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Assessment of macroinvertebrate diversity and water quality of the Malaprabha river near Munavalli, Belagavi district, Karnataka state, India

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ABSTRACT

This research examines the relationship between the diversity of macroinvertebrate species and water quality in the Malaprabha river near Munavalli, Savadatti taluk, Belagavi district, Karnataka, India. Seasonal assessments of macroinvertebrate communities were conducted over one year (November 2021–October 2022) at five designated sampling sites (S1–S5) using the Kick Net method. A total of 24 species were identified, representing three phyla: Annelida (2 species), Arthropoda (15 species), and Mollusca (7 species). Arthropoda was the most dominant phylum, while the presence of pollution indicator species such as *Chironomus* larvae, *Limnodrilus* sp., and *Lymnaea* sp. reflected pollution levels in the river ecosystem. Diversity indices and correlations between macroinvertebrate abundance and sixteen water quality variables were evaluated using Canonical Correspondence Analysis (CCA) in PAST software. Interrelationships among physico-chemical parameters were examined using Pearson's correlation coefficient in SPSS (IBM, Version 21). The results indicate that variations in water quality have a significant influence on macroinvertebrate assemblages.

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INTRODUCTION

Macroinvertebrates are visible, invertebrate aquatic organisms that inhabit riverine environments. They represent a vital component of freshwater ecosystems and are widely recognized as reliable indicators of stream and river health. Some species are sensitive to pollution, while others are able to tolerate degraded conditions. Variations in their community structure and abundance provide insight into water quality (Bonada *et al.,* 2006).

These organisms are taxonomically diverse and relatively long-lived, exhibiting measurable responses to anthropogenic impacts on aquatic systems (Sharma and Chaudhary, 2011). Most benthic forms feed on detritus deposited on the substrate, thereby serving as an important food source for several fish species (Imevbore and Bakare, 1970; Adebisi, 1989; Ajao, 1990; Oke, 1990; Idowu and Ugwumba, 2005). Furthermore, they enhance the breakdown of organic materials into simpler nutrients such as nitrates and phosphates (Gallep *et al.,* 1978).

Consequently, macroinvertebrates occupy a crucial position in the aquatic food web, supporting higher trophic levels including fish, birds, and mammals (Bernes and Hughes, 1988).

Macroinvertebrates offer a more precise and enduring reflection of evolving aquatic conditions compared to chemical and microbiological assessments (Ravera, 1998, 2000; Ikomi *et al.,* 2005). The study of macroinvertebrates is one of the most widely accepted biological methods for evaluating freshwater bodies affected by industrial wastewater (Odiete, 1999). The diversity, abundance, and spatial distribution of macroinvertebrates are significantly influenced by various water quality parameters (Imevbore, 1967; Haslam, 1990; APHA/WWA/WEF, 1998; Odiete, 1999). Studies have demonstrated that shifts in macroinvertebrate community structure often reflect alterations in local environmental conditions, serving as valuable indicators for assessing the ecological health of aquatic ecosystems.

Extensive research has been conducted on freshwater macroinvertebrates in India, including studies by Srivastava (1956), Krishnamurthy (1966), Dev *et al.* (1993), Mandal and Moitra (1975), Raman *et al.* (1976), Gupta (1976), Misra *et al.* (1981), Gupta and Pant (1983), and Barbhuiyan and Khan (1992). However, there is a notable gap in the literature regarding the macroinvertebrate fauna of the Malaprabha River in Munavalli Town, Belagavi District, Karnataka. This river is a vital resource for the local community, providing water for drinking, irrigation, recreation, and fishing. Despite its significance, the river faces pollution challenges from various anthropogenic activities. These include industrial discharges, agricultural runoff, and sewage contamination, which degrade water quality. Additionally, practices such as bathing, cloth washing, animal washing, vehicle washing, idol immersion, floral offerings, and human waste disposal further contribute to the pollution, compromising the river's ecological health.

The primary aim of this study is to assess the diversity of macroinvertebrates and investigate how their distribution correlates with the physico-chemical characteristics of selected sites along the Malaprabha River in Munavalli Town, Belagavi District, Karnataka.

MATERIALS AND METHODS

Study area

The Malaprabha River is one of the prominent rivers in North Karnataka and serves as a tributary of the Krishna River. It originates in the Western Ghats at Kanakumbi village, located at 15°42'20" North latitude and 74°13'9" East longitude. The selected study area is near Munavalli along the Malaprabha River, situated at 15°51'13" North latitude and 75°7'13" East longitude (Map B). Macroinvertebrate assemblages in the Malaprabha River were assessed seasonally over a one-year period from November 2021 to October 2022. Five sampling sites—S1, S2, S3, S4, and S5—were chosen for macroinvertebrate collection (Map C1 and C2) (Fig. 1).

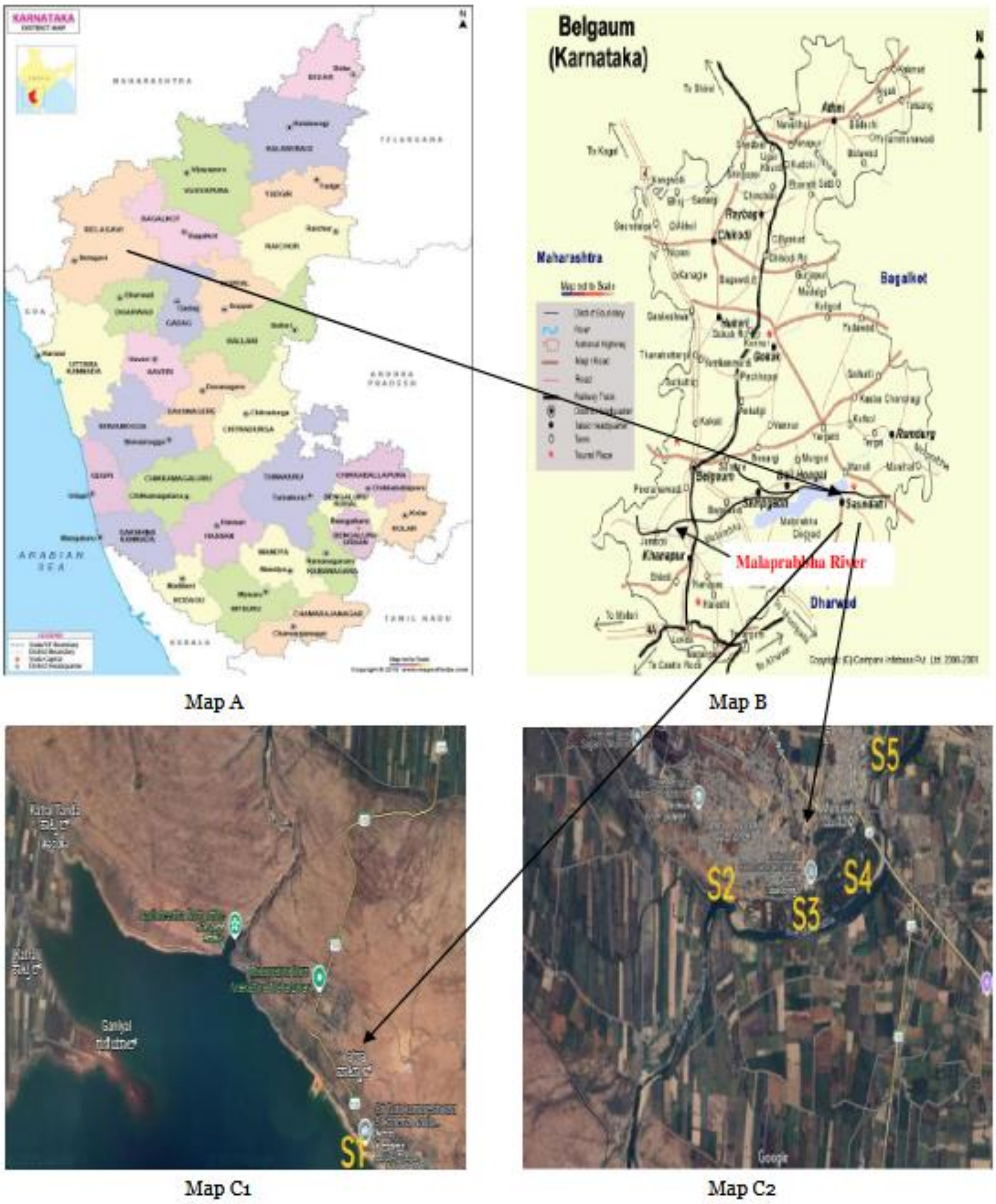

Fig. 1. Study area

Map A: Karnataka districts map, Map B: Belagavi district map showing Malaprabha river (Source: d-maps.com), Map C1 & C2: Location of the sampling sites near Munavalli, Savadatti taluk, Belagavi district, Karnataka (Source: Google map)

Methodology

Macroinvertebrate sampling was carried out seasonally at three time intervals: winter (November 2021 to February 2022), summer (March to June 2022), and monsoon (July to October 2022). Sampling was always carried out between 10:00 AM and 4:00 PM. The Kick Net method was employed for macroinvertebrate collection. This technique involves positioning a "D" frame net in the direction of water flow and the riverbed was disturbed by kicking to dislodge organisms, which were carried into the net. The collected material was poured into a shallow (≈2 cm depth) tray of clean water to allow sediment to settle.

Macroinvertebrates were observed moving in the water and carefully removed with forceps, a dropper, or a small spoon. Specimens were then transferred to pre-labeled, wide-mouthed containers and preserved in a 10% formalin solution. In the lab, specimens were sorted and identified to species level using established taxonomic keys (Edmondson, 1959; Tonapi, 1980; Subba Rao, 1989; Pennak, 1989; Naidu, 2005), and photographic records were taken.

At the same time, water samples were collected in clean, sterilized 1-liter polyethylene bottles. Field measurements of pH and temperature were made on site, and other parameters-including turbidity, dissolved oxygen (DO), biological oxygen demand (BOD), total dissolved solids (TDS), electrical conductivity (EC), nitrate, sulfate, chloride, total hardness (TH), calcium, magnesium, sodium, potassium, and iron- were analyzed in the laboratory, following standard procedures outlined by APHA (1985).

RESULTS

In the current study, 24 macroinvertebrate species were documented across five sampling locations (S1 through S5). These species spanned three principal invertebrate phyla: Annelida (8.33 %), Arthropoda (62.5 %), and Mollusca (29.16 %). These species were classified into 06 classes, 13 orders, and 21 families (Table 1 and Fig. 2). Among them, the phylum Arthropoda was the most dominant, contributing 62.50% of the total macroinvertebrate fauna. It consisted of 15 species from eight orders across three classes.

Class Malacostraca (subphylum: Crustacea) accounted for 12.50% of the total macroinvertebrate fauna, represented by two orders—Decapoda and Isopoda—with three families: Palaemonidae, Gecarcinucidae, and Aegidae (Table 1 and Fig. 2). Class Arachnida contributed 4.16% of the total macroinvertebrate fauna, consisting of a single order, Araneae, represented by the family Dolomedidae (Table 1 and Fig. 2). Class Insecta was the single most abundant group among the macroinvertebrates, making up 45.83% of all individuals sampled. The orders Diptera and Odonata were especially prominent. Diptera accounted for 12.50% of the total macroinvertebrate fauna, with representatives from the Culicidae, Muscidae, and Chironomidae families. Similarly, Order Odonata also contributed 12.50%, represented by three families: Libellulidae, Gomphidae, and Coenagrionidae.

Order Hemiptera accounted for 8.33%, with two families: Corixidae and Notonectidae. Order Ephemeroptera represented another 8.33%, comprising families Baetidae and Caenidae. Order Coleoptera made up 4.16%, represented by the family Dysticidae (Table 1 and Fig. 3).

In this study, the phylum Mollusca was the second most prevalent group, comprising 29.16% of the total macroinvertebrate population. This phylum included six species from the class Gastropoda (25%) and one species from the class Bivalvia (4.16%) (Table 1 and Fig. 3).

Gastropods showed dominance over bivalves, consisting of three orders: Architaenioglossa (16.66%), Neotaenioglossa (4.16%), and Basommatophora (4.16%). The order Architaenioglossa was represented by two families: Viviparidae and Ampullariidae. Neotaenioglossa included one family, Thiaridae, while Basommatophora was represented by the family Lymnaeidae. The class Bivalvia was represented by order Unionida, belonging to the family Unionidae.

Phylum Annelida contributed 8.33% of the total macroinvertebrate fauna, comprising two species from class Clitellata (8.33%), which belonged to order Tubificida of the family Naididae (Table 1 and Fig. 2 and 2).

Table 2 presents the seasonal fluctuations in various physico-chemical parameters of the Malaprabha River from November 2021 to October 2022. Throughout the study period, water temperature fluctuated between a minimum of 26.8°C in winter and a maximum of 37°C in summer. pH levels measured between 6.6 in winter and 7.2 during the monsoon season.

Table 1. Macroinvertebrate fauna identified in river Malaprabha (From November 2021 to October 2022), Munavalli, Dist.-Belagavi, State-Karnataka, India

Phylum	Class	Order	Family	Genus and species
Annelida	Clitellata	Tubificida	Naididae	*Tubifex tubifex*
				Limnodrilus sp.
Arthropoda	Malacostraca	Decapoda	Palaemonidae	*Macrobrachium* sp.
	(Subphylum:		Gecarcinucidae	*Barytelphusa* sp.
	Crustacea)	Isopoda	Aegidae	*Alitropus typus*
	Arachnida	Araneae	Dolomedidae	*Dolomedes* sp.
	Insecta	Coleoptera	Dytiscidae	*Laccophilus* sp.
		Hemiptera	Corixidae	*Corixa* sp.
			Notonectidae	*Notonecta* sp.
		Diptera	Culicidae	*Culex larvae*
			Muscidae	*Limnophora* sp.
			Chironomidae	*Chironomous* sp.
		Odonata	Libellulidae	Dragonfly nymph (*Libellula* sp.)
			Gomphidae	Dragonfly nymph (*Gomphus* sp.)
			Coenagrionidae	Damsefly nymph sp.
		Ephemeroptera	Baetidae	*Baetis* sp.
			Caenidae	*Caenis* sp.
Mollusca	Gastropoda	Architaenioglossa	Viviparidae	*Bellamya dissimilis*
				Bellamya bengalensis
				Vivipara bengalensis
			Ampullariidae	*Pila globosa*
		Neotaenioglossa	Thiaridae	*Melanoides* sp.
		Basommatophora	Lymnaeidae	*Lymnaea* sp.
	Bivalvia	Unionida	Unionidae	*Lamellidens* sp.

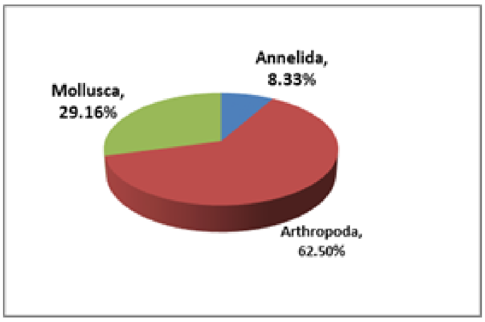

Fig. 2. Proportional representation of macroinvertebrate phyla

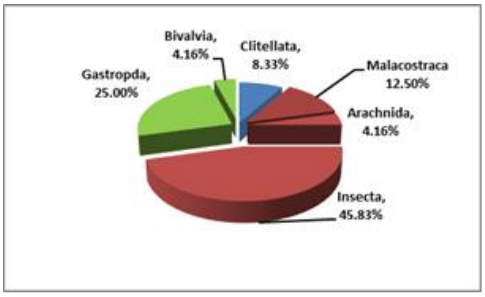

Fig. 3. Proportional representation of invertebrate classes

Turbidity varying from 4.42 NTU in summer to 22.4 NTU in the monsoon. Dissolved oxygen (DO) concentrations fluctuated between 6.6 mg/L in summer and 7.2 mg/L in the monsoon. Biochemical oxygen demand (BOD) covered a spectrum from 5.9 mg/L in winter to 7.1 mg/L in summer. Total dissolved solids (TDS) varied from 101 mg/L in the monsoon to 150 mg/L in summer. Electrical conductivity (EC) ranged between 208 µS/cm in the monsoon and 280 µS/cm in summer.

Nitrate concentrations varying from 1.1 mg/L in summer to 2.5 mg/L in the monsoon. Sulfate levels fluctuated between 17 mg/L in the monsoon and 23 mg/L in summer. Chloride content measured between 20 mg/L in the monsoon and 35 mg/L in summer. Total hardness (TH) levels differed from 78 mg/L in the monsoon to 126 mg/L in summer.

Calcium concentrations varied from 22 mg/L in the monsoon to 37 mg/L in summer, while magnesium levels ranged from 7 mg/L in the monsoon to 11 mg/L in winter. Sodium concentrations ranged from 15 mg/L in the monsoon to 28 mg/L in summer and potassium from 2.3 mg/L in winter to 2.8 mg/L in the monsoon. Iron was the least concentrated element in the river, with levels ranging from a minimum of 0.2 mg/L in summer to a maximum of 1.51 mg/L during the monsoon.

Table 2. Seasonal water quality variables, minimum, maximum, mean, and standard deviation of the physico-chemical characteristics of water samples from the Malaprabha river (November 2021 to October 2022), Munavalli, Belagavi district, Karnataka, India

Parameters	Winter	Summer	Monsoon	Min.	Max.	Mean±SD
Temp (°C)	26.8	37	27	26.8	37	30.26±5.83
pH	6.6	6.8	7.2	6.6	7.2	6.86±0.30
Turbidity (NTU)	5.1	4.42	22.4	4.42	22.4	10.64±10.19
DO (mg/l)	6.8	6.6	7.2	6.6	7.2	6.86±0.30
BOD (mg/l)	5.9	7.1	6.2	5.9	7.1	6.4±0.62
TDS (mg/l)	115	150	101	101	150	122±25.23
EC (mS/cm)	220	280	208	208	280	236±38.5
No_3 (mg/l)	2.1	1.1	2.5	1.1	2.5	1.9±0.72
So_4 (mg/l)	18	23	17	17	23	19.3±3.21
Cl (mg/l)	23	35	20	20	35	26±7.93
TotalHardness (mg/l)	99	126	78	78	126	101±24.06
Ca (mg/l)	26	37	22	22	37	28.3±7.76
Magnesium (mg/l)	11	10	7	7	11	9.3±2.08
Sodium (mg/l)	18	28	15	15	28	20.3±6.80
Potassium (mg/l)	2.3	2.5	2.8	2.3	2.8	2.5±0.25
Fe (mg/l)	0.43	0.2	1.51	0.2	1.51	0.71±0.69

NTU- Nephelometric Turbidity Unit, EC - mS/cm (MicroSiemens/Centimeter

Table 3. Correlation coefficients (r) between macroinvertebrates and physico-chemical characteristics of water samples from the Malaprabha River (November 2021 to October 2022), Munavalli, Belagavi district, Karnataka, India

Parameters	Annelida	Arthropoda	Mollusca
Temp (°C)	.017	-.973**	.987**
pH	.982***	.396	-.013
Turbidity (NTU)	.849**	.699*	-.371
DO (mg/l)	.655*	.879**	-.629*
BOD (mg/l)	.240	-.896**	.998*
TDS (mg/l)	-.277	-.998***	.897**
EC (mS/cm)	-.156	-.998***	.945***
NO_3 (mg/l)	.277	.998***	-.897**
SO_4 (mg/l)	-.156	-.998***	.945***
Cl (mg/l)	-.189	-1.000***	.933***
Total Hardness (mg/l)	-.436	-.973**	.809**
Ca (mg/l)	-.257	-.999*	.906***
Magnesium (mg/l)	-.961***	-.478	.104
Sodium (mg/l)	-.220	-1.000***	.921***
Potassium (mg/l)	.993**	.326	.062
Fe (mg/l)	.772**	.787**	-.489

*/**= Indicates moderately correlated and significant at the 0.05 level (2-tailed), ***= Indicates highly correlated and significant at the 0.05 level (2-tailed).

The relationship between physico-chemical parameters and macroinvertebrate density was analyzed, as summarized in Table 3. The Annelida phylum exhibited a highly significant positive correlation with pH levels, a moderately significant positive correlation with turbidity, dissolved oxygen, potassium, and iron concentrations, and a highly significant negative correlation with magnesium levels.

Arthropoda displayed a highly significant positive correlation with nitrate levels, a moderately significant positive correlation with turbidity, dissolved oxygen, and iron concentrations. In contrast, it exhibited a highly significant negative correlation with total dissolved solids, electrical conductivity, sulfate, chloride, and sodium levels, and a moderately significant negative correlation with temperature, biochemical oxygen demand, total hardness, and calcium concentrations. Mollusca showed a highly significant positive correlation with EC, sulfate, chloride, calcium, and sodium, a moderately significant positive correlation with Temperature, BOD, TDS and total hardness, and a moderately significant negative correlation with DO and nitrate.

Table 4. Seasonal population density of macroinvertebrates (individuals/m²) at different sites in the Malaprabha river, Munavalli, Belagavi district, Karnataka, India (November 2021 – October 2022)

Macroinvertebrates	Winter						Summer						Monsoon					
	S1	S2	S3	S4	S5	Total	S1	S2	S3	S4	S5	Total	S1	S2	S3	S4	S5	Total
Annelida																		
Tubifex tubifex	0	0	0	0	0	0	1	1	0	0	0	02	0	0	0	0	0	00
Limnodrilus sp.	0	0	0	0	0	0	0	0	0	0	0	00	3	0	0	0	1	04
Total	0	0	0	0	0	0	1	1	0	0	0	02	3	0	0	0	1	04
Arthropoda																		
Macrobrachium sp.	1	1	0	0	0	02	0	0	0	0	1	01	0	0	0	0	0	00
Barytelphusa sp.	0	0	0	0	0	00	0	0	0	0	0	00	1	0	0	0	0	01
Alitropus typus	0	0	0	0	0	00	0	0	0	0	0	00	0	0	1	1	0	02
Dolomedes sp.	0	0	0	1	1	02	0	0	0	0	0	00	0	0	1	0	0	01
Laccophilus sp.	0	0	0	0	0	00	0	0	0	0	0	00	1	1	0	0	0	02
Corixa sp.	0	0	1	4	0	05	1	1	1	0	1	04	2	4	1	4	0	11
Notonecta sp.	0	0	0	0	0	00	0	0	0	0	0	00	1	0	0	0	0	01
Culex larvae	0	1	0	0	0	01	0	0	0	0	0	0	0	3	0	0	0	03
Limnophora sp.	0	0	0	0	0	00	0	1	0	0	0	01	0	0	0	0	0	00
Chironomous sp.	5	1	6	0	3	15	1	0	0	0	1	02	0	4	0	0	1	05
Dragonfly nymph (*Gomphus* sp.)	2	0	0	1	0	03	0	0	0	0	0	00	0	1	0	0	0	01
Dragonfly nymph (*Libellula* sp.)	0	0	0	2	0	02	0	1	0	0	1	02	1	0	0	0	0	01
Damselfly nymph sp.	0	2	1	0	0	03	0	0	0	0	0	00	0	0	1	0	0	01
Baetis sp.	0	1	0	0	2	03	0	0	0	0	0	00	0	0	0	0	0	00
Caenis sp.	1	0	0	0	2	03	2	0	0	1	2	05	0	0	0	10	7	17
Total	09	06	08	08	08	39	04	03	01	01	06	15	06	13	04	15	08	46
Mollusca																		
Bellamya dissimilis	0	0	0	1	2	03	0	0	0	2	1	03	0	0	0	0	0	00
Bellamya bengalensis	1	1	0	0	1	03	0	0	0	1	1	02	0	0	1	0	0	01
Vivipara bengalensis	0	3	0	2	0	05	14	5	1	0	3	23	2	2	1	1	8	14
Melanoides sp.	0	0	1	0	0	01	3	3	1	2	3	12	2	2	3	1	1	09
Pila globosa	1	1	0	6	0	08	0	1	0	0	1	02	1	1	1	2	0	05
Lymnaea sp.	1	1	0	1	0	03	0	2	0	0	1	03	0	0	0	1	0	01
Lamellidens sp.	1	0	0	3	3	07	7	1	1	5	3	17	1	2	0	0	3	06
Total	04	06	01	13	06	30	24	12	03	10	13	62	06	07	06	05	12	36

The population density of macroinvertebrates (individuals/m²) recorded at various sites during different seasons is summarized in Table 4. Arthropoda emerged as the most, predominant phylum in the study area, comprising 100 individuals from 15 species. Of these, 46 individuals were recorded during the monsoon, 39 during winter, and 15 during the summer season.

Among arthropods, insects represented the most dominant subgroup, accounting for 89 out of the 100 individuals. Within this group, *Caenis* sp. was the most abundant species, with a total of 25 individuals—17 recorded during the monsoon (sites S4 and S5), five during the summer (sites S1, S4, and S5), and three during winter (sites S1 and S5). *Chironomus* sp. was the second most abundant species, with 22 individuals—15 collected during winter (sites S1, S2, S3, and S5), five in the monsoon (sites S2 and S5), and two in summer (sites S1 and S5).

Corixa sp. ranked third in abundance, with 20 individuals recorded—11 during the monsoon across all sites except S5; 5 in winter at sites S3 and S4; and 4 in summer at all sites except S4. Other insect species observed included *Laccophilus* sp. (2 individuals), *Notonecta* sp. (1 individual), *Culex* larvae (4 individuals), *Limnophora* sp. (1 individual), dragonfly nymphs (*Gomphus* sp., 4 individuals); *Libellula* sp. (5 individuals), damselfly nymphs (4 individuals), and *Baetis* sp. (3 individuals). The class Malacostraca was represented by three species: *Macrobrachium* sp. (3 individuals), *Barytelphusa* sp. (1 individual), and *Alitropus typus* (2 individuals). The class Arachnida included only a single species, *Dolomedes* sp., with 3 individuals recorded.

Table 5. Diversity indices of macroinvertebrates in the study area

	Annelida	Arthropoda	Mollusca
Taxa_S	2	15	7
Individuals	6	100	128
Dominance_D	0.5556	0.162	0.2133
Simpson_1-D	0.4444	0.838	0.7867
Shannon_H	0.6365	2.148	1.705
Evenness_e^H/S	0.9449	0.5711	0.7863

From the phylum Annelida, two species were observed: *Tubifex tubifex* and *Limnodrilus* sp. Two individuals of *Tubifex tubifex* were recorded during the summer season at sites S1 (1 individual) and S2 (1 individual), with no presence during the monsoon or winter. Four individuals of *Limnodrilus* sp. were recorded during the monsoon at sites S1 (3 individuals) and S5 (1 individual).

The phylum Mollusca was the second most dominant group in the study, with 128 individuals from 7 species. Of these, 62 individuals were collected during summer, 36 during the monsoon, and 30 during winter. Gastropods were the most dominant subgroup within this phylum, comprising 64 individuals. *Vivipara bengalensis* was the most abundant gastropod species, with a total of 42 individuals—In summer, 23 individuals were observed across all sites except S4; during the rainy season, 14 individuals were recorded at all sites; and in winter, 5 individuals were found at sites S2 and S4. Melanoides sp. was the next most abundant, with 22 individuals—12 in summer (all sites), 9 during the rainy season (same sites), and 1 in winter (S3). Other gastropod species included *Pila globosa* (15 individuals), *Lymnaea* sp. (7 individuals), *Bellamya bengalensis* (6 individuals), and *Bellamya dissimilis* (6 individuals). The class Bivalvia was represented by a single species, *Lamellidens* sp., which was the second most abundant mollusc overall. It totaled 30 individuals—17 in summer (sites S1 to S5), 7 in winter (sites S1, S4, and S5), and 6 during the monsoon (sites S1, S2, and S5).

Diversity indices

Arthropoda showed the highest species diversity as measured by the Shannon index (2.14), whereas Annelida had the lowest (0.63). Likewise, Simpson's index was greatest for Arthropoda (0.83) and lowest for Annelida (0.44).

Simpson's dominance index showed the lowest dominance (0.162) for Arthropoda, indicating higher diversity, and the highest dominance (0.5556) for Annelida, indicating lower diversity. The evenness index for Annelida (0.9449) was nearly equal to 1, indicating that Annelida were more evenly distributed (despite low richness) than Arthropoda (0.5711) (Table 5).

Canonical correspondence analysis (CCA)

CCA is a multivariate ordination technique applied to relate species assemblages to environmental (physico-chemical) variables. In this investigation, the first axis (horizontal) accounted for 57.3 % of the relationship between species and environment, and the second axis (vertical) accounted for 42.7 %, indicating the extent to which environmental gradients shape macroinvertebrate distribution. The eigenvalues associated with each axis reflect how much of the explained variance each axis carries, with a larger eigenvalue denoting a stronger contribution. In our data, Axis 1 captured the greater proportion of variation in the species–environment relationships. The *p*-value denotes the statistical significance of the overall correlation: typically $p \leq 0.05$ is considered significant. In this study, the p-value was not significant, which supports the null hypothesis that there is no meaningful association between the sets of variables (Table 6). The graphical CCA biplot depicts environmental parameters as vectors (arrows) and species as points (Fig. 3).

Table 6. Eigen values for CCA in the study area

Axis	Eigenvalue	Percentage computation (%)	p
01	0.27829	57.3	0.53
02	0.20735	42.7	0.699

Species composition and environmental variables showed both positive and negative responses, reflecting variations at the study site. Water temperature was positively associated with BOD, TDS, EC, sulfate, chloride, calcium, sodium, and *Lamellidens* sp., and negatively associated with DO, nitrate, potassium, *Dolomedes* sp., and *Pila globosa*. pH showed a positive response to turbidity, potassium, *Barytelphusa* sp., *Alitropus typus*, *Laccophilus* sp., *Notonecta* sp., and *Caenis* sp., but a negative response to magnesium, *Macrobrachium* sp., *Bellamya bengalensis*, and *Lymnaea* sp. Turbidity was positively related to pH, DO, potassium, Fe, *Limnodrilus* sp., *Barytelphusa* sp., *Alitropus typus*, *Laccophilus* sp., *Corixa* sp., *Notonecta* sp., *Culex* larvae, and *Caenis* sp., but negatively associated with magnesium, dragonfly nymph (*Libellula* sp.), *Bellamya dissimilis*, and *Lymnaea* sp.

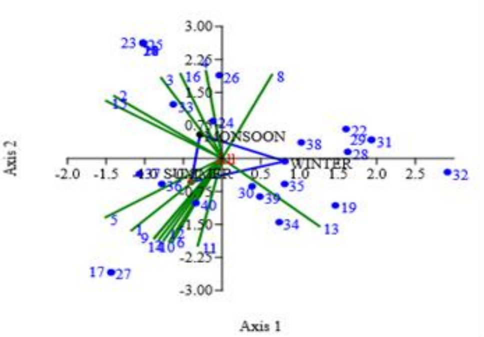

Fig. 3. CCA in the study area

Dissolved oxygen (DO) was positively correlated with turbidity, nitrate, Fe, *Barytelphusa* sp., *Alitropus typus*, *Laccophilus* sp., *Corixa* sp., *Notonecta* sp., and *Culex* larvae, and negatively with temperature, TDS, total hardness, dragonfly nymph (*Libellula* sp.), *Bellamya dissimilis*, and *Lymnaea* sp. Biological oxygen demand (BOD) showed positive responses to temperature, EC, sulfate, chloride, *Tubifex* sp., *Limnophora* sp., *Vivipara bengalensis*, *Melanoides* sp., and *Lamellidens* sp., and negative responses to nitrate, *Dolomedes* sp., and *Pila globosa*. Total dissolved solids (TDS) were positively related to temperature, EC, chloride, total hardness, calcium, sodium, *Tubifex* sp., *Limnophora* sp., and *Lamellidens* sp., and negatively to DO, nitrate, Fe, and *Culex* larvae.

Electrical conductivity (EC) showed positive associations with temperature, BOD, TDS, sulfate, chloride, total hardness, calcium, sodium, *Tubifex* sp., *Limnophora* sp., and *Lamellidens* sp., and negative associations with nitrate, *Culex* larvae, *Dolomedes* sp., and *Pila globosa*. Nitrate demonstrated a positive association with dissolved oxygen, iron, and Culex larvae, whereas it was negatively associated with temperature, BOD, TDS, electrical conductivity, sulfate, chloride, total hardness, calcium, sodium, and the taxa *Tubifex* sp., *Limnophora* sp., and *Lamellidens* sp. Sulfate showed positive relationships with temperature, BOD, EC, chloride, total hardness, calcium, sodium, *Tubifex* sp., *Limnophora* sp., and *Lamellidens* sp., and negative relationships with nitrate, Fe, *Dolomedes* sp., and *Pila globosa*. Chloride was positively related to temperature, BOD, TDS, EC, sulfate, total hardness, calcium, sodium, *Tubifex* sp., *Limnophora* sp., and *Lamellidens* sp., and negatively related to nitrate, Fe, *Dolomedes* sp., and *Pila globosa*.

Total hardness exhibited positive associations with TDS, EC, sulfate, chloride, calcium, magnesium, sodium, *Limnophora* sp., and *Lamellidens* sp., and negative associations with DO, nitrate, Fe, *Culex* larvae, *Alitropus typus*, and *Notonecta* sp. Calcium was positively related to temperature, TDS, EC, sulfate, chloride, total hardness, sodium, *Tubifex* sp., *Limnophora* sp., and *Lamellidens* sp., and negatively to nitrate, Fe, and *Culex* larvae. Magnesium responded positively to total hardness, *Macrobrachium* sp., dragonfly nymph (*Libellula* sp.), *Bellamya bengalensis*, and *Lymnaea* sp., but negatively to pH, turbidity, potassium, Fe, *Limnodrilus* sp., *Barytelphusa* sp., *Laccophilus* sp., *Corixa* sp., *Notonecta* sp., and *Caenis* sp. Sodium showed positive relationships with temperature, TDS, EC, sulfate, chloride, total hardness, calcium, *Tubifex* sp., and *Lamellidens* sp., and negative relationships with nitrate, *Dolomedes* sp., *Corixa* sp., *Pila globosa*, and *Culex* larvae.

Potassium was positively associated with pH, turbidity, Fe, *Barytelphusa* sp., *Alitropus typus*, *Laccophilus* sp., *Notonecta* sp., and *Caenis* sp., and negatively with magnesium, *Culex* larvae, *Alitropus typus*, and *Notonecta* sp. Iron (Fe) showed positive relationships with pH, turbidity, DO, nitrate, potassium, *Limnophora* sp., *Barytelphusa* sp., *Alitropus typus*, *Laccophilus* sp., *Corixa* sp., *Notonecta* sp., *Culex* larvae, and *Caenis* sp., and negative relationships with total hardness, magnesium, TDS, dragonfly nymph (*Libellula* sp.), and *Bellamya dissimilis*.

Pearson's correlation

Pearson's correlation was assessed using IBM SPSS (version 21) in order to explore relationships among water quality parameters and macroinvertebrate metrics (Table 7). All correlations reported were highly significant (p<0.01). In our analysis, sulfate exhibited a perfect positive correlation with electrical conductivity (r = 1.000).

Chloride exhibited a strong positive association with sulfate (r= 0.999), electrical conductivity (EC) (r= 0.999), and total dissolved solids (TDS) (r= 0.996). Similarly, EC correlated positively with TDS (r= 0.992), while calcium showed a perfect positive relationship with TDS (r = 1.000). Sodium displayed significant positive correlations with both chloride (r= 0.999) and calcium (r= 0.999). Nitrate, in contrast, was negatively associated with several parameters, including TDS (r= -1.000), EC (r = -0.992), sulfate (r= -0.992), temperature (r= -0.956), calcium (r= -1.000), and chloride (r= -0.996).

Among the biological variables, water temperature had a perfect positive correlation with the abundance of *Tubifex* sp. and *Limnophora* sp. (r= 1.000). Turbidity showed strong positive correlations with *Limnodrilus* sp., *Barytelphusa* sp., *Alitropus typus*, *Laccophilus* sp., and *Notonecta* sp. (r= 0.999), whereas it was negatively correlated with dragonfly nymphs (*Libellula* sp.), *Bellamya dissimilis* and *Lymnaea* sp. (r= -0.999). Furthermore, *Chironomus* sp. abundance was positively related to damselfly nymphs (r= 0.994), while *Lymnaea* sp. showed a strong negative correlation with *Notonecta* sp. (r= -1.000).

Table 7. Correlation coefficients of Malaprabha river water parameters at Munavalli

#	Relationships	r	Significance
01	Sulfate in relation to EC	1.000	p<0.01
02	Chloride in relation to Sulfate	0.999	
03	Chloride in relation to EC	0.999	
04	Chloride in relation to TDS	0.996	
05	Electrical Conductivity (EC) in relation to TDS	0.992	
06	Cacium in relation to TDS	1.000	
07	Sodium (Na) in relation to Chloride	0.999	
08	Sodium (Na) in relation to Calcium	0.999	
09	Nitrate in relation to Total Dissolved Solids(TDS)	-1.000	
10	Nitrate in relation to Electrical Conductivity (EC)	-0.992	
11	Nitrate in relation to Sulfate	-0.992	
12	Nitrate in relation to Temperature	-0.956	
13	Nitrate in relation to Calcium	-1.000	
14	Nitrate in relation to Chloride	-0.996	
15	Temp. in relation to *Tubifex* sp./*Limnophora* sp.	1.000	
16	Turbidity in relation to *Limnodrillus* sp./ *Barytelphusa* sp.,/ *Alitropus typus*,/ *Laccophilus* sp.,/ *Notonecta* sp.	0.999	
17	Turbidity in relation to Dragonfly nymph (*Libellula* sp.)/ *Bellamya dissimilis* / *Lymnaea* sp.	-0.999	
18	*Chironomous* sp. in relation to Damselfly nymph sp.	0.994	
19	*Lymnaea* sp. in relation to *Notonecta* sp.	-1.000	

DISCUSSION

The present investigation recorded macroinvertebrates belonging to Clitellata, Malacostraca, Arachnida, Insecta, Gastropoda, and Bivalvia. Within the arthropod group, insects constituted the dominant taxa in the study region. Among them, Chironomus larvae, a recognized pollution indicator, were most abundant during winter, with reduced numbers in the monsoon and summer seasons. Their occurrence reflects elevated organic enrichment of the water, largely due to human-induced activities. Chironomids are well-documented for their tolerance to pollution (Milbrink, 1980) and association with organically enriched habitats (Kaushik *et al.,* 1991; Pandit, 1992). The peak abundance of *Chironomus* during winter may be explained by reduced river discharge and slower water flow, conditions favorable for their proliferation, as also suggested by Sunder and Subla (1986), Paoletti *et al.* (1980), and Dutta and Malhotra (1986). The consistent presence of chironomids throughout the year highlights the nutrient-rich and polluted status of the river ecosystem, a trend corroborated by earlier studies (Callisto *et al.,* 2005; Clemente *et al.,* 2005; Olomokoro and Ezemonye, 2006; Manoharan *et al.,* 2006).

Annelids showed their dominance during monsoon followed by summer in the present study. No annelids were observed during the winter season. This absence may be due to the extended breeding period of some tubificid species, whose cocoons are primarily produced during late winter and early spring, potentially leading to a temporary decline in the adult population during colder months (Lazim and Learner, 1986).

Within the annelid community, *Tubifex* sp. (Class: Clitellata, Subclass: Oligochaeta), a recognized indicator of pollution, was observed exclusively during the summer season when water temperature reached its peak (37°C). Hawkes (1979) highlighted that oligochaetes, particularly *Tubifex*, thrive in habitats with intense sewage contamination and oxygen-depleted conditions. In the present investigation, annelid density was greatest during the monsoon, a pattern likely linked to the abundance of organic detritus. Similar associations between organic matter and oligochaete populations have been documented by Takeda (1999), Nocentini *et al.* (2001), Callisto *et al.* (2005), Chakraborty and Das (2006), Manoharan (2006), and Gasim *et al.* (2006).

Another pollution indicator, *Limnodrilus* sp., was encountered only during the monsoon season. Aston (1973) and Marshal (1978) suggested that the occurrence of this taxon is typically associated with enhanced eutrophication or higher organic sedimentation rates.

In the case of molluscs, their dominance was most pronounced in summer, followed by monsoon and winter. A positive correlation was observed between molluscan abundance and water temperature, suggesting that elevated temperatures within the studied range supported their growth. Similar temperature-related patterns have been reported by Michael (1968), Dutta and Malhotra (1986), and Malhotra *et al.* (1966). The increased molluscan density in summer may be explained by two ecological processes: (1) the peak abundance of decomposers and macrophytes at the substrate level, and (2) the acceleration of decomposition driven by enhanced microbial activity at higher temperatures. Comparable findings were noted by Bath *et al.* (1999).

The richness of molluscs observed during the study appears to be influenced by the alkaline nature of water, elevated calcium levels, and the presence of macrophytes that provide both food and habitat. Tonapi (1980) and Pennak (1989) reported similar relationships.

Statistically, molluscan abundance showed strong positive correlations with EC, sulfate, chloride, calcium, and sodium, while temperature, BOD, TDS, and total hardness exhibited moderate positive correlations. Garg *et al.* (2009) also documented a positive association between molluscs and total hardness in Ramsagar Reservoir (M.P.), while Dutta and Malhotra (1986) reported molluscan predominance in Jammu, linked to high calcium concentrations. *Lymnaea* sp., another indicator species, was present in the study area but in low abundance, suggesting mild pollution effects, largely influenced by anthropogenic activities along river margins a trend previously reported by Das *et al.* (1978).

CONCLUSION

The detection of recognized pollution-indicating taxa, including *Tubifex tubifex*, *Limnodrilus* sp. (Annelida), *Chironomus* sp. (Arthropoda), and *Lymnaea* sp. (Mollusca), within the study area reflects a gradual shift of the river ecosystem from relatively clean to polluted conditions.

Although these taxa were not highly abundant and did not occur at every sampling location, their occurrence points to the presence of mild contamination, mainly linked to human activities along the river margins. Insects emerged as the most dominant group across all sites, underscoring their tolerance and ecological flexibility in environments affected by organic pollution. Evaluating the macroinvertebrate assemblages therefore provides critical insights into the ecological status of the river and represents an effective approach for biomonitoring and restoration planning.

The decline in water quality is largely driven by the release of industrial waste, domestic sewage, and runoff from agricultural land, along with other human-induced factors. These pollutants threaten aquatic habitats and lead to a decline in biodiversity of macroinvertebrate, posing a serious risk to the river's ecological integrity. Without effective intervention, such pollution may intensify, further harming aquatic organisms and upsetting the ecological balance.

Therefore, enhancing public understanding of water conservation and ecosystem protection is crucial. Strict enforcement of environmental regulations aimed at reducing pollutant discharge is needed to halt further degradation. Sustainable river management practices, supported by community involvement, are key to safeguarding the Malaprabha River's ecological health for the future. The governance has already been taking measures to control river pollution but people and beneficiaries henceforth should also take measures to reduce dumping of waste into river ecosystem.

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