

# Assessment of water quality and zooplankton community structure in the Gambhiri River (Chittorgarh, Rajasthan, India)

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**ABSTRACT.** This study examines water quality parameters and zooplankton community structure in the Gambhiri River, Chittorgarh district of Rajasthan, India, to assess the ecological health and trophic state of this vital freshwater ecosystem. Seasonal sampling was conducted from January to December 2023 at six sampling sites to observe spatial and temporal variations in physicochemical parameters and zooplankton communities. Key water quality parameters, including water temperature, pH, total dissolved solids, turbidity, electrical conductivity, total hardness, chloride, alkalinity, dissolved oxygen, and biological oxygen demand, were measured using standard analytical techniques. Zooplankton samples were collected with a plankton net, preserved, and identified to the lowest possible taxonomic level, following standard keys. In the study period, 65 species of zooplankton were analyzed, of which 26 species of Rotifera, 25 species of Cladocera, 8 species of Copepoda, and 6 species of Ostracoda were recorded. Cladocera appeared as the dominant group of zooplankton with a higher density (38.67%), followed by Rotifera (35.72%), Copepoda (18.57%), and Ostracoda (7.03%). The season-wise zooplankton analysis revealed that Cladocera and Rotifera were the dominant groups across all seasons, while Copepoda and Ostracoda contributed comparatively less to the total density. Cladocera showed higher density than Rotifera during summer and post-monsoon seasons, whereas during monsoon and winter, Rotifera slightly dominated over Cladocera. Copepoda consistently remained the third dominant group in all seasons, while Ostracoda recorded the lowest density throughout the study period. The study highlights the importance of zooplankton as sensitive bioindicators for evaluating the health of freshwater ecosystems and recommends routine monitoring and pollution control measures to preserve the ecological integrity of this crucial water resource in Rajasthan's semi-arid region.

**Keywords:** Gambhiri River, zooplankton diversity, physicochemical parameters, seasonal variation

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## 1. Introduction

Water is the essential factor for the emergence, development, and protection of life. Rivers are crucial for the progress of any community or country, fulfilling needs in various sectors, including domestic, agricultural, aquatic, industrial, and hydroelectric. Freshwater ecosystems, particularly rivers, are among the most vital natural resources on Earth, providing essential ecosystem services, including water supply, nutrient cycling, and support for aquatic biodiversity (Dudgeon et al., 2006). Despite covering less than 1% of the Earth's surface, freshwater ecosystems harbor approximately 10% of all known species, making them biodiversity hotspots

of global significance (Strayer and Dudgeon, 2010). In the Indian subcontinent, rivers have long played a central role in shaping human civilization by sustaining large populations and acting as hubs of economic activity as well as cultural and traditional practices (Gopal and Chauhan, 2006). However, rapid urbanization, industrialization, and agricultural intensification have led to severe deterioration of water quality in rivers across the country, with developing regions facing particularly acute challenges (Vörösmarty et al., 2010; Singh et al., 2004).

The diversity and seasonal variation studies of zooplankton are of great importance in water bodies because they are the intermediate link between phyto-

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plankton and fish. It has been reported that zooplankton are predators of phytoplankton and are very sensitive to changes in environmental conditions (Xiong et al., 2016). Zooplankton are an integral component of the food chain; they occur in all waterbodies and are important to nutrient recycling and regeneration of primary production. According to Dudgeon et al. (2006), factors such as anthropogenic activities and climate change are obstructing the stability of most freshwater ecosystems, thereby causing a loss in the diversity of zooplankton (Alahuhta et al., 2019). A lot of research has been carried out on the diversity of various types of plankton, many of which are associated with far-ranging ecological and economic impacts (Anyanwu et al., 2023).

Plankton thrive in diverse environmental conditions but are highly responsive to changes in the physicochemical properties of their habitats. Research indicates that factors such as dissolved oxygen, temperature, salinity, and other physicochemical variables influence various zooplankton species (Anyanwu et al., 2023).

The ecological integrity of riverine systems depends on complex interactions between physical, chemical, and biological components. Among these, zooplankton communities form a crucial link in aquatic food webs, serving as primary consumers that convert phytoplankton and detrital matter into biomass available to higher trophic levels, including fish (Dutta et al., 2025). Beyond their ecological role, zooplankton have emerged as effective bioindicators of water quality due to their sensitivity to environmental changes, short generation times, and differential species-specific tolerances to pollution (Jeppesen et al., 2011; Gannon and Stemberger, 1978). Studies across Indian freshwater systems demonstrated strong correlations between zooplankton diversity metrics and physicochemical parameters such as dissolved oxygen, nutrients, conductivity, and temperature (Roychoudhury et al., 2013; Thakur et al., 2013).

Like many rivers in rapidly developing regions of India, the Gambhiri faces multiple anthropogenic pressures, including discharge of untreated or partially treated sewage from Chittorgarh city and smaller towns, agricultural runoff containing fertilizer and pesticide residues, potential small industrial effluents, water abstraction for irrigation and domestic use, and sedimentation from land use changes (Rodell et al., 2009). In the present study, we attempted to assess water quality and investigate the species composition, distribution, and seasonal variation of zooplankton at the Gambhiri River, Chittorgarh District, Rajasthan.

## 2. Materials and methods

### 2.1. Location of the study area

Chittorgarh is an important city of Rajasthan in western India. The city lies between the Berach and Gambhiri rivers and is situated at an average elevation of approximately 394 m (1292 ft) above mean sea level. It occupies a location in the southern region of Rajasthan and the northwestern part of India. Chittorgarh is situated adjacent to a prominent hill, on which the historic Chittorgarh Fort is located, near the Gambhiri River. Geographically, the area extends between latitudes 23°32' and 25°13'N and longitudes 74°12' and 75°49'E, falling within the southeastern part of Rajasthan (Fig. 1) (Loth and Panchal, 2023).

### 2.2. Collection of water samples

Water samples were collected from January to December 2023 from the effluent discharge points into the Gambhiri River in Chittorgarh district of Rajasthan, India. Sampling was carried out at six designated sites along the river. The samples were gathered in 1-liter plastic bottles that had been thoroughly pre-cleaned and rinsed, adhering to standard safety and contamination prevention protocols.



Fig.1. Map showing sampling sites at the Gambhiri River.

### 2.3. Analysis of water samples

The physicochemical parameters of water were analyzed following standard procedures recommended by the Indian Standards (IS) and the American Public Health Association (APHA). Water temperature was recorded using a mercury thermometer (°C) (IS 3025 pt-9, 1984). The hydrogen ion concentration (pH) was measured in situ with a calibrated digital pH meter in accordance with IS 3025 pt-11 (1983). Total dissolved solids (TDS), turbidity, and electrical conductivity (EC) were determined using standard instruments as prescribed under IS 3025 guidelines. Total hardness was estimated by the EDTA titrimetric method, employing Eriochrome Black T as an indicator (IS 3025 pt-21, 2009). Chloride content was analyzed through argentometric titration using a standard silver nitrate solution with potassium chromate as an indicator, following IS 3025 pt-32 (1988) procedures. Alkalinity was determined by titration with standard sulfuric acid using phenolphthalein as an indicator (IS 3025 pt-23, 1986). Nitrate concentration was measured by the UV spectrophotometric method (APHA 4500-NO<sub>3</sub>⁻; 1992), with absorbance recorded at 220 nm and correction applied at 275 nm. Dissolved oxygen (DO) was estimated by Winkler's iodometric method in accordance with IS 3025 pt-38 (1989). Biochemical oxygen demand (BOD) was calculated from the difference in DO values measured initially and after a five-day incubation period, following standard IS 3025 pt-44 (1993) protocols. Phosphorus was analyzed using a colorimetric technique based on the formation of a molybdate complex, as described in APHA Method 4500-P (1992). Sulphate concentration was determined by the turbidimetric method, wherein sulphate was precipitated as barium sulfate and measured at 420 nm using a spectrophotometer, in accordance with APHA Method 4500-SO<sub>4</sub>²⁻ (1992).

### 2.4. Collection and identification of zooplankton

For the zooplankton study, samples were collected from surface waters. Quantitative samples were obtained by towing a Hensen standard plankton net at a constant speed. The net was made of nylon with a mesh size of 50 µm. Immediately after collection, plankton samples were transferred to a polyethylene bottle (100 mL) and preserved in 70% ethyl alcohol for further analysis. For quantitative estimation, 50 L of surface water were filtered through a small plankton net made of nylon with a mesh size of 50 µm. The concentrated samples were thoroughly mixed, and 10 mL was withdrawn for counting. Zooplankton enumeration was carried out using a counting chamber under a compound microscope (Olympus CH20iBIMF). Zooplankton abundance was expressed as the number of individuals per liter of water. Zooplankton taxa were identified using standard identification keys, reference books, and relevant monographs (Edmondson, 1992; Battish, 1992; Tonapi, 1980; Khan, 2003; Sharma et al., 2012; Horne et al., 2019).

### 2.5. Statistical analysis

The statistical methods to analyze data were as follows: mean, standard deviation, one-way ANOVA, two-way ANOVA, and Karl Pearson's Coefficient of Correlation. The R software was used for data analysis (<https://www.r-project.org/about.html>).

## 3. Results and discussion

Table 1 shows season-wise physicochemical parameters of water samples collected. Most of the test results revealed significant differences in water quality parameters across seasons. Seasonal variation in water temperature regarding each sampling site demonstrated a highly significant difference in electrical conductivity, hardness, chloride, alkalinity, nitrate, and sulfate. A significant difference was found for TDS and turbidity. At the same time, a non-significant difference was found for pH, dissolved oxygen, BOD, and phosphorus.

In river ecology, water temperature is the most critical environmental parameter influencing aquatic organisms as well as the biological and chemical processes in water. Natural variations in water temperature are commonly governed by several environmental factors, including seasonal changes, water depth, wave activity, latitude, solar radiation, wind patterns, and heat exchange in near-shore zones (Saad et al., 2017). Statistical analysis revealed a highly significant variation in water temperature ( $F=128.73$ ;  $p<0.001$ ). As shown in Table 1, surface water temperature in the Gambhiri River varied from  $21.15 \pm 1.07$  °C to  $30.50 \pm 1.07$  °C during different seasons of the study period.

The ecological performance of aquatic environments is strongly influenced by pH, as it regulates metabolic activity and the availability of nutrients. In the present investigation, river water pH showed moderate seasonal variation, which can be attributed to the combined influence of domestic sewage, surface runoff, and occasional industrial effluent inputs. Throughout the study period, pH values remained within a narrow range of  $7.71 \pm 0.40$  to  $7.94 \pm 0.51$  (Table 1). The lowest pH values were recorded during winter, whereas higher values were observed in the post-monsoon period. The increase in pH during post-monsoon may be linked to intensified photosynthetic activity, resulting in greater assimilation of dissolved CO<sub>2</sub> and a subsequent rise in pH (Islam et al., 2025). Comparable seasonal patterns were also reported by Islam et al. (2025) for the Kangsabati River, West Medinipur, and Khairy et al. (2015) for the Mediterranean Lakes in Egypt.

Total dissolved solids (TDS) consist primarily of inorganic ions, including calcium, magnesium, sodium, potassium, bicarbonate, chloride, and sulphate, which accumulate in aquatic systems through natural and anthropogenic processes (Adimalla et al., 2018). The overall concentration of dissolved solids serves as a general indicator of water suitability for various purposes. In the present study, total dissolved solids (TDS) ranged from  $408.67 \pm 43.78$  to  $510.83 \pm 48.83$  mg/L, with the lowest concentrations recorded during winter and the

**Table 1.** Season-wise physicochemical parameter

Parameter	Season				Sig.
	Winter	Summer	Monsoon	Post-Monsoon	
Water Temp. (°C)	27.62 ± 0.57	30.50 ± 1.07	29.07 ± 0.75	21.15 ± 1.07	F = 128.73 p = 0.000 ***
pH	7.71 ± 0.40	7.81 ± 0.57	7.77 ± 0.64	7.94 ± 0.51	F = 0.21 p = 0.889 NS
TDS (mg/L)	408.67 ± 43.78	510.83 ± 48.83	485.67 ± 36.48	421.50 ± 111.39	F = 3.24 p = 0.044 *
Turbidity (NTU)	4.12 ± 2.43	12.83 ± 8.28	5.43 ± 4.20	2.87 ± 2.41	F = 4.90 p = 0.010 *
EC (µS cm <sup>-1</sup> )	691.33 ± 125.04	995.17 ± 84.53	933.50 ± 109.66	840.67 ± 86.35	F = 9.92 p = 0.000 ***
Hardness (mg/L)	251.67 ± 23.17	175.00 ± 36.74	156.67 ± 42.74	173.33 ± 24.22	F = 10.07 p = 0.000 ***
Chloride (mg/L)	102.80 ± 14.8200	48.43 ± 10.67	60.75 ± 10.55	70.57 ± 11.48	F = 22.55 p = 0.000 ***
Alkalinity (mg/L)	281.02 ± 25.04	148.33 ± 38.69	153.33 ± 47.61	195.00 ± 48.89	F = 13.35 p = 0.000 ***
Nitrate (mg/L)	19.18 ± 6.82	13.33 ± 2.97	6.54 ± 4.80	6.30 ± 2.96	F = 10.46 p = 0.000 ***
DO (mg/L)	6.47 ± 2.19	4.65 ± 1.15	7.10 ± 0.85	6.68 ± 2.02	F = 2.57 p = 0.083 NS
BOD (mg/L)	4.12 ± 2.22	4.92 ± 4.40	4.65 ± 1.22	6.28 ± 2.97	F = 0.59 p = 0.628 NS
Phosphorus (mg/L)	0.17 ± 0.17	0.19 ± 0.01	0.25 ± 0.06	0.14 ± 0.10	F = 1.20 p = 0.334 NS
Sulphate (mg/L)	28.19 ± 4.58	33.74 ± 1.65	39.99 ± 3.49	47.64 ± 3.91	F = 32.82 p = 0.000 ***

**Note:** NS =  $p > 0.05$ ; \* =  $p < 0.05$ ; \*\* =  $p < 0.01$ ; \*\*\* =  $p < 0.001$

highest during summer. A comparable seasonal result in TDS was also reported by Chauhan et al. (2020).

Turbidity showed a statistically significant seasonal variation ( $F = 4.90$ ;  $p = 0.010$ ) (Table 1), with maximum values recorded during summer ( $12.83 \pm 8.28$  NTU). A similar seasonal trend in turbidity was also reported by Chauhan et al. (2020). Elevated turbidity during this period is likely associated with increased runoff and a higher sediment load. Turbidity showed a positive relationship with water temperature ( $r = 0.468$ ;  $p < 0.05$ ) and strong correlations with TDS ( $r = 0.658$ ;  $p < 0.001$ ) and electrical conductivity ( $r = 0.632$ ;  $p < 0.001$ ), suggesting a concurrent rise in suspended particles and dissolved constituents, primarily driven by runoff and erosion processes (Table 2).

Water temperature, along with the concentration and mobility of dissolved ions, determines electrical conductivity (EC). The World Health Organization recommends an upper limit of  $1500 \mu\text{S cm}^{-1}$  for EC in drinking water (WHO, 2017). In the present study, EC values remained within the permissible range, varying from  $691.33 \pm 125.04$  to  $995.17 \pm 84.53 \mu\text{S cm}^{-1}$  (Table 1). Similar EC values were reported by Reddy et al. (2025). A strong positive relationship was observed between EC and total dissolved solids ( $r = 0.772$ ;  $p < 0.001$ ) (Table 2), indicating that EC effectively reflects the overall ionic composition of the river water.

Seasonal variation in total hardness was evident, with values ranging from  $156.67 \pm 42.74$  mg/L during the monsoon to  $251.67 \pm 23.17$  mg/L in winter

**Table 2.** Intercorrelation between physicochemical parameters

	Water temp.	pH	TDS	Turbidity	EC	Hardness	chloride	Alkalinity	Nitrate	DO	BOD	Phosphorus
pH	-0.076 NS											
TDS	0.382 NS	0.281 NS										
Turbidity	0.468 *	0.008 NS	0.658 ***									
EC	0.336 NS	0.275 NS	0.772 ***	0.632 ***								
Hardness	0.049 NS	-0.096 NS	0.036 NS	0.247 NS	-0.235 NS							
chloride	-0.212 NS	0.037 NS	-0.206 NS	-0.213 NS	-0.466 *	0.774 ***						
Alkalinity	-0.187 NS	0.374 NS	-0.230 NS	-0.199 NS	-0.412 *	0.660 ***	0.817 ***					
Nitrate	0.348 NS	-0.049 NS	0.092 NS	0.300 NS	-0.003 NS	0.756 ***	0.544 **	0.590 **				
DO	-0.200 NS	-0.131 NS	-0.616 **	-0.602 **	-0.476 *	-0.196 NS	0.085 NS	-0.098 NS	-0.466 *			
BOD	-0.168 NS	0.479 *	0.576 **	0.256 NS	0.386 NS	0.110 NS	0.161 NS	0.197 NS	0.097 NS	-0.518 **		
Phosphorus	0.232 NS	0.204 NS	0.387 NS	0.159 NS	0.439 *	-0.037 NS	0.039 NS	-0.013 NS	0.202 NS	-0.220 NS	0.021 NS	
Sulphate	-0.639 ***	0.153 NS	0.060 NS	-0.248 NS	0.282 NS	-0.503 *	-0.230 NS	-0.323 NS	-0.637 ***	0.139 NS	0.244 NS	0.193 NS

**Note:** NS =  $p > 0.05$ ; \* =  $p < 0.05$ ; \*\* =  $p < 0.01$ ; \*\*\* =  $p < 0.001$

(Table 1). Total hardness exhibited significant positive correlations with chloride ( $r = 0.774$ ;  $p < 0.001$ ) and alkalinity ( $r = 0.660$ ;  $p < 0.001$ ), suggesting that these parameters together represent the mineral richness of the water (Table 2).

Chloride concentrations showed a substantial seasonal decline, decreasing from  $102.80 \pm 14.82$  mg/L in winter to  $48.43 \pm 10.67$  mg/L in summer. This variation was statistically significant ( $F = 22.55$ ;  $p < 0.001$ ) and likely reflects seasonal changes in anthropogenic inputs and natural dilution processes (Table 1).

Alkalinity exhibited significant seasonal differences ( $F = 13.35$ ;  $p < 0.001$ ), with the highest values observed in winter ( $281.02 \pm 25.04$  mg/L). This variation may be attributed to changes in carbonate and bicarbonate concentrations, influenced by biological activity and runoff. Alkalinity of the Gambhiri River also showed a positive correlation with hardness and chloride (Table 2).

Nitrate concentrations were significantly higher in winter ( $19.18 \pm 6.82$  mg/L) compared to monsoon and post-monsoon periods ( $F = 10.46$ ;  $p < 0.001$ ), suggesting enhanced inputs from agricultural runoff or reduced dilution during comparatively dry conditions. Variations in nitrogen levels are often linked to changes in dissolved oxygen, reflecting microbial activity asso-

ciated with nutrient-rich inputs from domestic sewage, industrial effluents, and agricultural waste. Elsayed et al. (2019) reported similar observations. Nitrate exhibited strong positive correlations with total hardness ( $r = 0.756$ ;  $p < 0.001$ ), chloride ( $r = 0.544$ ;  $p < 0.01$ ), and alkalinity ( $r = 0.590$ ;  $p < 0.01$ ), indicating that nutrient enrichment may be associated with increased mineral and ionic loads (Table 2).

Among the physicochemical parameters analyzed, dissolved oxygen (DO) displayed considerable seasonal fluctuation (Table 1). DO concentrations in the Gambhiri River ranged from  $4.65 \pm 1.15$  mg/L during summer to  $7.10 \pm 0.85$  mg/L in the monsoon season. Statistical analysis revealed negative correlations between DO and other water parameters, such as water temperature, pH, total hardness, and alkalinity (Table 2). A similar trend was also reported by Muthukumaravel et al. (2025). Reduced dissolved oxygen levels can adversely affect aquatic organisms, as oxygen availability is critical for sustaining aquatic life. Higher DO values during cooler periods may be attributed to lower temperatures and increased vegetation growth, as cooler water holds more dissolved oxygen than warmer water (Sherif et al., 2018). Additionally, DO showed negative correlations with TDS ( $r = -0.616$ ;  $p < 0.01$ ), turbidity ( $r = -0.602$ ;

$p < 0.01$ ), electrical conductivity ( $r = -0.476$ ;  $p < 0.05$ ), and nitrate ( $r = -0.466$ ;  $p < 0.05$ ) (Table 2), suggesting that elevated levels of dissolved solids and nutrients can reduce oxygen availability, thereby impacting aquatic ecosystem health.

Biochemical oxygen demand (BOD) represents the quantity of dissolved oxygen, which microorganisms utilize during the decomposition of organic matter in aquatic systems. In the present study, BOD values in the river water ranged from  $4.12 \pm 2.22$  mg/L during winter to  $6.28 \pm 2.97$  mg/L in the post-monsoon season (Table 1). Comparable trends were also reported in previous studies. The observed BOD levels indicate favorable conditions for fish breeding, as they lie close to the optimum range recommended for fish growth (Bhatnagar and Devi, 2013). BOD exhibited positive correlations with pH ( $r = 0.479$ ;  $p < 0.05$ ) and total dissolved solids (TDS) ( $r = 0.576$ ;  $p < 0.01$ ), suggesting a close relationship between organic matter decomposition and water chemistry (Table 2).

Phosphorus plays a vital role in cellular metabolism and enzyme synthesis, commonly occurring in aquatic systems in various phosphate forms derived from both natural and anthropogenic sources. In the present investigation, phosphorus concentrations ranged from  $0.14 \pm 0.10$  mg/L during the post-monsoon season to  $0.25 \pm 0.06$  mg/L in the monsoon period (Table 1). No statistically significant seasonal variation in phosphorus levels was observed ( $p > 0.05$ ). Elevated concentrations at certain sites may be associated with industrial effluent discharge, whereas lower values may result from increased planktonic uptake, leading to nutrient depletion in the water column (Lawson, 2011).

Sulphate concentrations in the Gambhiri River varied from  $28.19 \pm 4.58$  mg/L in winter to  $47.64 \pm 3.91$  mg/L during the post-monsoon season. Similar seasonal variation reported by Singh et al. (2025) for the River Ganga, India. Statistical analysis revealed a significant increase in sulphate levels from winter to post-monsoon ( $F = 32.82$ ,  $p < 0.001$ ), which may be attributed to

enhanced oxidation of sulphur-containing compounds and increased anthropogenic inputs during later seasons. Sulphate exhibited strong negative correlations with water temperature ( $r = -0.639$ ,  $p < 0.001$ ) and nitrate ( $r = -0.637$ ,  $p < 0.001$ ) (Table 2), indicating an inverse relationship with thermal conditions and nutrient dynamics.

The zooplankton community in the study area was classified into four major groups: Cladocera, Copepoda, Ostracoda, and Rotifera, accounting for 38.67%, 18.57%, 7.03%, and 35.72% of the total abundance, respectively (Fig. 2, 3). The seasonal variation in zooplankton density across all six sampling sites (Table 3) revealed marked fluctuations among different seasons and groups. The highest total zooplankton density was recorded during summer ( $3381 \pm 24.71$  ind./L), followed by winter ( $1501 \pm 11.24$  ind./L), monsoon ( $1192 \pm 9.28$  ind./L), while the lowest density was observed during the post-monsoon season ( $1109 \pm 11.19$  ind./L). Group-wise analysis indicated that Cladocera was the most dominant group ( $2778 \pm 17.77$  ind./L), followed by Rotifera ( $2566 \pm 16.42$  ind./L), Copepoda ( $1334 \pm 36.28$  ind./L), and Ostracoda ( $505 \pm 15.39$  ind./L), which showed the least contribution. All zooplankton groups exhibited peak densities during summer, with Cladocera ( $1345 \pm 13.08$  ind./L) and Rotifera ( $1111 \pm 16.56$  ind./L) being particularly abundant, whereas comparatively lower densities of all groups were observed during the post-monsoon season. During the monsoon season, Cladocera (38.59%) and Rotifera (37.84%) were the dominant groups, contributing almost equally to the total density, while Ostracoda showed the least contribution (5.12%). A similar trend was observed in the post-monsoon season, where Rotifera (37.87%) and Cladocera (35.62%) remained dominant, with a slight increase in Ostracoda (8.39%). In summer, all zooplankton groups showed a marked increase in density, with Cladocera (39.78%) maintaining dominance, followed by Copepoda (20.11%), Rotifera (32.86%), and Ostracoda (7.25%). The winter

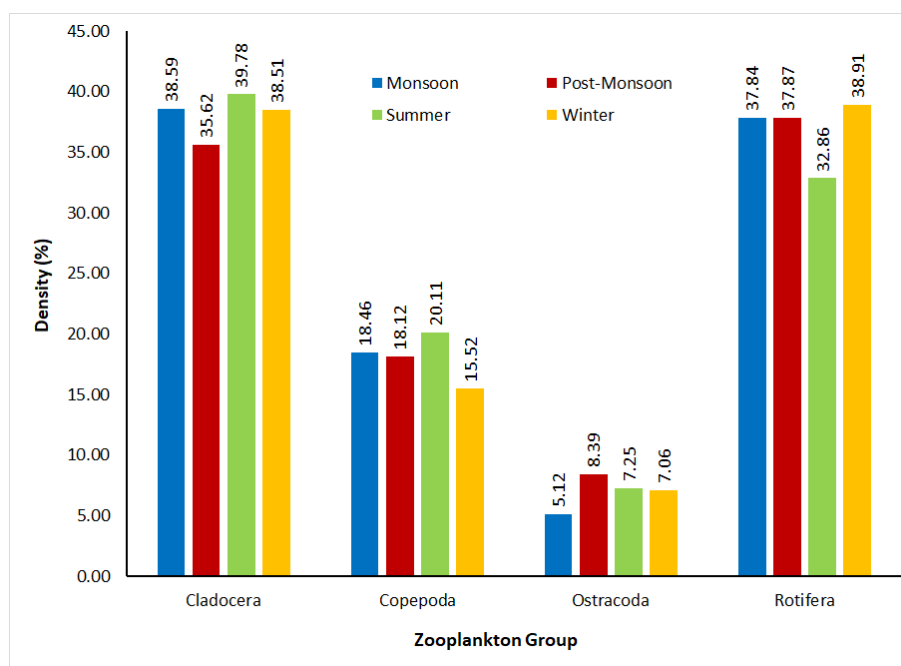
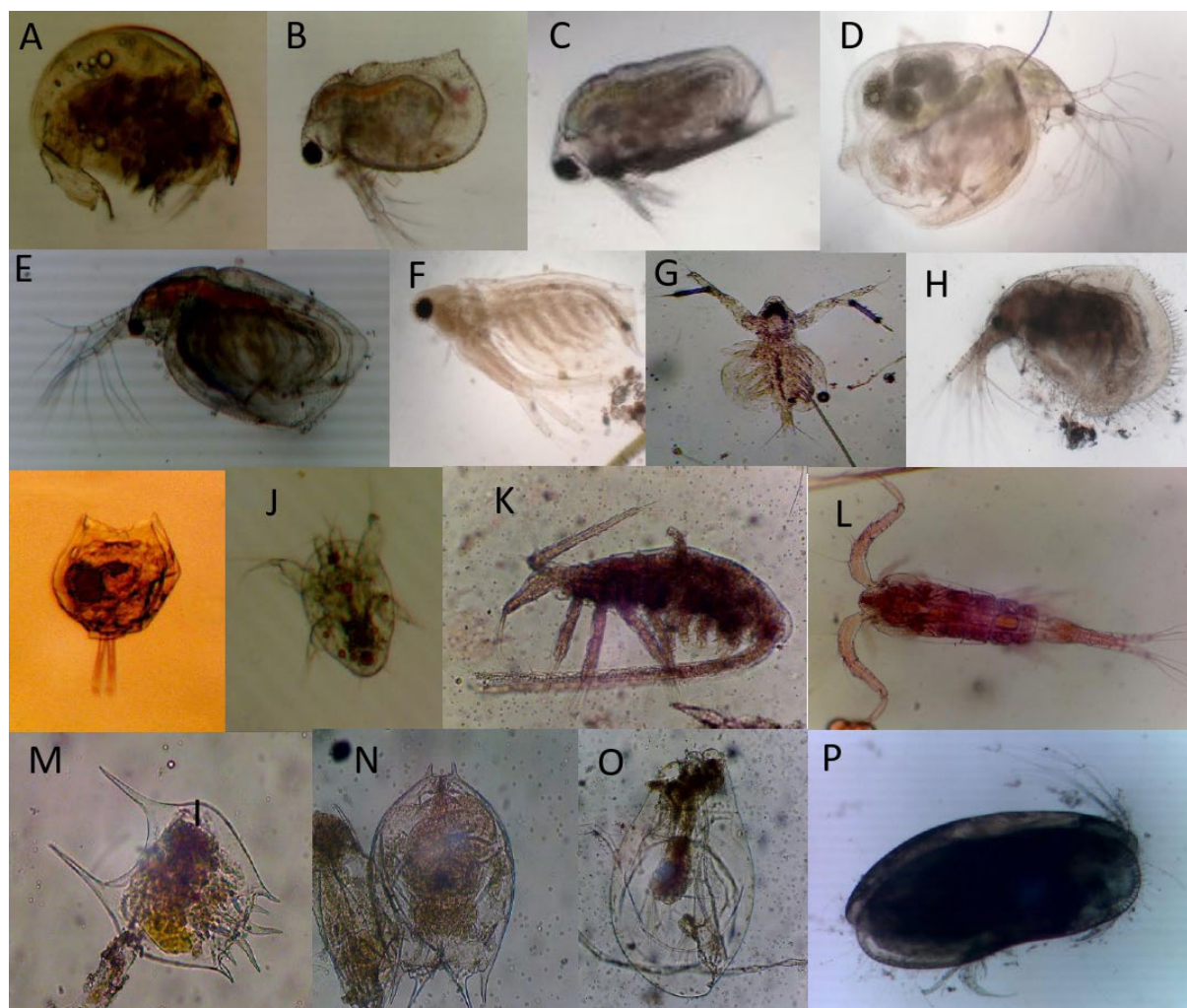


Fig.2. Seasonal and groupwise zooplankton percentage density.



**Fig.3.** Examples of common zooplankton species collected during the study period: (A) *Chydorus ovalis*, (B) *Ceriodaphnia laticaudata*, (C) *Scapholeberis kingi*, (D) *Simocephalus serrulatus*, (E) *Simocephalus vetulus*, (F) *Diaphanosoma sarsi*, (G) *Diaphanosoma brachyurum*, (H) *Ilyocryptus spinifer*, (I) *Lecane leontina*, (J) *Nauplius*, (K) *Sinodiaptomus indicus*, (L) *Thermocyclops hyalinus*, (M) *Brachionus quadridentata*, (N) *Brachionus elevatus*, (O) *Asplanchna brightwelli*, and (P) *Stenocypris major*.

season exhibited a balanced distribution, with Rotifera (38.91%) slightly dominating over Cladocera (38.51%), while Copepoda (15.52%) and Ostracoda (7.06%) contributed comparatively less (Fig. 2). Elevated zooplankton species diversity during the summer season has also been documented in other freshwater ecosystems. Comparable observations were also recorded by Muthukumaravel et al. (2025) in Chellikurichi Lake, Thanjavur District, Tamil Nadu, India

To compare the mean densities of different groups and in different seasons, analysis of variance tests were conducted. An interaction test between two factors was also conducted. The test results show a highly significant difference in the mean densities of zooplankton species in different seasons ( $F = 27.03$ ,  $p < 0.001$ ). The

mean densities differed significantly among groups, indicating a highly significant variation ( $F = 20.41$ ,  $p < 0.001$ ). The test results also indicated that the interaction between season and group was significant ( $F = 1.97$ ,  $p < 0.05$ ) (Table 4). It can be observed that the mean density of Cladocera and Rotifera were the dominant zooplankton groups throughout all seasons, whereas Copepoda and Ostracoda contributed comparatively less to the overall density. Cladocera exhibited higher densities than Rotifera during the summer and post-monsoon seasons, while Rotifera slightly dominated during the monsoon and winter periods. Copepoda consistently ranked as the third most abundant group across all seasons, whereas Ostracoda recorded the lowest density throughout the study period (Table 3).

**Table 3.** Season and groupwise zooplankton density at all six sites (Individual per L)

Season	Cladocera	Copepoda	Ostracoda	Rotifera	Total
Monsoon	460 ± 6.26	220 ± 13.85	61 ± 4.92	451 ± 8.96	1192 ± 9.28
Post-Monsoon	395 ± 8.09	201 ± 16.77	93 ± 9.81	420 ± 11.66	1109 ± 11.19
Summer	1345 ± 13.08	680 ± 46.16	245 ± 16.99	1111 ± 16.56	3381 ± 24.71
Winter	578 ± 7.62	233 ± 18.89	106 ± 4.18	584 ± 12.05	1501 ± 11.24
Total	2778 ± 17.77	1334 ± 36.28	505 ± 15.39	2566 ± 16.42	7183 ± 20.94

**Table 4.** Density Comparison of different zooplankton groups

Variable	SSR	df	MSR	Sig.
Season	205.56	3	68.52	F = 27.03; p = 0.000***
Group	155.24	3	51.75	F = 20.41; p = 0.000***
Interaction	44.99	9	5.00	F = 1.97; p = 0.039*
Residual	3731.33	1472	2.53	

**Note:** NS =  $p > 0.05$ ; \* =  $p < 0.05$ ; \*\* =  $p < 0.01$ ; \*\*\* =  $p < 0.001$

The results indicate that, among the 65 identified zooplankton species, the community is diverse and well-structured, with a few species showing higher mean densities. *Nauplii* and *Thermocyclops hyalinus* (Rehberg, 1880) were the most dominant, followed by rotifers such as *Keratella tropica* (Apstein, 1907), *Brachionus falcatus* (Zacharias, 1898), and *Lecane leontina* (Turner, 1892). Other species, including *Ceriodaphnia pulchella* (Sars, 1862), *Brachionus elevatus* (Michaloudi et al., 2018), and *Asplanchna brightwelli* (Gosse, 1850), also contributed significantly to the overall community

composition. Moderate densities were observed in such species as *Daphnia magna* (Straus, 1820), *Eucyclops elegans* (Herrick, 1884), and *Ilyocryptus spinifer* (Herrick, 1882), indicating balanced distribution. In contrast, a few species, such as *Testudinella* sp., *Philodina citrina* (Ehrenberg, 1832), and *Testudinella patina* (Hermann, 1783) showed very low densities (Table 5). Overall, the findings suggest a highly diverse zooplankton assemblage characterized by the dominance of a few species and the presence of many others in moderate to low proportions.

**Table 5.** List of zooplankton species recorded and percentage in the Gambhiri River during the study period

Zooplankton species	Density %	Zooplankton species	Density %
<i>Alona guttata</i> (Sars, 1862)	1.60	<i>Hexarthra mira</i> (Hudson, 1871)	1.04
<i>Alona quadranhularis</i> (O.F. Muller, 1785)	1.59	<i>Ilyocryptus spinifer</i>	1.68
<i>Asplanchna brightwelli</i>	1.28	<i>Indialona Ganpati</i> (Petkovski, 1966)	1.49
<i>Asplanchna priodonta</i> (Gosse, 1850)	1.21	<i>Keratella</i> sp.	1.99
<i>Bosmina longirostris</i> (O.F. Muller, 1785)	1.67	<i>Keratella tropica</i>	2.12
<i>Bosminopsis deitersi</i> (Richard, 1895)	1.66	<i>Keratella valga</i> (Ehrenberg, 1834)	0.78
<i>Brachionus calyciflorus</i> (pallas, 1766)	1.64	<i>Lecane leontina</i>	2.59
<i>Brachionus caudatus</i> (Barrois & Daday, 1894)	1.48	<i>Lecane luna</i> (O.F. Muller, 1776)	1.24
<i>Brachionus diversicornis</i> (Daday, 1883)	2.23	<i>Lecane papuana</i> (Murray, 1913)	1.02
<i>Brachionus elevatus</i>	2.26	<i>Lecane unguolata</i> (Gosse, 1887)	1.10
<i>Brachionus falcatus</i>	2.49	<i>Macrothrix laticornis</i> (Jurine, 1820)	1.46
<i>Brachionus forficula</i> (Wierzejski, 1891)	1.88	<i>Macrothrix rosea</i> (Jurine, 1820)	1.07
<i>Brachionus havanaensis</i> (Rousselet, 1911)	1.85	<i>Mesocyclops leuckarti</i> (Claus, 1857)	1.11
<i>Brachionus quadridentatus</i> (Hermann, 1783)	1.34	<i>Mesocyclops</i> sp.	1.80
<i>Ceriodaphnia laticaudata</i> (P. E. Muller, 1867)	1.80	<i>Moina</i> sp.	1.85
<i>Ceriodaphnia pulchella</i>	1.85	<i>Monostyla bulla</i> (Gosse, 1851)	1.32
<i>Ceriodaphnia reticulata</i> (Jurine, 1820)	1.68	<i>Nauplii</i>	3.83
<i>Ceriodaphnia rigaudi</i> (Richard, 1894)	1.52	<i>Paracyclops affinis</i> (Sars, 1873)	1.42
<i>Chydorus ovalis</i> (Kurz, 1875)	1.14	<i>Philodina citrina</i>	0.57
<i>Chydorus sphaericus</i> (O.F. Muller, 1785)	1.56	<i>Philodina megalotrocha</i> (Ehrenberg, 1832)	0.65
<i>Cyprinotus cassidula</i> (Smith & Chang, 2020)	0.88	<i>Pleuroxus aduncus</i> (Jurine, 1820)	1.25
<i>Cypris</i> sp.	0.95	<i>Scapholeberis kingi</i> (Sars, 1888)	1.38
<i>Daphnia ambigua</i> (Scourfield, 1947)	1.42	<i>Scapholeberis mucronate</i> (O.F. Muller, 1785)	1.77
<i>Daphnia magna</i>	1.24	<i>Simocephalus serrulatus</i> (Koch, 1841)	0.93
<i>Daphnia pulex</i> (Leydig, 1860)	1.00	<i>Simocephalus vetulus</i> (O.F. Müller, 1776)	2.80
<i>Diaphanosoma brachyurum</i> (Lieven, 1848)	1.98	<i>Sinodiaptomus indicus</i> (Kiefer, 1936)	1.63
<i>Diaphanosoma sarsi</i> (Richard, 1894)	1.28	<i>Stenocypris major</i> (Baird, 1859)	1.38
<i>Eucyclops elegans</i>	1.88	<i>Strandesia</i> sp.	0.85
<i>Eucypris</i> sp.	0.97	<i>Testudinella patina</i>	0.63
<i>Filinia longiseta</i> (Ehrenberg, 1834)	0.88	<i>Testudinella</i> sp.	0.24
<i>Filinia opoliensis</i> (Zacharias, 1898)	0.93	<i>Thermocyclops hyalinus</i>	4.87
<i>Heliodiaptomus viduus</i> (Gurney, 1916)	2.03	<i>Trichocerca elongata</i> (Gosse, 1886)	0.97
<i>Heterocypris</i> sp.	2.00	<b>Total</b>	<b>100.00</b>

The predominance of Cladocera and Rotifera aligns with common patterns in freshwater ecosystems, where these groups contribute substantially to trophic dynamics. The findings of the present investigation are consistent with earlier studies, which were conducted in various freshwater bodies across India. Similar patterns were reported by Balai et al. (2014) from Jaisamand Lake, Udaipur, and by Khaire (2020) in Chandani Dam, Maharashtra. Comparable observations were also documented by Rajani (2023) in Mulukanoor Lake of Karimnagar district, Telangana, and by Muthukumaravel et al. (2025) from Chellikurichi Lake, Thanjavur District, Tamil Nadu, thereby reinforcing the results of the present study. The dominance of zooplankton species indicates environmental conditions that are conducive to their growth, reflecting their affinity for nutrient-rich waters. Seasonal variations in zooplankton density also reflect ecological responses to changes in temperature, food availability, and hydrological conditions. The summer and post-monsoon peaks in Copepoda and Cladocera densities likely reflect optimal thermal conditions and enhanced primary productivity, which promote reproductive success. Conversely, reduced densities during the monsoon season may result from dilution effects and increased turbidity, which negatively influence zooplankton populations (Banerjee et al., 2024).

#### 4. Conclusion

The present investigation of the Gambhiri River, Chittorgarh (Rajasthan), provides a comprehensive assessment of seasonal and spatial variability in physicochemical characteristics and zooplankton community structure, thereby elucidating the ecological status of this freshwater ecosystem. Statistically significant seasonal variations were observed in key water quality parameters, including temperature, electrical conductivity, total hardness, chloride, alkalinity, nitrate, and sulphate, reflecting the integrated influence of climatic variability, hydrological processes, and anthropogenic inputs. Although most parameters remained within or proximate to the permissible limits prescribed by WHO and ICMR, signs of localized ecological stress were obvious.

The zooplankton assemblage exhibited high taxonomic diversity, comprising 65 species across four main groups. Cladocera and Rotifera dominated in terms of relative abundance, while Copepoda contributed substantially to overall density. Seasonal trends revealed peak zooplankton densities during summer and winter, likely driven by optimal temperature regimes, enhanced nutrient availability, and elevated primary productivity. In contrast, reduced densities during the monsoon season were associated with dilution effects, increased turbidity, and hydrodynamic disturbances.

A strong and statistically supported relationship between physicochemical parameters and zooplankton distribution underscores the sensitivity of these communities to environmental fluctuations. The predominance of certain taxa indicates nutrient-enriched (mesotrophic to eutrophic) conditions and reaffirms the

utility of zooplankton as robust bioindicators of water quality and trophic dynamics. Furthermore, correlation and ANOVA analyses substantiated the pivotal role of water chemistry in regulating the composition and structure of zooplankton assemblages.

Collectively, the findings suggest that the Gambhiri River sustains a moderately healthy yet ecologically responsive aquatic system under increasing anthropogenic pressure. This study highlights the critical importance of integrating biological indicators with physicochemical monitoring for holistic ecosystem assessment and provides essential baseline data for long-term ecological evaluation. Implementation of continuous monitoring frameworks, along with targeted pollution control and conservation strategies, is strongly recommended to safeguard the ecological integrity of this vital river system in Rajasthan's semi-arid region.

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#### Conflict of Interest

The authors declare that they have no conflict of interest.

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