

# Spatiotemporal Variations in Physico-Chemical Parameters and Their Impact on Zooplankton Dynamics in River Shivana

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**Abstract** - The physico-chemical parameters of surface water from River Shivana, Mandsaur, Madhya Pradesh, were also analysed during the specified period 2024-2025, and their association with the zooplankton of the river was also analysed at three sampling stations (S1, S2 and S3). Water physical and chemical parameters like temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), total alkalinity, total hardness, nitrate, chloride, phosphate and sulphate were measured on the basis of standard methods. The results indicated that the water quality fluctuated throughout the season. The concentrations of temperature, EC, BOD, COD, and hardness were at their maximum during summer, while DO was at its minimum, indicating increased organic load during summer. The nitrate levels were found to be above the BIS permissible limit during the entire investigation, whereas BOD and COD were also found to be above the permissible limit in all seasons. A total of 5 major groups of zooplankton were found: Rotifera (1212), Cladocera (653), Copepoda (450), Protozoa (446) and Ostracoda (23), with Rotifera dominating the assemblage. Total abundance increased from the monsoon (473 individuals) to winter (809 individuals), peaking in summer (1502 individuals). The dominance of pollution-tolerant rotifers, protozoans and copepods at the eutrophic stations. Seasonal changes in physicochemical characteristics are the most significant in the structure and density of the zooplankton, according to this study. Zooplankton is a useful, sensitive bioindicator for monitoring the ecological health and water quality of the river Shivana.

**Keywords:** River Shivana, physico-chemical parameters, seasonal variation, zooplankton dynamics, water quality, bioindicators

## 1. INTRODUCTION

Rivers are living, dynamic freshwater systems with rich biological diversity and ecosystem services, including providing drinking water, fish, nutrient cycling, protecting floodplains, and cultural values (Reddy, 2010; Srivastava & Reddy, 2020; Reddy et al., 2025). Water quality is the most important criterion for river health, and it is influenced primarily by natural processes (such as seasonal hydrology, weathering and biogeochemical cycling) and by human pressures. Due to rapid urbanisation, industrialisation, intensified agriculture, and inadequate treatment of domestic sewage, the physicochemical characteristics of most rivers in

India have changed significantly, resulting in the degradation of river habitats and a reduction in aquatic biodiversity (Wetzel, 2001; APHA, 2023). It is therefore very important to monitor water quality regularly to evaluate ecosystem condition and management actions. The physicochemical parameters such as temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), alkalinity, hardness, nitrates, phosphates, chlorides, and sulphates are widely used to characterise water quality (Reddy, 2018). Changes in these variables throughout the year affect nutrient availability, primary productivity, DO dynamics and the distribution of aquatic organisms (Boyd, 2015). Eutrophication and algal blooms can result from excess nutrients and organic matter, leading to low dissolved oxygen and impacts to food webs, which can adversely affect fish, wildlife, and humans (Dodds & Smith, 2016).

Zooplankton play an important role in the freshwater ecosystem as an intermediate trophic level between phytoplankton and higher consumers like fish (Jana, B. B. 2024). They recycle nutrients, transfer energy in the food web, and help to stabilise the ecosystem (Lampert & Sommer, 2007). Zooplankton is very sensitive to changes in water quality due to its short life cycle, rapid reproductive rate, and need to respond quickly. Hence, their diversity, abundance, and community structure are used as reliable bioindicators for assessing pollution and trophic status in freshwater systems (Sharma & Sharma, 2008; Kumar et al., 2021). The hydrological regime, dissolved oxygen, nutrient levels, and temperature are among the most important factors influencing seasonal changes in zooplankton. The flooding of tropical rivers during the monsoon season may cause a marked seasonal change in diversity by reducing pollutant levels and zooplankton abundance (Michael, 1984). In organically polluted waters, where the nutrient levels are high, the fast-reproducing and stress-tolerant rotifers tend to be numerous and dominant, whereas cladocerans and copepods—the species more sensitive to food quality and habitat conditions—are reduced (Edmondson, 1959; Battish, 1992).

The River Shivana in Mandsaur district, Madhya Pradesh, provides freshwater for domestic purposes, irrigation, and cultural activities. But its ecological integrity is threatened by rapid urbanisation, untreated domestic sewage, agricultural runoff, and other anthropogenic pressures. Although the river is regionally significant, there is limited research that has considered water quality and zooplankton dynamics from an integrated, seasonal perspective. The importance of

understanding how environmental variables affect zooplankton communities cannot be overstated; it helps elucidate ecosystem processes and identify early warning signs of ecosystem degradation. Hence, the present study determined the physico-chemical characteristics of the surface water of River Shivana across different seasons during 2024-2025 and assessed their impact on the diversity and abundance of zooplankton. The results will provide reference information for conserving freshwater biodiversity, monitoring river water quality, and managing rivers for sustainable use.

## 2. MATERIALS AND METHODS

**Study area:** The study was conducted on the Shivana River in Mandsaur district, Madhya Pradesh, India, during the year 2024-2025. Three representative sampling sites (S1, S2, S3) were chosen to represent adjacent human activities, land use, and accessibility.

**Collection of samples:** Samples were collected seasonally during the monsoon, winter, and summer. Water samples were collected seasonally from each station in pre-cleaned polyethylene bottles in accordance with the APHA (2023) standard guidelines. Surface water samples were collected, and physicochemical analysis was carried out according to standard procedures. Portable digital pH, temperature and electrical conductivity (EC) meters were used to measure pH, temperature and EC in the field. The dissolved oxygen (DO) levels were measured using the Winkler iodometric method. Total dissolved solids (TDS), total alkalinity, total hardness, biological oxygen demand (BOD), chemical oxygen demand (COD), nitrate, chloride, phosphate and sulphate were measured analogously (Standard Methods for Examination of Water and Wastewater (APHA 2023)). Water quality assessment was done by comparing measured values with those specified by BIS (Bureau of Indian Standards) [BIS 10500:2012 (Revised 2015); <https://www.bis.gov.in>].

**Zooplankton collection and analysis:** During the summer, the first winter and the second winter, the surface water was sampled using a standard 60  $\mu\text{m}$  plankton net, and zooplankton were collected with the water. The material was concentrated, transferred to labelled polyethylene bottles, and fixed immediately in 4% neutral formalin. Samples were placed in specimen jars to allow them to settle, excess water was poured off to concentrate the material, and subsamples were taken and examined under a compound light microscope. The zooplankton were identified as far down as practicable by means of standard taxonomic keys (Edmondson, 1959; Battish, 1992). Sedgwick-Rafter counting chamber was used for quantification, and abundance was reported as individuals per litre (No. L<sup>-1</sup>). Variations in the abundance of zooplankton groups across seasons were analysed to determine their responses to changes in the river's physicochemical parameters.

## 3. RESULTS

Seasonal variation in physico-chemical parameters. Table 1 summarises seasonal changes in surface-water physico-chemical parameters at Shivana River stations S1–S3 during 2024–2025. Most variables displayed clear seasonality, reflecting combined climatic and anthropogenic influences.

Water temperature ranged from  $18.6 \pm 0.3^\circ\text{C}$  (winter, S2) to  $33.6 \pm 0.7^\circ\text{C}$  (summer, S3), peaking in summer (Fig. 1a). pH

remained mildly alkaline throughout the study ( $7.1\text{--}8.6$ ), indicating conditions generally suitable for freshwater biota. Electrical conductivity (EC) was high ( $742.82 \pm 9.28$  to  $930.7 \pm 14.8 \mu\text{mhos cm}^{-1}$ ) and exceeded the BIS drinking-water limit at all stations, suggesting elevated dissolved ion concentrations. Total alkalinity ( $40.4\text{--}53.4 \text{ mg L}^{-1}$ ) and total hardness ( $143.3\text{--}165.1 \text{ mg L}^{-1}$ ) stayed within acceptable ranges.

Dissolved oxygen (DO) varied between  $5.1 \pm 0.3$  and  $7.9 \pm 0.3 \text{ mg L}^{-1}$ , with lowest values in summer and highest in winter; DO at S1 and S3 during summer fell below the recommended  $6 \text{ mg L}^{-1}$ , indicating greater oxygen depletion in warmer months. Total dissolved solids (TDS) ranged from  $97.5 \pm 2.1$  to  $212.3 \pm 4.2 \text{ mg L}^{-1}$ , remaining well under the  $500 \text{ mg L}^{-1}$  limit. Organic pollution indicators were elevated: BOD ranged from  $4.4 \pm 0.6$  to  $12.8 \pm 0.4 \text{ mg L}^{-1}$  (exceeding guideline values of  $2\text{--}3 \text{ mg L}^{-1}$  in all seasons) and peaked in summer. COD values ( $26.4 \pm 2.1$  to  $37.5 \pm 3.8 \text{ mg L}^{-1}$ ) were substantially above the  $10 \text{ mg L}^{-1}$  standard, indicating a high organic load. Nitrate concentrations ( $73.3\text{--}107.4 \text{ mg L}^{-1}$ ) exceeded the BIS permissible limit ( $45 \text{ mg L}^{-1}$ ) throughout the study but declined from monsoon to summer. Chloride remained low ( $17.3\text{--}27.4 \text{ mg L}^{-1}$ ) and within permissible limits. Phosphate varied between  $0.2$  and  $1.1 \text{ mg L}^{-1}$ , exceeding recommended levels at some stations and pointing to nutrient enrichment. Sulphate ranged from  $128.4$  to  $292.8 \text{ mg L}^{-1}$ , with winter values at S1 and S2 surpassing the BIS threshold of  $250 \text{ mg L}^{-1}$ . Overall, seasonal patterns indicate the poorest water quality in summer, characterised by higher temperatures, EC, BOD, COD and nutrient concentrations coupled with reduced DO.

**3.1. Seasonal variation in the abundance and composition of zooplankton.** Five main taxa of zooplankton were recorded, including a total of 2,784 individuals L<sup>-1</sup> (Table 3). Rotifera was dominant (1,212 individuals; 43.5%), followed by Cladocera (653; 23.5%), Copepoda (450; 16.2%), Protozoa (446; 16.0%), and Ostracoda (23; 0.8%). There was a significant seasonal variation in the abundance (total density 473 L<sup>-1</sup> in monsoon, 809 L<sup>-1</sup> in winter and 1,502 L<sup>-1</sup> in summer, with a nearly threefold increase in abundance from monsoon to summer). The highest numbers of rotifers were recorded in summer, 418 (monsoon) to 560 (winter), and the common species were *Brachionus* spp., *Asplanchna intermedia*, *Keratella cochlearis*, *Filinia opoliensis*, and *Brachionus quadridentata*. The cladocerans, mainly *Daphnia magna*, *Daphnia pulex*, *Moina micrura*, *Ceriodaphnia cornuta* and *Macrothrix laticornis*, increased significantly from 118 in the monsoon to 371 in the summer. Eight species of copepods were recorded, the most abundant being *Mesocyclops varius*, *M. edax*, *M. longisetus*, *Thermocyclops crassus* and *Paracyclops vagus*, which occurred more abundantly in summer (276) than in monsoon (61). Protozoans (*Euglena viridis*, *Paramecium caudatum*, *Blepharisma* spp. and *Vorticella* spp.) exhibited significant seasonal increase with 278 individuals in summer and 58 in monsoon. The ostracods were rare ( $n = 23$ ) and abundant in the summer. In space, station S3 always had the highest density of zooplankton (particularly in summer), whereas S1 had the lowest (particularly in the monsoon season). Enhanced abundance of rotifers, protozoans and copepods at enriched sites was positively correlated to the levels of BOD, COD and nutrients, indicating that the pollution-tolerant taxa were preferred to the organic enrichment. In general, the overall response of the zooplankton to the physicochemical seasonal changes of the river was as

follows: higher zooplankton density during summer with higher temperature, nutrient enrichment, and organic loads, and lower density during the monsoon time of hydrological disturbance.

#### 4. DISCUSSION

This study revealed that there were significant variations in the physicochemical parameters of the River Shivana with the seasons, and these changes were correlated with changes in species composition, abundance and diversity of the zooplankton. Water temperature, dissolved oxygen, nutrient concentration and organic pollution played a pivotal part in the seasonal regulation of the distribution of major zooplankton groups, emphasising the high dependence of plankton communities on water quality. Temperature, as predicted by the seasons, was highest during summer and lowest during the winter and is a key variable that influences the metabolic rates, dissolved oxygen solubility, nutrient cycling and reproductive activity of aquatic organisms (Wetzel, 2001). The observed summer warming here is in consistence with the summer warming observed in Ganga, Narmada and Chambal rivers, which led to an increase in biological productivity and changed plankton succession (Singh & Sharma, 2018; Sharma et al., 2020). Similar seasonal variations have been observed in tropical rivers of Bangladesh, Brazil and Nigeria (Islam et al. 2021; Tundisi & Matsumura Tundisi 2008). Enhanced microbial decomposition and nutrient mineralisation during warmer summer conditions, likely contributing to a greater supply of food for zooplankton. The overall pH of River Shivana was in the mildly alkaline range between 7.1 and 8.6 which is generally favourable for freshwater plankton and is typical of productive tropical waters (Boyd, 2015). The range of pH is found to be similar in the Upper Ganga and Godavari (Joshi et al., 2017; Rao et al., 2019). The pH of Shivana remained almost stable and slightly alkaline (around 8.1), indicative of the presence of organic enrichment, as opposed to the urban rivers with high pollution levels where the pH can turn acidic with industrial effluents. The electrical conductivity at all the sites was above the BIS standard, which suggests that the amount of dissolved ions is high, most probably due to agricultural runoff, domestic sewage and industrial discharges (APHA, 2023). The conductivity patterns in these rivers are similar to that of the Kshipra, Musi and Yamuna rivers where increase of conductivity corresponds to the growing anthropogenic pressures (Sharma & Kansal, 2011; Verma et al., 2022). Shivana was less contaminated than severely contaminated systems such as Musi, but still shows moderate ionic enrichment. Dissolved oxygen was distinctly seasonal with a maximum in winter and a minimum in summer. The causes of low DO in summer are possible increase in temperature (which decreases the solubility of oxygen) and increased biological oxygen demand and microbial respiration, as reported in other rivers such as Chambal, Betwa, Gomti, and Cauvery (Kumar et al., 2021; Mishra et al., 2020). In summer, some sites encountered dry season hypoxia in them, reflecting increased ecological stress; but the DO levels were still significantly higher than that of highly polluted reaches of Yamuna and Hindon, which are typified by hypoxia. BOD and COD were always above the tolerable levels throughout the study and indicated high organic pollution. Many Indian River waters are found to have high BOD and COD which are attributed to domestic wastes, agriculture activities and decaying organic matter (Chapman, 1996) and many such examples can be found in the Indian rivers such as Ganga, Kshipra, Musi, Mithi etc. (CPCB, 2023; Kumar et al., 2022).

Despite this, the concentrations of BOD in Shivana were less than in very urbanized rivers, indicating high levels of organic loading, but the river is not as degraded as major urban rivers. Nitrate levels were consistently above the drinking water standard throughout the study period, while phosphate levels were high at several stations, clearly indicating external inputs of nutrients, which are likely from fertilisers, sewage and surface runoff. The two key contributors to eutrophication and enhanced phytoplankton production are high levels of nitrogen and phosphorus loads (Dodds & Smith 2016). Minimally impacted mountain streams have much lower nutrient levels and plankton productivity, while streams that are enriched with nutrients are reported from the Narmada, Krishna and Brahmaputra (Gupta et al., 2019; Das et al., 2022). The zooplankton community was dominated by the rotifers, which accounted for more than 43% of the total community, and included the other five main taxa. High reproductive rates, short generation time and wide tolerance to environmental conditions are considered to be the primary factors that cause rotifers to dominate in nutrient-rich tropical waters (Battish, 1992; Sharma & Sharma, 2008). Dominance of *Brachionus*, *Asplanchna* and *Keratella* species, has also been seen in Ganga, Godavari, Mahanadi and Chambal river system in India (Kumar et al., 2021; Sinha et al., 2018) and in eutrophic river systems of Brazil, China, Egypt etc. (Jeppesen et al., 2011; El Shabrawy et al., 2015). The genus *Brachionus* species were especially common during the summer, and are well known markers for nutrient- and organic-enriched waters (Sládeček, 1983). This is similar to the increased BOD, COD, nitrate and phosphate observed in summer in the reservoirs and rivers of central and southern India (Sharma et al., 2019) indicating enhanced eutrophication and organic load. The second most abundant group were cladocerans which included *Daphnia magna*, *D. pulex* and *Moina micrura* in highest abundance in summer. Although generally, cladocerans are benefactors of the growth of phytoplankton, they are more sensitive to acute pollution than rotifers (Lampert & Sommer, 2007). While cladoceran numbers seem to increase seasonally in reservoirs of Madhya Pradesh and Maharashtra (Patil et al., 2020), the pollen level in Shivana is not high enough to cause a reduction in cladoceran diversity. Copepods were observed to increase gradually from monsoon to the summer, with the groups of *Mesocyclops* and *Thermocyclops* dominating the summer period, as reported in freshwater systems of tropical India, Sri Lanka and Thailand (Fernando, 2002). In temperate systems (spring peaks), summer peaks in copepod abundance are usually correlated with increased food availability, increased water retention, and favorable reproductive conditions, while in tropical systems, copepod abundance may peak in the summer when primary production reaches its peak. Protozoans (*Euglena*, *Paramecium*, *Vorticella*) increased significantly during the summer months as habitats with organic enrichment and higher bacteria and suspended organic matter are favored. Such a relationship is observed in other polluted stretches of Ganga and Yamuna in which protozoan levels were found to rise with the increase in organic loading (Verma et al., 2022). However, the lack of large blooms of protozoans indicates that the pollution level is not severe.

The abundance of zooplankton was seasonal with high numbers in summer and a gradual transition from monsoon to winter. The monsoon season had low abundance due to increased river discharge, nutrient dilution and physical removal of plankton from the river downstream. There have been similar decreases in monsoon rainfall over the Narmada, Tapi, and Krishna rivers

(Gupta et al., 2019). The opposite is true during the summer, when water is more stable, more retained, and more productive for phytoplankton, with subsequent rapid generations of zooplankton. Many freshwater systems in the tropics have also been found to have similar seasonal trends (Jeppesen et al., 2011). Declines in water quality and increases in pollution-tolerant zooplankton evidence the use of zooplankton as an ecological indicator. Higher levels of BOD, COD, nitrate and phosphate were associated with more abundant rotifers and protozoans, and higher tolerance species were associated with lower dissolved oxygen. The results are in line with the ecological indicator paradigm of Sládeček (1983), which showed that the organisation of the zooplankton community was an indicator of trophic level and pollution in lentic freshwater systems. The study results indicate that most of the standard physico-chemical parameters are within acceptable limits, but the River Shivana is being subjected to ever-increasing anthropogenic pressure, as it has high concentrations of conductivity, nutrients, BOD and COD. A marked shift from clean-water species to pollution-tolerant zooplankton species is also indicative of gradual eutrophication and declining water quality. Nevertheless, there were many copepods and cladocerans, indicating that the river was relatively ecologically resilient. This means that frequent monitoring of zooplankton and water quality parameters is necessary to predict ecological damage in rivers and to formulate a sound management and conservation strategy. Novel finding: The current study revealed that physicochemical parameters significantly influenced the size and structure of the zooplankton community in the River Shivana across different seasons. Increased organic enrichment and nutrient inputs are indicated by summertime increases in temperature, electrical conductivity, biological oxygen demand, chemical oxygen demand, nitrate, and phosphate, along with a drop in dissolved oxygen. At the same time, the most abundant zooplankton group in the summer season was Rotifera, a group found in eutrophic conditions. The presence of pollution-tolerant organisms such as Brachionus, Asplanchna, and Keratella in certain sections of the river also indicated eutrophic conditions. However, it was found that multiple species of cladocerans and copepods are present, indicating that the river is not severely damaged. In general, the study could help affirm the usefulness of zooplankton in assessing the health status of freshwater systems and show the close connection between zooplankton and seasonal changes in water quality.

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Table 1. Seasonal Changes in the Physico-chemical parameters of surface waters of River Shivana at Mandsaur 2024-2025

| Parameters                       | Monsoon     |              |              | Winter      |             |             | Summer       |              |              | BIS Acceptable Limit |
|----------------------------------|-------------|--------------|--------------|-------------|-------------|-------------|--------------|--------------|--------------|----------------------|
|                                  | S1          | S2           | S3           | S1          | S2          | S3          | S1           | S2           | S3           |                      |
| Temp (0C)                        | 19.5± 0.2   | 19.1± 0.3    | 19.4 ± 0.2   | 19.3 ± 0.2  | 18.6.7±0.3  | 18.8±0.2    | 29.1 ± 0.5   | 30.3 ± 0.4   | 33.6 ± 0.7   |                      |
| EC (µmhos/cm)                    | 885.92±9.84 | 894.1± 11.3  | 842.82±9.28  | 742.82±9.28 | 786.1±10.6  | 830.2± 11.1 | 880.6 ± 14.5 | 830.4 ± 15.6 | 930.7 ± 14.8 | 100–500              |
| pH                               | 7.3±0.14    | 7.4±0.17     | 7.14±0.19    | 6.5-8.5     | 7.6±0.3     | 8.1±0.4     | 8.5±0.8      | 8.6±0.5      | 8.4±0.4      | 6.5 – 8.5            |
| Total Alkalinity (mg/l)          | 46.86 ±5.92 | 52.4±6.2     | 48.5±5.14    | 42.4±3.3    | 44.4±3.2    | 43.4±3.6    | 39.4±3.2     | 41.5±3.1     | 43.5±3.6     | 200                  |
| DO                               | 7.28 ± 0.2  | 7.3 ± 0.5    | 7.5±0.24     | 7.2 ±0.32   | 7.9±0.30    | 7.4±0.4     | 5.5±0.4      | 5.8±0.6      | 5.1±0.3      | 6                    |
| TDS (mg/l)                       | 205.4±4.1   | 212.3 ± 4.2  | 199.6±3.76   | 127.5±2.26  | 109.4±1.5   | 97.5± 2.1   | 113.3± 3.6   | 127.5±4.6    | 119.5±5.5    | 500                  |
| BOD (mg/L)                       | 8.2.2 ± 0.4 | 9.2.5 ± 0.6  | 10.4 ± 0.5   | 4.5 ± 0.3   | 4.4 ± 0.6   | 5.7 ± 0.7   | 12.3±0.3     | 12.2 ± 0.3   | 12.8 ± 0.4   | 2-3 (WHO)            |
| COD (mg/L)                       | 26.4±3.2    | 26.5±2.1     | 26.4±2.14    | 36.5±3.1    | 37.5±3.8    | 36.9±4.2    | 34.4±4.1     | 33.2±3.8     | 35.5±3.7     | 10                   |
| TH (mg/l)                        | 142.32±2.8  | 146.6 ± 3.3  | 154.8±4.8    | 144.1±4.2   | 146.8±5.2   | 151.4±5.3   | 152.3±5.6    | 157.9±5.7    | 164.1±5.3    | 200                  |
| Nitrate ( NO3 ), mg/l            | 107.4±3.88  | 104.1 ± 3.8  | 103.4±3.06   | 87.4±2.8    | 83..2 ± 4.2 | 78.4±4.6    | 77.4±2.1     | 73.3 ± 3.3   | 74.4±4.2     | 45                   |
| Chloride (Cl) mg/l               | 27.4 ±0.88  | 21.3.1 ± 0.8 | 22.34± .7    | 17.3± 0.6   | 18.2± 0.5   | 18.8± 0.8   | 19.3± 0.7    | 18.9± 0.5    | 19.6± 0.4    | 250                  |
| Phosphate (ppm)                  | 1.08±0.01   | 1.1 ± 0.01   | 1.07 ± 0.001 | 0.07-1.0    | 0.2± 0.01   | 0.6± 0.01   | 0.7± 0.01    | 0.8± 0.01    | 0.8± 0.01    | 0.1                  |
| Sulphate (SO <sub>4</sub> ) mg/l | 133.4±3.64  | 138.1 ± 3.7  | 128.4 ±3.9   | 250.5 ±7.2  | 289.6 ± 4.8 | 292.8± 7.1  | 144.4±5.3    | 263.2±6.6    | 273.4±3.64   | 250                  |

Table. 2. Distribution, abundance and population density of zooplankton

| S. No            | Rotifera                        | Seasons |        |        |
|------------------|---------------------------------|---------|--------|--------|
|                  |                                 | Rainy   | Winter | Summer |
| 1                | <i>Asplanchna sp.</i>           | +       | +++    | +++    |
| 2                | <i>Brachionus angularis</i>     | -       | +++    | +      |
| 3                | <i>Brachionus bidentata</i>     | +       | +++    | +++    |
| 4                | <i>Brachionus caudatus</i>      | +       | +++    | +++    |
| 5                | <i>Brachionus c. personatus</i> | +       | +++    | ++     |
| 6                | <i>Brachionus calyciflorus</i>  | +       | +++    | +++    |
| 7                | <i>Brachionus forficule</i>     | +       | ++     | ++     |
| 8                | <i>Brachionus patulus</i>       | +       | ++     | +++    |
| 9                | <i>Brachionus quadridentata</i> | +       | +++    | +++    |
| 10               | <i>Brachionus falcatus</i>      | +       | ++     | +++    |
| 11               | <i>Brachionus plicatilis</i>    | +       | ++     | +++    |
| 12               | <i>Dipleuchlanis propatula</i>  | +       | +++    | ++     |
| 13               | <i>Filinia longiseta</i>        | +       | +++    | ++     |
| 14               | <i>Euchlanis dilatata</i>       | +       | ++     | +      |
| 15               | <i>Filinia opoliensis</i>       | -       | +      | +      |
| 16               | <i>Hexartra mira</i>            | -       | +      | +      |
| 17               | <i>Keratella cochlearis</i>     | +       | ++     | +++    |
| 18               | <i>Lecane Aculeata</i>          | +       | +++    | +++    |
| 19               | <i>Lecane Bulla</i>             | +       | ++     | +      |
| 20               | <i>Polyarthra sp.</i>           | +       | ++     | ++     |
| 21               | <i>Rotaria,</i>                 | +       | +      | ++     |
| 22               | <i>Trichotria tetractis</i>     | +       | +      | ++     |
| <b>Cladocera</b> |                                 |         |        |        |
| 1                | <i>Bosmina hagmani</i>          | -       | +      | +      |
| 2                | <i>Ceriodaphnia cornuta</i>     | -       | +      | +      |
| 3                | <i>Cyclops bicuspidatus</i>     | +       | +++    | +++    |
| 4                | <i>Diaptomus minutes</i>        | +       | ++     | +++    |
| 5                | <i>Daphnia pulex</i>            | +       | ++     | +      |
| 6                | <i>Moina macrocopa</i>          | -       | +      | ++     |
| 7                | <i>Moina micrura</i>            | +       | +++    | +      |
| 8                | <i>Daphnia magna</i>            | +       | ++     | ++     |
| 9                | <i>Kurzia longirostris</i>      | +       | ++     | +++    |

|                  |                                        |   |     |     |
|------------------|----------------------------------------|---|-----|-----|
| <b>Copepoda</b>  |                                        |   |     |     |
| 1                | <i>Acanthocyclops vernalis</i>         | + | ++  | ++  |
| 2                | <i>Calanoida copepodites</i>           | + | ++  | ++  |
| 3                | <i>Cyclopoid copepods</i>              | - | +   | +   |
| 4                | <i>Harpacticoida</i>                   | - | +   | +   |
| 5                | <i>Mesocyclops longisetus</i>          | + | ++  | +++ |
| 6                | <i>Mesocyclops edax</i>                | + | ++  | +++ |
| 7                | <i>Microcyclops rubellus</i>           | + | +   | ++  |
| 8                | <i>Copepod Nauplii</i>                 | + | +++ | ++  |
| 9                | <i>Paracyclops chiltoni</i>            | + | ++  | ++  |
| 10               | <i>Tropocyclops prasinus mexicanus</i> | + | ++  | +++ |
| <b>Ostracoda</b> |                                        |   |     |     |
| 1                | <i>Hemicypris fossulata</i>            | + | ++  | ++  |
| 2                | <i>Cypris globosa</i>                  | - | +   | +   |
| <b>Protozoa</b>  |                                        |   |     |     |
| 1                | <i>Blepharisma elongatum</i>           | + | ++  | +++ |
| 2                | <i>Euglena</i>                         | + | ++  | +++ |
| 3                | <i>Paramecium cadatum</i>              | + | ++  | +++ |
| 4                | <i>Lacrymaria</i>                      | + | +   | ++  |
| 5                | <i>Litonotus</i>                       | + | +   | +   |
| 6                | <i>Tetrahymena</i>                     | + | +   | +++ |
| 7                | <i>Vorticella companula</i>            | + | ++  | ++  |

Table 3. Distribution, abundance and population density of zooplankton (no. /L) in Shivna River at Mandsaur during 2024-25

| S. No | Class                        | Monsoon |     |     | Winter |     |     | Summer |     |     |
|-------|------------------------------|---------|-----|-----|--------|-----|-----|--------|-----|-----|
|       |                              | S 1     | S 2 | S 3 | S 1    | S 2 | S 3 | S 1    | S 2 | S 3 |
| 1     | <i>Asplanchna intermedia</i> | 2       | 8   | 6   | 8      | 9   | 12  | 12     | 12  | 11  |
| 2     | <i>Brachionus angularis</i>  | 4       | 5   | 6   | 9      | 8   | 11  | 19     | 18  | 17  |
| 3     | <i>Brachionus bidentata</i>  | 5       | 6   | 8   | 9      | 11  | 12  | 14     | 12  | 22  |
| 4     | <i>Brachionus caudatus</i>   | 8       | 9   | 7   | 8      | 7   | 8   | 12     | 14  | 18  |

|    |                                               |        |        |        |             |             |             |             |             |             |
|----|-----------------------------------------------|--------|--------|--------|-------------|-------------|-------------|-------------|-------------|-------------|
| 5  | <i>Brachionu<br/>s c.<br/>personatu<br/>s</i> | 8      | 7      | 7      | 6           | 8           | 7           | 1<br>3      | 1<br>4      | 1<br>2      |
| 6  | <i>Brachionu<br/>s<br/>calyciflor<br/>us</i>  | 6      | 6      | 7      | 8           | 6           | 7           | 1<br>4      | 1<br>6      | 1<br>3      |
| 7  | <i>Brachionu<br/>s forficula</i>              | 6      | 9      | 1<br>2 | 8           | 6           | 5           | 7           | 5           | 1<br>4      |
| 8  | <i>Brachionu<br/>s patulus</i>                | 8      | 7      | 6      | 7           | 8           | 6           | 1<br>4      | 1<br>7      | 1<br>8      |
| 9  | <i>Brachionu<br/>s<br/>quadriden<br/>tata</i> | -      | -      | 1      | 0           | 8           | 9           | 1<br>1      | 1<br>3      | 2<br>2      |
| 10 | <i>Brachionu<br/>s falcatus</i>               | 2      | 3      | 4      | 3           | 7           | 5           | 1<br>4      | 1<br>3      | 1<br>1      |
| 11 | <i>Brachinou<br/>s plicatilis</i>             | 4      | 5      | 8      | 7           | 2           | 5           | 9           | 8           | 1<br>1      |
| 12 | <i>Dipleuchl<br/>anis<br/>propatula</i>       | 7      | 8      | 7      | 1<br>1      | 5           | 1           | 8           | 1<br>1      | 1<br>2      |
| 13 | <i>Filinia<br/>opoliensis</i>                 | 4      | 3      | 2      | 1<br>0      | 1<br>0      | 0<br>9      | 1<br>1      | 1<br>8      | 1<br>0      |
| 14 | <i>Keratella<br/>cochlearis</i>               | 4      | 6      | 3      | 9           | 1<br>0      | 1<br>2      | 1<br>1      | 1<br>9      | 1<br>4      |
|    | TOTAL                                         | 6<br>8 | 8<br>2 | 8<br>4 | 1<br>1<br>3 | 1<br>0<br>5 | 2<br>0<br>0 | 1<br>6<br>5 | 1<br>9<br>0 | 2<br>0<br>5 |
|    | Cladocera                                     |        |        |        |             |             |             |             |             |             |
| 1  | <i>Ceriodaph<br/>nia<br/>cornuta</i>          | 7      | 6      | 4      | 6           | 9           | 8           | 1<br>8      | 2<br>2      | 1<br>8      |
| 2  | <i>Daphnia<br/>magna</i>                      | 6      | 7      | 8      | 9           | 1<br>0      | 1<br>1      | 1<br>9      | 2<br>1      | 2<br>3      |
| 3  | <i>Daphnia<br/>pulex</i>                      | 6      | 8      | 4      | 1<br>0      | 8           | 1<br>1      | 2<br>4      | 2<br>2      | 2<br>1      |
| 4  | <i>Kurzia<br/>longirostri<br/>s</i>           | 2      | 6      | 4      | 7           | 5           | 5           | 1<br>0      | 1<br>1      | 9           |
| 5  | <i>Macrothri<br/>x<br/>laticornis</i>         | 5      | 4      | 6      | 4           | 7           | 6           | 1<br>6      | 1<br>5      | 1<br>9      |
| 6  | <i>Moina<br/>macrocop<br/>a</i>               | 4      | 5      | 3      | 8           | 7           | 6           | 1<br>2      | 1<br>8      | 1<br>8      |
| 7  | <i>Moina<br/>micrura</i>                      | 8      | 9      | 6      | 8           | 1<br>0      | 9           | 1<br>8      | 1<br>8      | 1<br>9      |

|              |                                               |        |        |        |        |        |        |             |             |             |
|--------------|-----------------------------------------------|--------|--------|--------|--------|--------|--------|-------------|-------------|-------------|
|              | TOTAL                                         | 3<br>8 | 4<br>5 | 3<br>5 | 5<br>2 | 5<br>6 | 5<br>6 | 1<br>1<br>7 | 1<br>2<br>7 | 1<br>2<br>7 |
| Cope<br>poda |                                               |        |        |        |        |        |        |             |             |             |
| 1            | <i>Heliodiapt<br/>omus<br/>viduus</i>         | 0      | 0      | 1      | 0      | 1      | 1      | 5           | 3           | 4           |
| 2            | <i>Heliodiap<br/>tomus<br/>cinctus</i>        | 1      | 0      | 1      | 1      | 1      | 2      | 2           | 4           | 3           |
| 3            | <i>Neodiapt<br/>omus<br/>strigilipe<br/>s</i> | 2      | 2      | 1      | 4      | 4      | 5      | 7           | 6           | 8           |
| 4            | <i>Mesocyclo<br/>ps varius</i>                | 2      | 4      | 4      | 1<br>1 | 9      | 8      | 1<br>6      | 1<br>6      | 1<br>8      |
| 5            | <i>Mesocyclo<br/>ps<br/>longisetus</i>        | 3      | 2      | 2      | 3      | 4      | 3      | 1<br>2      | 1<br>4      | 1<br>7      |
| 6            | <i>Mesocyclo<br/>ps edax</i>                  | 6      | 2      | 3      | 4      | 6      | 5      | 1<br>5      | 1<br>4      | 1<br>9      |
| 7            | <i>Paracyclo<br/>ps vagus</i>                 | 3      | 2      | 4      | 6      | 7      | 8      | 1<br>2      | 1<br>3      | 1<br>5      |
| 8            | <i>Thermocy<br/>clops<br/>crassus</i>         | 4      | 6      | 6      | 5      | 7      | 8      | 1<br>8      | 1<br>7      | 1<br>8      |
|              | TOTAL                                         | 2<br>1 | 1<br>8 | 2<br>2 | 3<br>4 | 3<br>9 | 4<br>0 | 8<br>7      | 8<br>7      | 1<br>0<br>2 |
|              | Ostracoda                                     |        |        |        |        |        |        |             |             |             |
| 1            | <i>Hemicypri<br/>s<br/>futunaensi<br/>s</i>   | 1      | 0      | 0      | 1      | 0      | 1      | 2           | 2           | 3           |
| 2            | <i>Cyclocypr<br/>is globosa</i>               | 0      | 0      | 1      | 0      | 1      | 1      | 3           | 2           | 5           |
|              | TOTAL                                         | 1      | 0      | 1      | 0<br>1 | 0<br>1 | 0<br>2 | 0<br>5      | 0<br>4      | 0<br>8      |
| Proto<br>zoa |                                               |        |        |        |        |        |        |             |             |             |
| 1            | <i>Blepharis<br/>ma Sp.</i>                   | 2      | 2      | 3      | 2      | 4      | 5      | 6           | 8           | 9           |
| 2            | <i>Euglena<br/>clara Skuj<br/>a</i>           | 1      | 1      | 0      | 3      | 1      | 1      | 7           | 7           | 8           |
| 3            | <i>Euglena<br/>viridis</i>                    | 3      | 4      | 4      | 1<br>5 | 1<br>2 | 1<br>0 | 3<br>1      | 3<br>4      | 3<br>6      |
| 4            | <i>Parameci<br/>um<br/>caudatum</i>           | 5      | 6      | 7      | 6      | 6      | 7      | 1<br>5      | 1<br>4      | 1<br>1      |

|   |                              |    |    |    |    |    |    |    |    |    |
|---|------------------------------|----|----|----|----|----|----|----|----|----|
| 5 | <i>Paramecium bursaria</i>   | 2  | 3  | 4  | 3  | 4  | 6  | 10 | 11 | 11 |
| 6 | <i>Holophrya bengalensis</i> | -  | -  | 1  | -  | -  | -  | -  | -  | -  |
| 7 | <i>Lacrymaria olor</i>       | 1  | -  | 1  | -  | 1  | 2  | 2  | 1  | 1  |
| 8 | <i>Vorticella campanulla</i> | 1  | 2  | 2  | 3  | 4  | 4  | 5  | 7  | 8  |
| 9 | <i>Vorticella microstoma</i> | 0  | 1  | 2  | 4  | 3  | 4  | 9  | 13 | 14 |
|   | TOTAL                        | 15 | 19 | 24 | 36 | 35 | 39 | 85 | 95 | 98 |

Table 4. Seasonal distribution of zooplankton at Shivna River during 2024-25

|           | RAINY | WINTER | SUMMER | TOTAL |
|-----------|-------|--------|--------|-------|
| ROTIFERA  | 234   | 418    | 560    | 1212  |
| CLADOCERA | 118   | 164    | 371    | 653   |
| COPEPODA  | 61    | 113    | 276    | 450   |
| OSTRACODA | 02    | 04     | 17     | 23    |
| PROTOZOA  | 58    | 110    | 278    | 446   |
| TOTAL     | 473   | 809    | 1502   | 2784  |