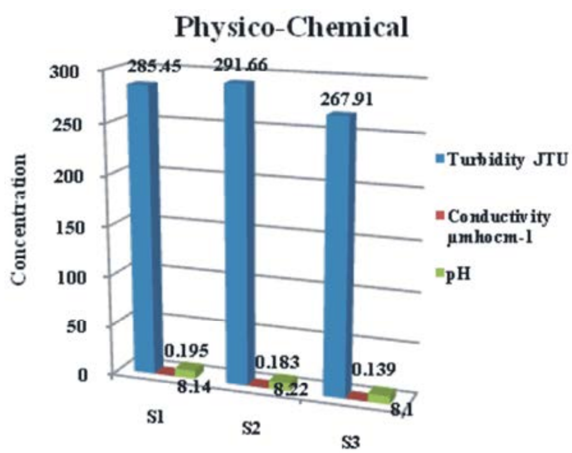

Fig. 2: Showing average variation in Turbidity, Conductivity and pH at S1, S2, S3 of River Yamuna for the year April 2011-March 2012

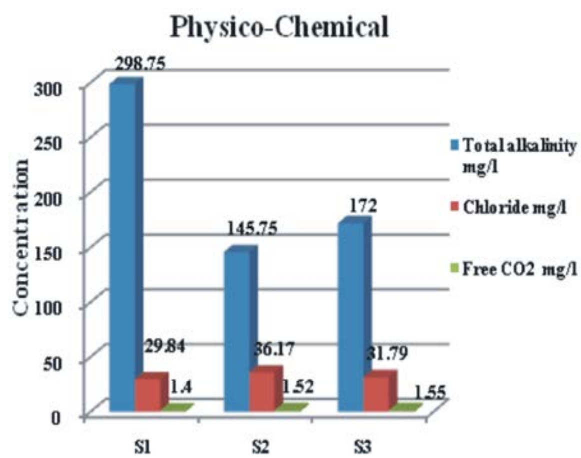

Fig. 5: Showing average variation in Total Alkalinity, Chloride and Free CO_2 S1, S2, S3 of River Yamuna for the year April 2011-March 2012

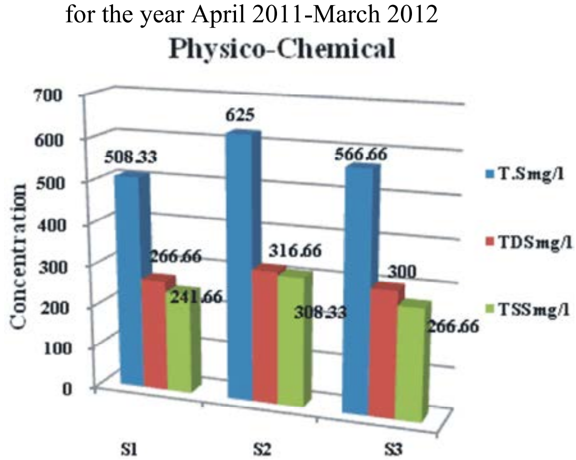

Fig. 3: Showing average variation in TS, TDS and TSS at S1, S2, S3 of River Yamuna for the year April 2011-March 2012

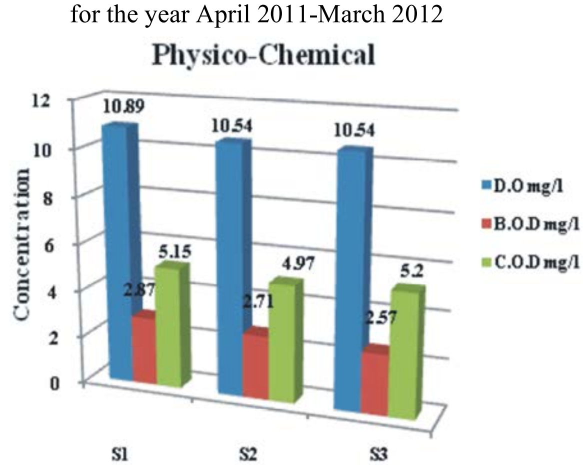

Fig. 6: Showing average variation in DO, BOD and COD at S1, S2, S3 of River Yamuna for the year April 2011-March 2012

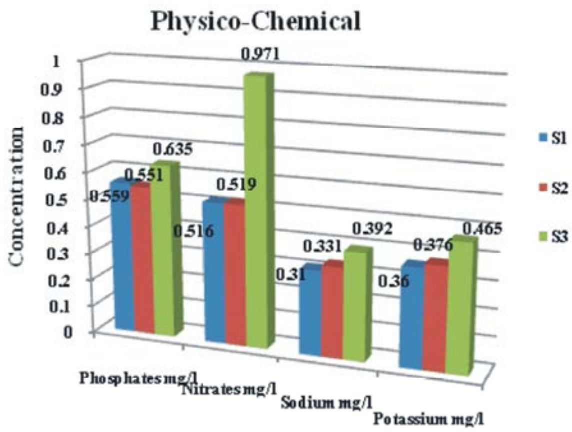

Fig. 7: Showing average variation in Phosphate, Nitrate, Sodium and Potassium at S1, S2, S3 of River Yamuna for the year April 2011-March 2012

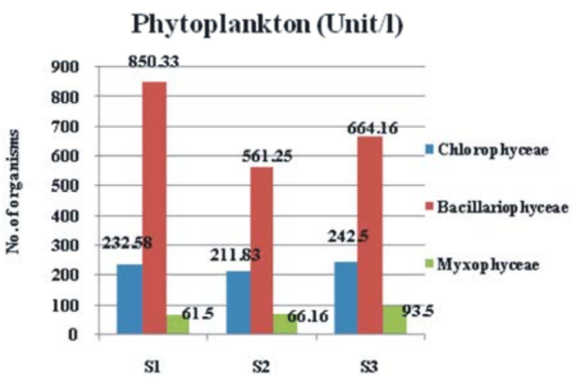

Fig. 8: Showing Phytoplankton (Unit/l) at S1, S2, S3 of River Yamuna for the year April 2011-March 2012

highest for Bacillariophyceae (561.25±228.03) followed by Chlorophyceae (211.83±97.40) and lowest for Myxophyceae (66.16±28.48). The diversity recorded at S3 was maximum for Bacillariophyceae (664.16±210.30) followed by Chlorophyceae (242.5±75.71) and minimum for Myxophyceae (93.5±38.81). However the overall density was found to be highest at S1 (1144.41) followed by S3 (1000.16) and lowest at S2 (839.24) showing the trend (S1>S3>S2). The qualitative study of phytoplankton in River Yamuna of Doon Valley revealed that the family Chlorophyceae was represented by *Chlorella, Chlaymydomonas, Spirogyra, Ulothrix, Hydrodictyon, Cladophore, Cosmarium, Chlorococcum, Oedogonium, Microspora, Desmidium, Chara, Zygenema, Syndesmus and Volvox.* The family Bacillariophyceae was represented by *Ceratoneis, Amphora, Caloneis, Fragilaria, Navicula, Synedra, Diatoms, Gomphonema, Pinnularia, Melosira,*

Table 2: Qualitative and quantitative distribution (mean values of three sites) of phytoplankton (Unit/l) in River Yamuna for the period of April 2011- March 2012

Phytoplankton	S1	S2	S3
Chlorophyceae			
Chlorella	19.5±18.24	22.08±15.06	26.25±17.29
Chlaymydomonas	23.58±11.11	19.66±7.20	16.41±5.75
Spirogyra	18.41±5.04	19.16±7.06	21.83±10.47
Ulothrix	17.00±9.91	12.75±7.16	26.25±13.72
Hydrodictyon	13.75±13.82	8.75±6.92	13.16±6.88
Cladophore	20.66±15.32	14.33±10.87	15.66±7.16
Cosmarium	18.75±19.85	13.58±8.58	14.75±6.98
Chlorococcum	10.91±10.96	8.91±7.25	11.91±7.11
Oedogonium	9.41±8.41	10.08±8.93	11.91±4.66
Microspora	12.33±10.06	13.50±8.35	14.25±6.55
Desmidium	19.66±14.81	19.58±16.68	17.50±11.60
Chara	9.91±5.69	12.58±7.29	11.58±4.75
Zygenema	13.41±12.45	13.33±11.80	13.58±10.61
Syndesmus	12.33±7.35	11.00±6.75	15.16±10.16
Volvox	12.91±9.74	12.50±7.59	12.25±5.61
Total	232.58±123.32	211.83±97.40	242.5±75.71
Bacillariophyceae			
Ceratoneis	14.08±7.94	18.91±5.50	14.41±6.62
Amphora	16.33±10.01	10.00±7.13	17.50±8.24
Caloneis	7.25±8.19	9.25±7.78	13.41±11.04
Fragilaria	133.75±76.51	116.75±63.16	169.5±60.94
Navicula	175.0±81.04	135.41±53.51	123.5±39.17
Synedra	41.58±14.45	26.41±9.02	23.91±9.79
Diatoms	65.16±38.84	37.75±12.90	105.5±38.13
Gomphonema	36.83±24.69	19.91±5.97	33.25±16.80
Pinnularia	21.16±12.07	12.25±8.08	19.08±9.82
Melosira	12.66±9.55	5.08±4.87	12.58±8.30
Tabellaria	44.33±16.76	95.91±67.21	33.33±12.81
Denticula	39.16±18.99	14.75±10.88	28.58±14.99
Cymbella	48.16±26.55	53.33±15.67	52.41±49.11
Cyclotella	22.91±19.37	5.50±4.05	17.16±8.37
Total	850.33±287.70	561.25±228.03	664.16±210.30
Myxophyceae			
Nostoc	15.00±10.66	9.75±6.56	17.00±9.50
Anabaena	8.58±8.62	8.91±5.59	17.58±8.39
Oscillatoria	12.66±10.65	13.33±11.56	15.08±5.43
Rivularia	10.08±10.27	11.33±8.35	18.58±4.90
Coccochloris	4.58±4.92	8.58±5.35	10.75±8.82
Phormidium	10.58±6.31	14.25±5.36	14.5±9.52
Total	61.5±47.24	66.16±28.48	93.5±38.81

Tabellaria, Denticula, Cymbella and Cyclotella. The Myxophyceae was represented by *Nostoc, Anabaena, Oscillatoria, Rivularia, Coccochloris, Phormidium*.

Zooplankton inhabits the River Yamuna at S1, S2 and S3 include 28 taxa out of which Protozoa consist of (10 genera), Rotifera (10 genera), Copepoda (6 genera) and Ostracoda (2 genera). Mean variation of all the three sites is shown in Table 3 and Fig. 9. The maximum diversity at S1 was found maximum to be for Rotifera (274.33±120.38)

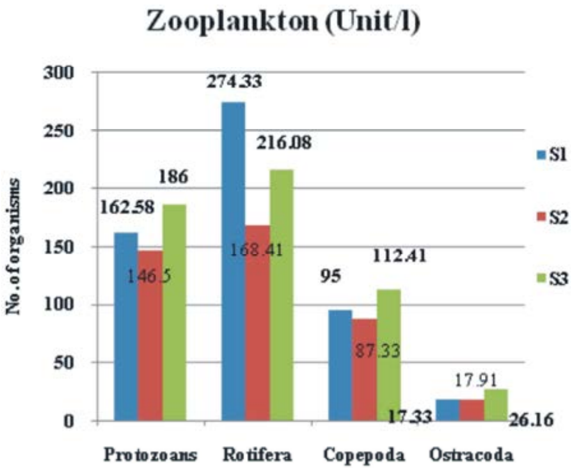

Fig. 9: Showing Zooplankton (Unit/l) at S1, S2, S3 of River Yamuna for the year April 2011-March 2012

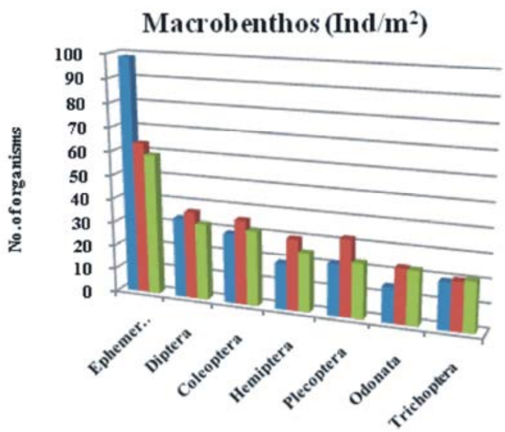

Fig. 10: Showing Macrobenthos (ind/m^2) at S1, S2, S3 of River Yamuna for the year April 2011-March 2012

Table 3: Qualitative and quantitative distribution (mean values of three sites) of Zooplankton (Unit/l) in River Yamuna for the period of April 2011- March 2012

Zooplankton	S1	S2	S3
Protozoans			
Actinophrys	15.66±8.77	11.50±8.16	19.91±12.68
Actinosphaerium	13.91±11.55	11.58±9.88	21.66±14.49
Euglena	14.83±11.74	15.50±13.11	18.41±12.52
Paramecium	16.16±14.32	13.50±11.30	21.33±13.91
Peridinium	14.41±9.92	15.83±12.07	14.50±9.55
Campenella	14.83±8.70	15.16±11.76	14.41±11.82
Epistylis	16.66±12.07	11.91±11.32	11.50±7.25
Vorticella	14.33±11.65	17.83±12.29	19.33±9.74
Arcella	21.41±14.86	17.66±15.82	23.00±14.67
Diffugia	20.33±13.62	16.00±10.34	21.91±10.56
Total	162.58±111.51	146.5±113.99	186.00±114.34
Rotifera			
Keratella	14.75±9.91	16.25±10.30	23.66±20.90
Rotatoria	17.58±10.88	11.66±7.48	17.16±8.69
Testudinella	21.83±14.21	14.50±9.20	14.41±11.91
Ascomorpha	16.16±12.74	17.75±10.98	21.58±10.81
Polyarthra	18.08±14.87	13.50±11.32	19.83±17.11
Philodina	16.50±11.90	15.50±14.58	17.50±16.29
Asplanchna	25.66±13.30	18.25±9.15	25.50±14.16
Pompholix	24.25±20.71	12.83±10.38	17.83±12.17
Brachionus	20.83±9.29	18.50±10.08	24.00±10.34
Trichocera	12.91±9.86	14.33±12.43	14.50±10.14
Total	274.33±120.38	168.41±114.92	216.08±140.38
Copepoda			
Cyclops	24.50±13.70	16.33±10.74	28.66±15.32
Diaptomus	12.41±6.99	11.83±8.86	15.50±9.96
Daphnia	22.08±15.88	17.16±12.36	20.41±15.32
Bosmina	11.91±10.01	14.25±11.96	12.08±8.03
Helobdella	10.50±9.27	14.25±12.28	13.16±9.74
Nauplius Stages	13.58±11.34	13.50±7.26	22.58±11.12
Total	95.00±64.21	87.33±61.74	112.41±67.48
Ostracoda			
Cypris	9.08±8.70	10.25±8.11	13.41±8.18
Stenocypris	8.16±6.91	7.66±6.86	12.75±8.70
Total	17.33±15.51	17.91±14.92	26.16±16.38

followed by Protozoa (162.58±111.51), Copepoda (95.00±64.21) and Ostracoda (17.33±15.51). The diversity recorded at S2 was found to be maximum for Rotifera (168.41±114.92) followed by Protozoa (146.5±113.99), Copepoda (87.33±61.74) and Ostracoda (17.91±14.92). At S3 the diversity was recorded to be highest for Rotifera (216.08±140.38) followed by Protozoa (186.00±114.34), Copepoda (112.41±67.48) and lowest for Ostracoda (26.16±16.38). However the overall density was found to be highest for S1 (549.24), followed by S3 (540.65) and lowest for S2 (420.15) showing a trend (S1>S3>S2). The qualitative analysis of Zooplankton in River Yamuna in Doon Valley revealed that the Protozoans were represented by *Actinophrys, Actinosphaerium, Euglena, Paramecium, Peridinium, Campenella, Epistylis, Vorticella, Arcella and Diffugia*. The Rotifera was represented by *Keratella, Rotatoria, Testudinella, Ascomorpha, Polyarthra, Philodina, Asplanchna, Pompholix, Brachionus and Trichocera.* The Copepoda was represented by *Cyclops, Diaptomus, Daphnia, Bosmina, Helobdella and Nauplius Stages*. The Ostracoda was represented by *Cypris and Stenocypris*.

The Macrobenthos dwelling in the River Yamuna at S1, S2 and S3 was dominated by 27 taxa and 7 orders. The order Ephemeroptera comprise of (6 genera), Diptera (5 genera), Coleoptera (4 genera), Hemiptera (3 genera), Plecoptera (3 genera), Odonata (3 genera) and Tricoptera (3 genera). Mean variation of all the three sites is shown in Table 4 and Fig. 10. The maximum diversity at S1 was found to be maximum for Ephemeroptera

Table 4: Qualitative and quantitative distribution (mean values of three sites) of Macrobenthos (ind. m^2) in River Yamuna for the period of April 2011- March 2012

Macrobenthos	S1	S2	S3
Ephemeroptera			
Ephemera	15.25±13.77	7.33±7.43	12.16±10.37
Baetis	15.25±10.98	12.66±10.10	12.83±12.37
Caenis	15.16±14.20	10.58±9.18	12.00±9.30
Leptophlebia	18.16±13.97	9.91±7.11	8.50±7.69
Cleon	11.41±11.00	9.08±8.65	6.08±7.15
Heptagenia	23.41±17.27	14.08±10.11	7.50±7.00
Total	98.66±77.78	63.66±49.12	59.08±52.56
Diptera			
Dixa	10.16±7.33	8.58±7.05	7.41±6.30
Chironomous	2.75±1.86	1.66±1.77	2.08±2.10
Simulium	3.00±2.52	9.41±7.19	8.16±7.46
Antoch	9.83±9.29	8.16±6.73	7.41±7.45
Bibiocephala	7.75±7.05	8.83±7.88	7.00±8.26
Total	33.5±25.58	36.66±27.26	32.08±27.53
Coleoptera			
Laccobius	6.83±6.36	8.08±7.39	7.75±5.84
Hydraticus	7.00±7.03	9.41±7.72	6.58±8.09
Hydrophilus	9.66±9.10	9.75±8.95	9.25±8.33
Dryops	5.75±6.57	8.16±7.77	7.91±7.66
Total	29.25±28.55	35.41±30.93	31.50±27.33
Hemiptera			
Micronecta	4.66±3.77	12.58±10.57	8.41±7.41
Heleoceris	8.16±7.63	9.08±7.24	8.83±8.45
Gerris	6.41±7.63	8.25±6.95	7.41±7.70
Total	19.25±18.10	29.91±24.49	24.66±22.54
Plecoptera			
Perla	6.75±4.78	10.66±8.54	9.91±7.73
Isoperla	4.91±3.87	11.50±10.28	7.00±6.86
Capnia	9.75±10.24	10.16±7.20	6.08±6.84
Total	21.41±16.76	32.33±24.87	23.00±20.56
Odonata			
Corixa	9.00±8.16	7.75±7.17	7.41±6.97
Agrion	1.41±2.10	8.50±8.74	7.83±7.14
Matrona	4.25±4.76	6.66±6.77	7.33±7.37
Total	14.66±14.38	22.91±22.10	22.58±20.31
Tricoptera			
Hydrosyche	7.66±7.02	6.50±7.37	5.00±4.72
Glossoma	5.75±8.52	6.58±5.82	7.5±7.10
Hydroptila	6.00±8.52	7.25±7.85	8.41±7.26
Total	19.41±20.32	20.33±20.76	20.91±18.74

(98.66±77.78), followed by Diptera (33.5±25.58), Coleoptera (29.25±28.55), Plecoptera (21.41±16.76), Hemiptera (19.25±18.10), Odonata (14.66±14.38), Tricoptera (19.41±20.32). The diversity recorded at S2 was highest in case of Ephemeroptera (63.66±49.12) followed by Diptera (36.66±27.26), Coleoptera (35.41±30.93), Plecoptera (32.33±24.87), Hemiptera (29.91±24.49), Odonata (22.91±22.10) and Tricoptera (20.33±20.76). The diversity at S3 was found to be maximum for Ephemeroptera (59.08±52.56) followed by Diptera (32.08±27.53), Coleoptera (31.50±27.33), Hemiptera (24.66±22.54), Plecoptera (23.00±20.56), Odonata (22.58±20.31), Tricoptera (20.91±18.74). However the overall density was highest S2 (241.21) followed by S1 (236.14) with lowest at S3 (213.81) showing a trend from S2>S1>S3. The qualitative measurement of Macrobenthos in the River Yamuna in Doon Valley revealed that the Ephemeroptera was represented by *Ephemera, Baetis, Caenis, Leptophlebia, Cleon and Heptagenia.* The Diptera was represented by *Dixa, Chironomous, Simulium, Antoch and Bibiocephala.* The Coleoptera was represented by *Laccobius, Hydraticus, Hydrophilus and Dryops* and Hemiptera was represented by *Micronecta, Heleoceris and Gerris.* The Plecoptera was represented by *Perla, Isoperla and Capnia* and Odonata was represented by *Corixa, Agrion and Matrona.* The Tricoptera was represented by *Hydrosyche, Glossoma and Hydroptila*.

Relationship Between Physico-Chemical Attributes: Karl Pearson correlation (r-values) calculated for the quantification of relationship between various physical and chemical parameters (Table 5) revealed that transparency was positively correlated with temperature (r=0.98, p>0.001). Velocity was negatively correlated with temperature (r=-0.59, p>0.05). Turbidity was negatively correlated with temperature (r=-0.70, p>0.01). Turbidity was also negatively correlated with transparency (r = -0.58, p>0.05). Conductivity was negatively correlated with temperature (r=-0.94, p>0.001). Conductivity was positively correlated with turbidity (r = 0.89, p>0.001). Total Solids were positively correlated with transparency (r=0.50, p<0.05). Total Solids were positively correlated with turbidity (r=0.25, p<0.001). TDS was positively correlated with transparency (r=0.76, p<0.001).TDS was negatively correlated with conductivity (r=-0.38, p<0.10). TSS was positively correlated with turbidity (r = 0.38, p<0.10). pH was negatively correlated with temperature (r=-0.32, p<0.10). pH was positively correlated with velocity (r= 0.89, p>0.001). pH was negatively correlated with conductivity (r=0.60, p<0.02). pH was positively correlated with TDS (r = 0.49, p<0.05). Total alkalinity was positively correlated with conductivity (r=0.53, p<0.05). Total Hardness was negatively correlated with Total Solids (r=-0.99, p>0.001). Calcium was negatively correlated with TDS (r=-0.94, p>0.001). Magnesium was negatively correlated with hardness (r=-0.80, p<0.001). Chloride was positively correlated with conductivity (r = 0.01, p<0.10). Chloride was negatively correlated with Hardness (r=-0.99, p > 0.001). Free CO_2 was positively

Table 5: Pearson Correlation (r-values) calculated between physicochemical Parameters of River Yamuna in Doon Valley for the year April 2011-March 2012

	Temp.	Transparency	Velocity	Turbidity	EC	TS	TDS	TSS	pH	T Alk	T HD	Ca	Mg	Cl	FCO_2	D.O	B.O.D	C.O.D	PO_4	NO_3	Na	K
Temp.	1																					
Transparency	0.98	1																				
Velocity	-0.59	-0.59	1																			
Turbidity	-0.70	-0.58	0.99	1																		
EC	-0.94	-0.88	0.90	0.89	1																	
TS	0.50	0.50	0.24	0.25	-0.20	1																
TDS	0.65	0.76	0.05	0.06	-0.38	0.98	1															
TSS	0.37	0.51	0.37	0.38	-0.06	0.98	0.94	1														
pH	-0.32	-0.16	0.89	0.89	0.60	0.65	0.49	0.75	1													
TAlk	-0.77	-0.86	0.11	0.10	0.53	-0.93	-0.98	-0.87	-0.34	1												
T HD	-0.39	-0.54	-0.35	-0.36	0.08	-0.99	-0.95	-0.99	-0.73	0.88	1											
Ca	-0.86	-0.93	0.27	0.26	0.66	-0.86	-0.94	-0.78	-0.18	0.98	0.80	1										
Mg	0.86	0.93	-0.27	-0.26	-0.66	0.86	0.94	0.78	0.18	-0.98	-0.80	-1	1									
Cl	0.30	0.45	0.44	0.45	0.01	0.97	0.91	0.99	0.80	-0.83	-0.99	-0.73	0.73	1								
F CO_2	0.94	0.98	-0.45	-0.44	-0.79	0.75	0.86	0.65	-1	-0.93	-0.67	-0.98	0.98	0.59	1							
D.O	-0.86	-0.93	0.27	0.26	0.66	-0.86	-0.94	-0.78	-0.18	0.98	0.80	1	-1	-0.73	-0.98	1						
B.O.D	-0.99	-0.99	0.69	0.68	0.93	-0.53	-0.68	-0.40	0.29	0.79	0.43	0.88	-0.88	-0.33	-0.95	0.88	1					
C.O.D	0.20	0.04	-0.82	-0.83	-0.50	-0.74	-0.60	-0.83	-0.99	0.45	0.81	0.31	-0.31	-0.87	-0.12	0.31	-0.16	1				
Po_4	0.81	0.71	-0.98	-0.98	-0.95	-0.08	0.10	-0.22	-0.81	-0.27	0.20	-0.42	0.42	-0.29	0.58	-0.42	-0.79	0.72	1			
No_3	0.86	0.77	-0.96	-0.96	-0.98	0.005	0.19	-0.13	-0.75	-0.35	0.11	-0.50	0.50	-0.21	0.65	-0.50	-0.84	0.66	0.99	1		
Na	0.96	0.90	-0.88	-0.87	-0.99	0.24	0.42	0.10	-0.57	-0.57	-0.13	-0.69	0.69	0.03	0.82	-0.69	-0.95	0.46	0.94	0.97	1	
K	0.92	0.85	-0.92	-0.92	-0.99	0.14	0.32	-0.001	-0.65	-0.48	-0.02	-0.61	0.61	-0.07	0.75	-0.61	-0.91	0.55	0.97	0.99	0.99	1

Abbreviations: Temp. = Temperature, EC = Electric Conductivity, TS = Total Solids, TDS = Total Dissolved Solids, TSS =Total Suspended Solids, T ALK = Total Alkalinity, T HD= Total Hardness, Ca = Calcium, Mg = Magnesium, FCO_2 = Free Carbon Dioxide, D.O = Dissolved Oxygen, BOD = Biological Oxygen Demand, COD = Chemical Oxygen Demand, PO_4= Phosphate, NO_3 = Nitrate, Na = Sodium, K = Potassium

Table 6: Pearson Correlation (r-values) calculated between Phytoplankton and Zooplankton diversity and physicochemical environmental variables of River Yamuna in Doon Valley for the year April 2011-March 2012

	Temp.	Transparency	Velocity	Turbidity	EC	TS	TDS	TSS	pH	T Alk	T HD	Ca	Mg	Cl	FCO_2	DO	BOD	COD	PO_4	NO_3	Na	K
Chlorophyceae	0.31	0.15	-0.88	-0.89	-0.59	-0.66	-0.50	-0.76	-0.99	0.35	0.74	0.19	-0.19	-0.80	-0.01	0.2	-0.28	0.99	0.80	0.74	0.56	0.64
Bacillariophyceae	-0.63	-0.75	-0.08	-0.08	0.36	-0.98	-0.99	-0.95	-0.52	0.98	0.96	0.93	-0.936	-0.92	-0.85	0.93	0.66	0.62	-0.08	-0.17	-0.40	-0.30
Myxophyceae	0.92	0.85	-0.92	-0.92	-0.99	0.13	0.31	-0.00	-0.66	-0.47	-0.02	-0.61	0.612	-0.08	0.75	-0.61	-0.91	0.56	0.97	0.99	0.99	0.99
Protozoans	0.58	0.44	-0.98	-0.98	-0.81	-0.40	-0.22	-0.53	-0.95	0.05	0.05	-0.11	0.107	-0.59	0.29	-0.11	-0.56	0.91	0.94	0.91	0.78	0.84
Rotifera	-0.55	-0.67	-0.18	-0.19	0.25	-0.99	-0.99	-0.9	-0.61	0.95	0.98	0.89	-0.893	-0.96	-0.79	0.89	0.58	0.70	0.02	-0.06	-0.30	-0.19
Copepoda	0.67	0.54	-0.99	-0.99	-0.87	-0.29	-0.11	-0.43	-0.91	-0.05	0.40	-0.22	0.219	-0.49	0.39	-0.22	-0.65	0.86	0.97	0.95	0.85	0.90
Ostracoda	0.89	0.80	-0.95	-0.95	-0.98	0.05	0.24	-0.08	-0.71	-0.40	0.05	-0.55	0.55	-0.15	0.69	-0.55	-0.88	0.62	0.98	0.99	0.98	0.99

Abbreviations: Temp. = Temperature, EC = Electric Conductivity, TS = Total Solids, TDS = Total Dissolved Solids, TSS =Total Suspended Solids, T ALK = Total Alkalinity, T HD= Total Hardness, Ca = Calcium, Mg = Magnesium, FCO_2 = Free Carbon Dioxide, D.O = Dissolved Oxygen, BOD = Biological Oxygen Demand, COD = Chemical Oxygen Demand, PO_4= Phosphate, NO_3 = Nitrate, Na = Sodium, K = Potassium

correlated with temperature (r=0.94, p>0.001). Free CO_2 was negatively correlated with pH (r=-1.0, p>0.001). Dissolved Oxygen was negatively correlated with temperature (r=-0.86, p>0.001). Dissolved Oxygen was positively correlated with turbidity (r=0.26, p<0.10). Dissolved Oxygen was negatively correlated with Free CO2 (r=-.073, p>0.01). BOD was negatively correlated with temperature (r=-0.99, p>0.001). BOD was positively correlated with Dissolved Oxygen (r=0.88, p>0.001). COD was positively correlated with Dissolved Oxygen (r=0.31, p<0.10). Phosphate was negatively correlated with turbidity (r=-0.98, p>0.001). Nitrate was negatively correlated with BOD (r=-0.84, p>0.001). Sodium was negatively correlated with conductivity (r=-0.99, p>0.001). Potassium was positively correlated with Sodium (r=0.99, p>0.001) and turbidity (r=-0.92, p>0.001).

Relationship Between Hydrological Parameters and Plankton Diversity: Pearson correlation coefficient (r values) calculated between physico-chemical variables and Plankton population (Table 6) inhabit River Yamuna revealed that Chlorophyceae was positively correlated with pH (r=-0.99, p>0.001). Chlorophyceae was positively correlated with temperature (r=0.31, p<0.10). Chlorophyceae was positively correlated with Dissolved Oxygen (r=0.20, p<0.10). Bacillariophyceae was negatively correlated with temperature (r=-0.63, p<0.01). Bacillariophyceae was positively correlated with Dissolved Oxygen (r = 0.93, P>0.001). Myxophyceae was negatively correlated with Dissolved Oxygen (r=-0.61, p<0.02). Protozoans were negatively correlated with turbidity (r=-0.98, p>0.001). Protozoans were positively correlated with temperature (r=0.58, p>0.05).

Table 7: Pearson Correlation (r-values) calculated between Macrobenthos diversity and physicochemical environmental variables of River Yamuna in Doon valley for the year April 2011-March 2012

	Temp.	Transparency	Velocity	Turbidity	EC	TS	TDS	TSS	pH	T A	T H	Ca	Mg	Cl	FCO_2	DO	BOD	COD	PO_4	NO_3	Na	K
Ephemeroptera	-0.91	-0.96	0.37	0.36	0.74	-0.80	-0.91	-0.71	-0.08	0.96	0.73	0.99	-0.99	-0.66	-0.99	0.99	0.92	0.20	-0.52	-0.59	-0.77	-0.69
Diptera	-0.29	-0.14	0.88	0.88	0.58	0.67	0.52	0.77	0.99	-0.36	-0.75	-0.21	0.21	0.81	0.02	-0.21	0.26	-0.99	-0.79	-0.73	-0.55	-0.63
Coleoptera	0.36	0.50	0.38	0.39	-0.05	0.98	0.94	0.99	0.76	-0.86	-0.86	-0.77	0.77	0.99	0.64	-0.77	-0.39	-0.83	-0.24	-0.15	0.09	-0.01
Hemiptera	0.51	-0.93	0.23	0.24	-0.21	0.99	0.98	0.98	0.64	-0.93	-0.99	-0.87	0.87	0.97	0.76	-0.87	-0.54	-0.73	-0.08	0.01	0.25	0.15
Plecoptera	0.14	0.29	0.59	0.59	0.18	0.92	0.83	0.97	0.89	-0.73	-0.96	-0.61	0.61	0.98	0.45	-0.61	-0.17	-0.94	-0.46	-0.37	-0.14	-0.24
Odonata	0.85	0.92	-0.24	-0.23	-0.63	0.88	0.95	0.80	0.22	-0.99	-0.82	-0.99	0.99	0.76	0.97	-0.99	-0.86	-0.34	0.39	0.47	0.67	0.58
Trichoptera	0.99	0.99	-0.62	-0.61	-0.90	0.60	0.74	0.48	-0.20	-0.85	-0.51	-0.92	0.92	0.42	0.97	-0.92	-0.99	0.07	0.74	0.79	0.91	0.87

Abbreviations: Temp. = Temperature, EC = Electric Conductivity, TS = Total Solids, TDS = Total Dissolved Solids, TSS =Total Suspended Solids, T ALK= Total Alkalinity, T HD= Total Hardness, Ca = Calcium, Mg = Magnesium, FCO_2 = Free Carbon Dioxide, D.O = Dissolved Oxygen, BOD= Biological Oxygen Demand, COD= Chemical Oxygen Demand, PO_4= Phosphate, NO_3= Nitrate, Na= Sodium, K= Potassium

Rotifera were negatively correlated with velocity (r=-0.18, p<0.10). Rotifera were negatively correlated with pH (r=0.61, p<0.02). Copepoda were negatively correlated with turbidity (r=-0.99, p>0.001). Copepoda were negatively correlated with Dissolved Oxygen (r=-0.22, p<0.10). Copepoda were positively correlated with Phosphate (r=0.97, p>0.001). Ostracoda were positively correlated with temperature (r=0.89, p>0.001). Ostracoda were negatively correlated with pH (r=-0.71, p>0.01) and Dissolved Oxygen (r=-0.55, p<0.02).

Relationship Between Hydrological Parameters and Macro Benthos: Pearson correlation coefficient (r values) calculated between physico-chemical variables and Macro benthic fauna (Table 7) dwelling the River Yamuna in Doon Valley revealed that Ephemeroptera were negatively correlated with temperature (r=-0.91, p>0.001) and positively correlated with Dissolved Oxygen (r=0.99, p>0.001). Diptera were positively correlated with velocity (r=0.88, p>0.001) and negatively correlated with Total hardness (r=0.75, p>0.01). Coleoptera were positively correlated with TS (r=0.98, p>0.001), TDS (r=0.94, p >0.001), TSS (r=0.76, p>0.01) and negatively correlated with Dissolved Oxygen (r=-0.77, p>0.01). Hemiptera were positively correlated with temperature (r=0.51, p<0.05) and negatively correlated with Dissolved Oxygen (r=-0.87, p>0.001). Plecoptera were positively correlated with turbidity (r=0.59, p<0.02) and negatively correlated with Dissolved Oxygen (r = -0.61, p <0.02). Odonata were positively correlated with temperature (r=0.85, p>0.001) and negatively correlated with Conductivity (r=-0.63, p>0.05) and Total Alkalinity (r=-0.99, p>0.001). Tricoptera were positively correlated with transparency (r=0.99, p>0.001) and negatively correlated with Dissolved Oxygen (r=-0.92, P>0.001) and BOD (r=-0.99, p >0.001).

DISCUSSION

The Physico-chemical variables are important environmental factors of water in which all the biological communities live in association with each other [39]. The biological communities are the sensitive indicators of physical and chemical changes of aquatic ecosystem. The Physico-chemical factors influence the distribution as well as growth of aquatic diversity in river system. The most important controlling factors of growth include temperature, velocity, Dissolved oxygen, pH and turbidity and have direct and indirect effect bearing upon physical and chemical as well as biological activities in aquatic ecosystem [40]. Physicochemical variables such as water temperature, Dissolved oxygen, nutrients influence community structure and functions of aquatic organisms [32, 41]. The study of abiotic factors indicates that the magnitude of various parameters was partially or wholly associated with the level of river ecosystem. In the present study the parameters like temperature, velocity, pH and D.O have direct impact on the growth of biotic communities. However the other physico-chemical variables have a direct as well as indirect effect on the biological diversity. Similar results were found during the study on the river Bhagirathi [40]. The physicochemical parameters are useful in detecting the effect of pollution on the water quality, but changes in trophic conditions of water are reflected in the biological community structure including species pattern, distribution and diversity [42]. The most common physical assessment of water quality is the measurement of temperature. Temperature impacts both the chemical and biological characteristics of surface water [43]. In the present study the temperature showed a variation from S1 to S3. It was found highest at S3 (19.08±2.06°C) whereas it was lowest at S1 (17.91±2.02 °C). pH is the measure of the intensity of acidity or alkalinity and the concentration of hydrogen ions in water. pH has no direct adverse effect on health however the value of pH hasten the scale formation in water heating apparatus and also reduce germicidal potential of chloride. High pH also induces the formation of trihalomethanes which are toxic [5]. pH affects the dissolved oxygen level of the water, photosynthesis of aquatic organisms (phytoplankton) and the sensitivity of these organisms to pollution, parasites and diseases [44]. In the present study the range of pH showed a little variation from S1 to S3. The pH recorded at S1 was (8.14±0.12), S2 (8.22±0.16) and S3 (8.10± 0.12). A change in pH also affects aquatic life indirectly by altering other aspects of water chemistry [45]. Turbidity is an important measure of water clarity that tells us the degree to which light entering a column of water is scattered by suspended solids. The more turbidity means less penetration of light into the water. Therefore the amount of photosynthesis can decrease. This results in a decrease in the amount of oxygen produced by aquatic plants [46]. The turbidity was found maximum at S2 (291.66±397.28 JTU) however it was minimum at S3 (267.91±354.20 JTU). Similar results were obtained during the study on the rivers of Uttarakhand [5]. Total suspended solids absorb the heat from sunlight and raise the temperature of water. This also limits the amount of DO that water can hold [47]. The concentration of TSS was found highest at S2 (308.33±202.07 mg/l) and lowest at S1 (241.66± 50.50 mg/l). Thus D.O was found maximum at S1 (10.89±0.95 mg/l) and minimum at S2 (10.54±0.41 mg/l). These results showed the effect of TSS on the concentration of dissolved oxygen of River Yamuna in present study. D.O is of great importance to all living organisms of water. It may be present in water due to direct diffusion and photosynthetic activity of autotrophs [48]. The concentration of DO is one of the most important parameter to indicate water purity and to determine the distribution of various algal groups [49]. In present study the value of alkalinity was found highest at S1 (298.75±422.59 mg/l) and lowest at S2 (145.75±10.33). Alkalinity is measured to determine the ability of river to resist changes in pH. That is to say alkalinity allows scientists to determine rivers buffering capacity [44]. Alkalinity values of 20-200 mg/l are common in fresh water ecosystems. Alkalinity below 10 mg/l indicates poorly buffered rivers. These rivers are least capable of resisting changes in pH, therefore they are more susceptible to problems which occur as a result of acidic pollutants [47]. Total hardness of River Yamuna ranged from (81.91±9.59 mg/l) to (91.33±14.04 mg/l) which showed the desirable limit as per Indian standards [50]. Calcium and magnesium ranged from (30.59±4.21 to 45.64±4.46 mg/l) and (11.14±2.59 to 13.90±3.90 mg/l) respectively. Total hardness has got no adverse effect on human health. Water with hardness above 200 mg/l can cause scale deposition in water distribution systems and more soap consumption [34]. BOD is the amount of oxygen required by the living organisms engaged in the utilization and ultimate destruction or stabilization of organic water [51]. It is very indicator of the pollution status of a water body. The values of BOD showed a higher concentration in range of (2.56± 0.22 to 2.87±0.31 mg/l). Chloride is one of the important indicators of pollution. It is present in sewage, effluents and farm drainage. The value of chloride in the present study was in the lower range as found in different river systems of India [52, 53]. The concentration of nitrate and phosphate at all the sites were in the minimum possible amounts. The nitrate concentration depends on the activity of nitrifying bacteria which in turn gets influenced by presence of DO. The phosphate is an important constituent not only for aquatic vascular plants but also for growth of other aquatic life. The low concentration of phosphate affects the growth of aquatic flora as it is very essential plant nutrient [54, 55].

In the present study the quantitative and qualitative differences in phytoplankton population of all the three sites indicate that nutrient composition influences phytoplankton inhabitant of the water. It is expected that more than 90% variation in phytoplankton density is influenced by physicochemical factors and only 10% by other factors [56]. The fluctuations in phytoplankton groups at all the three sites were shown (Table 2). Maximum number of total phytoplankton indicates good physicochemical conditions. In the present study Chlorophyceae and Myxophyceae was found highest at S3 where as Bacillariophyceae was maximum at S1. Their occurrence might be the ability of these groups to survive in the conditions and to adjust and adapt with the environment whether it is suitable or not. The presence of phytoplankton diversity in River Yamuna indicates good water quality to a much extent showed less effect of pollution load. The Zooplankton population was found to be sufficient at all the three sites with Rotifera dominant at S1 and Protozoans, Copepoda and Ostracoda maximum at S3. As the S3 represents a lake ecosystem, it might be the reason for maximum growth of plankton diversity due to increased concentration of nutrients. According to Murugan *et al*. [36] and Dahdich and Saxena [57] Zooplankton plays an integral role and serves as bioindicators and it is well suited tool for understanding water pollution status [10, 58]. The abundance of benthic macro invertebrates dwelling the River Yamuna has been found maximum at S2 followed by S1 and S3 showing an irregular trend (S2> S1> S30. The variation may be due to the variation in substrate combination as well as the hydrological parameters prevailing at all the sites. Despite all the conditions the diversity of River Yamuna in Doon Valley was fairly good suggesting that the water quality is not much affected. Among all the Macroinvertebrates the diversity of Ephemeroptera was maximum followed by Diptera, Coleoptera, Plecoptera, Hemiptera, Odonata and Tricoptera respectively. From the present study the total diversity recorded in the River Yamuna in Doon Valley was good enough to indicate that the physicochemical conditions of river provide a healthier environment for the growth and Survival of biological communities, but it does not mean that the river is free from pollution and it is important to monitor it regularly. Besides this management efforts should be made for the conservation of River Yamuna in Doon Valley otherwise it will rapidly turn into the state that would not be fit for the growth and survival of aquatic life present in it.

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