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Diversity and Distribution of Freshwater Fishes of the Dano, Banganga, and Arung Khola Rivers of Western Nepal

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This study was conducted to generate foundational data on the fish diversity of three rivers in western Nepal. Three sampling sites were selected on each of the following rivers: the Dano River, the Banganga River, and the Arung Khola. Cast netting was conducted with the help of local fishermen during the post-monsoon, winter, and pre-monsoon seasons from 2018 to 2022. A total of 52 species belonging to 7 orders, 16 families, and 36 genera were recorded. Cypriniformes was the most dominant order across all river systems. *Garra simbalbaraensis* and *Glyptothorax striatus* were reported as new species for Nepal. The most abundant species were *Garra gotyla* in the Dano River and *Puntius sophore* in both the Banganga and Arung Khola. In contrast, *Schismatorhynchos nukta* and *Glyptothorax striatus* were each observed only once. The Dano River exhibited the highest species richness and diversity, suggesting more heterogeneous habitat with a balanced species distribution. All three river systems showed relatively high evenness, indicating that species were evenly distributed across the sampling sites. These findings provide vital baseline data and underscore the importance of continued research to monitor biodiversity trends and to support evidence-based conservation and management strategies for sustaining freshwater ecosystems in western Nepal.

Keywords: Fish diversity, *Garra simbalbaraensis*, *Glyptothorax striatus*, Richness, Species distribution

Freshwater ecosystems, which include lakes, rivers, streams, and wetlands, cover less than 1% of the Earth's surface yet support 9.5% of all described fauna (Reid et al., 2019). They are essential for biodiversity conservation, human water security, and ecological balance, playing a crucial role in regulating water flow and sustaining environmental health (Dudgeon, 2006). These ecosystems also provide critical habitats for diverse species, including aquatic plants, fish, reptiles, birds, and mammals (De Groot et al., 2002). Despite covering only, a small fraction of the Earth's surface, freshwater ecosystems are biodiversity hotspots supporting migratory and threatened species (Shuter et al., 2011). With over 400 major ecoregions and thousands of diverse aquatic habitats, these systems provide essential resources such as food, shelter, and breeding grounds, all of which play a vital role in species survival (Schofield et al., 2018). However, freshwater ecosystems face numerous threats, including pollution, agricultural runoff, industrial discharges, and urbanization (Camara et al., 2019); habitat destruction due to dam construction, deforestation, and land conversion (Scanes, 2018); and climate change, which disrupts hydrological cycles and alters precipitation patterns (Carpenter et al., 2011). Furthermore, the introduction of invasive species significantly disrupts ecological balance (David et al., 2017). A recent study highlights the alarming decline in freshwater biodiversity, showing that 24% of freshwater species are at risk of extinction, with nearly 1,000 considered critically endangered and 200 potentially already lost (Sayer et al., 2025).

Freshwater fish are a keystone of global biodiversity, with an estimated 37,106 species worldwide; 18,898 of these live exclusively in freshwater habitats (Fricke

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et al., 2025). Asia is particularly rich in freshwater fish diversity, hosting approximately 3,500 species with 559 endemics, with Cyprinidae and Balitoridae being prominent families (De Silva et al., 2007). Although they contribute to essential ecosystem functions such as nutrient cycling, sediment regulation, and habitat connectivity (Miranda & Miqueleiz, 2021), one-third of all freshwater fish species are threatened with extinction due to habitat destruction, overfishing, and pollution (WWF, 2021). For instance, over the past few decades, a significant decline in freshwater fish diversity and population has been reported from their natural habitats. Some species experienced up to 81% population decline between 1970 and 2012 (WWF Nepal, 2017), primarily due to various anthropogenic activities such as overfishing, pollution, destructive fishing practices, and developmental interventions (Saund & Shrestha, 2007; ADB, 2018).

Nepal harbors a significant portion of the world's biodiversity, including numerous endemic species across 118 ecosystems. It is home to over 200 fish species, with some estimates recording up to 258, reflecting the country's rich ichthyofaunal diversity (Khatri et al., 2020; Shrestha & Thapa, 2020). Although most research in Nepal has historically focused on species inventories rather than fish ecology (Smith et al., 1996; Shrestha, 2012), recent studies have begun to examine fish assemblages and their relation to environmental variables (Jha et al., 2018; Pokharel et al., 2018; Tumbahangfe et al., 2021). One of the primary reasons for declining fish diversity and abundance is the degradation of water quality.

For instance, the Bagmati River supports 117 fish species (Shrestha & Thapa, 2020), including 26 in its upper stretches (Shrestha, 1990); however, severe pollution from untreated wastewater and solid waste disposal in the Kathmandu Valley threatens its biodiversity (Mishra et al., 2017). Preserving ichthyofaunal diversity and maintaining freshwater systems, particularly in biodiverse regions like Nepal, requires addressing these environmental challenges. This study aimed to provide a checklist of fish species in the Dano River, Banganga River, and Arung Khola of western Nepal. These rivers were selected due to their ecological significance, biodiversity richness, and increasing anthropogenic pressures, which necessitate a better understanding of species–environment interactions for effective conservation and management.

Materials and methods

Study area and duration

The study was carried out in selected stretches of the Banganga River in Kapilvastu, Dano River in Rupandehi, and Arung Khola in Nawalpur, all located in western Nepal. Sampling was conducted at three sites on each river during three distinct seasons: pre-monsoon, post-monsoon, and winter between 2018 and 2022 (Figure 1).

Fish sampling and identification

Fish samples were collected with the help of local fishermen using cast nets (5mm and 15 mm mesh size) covering a 300-meter stretch both upstream and downstream. To validate the findings, local fishing gears - Ghorlang, Paso, Duwali Thunne, Dhadiya, Khoka, and Heluka-were also used. Relevant information, including fish count, length, weight, colour pattern, body form, morphological characteristics, and photographs, was recorded onsite. The representative individuals were preserved in 70% ethanol and brought to the laboratory of the Central Department of Zoology, Tribhuvan University, for further analysis. The remaining individuals were released back into their natural habitat. Finally, the collected samples were identified using standard literature (Shrestha, 1981, 1994; Talwar & Jhingran, 1991; Jayaram, 2012; Nebeshwar & Vishwanath, 2017; Rath et al., 2019; Shrestha, 2019; Vishwanath, 2021; Jayaram, 2022), and voucher specimens were deposited at Central Department of Zoology Museum, Tribhuvan University (CDZMTU), Kirtipur, Nepal.

Diversity indices

Various diversity indices were calculated to elucidate the seasonal diversity of fish. These included the Shannon-Weiner diversity index (H') (Shannon & Weaver, 1948), Simpson's index of diversity (1-D) (Simpson, 1949), Pielou's Evenness (J) (Pielou, 1966), and Margalef's diversity index (D_{Mg}) (Margalef, 1958)

Statistical analyses

Seasonal variations in fish assemblages were analyzed using the Kruskal-Wallis test (H) for multiple comparisons of abundance data across seasons. Temporal differences were further examined using Analysis of Similarity (ANOSIM). To assess the percentage contribution of species and the average dissimilarity between seasons, Similarity Percentage

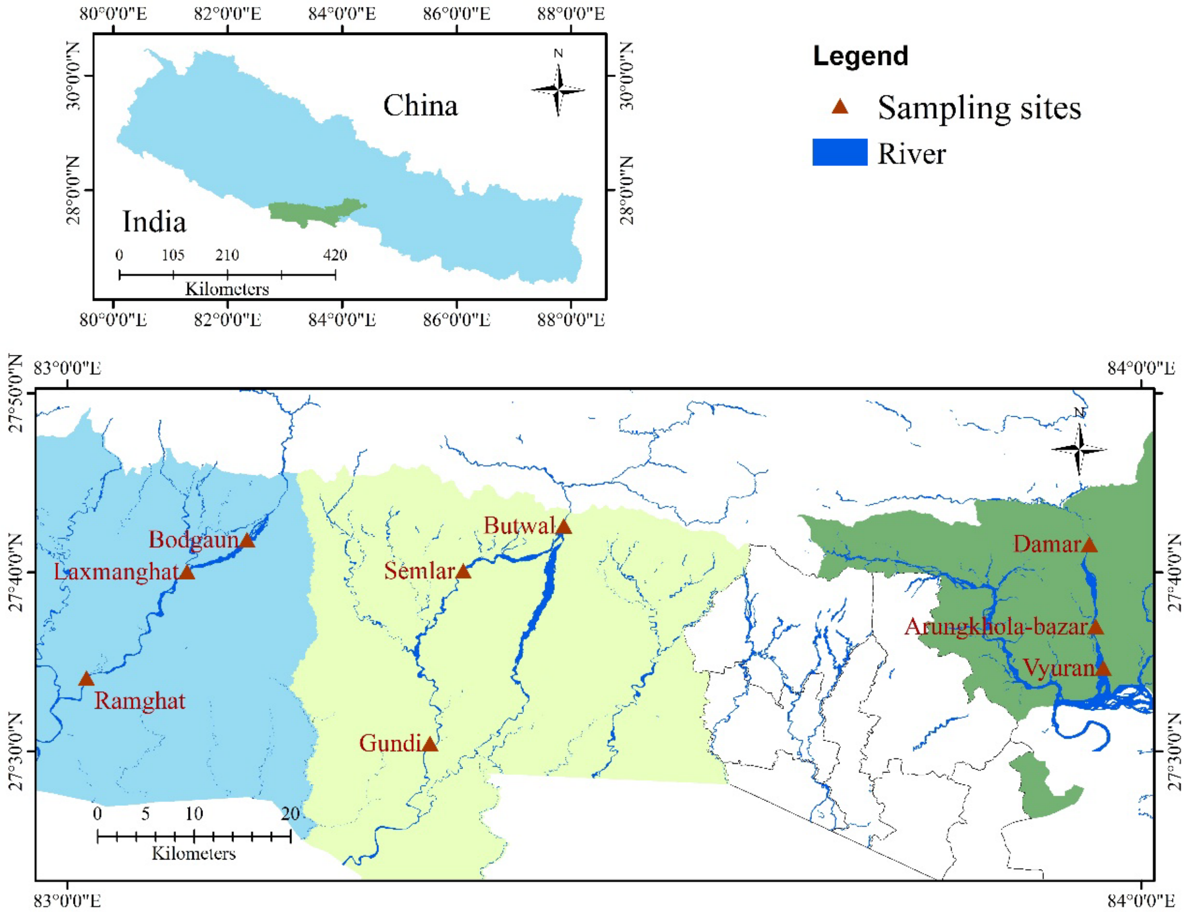

Figure 1: Map showing sampling sites marked with red triangles indicate the sampling sites in the three rivers

(SIMPER) analysis was also conducted (Clarke & Warwick, 1994). ANOSIM, SIMPER, and diversity indices were analyzed using R version 4.2.0 (R Core Team, 2022) in R Studio.

Results

Fish diversity

A total of 5,688 individuals, representing 52 species belonging to 7 orders, 16 families, and 36 genera, were recorded from the study area (Table 1). The Order *Cypriniformes* was the most dominant, comprising 29 species across all water bodies. A total of 1503 individuals belonging to 6 orders, 14 families, 26 genera, and 37 species were observed in the Dano River, whereas 20 species belonging to 6 orders, 11 families, and 16 genera with a total of 2360 individuals were observed in the Bangana River. Similarly, a total of 1825 individuals belonging to 4 orders, 9 families, 23 genera, and 31 species were observed in the Arung Khola (Table 1). Two species, *Garra simbalbaraensis* from the Dano River and *Glyptothorax striatus* from the Arung Khola, were recorded as new additions to the ichthyofaunal diversity of Nepal.

In the Dano River, Cypriniformes was the most diverse order, comprising five families and 22 species. It was followed by Siluriformes (four families, seven species), Anabantiformes (two families, three species), and Synbranchiformes (one family, three species). Beloniformes and Gobiformes were each represented by a single family and one species (Table 1; Figure 2).

In the Banganga river, Cypriniformes included five families with 13 species, followed by Siluriformes (two families, three species). The orders Anabantiformes, Beloniformes, Gobiformes, and Perciformes were each represented by one family and one species (Table 1; Figure 2).

In the Arung Khola, Cypriniformes was again the most diverse, with four families comprising 22 species. It was followed by Siluriformes (two families, five species), while Anabantiformes and Synbranchiformes were each represented by one family and one species (Table 1; Figure 2).

Table 1: Diversity of freshwater fishes from the three river systems of western Nepal

Order	Family	Species name	Dano	Bangana	Arung
		Channa gachua	√	×	√
Anabantiformes	Channidae	*Channa punctata*	√	√	×
		Channa stewartii	×	×	√
	Osphronemidae	*Trichogaster fasciata*	√	×	×
Beloniformes	Belonidae	*Xenontodon cancila*	√	√	×
	Botiidae	*Botia lohachata*	√	√	×
	Cobitidae	*Lepidocephalychthys guntea*	√	√	√
		Garra annandalei	√	√	√
		Garra gotyla	√	√	√
		Garra simbalbaraensis	√	×	×
		Tariqilabeo latius	√	×	√
		Chagunius chagunio	√	×	×
		Pethia conchonius	√	√	√
	Cyprinidae	*Puntius sophore*	√	√	√
		Pethia ticto	×	√	√
		Osteobrama cotio	×	√	×
		Cyprinion semiplotum	×	×	√
		Schismatorhynchos nukta	×	×	√
		Danio rerio	×	×	√
		Devario devario	×	×	√
		Amblypharyngodon mola	×	×	√
		Barilius barila	√	√	√
Cypriniformes		*Barilius vagra*	√	×	√
		Cabdio morar	√	×	×
	Danionidae	*Opsarius barna*	√	√	√
		Opsarius bendelisis	√	√	√
		Salmostoma bacaila	√	×	√
		Laubuka laubuca	√	×	×
		Esomus danrica	√	√	√
		Acanthocobitis botia	√	√	√
		Nemacheilus corica	√	×	×
		Schistura beavani	√	×	√
	Nemacheilidae	*Schistura sps 1*	√	×	×
		Schistura sps 2	√	×	×
		Schistura sps 3	×	×	√
		Schistura sps 4	×	×	√
Gobiformes	Gobiidae	*Glossogobius giuris*	√	√	×
Perciformes	Ambassidae	*Chanda nama*	×	√	×
	Amblycipitidae	*Amblyceps mangois*	√	×	√
		Mystus bleekeri	√	×	×
		Mystus cavasius	√	×	×
	Bargidae	*Mystus tengara*	√	√	×
		Mystus vittatus	√	√	×
	Heteropneustidae	*Heteropneustes fossilis*	√	×	×
Siluriformes	Schilbeidae	*Eutropiichthys vacha*	×	√	×
		Pseudecheneis sulcata	√	×	√
		Myersglanis blythii	×	×	√
	Sisoridae	*Glyptothorax trilineatus*	×	×	√
		Glyptothorax striatus	×	×	√
		Mastacembelus armatus	√	×	√
		Macrognathus pancalus	√	×	√
Synbranchiformes	Mastacembelidae	*Macrognathus lineatomaculatus*	√	×	×

Note: √ = Present, × = Absent

Fish richness, abundance, and community composition

Out of 52 species, twelve species were found only in the Dano River, and three species were observed only in the Banganga River, while eleven species were found only in the Arung Khola. Ten species - *Lepidocephalychthys guntea, Garra annandalei, Garra gotyla, Pethia conchonius, Puntius sophore, Barilius barila, Opsarius barna, Opsarius bendelisis,* *Esomus danrica,* and *Acanthocobitis botia* were common to all river systems. The orders Beloniformes and Gobiformes were not recorded in the Arung Khola; Perciformes were absent from both the Dano River and Arung Khola, while Synbranchiformes were absent from the Banganga River. In the Dano River, *Garra gotyla* was the most abundant species with 271 individuals, while *Nemacheilus corica*, *Mystus bleekeri*, and *Macrognathus lineatomaculatus* were represented by only two individuals each. In the Banganga River, *Puntius sophore* was the most abundant species with 683 individuals, whereas *Botia lohachata* was the least abundant, with just 6 individuals. In the Arung Khola, 333 individuals of *Puntius sophore* were recorded, while *Schismatorhynchos nukta* and *Glyptothorax striatus* were rare, with only a single individual of each recorded during sampling.

The site-wise values of species richness and various species diversity indices, including the Shannon–Wiener diversity index (H'), Simpson's index of diversity (1-D), Pielou's Evenness (J), and Margalef's diversity index (D_{Mg}), were calculated. In the Dano River system, the Shannon–Wiener index (H') ranged from 1.96 to 2.74, with a mean value of 2.32 ± 0.40. Simpson's index of diversity (1-D) ranged from 0.77 to 0.91, with a mean of 0.85 ± 0.07. Pielou's evenness (J) ranged from 0.66 to 0.85, with a mean of 0.78 ± 0.10. Margalef's diversity index ranged from 2.36 to 4.05, with a mean of 3.04 ± 0.89. In the Banganga River system, the mean Shannon–Wiener index (H') was 1.95 ± 0.11, Simpson's index of diversity (1-D) was 0.82 ± 0.03, Pielou's evenness (J) was 0.78 ± 0.07, and Margalef's diversity index was 1.74 ± 0.37. In the Arung Khola system, the mean Shannon–Wiener index (H') was 2.25 ± 0.37, Simpson's index of diversity (1-D) was 0.85 ± 0.05, Pielou's evenness (J) was 0.78 ± 0.05, and Margalef's diversity index was 2.75 ± 0.88 (Table 2).

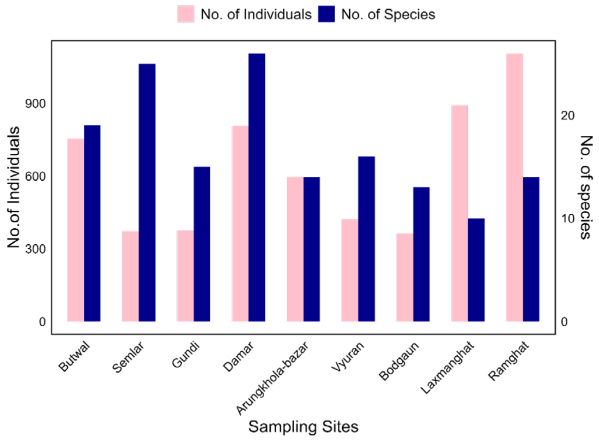

Figure 2: Total number of catches and fish species recorded at different sites from the Dano River, Banganga River, and Arung Khola

The Kruskal-Wallis test revealed significant differences in species abundance among the three sites of the Dano River (H = 10.82, df = 2, P = 0.004). Post hoc Dunn's test identified significant pairwise differences: 13 species differed between Butwal and Gundi, 12 species between Butwal and Semlar, and eight species between Gundi and Semlar (Table 3). Further analysis using ANOSIM (R = 0.92, P = 0.0001) confirmed significant differences in species composition among sites. SIMPER analysis indicated an overall average dissimilarity of 78.57%, with key contributing species including *Garra gotyla*, *Garra annandalei*, and *Salmostoma bacaila* (Table 4). Similarly, the Kruskal-Wallis test revealed significant differences in species abundance among the three sampling sites of the Banganga River (H = 13.35, df = 2, P = 0.001). Post hoc Dunn's test indicated significant pairwise differences, with five species

Table 2: Diversity Indices of different sites of the three river system of Western Nepal

River	Sample	Species Richness	H′	(1−D)	J	D_{Mg}
Dano	Butwal	19.00	1.96	0.77	0.66	2.72
	Gundi	15.00	2.26	0.87	0.83	2.36
	Semlar	25.00	2.74	0.91	0.85	4.05
	Mean		**2.32**	**0.85**	**0.78**	**3.04**
	SD		**0.40**	**0.07**	**0.10**	**0.89**
Banganga	Bodgaun	13.00	2.08	0.85	0.81	2.04
	Laxmanghat	10.00	1.91	0.82	0.83	1.32
	Ramghat	14.00	1.87	0.78	0.71	1.85
	Mean		**1.95**	**0.82**	**0.78**	**1.74**
	SD		**0.11**	**0.03**	**0.07**	**0.37**
Arungkhola	Arungkhola-bazar	14.00	1.89	0.80	0.72	2.03
	Damar	26.00	2.62	0.90	0.80	3.74
	Vyuran	16.00	2.24	0.85	0.81	2.48
	Mean		**2.25**	**0.85**	**0.78**	**2.75**
	SD		**0.37**	**0.05**	**0.05**	**0.88**

differing between Bodgaun and Laxmanghat, eight species between Bodgaun and Ramghat, and nine species between Laxmanghat and Ramghat (Table 3). ANOSIM confirmed a significant difference in species composition (R = 0.84, P = 0.001), and SIMPER analysis revealed an average dissimilarity of 61.69%, with *Pethia conchonius*, *Esomus danrica*, and *Chanda nama* contributing most to the dissimilarity (Table 4).

In the Arung Khola, the Kruskal-Wallis test (H) also showed significant differences in species abundance (H = 9.84, df = 2, P = 0.007). Dunn's post hoc test identified 11 species differing between Arungkhola Bazar and Damar, one species between Arungkhola Bazar and Vyuran, and 10 species between Damar and Vyuran (Table 3). ANOSIM confirmed significant compositional differences (R = 0.78, P = 0.001), and SIMPER analysis indicated an overall average dissimilarity of 61.82%, with major contributors being *Cyprinion semiplotum*, *Puntius sophore*, and *Pethia conchonius* (Table 4). In contrast, the Kruskal-Wallis test (H) revealed no significant differences (P > 0.05) in overall abundance patterns across the three seasons in any of the river systems. However, Dunn's post hoc test identifies significant variation in specific species during the study period.

Discussion

The presence of 52 fish species across just three water bodies reflects the rich ichthyofaunal diversity of the study area. The predominance of the order Cypriniformes, represented by 29 species, aligns with earlier findings that highlight the dominance of cyprinids in South Asian freshwater ecosystems, attributed to their ecological adaptability and evolutionary radiation (Talwar & Jhingran, 1991; Jayaram, 2012). Among the families, Danionidae and Cyprinidae were the most dominant, consistent with prior studies from various freshwater systems in Nepal (Shrestha, 2012; Rajbanshi, 2012; Jha et al., 2018; Khatri et al., 2024) and also globally (Cheok & Soo, 2022; Debnath et al., 2022).

Species composition varied across water bodies, with some species absent compared to historical records. For instance, Shrestha (2005) reported species such as *Channa orientalis*, *Pethia ticto*, *Schistura devdevi*, and *Schistura rupecula* in the Dano River, but these were not recorded in this study. Likewise, Jha (2006) recorded 21 species in the Arung Khola with a dominance of loaches. These differences in species richness could be attributed to variations in sampling frequency, site selection, and seasonal changes (Zhao et al., 2017).

Among the recorded species, the consistent presence of *Pethia conchonius*, *Puntius sophore*, *Acanthocobitis botia*, *Esomus danrica*, and *Lepidocephalichthys guntea* across all sites and seasons suggests that these species possess broad ecological tolerance and a high degree of resilience to environmental variability (Fausch et al., 1990; Pinna et al., 2023).

Table 3: List of fish species across seasons in the sampled water bodies

Water bodies	Species name	H	df	P value	Dunn's Test
Dano River	*Barilius barila*	6.25	2	0.044	Pre-monsoon-Winter
	Schistura beavani	7.16	2	0.028	Post monsoon- Winter
	Mastacembelus armatus	6.73	2	0.035	Post monsoon-pre monsoon, Post monsoon- Winter
Banganga River	*Channa punctata*	6.73	2	0.035	Post monsoon- Pre monsoon, Post monsoon- Winter
	Xenentodon cancila	7.81	2	0.02	Post monsoon- Winter
	Garra annandalei	6.42	2	0.04	Post monsoon-Pre monsoon
Arung Khola	*Lepidocephalychthys guntea*	10.89	2	0.004	Post monsoon- Winter
	Barilius barila	11.98	2	0.003	Post monsoon-Pre monsoon, Post monsoon- Winter
	Laubuka laubuca	14.29	2	0.001	Post monsoon-Pre monsoon, Pre-monsoon- Winter
	Esomus danrica	7.86	2	0.02	Post monsoon-Pre monsoon, Pre-monsoon- Winter

Table 4: Average dissimilarity and key contributors of different water bodies of Western Nepal

Water bodies	R	P value	Dissimilarity	Key Contributors
Dano River	0.92	0.001	78.57%	*Garra gotyla*, *Garra annandalei*, *Salmostoma bacaila*
Banganga River	0.84	0.001	61.69%	*Pethia conchonius*, *Esomus danrica*, *Chanda nama*
Arung Khola	0.79	0.001	61.82%	*Cyprinion semiplotum*, *Puntius sophore*, *Pethia conchonius*

In contrast, the rare occurrence of species like *Garra simbalbaraensis* and *Glyptothorax striatus* suggests niche specialization and higher sensitivity to habitat changes, as *Garra simbalbaraensis* typically inhabits benthopelagic zones with muddy or sandy substrates, while *Glyptothorax striatus* prefers fast-flowing streams and adheres to rocks using its specialized thoracic adhesive organs (Rath et al., 2019; Pathak et al., 2023).

Among the three river systems, the Dano River supported the highest species richness (37 species), likely due to its greater habitat heterogeneity and availability of diverse microhabitats that support various ecological niches (Allan & Castillo, 2009). The dominance of Cypriniformes (22 species, five families), followed by Siluriformes and Anabantiformes, indicates a balanced community structure comprising both benthic and pelagic species (Kantharajan et al., 2022). In contrast, the Banganga River, despite having the highest number of individuals (2,360), supported only 20 species. This pattern of low richness but high abundance may reflect ecological stress or habitat simplification, conditions that often favor a limited number of tolerant species (Karr & Dudley, 1981). The Arung Khola exhibited moderate species richness (31 species from 4 orders). Although fewer taxonomic orders were represented, the dominance of Cypriniformes (22 species) once again highlights their ecological plasticity. Notably, the presence of Synbranchiformes in the Arung Khola reflects the occurrence of species adapted to specialized or low-oxygen environments (Nelson et al., 2016). Overall, the variation in taxonomic composition and species richness among the river systems underscores the influence of environmental conditions, stream order, substrate diversity, and anthropogenic pressures on fish assemblages.

Biodiversity indices such as the Shannon–Wiener index, Simpson's index, and Margalef's diversity index provide insights into species richness and distribution across seasons. The highest species richness was observed in the Dano River, particularly during the post-monsoon season, while the Banganga River exhibited the lowest diversity. These indices revealed notable variations in fish community structure among the three river systems. The Dano River recorded the highest species richness and diversity, suggesting a more heterogeneous habitat and a well-balanced species distribution—likely due to favorable environmental conditions and relatively low levels of anthropogenic disturbance (Massicotte et al., 2015; Spurgeon et al., 2018). In contrast, the Banganga River showed lower diversity, reflecting a relatively species-poor community. This reduced diversity may be attributed to factors such as habitat degradation, water abstraction, and pollution, all of which are known to negatively impact aquatic biodiversity (Allan & Castillo, 2009). The Arung Khola displayed intermediate levels of diversity, with relatively high evenness and diversity, suggesting that species were more evenly distributed across the sampling sites.

The observed significant spatial variations in fish abundance and community composition across the sampling sites indicate the influence of localized environmental factors and habitat heterogeneity on fish distribution. The Kruskal–Wallis and Dunn's tests revealed clear differences in species abundance among sites within each river system, suggesting that habitat conditions such as flow regime, substrate type, and anthropogenic disturbances likely shape species assemblages (Gorman & Karr, 1978; Oberdorff et al., 1993). High dissimilarity values from SIMPER analysis, along with strong ANOSIM results, further confirm distinct community structures among sites. Key contributing species such as *Garra gotyla*, *Puntius sophore*, and *Pethia conchonius* demonstrated varying dominance across locations, reflecting differences in ecological preferences and tolerance levels (Bose et al., 2019; Yang et al., 2021). The high R-values from ANOSIM (e.g., $R = 0.92$) indicate strong spatial segregation in fish communities, supporting the idea of habitat partitioning and site-specific pressures influencing species distribution (Jackson et al., 2001).

In contrast, seasonal variation in overall species abundance was not significant, indicating temporal stability in community composition. However, Dunn's test revealed some species-specific responses to seasonal changes, likely due to reproductive cycles or migratory behavior (Lévêque et al., 2008). This suggests that, while the overall community structure remains stable, certain species may be more sensitive to temporal environmental shifts.

Conclusion

This study provides valuable baseline information on the ichthyofaunal diversity of three river systems, documenting a total of 52 fish species, with a dominance of the order Cypriniformes. The dominance of species such as *Garra gotyla* in the Dano River and *Puntius sophore* in both the Banganga

River and the Arung Khola highlights the ecological adaptability and resilience of these taxa. Conversely, the rare occurrences of *Schismatorhynchos nukta* and *Glyptothorax striatus* indicate the presence of specialized and potentially vulnerable taxa.

High values of species evenness and diversity across sites suggest relatively balanced community structures. In contrast, significant differences in species composition and high dissimilarity among sites, as revealed by ANOSIM and SIMPER analyses, underscore the unique ecological character of each river system. These findings provide crucial baseline data for long-term ecological monitoring and freshwater biodiversity assessments in the region. Continuous monitoring and integrative habitat assessment will be essential to support sustainable management and conservation planning for these freshwater ecosystems.

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Author contribution

SS: Conducted fieldwork, laboratory analysis, data preparation, statistical analysis, manuscript conception, design, and drafting; **KK**: Performed laboratory work, data analysis, manuscript conception, design, and drafting; **NS**: Assisted in fieldwork, laboratory analysis, data preparation, and logistical arrangements; **RCP**: Provided conceptualization, supervision, manuscript review, and editing; **KS**: Contributed to conceptualization, supervision, manuscript review, and final approval

Conflict of interests

The authors declare no conflict of interest.

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