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Seasonal Distribution and Diversity of Fish Community in Anthropogenic Prone Zone of Ganga River

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***Abstract*:** This study investigates fish biodiversity in the midstream region between Kanpur and Ramnagar, focusing on the effects of anthropogenic pressures like as pollution and habitat fragmentation on species diversity and distribution Seasonal sampling at nine sites during three years (2022-2024) documented 109 fish species from 71 taxa and 31 families, with Cyprinidae being the most abundant. The Shannon-Wiener Diversity Index (H') peaked at 4.25 at site Prayagraj while the Evenness Index (E^H/S) reached 0.52 at site Varanasi post-winter and the Margalef Index peaked at 4.67 at site Varanasi post-summer. Relative abundance (RA) data revealed seasonal dynamics, with *Channa striata* having consistent RA values of 7.92 (post-summer), 6.57 (post-winter), and 5.82 (post-monsoon), whereas *Acanthocobitis botia* had lower, inconsistent values of 0.20 (post-summer), 0.34 (post-winter), and 0.12 (post-monsoon). Sites Prayagraj and Varanasi were classified as biodiversity hotspots, while Bahupura and Chunar had lower richness. The findings emphasize the impact of environmental and anthropogenic variables on fish biodiversity. Sustainable fishing and habitat restoration are critical conservation techniques for maintaining biodiversity and the Ganga River's ecological health.

***Keywords*:** Ganga River, Fish biodiversity, Biodiversity indices, Threats, Conservation

Fish variety is important for local food security, income, and cultural traditions (Garcia et al., 2021), as well as the survival of endangered species like dolphins (*Platanista gangetica*) and gharials (*Gavialis gangeticus*) (Chaudhary et al., 2023). Fish health is critical for maintaining ecological stability and resilience (Singh and Das 2022). However, anthropogenic activities such as overfishing, habitat fragmentation, pollution, and climate change pose a serious danger to freshwater fish diversity by degrading habitats and reducing populations (Kumar et al., 2023, Roy and Sharma 2023). Conservation methods such as sustainable fishing, ecosystem restoration, and pollution reduction are critical for ecological balance and long-term community livelihoods (Sharma et al., 2022).

Fish diversity studies employing measures such as Species Richness, Shannon-Wiener Diversity Index (H'), Simpson's Diversity Index (D), and Evenness Index (J') provide information about biodiversity and ecological complexity (Magurran, 2013; Shannon 1948, Pielou 1966). The Fish Community Index (FCI) is an effective measure for correlating fish community health to environmental factors (Bouvier et al., 2022). Monitoring these metrics aids in developing effective conservation strategies for sustainable fisheries management (Patel and Joshi 2024).

The Ganga River, which stretches over 2,500 kilometres, is ecologically, culturally, and historically significant. Its midstream portion between Kanpur and Varanasi supports around 140 native fish species, including economically important carps that benefit local fishing populations (Sarkar et al., 2011). This area is crucial for balancing upstream purity and downstream stresses, but it confronts difficulties from temperature changes, changed flow regimes, and invasive species including *Cyprinus carpio* and *Oreochromis mossambicus* (Krishnamurti et al., 2021, Lakra et al., 2022).

The key objectives are to measure seasonal fish diversity, analyse the effects of pollution and habitat fragmentation, investigate community conservation activities, and propose strategies for sustainable fishing and habitat restoration in the Ganga River.

MATERIAL AND METHODS

The study was carried out over the 340-kilometer main stretch of the Ganga River from Kanpur to Ramnagar, which included areas upstream and downstream of Prayagraj which, because of their high levels of urbanization, industrial discharge, agricultural runoff, and religious activities, are acknowledged as anthropogenic prone zones. Nine sampling sites were strategically selected to represent varied land use patterns and anthropogenic pressures-including industrial, agricultural, semi-urban, urban, pilgrimage, and residential areas (Table 1, Fig. 1). Seasonal fish migratory and spawning cycles, which are important for riverine fish biodiversity, were investigated from 2022 to 2024 during the post-monsoon, post-winter, and post-summer seasons.

Sampling design and frequency: For representative sample, several local fishing methods were utilized, such as weirs, trap nets, gillnets, cast nets, hook and line, and lift nets. Trap nets had the largest species diversity, validating the idea

that gear type effects freshwater fish composition (Pandey et al., 2023). Standardized fishing with varied mesh sizes, as well as cooperation from local fishermen, enabled a wide range of species representation.

Sampling was recorded seasonally at each location, with one sampling session per season. Each session included systematic experimental fishing from 07:00 to 13:00 hours to account for diel fluctuations in fish activity. Standard fishing gear with varied mesh sizes were utilized, including:

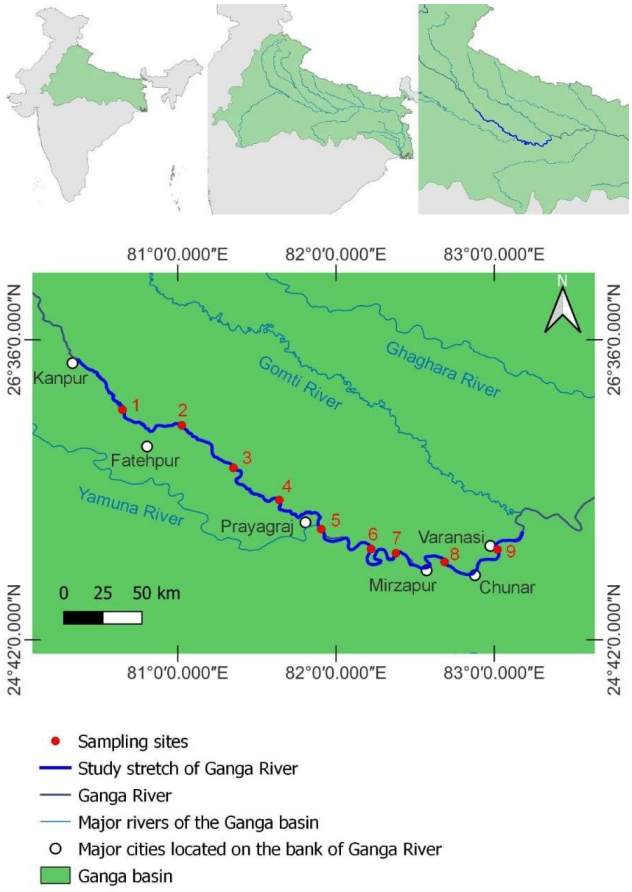

Fig. 1. Study area showing study sites, Ganga River, India

Gill nets: 2.5×2.5 cm, 3×3 cm, and 7×7 cm mesh sizes, with dimensions 75×1.3 m and 50×1 m.

Cast nets: 6×6 mm mesh, deployed 30 times per session with a settling time of 3 to 5 minutes, covering approximately 100 m² per river reach as per Bain and Knight (1996).

Drag nets: 7×7 mm mesh, measuring 80×2.5 m.

Fry collection nets*:* Nylon mosquito mesh for capturing juvenile and smaller fish species.

Approximately 10% of specimens were kept in 10% formaldehyde for identification (Talwar and Jhingran 1991, Jayaram 1999). Fish market trips helped to identify commercially valuable species (Ramesh and Gupta 2023). Primary and secondary data were used to examine fish biodiversity and ecological health under anthropogenic stress at nine sites (Kanpur- Ramnagar) (S1-S9) throughout the post summer, post winter and post monsoon seasons. The analysis uses three ecological metrics:

Shannon-Wiener Diversity Index (H'):

$H = -\Sigma (ni/N) \log 2 (ni/N)$

Where: H = Shannon–Wiener index of diversity, ni = Total numbers of individuals of species, N = Total number of individuals of all species.

Pielou's Evenness Index (E^H/S):

$E = H/\ln S$

Where: H =Diversity index, S = Total number of species

Margalef's Richness Index (D_Mg):

$d = S-1/\ln N$

Where: S = Total No. of species, N = Total No. of individuals of all species

RESULTS AND DISCUSSION

Fish diversity and taxonomic composition: The 109 fish species in nine Ganga River localities, representing 71 taxa and 31 families were recorded. Five families (Bagridae, Channidae, Siluridae, Schilbeidae, and Cyprinidae) were observed at every location, indicating widespread dispersion. Midstream zones had increased species

Table 1. Details of the sampling sites

Site	Location	Coordinates (Latitude, Longitude)	Altitude (ft)	Land use pattern
S1	Kanpur	26.4499° N, 80.3319° E	~410	Industrial, urban
S2	Dalerganj	25.6470° N, 81.9245° E	~300	Agricultural, rural
S3	Fatehpur	25.9273° N, 80.8135° E	~331	Agricultural, semi-urban
S4	Prayagraj	25.4358° N, 81.8463° E	~299	Urban, pilgrimage, cultural
S5	Bahupura	25.1330° N, 82.5654° E	~260	Agricultural, rural
S6	Mirzapur	25.1450° N, 82.5698° E	~266	Urban, semi-industrial
S7	Chunar	25.1263° N, 82.8839° E	~275	Agricultural, rural
S8	Varanasi	25.3176° N, 82.9739° E	~266	Urban, pilgrimage, cultural
S9	Ramnagar	25.2766° N, 82.9950° E	~275	Urban, residential

richness owing to steady flow and nutrients, which supported piscivorous and omnivorous fish such as Bagridae and Schilbeidae (Rai and Singh 2022, Sharma and Singh 2022). Cyprinidae, known for their ecological endurance, accounted for 45% of the fauna (43 species). Cyprinidae accounted for 39%, followed by Bagridae, Sisoridae and Channidae (Sinha et al., 2023). The majority of species were classified as Least Concern (LC), with *Ailia coila* and *Pangasius pangasius* listed as Vulnerable (VU). The RA suggested seasonal fluctuation; *Puntius terio* peaked in PS (12.50) but declined in PM (3.42), but *Bagarius bagarius* had consistently low RA, indicating the need for conservation (Table 2).

Spatial and seasonal variations in species richness The Shannon-Wiener diversity map (Fig. 3) revealed hotspots in Prayagraj (4.253) and Varanasi (4.175), whereas Bahupura (3.69) had the least diversity. Contour lines demonstrated biodiversity shifts, linking pollution and habitat degradation to

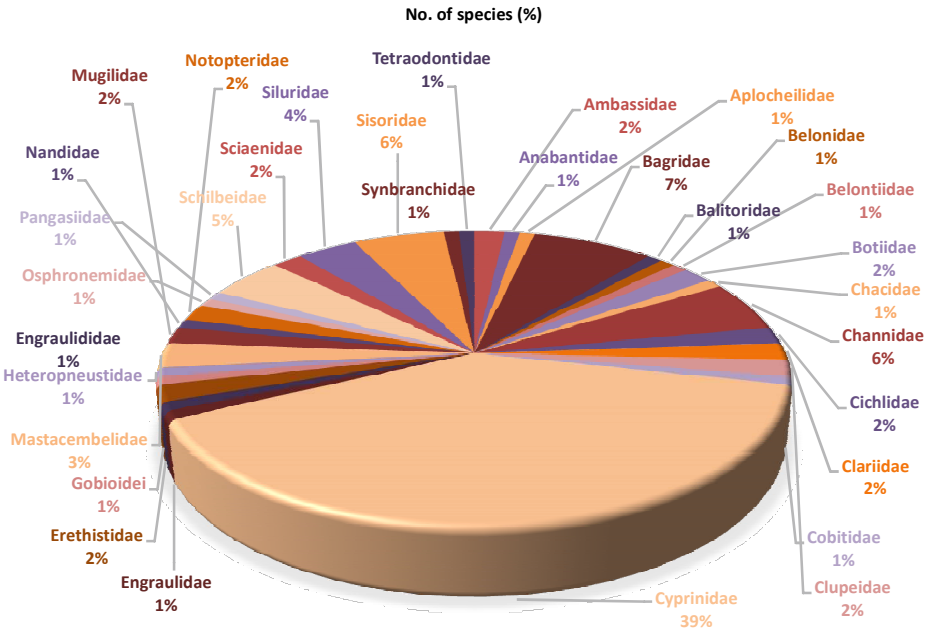

Fig. 2. Percentage composition of different fish species (families), Ganga River, India

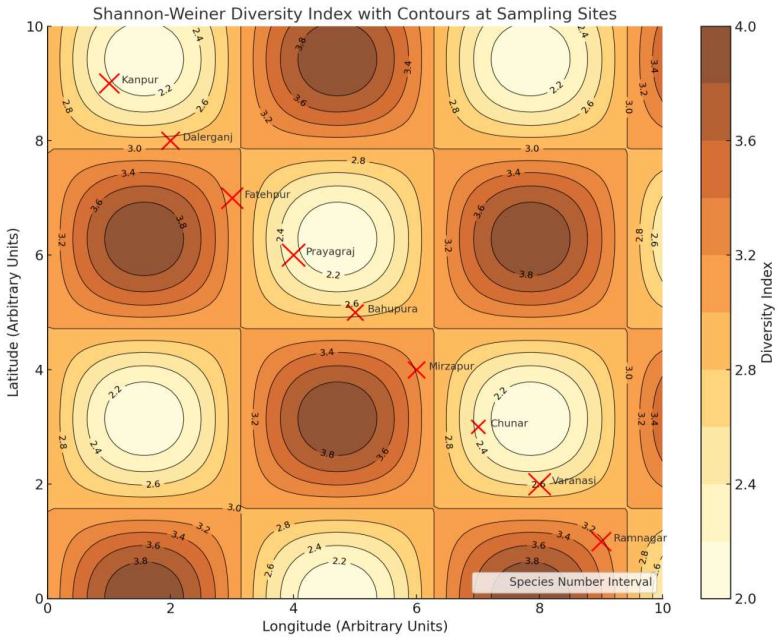

Fig. 3. Shannon-Weiner diversity index at different sampling sites of Ganga River

Table 2. Native and non-native fish species in the middle stretch of the Ganga River with conservation status and seasonal relative abundance (RA)

Scientific name	Order	Family	Abbreviation	iucn status	RA (PS)	RA (PW)	RA (PM)	Nativity
Acanthocobitis botia	Cypriniformes	Balitoridae	ABC	(LC)	0.20	0.34	0.12	Native
Ailia coila	Siluriformes	Schilbeidae	ACS	(VU)	3.52	0.34	3.04	Native
Ambastaia lohachata	Cypriniformes	Botiidae	ALC	(LC)	2.84	2.97	2.22	Native
Amblipharyngodon mola	Cypriniformes	Cyprinidae	AMC	(LC)	2.21	3.85	2.19	Native
Anabas testudineus	Anabantiformes	Anabantidae	ATA	(LC)	0.45	2.00	1.14	Native
Aplocheilus panchax	Cyprinodontiformes	Aplocheilidae	APC	(LC)	3.52	1.56	0.83	Native
Aspidoparia jaya	Cypriniformes	Cyprinidae	AJC	(LC)	2.02	2.32	2.43	Native
A. morar	Cypriniformes	Cyprinidae	AOC	(LC)	0.44	1.29	1.14	Native
Bagarius bagarius	Siluriformes	Sisoridae	ABS	(EN)	0.58	0.68	0.25	Native
Batasio batasio	Siluriformes	Bagridae	BBS	(LC)	1.59	1.66	0.70	Native
Bengala elanga	Cypriniformes	Cyprinidae	BEC	(DD)	1.81	4.58	1.93	Native
Botia dario	Cypriniformes	Botiidae	BDC	(LC)	3.36	5.42	2.56	Native
Brachydanio rerio	Cypriniformes	Cyprinidae	BRC	(LC)	1.80	0.66	1.11	Native
Chaca chaca	Siluriformes	Chacidae	CCS	(LC)	0.48	1.56	0.25	Native
Chagunius chagunio	Cypriniformes	Cyprinidae	CHY	(LC)	1.34	2.48	1.12	Native
Chanda nama	Perciformes	Channidae	CNP	(LC)	1.03	1.23	0.49	Native
Channa marulius	Anabantiformes	Channidae	CMA	(LC)	4.66	7.47	3.46	Native
C. orientalis	Perciformes	Channidae	COP	(LC)	1.05	1.39	0.74	Native
C. punctatus	Perciformes	Channidae	CPP	(LC)	5.26	1.89	3.39	Native
C. stewartii	Perciformes	Channidae	CSP	(LC)	0.55	1.34	0.49	Native
C. striata	Perciformes	Channidae	CTP	(LC)	7.92	6.57	5.82	Native
Chela cachius	Cypriniformes	Cyprinidae	CAC	(LC)	0.64	1.68	0.49	Native
C. laubuca	Cypriniformes	Cyprinidae	CLC	(LC)	0.68	1.29	0.25	Native
Chitala chitala	Osteoglossiformes	Notopteridae	CCO	(LC)	0.48	2.05	0.00	Native
Cirrhinus mrigala	Cypriniformes	Cyprinidae	CMC	(LC)	1.02	1.16	0.97	Native
C. reba	Cypriniformes	Cyprinidae	CRC	(LC)	6.35	1.00	4.25	Native
Clarias batrachus	Siluriformes	Clariidae	CBS	(LC)	4.88	8.10	3.18	Native
C. gariepinus	Siluriformes	Clariidae	CGS	(LC)	3.38	3.95	3.11	Non-Native
Clupisoma garua	Siluriformes	Schilbeidae	CAS	(LC)	2.56	1.16	2.47	Native
Colisa fasciatus	Perciformes	Belontiidae	CFP	(LC)	4.03	5.68	3.81	Native
Crossocheilus latius	Cypriniformes	Cyprinidae	CLP	(LC)	0.90	2.32	0.84	Native
Ctenopharyngodon idella	Cypriniformes	Cyprinidae	CIC	(LC)	0.41	1.56	1.49	Non-Native
Cyprinus carpio	Cypriniformes	Cyprinidae	CPC	(LC)	2.67	2.68	3.13	Non-Native
Danio devario	Cypriniformes	Cyprinidae	DDC	(LC)	4.07	3.71	2.89	Native
Erethistes pusilus	Siluriformes	Erethistidae	EPS	(LC)	2.11	2.07	1.10	Native
Eutropiichthys murius	Siluriformes	Schilbeidae	EMS	(VU)	0.49	1.39	0.84	Native
E. vacha	Siluriformes	Schilbeidae	EVS	(LC)	0.68	0.34	0.76	Native
Gagata cenia	Siluriformes	Sisoridae	GCS	(LC)	3.02	1.63	1.66	Native
G. gagata	Siluriformes	Sisoridae	GGS	(LC)	0.65	3.29	0.77	Native
Garra gotyla	Cypriniformes	Cyprinidae	GGC	(LC)	3.54	2.05	1.19	Native
Glossogobius giuris	Perciformes	Gobioidei	GGP	(LC)	1.54	4.05	0.36	Native
Gonialosa manmina	Clupeiformes	Clupeidae	GMC	(LC)	0.39	0.95	0.64	Native

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Scientific name	Order	Family	Abbreviation	iucn status	RA (PS)	RA (PW)	RA (PM)	Nativity
Gudusia chapra	Clupeiformes	Clupeidae	GCC	(LC)	0.94	3.70	2.04	Native
Hara hara	Siluriformes	Erethistidae	HHS	(LC)	5.32	9.44	2.53	Native
Heteropneustes fossilis	Siluriformes	Heteropneustidae	HFS	(LC)	0.49	5.18	2.09	Native
Hypophthalmichthys molitrix	Cypriniformes	Cyprinidae	HMC	(LC)	1.83	4.76	2.03	Non-Native
H. nobilis	Cypriniformes	Cyprinidae	HNC	(LC)	0.76	2.44	1.11	Non-Native
Johnius coitor	Perciformes	Sciaenidae	JCP	(LC)	1.84	1.39	1.08	Native
J. gangeticus	Perciformes	Sciaenidae	JGP	(LC)	1.34	4.54	0.88	Native
Labeo angra	Cypriniformes	Cyprinidae	LCC	(LC)	2.23	0.89	0.96	Native
L. bata	Cypriniformes	Cyprinidae	LBC	(LC)	5.55	1.66	1.13	Native
L. boga	Cypriniformes	Cyprinidae	LOC	(LC)	2.36	0.27	1.07	Native
L. boggut	Cypriniformes	Cyprinidae	LGC	(LC)	0.68	1.69	1.78	Native
L. calbasu	Cypriniformes	Cyprinidae	LAC	(LC)	2.54	3.32	1.61	Native
L. catla	Cypriniformes	Cyprinidae	LTC	(LC)	5.63	3.26	3.54	Native
L. dero	Cypriniformes	Cyprinidae	LDC	(LC)	5.67	1.23	2.74	Native
L. gonius	Cypriniformes	Cyprinidae	LNC	(LC)	1.95	1.00	0.49	Native
L. pangusia	Cypriniformes	Cyprinidae	LPC	(LC)	1.18	0.89	0.61	Native
L. rohita	Cypriniformes	Cyprinidae	LRC	(LC)	0.44	1.23	1.03	Native
Lepidocephalichthys guntea	Cypriniformes	Cobitidae	LUC	(LC)	0.65	2.53	1.49	Native
Macrognathus aral	Perciformes	Mastacembelidae	MAP	(LC)	1.25	1.71	1.62	Native
M. pancalus	Perciformes	Mastacembelidae	MPP	(LC)	5.35	2.10	7.41	Native
Mastacembelus armatus	Perciformes	Mastacembelidae	MRP	(LC)	16.50	0.95	8.06	Native
Monopterus cuchia	Synbranchiformes	Synbranchidae	MCS	(LC)	8.86	3.29	3.89	Native
Mystus bleekeri	Siluriformes	Bagridae	MBS	(LC)	6.19	3.74	2.00	Native
M. cavasius	Siluriformes	Bagridae	MAS	(LC)	1.18	2.76	4.14	Native
M. tengara	Siluriformes	Bagridae	MTS	(LC)	7.32	1.23	3.30	Native
M. vittatus	Siluriformes	Bagridae	MVS	(LC)	1.47	2.57	1.77	Native
Nandus nandus	Perciformes	Nandidae	NNP	(LC)	4.24	5.33	1.30	Native
Nangra nangra	Siluriformes	Sisoridae	NNS	(VU)	0.54	2.11	0.74	Native
N. punctata	Siluriformes	Sisoridae	NPS	(LC)	1.25	3.87	0.62	Native
Notopterus notopterus	Osteoglossiformes	Notopteridae	NNO	(LC)	1.97	1.00	0.48	Native
Ompok bimaculatus	Siluriformes	Siluridae	OBS	(LC)	0.99	3.06	1.12	Native
O. pabda	Siluriformes	Siluridae	OPS	(LC)	2.74	4.81	1.93	Native
O. pabo	Siluriformes	Siluridae	OAS	(LC)	1.38	1.73	1.12	Native
Oreochromis mossambicus	Cichliformes	Cichlidae	OMC	(LC)	0.59	1.55	0.83	Non-Native
O. niloticus niloticus	Cichliformes	Cichlidae	ONC	(LC)	1.44	4.39	2.30	Non-Native
Osteobrama cotio	Cypriniformes	Cyprinidae	OCC	(LC)	3.47	5.93	3.53	Native
Pangasius pangasius	Siluriformes	Pangasiidae	PPS	(VU)	13.00	5.00	1.36	Native
Parambassis baculis	Perciformes	Ambassidae	PBP	(LC)	5.15	1.34	4.26	Native
P. ranga	Perciformes	Ambassidae	PRP	(LC)	0.99	1.86	4.16	Native
Pseudeutropius atherinoides	Cypriniformes	Cyprinidae	PAC	(LC)	2.50	0.95	7.23	Native
Puntius chola	Cypriniformes	Cyprinidae	PCC	(LC)	2.97	2.88	4.86	Native

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Scientific name	Order	Family	Abbreviation	iucn status	RA (PS)	RA (PW)	RA (PM)	Nativity
P. conchonius	Cypriniformes	Cyprinidae	POC	(LC)	7.22	1.76	1.27	Native
P. gelius	Cypriniformes	Cyprinidae	PGC	(LC)	0.39	1.78	2.90	Native
P. puntio	Cypriniformes	Cyprinidae	PPC	(LC)	1.53	2.25	2.99	Native
P. sarana	Cypriniformes	Cyprinidae	PSC	(LC)	0.54	0.62	1.34	Native
P. sophore	Cypriniformes	Cyprinidae	PHC	(LC)	1.24	2.63	4.66	Native
P. terio	Cypriniformes	Cyprinidae	PTC	(LC)	12.50	3.42	9.39	Native
P. ticto	Cypriniformes	Cyprinidae	PIC	(LC)	0.44	1.76	6.42	Native
Raiamas bola	Cypriniformes	Cyprinidae	PBC	(LC)	2.24	3.71	7.86	Native
Rasbora rasbora	Cypriniformes	Cyprinidae	RRC	(LC)	0.89	0.60	3.87	Native
daniconius	Cypriniformes	Cyprinidae	RDC	(LC)	0.58	1.52	1.68	Native
Rhinomugil corsula	Perciformes	Mugilidae	RCP	(LC)	0.87	1.32	2.81	Native
Rita rita	Siluriformes	Bagridae	RRS	(LC)	2.08	1.36	0.68	Native
Salmophasia phulo	Cypriniformes	Cyprinidae	SPC	(LC)	1.89	1.23	1.29	Native
Salmostoma bacaila	Cypriniformes	Cyprinidae	SBC	(LC)	1.95	2.77	3.76	Native
Securicula gora	Cypriniformes	Cyprinidae	SGC	(LC)	2.79	2.66	3.83	Native
Setipinna brevifilis	Clupeiformes	Engraulidae	SRC	(LC)	2.80	2.29	3.11	Native
S. phasa	Clupeiformes	Engraulidae	SHC	(LC)	4.14	2.18	6.78	Native
Sicamugil cascasia	Perciformes	Mugilidae	SCP	(LC)	3.94	3.62	0.34	Native
Silonia silondia	Siluriformes	Schilbeidae	SSS	(VU)	4.96	1.64	0.00	Native
Sisora rhabdophorus	Siluriformes	Sisoridae	SRS	(LC)	0.63	0.25	0.68	Native
Sperata aor	Siluriformes	Bagridae	SAS	(VU)	0.44	1.27	0.34	Native
S. seenghala	Siluriformes	Bagridae	SES	(LC)	5.92	3.80	1.34	Native
Tetraodon cutcutia	Tetraodontiformes	Tetraodontidae	TCT	(LC)	4.71	3.34	1.02	Native
Trichogaster lalius	Anabantiformes	Osphronemidae	TLA	(LC)	1.31	0.63	2.50	Native
Wallago attu	Siluriformes	Siluridae	WAS	(VU)	2.89	0.97	1.02	Native
Xenentodon cancila	Cyprinodontiformes	Belonidae	XAC	(LC)	7.60	2.89	3.39	Native

changes in diversity (Bhatt et al., 2023).Temporal diversity varies by region between 2022 and 2024 (Fig. 4). Kanpur (S1) and Dalerganj (S2) remained steady, but Fatehpur (S3), Mirzapur (S6), and Chunar (S7) exhibited fluctuation. Prayagraj (S4) peaked at 66 species in 2024. Bahupura (S5) fluctuated, whereas Varanasi (S8) increased from 48 species in 2022 to 59 in 2023 before stabilizing. Ramnagar (S9) has remained consistent at 35 species. Increases in Prayagraj (S4) and Varanasi (S8) may indicate the National Mission for Clean Ganga's efforts. The post-summer variety (Fig. 5) varied greatly. Prayagraj (S4) peaked at 56 species in 2022, declined to 38 in 2023, then returned to 51 in 2024. S7 increased to 59 species by 2024, showing habitat improvement. Varanasi (S8) peaked at 59 in 2023 and declined to 25 in 2024, most likely owing to habitat changes. Bahupura (S5) rose from 20 in 2023 to 42 in 2024, suggesting better environmental circumstances. Cypriniformes (47), Siluriformes (30), and Perciformes (17) accounted for the majority of the 109 species. Of these, 102 were native and seven were non-native, introduced through aquaculture or habitat disturbance, including *Clarias gariepinus* and *Cyprinus carpio*.

Temporal patterns in post-winter and post-monsoon seasons: In post winter season biodiversity decreased in 2023, but recovered in 2024 (Fig. 6). Kanpur-Fatehpur (S1-S3) dropped in 2023, but rebounded by 2024. Prayagraj (S4) varied the greatest, decreasing to 21 species in 2023 before increasing to 65 in 2024 as a result of habitat restoration. Bahupura (S5) and Mirzapur (S6) exhibited small increases, whereas Ramnagar (S9) remained stable. In 2023 dip was most likely caused by pollution or climate change, but the 2024 comeback demonstrated conservation success. In post monsoon season composition trends varied according to location. S3 (Fatehpur), S5 (Bahupura), and S6 (Mirzapur) exhibited increasing variety by 2024, however S7 (Chunar) dropped. S4 (Prayagraj) maintained a high level of variety

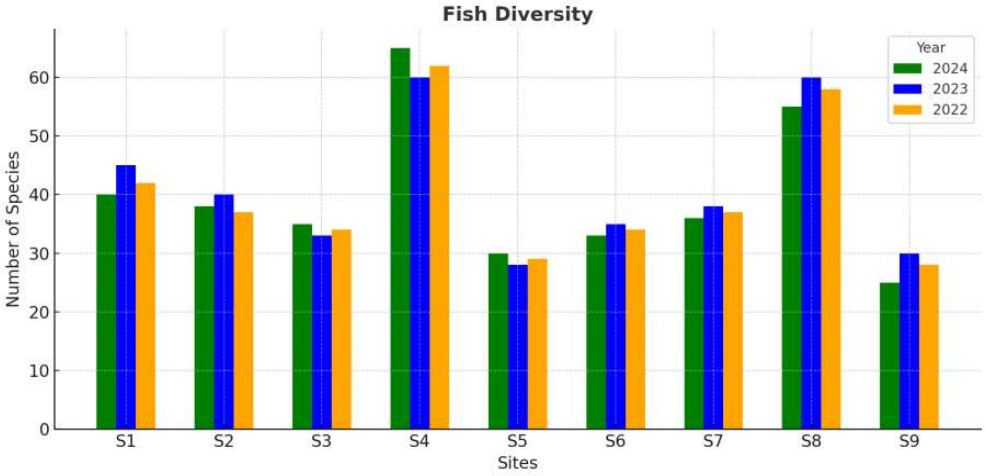

Fig. 4. Annual variation in fish species diversity across sampling sites (2022-2024)

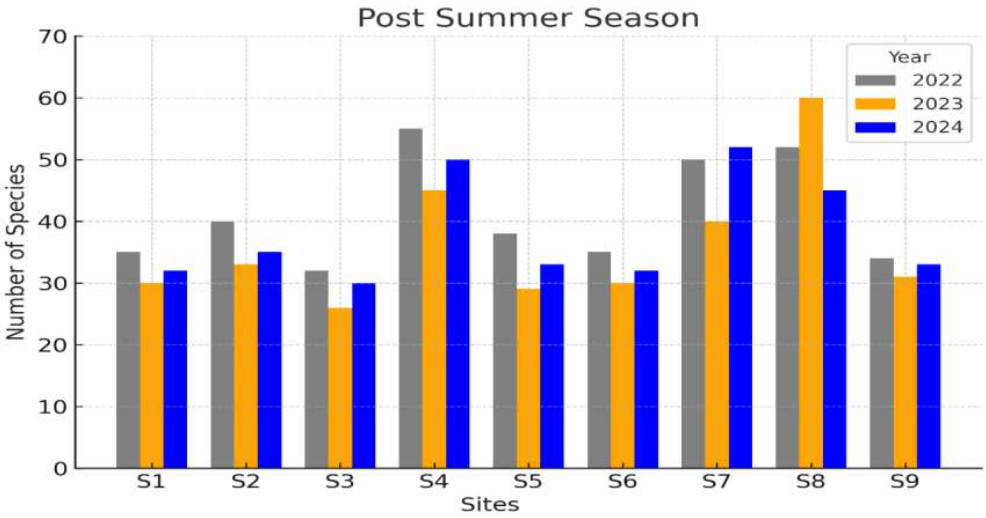

Fig. 5. Yearly fluctuations in species count post summer season

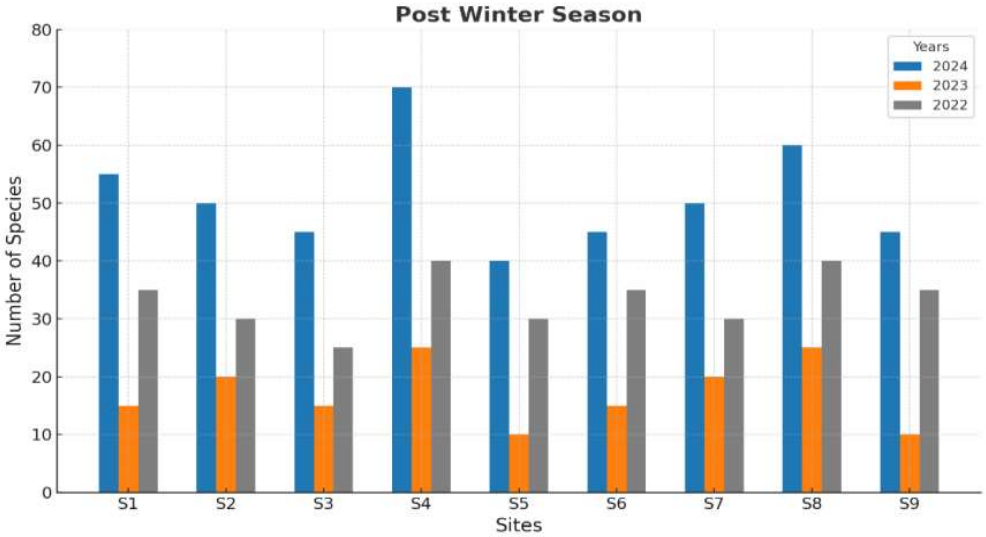

Fig. 6. Yearly fluctuations in species count post winter season

despite oscillations. Changes reflect environmental circumstances or conservation initiatives (Fig. 7). Hierarchical clustering with Jaccard indices indicated two ecological clusters: S1 (Kanpur), S2 (Dalerganj), S4 (Prayagraj) (Fig. 8). S5 (Bahupura), and S8 (Varanasi) formed a cohesive group, whereas S3 (Fatehpur), S6 (Mirzapur), S7 (Chunar), and S9 (Ramnagar) diverged due to site-specific environmental impacts.

Ecological indices, trends, and management implications: Seasonal biodiversity indices differed substantially (Table 3). The Shannon Diversity Index (H) reached peak in S4 (Prayagraj) (1.46, post monsoon) and S8 (Varanasi) (1.56, post winter), showing substantial diversity. The Evenness Index (E^H/S) was maximum in S8 (Varanasi) (0.52, post winter) and S4 (Prayagraj) (0.48, post winter), showing a balanced distribution. S8 (Varanasi) has the highest level of richness (4.67, post summer), demonstrating the value of biodiversity. S5 (Bahupura) and S7 (Chunar) exhibited the lowest markers, indicating ecological stress.

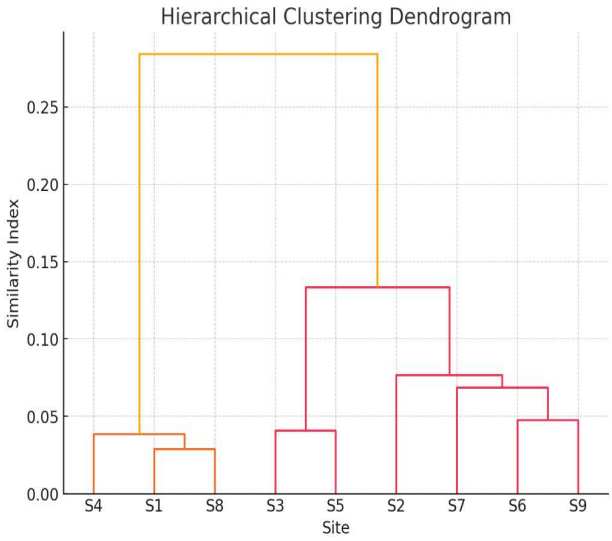

Fig. 8. Hierarchical clustering of nine different sites (S1 to S9) based on their similarity, measured through the Jaccard index across three parameters: PS, PW, and PM

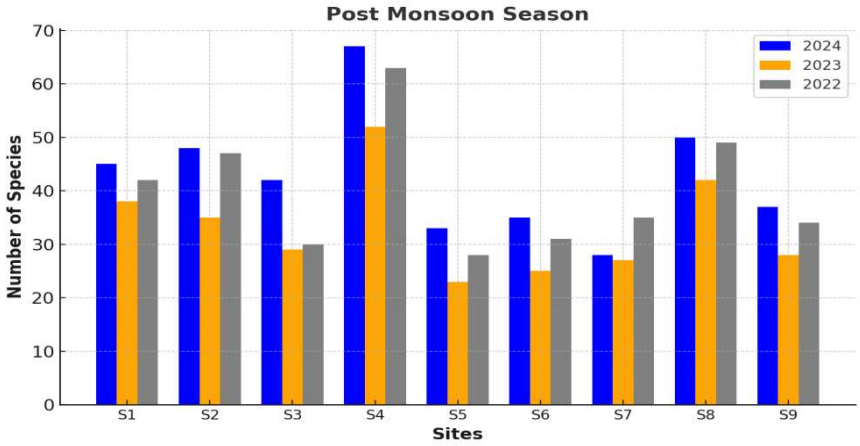

Fig. 7. Yearly fluctuations in species count post monsoon season

Table 3. Seasonal variations in biodiversity indices (Shannon diversity, evenness and species richness) across different sites

Site	Post -summer (PS)			Post-winter (PW)			Post-monsoon (PM)		
	Shannon	Evenness (E^H/S)	Richness (Margalef)	Shannon	Evenness (E^H/S)	Richness (Margalef)	Shannon	Evenness (E^H/S)	Richness (Margalef)
S1	1.36	0.27	4.16	1.39	0.46	0.15	1.39	0.29	4.21
S2	1.30	0.23	3.96	1.32	0.44	0.15	1.34	0.26	3.99
S3	1.38	0.33	4.06	1.35	0.45	0.15	1.39	0.35	4.04
S4	1.42	0.28	4.35	1.45	0.48	0.16	1.46	0.29	4.65
S5	1.23	0.27	3.14	1.05	0.35	0.12	1.28	0.29	3.37
S6	1.28	0.27	3.46	1.15	0.38	0.13	1.29	0.29	3.40
S7	1.21	0.22	3.31	1.10	0.37	0.12	1.33	0.29	3.78
S8	1.39	0.26	4.67	1.56	0.52	0.17	1.41	0.28	4.54
S9	1.36	0.33	3.79	1.26	0.42	0.14	1.40	0.33	4.30

Shannon = Shannon Diversity Index, Evenness/S = Pielou's Evenness Index, Richness = Margalef's Richness Index

The most biodiversity was seen after winter, emphasizing the necessity of conservation. The Ganga supports both top-down (predator-driven) and bottom-up (resource-driven) processes.

CONCLUSIONS

The Ganga River's fish diversity differed by site, with Bahupura and Chunar experiencing ecological stress and Prayagraj and Varanasi serving as hotspots for biodiversity. The growth of non-native species and the decrease of sensitive species demonstrate the growing influence of humans. Management of invasive species, pollution prevention, and conservation initiatives are essential. Stricter laws, ongoing monitoring, and habitat restoration should be the main focuses of future plans.

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