Journal of Institute of Science and Technology, 31(1), 239-252 (2026)
ISSN: 2467-9062 (print), e-ISSN: 2467-9240
https://doi.org/10.3126/jist.v31i1.86008

Research Article

FISH DIVERSITY AND ENVIRONMENTAL DRIVERS IN THE BAGMATI RIVER, KATHMANDU, CENTRAL NEPAL

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*(**Received**: November 6, 2025; **Revised**: June 8, 2026; **Accepted**: June 9, 2026)*

ABSTRACT

This study examined the spatiotemporal variation in fish diversity and its environmental drivers along the Bagmati River, Kathmandu, Nepal. Fish and water sampling was conducted across five sites during premonsoon, monsoon, and post monsoon on the year 2021-2022 A.D. Physicochemical parameters (Temperature (^{0}C), Turbidity (NTU), EC (µS/cm), TDS (mg/L), pH, Hardness (mg/L as $CaCO_3$), Total Alkalinity (mg/L of $CaCO_3$), DO (mg/L), Free CO_2 (mg/L), Chloride (mg/L), Zn (mg/L)) were measured to assess habitat conditions. Diversity indices, including Shannon, Simpson, Inverse Simpson, Pielou's evenness, Margalef's, and Menhinick's indices, were calculated. Principal Component Analysis (PCA) and Canonical Correspondence Analysis (CCA) were used to explore the relationship between environmental gradients and species-environment respectively. Spatial variation was found on the fish abundance and diversity however no significant variation was observed between seasons. Upstream site (U1) consistently recorded the lowest abundance (21 - 34 individuals) and diversity (Shannon: 0.98 - 1.08; Simpson: 0.58 - 0.66), whereas far-downstream sites D3 - D4 showed the highest abundance (up to 166 individuals) and diversity (Shannon: 2.68 - 2.88; Simpson: 0.92 - 0.94). Environmental variables varied significantly across sites and seasons ($p < 0.05$). PCA revealed that the first two components explained 57.73% of the total variance, driven by electrical conductivity, total dissolved solids, hardness, and chloride. CCA indicated that fish assemblage structure was strongly associated with temperature ($F = 15.54$, $p < 0.001$), electrical conductivity ($F = 7.93$, $p < 0.001$), total alkalinity ($F = 4.22$, $p = 0.0025$), dissolved oxygen ($F = 3.80$, $p = 0.0031$), and free CO_2 ($F = 2.90$, $p = 0.019$). Overall, results indicate that fish diversity and community composition significantly varies along the location in the Bagmati River. So, conservation and management strategies should focus on maintaining habitat quality, particularly at upstream sites, to support sustainable fish diversity.

Keywords: Biodiversity conservation, Fish diversity, Freshwater, Monsoon dynamics, Urban River ecology

INTRODUCTION

Freshwater ecosystems are among the most productive and biodiverse habitats on Earth, supporting a diverse range of aquatic organisms, including fish, invertebrates, and macrophytes (Hitt et al., 2015). Fish communities are important indicators of aquatic ecosystem health because of their sensitivity to physicochemical and hydrological changes (Hamayoon et al., 2024). However, increasing urbanization has placed tremendous pressure on freshwater systems (Matthews, 2016). Due to high pollution levels, , altered flow patterns, and habitat degradation, urban rivers often exhibit reduced aquatic biodiversity and poor water quality (Anim & Banahene, 2021; Chakraborty, 2021). These anthropogenic pressures directly affect fish assemblages by altering food availability, spawning habitats, and dissolved oxygen levels, ultimately contributing to biodiversity loss (Matono et al., 2014; Gebrekiros, 2016).The Bagmati River one of the major freshwater systems in central Nepal, originates in the Shivapuri Hills and flows through the densely populated Kathmandu Valley, before entering Madesh Province (Shrestha & Tamrakar, 2012). Its hydrology is strongly influenced by the South Asian monsoon, which causes major seasonal variations in discharge, turbidity and nutrient concentration (Dhital et al., 2013). During the monsoon period, increased rainfall leads to higher surface runoff, which can alter water chemistry and affect microhabitats and fish community composition (Oli et al., 2013; Rijal et al., 2025). In contrast, the dry season is characterized by low flow conditions, which intensify anthropogenic impacts such as domestic sewage inflow and solid waste accumulation, making the Bagmati a typical example of a stressed monsoon-driven urban river (Oli et al., 2013). Understanding hydrochemistry and biota assemblages is essential for evaluating the health of aquatic ecosystems, especially in the context of the ongoing degradation and urbanization (Giri et al., 2022; Phuyal et al., 2025). This study aims to assess the spatial variation in fish diversity along the Bagmati River during premonsoon, monsoon and post monsoon seasons, and to analyze the physicochemical parameters influencing fish community structure, thereby providing information essential for evaluating ecological integrity, supporting biodiversity monitoring and guiding the sustainable management and conservation of freshwater ecosystems in rapidly urbanizing regions.

MATERIALS AND METHODS

Study area

The study was done in Bagmati River, which lies in the Central Nepal. The sampling location covers the extension of the river from Bagdwar to the Sarlahi district in the south. Bagmati river originates in the Shivapuri Hills of the Mahabharat Range and then flows southward through the Terai plains before entering India (Fig. 1). It lies between 27°46'16"N–85°25'38"E and 25°43'56.1"N–86°21'53.0"E (Baral et al., 2024). The Bagmati River, which holds significant religious, cultural, economic, and ecological importance in Nepal, flows through the Kathmandu Valley and it severely impacted by pollution resulting from rapid urbanization, population growth, and the discharge of untreated municipal and industrial wastes (Giri et al., 2022). For this study, five sampling sites were selected based on the confluences of the Bagmati River and its tributary streams (Table 1).

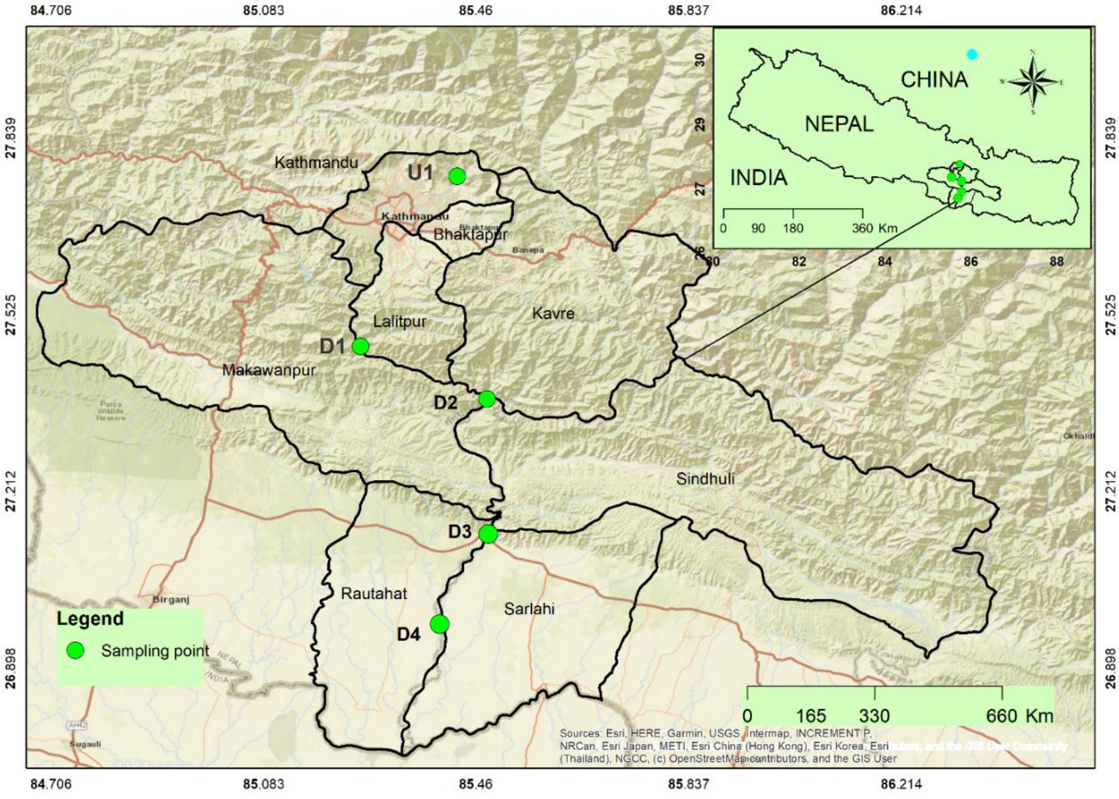

Figure 1. Map of study area showing sampling sites along the Bagmati River

Methods

The sampling sites included Sundarijal, Mahadevsthan, Taaldhunga, Bagmati Bridge and Hajariya (Table 1).

Table 1. Location of sampling sites

SN	Site code	Location	Latitude	Longitude	Elevation (m)
1	U1	Sundarijal	27º46'18.1"	085º25'35.0"	1590
2	D1	Mahadevsthan	27º28'12.8"	085º15'18.2"	682
3	D2	Taaldhunga	27º22'36.1"	085º28'44.8"	284
4	D3	Bagmati Bridge (E-W Highway)	27º68'14.2"	085º28'54.3"	111
5	D4	Hajariya (Bagmati Bridge)	27º58'39.8"	085º23'42.7"	68

Water sampling and physicochemical parameters

Water samples were collected from the river surface at five sites of the Bagmati River. Among them, one site was from Sundarijal and is designated as up-stream (U1), two sites from Mahadevsthan and Taaldhunga designated as downstream (D1 and D2) and two from Bagmati Bridge of East-West Highway and Hajariya designated as far down stream (D3 and D4). Water samples were collected from three seasons i.e., Premonsoon (March), Monsoon season (June) and Post monsoon (September) of year 2021 and 2022. Water samples were collected over two consecutive years, and seasonal data from both years were pooled to account for immediate temporal variation. This provided two replicates (n=2) per site per season for analysis. At each site, selected physicochemical parameters such as pH, temperature, TDS (Total Dissolved Solid) and EC (Electrical Conductivity) were measured on-site using multimeter probes (Hanna Probe), while turbidity was measured in laboratory by using TL-1000NTU Turbidity meter. At each site, 1000 mL water samples were collected in high-density polyethylene (HDPE) bottles and stored at 4°C in an icebox until analysis. These samples were analyzed for free carbon dioxide (CO_2), Chloride ion, total alkalinity and total hardness. In addition, 300 mL water samples were collected in Biochemical Oxygen Demand (BOD) bottles and fixed with KI and $MnSO_4$ for the Dissolved Oxygen (DO) analysis. The DO, free CO_2, Chloride ion, total hardness (as $CaCO_3$), and total alkalinity were determined using standard methods, following American Public Health Association (APHA, 2005) at the laboratory of Central Department of Zoology, Tribhuvan University, Kathmandu, Nepal. Additionally, the water samples for Zinc analysis were collected in 100 mL polyethylene bottles. The bottles were thoroughly cleaned by rinsing with tap water, soaking in 1% nitric acid, and washing with double distilled water to avoid contamination. Precautions were taken to prevent air bubbles during sampling. Immediately after collection, 0.5 mL of concentrated nitric acid was added to stabilize the sample. Three replicates were taken from each site to determine the mean concentration. The samples were stored in a refrigerator at 4°C until analysis. The water samples were then acid digested in the laboratory of Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal. For acid digestion, the sample (100 mL) was placed in a 250 mL Erlenmeyer flask and 5 mL concentrated nitric acid was added in it. The mixture was slowly heated in a digestion chamber until the volume reduced to 10-20 mL and then made up to 100 mL with double distilled water (Gaba & Abubakar, 2023). A Flame Atomic Absorption Spectrometer (Model 200 Series AA of Agilent Technologies) using an air acetylene flame was used to measure the concentration of heavy metals in the digested water samples at Analytical Service Center, Nepal Academy of Science and Technology, Lalitpur, Nepal. Prior to analysis, instrument settings such as cathode lamp and fuel pressure were adjusted according to the manufacture's specification for each element. The instrument was first calibrated using a blank solution to ensure accuracy. Standard solutions prepared from stock solutions of known concentrations were then analyzed to develop calibration curves for each metal. Metal concentration in the samples was subsequently determined from the corresponding calibration curves based on their absorbance value (Llaver et al., 2021).

Fish sampling and identification

Fish samples were collected with assistance from local fishermen using cast nets with a mesh size of 0.5 cm at the selected locations within each lentic system, covering all four directions (East, West, North, and South directions). The fish species that were collected were promptly counted on-site and preserved in 10% formalin solution for future analysis at the Central Department of Zoology, Tribhuvan University, Nepal. The morphological features were measured, and specimen identification was conducted in accordance with standard literature (Shrestha, 1981, 1984; Jayaram, 2012; Shrestha, 2019; Vishwanath, 2021). The voucher specimens were deposited at the Central Department of Zoology Museum of Tribhuvan University (CDZMTU).

Statistical analysis

Differences in fish diversity among sites were assessed using the Kruskal–Wallis rank-sum test. To determine pairwise differences between sites, a post-hoc Dunn’s test with Bonferroni adjustment was applied. Significant pairwise comparisons were summarized using compact letter display (CLD) to assign group letters, indicating which sites differed significantly in diversity. Principal component analysis was done for the relationship between the water physiochemical parameters. DCA was done which yield axis length of 3.5 thus CCA was applied using *Vegan* package, permutation analysis (number of permutations = 9999) was done to determine the significant properties of water to affect the fish assemblage and community composition. All the analysis was performed in R studio 4.0.2 (R-core Team, 2025).

RESULTS

Spatial and seasonal variation of fish diversity

A total of 29 fish species were recorded in this study (Table 2). The mean abundance of fish varied across sites but not among the season (Table 3). The upstream site (U1) consistently had the lowest abundance (21 individuals) during monsoon and premonsoon respectively. At site D1, abundance remained relatively stable across seasons, with 50.5 ± 0.71 individuals in premonsoon, 57.5 ± 4.95 in monsoon, and 54 ± 1.41 in post monsoon. A similar pattern was observed at D2, where abundance varied slightly from 56 ± 7.07 in premonsoon to 57.5 ± 0.71 in monsoon and 53 ± 0.1 in post monsoon. In contrast, downstream sites D3 and D4 exhibited markedly higher abundances, particularly during the monsoon season, with 139 ± 19.8 and 166.5 ± 7.78 individuals, respectively. Post monsoon and premonsoon abundances at D3 (76.5 ± 3.54 and 71.5 ± 2.12) and D4 (92.5 ± 7.78 and 81 ± 1.41) were comparatively lower (Fig. 2).

Species richness varied spatially across sites (Table 3). The upstream site U1 has the lowest richness with only 3 ± 0 species recorded in all seasons. At D1, species richness ranged from 11.5 ± 0.71 species in premonsoon to 11 ± 0 in monsoon and decreased to 8 ± 0 in post monsoon. Similarly, at D2 species richness was 11.5 ± 0.71 in premonsoon, 10.5 ± 0.71 in monsoon and 8 ± 0 in post monsoon. Downstream site D3 has 16 ± 1.41 species in premonsoon, 19.5 ± 0.71 in monsoon, and 15 ± 1.41 in post monsoon. The highest richness was recorded at D4, where 17 ± 0 species were observed in premonsoon, 20.5 ± 0.71 in monsoon, and 20 ± 0 in post monsoon (Fig. 2)

Table 2. List of fish species recorded in the Bagmati River during the study. Symbol (–) represent absent and (+) represent present of specific species in each location for premonsoon, monsoon and post monsoon, respectively

Name of fish species	Abbrevation	Common Name	U1	D1	D2	D3	D4
Chagunius chagunio	*Cha_cha*	Chaguni	---	---	---	+++	+++
Pethia conchonius	*Pet_con*	Rosy Barb	---	+++	+++	+++	+++
Puntius sophore	*Pun_sop*	Spotfin Swap Barb	---	+++	+++	+++	+++
Salmostoma acinaces	*Sal_aci*	Silver razorbelly minnow	---	++-	+++	+++	+++
Salmostoma bacaila	*Sal_bac*	Large razorbelly minnow	---	-+-	-+-	+++	+++
Opsarius bendelisis	*Ops_ben*	Indian Hill Trout	---	+-+	+-+	---	---

Barilius bola	*Bar_bol*	Trout barb	---	+--	+--	+++	---
Barilius vagra	*Bar_vag*	Vagra Baril	---	++-	+--	+++	+++
Danio devario	*Dan_dev*	Sind danio	---	++-	+--	++-	+++
Schizothorax richardsonii	*Sch_ric*	Snowtrout	+++	---	---	---	---
Labeo boga	*Lab_bog*	Boga Labeo	---	---	---	+++	+++
Garra lissorhynchus	*Gar_lis*	Khasi Garra	---	+++	+++	+++	+++
Garra annandalei	*Gar_ann*	Annandale Garra	+++	+++	+++	+++	+++
Psilorhynchus pseudecheneis	*Psi_pse*	Nepalese minnow	---	--+	-++	---	---
Acanthocobitis botia	*Aca_bot*	Mottled loach	---	++-	++-	+++	+++
Schistura spp.	*Sch_spp*	Loach	+++	+++	+++	+++	+++
Botia lohachata	*Bot_loh*	Tiger loach	---	--+	+++	+++	+++
Mystus bleekeri	*Mys_ble*	Day's mystus	---	---	---	+++	+++
Mystus gulio	*Mys_gul*	Long whiskers catfish	---	---	---	-+-	+++
Amblyceps mangois	*Amb_man*	Torrent catfish	---	---	---	+++	+++
Bagarius bagarius	*Bag_bag*	Gangetic Goonch	---	---	---	---	--+
Bagarius yarrelli	*Bag_yar*	Goonch	---	---	---	--+	--+
Glyptothorax pectinopterus	*Gly_pec*	River cat	---	---	++-	---	---
Clarias batrachus	*Cla_bat*	Walking catfish	---	---	---	+++	+++
Xenentodon cancila	*Xen_can*	Freshwater garfish	---	---	---	---	-+-
Macrognathus lineatomaculatus	*Mac_lin*		---	---	---	+++	+++
Chanda nama	*Cha_nam*	Elongate glass-perchlet	---	---	---	-+-	+++
Channa orientalis	*Cha_ori*	Asiatic snakehead	---	+++	---	---	---
Glossogobius giuris	*Glo_giu*	Tank goby	---	---	---	---	-+-

The Shannon diversity index varied markedly among the sites (Table 3, Fig. 2). The upstream site U1 showed the lowest diversity (0.98-1.08), whereas diversity increased progressively downstream. Intermediate values were recorded at D1 and D2 (1.93-2.29), while the highest diversity occurred at D3 (2.45-2.83) and D4 (2.68-2.88). At most sites, diversity peaked during the monsoon and declined slightly during the post monsoon season.

The Simpson diversity index showed clear spatial variation across sites (Table 3, Fig. 2). The upstream site U1 had the lowest diversity (0.58-0.66), while diversity increased gradually downstream. The highest diversity occurred at D3 (0.90-0.93) and D4 (0.92-0.94). Across most sites, Simpson diversity was the highest during the monsoon season. The inverse Simpson, Pielou's evenness, Menhinick's and Margalef's indices all showed a consistent pattern of significant spatial variation with weak seasonal effect (Table 3, Fig. 2-3). Across all indices, the upstream site U1 had the lowest diversity, while values progressively increased downstream, reaching the highest level at D3 and D4. Evenness was highest and relatively stable across sites, whereas richness and diversity-based indices peaked in downstream sites, particularly D4, indicating higher diversity and species richness in lower reaches of the river system (Fig. 2).

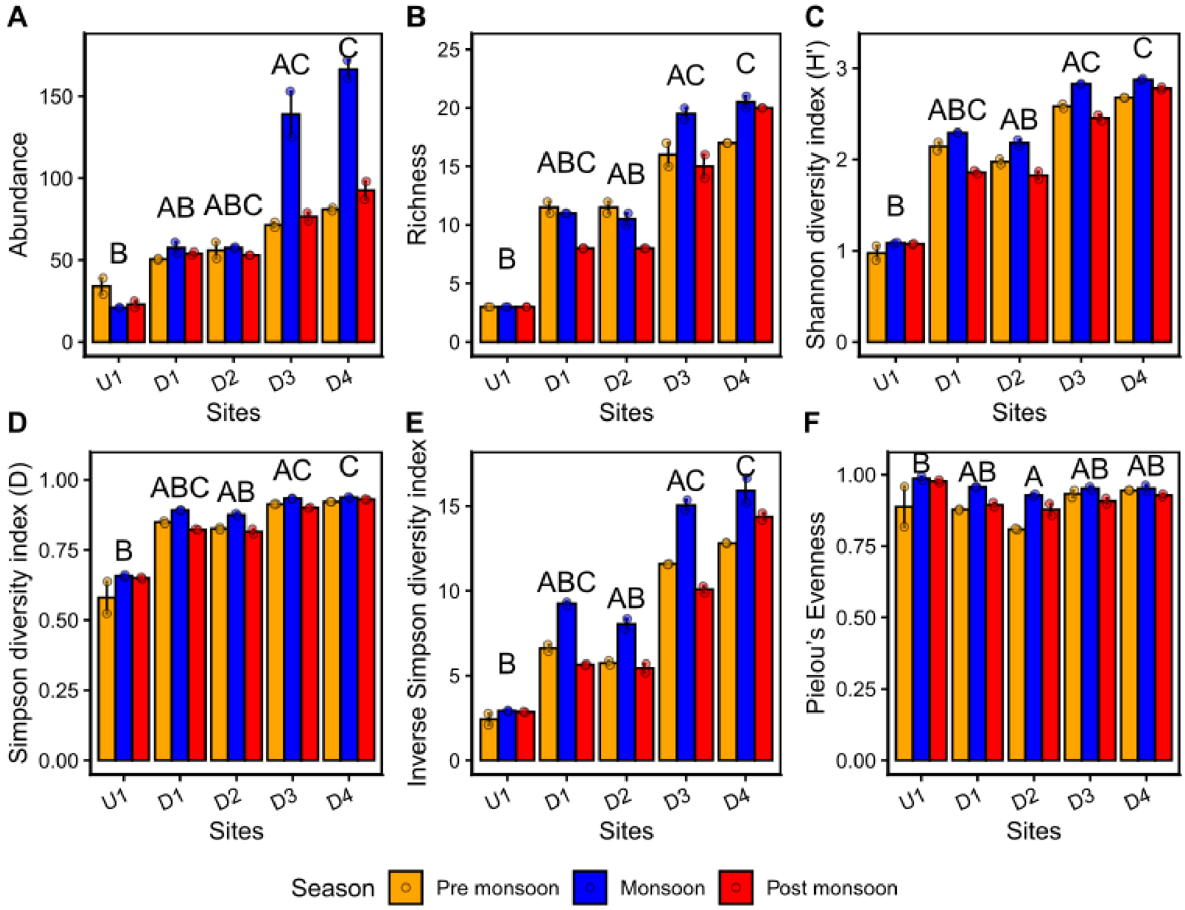

Figure 2. Spatial and seasonal variation in fish community structure across five sampling sites (U1-D4) of the Bagmati River. A) Abundance, B) Species Richness, C) Shannon-Wiener Index (H′), D) Simpson Diversity Index (D), E) Inverse Simpson Index (1/D), and F) Pielou's Evenness (J′). Error bar shows standard errors and Letters above the bar indicate significant differences among sites based on Dunn's post-hoc test ($p < 0.05$)

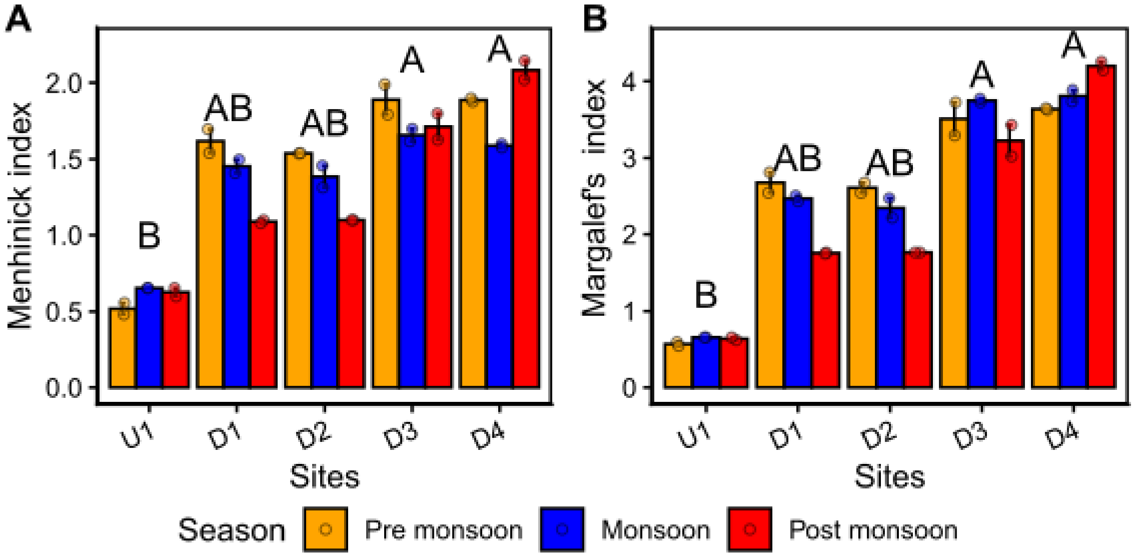

Figure 3. Spatial and seasonal variation in fish species richness across five sampling sites (U1 – D4) of the Bagmati River, A) Menhinick's and B) Margalef's indices. Letters above boxes represent statistically significant differences among sites ($p < 0.05$)

Table 3. Kruskal–Wallis test results showing the effects of site and season on fish community diversity and abundance indices

Indices	Factor	Kruskal-Wallis Test Statistic (H)	df	p-value
Shannon	Sites	25.669	4	**<0.001**
	Season	2.33	2	0.312
Abundance	Sites	25.64	4	**<0.001**
	Season	1.21	2	0.545
Species richness	Sites	26.12	4	**<0.001**
	Season	0.79	2	0.673
Simpson	Sites	25.57	4	**<0.001**
	Season	2.47	2	0.289
InvSimpson	Sites	25.57	4	**<0.001**
	Season	2.47	2	0.289
Pielou_Evenness	Sites	11.47	4	**<0.001**
	Season	8.51	2	**0.014**
Menhinick	Sites	24.49	4	**<0.001**
	Season	10.5	2	0.589
Margalef	Sites	25.65	4	**<0.001**
	Season	0.4	2	0.817

Physico-chemical properties

The physicochemical characteristics of water varied considerably across sites and seasons (Table 4). Temperature ranged from 11.5 ± 0.71 °C to 29.5 ± 0 °C, showing significantly higher values during the monsoon and at downstream sites (H = 16.13, p = 0.002 for sites; H = 10.38, p = 0.005 for seasons). Turbidity and total dissolved solids (TDS) also differed significantly among sites (p < 0.01), with elevated concentrations during the monsoon season, particularly at midstream sites (D2–D4). Electrical conductivity (EC) showed significant spatial (p = 0.013) and seasonal (p = 0.025) variations, with higher mean values in the premonsoon period. In contrast, pH showed no significant variation among sites or seasons (p > 0.05), remaining within slightly alkaline ranges (7.45–8.20). Total hardness and dissolved oxygen (DO) varied significantly with season (p = 0.034 and p = 0.021, respectively), while spatial variation was not observed. Chloride concentration and zinc (Zn) content also showed significant seasonal variation (p = 0.007 and p < 0.001, respectively), with higher Zn during the post-monsoon period. Free CO_2, total alkalinity, and other ionic parameters exhibited moderate variation but were not statistically significant across sites (p > 0.05). Overall, monsoonal influence and longitudinal gradients markedly structured the spatiotemporal variation in the river's physicochemical environment (Table 4).

Principal Component Analysis (PCA) was performed on eleven environmental parameters to examine the major gradients influencing the sampling sites. The first two principal components (PC1 and PC2) together explained 57.73% of the total variance, with PC1 accounting for 41.49% and PC2 for 16.24% of the total variability. Together, PCA1 and 2 cumulatively explained the variance of 57.73%. The parameters electrical conductivity (EC), total dissolved solids (TDS), hardness, total alkalinity, and chloride contribute to PC1, indicating that this axis primarily represents a gradient in ionic and mineral content. In contrast, zinc (Zn), pH, turbidity, and dissolved oxygen (DO) were the dominant contributors to PC2, reflecting variations in water chemistry and oxygenation conditions (Fig. 4).

To explore species - environment relationships, a Detrended Correspondence Analysis (DCA) was performed, which showed the length of the first axis (3.54) exceeding 3 SD units, indicating a unimodal species response. Therefore, Canonical Correspondence Analysis (CCA) was applied to assess the influence of environmental variables on fish assemblage structure.

Canonical Correspondence Analysis (CCA) revealed distinct relationships between fish assemblage structure and environmental gradients across seasons and sampling sites. The first two canonical axes (CCA1 and CCA2) effectively summarized the species–environment relationships, showing clear seasonal clustering of sites along these axes. Premonsoon and post monsoon sites (particularly U1) were positioned toward the negative end of CCA1, whereas monsoon sites (D3-D4) were located on the positive side, indicating shifts in community composition with hydrological variation (Fig. 5).

Table 4. Seasonal and spatial variation in physicochemical properties of Bagmati River, Kathmandu, Nepal. Values are presented as mean ± standard deviation. Kruskal–Wallis tests were performed to assess differences among sites and seasons; results are shown as H (p-value)

Sites	**Season**	**Temperature (^{0}C)**	**Turbidity (NTU)**	**EC (µS/cm)**	**TDS (mg/L)**	**pH**	**Hardness(mg/L as $CaCO_3$)**	**Total. Alkalinity (mg/L of $CaCO_3$)**	**DO (mg/L)**	**Free CO_2 (mg/L)**	**Chloride (mg/L)**	**Zn (mg/L)**
D1	Monsoon	24.9 ± 0.42	182.5 ± 115.26	274 ± 19.8	138 ± 7.07	7.55 ± 0.07	106 ± 8.49	40 ± 35.36	14.1 ± 6.75	26.4 ± 9.33	16.33 ± 9.04	0.28 ± 0.24
D1	Post Monsoon	18.35 ± 0.21	36.84 ± 33.04	321 ± 86.27	155 ± 35.36	7.6 ± 0.28	101 ± 7.07	72.5 ± 10.61	14.3 ± 2.81	41.8 ± 24.89	16.33 ± 3.01	0.8 ± 0.71
D1	Pre Monsoon	22.5 ± 2.12	45.2 ± 1.98	379.5 ± 55.86	193 ± 22.63	7.75 ± 0.64	197 ± 83.44	130 ± 134.35	7.74 ± 1.12	24.2 ± 6.22	26.98 ± 8.03	0.12 ± 0.01
D2	Monsoon	24.55 ± 1.91	177.55 ± 147.71	281.5 ± 26.16	141 ± 12.73	7.85 ± 0.21	102 ± 11.31	37.5 ± 17.68	14.7 ± 1.68	22 ± 9.33	11.36 ± 4.02	0.3 ± 0.28
D2	Post Monsoon	15.1 ± 0.85	128.3 ± 155.14	247.5 ± 6.36	123.5 ± 2.12	7.85 ± 0.07	107 ± 24.04	42.5 ± 10.61	19.46 ± 0.28	39.6 ± 24.89	17.04 ± 2.01	0.57 ± 0.42
D2	Pre Monsoon	24.1 ± 2.97	119.81 ± 154.42	425.5 ± 270.82	211 ± 137.18	7.55 ± 0.64	188 ± 118.79	102.5 ± 109.6	6.95 ± 0	17.6 ± 6.22	25.56 ± 18.07	0.05 ± 0.03
D3	Monsoon	27.5 ± 0.99	135 ± 152.74	198 ± 49.5	99 ± 25.46	7.6 ± 0.42	92 ± 42.43	55 ± 28.28	18.17 ± 1.27	18.7 ± 7.78	9.94 ± 2.01	0.26 ± 0.3
D3	Post Monsoon	21.4 ± 0.85	16.54 ± 3.05	266 ± 36.77	133 ± 19.8	7.55 ± 0.21	98 ± 22.63	37.5 ± 10.61	26.42 ± 0.28	30.8 ± 24.89	17.75 ± 3.01	0.44 ± 0.24
D3	Pre Monsoon	27.4 ± 1.98	10.92 ± 0.74	412 ± 11.31	211 ± 11.31	7.95 ± 1.34	163 ± 43.84	120 ± 63.64	17.38 ± 16.15	16.5 ± 1.56	39.05 ± 3.01	0.08 ± 0.05
D4	Monsoon	29.5 ± 0	213.44 ± 273.74	206.5 ± 33.23	103 ± 16.97	7.65 ± 0.21	84 ± 28.28	47.5 ± 3.54	16.09 ± 0.56	16.5 ± 4.67	10.65 ± 3.01	0.25 ± 0.29
D4	Post Monsoon	22.95 ± 0.07	42.25 ± 3.75	266.5 ± 41.72	133 ± 19.8	7.6 ± 0.42	100 ± 11.31	35 ± 7.07	22.44 ± 5.04	28.6 ± 21.78	19.17 ± 1	0.51 ± 0.38
D4	Pre Monsoon	28.9 ± 1.27	10.79 ± 1.54	421.5 ± 23.33	210.5 ± 12.02	8.2 ± 1.27	181 ± 57.98	112.5 ± 67.18	16.98 ± 14.76	18.7 ± 14	39.05 ± 5.02	0.06 ± 0.06
U1	Monsoon	19.35 ± 1.2	7.3 ± 5.73	36 ± 2.83	18 ± 1.41	7.45 ± 0.64	31 ± 18.38	27.5 ± 3.54	6.26 ± 0.7	23.1 ± 7.78	14.2 ± 6.02	0.24 ± 0.27
U1	Post Monsoon	11.5 ± 0.71	5.46 ± 0.21	32.5 ± 0.71	16.5 ± 0.71	7.85 ± 0.07	77 ± 46.67	17.5 ± 3.54	18.58 ± 9.41	11 ± 9.33	7.81 ± 3.01	0.6 ± 0.21
U1	Pre Monsoon	15.5 ± 2.12	8.91 ± 2.42	142.5 ± 136.47	66.5 ± 61.52	7.7 ± 0	53 ± 38.18	60 ± 42.43	8.34 ± 0.85	4.4 ± 0	12.07 ± 1	0.08 ± 0.02
Sites [χ^2 (p-Value)]		16.13 (0.002)	14.14 (0.006)	12.57 (0.013)	13.97 (0.007)	1.27 (0.865)	9.09 (0.058)	5.25 (0.262)	6.33 (0.175)	7.04 (0.133)	5.37 (0.250)	0.82 (0.935)
Season [χ^2 (p-Value)]		10.38 (0.005)	5.19 (0.074)	7.37 (0.025)	6.17 (0.045)	0.18 (0.911)	6.76 (0.034)	5.89 (0.052)	7.73 (0.021)	2.63 (0.268)	9.71 (0.007)	14.37 (<0.001)

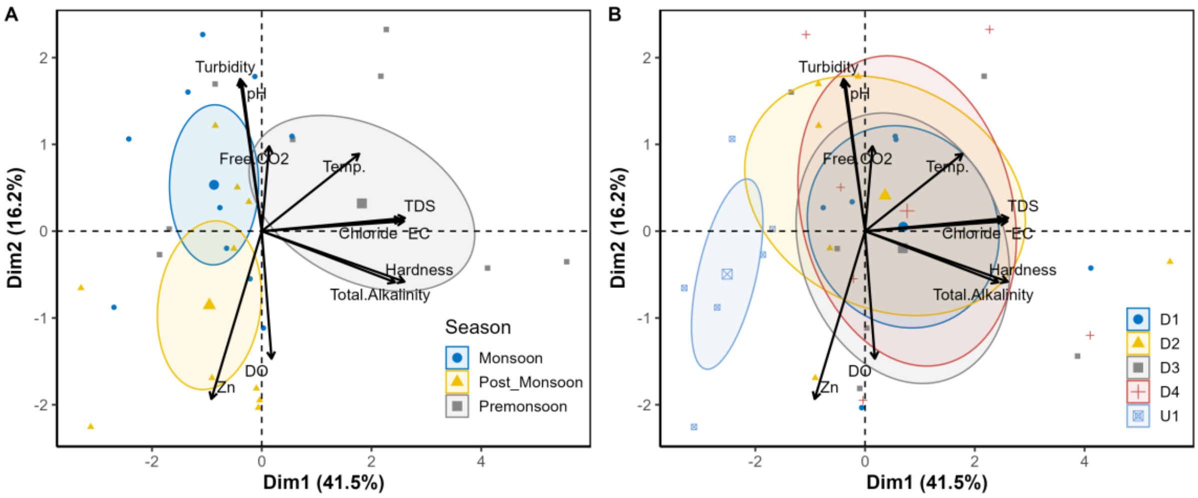

Figure 4. Principal Component Analysis (PCA) of environmental variables across sampling sites in Bagmati River, Kathmandu, Nepal. The first two principal components (PC1 and PC2) explain 41.49% and 16.24% of the total variance, respectively. Arrows indicate the direction and strength of each environmental variable's contribution to the ordination. A) Seasons B) Sites

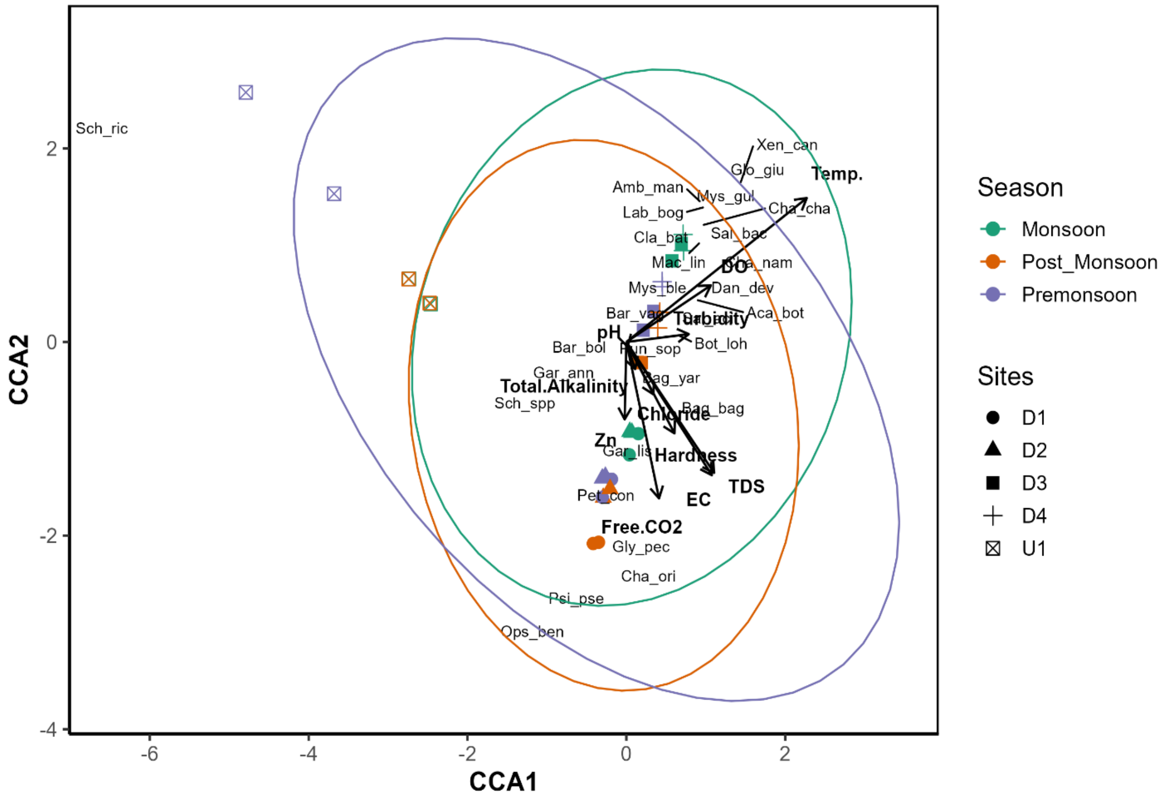

Figure 5. Canonical Correspondence Analysis (CCA) ordination diagram showing the relationship between fish assemblage structure and environmental variables across seasons. Points represent sampling sites grouped by season (ellipses indicate 95% confidence intervals), arrows indicate the direction and strength of environmental gradients, and species names denote the weighted average positions of taxa along the environmental axes

Among the environmental variables, temperature (0.73, 0.48 on CCA1 and CCA2, respectively), total dissolved solids (0.36, - 0.44), and electrical conductivity (0.35, - 0.44) showed strong correlations with the ordination axes, suggesting that these parameters primarily structured fish assemblages.

Dissolved oxygen (0.34, 0.19) and free CO_2 (0.13, -0.52) also contributed moderately to species distribution patterns.

Species such as *Xenentodon cancila*, *Glossogobius giuris*, *Mystus gulio*, and *Amblyceps mangois* were associated with higher temperature and DO, clustering toward the positive CCA1 and CCA2 quadrants. In contrast, *Schizothorax richardsonii* , *Opsarius bendelisis*, and *Glyptothorax pectinopterus* were positioned on the negative side of CCA1, indicating a preference for cooler and less conductive habitats. Overall, the ordination demonstrates that both seasonal variation and key physicochemical variables strongly influence the spatial distribution of fish assemblages in the studied river system.

A permutation-based ANOVA of the canonical correspondence analysis (CCA) was conducted with 9,999 permutations to evaluate the influence of environmental variables on fish community composition. The results showed that temperature ($F = 15.54$, $p < 0.001$), electrical conductivity ($F = 7.93$, $p < 0.001$), total alkalinity ($F = 4.22$, $p = 0.0025$), dissolved oxygen ($F = 3.80$, $p = 0.0031$), and free CO_2 ($F = 2.90$, $p = 0.019$) significantly influenced fish assemblages. Turbidity, TDS, pH, hardness, chloride, and zinc had non-significant or marginal effects ($p > 0.05$).

DISCUSSION

The present study revealed significant spatial variation in fish diversity and abundance along the Bagmati River, strongly shaped by physicochemical gradients and seasonal variation. The downstream sections (D3 - D4) supported significantly higher species richness and diversity indices (Shannon, Simpson, and Margalef) compared to the upstream site (U1), indicating that longitudinal environmental gradients are major determinates of stream fish community organization, influencing species turnover and community structure (Almeida & Cetra, 2016). In contrast, seasonal effects were relatively weak, suggesting that spatial heterogeneity in habitat conditions and water chemistry exerts a stronger influence on fish assemblage structure than short-term seasonal fluctuations, a pattern reported in several riverine ecosystems (Hued et al., 2010; G.C. & Limbu, 2019). Our findings are consistent with those of Rajbanshi et al., (2021), who reported significant spatial variations in fish community structure along elevational and environmental gradients in Ratuwa River in eastern Nepal, whereas temporal variation was relatively weak. They identified altitude, water temperature, flow velocity, dissolved oxygen, and pH as key factors shaping species distribution. Similarly, Rumschlag et al. (2025) found that warmer streams (>23.8 °C) supported higher fish richness and abundance than colder streams, likely because favorable thermal conditions enhance productivity and habitat suitability for many species. Consistent with these findings, our study recorded higher species richness at warmer sites, highlighting the important role of temperature in structuring fish communities.

Spatial variation and ecological integrity

The consistently low diversity and abundance at the upstream site (U1) likely reflect the combined effects of habitat degradation and limited ecological (Bunn, & Arthington, 2002). Being located north of the urban core of Kathmandu and near the origin of the Bagmati River, the upstream site (U1) experiences limited water flow compared to the downstream sections (Bunn, & Arthington, 2002). The absence of fish in the core urban stretch further indicates that the river there lacks suitable habitat and sufficient space to support fish populations (Aryani et al., 2020). Several studies have also shown that longitudinal gradients in fish diversity in rivers show the upstream low diversity, while the downstream has higher diversity (Grossman, et al., 2010; Aryani et al., 2020). The high Pielou's evenness despite low richness at U1 suggests that the few species present have similar abundances, indicating community simplification (Pielou, 1966).

In contrast, downstream sections (D3 - D4) exhibited richer assemblages and higher diversity indices, especially during the monsoon season. This result is in alignment with the study by Oli et al (2013) who reported higher numbers and diversity of fish species occurred in monsoon and post-monsoon seasons, which is attributed to the presence of sufficient water, ample food resources and less anthropogenic activities. In our study, this increase may also result from sufficient water from upstream inflow and improved dilution of pollutants during higher discharge. The pattern aligns with the longitudinal river continuum concept, which predicts that downstream areas support greater species richness due to more stable physicochemical conditions and diverse habitats (Stoffels et al., 2016).

Environmental drivers of community structure

Multivariate analyses (PCA and CCA) identified temperature, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), total alkalinity, and free CO_2 as key environmental determinants of fish assemblage structure. These parameters collectively explain much of the variation in community composition, consistent with prior studies in Himalayan and Indo-Gangetic rivers (Oli et al., 2013; Hamayoon et al., 2024).

The strong influence of EC, TDS, and hardness on the first PCA axis indicates that ionic and mineral gradients- often driven by anthropogenic runoff, domestic effluents, and erosion- shape the chemical habitat template for fish (Shrestha & Basnet, 2018; Hamid et al., 2020). Fish compositional variation was found to be correlated with temperature, electrical conductivity (EC), and total dissolved solids (TDS) (Ghimire & Koju, 2021). Elevated conductivity and hardness at mid- to downstream sites suggest higher nutrient loading (Islam et al., 2025), which can increase productivity but also favor tolerant and generalist species. Conversely, low EC and TDS at U1 reflect dilution effects in the headwaters. The low mineral content does not necessarily equate to good water quality (Bhatnagar & Thakral, 2024).

Temperature emerged as the strongest environmental predictor in the CCA, reflecting its central role in regulating metabolic rates, oxygen solubility, and breeding behavior of tropical freshwater fish (Volkoff & Rønnestad, 2020). The observed downstream increase in temperature corresponds with broader channel width and reduced canopy cover, enhancing solar radiation exposure. Meanwhile, low dissolved oxygen (DO) and free CO_2 levels showed inverse relationships, suggesting that oxygen limitation and carbon enrichment jointly constrain sensitive taxa (Bulbul Ali & Mishra, 2022) , especially during low-flow conditions.

Total alkalinity and chloride concentrations are moderate contributors to species assemblage. However, they reflect urban influences on water chemistry. These ionic parameters often increase due to domestic waste, detergents, and fertilizer residues (Kaushal et al., 2025), which may alter osmoregulatory balance and indirectly affect species composition (Mariu et al., 2023).

Seasonal influence and monsoon dynamics

Although monsoonal variation did not significantly alter most diversity indices, community composition shifted along hydrological gradients, as shown in the CCA ordination. The monsoon season corresponded with higher abundance and diversity at downstream sites, possibly due to enhanced habitat connectivity, recruitment of migratory species, and dilution of pollutants (Bunn & Arthington, 2002). Increased turbidity and suspended solids during monsoon can, however, temporarily reduce visual feeding efficiency and favor species adapted to low-visibility environments (Fitzgibbon, 2020). The absence of strong seasonal effects on diversity indices suggests that the resilience of fish communities in the Bagmati River is more influenced by spatial environmental stress than by short-term hydrological pulses.

Implications for conservation and management

The observed spatial pattern of fish diversity in the Bagmati River reflects a strong interaction between physicochemical gradients and anthropogenic stress. Upstream sites have low richness and diversity, indicating habitat degradation and strong environmental filtering, likely driven by sand extraction, riparian disturbance, and reduced habitat complexity (Doretto et al., 2020). In contrast, downstream reaches supported higher richness and diversity during the monsoon, suggesting that increased hydrological connectivity, habitat heterogeneity, and warmer conditions enhance fish assemblage stability (Poff et al., 1997). This pattern is consistent with evidence that warmer freshwater systems often sustain higher fish richness due to increased metabolic rates, productivity, and ecological opportunities for warm-adapted species (Rumschlag et al., 2025).

The strong association of fish assemblages with temperature, dissolved oxygen, conductivity, and TDS indicates that water quality and thermal regime are key drivers of community structure. Similar studies have shown that physicochemical gradients act as primary filters shaping riverine fish assemblages in disturbed systems where sensitive taxa are replaced by tolerant generalists (Gavioli et al., 2024; Ma et al., 2026). Higher diversity during monsoon at downstream sites, further suggests that flow pulses enhance dispersal and temporary habitat expansion, which increases species mixing and abundance (Bunn & Arthington, 2002).

From a management perspective, the extreme reduction in diversity at upstream sites and lack of fish in sampling procedure at core urban sites highlights the need for restoration of riparian buffers, regulation of gravel and sand extraction, and reduction of untreated runoff inputs. Although downstream reaches currently act as biodiversity refugia, increasing urban pressure may progressively erode these assemblages. Therefore, integrated river basin management combining water quality improvement, habitat restoration, and long-term biomonitoring is essential to sustain fish diversity and ecological integrity in monsoon-influenced urban rivers (Tonkin et al., 2026; Rumschlag et al., 2025). Our findings support the need for integrated management approaches, such as the one successfully demonstrated by Wagley & Karki, (2020) in the Shivapuri area. Continuous biomonitoring, coupled with community-based conservation strategies, is essential to sustain the ecological function and biodiversity of the Bagmati River system.

CONCLUSION

Fish diversity in the studied river system showed clear spatial patterns. Upstream sites (U1) showed the lowest abundance, richness, and diversity across all indices (Shannon, Simpson) reflecting limited species presence and dominance of a few species. In contrast, downstream sites (D3 and D4) supported significantly higher abundance and diversity, with the highest values generally observed during the monsoon season, indicating peak fish activity and optimal environmental conditions in comparison with other sampled sites. Midstream sites (D1 and D2) showed intermediate diversity. Evenness (Pielou's index) was generally high across all sites, suggesting a relatively uniform distribution of species. Multivariate analyses identified temperature, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), total alkalinity, and free CO_2 as key environmental determinants of fish assemblages. These parameters collectively structured community composition by influencing habitat quality and water chemistry. The upstream site exhibited low diversity and evenness due to limited ecological niches, whereas the downstream sections supported richer assemblages under more favorable physicochemical conditions. Overall, the results highlighted the ecological degradation of the upper Bagmati River and the need for targeted management interventions. Restoring water quality, reducing urban effluent discharge, and rehabilitating riparian zones are crucial for reestablishing ecological integrity and promoting the recolonization of sensitive taxa. Moreover, the demonstrated linkage between fish assemblage patterns and key water quality parameters reinforces the value of fish-based bioassessment as an effective tool for long-term ecological monitoring and sustainable watershed management in Nepal's urban river systems.

ACKNOWLEDGMENTS

The authors also appreciate Dr. Gana Bahadur Bajracharya, the head of analytical laboratory of Nepal Academy of Science and Technology (NAST) for his support. Mr. Ramesh Basnet, laboratory technician of Central Department of Environmental Science (CDES), Tribhuvan University for his technical support during laboratory work. Local fishermen who helped during fish sample collection were also appreciated.

AUTHORS CONTRIBUTION

Conceptualization: KPM; Methodology: KPM; Validation: TBT, KS; Investigation: KPM; Data analysis: KPM, JNA; Writing-original draft: KPM; Writing-review & editing: KPM, JNA, BRP, KS, TBT; Supervision: TBT; Funding acquisition: KPM

FUNDING

Nepal Academy of Science and Technology (NAST) (Grant number: 33; FY: 2022–2023).

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this article.

ETHICAL STATEMENT

We declare that it is our original work and has not been previously published or submitted for publication elsewhere.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available from the corresponding author, upon reasonable request.

SUPPLEMENTARY INFORMATION

None

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