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Physico-Chemical Properties, Diversity and Adaptive Structural Modification of Hill Stream Fishes of the Dikhu River, Mokokchung, Nagaland, India

Rajesh Singh Pukhrambam[1,*], Bendang AO[1]
[1]Department of Zoology, Nagaland University, Lumami, Nagaland, India

Abstract.

Problem: Threats to species, biodiversity and ecosystems due to anthropogenic activities are increasing day by day. Preparation of a checklist of the existing organisms is the need of the hour. Therefore, the present study was carried out todocument the diversity of ichthyofaunal species and their adaptive structural modification with the spatial and temporal fluctuations in the riverine ecosystem.Three sites (designated as I, II, and III) were selected for the study. **Approach**: Water and fish samples were collected monthly for two years, from February 2021 to January 2023. The habscore of the river, along with key physicochemical parameters (such as Air temperature, water temperature, Dissolved oxygen, Total alkalinity, pH, TDS, EC and FCO_2), organic matter composition (OMC), substrate composition, and fish species diversity, were also assessed. Diversity indices such as Shannon- Wiener diversity index (H),Simpson's diversity index (1-D) and $E_H$were calculated. The Canonical Correspondence analysis (CCA) and Bray-Curtiss dissimilarity matrix (SIMPER) were performed. **Findings:** Altogether, 43 species of fish belonging to 5 orders, 11 families, and 26 genera were recorded. The highest habscore of 8.04 was recorded in the upstream region (Site I), while OMC was the highest in the mid-stream (Site II) with 7.9. Fish diversity was evaluated through indices like the Shannon-Wiener diversity index (highest in site III with 3.25) and Simpson's diversity index showed its highest value in site I (0.949), while the evenness index was the greatest in site II and site III (0.86).The Canonical Correspondence analysis (CCA) showed that water parameters like TDS, pH, EC and DO indicate a close relationship and are positively correlated with Amblyceps, Bangana, Badis, Channa, Danio, Devario, Glyptothorax, Pethia and Puntius, while showing negative correlation with AT, WT, FCO_2 and TA. The Bray-Curtiss dissimilarity matrix (SIMPER) showed the similarity of fish species between seasons is 37% (pre-monsoon and monsoon), 79% (pre-monsoon and post-monsoon) and 29% (Monsoon and Post-monsoon). Among the sites, the average similarity between Site I and Site II is 70% between Site I and Site III is 63% and between Site II and Site III is 62%.The genera such as Garra, Glyptothoraxand Paracanthocobitis showed thoracic modifications and bore suctorial discs for adhesion. **Conclusion:** The total number of fish documented in this study has indicated that this river provides a suitable habitat and rich biodiversity.

Keywords: Habscore, Devario, Psilorhynchus, Canonical Correspondence analysis and Bray Curtiss dissimilarity matrix.

1. Introduction

Nagaland is a state of northeast India with a geographical area of 16,579 km^2 and is located between 93^0 20'E and 95^0 15' E longitude and 25^0 60'N and 27^0 40' N latitude. It is a land of rich natural landscape, including hills and mountains, forests, rivers, hill streams, and lakes. The state is known for its unique culture, topography, forests, numerous riverine bodies and altitudinal variations from 200 meters to 3826.15 meters (9). Nagaland falls under two biodiversity hotspots - the Eastern Himalayas and Indo Burma (10) and 11 major rivers drain from Nagaland into the Brahmaputra and the Chindwin River.Indo-Gangetic plains and Indo-Burma share fish diversity resources with thestate (11).

The northeastern Indian states, being a part of the Eastern Himalayas, are considered to be the granary of freshwater fish diversity. Sen (2000) (4) documented 267 fish species belonging to 114 genera, 38 families and10 orders from the region. Among the northeast states, Assam recorded the highest number of fish species with 216, followed by Arunachal Pradesh 167, Meghalaya (165), Tripura (134), Manipur (121), Nagaland (68) and Mizoram (48) (5). Nevertheless, as time passes, many new species have been reported from the region. A total of 296 Fin fish from Northeast India was reported by Vishwanath et al. (2007). Goswami et al (2012) reported 422 species of fish belonging to 38 families and 133 genera and the most dominant family Cyprinidae, represented by 154 species (6). Gurumayum et al (2016) enlisted 259 fish species from Arunachal Pradesh alone (7). The current recorded diversity of fish in Nagaland state is 197 species of fish belonging to ten orders, twenty-six families and eighty-seven genera (8). The fish fauna of this region is highly similar to the Indo-Gangetic fish fauna but shares a little similarity with South Asian countries (9). Earlier literatureshows that the fish diversity of Nagaland has been studied by many workers. For instance, Chaudhuri (10) reported two species from the streams of the Naga hills; Hora (11) recorded 16 species from the Southern watershed, Tizu Valley, Chinwin drainage and 17 species from the northern watershed, Brahmaputra drainage; 12 species of fish were recorded in the Naga Hills by Prasad and Chopra (12) recorded 12 species of fish; Vishwanath &Linthoingambi (13) redescribed Amblycepapangi Nath and Dey (14) and Amblycepsarunachalensis Nath & Dey (14) from Wokha district, Nagaland; S.Ao et al., (15) recorded 149 species of fishes belonging to 22 families; Acharjee et al., (16) reported 34 species of fish belonging to 5 orders, 13 families, and 24 genera from Dhansiri River, Dimapur, Nagaland; Pseudolaguvia vespa, a new catfish, was reported from Tsucha river, Mokokchung, Nagaland, India (17); Pethiadikhunensis, a new species of the cyprinidae family, was recorded from the Dikhu river Mokokchung, Nagaland (18).

Hill Streams are fast-flowing water bodies with a unique lotic ecosystem represented by high oxygen levels, low temperature, high transparency, rock and gravel substratum and seasonal variations in the volume of flow. Hill streams normally confluence with larger rivers and forms the source of hill stream fishes and aquatic organisms. Most hillstream fishesare considered ornamental fish due tobrilliantcolour patterns, modified adhesive structures and feeding apparatuses. The adaptive structural modifications are permanently exhibited in integuments which help in clinging to the hard substratum of the fast-flowing hill rivers (19) and are used to describe new species in the hill streams. The upstream section of the river provides a suitable habitat for coldwater fishes, characterized by higher dissolved oxygen levels and cooler temperatures. In contrast, the downstream section exhibits a suitable condition for normal water fishes, with slower currents, and wider breadth, creating a more favourable environment for species adapted to such conditions. Although many ichthyologists have tried to document the fish of Nagaland, there are still many untouched areas in the difficult mountain terrain of Nagaland, where numerous undescribed species are believed to exist. Hence, the present study was carried out to document the fish diversity and adaptive structural modification of the fish of the Dikhu river, Mokokchung, Nagaland.

Material and Methods

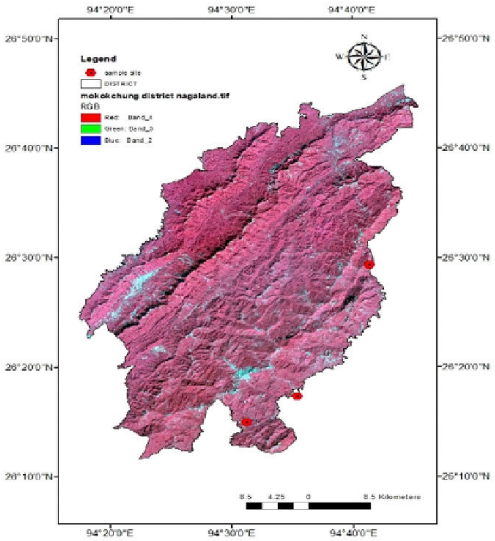
2.1. Study area

Mokokchung district lies between 94˚29 E to 94˚76 E longitude and 26°20 N to 26˚77 N latitude (20)and is bounded by Longleng and Tuensang district in the east, by Wokha in the west, by Zunheboto district in the south and by Assam in the north.Mokokchung has numerous rivers, both perennial and non-perennial, and some notable rivers flowing in the district are Milak, Dikhu, Tsurang or Desai, Tsumok and Menung (21). The Dikhu river with a total length of 160 km originates in the Nuroto hills of Zunheboto district and its main tributaries are the Yangyu and Nanung rivers. Three study sites were selected randomly along the Mokokchung section of Dikhu river. Geographical coordinates of the selected sites are as follows: Site I ($26^0$25’ N, $94^0$52’E), Site II ($26^0$29’ N, $94^0$59’ E), Site II ($26^0$49’ N, $94^0$69’ E). Site I is located upstream, followed by Site II and Site III along the river.

Fig 1:Study Area

India map

Mokokchung river map



Satellite image of study sites

2.2. Habscoire Analysis

Study of habscore analysis or riverine habitat quality comprehensively includes the morphology of the river, riparian vegetation and biotic component of the study area along with substrate and organic matter composition (OMC). Habscore was studied with the help of stream visual assessment protocol, USDA, 1998 (22). This protocol provides an assessment based primarily on physical conditions within the study areas.

2.3. Substrate and organic matter composition

According to the size of substrate materials in the river bed, the substrate material was classified as boulders (>256.00mm), cobble (64.00-256.00mm), pebbles (16.00- 63mm), gravels (2.00-15.00mm), sand (<1.00mm) and mud (<0.25mm), clay and peat, Brain and Stevenson, 1999, (23); Kristensen et al., 2011, (24). The OMC in the river substratum was also analyzed following the method of Walkley and Black, 1934, (25).

2.4. Physico-chemical parameter analysis

The present study was carried out for two years starting from February 2021 to January 2023. Water samples were collected from all the selected sites of the Dikhu River. Water parameters like air temperature [AT (°C)] and water temperature [WT (°C)] were measured using a mercury thermometer. Dissolved oxygen [DO (mg/L)], total alkalinity [TA (mg/L)] and free carbon dioxide [Free CO2 (mg/L)] were estimated in situ through titration methods following the guidelines of APHA, 2017 (26), whereas, Electrical conductivity (EC), total dissolved solids [TDS (ppm)] and pH were measured by Systronic conductivity meter (306), TDS/ Conductivity meter (Systronics MK-509) and μ pH meter (Systronics 361) respectively. The results of various parameters are shown in Table 2.

2.5. Sample collection and identification

The fish specimens, with the help of local fishermen, were collected using gill net, cast net, Scoop net (Table 1) and indigenous fishing gear. The collection was concentrated in a radius of I km around each site. Local fish markets and other landing centres related to the studied river were regularly monitored for the availability of species not documented during the experimental period. All the specimens were fixed in 10% formaldehyde and preserved in 70% alcohol. The collected fish specimens were taxonomically identified following the standard literature of Talwar and Jhingran (1991) (27), Jayaram(28), Nath & Day (29), Vishwanath et al., (30) and Darshan et al., (31). The current nomenclature of the fish was followed based on Eschmeyer's Catalog of Fishes (Online Version, Updated 2 Oct 2024) (32) and the latest conservation status was assigned according to the IUCN Red data book (IUCN, 2018) (33).

Table 1: Details of Fishing Nets

Types of Net	Material	Mesh size	Length of net or handle	Diameter	Weight of Sinker	Height/depth
Cast Net	Nylon	1 cm	3.2 m	2-3 m	5	-
Gill Net	Nylon	1-2cm	5 – 25 m	-	-	40 – 75 cm
Scoop Net	Polyester	4 mm	1.52 m	30.48 cm	-	30 m

2.6: Relative Abundance (RA) and Diversity indices

The RA of fish species was calculated using a standard formula, Dey &Sharma, 2018, (34):

RA = Number of individuals of a particular species multiplied by 100 and divided by the total number of all the individuals of all the species.

Species diversity in the sites was calculated by the Shannon index, Shannon-Wiener, 1949, (35) using the formula

$H = \sum_{i=1} - (Pi * \ln Pi)$

Where:

H: Shannon – Wiener Index of Diversity,

∑: Sum.

P_i: Proportion of species i, relative to the total number of species i,

In Pi: Natural Log of Pi,

Simpson index of dominance and diversity, Simpson, 1949, (36): [1-D], Simpson diversity index is measured by subtracting the value of D from 1.

Simpon's diversity index: $D = \sum ni(ni-1)/N(N-1)$

Where, D = The Simpson's diversity index; ni = total number of organisms of a particular species; N = total number of organisms of all species

Evenness in the population of the species was calculated by E_H (Shannon's equitability),

$E_H = H/InS$

Where:

H: Shannon – Wiener Index of Diversity,

S: Total number of species in the habitat (Species richness)
InS: Natural log of S

The total number of species recorded in this study was taken as species richness.

2.7. Statistical Analysis

Statistical analysis for physicochemical parameters of water, diversity, abundance, and distribution of fishes in the riverine system was carried out using MS Excel, SPSS 20, and PAST software. Analysis of Variance (ANOVA) was analyzed to find the significant mean difference among the variables. Canonical Correspondence analysis (CCA) was used to study the relationship between the water physicochemical parameters and Fish species while the Bray-Curtis dissimilarity matrix (SIMPER) was used to study the species similarity among the study sites.

3. Result and Discussion

3.1. Habscore (habitat quality)

Based on the environmental conditions and habitat ecology in the Dikhu river of Mokokchung district, the quality assessment indicators of the hill stream were established (Table 2). Through stream visual assessment protocol of all the study sites, habscore was assessed as the ratio of total score to the sum of characters (such as barriers to fish movement, water appearance, riparian zone, bank stability, etc.). The highest habscore was recorded in Site I (8.04±0.08) and the lowest in Site II (7.02±0.15).

3.2. Substrate composition

The streambed was composed of rocky substratum, distributed evenly over the upper and lower reach at all the studied sites. The streambed of Site I, was boulders, pebbles with gravels >20mm, sand and mud, for Site II, boulders, cobbles, pebbles with gravels and sand < 15mm, and for Site III, cobbles, pebbles blended with gravels and sand < 1mm. The OMC of the study sites ranged from 7.4 to 7.9 (Table 2).

Table (2): Habitat inventory, OMC composition and Habscore analysis of Dikhu river (Mean ±SD)

Sites	Altitude (m)	Average depth (m)	River width (m)	Substrate type	Substrate Dominance	Habscore	OMC	Classification criteria of riverian ecosystem and health assessment.	
								Remarks	Habscore
Site I	648	0.86±0.12	10.2	Boulder, cobbles, pebbles with gravels, sand and mud	Pebbles with Gravels and sand	8.04±0.08	7.4±0.4	Excellent	>9
Site II	511	1.00±0.2	15.5	Boulder, cobbles, pebbles with gravels	Boulder and gravels, pebbles	7.02±0.15	7.9±0.46	Good	9.50-8.90
Site III	329	1.13±0.12	20.3	Boulder, cobbles, pebbles blended	Cobbles Pebbles Gravels and sand	7.56±0.26	7.73±0.49	Moderate	6.10-7.40

				with gravels and sand					

Boulder > 256mm, Cobbles 64-256 mm, pebbles 4-64mm, gravel 3-75mm

3.3 **Physico-chemical parameters of the water**

These were analyzed to assess river water quality. Sample collection was done in the morning from 6.30 am to 8.30 am of every month. Parameters like AT, WT, DO, TA, and FCo_2 were measured in situ. Other parameters such as pH, EC and TDS were measured in the laboratory. The results of various parameters are shown in Table 3.

The mean air and water temperature ranged from 12.3±0.29 (January) to 26.6±0.58 ^{0}C (August) and 11.3±0.29 ^{0}C (January) to 24.0±0.00 ^{0}C (August) respectively. Similarly Average DO ranges from 7.0±0.40 mg/l in Jun to 8.5±0.61 mg/l in January, the average TA value ranges from 52.0±3.46 mg/L in July to 60.3±2.52 mg/L in January, the average FCO_2 value ranged from 4.1±1.16 mg/l in Dec to 7.3±0.70 mg/l in Jun, average pH value ranges from 7.0±0.20 to 8.3±0.15, average electrical conductivity ranges from 95.0±3.61µS/cm in December to 130.7±4.10 µS/cm in July, average TDS recorded ranges from 47.4±1.04 mg/l in December to 67.1±1.45 mg/l in July.

Table 3. Average variations of physico-chemical parameters of Dikhu river (Three sites

Month	Air Temp. (^{0}C)	Water Temp. (^{0}C)	DO (mg/l)	TA (mg/l)	FCO_2 (mg/l)	pH	EC (µS/cm)	TDS (mg/l)
February	14.8±0.20	13.6±0.58	7.8±0.61	59.6±2.08	4.5±1.01	**8.3±0.15**	107.1±2.58	52.1±0.49
March	15.2±0.20	14.1±0.23	7.7±0.42	58.0±2.00	5.2±0.59	7.4±0.04	111.3±2.49	54.4±0.40
April	20.6±0.58	17.0±0.50	7.6±0.40	59.3±3.06	5.2±0.72	7.8±0.06	107.3±3.06	54.3±3.15
May	21.6±0.58	20.3±0.58	7.2±0.40	59.6±2.08	6.2±2.15	7.5±0.16	102.4±3.86	51.7±1.20
Jun	22.6±1.00	23.0±1.00	**7.0±0.40**	53.3±3.06	**7.3±0.70**	**7.0±0.20**	121.7±3.37	58.8±0.76
July	25.0±1.	23.6±0.	7.0±0.	**52.0±3.**	4.9±0.	7.1±0.	**130.7±4.**	**67.1±1.**

	00	58	61	**46**	46	21	**10**	**45**
August	**26.6±0.58**	**24.0±0.00**	7.6±0.40	56.3±1.53	4.5±0.67	7.1±0.28	119.2±2.90	59.2±2.84
September	24.3±0.52	21.6±0.58	7.5±0.42	55.3±3.06	4.4±0.72	7.6±0.06	96.0±4.00	49.0±3.41
October	21.0±1.00	17.0±1.00	7.6±0.70	57.0±2.65	5.7±1.21	7.5±0.15	99.3±4.16	51.0±3.86
November	15.0±1.00	14.0±1.00	8.0±0.40	57.3±2.31	5.1±0.75	7.7±0.08	96.6±2.31	48.7±1.90
December	14.1±0.23	12.0±0.00	8.1±0.55	56.6±1.15	**4.1±1.16**	7.6±0.20	**95.0±3.61**	**47.4±1.04**
January	**12.3±0.29**	**11.3±0.29**	**8.5±0.61**	**60.3±2.52**	4.2±0.72	7.6±0.15	102.0±4.00	49.6±0.96

Note: ^{0}C = degree Celsius; mg/L = Milligram per liter, µS/cm = micro-Siemens per centimeter;

3.2. Fish diversity

A total of 1058 fishes were collected out of which 43 species of fish belonging to 26 genera, 11 families and 5 orders have been documented. The order cypriniformes, with 28 species and 65.11% of the total catch, showed the maximum diversity followed by siluriformes with 9 species and 20.93 %, anabantiformes with 4 species and 9.30%, synbranchiformes and beloniformes with 1 species each and 2.33% (Fig. 2).

Among the families, Cyprinidae with 22 species and 51.16% of the total species recorded showed the highest diversity, followed by nemachielidae with 5 species and 11.62%, siluridae, channidae with 3 species each and 6.97% each, amblycidae, bagridae, and sisoridae with 2 species each and 4.65% each, badidae, belonidae, cobitidae, and mastacembelidae with 1 species each and 2.32 % each diversity (Fig. 3).

3.3. Relative abundance

The RA of all the recorded fishes is shown in Table 4. The most dominant species with highest RA (10.86%) was Psilorhynchusbaliptora ,followed by Devario aequipinnatus (10.30%), Opsariusbendelesis(9.92%), Amblycepsapangi (7.08%), Devario

assamensis and Olyralongicaudata (4.44%) each, Schistura fasciatus (4.34%). The RA of other recorded fishes were less than 4%.

Table 4. Fish species distribution, Conservative studies, Frequency and relative abundance.

Order	Family	Scientific Name	IUCN Status	Frequency	RA %	Site I	Site II	Site III
Cypriniformes	Cyprinidae	Banganadero(Hamilton 1822)	LC	8	0.75	-	+	+
		Opsariusbarna (Hamilton 1822)	LC	16	1.51	+	+	+
		Opsariusbendelesis (Hamilton 1807))	LC	105	9.92	+	+	+
		OpsariusVagra (Hamilton 1822)	LC	6	0.56	-	+	+
		Tariqilabeolatius (Hamilton 1822)	LC	13	1.22	+	+	+
		Danio assamila (Kullander 2015)	DD	28	2.64	+	+	+
		Danio dangila (Hamilton 1822)	LC	18	1.70	+	+	+
		Devario assamensis (Barman, 1984)	Vu	47	4.44	+	+	+
		Devario aequipinnatus (McClelland 1839)	LC	109	10.30	+	+	+
		Devario coxi (Kullander 2017)	EN	16	1.51	+	+	+
		Garralissorhynchus (McClelland 1842)	LC	35	3.30	+	+	+
		Garra minima (Arunachalam 2013)	NEv	25	2.36	+	+	+
		Garranaganensis (Hora 1921)	LC	5	0.47	+	-	+
		Garrakempi (Hora 1921)	Vu	6	0.56	-	-	+
		Neolissochilahexagono	NT	15	1.41	+	+	+

		lepis (McClelland 1842)						
		Pethiadikhunensis (Praveenraj 2022)	NEv	6	0.56	+	+	+
		Pethiaticto (Hamilton 1822)	LC	14	1.32	+	+	+
		Puntius chola (Hamilton 1822)	LC	16	1.51	+	+	+
		Puntius sophor (Hamilton 1822)	LC	12	1.13	+	+	+
		Schizothoraxrichardsonii (Gray 1832)	Vu	15	1.41	+	+	+
		Securicula gora (Hamilton 1822)	LC	12	1.13	-	+	+
		Tor tor (Hamilton 1822)	NT	5	0.47	-	-	+
	Nemachielidae	Paracanthocobitisbotia (Hamilton 1822)	LC	36	3.40	+	+	+
		Schistura fasciatus (Lokeshwor& Vishwanath 2011)	Vu	46	4.34	+	+	+
		Schisturanaganensis(Menon 1987)	Vu	16	1.51	+	+	+
		Psilorhynchusbalitora (Hamilton 1822)	LC	115	10.86	+	+	+
		Psilorhynchushomolopt era (Hora & Mukerji 1935)	LC	21	1.98	+	+	+
	Cobitidae	Lepidocephalichthysguntea (Hamilton 1822)	Vu	24	2.26	+	+	+
Siluriformes	Siluridae	Ompokbimaculatus (Bloch 1794)	LC	9	0.85	+	+	+
		Ompokpabda (Hamilton 1822)	NT	7	0.66	+	-	+
		Pterocryptis indica (Dutta, Barman &Jayaram 1987)	DD	5	0.47	+	-	+
	Bagridae	Olyrakempi (McClelland 1842)	LC	7	0.66	+	+	+
		Olyralongicaudata	LC	47	4.44	+	+	+

		(Chaudhuri 1912)						
	Amblycidae	Amblycepsapangi (Nath & Dey 1989)	LC	75	7.08	+	+	+
		Amblycepslaticep (McClelland 1842)	LC	10	0.94	+	+	+
	Sisoridae	Glyptothoraxmaceriatus (Ng &Lalramliana 2012)	NEv	10	0.94	+	+	+
		Exostomalabiatus (McClelland 1842)	LC	8	0.75	+	-	+
Synbranchiformes	Mastacembelidae	Mastacembelusarmetus (Lacepede 1800)	LC	8	0.75	-	+	+
Anabantiformes	Channidae	Channa gachua (Hamilton 1822)	LC	18	1.70	+	+	+
		Channa stewatii (Playfair 1867)	NEv	10	0.94	-	+	+
		Channa quinquefasciata (Praveenraj, Uma, Knight, Moulitharan, Balasubramanian, Bineesh &Bleher 2018.)	EN	20	1.89	+	+	+
	Badidae	Badis badis (Hamilton 1822)	LC	28	2.64	+	+	+
Beloniformes	Belonidae	Xenentodoncancila (Hamilton 1822)	LC	6	0.56	-	+	+

LC- Least concern, DD - Data Deficient, EN - Endangered, VU - Vulnerable, NT- Near Threatened, NEv – Not Evaluated, + recorded, - Not recorded.

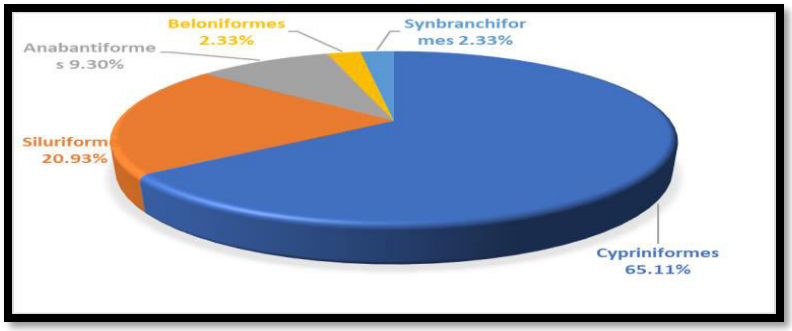


Fig. 2. Percentage of composition of Fish Order

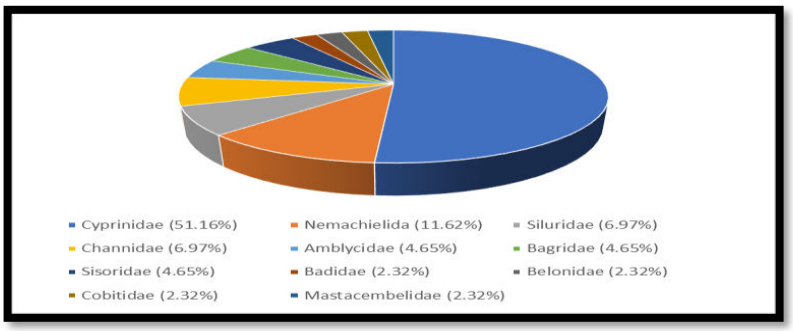


Fig. 3. Percentage of composition of Families

Adaptive structural modification.

Hill stream fish are small, short, thick, ventrally flattened, dorsally curved and brilliant in colour due to which they are considered ornamental fish. Adaptive structural modifications such as adhesive apparatus, suctorial plate, strong fins and thick lips are manifested in most hillstream fish.

Shape & Size: The genera Lepidocephalichthys, Amblyceps,Badis, Garra, Paracanthocobitis, and Psilorhynchus were documented as fish species with small, short and thicker bodies and short tubercles in the snout.

Eye: The small-sized eyes, placed toward the dorsal surface of the head,were seen in genera such asLepidocephalichthys,Garra, Glyptothorax, Olyra and Xenentondon.

Barbels: Barbels are specialized for testing the water and food. Long barbels were seen in Pterocryptis indica. Short and stumpy barbels were seen in Amvlyceps apangi, Olyralongicaudata, Garralissorhynchus, and Schisturafasciata.

Mouth: In the genera Garra, Glyptothorax, Psilorhynchus, Olyra and Schistura, the mouth was placed on the ventral side of the head.Swollen, suctorial discs, highly muscular fringes and ring-like sucker lips are seen in generaGarra,Paracanthocobitis and schistura.

Fins: Modified finsperformed special functions such as balancing, swimmingand clinging to the rocks of a fast-flowing current. The types of the fins were as follows:

Paired fins: The fish such as Opsariusbendelesis, Glyptothoraxmaceriatus, and Schisturafasciata, the outer rays of fins were modified for clinging. The presence of large

pectoral and pelvic finsplaced at the lateral ventral side was seen in genera such as Garra, Opsarius, and Glyptothorax

Caudal fin: The species Glyptothoraxmaceriatus, Olyralongicaudataand Opsariusbendelesis possessed a muscular caudal peduncle.

Adhesive apparatus: The adhesive apparatus found in some fish was the modified form of integuments of the thoracic region of fish. In Schistura, Lepidocephalichthys, Paracanthocobitis andGarra, the lips were modified as suctorial plates which served as adhesive apparatus.The speciesGlyptothoraxmaceriatusbore several ridges on the thoracic region of the body, which served to attach to the hard substratum.

fig 4 (A-C): ***A: Modification in the body shape, size, eyes and head***

Glyptothorax maceriatus

Badis badis

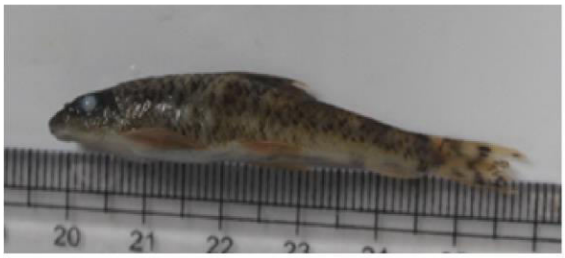
Olyra longicaudata

Devario aequipinnatus

Garra lissorhynchus

Lepidocephalichthys guntea

Schistura fasciata



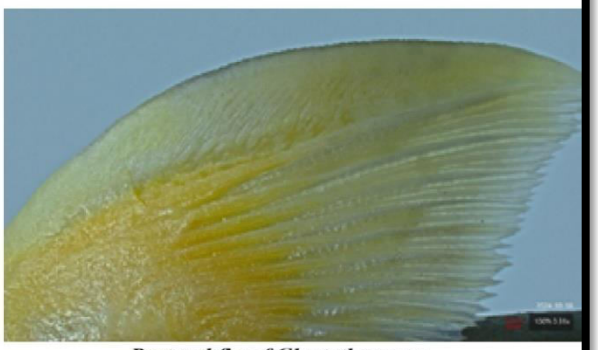
Psilorhynchus balitora

Eyes and Head of Glyptothorax sp.

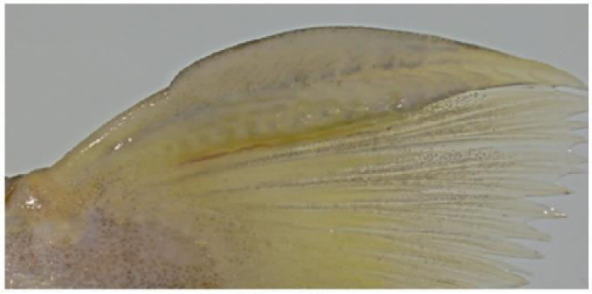
Eyes anf head of Schistura sp

Fig 4: B- Modification in the fins

Pectoral fin of Schistura fasciata



Pectoral fin of Glyptothorax sp.

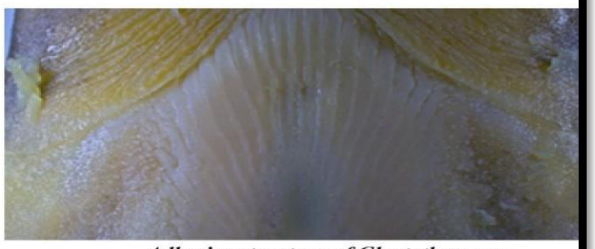


pectoral fin of Glyptothorax sp.

Pectoral fins of Psilorhynchus sp.

Fig. 4 C: Modification in the mouth, Thoracic region and presence of adhesive structure.

Mouth part of Glyptothorax sp.



Adhesive structure of Glyptothorax sp.

Suctorial disc of Garra lissorhynchus

Mouth parts of Amblyceps apangi

Table 5. Fish community diversity index of the study sites

Diversity indices, species richness and evenness	Sampling Sites			
	Site I	Site II	Site III	Cumulative
Species richness	35	37	43	43
Total catch	257	278	523	1058
Shannon-Weinner index (H)	3.19	3.23	3.25	3.32
Simpson's dominance index (D)	0.051	0.052	0.057	0.050
Simpson diversity index (1-D)	0.949	0.948	0.943	0.949
Evenness index (E_H)	0.84	0.86	0.86	0.88

2.1. Diversity index

H indicates high values with a narrow range of variation from 3.19 to 3.25. Site III shows maximum diversity, followed by Site II and Site I. The higher H indicates a balance between species richness and the total number of individuals of every species. The Simpson diversity index (1-D) values were found between 0.943 & 0.949. Species evenness measured by E_H varied from 0.84 to 0.86. The maximum evenness was tied between Site III and Site II. The least species evenness was recorded at Site I. The high diversity in all the sites may be due to the absence of big predatory fishes and the suitable habitat of the selected sites, etc. The structure of the habitat of a hill stream includes depth, water current, substrate composition, light and temperature, etc., within which an aquatic organism makes its home. This determines the abundance and diversity of the aquatic organisms. The cumulative species richness, total catch, H, D, 1-D and E_H, showed relatively high values with 43 species, 1058 individuals, 3.32, 0.050, 0.949 and 0.88, respectively (Table 5).

Table 6: Seasonal abundance of fish

Season	Post-monsoon	Pre-monsoon	Monsoon	Total
No. of fish	545	408	105	1058

Table 7. Physico-chemical parameters of water in the study area across different seasons.

Water Parameters	Pre-monsoon	Monsoon	Post-monsoon
AT (C°)	16.28±2.81[a]	23.08±1.08[b]	13.58±2.38[c]
WT (C°)	7.60±0.47[a]	7.30±0.48[a]	8.09±0.59[b]
DO (mg L^{-1})	59.16±2.12[a]	54.25±3.01[b]	57.83±2.44[a]
TA (mg L^{-1})	5.36±1.26[a]	5.32±1.34[a]	4.82±1.09[a]
FCO2 (mg L^{-1})	7.76±0.39[a]	7.22±0.32[b]	7.64±0.15[a]
pH	107.05±4.21[a]	116.93±13.74[b]	98.25±4.13[c]
EC (µS cm^{-1})	53.09±1.90[a]	58.57±7.00[b]	49.12±2.39[c]
TDS (mg L^{-1})	18.08±3.26[a]	24.64±1.67[b]	15.61±3.45[c]

Mean with different superscripts among the seasons indicates a statistical difference at $p<0.05$

The CCA was performed to observe the relationships between the environmental variables and the fish population. The axis 1 and axis 2 were shared a cumulative variance of 50.26 %. In Fig. 5, the lines represent the significance of the physico-chemical variable and positive or negative correlations with the axis and black dots indicate the fish genus recorded in all the sites. Water parameters like TDS, pH, EC and DO indicate a close relationship and are positively correlated with Amblyceps, Bangana, Badis, Channa, Danio, Devario, Glyptothorax, Pethia and Puntius. These genera showed a negative with AT, WT, FCO_2 and TA. The dominant genus such Psilorhynchus, Opsarius, Olyra, Garra and Schistura
showed a close relationship AT, WT, FCO_2 and TA, which indicates a negative correlation with axis 2.

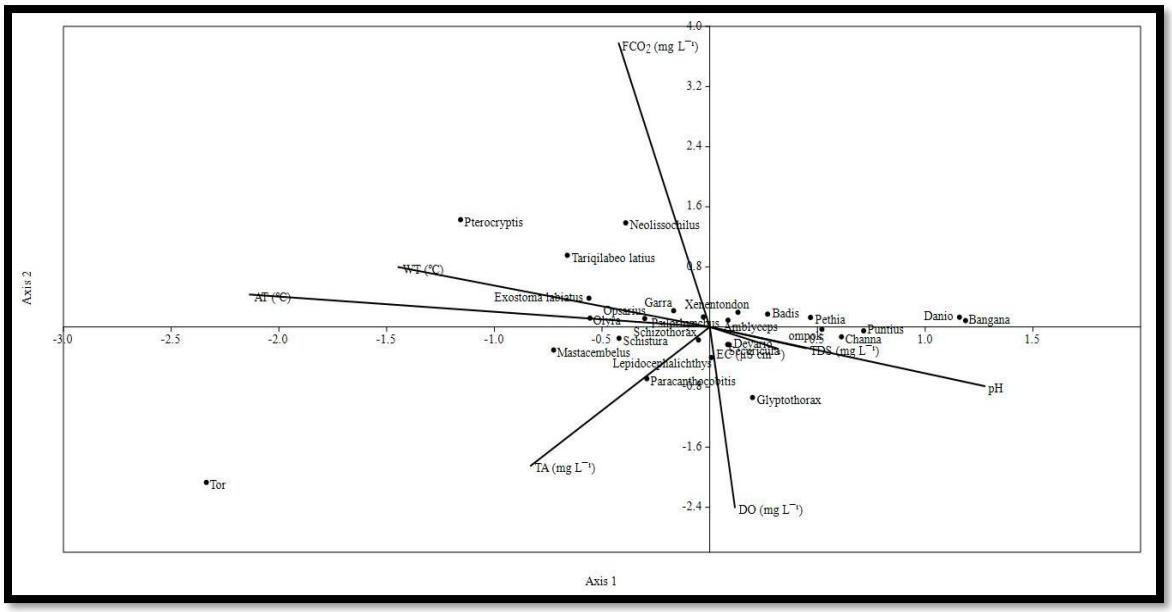


FIG 5: CCA biplot of fish abundance and the physico-chemical parameters of the water

To determine the similarity percentage of fishes between the seasons and between the sites (Fig 6 and Fig 7), SIMPER analysis (Bray-Curtiss Dissimilarity matrix) was performed. The fish species between the pre-monsoon and monsoon share 37% similarity and between the pre-monsoon and post-monsoon 79% similarity while between the Monsoon and Post-monsoon share 29% similarity. Among the sites, the average similarity between Site I and Site II is 70%, between Site I and Site III is 63% and between Site II and Site III is 62%.

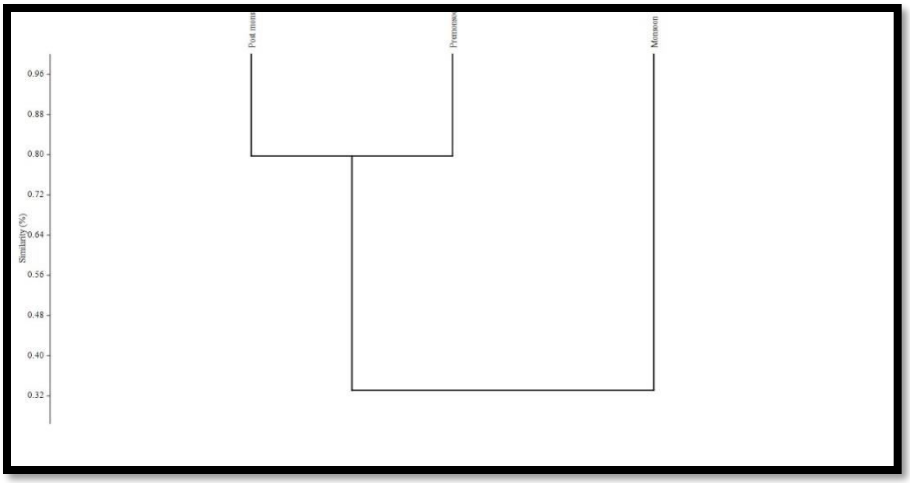


FIG 6: Similaty analysis between the seasons

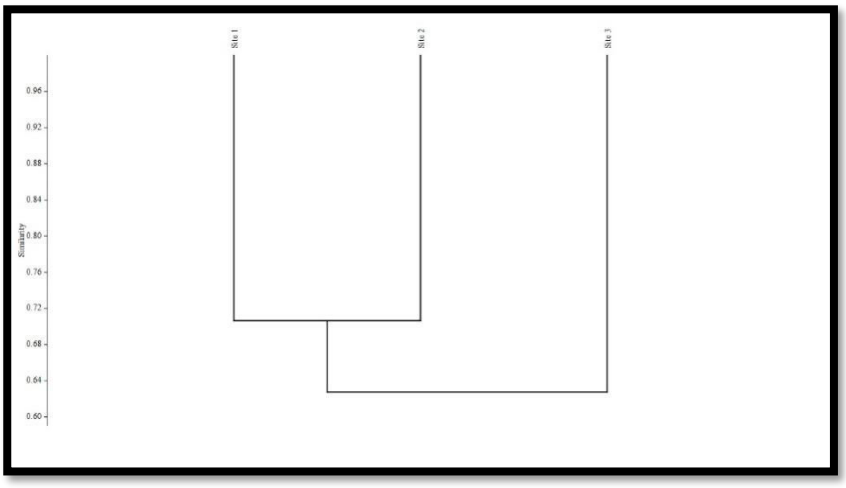


FIG 7: Similarity analysis between the sites.

3. Discussion:

The presence of living organisms in aquatic ecosystems is associated with the interaction between the abiotic and biotic factors (37). The present study heavily relied on physical parameters such as substrate material, riparian vegetation, nutrient condition, fish diversity and physiochemical parameters of the Dikhu river. In the hill stream, substrate materials of the river bed play an essential role in reproduction, predation, and growth and act as an essential aspect of the riverine ecosystem. Heterogenous microhabitats are created by the structure of river bed substratum and types of food available for the hill stream fish and compelled fish to modify some of the structures to adapt to the microhabitats (37). Riparian vegetations provide valuable ecological inputs such as habitat conditions and stabilization of river banks. Moderate to good habscore value signifies superior quality habitat (30) as a result of which, the ichthyofaunal diversity is also enhanced.

Species richness and fish distribution patterns in the riverine system are directly related to the seasonal variation in the physicochemical attributes such as AT, WT, DO, TA, FCO_2, pH, EC and TDS, velocity, depth and nutrient condition. The temperature of river water increases steadily from the origin of the river to its mouth. Hydrological factors such as volume of water, rate of flow, catchment area and inflow from tributaries influence water temperature (38). On the other hand, air temperature is influenced by climatic factors such as longitude, latitude, altitude, the region's topography, vapour pressure and wind speed. Air temperature coincides with water temperature (39) which in turn influences biological activities such as spawning, development, feeding, migration of fishes and distribution of organisms (40) and also

strongly affects water parameters like pH, alkalinity and solubility of DO (41). Similar results of DO were obtained by other workers in the Tigris River and Baldi stream of the Garhwal Himalayas (42,43). The lower DO values during monsoon and summer months might be due to higher temperatures, turbidity and TDS. High photosynthetic rate, turbulent water and cold-water temperature also contribute to high DO values (44). TA is a measure of bicarbonates, carbonates and hydroxides, which neutralize acids and, therefore, is an indicator of buffering capacity. Alkalinity is vital for aquatic organisms because it resists rapid pH changes (45). The mean lowest and highest TA values were recorded in July and January respectively. The values of TA start to decline with the onset of monsoon season and this aligns with the findings of Toshi and Sharif (46). FCO_2 is one of the components of both air and natural water bodies. Dissolved Carbon and cellular oxidation increase the level of CO_2 in water. Similar results of FCO_2 were observed by workers like Temjen and Singh (5), and Renu (47). Anthropogenic activity and pollutants can increase the level of FCO_2. The high rate of influx of rainwater and decomposition increases the level of FCO_2, while algal bloom decreases the level. pH generally indicates the degree of alkalinity or acidity of the water body. The lowest average pH was recorded in June, while the highest was observed in February. Bora and Goswami (48) also recorded similar results in the Kolong river Assam. High photosynthetic activity in winter is usually associated with higher pH values. The capability of water to carry an electrical current is the conductivity of the water. This is because of the presence of salts dissolved in the water, basically via erosion of rocks and siltation. The higher conductivity in summer and monsoon months may be due to the influx of salts with the rainwater. The TDS is measured for the amount of solid matter – both organic and inorganic dissolved in the water. The average minimum and maximum TDS were recorded in December and in July. The maximum value of TDS in monsoon may be due to the influx of rainwater, as well as anthropogenic activities. The values recorded are within permissible limits. The study reveals that all the physicochemical parameters of the water investigated were found to be within the permissible limit and free from pollution.

Ichthyofaunal diversity is defined as the species richness (number of species) and abundance of each species that live in a particular period and location. It also refers to the variety of genes and species within the fish population (49). Biodiversity is an extremely necessary part of nature's precious assets that provide for every individual's needs (50). In light of global warming, pollution, deterioration of the ecosystem, and extinction of species, documentation of flora and fauna has become essential to know the current status of biodiversity (51). In a riverine ecosystem, Fish species show a unique pattern of distribution where upstream is less diverse with species richness as compared to downstream (52). In this study also, Similar distribution was observed with 43 species at site III.

Based on the CCA, the relationship between the environmental variables and the fish population is determined. The most dominant genus Psilorhynchus, Opsarius and Olyra are influenced by AT, WT, FCO_2 and TA. While other genera such as Devario, Amblyceps and Danio are influenced by DO, pH, EC and TDS. The Bray-Cuetiss Dissimilarity matrix shows the significant similarity between the seasons and between the sites. The result of the analysis of the variance of water parameters between the seasons is given in table 7.

The diversity indices (Shanon-Wiener, Simpson's diversity index, Species evenness) revealed the unstable characteristics of fish species of the hill streams. Both species richness and rare species strongly influenced the H index and it is quite sensitive to even an insignificant change in diversity. It is generally used to monitor the exact state of the environment. D index gives more weightage to evenness and dominant species. It is not affected by less abundant species. D indices are utilized to show how ecological diversity proceeds positively.

The substrate composition of the river bed plays a crucial role in the physiological process such as growth, and reproduction of the fish. Diverse microhabitat conditions created bythe structure of the riverine substratum helphillstream fishes acquire structural adaptation (Hora, 1921). Besides, toavoid being taken away by the rapid and turbulent currents, adaptivestructuresdeveloped by these fish are used to cling to the rocky substratum. it bears evolutionary significance and providesphenotypic andgenotypic divergence in the hill stream fish

4. Conclusion:

The present study revealed that the water parameters vary depending on anthropogenic factors around the selected sites. Although human activities such as the construction of bridges and harmful fishing practices such as using batteries, bleaching powder, chemicals and pesticides altered the river's physicochemical parameters of water up to a certain extent. Besides, Boulder removal, Jhum cultivation in the catchment area, and fishing during breeding season are some issues that need to be addressed. These activities are the primary causes of habitat destruction and consequently lead to the reduction of species diversity. A matter of concern is that some fishes like Ompokpabda and Neolisssochilushexagonolepis are already near the threatened species level, and if mitigating steps are not taken other species may also be endangered. We know that over-exploitation of resources and other destructive methods are the main reasons for reducing fish abundance in other water bodies too. Therefore, it is important to create awareness among the fishermen in particular and the public in general. In conclusion, it is to be mentioned that further

assessment of fish assemblage has to be carried out to know the exact fish diversity of the Dikhu river.

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