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Community Dynamics and Population Structure of Macro-Zoobenthos: An Evaluation of the Ecological Health of the Snow-Fed Kali River of Uttarakhand, India

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Authors' contributions

This work was carried out in collaboration between both authors. Author LU Data collection, data analysis, original draft of the manuscript. Author RV Supervision, review and editing of the study. Both authors read and approved the final manuscript.

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ABSTRACT

Macro-zoobenthos are aquatic benthic invertebrates that inhabit freshwater ecosystems and act as bioindicators of ecosystem health. This study evaluates the ecological health of the snow-fed Kali River system of Uttarakhand, India, by examining macrozoobenthos taxonomy, diversity, and ecological dynamics. Monthly samples were collected on a yearly basis from three ecologically distinct sites along the river, using stratified sampling methods. Standard methods were used for

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benthos collection, identification, classification, species diversity, and alpha-beta diversity indices. Taxonomic identification and diversity index analysis revealed 79 genera and 2,458 individuals from three major phyla: Arthropoda (52 families, 76 species), Annelida (1 family, 1 species), and Mollusca (2 families, 2 species). Diversity indices, including Simpson (0.69-0.79), are highest in July and lowest in December. Shannon Wiener (H') index values (1.37 to 1.74) peaked in June and dipped in January. The evenness index (0.66 to 0.80) was highest in July and lowest in December. Margalef Index (0.91 to 1.54) peaked in August and was lowest in January. Equitability index values (0.73 to 0.89) were highest in July and lowest in September. Whittaker's beta diversity analysis yielded a value of 0.4433, signifying substantial dissimilarity in community composition. These findings highlight macrozoobenthos as vital bioindicators, offering key data for river management and biodiversity. They also highlight the need for long-term monitoring and physicochemical integration.

Keywords: Benthos; taxonomy; diversity index; classification; species diversity.

1. INTRODUCTION

Macrozoobenthos, or benthic macroinvertebrates, are a diverse group of organisms that inhabit the bottom substrates of freshwater ecosystems (Mishra, et al., 2024). They include insects, crustaceans, mollusks, and annelids, which play pivotal roles in maintaining ecosystem functioning (Beena, et al., 2020). River ecosystems, in particular, provide crucial habitats for these organisms, contributing to the overall biodiversity and ecological stability of aquatic environments (Jacobson, et al., 2003). Benthic macroinvertebrates are integral to nutrient cycling and serve as a food source for higher trophic levels (Ward & Tockner, 2001). Additionally, they act as bioindicators of environmental health, reflecting the quality of their habitats and the impact of human activities on aquatic ecosystems (Sharma & Rawat, 2009). Their ecological importance highlights the need to understand their roles within river ecosystems comprehensively (Malik, et al., 2020).

Classification of macrozoobenthos involves categorizing these organisms based on their taxonomic groups, such as phyla, classes, orders, families, and species (Beena, et al.,2019). Each taxonomic group possesses unique characteristics and ecological roles, contributing to the overall diversity and functioning of the ecosystem (Sharma, et al., 2008). The diversity of macrozoobenthos is influenced by various factors, including habitat type, water quality, substrate composition, and geographical location (Sudaryanto, 2001). High biodiversity of macrozoobenthos is often associated with healthy and stable aquatic ecosystems, while alterations in environmental conditions can lead to shifts in species composition and abundance (Savenije, 2012).

While previous studies have explored the diversity of macrozoobenthos in various freshwater ecosystems, research focusing specifically on the River Kali is limited. Studies in similar river systems have highlighted the ecological importance of macrozoobenthos and their responsiveness to environmental changes, particularly pollution and habitat degradation. These findings underscore the critical role of macrozoobenthos in monitoring ecosystem health and guiding conservation efforts (Dar, et al., 2010). Despite this, little is known about the taxonomy and diversity of macrozoobenthic species in the River Kali, leaving a significant knowledge gap regarding their composition and distribution in this ecologically significant waterway.

To address this gap, the present study focuses on examining the taxonomy and diversity of macrozoobenthos in selected sites of the River Kali. The study has two primary objectives: first, to identify and classify the macrozoobenthic species present in the region, and second, to estimate the diversity and abundance of these species. Given their susceptibility to environmental changes and pollutants, macrozoobenthos serve as valuable bioindicators, and understanding their diversity can support future conservation efforts. This research aims to provide critical baseline data for assessing ecosystem health, understanding the impacts of environmental stressors, and developing effective management strategies for the River Kali.

2. MATERIALS AND METHODS

2.1 Study Area and Site Selection

This study was conducted on the snow-fed Kali River, originating from the Kalapani area in the

Vyas Valley of Pithoragarh district, Uttarakhand, within the Kumaun Himalaya region (Fig.1). To examine macrozoobenthic diversity, three sampling sites were selected based on variations in altitude, habitat characteristics, and accessibility, Pipli (S1), Jauljibi (S2) and Dharchula (S3) (Table 1). These sites reflect ecological gradients along the river, with S2 and S3 situated at a lower altitude featuring mixed substrates and warmer waters, while S1 represent higher-altitude, colder regions with rocky substrates. This stratified site selection captures spatial and environmental variations essential for understanding benthic diversity.

Table 1. Location of study area selected for sample collection

River	Sampling site	Latitude	Longitude	Altitude
Kali river	Pipli	29°42'16"N	80°21'09"E	1200m
	Jauljibi	29°70'07"N	80°37'64"E	600m
	Dharchula	29°71'23"N	80°37'19"E	915m

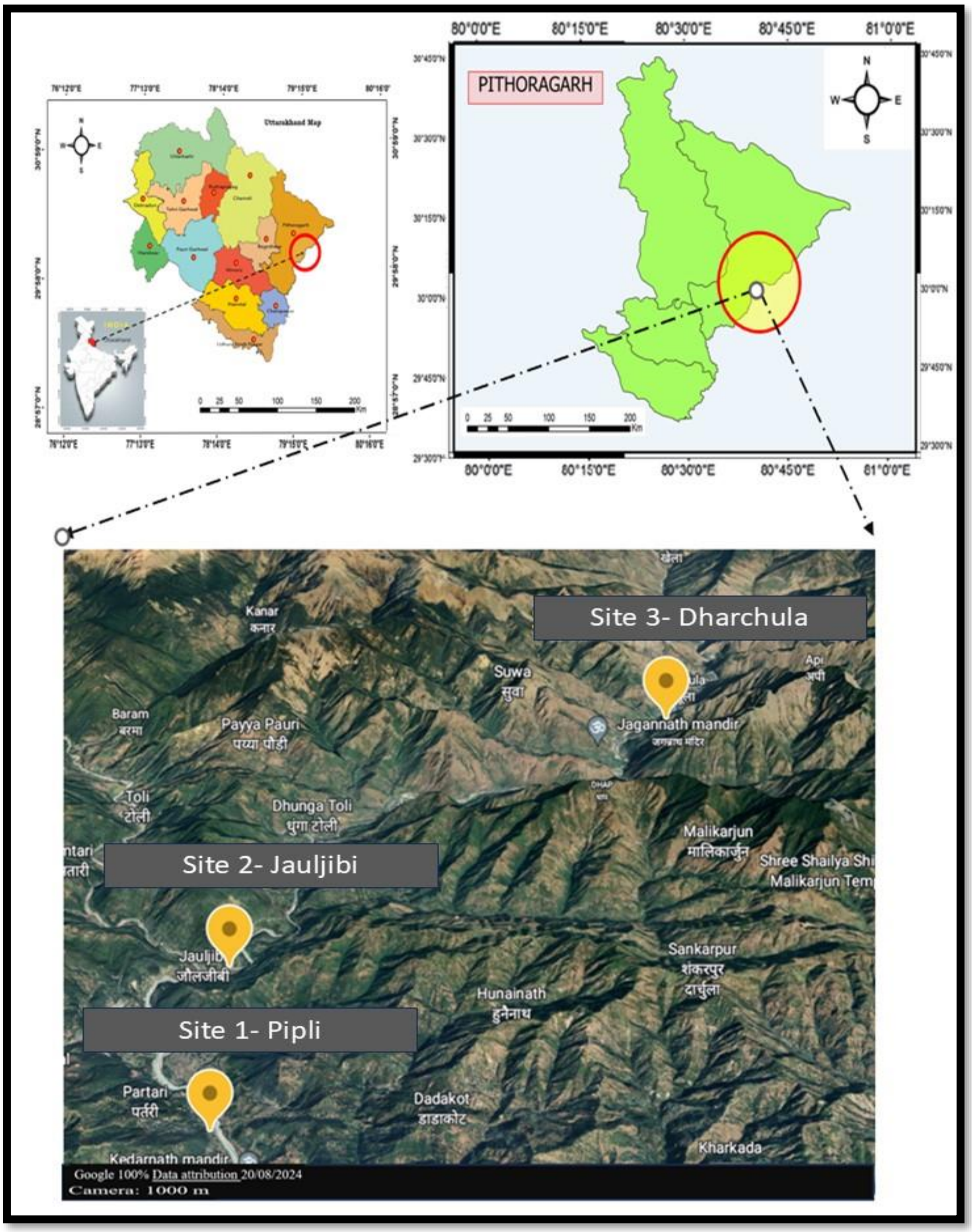


Fig.1. Map of sampling site

2.2 Macroinvertebrate Sampling, Collection, and Identification

For the estimation of benthic diversity, samples of macrozoobenthos were collected using a square-frame Surber Sampler, as described by Loke, et al., (2010). The sampler was placed on the riverbed to capture benthic organisms within the defined area, and collected specimens were preserved in glass tubes with 5% formalin for further laboratory analysis, following the methodology outlined by Soliman (2001). In the laboratory, the preserved macroinvertebrates were carefully sorted and identified. Using petri dishes, sorting needles, and fine forceps, the macro-benthic fauna were separated and distinguished. Identification was performed using region-specific taxonomic keys and online resources such as macroinvertebrates.org (2017), based on the methodology of Bouchard (2010) and Oscoz and Galicia (2011). The taxonomic classification process focused on morphological traits, including jointed legs, wings or wing pads, cases, shells, segmented bodies, antennae, tails, hooks, lateral filaments, branched gills, and mouthparts. These character were based on the key features identified by Diaz et al., (2004) and Althaus et al., (2015).

2.3 Data Analysis

To evaluate the diversity and distribution of macrozoobenthos across the sampling sites, all identified and classified specimens were photographed. Species diversity was assessed using alpha diversity indices, including Dominance_D (Odum, 1971), Simpson_1-D (Simpson, 1949), Shannon_H (Shannon & Weaver, 1949), Evenness_e^H/S (Pielou, 1966), Brillouin (Brillouin, 1956), Menhinick (Menhinick, 1964), Margalef (Margalef, 1967), Fisher_alpha (Fisher, 1943), and Berger-Parker (Berger & Parker, 1970). Beta diversity, which quantifies variation in species composition between communities, was calculated following Whittaker (1972). Statistical analyses of both alpha and beta diversity indices were conducted using PAST software (Hammer, 2008) and Microsoft Office Excel 2019 to ensure accurate computation and visualization of results.

3. RESULTS

The research was centered on exploring the taxonomy and diversity of macro-invertebrates inhabiting the Kali River. The taxonomic investigation involved collecting, identifying, and classifying macrozoobenthos. To assess the diversity of macrozoobenthos, both alpha and beta diversity indexes were computed.

3.1 Macroinvertebrate Composition and Abundance

A total of 2,458 macrozoobenthic specimens were collected from the Kali River and classified into three main phyla: Arthropoda, Annelida, and Mollusca (Table 2). Taxonomic identification utilized distinctive morphological traits to construct identification keys. The study focused on the classification and diversity indices of macro-invertebrates in the Kali River, A total of 2458 invertebrate specimens were collected and categorized into three main phyla: Arthropoda, Annelida, and Mollusca is given in Table 2. Taxonomic keys were constructed using distinctive characteristics present in organisms to help identify and classify them. The order Coleoptera is identified by its elongated body with exposed legs, flat disk or oval shape, comprises 4 families, 5 species and 141 individuals. Diptera, is marked by suckers, hardened head, worm-like body, and prolegs and this order includes 6 families, 8 species and 269 individuals. Ephemeroptera has hair-like tail filaments and abdominal feathery gills with a presence in 14 families, 25 species, and a population of 935 individuals. Lepidoptera exhibits soft abdomen, caterpillar-like legs, and variable textures is represented by a single family, a single species, and a total of 22 individuals (Fig. 2).

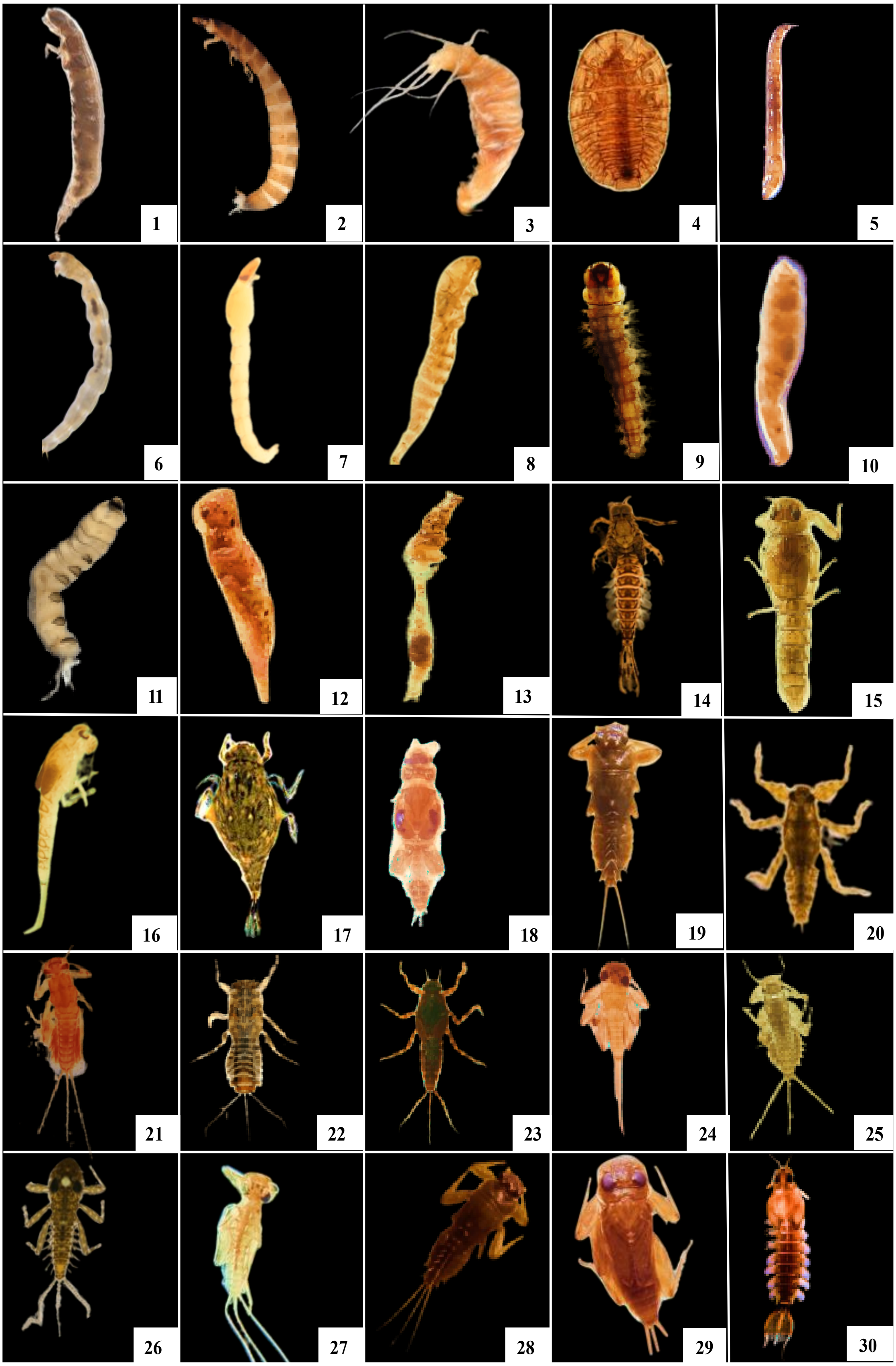
Odonata presents broad paddle-shaped tails, no abdominal gills, wide abdomen, is distributed across three families, with three species and a population of 114 individuals. Plecoptera showcases hair-like tail filaments without attached abdomen gills and is present in 16 families, with 9 species and 302 individuals. Trichoptera features forked hooks and tail-like structures, encompassing five families, 25 species, and a population of 606 individuals. Order clitella has flattened segmented body, suction disks, and potential eyespots and order Basommatophora features a soft body, no legs, operculum absent and single shell, each order belongs to single family, single species each, with 32 individuals in the Hirudinea order and 37 individuals in the Basommatophora order (Fig. 3).

Table 2. Enumeration of benthic organism categorization up to the level of genus

Phylum	Class	Order	Family	Genus	Species name	Common name
Arthropoda	Insecta	Coleoptera	Elmidae	*Dubiraphia*	*bivittata*	Riffle beetle larvae
				Stenelmis	*canaliculata*	Riffle beetle larvae
			Hydrophilidae	*Berosus*	*affinis*	Water scavenger beetle larvae
			Psephenidae	*Psephenus*	*herricki*	Weter pennies
			Ptilodactylidae	*Anchytarsus*	*folliculipalpus*	Toe winged beetle larvae
		Diptera	Chironomidae	*Chironomus*	*crassicaudatus*	Midges
				Diamesa	*mendotae*	Midges
				Orthocladius	*dentifer*	Non-biting midges
			Culicidae	*Aedes*	*aegypti*	Mosquitoes
			Ephydridae	*Ephydridae*	*griseola*	Shore flies
			Limoniidae	*Antocha*	*obtusa*	Linoniid crane flies
			Muscidae	*Musca*	*aethiops*	House flies
			Simuliidae	*Simulium*	*damnosum*	Black flies
		Ephemeroptera	Ameletidae	*Ameletus*	*cryptostimulus*	Comb mouthed minnow mayflies
			Baetidae	*Baetis*	*acuminatus*	Small minnow mayflies
				Heterocloeon	*curiosum*	Small minnow mayflies
			Baetiscidae	*Baetisca*	*berneri*	Armored mayflies
			Caenidae	*Caenis*	*horaria*	Small square-gilled mayflies
			Ephemerellidae	*Attenella*	*delantala*	Spiny crawler mayfly
			Ephemerellidae	*Drunrlla*	*cornutella*	Spiny crawler mayflies
				Ephemerella	*subvaria*	Spiny crawler mayflies
				Eurylophella	*karelica*	Spiny crawler mayflies
				Serratella	*serrata*	Spiny crawler mayflies
			Heptageniidae	*Epeorus*	*assimilis*	Cookie headed mayflies
				Heptagenia	*flavata*	Flat headed or cookie- headed mayflies
				Leucrocuta	*aphrodite*	Flat headed mayflies
				Maccaffertium	*lenati*	Flat-headed mayflies
				Rhithrogena	*germanica*	Flat headed mayflies
				Stenacron	*interpunctatum*	Flat headed mayflies
			Isonychiidae	*Isonychia*	*campestris*	Brush legged mayflies

		Leptohyphidae	*Tricorythodes*	*curvatus*	Little stout crawler mayflies
		Leptophlebiidae	*Habrophlebia*	*tenella*	Prong gilled mayflies
			Leptophlebia	*marginata*	Prong gilled mayflies
			Neoleptophlebia	*heteronea*	Prong gilled mayflies
		Metretopodidae	*Siphloplecton*	*basalis*	Cleft footed minnow mayflies
		Polymitarcyidae	*Ephoron*	*punensis*	Pale burrower mayflies
		Potamanthidae	*Anthopotamus*	*neglectus*	Hackle gills
		Siphlonuridae	*Siphlonurus*	*occidentalis*	Primitive minnow mayflies
	Lepidoptera	Crambidae	*Paraponyx*	*stratiotata*	Snout Moths
	Odonata	Aeshnidae	*Boyeria*	*irene*	Darners
		Cordulegastridae	*Cordulegaster*	*boltonii*	Biddies
		Libellulidae	*Libellula*	*saturata*	Skimmers
	Plecoptera	Capniidae	*Allocapnia*	*granulata*	Small winter stoneflies
		Leuctridae	*Leuctra*	*fusca*	Rolled winged stoneflies
		Peltoperlidae	*Tallaperla*	*cornelia*	Roach like stoneflies
		Perlidae	*Acroneuria*	*abnormis*	Common stoneflies
			Agnetina	*capitata*	Common stoneflies
			Neoperla	*leptophallus*	Common stoneflies
			Paragnetina	*indentata*	Common stoneflies
			Perlesta	*decipiens*	Common stoneflies
		Perlodidae	*Isoperla*	*bosnica*	Yellow Srones
	Trichoptera	Apataniidae	*Apatania*	*carpathica*	Mountain casemaker caddisflies
		Brachycentridae	*Micrasema*	*bactro*	Humpless casemaker caddisflies
			Brachycentrus	*cinerea*	Humpless casemaker caddisflies
		Calamoceratidae	*Heteroplectron*	*californicum*	Comb-lipped casemaker caddisflies
		Dipseudopsidae	*Phylocentropus*	*ligulatus*	Pitot-tube caddisflies
		Helicopsychidae	*Helicopsyche*	*borealis*	Snail casemaker caddisflies
		Hydropsychidae	*Arctopsyche*	*ladogensis*	Seine-net weaver caddisflies
			Cheumatopsyche	*falcifera*	Seine-net weaver caddisflies
			Diplectrona	*bulla*	Seine-net weaver caddisflies
			Hydropsyche	*siltalai*	Seine-net weaver caddisflies
			Macrostemum	*zebratum*	Seine-net weaver caddisflies
		Leptoceridae	*Ceraclea*	*dissimilis*	Long-horned caddisflies

				Oecetis	*intima*	Long-horned caddisflies
				Triaenodes	*lurideolus*	Long horned caddisflies
			Lepidostomatidae	*Lepidostoma*	*canthum*	Scaly-mouth caddisflies
			Limnephilidae	*Ironoquia*	*plattensis*	Northern casemaker caddisflies
			Molannidae	*Molanna*	*angustata*	Hooded casemaker caddisflies
			Philopotamidae	*Chimarra*	*lavensis*	Finger net caddisflies
				Dolophilodes	*distinctus*	Finger net caddisflies
			Polycentropodidae	*Nyctiophylax*	*adaequatus*	Trumpet net
				Neureclipsis	*bimaculata*	Trumpet-net
			Psychomyiidae	*Psychomyia*	*aigina*	Net tube caddisflies
			Rhyacophilidae	*Rhyacophila*	*lobifera*	Green caddisflies
			Sericostomatidae	*Agarodes*	*tuskaloosa*	Bush- tailed caddisflies
			Thremmatidae	*Neophylax*	*splendens*	Little northeastern casemakers
Annelida	Clitellata	Gnathobdellida	Hirudinea	*Hirudinaria*	*manillensis*	Indian cattle leech
Mollusca	Gastropoda	Basommatophora	Physidae	*Physa*	*fontinalis*	Bladder snails
			Planorbidae	*Helisoma*	*anceps*	Ramshorn Snails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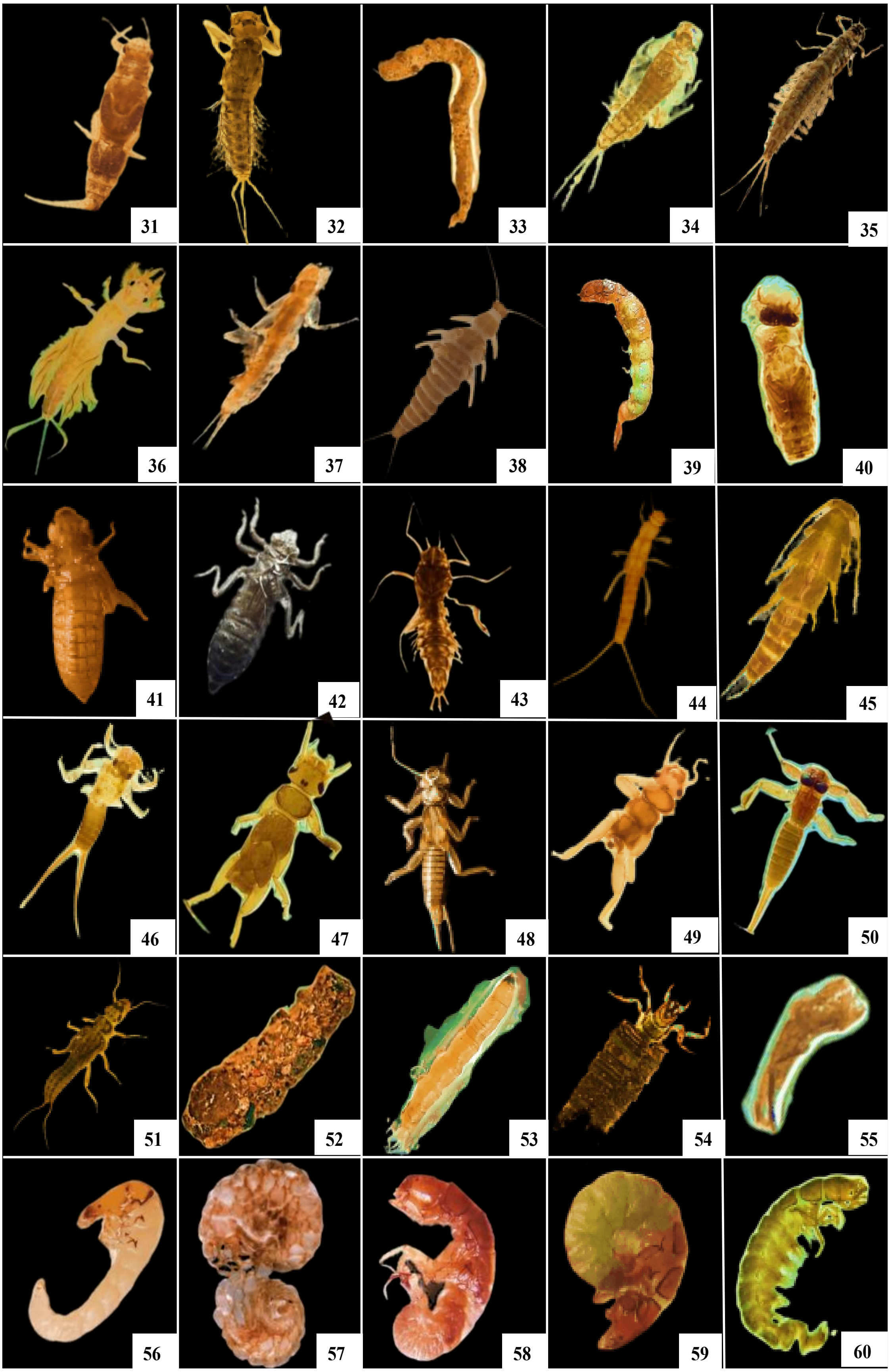
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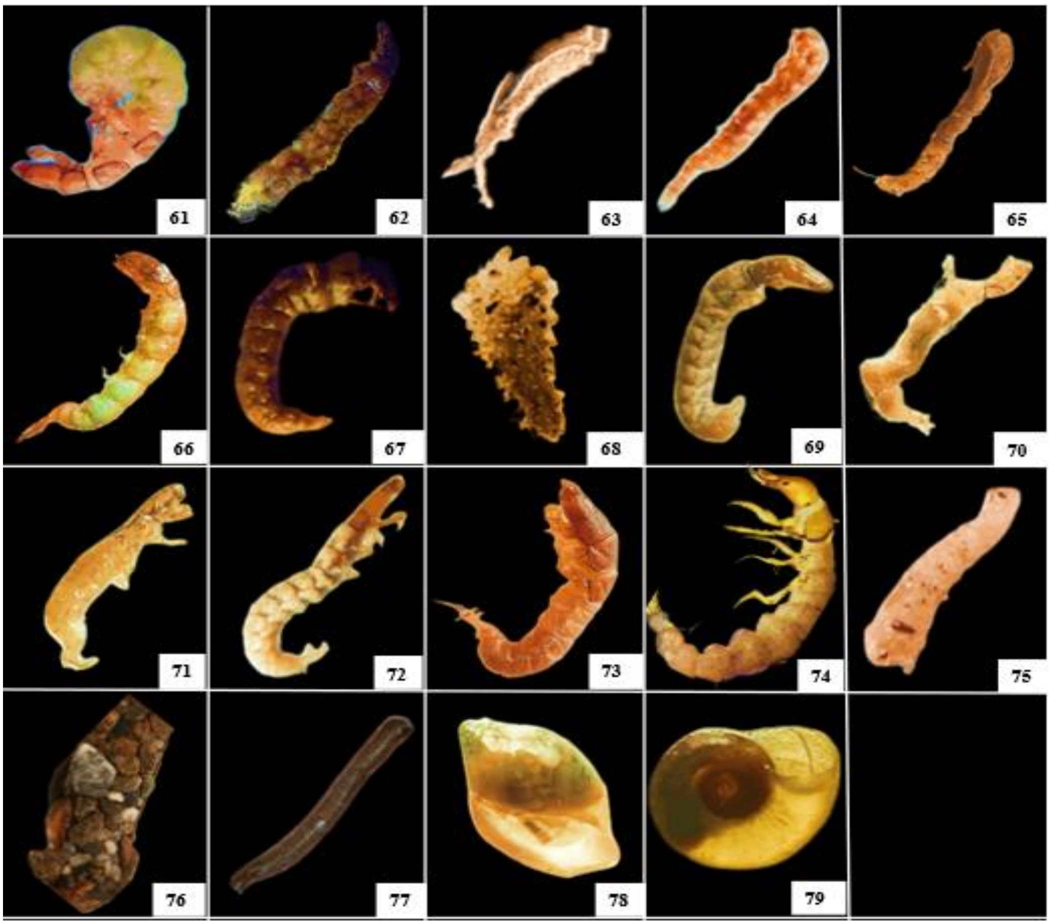
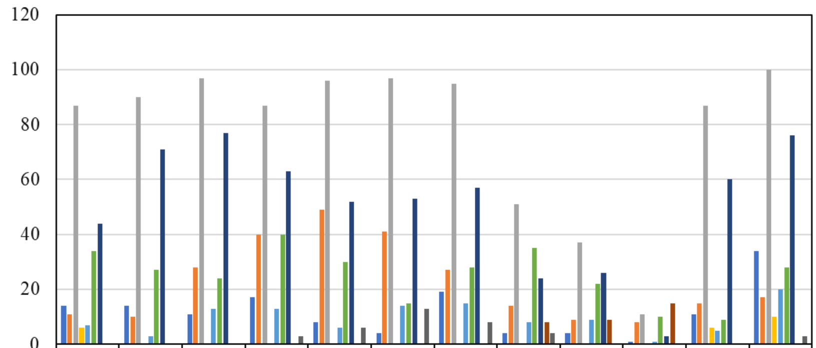


Fig. 2. Photographs of macroinvertebrates collected from the Kali River



	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct
Coleoptera	14	14	11	17	8	4	19	4	4	1	11	34
Diptera	11	10	28	40	49	41	27	14	9	8	15	17
Ephemeroptera	87	90	97	87	96	97	95	51	37	11	87	100
Lepidoptera	6	0	0	0	0	0	0	0	0	0	6	10
Odonata	7	3	13	13	6	14	15	8	9	1	5	20
Plecoptera	34	27	24	40	30	15	28	35	22	10	9	28
Trichoptera	44	71	77	63	52	53	57	24	26	3	60	76
Gnathobdellida	0	0	0	0	0	0	0	8	9	15	0	0
Basommatophora	0	0	0	3	6	13	8	4	0	0	0	3

Fig. 3. Graph showing total abundance of macroinvertebrates(order) found in Kali River

Table 3. Tabular representation presenting the Alpha diversity indices of macroinvertebrates computed using the PAST statistical software

Month	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct
Individuals	203	215	250	263	247	237	249	148	116	49	193	288
Dominance_D	0.27	0.31	0.27	0.22	0.25	0.26	0.23	0.22	0.21	0.22	0.31	0.22
Simpson_1-D	0.73	0.69	0.73	0.78	0.75	0.74	0.77	0.78	0.79	0.78	0.70	0.78
Shannon_H	1.56	1.37	1.49	1.66	1.56	1.57	1.67	1.74	1.73	1.65	1.43	1.71
Evenness_e^H/S	0.68	0.66	0.74	0.75	0.68	0.69	0.76	0.71	0.80	0.74	0.59	0.69
Brillouin	1.49	1.32	1.44	1.61	1.51	1.52	1.61	1.64	1.62	1.46	1.37	1.66
Menhinick	0.49	0.41	0.38	0.43	0.45	0.45	0.44	0.66	0.65	1	0.5	0.47
Margalef	1.13	0.93	0.91	1.08	1.09	1.1	1.09	1.4	1.26	1.54	1.14	1.24
Fisher_alpha	1.41	1.15	1.11	1.32	1.34	1.35	1.34	1.81	1.64	2.24	1.42	1.53
Berger-Parker	0.43	0.42	0.39	0.33	0.39	0.41	0.38	0.34	0.32	0.31	0.45	0.35

Table 4. Whittaker beta diversity pair wise comparison matrices between different sites

	Pipli (S1)	Pipli (S2)	Jauljibi (S1)	Jauljibi (S2)	Dharchula (S1)	Dharchula (S2)
Pipli (S1)	0	0.16279	0.16667	0.22951	0.44	0.13821
Pipli (S2)	0.16279	0	0.14074	0.232	0.35922	0.15873
Jauljibi (S1)	0.16667	0.14074	0	0.14063	0.35849	0.17829
Jauljibi (S2)	0.22951	0.232	0.14063	0	0.41667	0.27731
Dharchula (S1)	0.44	0.35922	0.35849	0.41667	0	0.4433
Dharchula (S2)	0.13821	0.15873	0.17829	0.27731	0.4433	0

3.2 Macroinvertebrate diversity indices

In the present study, various diversity indices were calculated to assess the macrobenthos diversity. The Simpson diversity index values ranged from 0.69 to 0.79, with the highest diversity observed in July and the lowest in December. The Shannon Wiener (H') index values for benthic fauna ranged from 1.37 to 1.74, reaching its maximum in June and its minimum in January (Table 3). Additionally, the evenness index values of benthos ranged between 0.66 and 0.80. The peak evenness was observed in July, while the lowest was recorded in December. Furthermore, the Margalef Index of macroinvertebrates species Richness ranged from 0.91 to 1.54, peaking in August and reaching its lowest in January. Lastly, the Equitability index (J) values of benthic fauna in the study ranged from 0.73 to 0.89, with the highest equitability observed in July and the lowest in September. These diversity indices provide valuable insights into the temporal variation and distribution patterns of macrobenthos in the study area throughout the year.

Whittaker's beta diversity analysis involved pairwise comparisons between different habitats to evaluate variations in community composition. The results revealed that the most closely resembling communities were observed in the comparison between Dharchula (S2) and Pipli (S1), with the smallest Whittaker's index value recorded at 0.13821. On the other hand, the highest level of dissimilarity in community composition, as indicated by the maximum Whittaker's beta diversity value of 0.4433, was evident between Dharchula (S1) and Dharchula (S2). This outcome is consistent with the survey results, where the benthic species in this spot displayed the most notable dissimilarity compared to all other comparisons (Table 4).

4. DISCUSSION

This study investigates the diversity, composition, and ecological patterns of macrozoobenthos in the Kali River, focusing on their temporal and spatial distribution across three sampling sites. A total of 79 genera are identified, representing a diverse array of benthic macroinvertebrates. The proportional representation of various taxonomic groups reveals dominance by Ephemeroptera and Trichoptera, each contributing 25 species, followed by Plecoptera (9 species) and Diptera (8 species). These results highlight the ecological significance of these groups in aquatic systems and align with findings from other studies in similar riverine ecosystems. For example, Mishra et al., (2024), Azrina et al., (2006) and Feldman, (2006) documented benthic macroinvertebrate assemblages in a plateau river of Bundelkhand, showcasing comparable diversity patterns, while Sharma et al., (2023), Kumar and Vyas (2014) and Hossain et al., (2009) emphasized the taxonomic diversity of macroinvertebrates in himalayan river systems. Similarly, Lei et al., (2017), Noman et al., (2019) and Rice et al., (2012) highlighted the role of environmental parameters, such as temperature and salinity, in shaping the distribution of benthic communities.

The temporal variability in diversity indices, such as Simpson, Shannon-Wiener, and Margalef species richness, underscores the dynamic nature of benthic communities. The Shannon-Wiener index values range from 1.37 in January to 1.74 in June, suggesting higher diversity during pre-monsoon and monsoon seasons. This seasonal variation is consistent with studies by Malik et al., (2020), Sarang and Sharma (2009) and Rosa et al., (2014) who reported similar trends in the River Ganga and its tributaries, and Panwar and Malik (2016), who highlighted seasonal biodiversity fluctuations in Bhimtal Lake. Enhanced nutrient availability and favourable habitat conditions during the monsoon, as observed by Chowdhary and Sharma (2013), Sharma et al., (2004) and Basu et al., (2018), further explain the peak diversity. Similarly, the evenness index ranges from 0.59 to 0.80, indicating a relatively balanced distribution of individuals among species during peak biodiversity periods, a trend also noted by Mahmoud et al., (2018) and Ysebaert and Herman (2002) in their ecological assessment of the River Nile.

The Whittaker beta diversity analysis reveals variations in species composition between sampling sites, with the smallest dissimilarity (0.13821) observed between Dharchula (S2) and Pipli (S1) and the highest dissimilarity (0.4433) between Dharchula (S1) and Dharchula (S2). This finding suggests that habitat variability and local environmental conditions play a significant role in shaping benthic communities, similar to the conclusions drawn by Sharma et al., (2023) in the Bhagirathi and Yamuna Rivers. The role of environmental gradients in driving species distribution patterns has also been emphasized by Lei et al., (2017) and Mahmoud et al., (2018). The observed diversity indices indicate that the Kali River maintains a moderately healthy ecological status, particularly during pre-monsoon and monsoon seasons when diversity values are highest. The presence of pollution-sensitive groups such as Ephemeroptera and Trichoptera further supports this observation, aligning with findings from Sharma et al., (2023) and Malik et al., (2020). However, the decline in diversity indices during winter months suggests seasonal stressors, potentially linked to lower temperatures, reduced flow, and habitat contraction, as also reported by Mishra et al., (2024) and Matin et al., (2018) in similar ecosystems.

These findings have important implications for understanding and managing the ecological health of the Kali River. The observed patterns of diversity and community composition highlight the river's capacity to support a wide range of macrozoobenthic taxa, which are critical for nutrient cycling and serving as a food source for higher trophic levels. The sensitivity of certain taxa to environmental changes underscores the importance of monitoring macrozoobenthos as bioindicators of ecosystem health. This study contributes to the growing body of knowledge on the biodiversity of Himalayan river ecosystems and provides a valuable baseline for future research. Maintaining the ecological integrity of the Kali River requires targeted conservation strategies to address potential stressors such as pollution, habitat degradation, and climate change. Further studies integrating physicochemical parameters, habitat assessments, and long-term monitoring of macrozoobenthos will provide a more comprehensive understanding of the river's ecological dynamics and resilience.

5. CONCLUSION

The current study provides a comprehensive understanding of the taxonomy and classification of macrobenthos, coupled with an exploration of various biodiversity indices. Throughout the study, the Kali River exhibits rich biodiversity among aquatic insects, prominently featuring established groups such as Coleoptera, Diptera, Ephemeroptera, and Trichoptera. Conversely, certain other orders like Odonata, Plecoptera, Basommatophora, Gnathobdellida, and Lepidoptera show lower levels of diversity among macroinvertebrates in this ecosystem. The consistent presence of a rich diversity of macroinvertebrates throughout the study period signifies a healthy benthic condition, which serves as a primary food source for fish. This observation underscores the overall good health of the river ecosystem. High value of alpha diversity indicates a high species diversity, healthy and stable ecosystem. Additionally, elevated Whittaker's beta diversity indicates substantial dissimilarity in community composition.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The author(s) hereby declare that generative AI technologies such as Large Language Models (e.g., ChatGPT) have been used during the writing or editing of this manuscript.

Details of the AI usage are given below:

1. **Grammar and Language Refinement:** ChatGPT-4 (OpenAI, Version: GPT-4.0, Source: OpenAI API) was used to refine the grammar and improve sentence structure.

2. **Brainstorming Ideas:** GPT-4 (OpenAI, Version: GPT-4.0) was consulted to suggest potential examples or frameworks for the discussion section.

3. **Summarization of Literature:** ChatGPT-4 (OpenAI) was used to summarize extensive technical documents for quick reference.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Althaus, F., Hill, N., Ferrari, R., Edwards, L., Przeslawski, R., Schönberg, C. H., & Gowlett-Holmes, K. (2015). A standardised vocabulary for identifying benthic biota and substrata from underwater imagery: the CATAMI classification scheme. *PloS one*, *10*(10), e0141039.

Azrina, M.Z.; Yap, C.K.; Ismail, A.R.; Ismail, A. and Tan, S.G. (2006). Anthropogenic impacts on the distribution and biodiversity of benthic macroinvertebrates and water quality of the Langat River, Peninsular Malaysia. *Ecotoxicology and Environmental Safety*, 64(3):337–347. DOI: 10.1016/j.ecoenv.2005.04.003

Basu, A.; Sengupta, S.; Dutta, S.; Saha, A.; Ghosh, P. and Roy, S. (2013). Studies on macrobenthic organisms in relation to water parameters at East Calcutta Wetlands. *Journal of Environmental Biology*, 34(4):733.

Beena, S. K, Sreejai. R, Athira U, Dani Benchamin, Jensy Roshan. F, Sujitha.S. (2020). Systematics of benthic fauna in achenkovil river- a segmental approach. Climate Change Impacts and Human Interventions on Biodiversity and Environment. *Daya Publishing House Astral International*. Pvt. Ltd. New Delhi.110002. ISBN. No:978-93-89719-38-3.

Beena, S. K., Sreejai. R., and Dani, B. (2019). Evaluation of some physicochemical parameters and benthic macroinvertebrates in Chaliyakkara River - Tributary of Kallada River. Proceedings of the Thirteenth All India Conference of KAAS. ISBN No. 978-93-81658-26-0. Zoology pp 1-4.

Berger, W. H., and F. L. Parker. (1970). "Diversity of Planktonic Foraminifera in Deep Sea Sediments." *Science* 168 (3937): 1345–47. DOI:10.1126/science.168.3937.1345.

Bouchard, R.W. Jr. (2010). Guide to the Aquatic Invertebrates of the Upper Midwest. Used with permission.

Brillouin, Leon. (1956). *Science and Information Theory*. New York: Academic Press.

Chowdhary S. and Sharma K.K. (2013). Evaluation of macrobenthic invertebrates in the longitudinal profile of a river (Tawi), originating from shivalik hills. Journal of Global Biosciences, 2(1): 31-39.

Dar, I.Y., Bhat, G.A., Dar, Z.A. (2010). Ecological distribution of macrozoobenthos in Hokera Wetland of J&K, India. *Journal of Toxicology and Environmental Health Sciences* 5: 63-72.

Diaz, R. J., Solan, M., & Valente, R. M. (2004). A review of approaches for classifying benthic habitats and evaluating habitat quality. *Journal of environmental management*, *73*(3), 165-181.

Feldman, D. (2006). Interpretation of New Macroinvertebrate Models by WQPB. Draft Report. Montana Department of Environmental Quality, Planning Prevention and Assistance Division, Water Quality Planning Bureau, Water Quality Standards Section.1520 E. 6th Avenue, Helena, MT 59620. 14.

Fisher, R. A., Corbet, A. S., Williams, C. B., (1943). The relation between the number of species and the number of individuals in a random sample of an animal population." *J. Anim. Ecol*., 12, 42-58.

Hammer, Ø., & Harper, D. A. (2008). *Paleontological data analysis*. John Wiley & Sons.

Hossain, M.B.; Das, N. and Sharmeen, R. (2009). Seasonal and spatial distribution of macrozoobenthos of the Meghna River estuarine bed. *International Journal of Sustainable Agriculture Technology*, 5: 11-16.

Jacobsen, D., Rostgaard, S., & Vasconez, J. J. (2003). Are macroinvertebrates in high altitude streams affected by oxygen deficiency. *Freshwater Biology*, *48*(11), 2025-2032.

Kumar A dan Vyas V. (2014). Diversity of macrozoobenthos in the selected reach of River Narmada (Central Zone), India. *International Journal of Research in Biological Sciences* 4 (3): 60-68.

Lei, Y., Li, T., Jian, Z., & Nigam, R. (2017). Taxonomy and distribution of benthic foraminifera in an intertidal zone of the Yellow Sea, PR China: Correlations with sediment temperature and salinity. *Marine Micropaleontology*, *133*, 1-20.

Loke, L. H., Clews, E., Low, E. W., Belle, C. C., Todd, P. A., Eikaas, H. S., & Ng, P. K. (2010). Methods for sampling benthic macroinvertebrates in tropical lentic systems. *Aquatic Biology*, *10*(2), 119-130.

Macroinvertebrates.org, (2017). https://www.macroinvertebrates.org/.Accessed 18 August.2023.

Mahmoud K.M.; Sayed S. M. and Habib, M.R. (2018). Ecological Assessment of the River Nile Status around Gizert El-Warrak using Phytoplankton and Macroinvertebrates Assemblages. *Egypt. J. Aquat. Biol. Fish*., 22: 13-24

Malik, D. S., Sharma, A. K., & Sharma, A. K. (2020). Current status of macrobenthic diversity and their habitat ecology in River Ganga and its tributaries, Uttarakhand. *Journal of Experimental Zoology India*, *23*(2).

Margalef, R., (1967). Some concepts relative to the organization of plankton. *Oceanogr. Mar. Biol. Ann. Rev*. 5, 257–289.

Matin, A; Hossain, M.B.; Iqbal, M.; Billah, M.M.; Asif, A.A. and Billah, M.M. (2018). Diversity and abundance of macrobenthos in a subtropical estuary, Bangladesh. Species, 19:140-150

Menhinick, E.F. (1964). A Comparison of Some Species-Individuals Diversity Indices Applied to Samples of Field Insects. Ecology, 45, 859-861.

Mishra, A. S., Pandey, C. K., & Tiwari, S. (2024). Environmental Drivers for Benthic Macroinvertebrate Assemblages and Distributional Patterns in a Plateau River of Bundelkhand Region, India: Benthic macroinvertebrate assemblages in Bundelkhand River. *International Journal of Ecology and Environmental Sciences*, *50*(3), 367-375.

Noman, MA.; Mamunur, R.; Islam, M.S. and Hossain, M.B. (2019). Spatial and seasonal distribution of intertidal macrobenthos with their biomass and functional feeding guilds in the Naf River Estuary, Bangladesh. *Journal of Oceanology and Limnology*, 37(3):1010-1023.
DOI: 10.1007/s00343-019-8063-7

Odum EP. (1971). Fundamentals of Ecology, 3rd Edition. W. B. Saunders Co. Philadelphia. London. Toronto. 574 p.

Oscoz, J., Galicia, D., & Miranda, R. (Eds.). (2011). Identification guide of freshwater macroinvertebrates of Spain. *Springer Science & Business Media*, 176.

Panwar, S., & Malik, D. S. (2016). Zooplankton diversity, species richness and their distribution pattern in Bhimtal Lake of Kumaun region, (Uttarakhand). *Hydrology Current Research*, *7*(1), 219.

Pielou, E.C., (1966). The measurement of diversity in different types of biological collections. *J. Theor. Biol*. 13, 131–144.
DOI:10.1016/ 0022-5193(66)90013-0.

Rice, E. W., Bridgewater, L., & American Public Health Association (Eds.). (2012). *Standard methods for the examination of water and wastewater* (Vol. 10). Washington, DC: American public health association.

Rosa, B.J., Rodrigues, L.F., de Oliveira, G.S., da Gama Alves, R. (2014). Chironomidae and oligochaeta for water quality evaluation in an urban river in Southeastern Brazil. *Environmental Monitoring Assesment* 186 (11): 7771-7779

Sarang, N. and Sharma, L.L. (2009). Macrobenthic fauna as bioindicator of water quality in Kishore Sagar Lake, Kota (Rajasthan) India. In 13th Conference Wuhan, Conference Papers. Wuhan:57-77.

Savenije, H.H. (2012). Salinity and Tides in Alluvial Estuaries. 2nd ed. Delft University of Technology. Delft.

Shannon, C. E. & Wiener, W. (1949). The Mathematical Theory of Communication. (Pp, 177) Urbana, University of Illinois Press.

Sharma RC, Bhanot G, Singh D (2004). Aquatic macro-invertebrate diversity in Nanda Devi Biosphere Reserve, India. Environmentalist 24:211–221.
DOI:10.1007/s10669-005-0996-z.

Sharma RC, Sharma A, Anthawal A (2008). Surveying of aquatic insect diversity of Chandragbhaga river, Garhwal Himalayas. Environmentalist.
DOI:10.1007/s10669-007-9155-z

Sharma, J., Raina, S., Jwala, V. H., Yadav, Y., & Shukla, V. K. (2023). Taxonomic Diversity and Biological Water Quality Assessment of Rivers Bhagirathi and Yamuna at Gangotri and Yamunotri Using Benthic Macroinvertebrates. In *Proceedings of the Zoological Society* (Vol. 76, No. 3, pp. 241-250). New Delhi: Springer India.

Sharma, R. C., & Rawat, J. S. (2009). Monitoring of aquatic macroinvertebrates as bioindicator for assessing the health of wetlands: A case study in the Central Himalayas, India. *Ecological indicators*, *9*(1), 118-128.

Simpson, E. H. (1949). Measurement of diversity. Nature, 163:688.

Soliman, G.N. (2001). Invertebrate Zoology. The Mideastern Invertebrates Fauna. Part Ⅱ: The Coelentrates. First Edition. Pp.250.

Sudaryanto, A. (2001). Struktur komunitas macrozoobenthos dan kondisi fisiko kimiawi sedimen di Perairan Donan, Cilacap – Jawa Tengah. Jurnal Teknologi Kelautan 2 (2): 119-123.

Ward JV, Tockner K (2001). Biodiversity: towards a unifying theme for river ecology. *Freshw Biol* 46(6):807–819. DOI:10.1046/ j.1365-2427.2001. 00713.x

Whittaker, R. H. (1972). Evolution and measurement of species diversity. *Taxon*, *21*(2-3), 213-251.

Ysebaert, T. and Herman, P.M. (2002). Spatial and temporal variation in benthic macrofauna and relationships with environmental variables in an estuarine, intertidal soft-sediment environment. *Marine Ecology Progress Series*, 244:105-124.

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