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Correlation between physico-chemical properties of water and zooplankton diversity and abundance in the freshwater ecosystem of the Gandak River

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Abstract
This study aims to test whether there is a link between water properties and zooplankton populations in the Gandak River of northern India. Since zooplankton are sensitive to changes in the quality of water, their presence and type in rivers play a key role in understanding how the ecosystem functions. Each month, water was taken from chosen points on the Gandak River during the six months of the study. Temperature, pH, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS) and concentrations of nitrates and phosphates in the water were measured by following regular procedures. During the same period, zooplankton samples were taken using plankton nets and recorded at the finest level possible. It was found that water quality varies throughout the year, with differences between places, and this is strongly linked to how zooplankton differ in diversity and numbers. Most of the organisms found were rotifers, copepods, cladocerans and protozoans. Despite varied nutrient levels, places with optimum DO and pH saw the most zooplankton. On the other hand, places with higher BOD and TDS had a lower zooplankton population. The zooplankton community showed a strong relationship with the quality of water, as confirmed by both Pearson's correlation and the Shannon-Wiener and Simpson's Index. By analysing zooplankton in rivers, the study points out that their presence in water indicates a healthy freshwater environment and suggests monitoring rivers such as the Gandak often to spot and reduce human effects on aquatic life.

Keywords: Gandak River, zooplankton diversity, physico-chemical parameters, freshwater ecosystem, bioindicators, water quality, ecological assessment

Introduction

Animals and plants in freshwater ecosystems interact closely with their environment. These various tiny organisms called zooplankton support the food chain in aquatic systems and show immediate changes if the water quality changes (Sharma & Sharma, 2019) [14]. Diversity and the presence of many organisms in water are affected by things like temperature, the pH level, dissolved oxygen, biological oxygen demand, chemical oxygen demand, total dissolved solids and nitrate and phosphate concentrations (Chen, 2020) [2]. Analysing the above factors along with the zooplankton helps to understand how healthy the freshwater ecosystems are. Several aspects of human life, like city population increase, manure from agriculture and discharges from factories, harm the Gandak River that crosses northern India. River-related activities may alter the water and chemical factors, which, after that change, affect the abundance of zooplankton (Priyadarshee *et al*., 2024) [13]. The management and assessment of the Gandak River require understanding how both water quality and the number of zooplankton change (Jose & Furio, 2015) [6].

There has been a great deal of focus in recent studies on the importance of these assessments. The study evaluated the link between zooplankton species and factors affecting the water in a pond in Jammu and revealed that over the year 2019, the water and zooplankton communities changed a lot from the different seasons (Paturej *et al*., 2016) [12]. In a related way, Chen (2020) [2] investigated whether levels of nutrients in water influence the population of zooplankton in urban lakes. It is also shown by Burhi Gandak River measurements in Samastipur, Bihar, that water quality constantly fluctuates, suggesting that human actions impact its health (Oparaku *et al*., 2022) [10].

Following earlier studies, the present research aims to identify how the main qualities of water impact the types and numbers of zooplankton in the Gandak River. It also aims to identify changes in water quality year-round and the zooplankton found in various areas along the Gandak River, and to encourage appropriate protection and management of the Gandak River.

Materials and Methods

The study was conducted to find out whether the zooplankton in the Gandak River in Bihar, India, are linked to the water's physical and chemical properties. The Gandak River begins in the Himalayas in Nepal and becomes an important tributary of the Ganga River (Fig. 1), given its water for farming, industrial use and homes in the Indo-Gangetic plains (Kaushal *et al*., 2022) [7]. The study included three areas, each with different levels of human activity and stream importance: Valmikinagar was upstream and least affected by people, in Muzaffarpur the water flows through town and downstream, Hajipur is a highly-used site by humans (Chaudhary & Singh, 2019) [1]. As there are human settlements set upon each riverside, these sites indicate how healthy the land and water are in that area.

Study Sites and Sampling Strategy

Water samples were collected in the pre-monsoon duration from April to June and in the post-monsoon duration from October to December to show the most significant changes in water in the study area. At each river location, water was collected from under 20 to 30 cm using polypropylene bottles, which were treated with acid (Liu *et al*., 2021) [8].

Immediately after picking up, samples were frozen and brought to the laboratory within 12 hours for evaluation. Each sample was tested three different times, and the average was used to keep the outcomes the same.

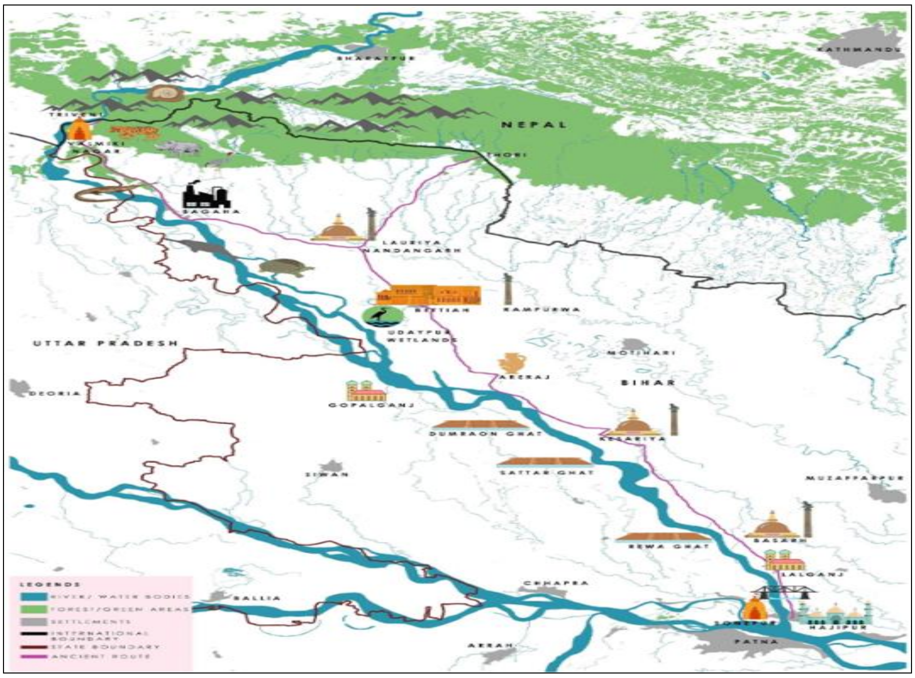

Fig 1: Gandak River Map (Living Waters Museum, 2024) [9]

Physico-Chemical Analysis

The parameters were temperature, pH, turbidity, TSS, total hardness, alkalinity, DO, BOD, COD and Chloride. Temperature was measured at the site using a mercury thermometer, and the pH was checked with a pH meter, both thoroughly calibrated (Liu *et al*., 2021) [8]. Turbidity was evaluated using the nephelometric method, and TSS was calculated using the results of gravimetric measurements. Laboratory titration was used for the alkalinity test, using acids, and for the total hardness, EDTA complexometric titration was used (Singh *et al*., 2017) [15]. Using Winkler's approach, DO was tested on the samples, and BOD was determined after the water samples had been left to incubate for five days at 20 °C and then titrated. A closed reflux titration was carried out using potassium dichromate digestion to determine the COD.

Zooplankton Analysis

Approximately fifty litres of surface water were passed through a plankton net with a 77 µm-sized mesh to collect zooplankton. The samples were concentrated and placed in a 5% formalin solution right away. Zooplankton were identified and sorted under a compound microscope using the taxonomic keys given by Gebrekidan *et al.* (2024) [4] in the laboratory. Groups of Rotifera, Cladocera, Copepoda and Ostracoda were observed during the task. A Sedgwick-Rafter counting chamber was used to count zooplankton under a standardized amount of water (D'Alelio *et al*., 2022) [3]. The species richness, abundance and evenness found in each group were assessed using the Shannon-Wiener Index (H′) and Simpson's Diversity Index (D) (Herrera *et al*., 2023) [5].

Data Collection

The information for this study covers a complete evaluation of water quality factors and zooplankton in the Gandak River, for both times of the year. This dataset consists of important water parameters such as temperature, pH, conductivity, turbidity, TDS, TSS, alkalinity, hardness, chloride levels, DO, BOD and COD. Figures for DO, BOD and COD varied with the season, suggesting that the samples became less polluted as the monsoon began.

Table 1: Water Quality parameters

Parameter	Pre-Monsoon Range	Post-Monsoon Range
Temperature (°C)	19.0 – 21.0	25.8 – 26.6
pH	8.2 – 8.4	7.5 – 8.0
Conductivity (µS/cm)	161.67 – 305.67	260 – 330
Turbidity (NTU)	11.49 – 124	130 – 190
TDS (mg/L)	163.33 – 208	158 – 225
TSS (mg/L)	85.67 – 109.67	102 – 145
Total Alkalinity (mg/L)	94 – 115	107 – 130
Total Hardness (mg/L)	103 – 128	110 – 135
Chloride (mg/L)	16 – 18.33	24 – 33
DO (mg/L)	5.47 – 10.47	4.5 – 6.3
BOD (mg/L)	5.5 – 6.5	2.2 – 2.8
COD (mg/L)	16 – 22.23	21 – 29

Table 2: Zooplankton Abundance and Diversity

Zooplankton Group	Pre-Monsoon	Post-Monsoon
Rotifera	146 – 420	110 – 580
Cladocera	2 – 30	5 – 160
Copepoda	2 – 36	4 – 140
Ostracoda	1 – 20	2 – 70
Total Zooplankton	151 – 506	121 – 950
Shannon-Wiener Index (H′)	2.1 – 2.6	2.6 – 3.1
Simpson's Index (D)	0.78 – 0.84	0.84 – 0.89

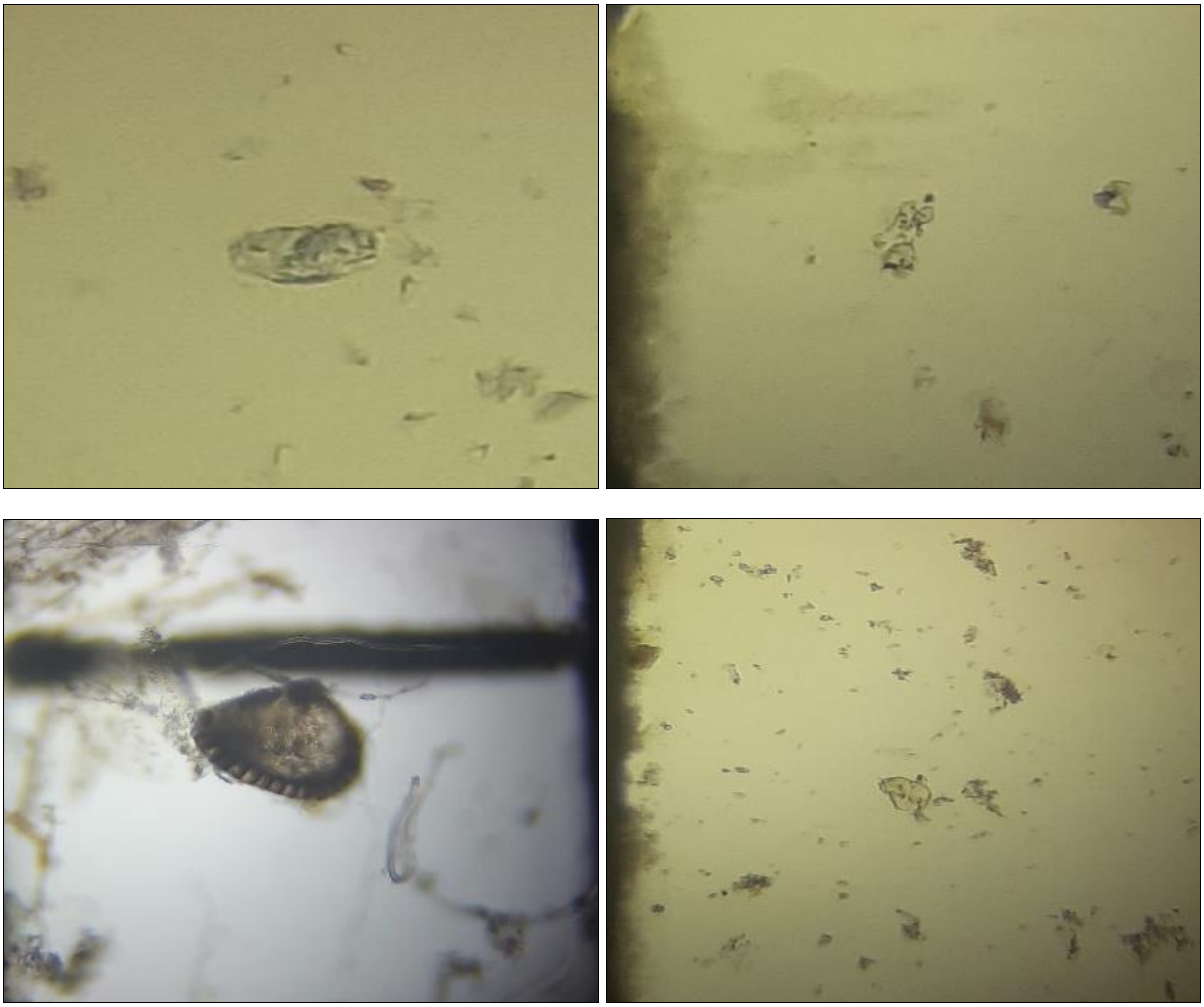

Fig 2: Zooplanktons observed during study

Statistical Analysis

The aforementioned analyses of mean, standard deviation and range were computed to examine water quality at each location for each season. To investigate spatial and seasonal changes, one-way ANOVA was carried out for both the physico-chemical measures and zooplankton metrics. The differences among different means were examined using Tukey's HSD test. A Pearson's correlation coefficient was applied to study how water quality factors affect the diversity and abundance of zooplankton. Models, graphs and analyses were prepared in Microsoft Excel 2008.

The detailed methodology allowed for a thorough examination of how zooplankton respond to changes in the environment, making it easier to support and create new plans for future conservation and water management.

Results and Discussion

The analysis in this study relies on the fact that changes in water quality relate to variations in the structure, numbers and diversity of the aquatic population, mainly among zooplankton. Because zooplankton live only briefly, respond to any changes in the water around them and are key in food webs, they serve as good indicators of biological health. The model states that temperature changes, dissolved oxygen, pH, BOD, COD and TDS can all have significant downstream effects on zooplankton communities.

In the model, when water quality deteriorates (for example, a higher BOD and less DO), the numbers of sensitive zooplankton are reduced, whereas groups like Rotifera might deal with it better and finally, dominate the water column. When the quality of water is better, there tend to be many different and numerous kinds of zooplankton. The model uses the Shannon-Wiener Index (H′) and Simpson's Diversity Index (D) to measure species richness and evenness as approximations of ecological unity.

The model also considers changes related to seasons, since monsoons change the water and its environment, so the zooplankton communities respond over time. Harvesting abundant zooplankton data and relating it to freshwater chemistry, the model allows for detecting ecological problems, identifying negative human impacts and understanding the health of the Gandak River.

Correlation

In the correlation matrices, we observe that the connections between different physico-chemical elements and zooplankton diversity are not the same for each monsoon period.

When the pre-monsoon period is considered, DO levels demonstrate a close relationship with zooplankton numbers (very high r value) and high structural diversity (correlation with the Shannon and Simpson indices). It suggests that higher DO benefits both the total number of zooplankton and their variety. Similarly, it was observed that higher levels of organic pollution go together with fewer sensitive taxa, as there are moderate negative relationships between BOD and Shannon Index (-0.579) and COD and Simpson Index (-0.369). A marginally positive correlation (r = 0.719) indicates that temperature promotes decomposition and increased organic matter in the sewer. There is a low but negative relationship between TDS and diversity, which suggests that increased salinity or minerals in water may lead to reduced numbers of different species.

The data from after the monsoon show stronger and clearer connections between weather and the economy. There is a very strong negative relationship between BOD, COD, pH and measurements of dissolved oxygen and zooplankton (e.g., BOD and the Shannon Index = r = -0.967, pH and Zooplankton = r = -0.988). As a result, more organic waste and lower pH after monsoons damage both the water and the life in the water. Even so, TDS and temperature are strongly linked to increases in both COD and BOD, likely because runoff is leading to an increased need for oxygen in waterways.

There is evidence from the post-monsoon data set that the river suffers additional stress because of discharge and inflow of pollution. Significantly, higher levels of zooplankton are seen when DO is higher and when BOD and COD are lower, as would be expected in an ecosystem. Altogether, the statistical tests support the theoretical idea that water quality directly affects zooplankton communities and highlights their usefulness as bioindicators. Post-monsoon conditions are linked to increased risks for aquatic life.

Table 3: Pre-Monsoon Correlation between the parameters

	Temperature (°C)	**pH**	**DO (mg/L)**	**BOD (mg/L)**	**COD (mg/L)**	**TDS (mg/L)**	**Zooplankton Abundance (ind./L)**	**Shannon Index (H′)**	**Simpson Index (D)**
Temperature (°C)	1								
pH	0.334597257	1							
DO (mg/L)	0.110137239	-0.278835582	1						
BOD (mg/L)	0.498523716	0.730625736	-0.509451458	1					
COD (mg/L)	0.719359509	0.386643307	0.431193172	0.077517382	1				
TDS (mg/L)	0.362005096	0.966152052	-0.03953215	0.625466345	0.530651797	1			
Zooplankton Abundance (ind./L)	0.131118145	-0.361985136	0.991072782	-0.574531694	0.450497667	-0.126221914	1		
Shannon Index (H′)	0.16212362	-0.39514072	0.980957655	-0.579710207	0.463138857	-0.161736737	0.997697275	1	
Simpson Index (D)	0.034418033	-0.455146665	0.973522564	-0.627357219	0.368806962	-0.217134671	0.987191177	0.987370036	1

Table 4: Post-Monsoon Correlation between the parameters

	Temperature (°C)	**pH**	**DO (mg/L)**	**BOD (mg/L)**	**COD (mg/L)**	**TDS (mg/L)**	**Zooplankton Abundance (ind./L)**	**Shannon Index (H′)**	**Simpson Index (D)**
Temperature (°C)	1								
pH	0.225448592	1							
DO (mg/L)	-0.43458808	-0.972235994	1						
BOD (mg/L)	-0.126045805	-0.992160934	0.943398964	1					
COD (mg/L)	0.42179327	0.972871458	-0.999019484	-0.944668125	1				
TDS (mg/L)	0.780722303	0.708823873	-0.852869329	-0.64018154	0.849239546	1			
Zooplankton Abundance (ind./L)	-0.109338985	-0.988751737	0.938733025	0.998919514	-0.939535275	-0.637093346	1		
Shannon Index (H′)	-0.241453091	-0.994490316	0.970626876	0.990518838	-0.967511244	-0.715041328	0.98927551	1	
Simpson Index (D)	-0.225448592	-1	0.972235994	0.992160934	-0.972871458	-0.708823873	0.988751737	0.994490316	1

Anova

To determine whether changes in season play a significant role, one-way ANOVA was used to examine physico-chemical parameters and zooplankton diversity indices in the Gandak River. A review of the data from before and after the monsoon season points to how the changing season influences water conditions.

Pre-Monsoon Analysis: There was a highly significant outcome on F-tests in the pre-monsoon dataset, resulting in an F-value of 90.27 that is far above the stated critical F-value (F crit = 2.15). With a p-value of 3.98×10^{-25} which is considerably less than 0.05, we can conclude that there are statistically significant differences between the group means for all parameters. The results prove that water quality and life forms vary greatly at various sites. There was significant variation in zooplankton abundance (9845.47), linked to movement in response to differences in TDS (variance = 353.87) and DO (variance = 4.47). The variability in BOD and pH measured only 0.14 and 0.0076, suggesting that both were similar at all sites.

Post-Monsoon Analysis: In the post-monsoon season, the data also showed group differences, with an F-value of 269.61 and p-value of 2.22×10^{-35}. The very low p-value shows that seasonal changes in water levels strongly affect the ecological markers measured. It was observed that zooplankton were very variable (4457.5), showing that more of them were present after the monsoon season due to increased feeding and more habitat. Low values of BOD (variance = 0.05) and Shannon Index (variance = 0.026) suggest that these parameters were steady at all stations. TDS and COD displayed the highest variances (834.17 and 9.47, respectively) because the runoff caused different contents of organic and inorganic components at various sites.

Results in both seasons suggest that zooplankton growth and the levels of biodiversity change mainly because of shifts in water quality. This means that abiotic variables are the main reasons behind changes in biotic variables, as shown by the research hypothesis and its supporting model. The data prove that zooplankton play an important role as signposts and demonstrate that routine seasonal checks are important for good management of the Gandak River.

Table 5: Pre-Monsoon ANOVA

ANOVA: Single Factor				
Summary				
Groups	**Count**	**Sum**	**Average**	**Variance**
Temperature (°C)	6	119.34	19.89	0.69704
pH	6	49.79	8.29833333	0.00761667
DO (mg/L)	6	45.83	7.63833333	4.47233667
BOD (mg/L)	6	35.73	5.955	0.14535
COD (mg/L)	6	115.46	19.2433333	5.41010667
TDS (mg/L)	6	1124.33	187.388333	353.872817
Zooplankton Abundance (ind./L)	6	2284	380.666667	9845.46667
Shannon Index (H′)	6	13.93	2.32166667	0.04801667
Simpson Index (D)	6	4.86	0.81	0.00056

Table 6: Post-Monsoon ANOVA

ANOVA: Single Factor				
Summary				
Groups	**Count**	**Sum**	**Average**	**Variance**
Temperature (°C)	6	157.5	26.25	0.095
pH	6	46.5	7.75	0.035
DO (mg/L)	6	33.3	5.55	0.503
BOD (mg/L)	6	14.9	2.483333333	0.053666667
COD (mg/L)	6	146	24.33333333	9.466666667
TDS (mg/L)	6	1103	183.8333333	834.1666667
Zooplankton Abundance (ind./L)	6	2925	487.5	4457.5
Shannon Index (H′)	6	16.8	2.8	0.026
Simpson Index (D)	6	5.19	0.865	0.00035

There were many differences in not only water quality but also the zooplankton community observed between the pre-monsoon and post-monsoon seasons. According to the data, both the zooplankton amount and their community structure are mostly driven by the quality of the water. Better conditions for zooplankton, such as Rotifera and Cladocera, arose during pre-monsoon because of increased DO and moderate temperatures at that time. It was obvious that DO closely followed changes in the Shannon-Wiener Index (r = 0.9809) and zooplankton abundance (r = 0.9910). At the same time, a higher concentration of organic pollution, measured by BOD and COD, was linked to a moderate decrease in species diversity. Although sites near the mouth showed pollution, the biological richness was maintained by enough oxygen and a balanced pH.

In the final season, water began to warm, and the pollutant particles in the water increased, yet BOD levels went down as the monsoons diluted the pollution. Still, when DO was pushed lower and nutrients were higher, certain areas became more stressful for water ecosystems. The abundance and diversity indicators (H′ and D) increased, probably driven by higher nutrients that let tolerant and opportunistic species grow. Seasonal variation was seen to be statistically important when the p-values were very low (less than 0.001) and F-values were high, confirming that differences in water and zooplankton indicators were due to real seasonal changes and not random error.

Essentially, what the study found makes it clear that the Gandak River shifts in response to the seasons and to changes caused by people. Changes in DO, BOD, COD and TDS were accurately displayed by shifts in zooplankton diversity. The study confirms that the qualities of water and its chemistry help determine freshwater biodiversity, showing it's important to constantly review aquatic life with biomonitoring.

Conclusion

The study investigated how water quality and zooplankton abundance and diversity are linked in the Gandak River during both pre-monsoon and post-monsoon seasons. It is clear from the results that there is a potent connection between how clean water is and the diversity in zooplankton groups, which aligns with the key hypothesis that physico-chemical conditions are the main factors shaping zooplankton populations. It was seen through seasons that higher dissolved oxygen and mild temperatures during the pre-monsoon period led to richer and better-balanced zooplankton groups. Some stretches showed high amounts of organic pollution, and this reduced the evenness of species present. Meanwhile, in the post-monsoon period, DO decreased, and more nutrients washed into reservoirs from the runoff, yet the quantity of zooplankton increased each week. The increased persistence comes from two main causes: nutrient enhancements and habitat expansions that helped strong species thrive. Both correlation and ANOVA analyses showed these results, especially for how DO, TDS, BOD and biodiversity indices like the Shannon-Wiener and Simpson's Index are connected. The consistent patterns found proved once again that zooplankton are reliable monitors of freshwater ecosystem health. All in all, the work highlights the dynamic environment of the Gandak River and stresses the importance of constant and combined observation of all ecological components. What we learn from changes in water quality and biological systems over the seasons forms the basis for informed decisions by policymakers, conservationists and those managing water resources. Assessing river health using zooplankton on a regular schedule can help us find early signs of balance disturbances and develop sustainable river management strategies for the future.

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