STUDIES ON ICHTHYOFAUNAL DIVERSITY OF DIKHU RIVER, NAGALAND WITH SPECIAL REFERENCE TO CONSERVATION AND DEVELOPMENTAL BIOLOGY OF *NEOLISSOCHILUS HEXAGONOLEPIS* (MCCLELLAND, 1839)

by

Metevinu Kechu

Reg. No.PhD/ZOO/00127 w.e.f. (24/08/2017)

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SCHOOL OF SCIENCES
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By

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Under the Supervision of

Dr. Pranay Punj Pankaj

Submitted

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Doctor of Philosophy in Zoology of Nagaland University

Lumami-798627

Nagaland, India

नागालैण्ड विश्वविद्यालय
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CERTIFICATE

This is to certify that **Ms. Metevinu Kechu**, a Research Scholar for the Ph.D. (Science) degree in **Zoology** at **Nagaland University**, bearing Registration Number **Ph.D./ZOO/00127**, dated **24/08/2017**, has been working under my guidance and supervision. Her thesis entitled **"Studies on ichthyofaunal diversity of Dikhu River, Nagaland with special reference to conservation and developmental biology of *Neolissochilus hexagonolepis* (McClelland, 1839)"** is being forwarded for submission in partial fulfillment of the requirements for the award of the Ph.D. (Science) degree from this university. It is certified that she has fulfilled all the necessary requirements as per the regulations of the university, and the research work embodied in this thesis is original and has not been submitted for the award of any other degree or diploma in this or any other university.

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DECLARATION

I, **Ms. Metevinu Kechu** (Reg. No. **Ph.D./ZOO/00127**, effective from **24/08/2017**), hereby declare that the thesis entitled **"Studies on ichthyofaunal diversity of Dikhu River, Nagaland with special reference to conservation and developmental biology of *Neolissochilus hexagonolepis* (McClelland, 1839)"** is based on my original research work. I further affirm that this thesis has not been submitted for any degree or diploma at any other university or institution.This submission is made to Nagaland University for the award of the Ph.D. degree in Zoology.

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DEDICATED TO MY MOTHER, SIBLINGS

AND EXTENDED FAMILY

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American Public Health Association (APHA)
Analysis of Variance (ANOVA)
Anglers Association Nagaland (AAN)
Biodiversity Management Committees (BMCs)
Bureau of Indian Standards (BIS)
Centimetres (cm)
Chi-square (x^2)
Coefficient of Determination ('r^2')
Coefficient of Variation (CV)
Community-Conserved Areas (CCAs)
Condition Factor (K)
Correlation Coefficient ('r')
Correspondence Analysis (CCA)
Data Deficient (DD)
Days After Hatching (DAH)
Directorate of Coldwater Fisheries Research (DCFR)
Dissolved Oxygen (DO)
Endangered (EN)
Eye Diameter (ED)
Fecundity (F)
Fiber-reinforced Plastic (FRP)
Food (Fd)
Gonad Weight (GW)
Gonado Somatic Index (GSI)
Gram (g)
Head Length (HL)
Hours After Fertilization (HAF)
Indian Council of Agricultural Research (ICAR)
Indian Council of Medical Research (ICMR)
Indian Network for Climate Change Assessment (INCCA)
Intellectual Property Rights (IPR)
International Union for Conservation of Nature (IUCN)
Least Concern (LC)
Length-Weight Relationship (LWR)
Millimetre (mm)
Nagaland State Rural Livelihoods Mission (NSRLM)
National Bank for Agriculture and Rural Development (NABARD)
National Biodiversity Authority (NBA)
National Cooperative Development Corporation (NCDC)
National Green Tribunal (NGT)
Near Threatened (NT)
Non-governmental organizations (NGOs)
North Eastern Council (NEC)
Not Accessed (NA)
Ornamental (Or)
Paleontological Statistics software (PAST)
Pradhan Mantri Matsya Sampada Yojana (PMMSY)
Self-Help Groups (SHGs)
Sport (Sp)
Standard Deviation SD
Standard length (SL)
State Biodiversity Boards (SBBs)
Total Alkalinity (TA)
Total Dissolved Solids (TDS)
Total Hardness (TH)
Total length (TL)
Total Weight (TW)
United Nations (UN)
Vulnerable (VU)
Water Velocity (V)
Weight (W)
World Health Organization (WHO)

CHAPTER 1

General introduction

CONTENTS

1.1 Introduction

1.2 Objectives

1.1 Introduction

1.1.1 Role of freshwater fishes in local livelihoods and biodiversity

Freshwater ichthyofauna represent one of the most diverse groups of vertebrates, playing critical roles in aquatic ecosystems and acting as bioindicators for evaluating the ecological health of rivers. It is estimated that freshwater habitats encompassing rivers, lakes and wetlands, host approximately 18,000 species of fish, with hundreds of new species being described annually (van der Sleen and Albert, 2022). The freshwater habitat comprises only a small proportion of the earth's surface water but contains an inappropriately large number of the world's fish species (Nelson *et al.,* 2016). Fish assemblage descriptors enhance our understanding of aquatic ecosystems by providing quantitative measures such as species richness, diversity, evenness, and biotic integrity that reflect the overall structure and health of fish communities. These descriptors allow scientists to monitor ecosystem changes, assess environmental impacts, and evaluate ecosystem health more effectively than single-species approaches. They offer a comprehensive view of how physical and biological factors influence fish populations, supporting better management and conservation decisions (Kwak and Peterson, 2007). There is an urgent need for sustainable management of river ecosystems, which face significant threats from human activities, including pollution, illegal fishing, domestic disposal, damming, and channelization (Lkr *et al.,* 2020; Dey and Majumdar, 2024). It highlights that 48% of rivers are moderately to severely impacted, with biodiversity loss accelerating since 1970 (Schmutz and Sendzimir, 2018).

1.1.2 Importance of river ecosystems in Northeast India

Northeast India, characterized by its distinct topography, diverse geomorphology, and intricate network of torrential hill streams and watersheds, harbors exceptional ichthyofaunal diversity. The region is part of two biodiversity hotspots of global importance, namely the Eastern region of the Himalayas and the Indo-Burma region, which together support a rich assemblage of freshwater fish species (Acharjee *et al.,* 2012; Sarma *et al.,* 2018; Chetry *et al.,* 2023). The ecological diversity in this region is largely a result of its varied geomorphology, comprising hills, plateaus, and valleys that supports numerous freshwater habitats, including fast-flowing streams, rivers, lakes, and swamps. In addition, tectonic processes in the Indo-China subregion,

driven by the convergence of the Indian, Chinese, and Burmese plates, have formed the Himalayas and Indo-Burman ranges, further influencing habitat heterogeneity (Goswami *et al.,* 2012).

1.1.3 Overview of the Dikhu River and its ecological significance

Nagaland with an area of 16,579 km² consists of a part of tributaries of three important rivers, Brahmaputra and Barak River of India and Irrawaddy (Chindwin) of Myanmar. Nagaland, a relatively small and mountainous state in the northwestern corner of India, contains numerous rivers and hill streams that support a unique assemblage of exotic fish fauna (Ao *et al.,* 2008). Previous works on the investigations in the drainages of Nagaland are very meager as compared to the investigations carried out on the fish and fisheries of other Indian river systems. Notable workers like Hora and Mukherji (1935) reported 44 species from the Naga hills, while Kosygin and Vishwanath (1998) reported 27 species of which 9 were the first record of the state from Tizu River of Nagaland. Ao et al. (2008) reported a maximum of 149 species of fish from different river systems of Nagaland. Ezung et al. (2020b) confirmed 197 valid species of fish distributed across 26 families in this region. Wewa-U et al. (2025) reported 216 species belonging to 29 families. Dikhu River, one of the major rivers of Nagaland flows westward and finally confluences with the Brahmaputra. It is perennial by nature and originates from the Hills of Nuruto, Zunheboto. It extends over a length of 170 km and encompasses a catchment area of 2,996 km². The river divides into two major tributaries, the Nanung which flows through the Langpangkong range of Mokokchung and Yangyu of Tuensang district district (Ao *et al*., 2008). Studies on fish diversity are scanty in this region with few recent studies conducted by Konyak and Limatemjen (2022), Pukhrambam and Bendang (2024) and Kechu and Pankaj (2025). It sustains local biodiversity, supporting numerous freshwater fish species, and supports livelihoods for sustenance (Kechu and Pankaj, 2023a). Recognizing its unique ichthyofaunal diversity and the threats from human encroachment and unsustainable fishing, preserving the health of its riverine ecosystems is now of paramount importance.

1.1.4 Significance of traditional fishing practices in Northeast, India

Studying indigenous fishing practices in Northeast India is vital for preserving traditional knowledge, safeguarding cultural heritage, and fostering sustainable

resource management. These age-old practices, carried forward across generations, demonstrate deep awareness of aquatic habitats while emphasizing the interdependence between communities and their natural environments. They hold the potential to contribute significantly to biodiversity conservation and food security. Moreover, they encompass multiple dimensions, including the preservation of traditional knowledge, cultural heritage, sustainable resource use, biodiversity conservation, food security, and even ethno-medicinal significance (Imchen and Joglekar, 2017; Ovung *et al.,* 2022; Basumatary and Khangembam, 2023). From a socio-economic perspective, traditional fishing practices support the livelihoods of both fishermen and fisherwomen, sustain local fish-based trade, and contribute to the overall economic resilience and well-being of communities (Akbari *et al.,* 2023). Recognizing and integrating these indigenous practices into modern conservation and fisheries management frameworks can bridge the gap between traditional wisdom and scientific approaches, creating more culturally grounded and ecologically effective strategies for sustaining freshwater resources.

1.1.5 A Comprehensive overview of mahseer

Mahseer are often called the "tiger among fishes" because of their large scales, striking appearance, and impressive size compared to other cyprinids. They have significant ecological, cultural, and economic value (Langer *et al*., 2001; Desai, 2003). Besides their importance for food and sport, mahseer are also recognized as an important part of cultural and natural heritage (Oliver *et al*., 2007). Mahseer belong to two main genera, Tor and Neolissochilus. These fish are identified by differences in their labial structure. Tor have a continuous labial groove, while Neolissochilus have an interrupted groove and thin lips that continue around the corners of the mouth, with the labial fold widely interrupted in the middle (Rainboth, 1985). In recent years, growing interest has transformed the mahseer into a cultural symbol, valued not just for its economic and recreational roles but also for its role in raising awareness about conservation (Nautiyal, 2006). Based on the catalog of fishes (Fricke *et al.,* 2025), the distribution of *Neolissochilus* in India is presented in Table 1.1.

Table 1.1 Distributional data for *Neolissochilus* in India, compiled from the catalog of fishes (Fricke *et al.,* 2025)

Sl.No.	Species	Distribution	Present status
1	*Neolissochilus acutirostris* (Arunachalam, Sivakumar and Murugan, 2017)	Cauvery River drainage, Karnataka	NA
2	*Neolissochilus capudelphinus* (Arunachalam, Sivakumar and Murugan, 2017)	Periyar River basin, Western hats	NA
3	*Neolissochilus dukai* (Day, 1878)	Teesta and Brahmaputra drainage, Northeastern Bengal, Arunachal Pradesh and Northern Assam	DD
4	*Neolissochilus heterostomus* (Chen and Yang, 1999)	Manipur (Chindwin and Irrawaddy drainage)	NA
5	*Neolissochilus hexagonolepis* (McClelland, 1839)	Eastern Himalaya	NT
6	*Neolissochilus hexastichus* (McClelland, 1839)	North-East regions	NT
7	*Neolissochilus kaladanensis* (Lalramliana, Lalronunga, Kumar and Singh, 2019)	Kaladan River drainage, Mizoram and Northeastern regions	NA

8	*Neolissochilus micropthalmus* (Arunachalam, Sivakumar and Murugan, 2017)	Valapatnam River basin, Kerala	NA
9	*Neolissochilus minimus* (Arunachalam, Sivakumar and Murugan, 2017)	Cumbam Valley, Western Ghats	NA
10	*Neolissochilus paucisquamatus (Smith, 1945)*	Manipur (Chindwin drainage)	LC
11	*Neolissochilus pnar* (Dahanukar, Sundar, Rangad, Proudlove and Raghavan, 2023)	Caves in Jaintia Hills, Meghalaya	NA
12	*Neolissochilus spinulosus* (McClelland, 1845)	Teesta drainage, Northern Bengal	DD
13	*Neolissochilus stevensonii* (Day, 1870)	Mizoram (Kaladan drainage)	DD
14	*Neolissochilus stracheyi* (Day, 1871)	Manipur (Chindwin-Irrawaddy drainage)	LC
15	*Neolissochilus tamiraparaniensis* (Arunachalam, Sivakumar and Murugan, 2017)	Tamiraparani River basin, Tamil Nadu	NA
16	*Neolissochilus wynaadensis* (Day, 1873).	Kerala and Karnataka (Southern India)	CR

Abbreviations: DD; data deficient; NA, not accessed; LC, least concern; NT, near threatened; CR, Critically Endangered.

1.1.5.1 Distribution of *Neolissochilus hexagonolepis*

N. hexagonolepis stands out as a flagship species in Nagaland, valued for both its food and recreational importance (Sarkar *et al.,* 2015). They are known to occur across several countries, including Bangladesh, Myanmar, China, Nepal, Bhutan, as well as in North and Northeast, India (Dasgupta, 1994; Mahapatra and Vinod, 2011; Sahoo *et al.,* 2015). The species *N. hexagonolepis*, commonly called the chocolate or copper mahseer, is present in nearly all major rivers and streams throughout India (Mahapatra *et al.,* 2004). In the northeastern region, particularly in Assam, Nagaland, and Meghalaya, this fish is reported to be relatively abundant (Dasgupta, 1994). Hussain (2012), in his investigation on the ichthyofauna and limnology of the Barak, Jatinga, Dhaleswari, and Ganol rivers in NE India, recorded the presence of *N. hexagonolepis*. Goswami (2012) similarly noted the occurrence of *N. hexagonolepis* in a region encompassed by both the Himalayan and Indo-Burma biodiversity hotspots.

1.1.5.2 Habitat and Ecological Preferences

Chocolate mahseer is remarkably adaptable, thriving primarily in fast-flowing and oxygen-rich streams of hilly terrains. It thrives in clean, moderately cool waters with rocky or sandy substrates and depends on a varied diet, including invertebrates and plant matter (Dasgupta, 1994; Mahapatra and Vinod, 2011). The ecological role of *N. hexagonolepis* as both a predator and prey species highlights its importance in maintaining freshwater ecosystem balance.

1.1.5.3 Threats and anthropogenic pressures

The important endemic mahseers are increasingly threatened in Northeast, India and across other regions of the country, largely due to escalating harvest pressure and a range of anthropogenic impacts (CAMP, 1998). In Northeast India, the scarcity of detailed knowledge on the biology, distribution, migration patterns, and precise taxonomic classification of mahseer has hindered a clear understanding of their conservation status. Equally concerning is the lack of research on their culture and growth in pond-based systems across the country. Evidence from the Northeastern Himalayan region paints a troubling picture, with mahseer populations plummeting by an estimated 45 - 60% (Marwein, 2000; Mahapatra *et al.,* 2004). This steep decline has already led to the species being recognized as endangered in several parts

of Northern and Northeastern India (Khan and Sinha, 2000). More recent findings confirm that *Neolissochilus hexagonolepis* continues to face endangered status in numerous rivers across the region (Khan and Sinha, 2000; Nath *et al.,* 2016; Sharma *et al.,* 2019), emphasising a pressing requirement for focused conservation efforts. The chocolate mahseer is currently classified as "Near Threatened" on the IUCN Red List (Arunachalam, 2010). The causes of this drastic reduction include overharvesting, anthropogenic disturbances, habitat alteration, pollution, river valley projects, introduction of exotic species, and weak enforcement of fishing regulations (Menon *et al.,* 2000; Nautiyal, 2006; Sarkar *et al.,* 2015; Debnath *et al.,* 2024b; Abass *et al.,* 2024). One notable example is the decline of fingerling and fry fishing of Mahseer in the Umiam Reservoir of Meghalaya, where subsistence collection by fishermen has significantly contributed to the depletion of their population (Vinod *et al.,* 2007). In addition, studies have highlighted the implications of climate change on breeding phenology in Himalayan Mahseer populations (Joshi *et al.,* 2018).

1.1.5.4 Breeding behavior and larval development studies for conservation strategies

The conservation of the chocolate mahseer now requires urgent attention owing to population decline caused by overfishing and habitat degradation (Sarkar *et al.,* 2015; Dash *et al.,* 2024; Kumar *et al.,* 2025). Understanding its breeding behavior and larval development is central to formulating effective conservation strategies, as reproductive success is shaped by environmental factors such as water temperature, depth, photoperiod, and substrate availability (Mahapatra and Vinod, 2011; Dash *et al.,* 2021b). In captivity, successful natural spawning has been achieved using gravel substrate trays, although manual stripping can be employed to enhance egg collection when spawning behaviors are observed (Dash *et al.,* 2021a). Fertilized eggs are transparent, spherical, non-adhesive, and demersal, with hatching and yolk sac absorption occurring over periods influenced by water temperature, followed by a transition from endogenous to exogenous feeding (Sarma *et al.,* 2015). Insights into these early developmental stages are necessary to foster effective captive breeding programs, maintaining genetic diversity, and supporting the enhancement of wild stocks (Basumatary and Islam, 2022). Moreover, understanding spawning site preferences and environmental triggers can guide targeted habitat restoration, while

geospatial mapping of suitable habitats enables the prioritization of critical conservation areas (Dash *et al.,* 2021a). By integrating reproductive biology, genetic knowledge, and spatial planning, conservation efforts can be strategically formulated to protect and restore *N. hexagonolepis* populations, ensuring the preservation of their ecological, cultural, and economic significance.

1.1.5.5 Remedial measures

Celebrated for its ecological importance and cultural heritage, the mahseer has become a flagship species for freshwater conservation in India, with its protection requiring a careful integration of scientific research, regulatory measures, and community-led initiatives. The critical need for its conservation was first highlighted by Kulkarni and Ogale (1978), who also assessed its national status. In response to overexploitation and destructive fishing practices, the Indian Fisheries Act of 1897 was amended in 1956 to enforce stricter regulations. It is valued both as a sport and food fish, and recognised as a cultural symbol among numerous Asian groups (Nautiyal, 2006), calling for thorough investigation of its taxonomy, biology, reproductive ecology, and aquaculture potential to inform effective management strategies. Notably, *N. hexagonolepis* has emerged as a popular target among anglers, contributing to recreational fishing experiences and supporting the growth of ecotourism initiatives (Jyrwa and Bhuyan, 2016). Conservation of mahseers through the positive role of recreational fisheries (Pinder and Raghavan, 2013; Bower *et al.,* 2017) with ecotourism (Baruah and Sarma, 2018) have shown to be a valuable approach in conservation. Gupta et al. (2016) also highlighted catch-and-release angling as an effective strategy for freshwater fish conservation in India.

1.2 Objectives

1. To assess the physico-chemical parameters of the Dikhu River across seasons.
2. To document the ichthyofaunal diversity and traditional fishing practices of the Dikhu River.
3. To examine the bionomic characteristics of *Neolissochilus hexagonolepis*.
4. To investigate the reproductive metrics and larval development of *N. hexagonolepis*.
5. To suggest conservation measures for sustainable management.

CHAPTER 2

Physico-chemical characterization of the Dikhu River

CONTENTS

2.1 Introduction

2.2 Materials and methods

2.3 Results

2.4 Discussion

2.1 Introduction

The Dikhu River, a significant tributary of the Brahmaputra, traverses the districts of Mokokchung and Zunheboto in Nagaland, India (Ao *et al.*, 2008). It plays a crucial role in supporting local communities by providing water for agriculture, fisheries, and domestic use. Assessing the ecological condition of the Dikhu River and its sustainable management would require understanding its physico-chemical characteristics.

The river serves as a source of surface water for natural resources and, in turn, supports living organisms (Shukla *et al.,* 2013; Mirza *et al.,* 2014). However, increasing anthropogenic pressures such as habitat fragmentation, deforestation, destructive fishing practices, and agricultural runoff pose significant threats to the river ecological balance (Tiwary, 2000; Krishnakumar *et al.,* 2022; Saraswat *et al.*, 2022; Kechu and Pankaj, 2025). As agriculture is the primary source of livelihood in the area, excess chemical fertilizer runoff can result in water body pollution (Sudhakaran *et al.,* 2020). Riverine ecosystems ensure cover for aquatic life but unfortunately dumping sites for domestic and industrial waste affecting water bodies (Liu *et al.,* 2021). Monitoring physicochemical water quality parameters plays a key role in understanding and managing the overall health of aquatic ecosystems, including their hydrochemistry and ecological condition (Sarkar *et al.,* 2016; Longchar *et al.,* 2023). Regular assessment of water quality is essential for sustaining freshwater resources and supporting effective ecosystem management. The riverine freshwater systems are rapidly deteriorating, threatening not only aquatic species but also human communities that rely on them. Evaluating spatial and temporal variations in physicochemical parameters provides critical insights into the health of these systems, helping to identify pressure points caused by short or long-term human activities (Ahmed *et al.,* 2024). Such analyses form the foundation for targeted conservation and management strategies.

Physico-chemical analyses involve systematic measurements of key parameters such as temperature, pH, dissolved oxygen, total dissolved solids, alkalinity, and hardness. These factors are fundamental in defining water quality and assessing the overall health of aquatic systems. Regular monitoring helps identify sources of pollution, track seasonal variations, and inform effective conservation strategies. By applying

regional and international water quality standards established by the Indian Council of Medical Research (ICMR), the Bureau of Indian Standards (BIS), and the World Health Organization (WHO), the chemical characteristics and pollution status of water bodies can be accurately evaluated (Lkr *et al.*, 2020; Longchar *et al.*, 2023). Such assessments are crucial not only for maintaining the ecological integrity of rivers but also for safeguarding the well-being of communities that depend on them.

Previous studies conducted by Longchar et al. (2017), Sarmah et al. (2020), and Longchar et al. (2023) have employed multivariate statistical approaches to provide a detailed assessment of the riverine condition. These observations highlight the importance of long-term monitoring for detecting changes associated with both natural and human-induced activities. Thus, systematic investigations linking river pollution and various anthropogenic activities are essential for devising future conservation strategies. These water quality assessments are crucial for evaluating ecosystem health, identifying and controlling pollution sources, and implementing long-term management plans (Nong *et al.,* 2020; Yang *et al.*, 2020).

In conclusion, assessment of the temporal primarily seasonal variation of the physico-chemical characteristics of the Dikhu River is essential for sustainable water resource management. Such evaluations provide critical data in policy making, support environmental conservation efforts, and safeguard the livelihoods of the local population.

2.2 Materials and methods

2.2.1 Study area and sample collection

For the physicochemical assessment of the Dikhu River, water samples were collected systematically on a monthly basis over a period of twelve months, from March 2019 to February 2020, encompassing all four major seasons: pre-monsoon (March-May), monsoon (June-August), post-monsoon (September-November), and winter (December-February). A total of six sampling stations, Alaphumi, Sumi Setsü, Longsa, Longkong, Chakba, and Salulamang were selected along the course of the river within Mokokchung and Zunheboto districts. Site selection was based on accessibility. At each station, water sampling was carried out monthly to capture seasonal variability in physicochemical parameters. The geographical coordinates, including latitude, longitude, and altitude, were recorded for each sampling location using a Garmin eTrex GPS device 10 to ensure spatial precision and reproducibility. The mapping, site images, and tabulated geographical coordinates are presented in Table 2.1 and Figures 2.1 - 2.7.

2.2.2 Physico-chemical analysis

To ensure precision and consistency in data collection, both air and water temperatures were measured at a depth of 20 cm above and below the water surface. Sampling and field analyses were conducted monthly between 8:00 AM and 10:00 AM, maintaining a fixed time frame to minimize diurnal variations and enhance data accuracy. All experiments were conducted within 24 hours of water collection, with each test performed in triplicate to ensure accuracy and reliability. The mean value was calculated based on the triplicate analyses conducted for each case.

Air and water temperatures were recorded using a standard mercury thermometer with a range of 0-100°C. The surface water velocity was determined using a float method involving a stopwatch and a measuring tape, following the method outlined by Saha (2010), Water velocity (V) was calculated using the empirical formula:

$V = d/ 1.2t$

Where:

V = velocity of water (m/s)

d = distance between two fixed points (meters)

t = time taken by the floating object to cover the distance (seconds)

1.2 = constant correction factor

pH and Total Dissolved Solids (TDS) were measured at site using a Generic portable pocket pH tester and Generic digital imported TDS meter. For parameters such as Dissolved Oxygen (DO), Total Alkalinity, and Total Hardness, analyses were conducted using the Aquamerck Water Analysis Kit (1.11151.0001), following standard procedures.

2.2.3 Statistical analysis

Physico-chemical parameters recorded from multiple sampling sites along the Dikhu River were systematically compiled and organized using google sheets for preliminary data handling. Descriptive statistics, including the mean (± SD), were calculated for each parameter across the different sampling sites and seasons to assess spatial variations and temporal variations in water quality.

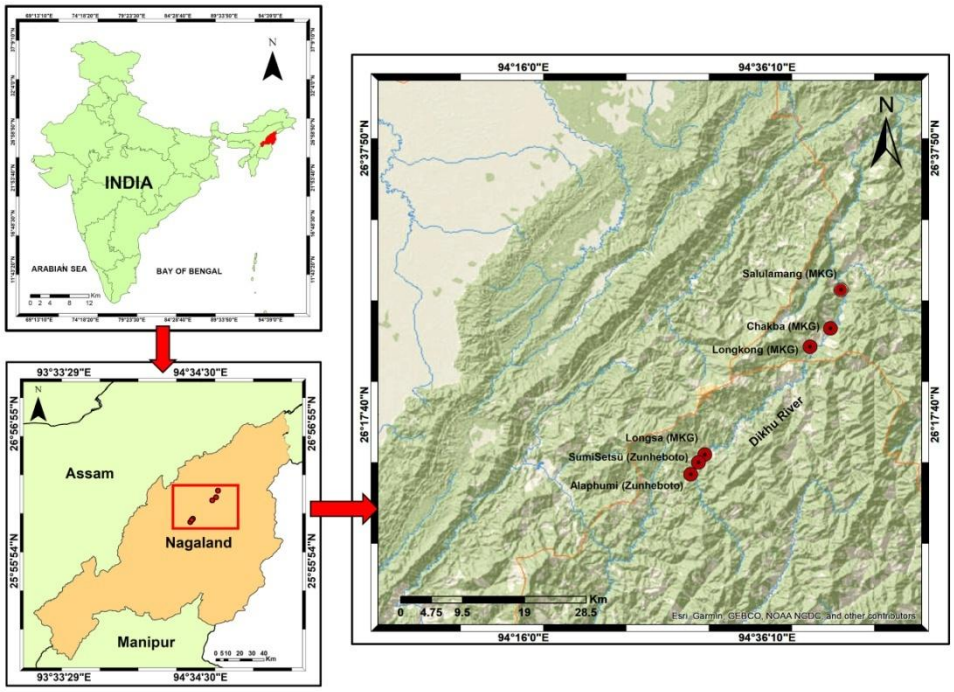

Figure 2.1: Geospatial mapping of study sites distribution along the Dikhu River, Nagaland

Table 2.1: Sampling stations at Dikhu River

Stations	Geographical coordinates	Altitude
Alaphumi (Zunheboto)	Latitude: 26.219° N Longitude: 94.497° E	726.3 m
Sumi Setsü (Zunheboto)	Latitude: 26.234° N Longitude: 94.508° E	692.2 m
Longsa (Mokokchung)	Latitude: 26.244° N Longitude: 94.517° E	679.7 m
Longkong (Mokokchung)	Latitude: 26.380° N Longitude: 94.662° E	423 m
Chakba (Mokokchung)	Latitude: 26.403° N Longitude: 94.690° E	393.8 m
Salulamang (Mokokchung)	Latitude: 26.452° N Longitude: 94.704° E	354.7 m

Figure 2.2: Alaphumi station (Zunheboto)

Figure 2.3: Sumi Setsü station (Zunheboto)

Figure 2.4: Longsa station (Mokokchung)

Figure 2.5: Longkong station (Mokokchung)

Figure 2.6: Chakba station (Mokokchung)

Figure 2.7: Salulamang station (Mokokchung)

2.3 Results

2.3.1 Physico chemical parameters

2.3.1.1 Air temperature

The mean air temperature from all the sampling stations ranged between 15°C at Longsa to 31.67°C at Chakba village with an overall average mean of 24.01 ± 4.15°C. Studies on the physico-chemical parameters of the Dikhu River reveal significant seasonal variations. Air temperatures peak during the monsoon season, with an average mean of 27.81 ± 0.99°C, while the lowest temperatures occur in winter, with an average mean of 18.38 ± 1.20°C for all the stations combined. The data is represented in Table 2.2 and visually interpreted in Figures 2.8 and 2.9.

In sampling station 1 (Alaphumi), the air temperature ranged between 16.33°C - 28.61°C. The lowest air temperature for seasonal variation was seen in winter with an average mean of 18.11 ± 1.68°C and highest was observed in monsoon with an average mean of 27.11 ± 1.68°C.

In sampling station 2 (Sumi Setsü), the air temperature ranged between 15.33 - 30.33°C. The lowest air temperature for seasonal variation was seen in winter with an average mean of 17.56 ± 2.17°C and highest was observed in monsoon with an average mean of 27.33 ± 2.65°C.

In sampling station 3 (Longsa), the air temperature ranged between 15.00 - 28.33°C. The lowest air temperature for seasonal variation was seen in winter with an average mean of 16.78 ± 1.68°C and highest was observed in monsoon with an average mean of 26.56 ± 1.68°C.

In sampling station 4 (Longkong), the air temperature ranged between 16.67 - 29.33°C. The lowest air temperature for seasonal variation was seen in winter with an average mean of 18.22 ± 1.90°C and highest was observed in monsoon with an average mean of 28.22 ± 1.02°C.

In sampling station 5 (Chakba), the air temperature ranged between 16.67 - 31.67°C. The lowest air temperature for seasonal variation was seen in winter with an average mean of 19.78 ± 3.01°C and highest was observed in monsoon with an average mean of 29.22 ± 2.22°C.

In sampling station 6 (Salulamang), the air temperature ranged between 18.33 - 30.33°C. The lowest air temperature for seasonal variation was seen in winter with

an average mean of 19.78 ± 1.71°C and highest was observed in monsoon with an average mean of 28.44 ± 2.01°C.

Table 2.2: Mean air temperature (°C) with its corresponding standard deviation values recorded at six stations along the Dikhu River.

Air Temperature (°C)					
Stations	**Mean Range**	**Seasons**			
		Pre-monsoon Mean ± SD	**Monsoon Mean ± SD**	**Post-monsoon Mean ± SD**	**Winter Mean ± SD**
Alaphumi	16.33	24.00 ± 3.84	27.11 ± 1.68	25.33 ± 2.08	18.11 ± 1.68
	28.67	19.67 - 27.00	25.33 - 28.67	23.67 - 27.67	16.33 - 19.67
Sumi Setsü	15.33	22.89 ± 1.58	27.33 ± 2.65	23.78 ± 2.50	17.56 ± 2.17
	30.33	21.67 - 24.67	25.33 - 30.33	21.33 - 26.33	15.33 - 19.67
Longsa	15.00	22.67 ± 3.06	26.56 ± 1.68	25.56 ± 1.92	16.78 ± 1.68
	28.33	19.33 - 25.33	25.00 - 28.33	23.33 - 26.67	15.00 - 18.33
Longkong	16.67	24.00 ± 1.45	28.22 ± 1.02	25.00 ± 3.28	18.22 ± 1.90
	29.33	22.33 - 25.00	27.33 - 29.33	22.33 - 28.67	16.67 - 20.33
Chakba	16.67	26.00 ± 2.03	29.22 ± 2.22	26.56 ± 2.83	19.78 ± 3.01
	31.67	23.67 - 27.33	27.33 - 31.67	23.67 - 29.33	16.67 - 22.67
Salulamang	18.33	26.33 ± 2.00	28.44 ± 2.01	27.11 ± 2.67	19.78 ± 1.71
	30.33	24.33 - 28.33	26.33 - 30.33	24.33 - 29.67	18.33 - 21.67

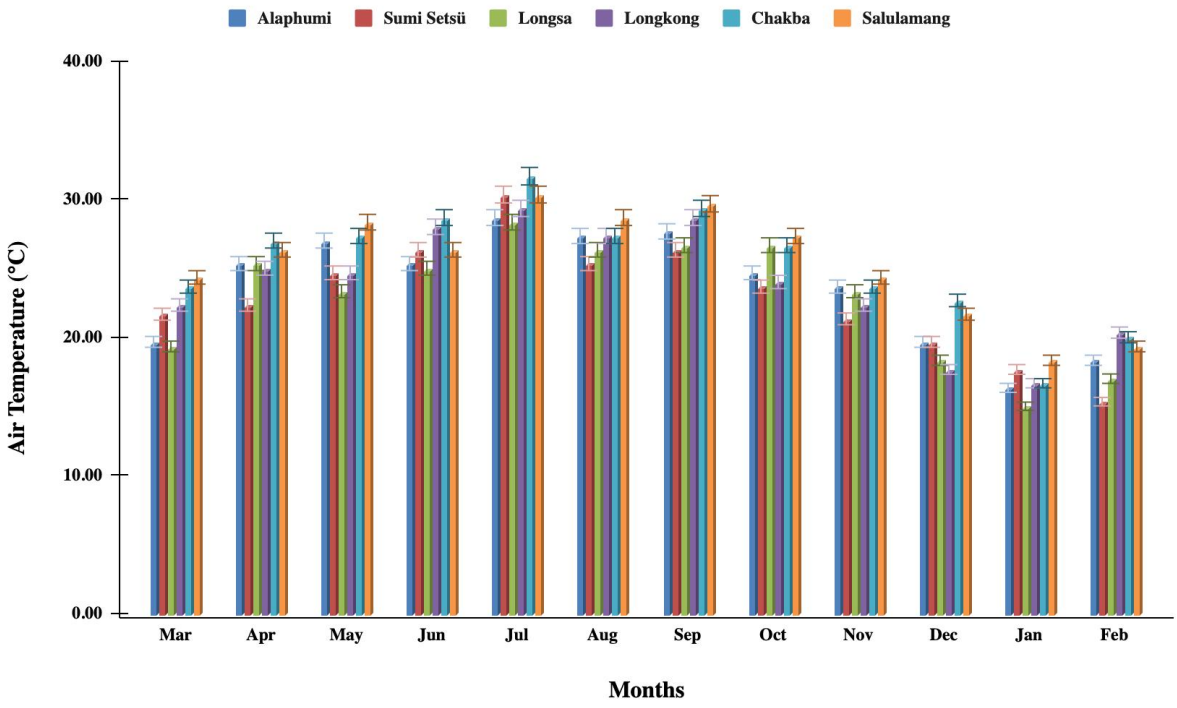

Figure 2.8: Monthly observations of air temperature (°C) in the Dikhu River

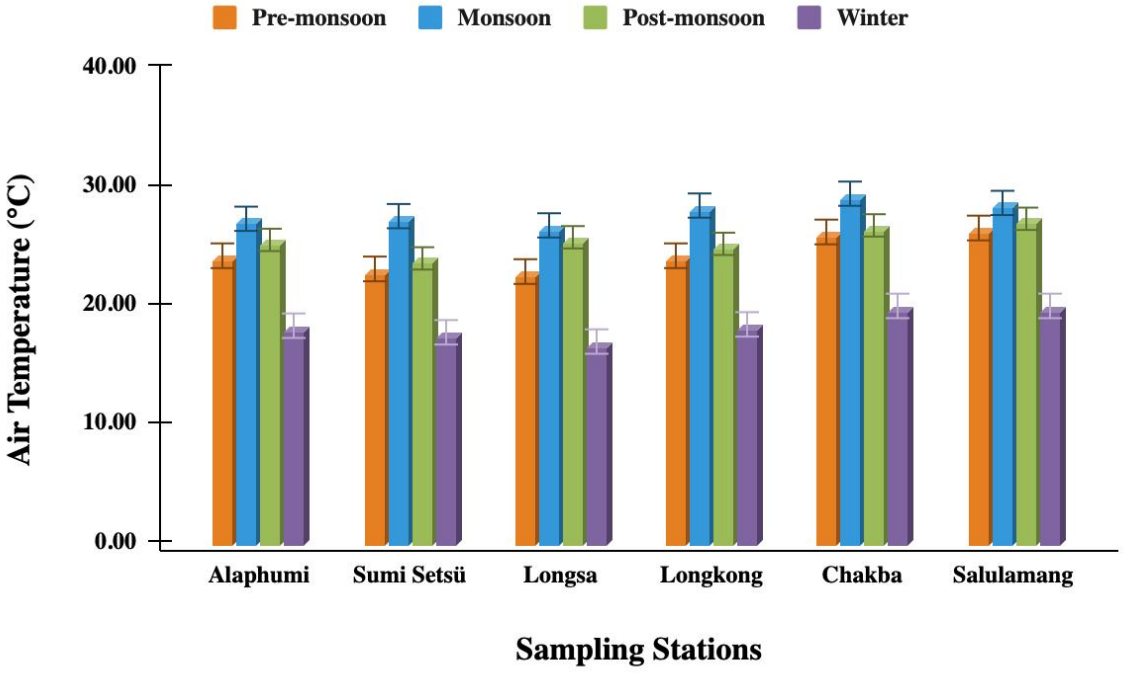

Figure 2.9: Seasonal observations of air temperature (°C) in the Dikhu River

2.3.1.2 Water temperature

The mean water temperature ranged from 10.33°C to 26.67°C at Sumi Setsü and Salulamang, with an annual average of 19.47 ± 4.29°C. Seasonal variations for water temperatures peak during the monsoon season, with an average mean of 23.30 ± 1.02°C, while the lowest temperatures occur in winter, with an average mean of 13.44 ± 1.22°C across all stations. Results are presented in Table 2.3 and Figures 2.10 - 2.11.

In sampling station 1 (Alaphumi), the water temperature ranged from 13.33°C - 25.33°C. The lowest water temperature for seasonal variation was observed in winter, with an average mean of 14.22 ± 1.26°C, while the highest was recorded during the monsoon season with an average mean of 22.89 ± 2.14°C.

In sampling station 2 (Sumi Setsü), the water temperature ranged between 10.33°C - 24.67°C. The lowest water temperature for seasonal variation was observed in winter, with an average mean of 11.44 ± 1.17°C, while the highest was recorded during the monsoon season with an average mean of 22.11 ± 2.27°C.

In sampling station 3 (Longsa), the water temperature ranged between 11.67°C - 23.33°C. The lowest water temperature for seasonal variation was observed in winter, with an average mean of 12.56 ± 1.02°C, while the highest was recorded during the monsoon season with an average mean of 22.22 ± 1.17°C.

In sampling station 4 (Longkong), the water temperature ranged between 12.33°C - 24.67°C. The lowest water temperature for seasonal variation was observed in winter, with an average mean of 13.56 ± 1.58°C, while the highest was recorded during the monsoon season with an average mean of 23.89 ± 0.69°C.

In sampling station 5 (Chakba), the water temperature ranged between 12.33°C - 26.33°C. The lowest water temperature for seasonal variation was observed in winter, with an average mean of 14.44 ± 2.01°C, while the highest was recorded during the monsoon season with an average mean of 24.22 ± 1.90°C.

In sampling station 6 (Salulamang), the water temperature ranged between 13.00°C - 26.67°C. The lowest water temperature for seasonal variation was observed in winter, with an average mean of 14.44 ± 1.35°C, while the highest was recorded during the monsoon season with an average mean of 24.44 ± 2.17°C.

Table 2.3: Mean water temperature (°C) with its corresponding standard deviation values recorded at six stations along the Dikhu River.

Water Temperature (°C)					
Stations	**Mean Range**	**Seasons**			
		Pre-monsoon Mean ± SD	**Monsoon Mean ± SD**	**Post-monsoon Mean ± SD**	**Winter Mean ± SD**
Alaphumi	13.33	20.33 ± 3.61	22.89 ± 2.14	21.11 ± 2.27	14.22 ± 1.26
	25.33	16.33 - 23.33	21.33 - 25.33	19.33 - 23.67	13.33 - 15.67
Sumi Setsü	10.33	18.44 ± 1.17	22.11 ± 2.27	20.22 ± 2.71	11.44 ± 1.17
	24.67	17.33 - 19.67	20.33 - 24.67	18.33 - 23.33	10.33 - 12.67
Longsa	11.67	18.11 ± 2.41	22.22 ± 1.17	20.67 ± 2.65	12.56 ± 1.02
	23.33	15.33 - 19.67	21.00 - 23.33	17.67 - 22.67	11.67 - 13.67
Longkong	12.33	19.44 ± 2.46	23.89 ± 0.69	21.44 ± 2.59	13.56 ± 1.58
	24.67	16.67 - 21.33	23.33 - 24.67	19.33 - 24.33	12.33 - 15.33
Chakba	12.33	21.11 ± 3.53	24.22 ± 1.90	21.56 ± 3.01	14.44 ± 2.01
	26.33	17.33 - 24.33	22.67 - 26.33	18.67 - 24.67	12.33 - 16.33
Salulamang	13.00	21.56 ± 2.83	24.44 ± 2.17	22.78 ± 2.87	14.44 ± 1.35
	26.67	18.33 - 23.67	22.33 - 26.67	19.67 - 25.33	13.00 - 15.67

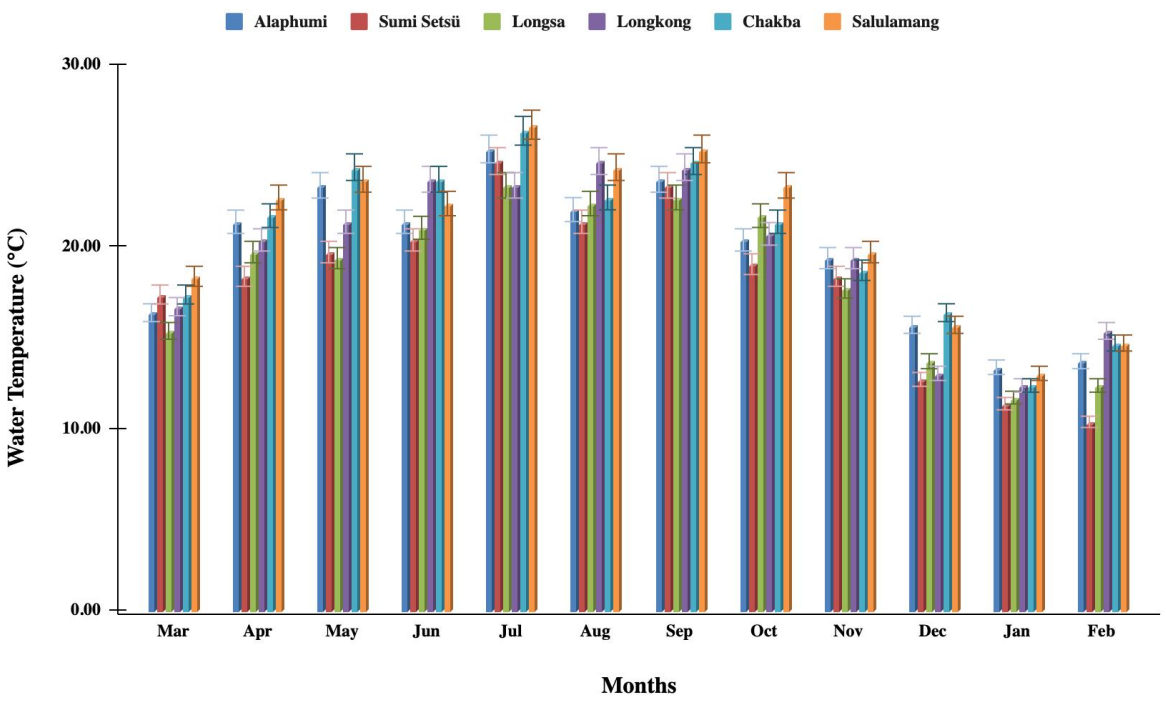

Figure 2.10: Monthly observations of water temperature (°C) in the Dikhu River

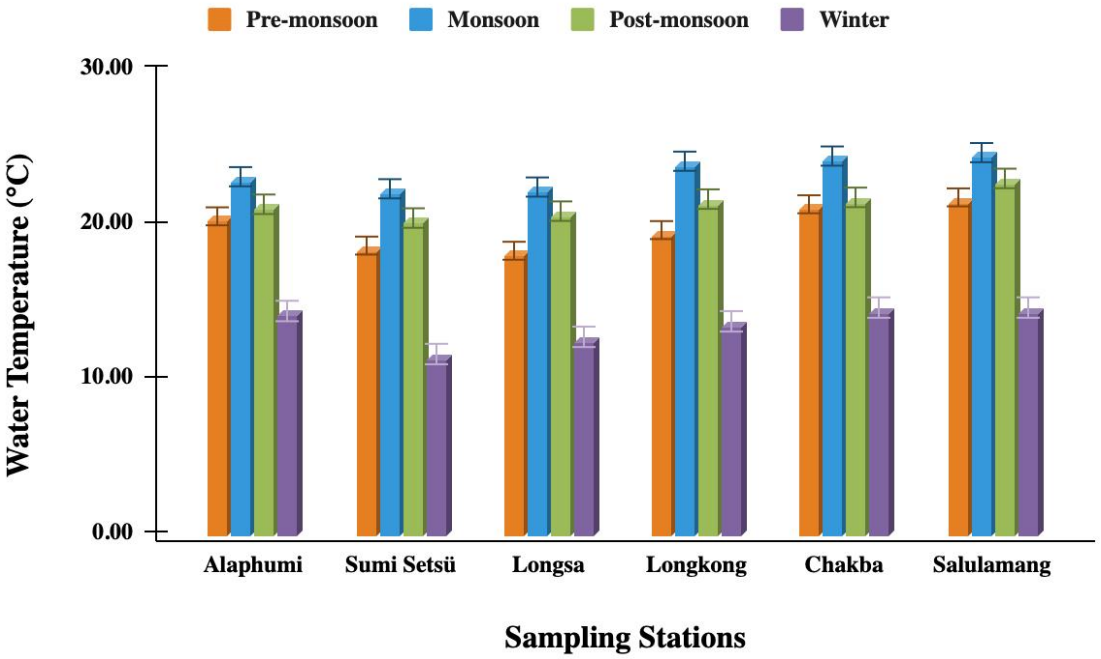

Figure 2.11: Seasonal observations of water temperature (°C) in the Dikhu River

2.3.1.3 Water velocity

The water velocity in the Dikhu River ranged from 0.06 m/s to 3.02 m/s at Sumi Setsü Salulamang respectively, with an annual average of 0.93 ± 0.82 m/s. Seasonal variation showed the highest velocity during the monsoon season at 1.83 ± 0.29 m/s, while the lowest was recorded in winter at 0.20 ± 0.04 m/s, based on data from all combined stations.These data are outlined in Table 2.4 and depicted in Figures 2.12 - 2.13.

The water velocity at sampling station 1 (Alaphumi), ranged from 0.08 m/s to 2.38 m/s. The lowest value, 0.19 ± 0.10 m/s, was recorded during the winter season, whereas the highest was recorded during the monsoon season, with an average of 1.50 ± 0.74 m/s.

The water velocity at sampling station 2 (Sumi Setsü), ranged from 0.06 m/s to 2.14 m/s. The lowest value, 0.16 ± 0.09 m/s, was recorded during the winter season, whereas the highest was recorded during the monsoon season, with an average of 1.75 ± 0.38 m/s.

The water velocity at sampling station 3 (Longsa), ranged from 0.09 m/s to 1.92 m/s. The lowest value, 0.26 ± 0.09 m/s, was recorded during the winter season, whereas the highest was recorded during the monsoon season, with an average of 1.63 ± 0.26 m/s.

The water velocity at sampling station 4 (Longkong), ranged from 0.08 m/s to 2.15 m/s. The lowest value, 0.17 ± 0.08 m/s, was recorded during the winter season, whereas the highest was recorded during the monsoon season, with an average of 1.80 ± 0.44 m/s.

The water velocity at sampling station 5 (Chakba), ranged from 0.11 m/s to 2.88 m/s. The lowest value, 0.21 ± 0.11 m/s was recorded during the winter season, whereas the highest was recorded during the monsoon season, with an average of 2.02 ± 0.88 m/s.

The water velocity at sampling station 6 (Salulamang), ranged from 0.07 m/s to 3.02 m/s. The lowest value, 0.23 ± 0.14 m/s, was recorded during the winter season, whereas the highest was recorded during the monsoon season, with an average of 2.31 ± 1.02 m/s.

Table 2.4: Mean water velocity with its corresponding standard deviation values recorded at six stations along the Dikhu River.

Water Velocity (m/s)					
Stations	**Mean Range**	**Seasons**			
		Pre-monsoon Mean ± SD	**Monsoon Mean ± SD**	**Post-monsoon Mean ± SD**	**Winter Mean ± SD**
Alaphumi	0.08	0.36 ± 0.29	1.50 ± 0.74	1.30 ± 0.94	0.19 ± 0.10
	2.38	0.10 - 0.68	0.95 - 2.34	0.69 - 2.38	0.08 - 0.26
Sumi Setsü	0.06	0.28 ± 0.18	1.75 ± 0.38	0.93 ± 0.22	0.16 ± 0.09
	2.14	0.08 - 0.44	1.38 - 2.14	0.77 - 1.18	0.06 - 0.25
Longsa	0.09	0.40 ± 0.34	1.63 ± 0.26	1.05 ± 0.36	0.26 ± 0.09
	1.92	0.09 - 0.76	1.41 - 1.92	0.77 - 1.46	0.16 - 0.33
Longkong	0.08	0.57 ± 0.48	1.80 ± 0.44	1.36 ± 0.63	0.17 ± 0.08
	2.15	0.13 - 1.08	1.31 - 2.15	0.77 - 2.02	0.08 - 0.23
Chakba	0.11	0.39 ± 0.32	2.02 ± 0.88	1.62 ± 0.83	0.21 ± 0.11
	2.88	0.14 - 0.75	1.12 - 2.88	0.85 - 2.51	0.11 - 0.33
Salulamang	0.07	0.46 ± 0.57	2.31 ± 1.02	1.41 ± 0.97	0.23 ± 0.14
	3.02	0.07 - 1.12	1.14 - 3.02	0.58 - 2.47	0.11 - 0.38

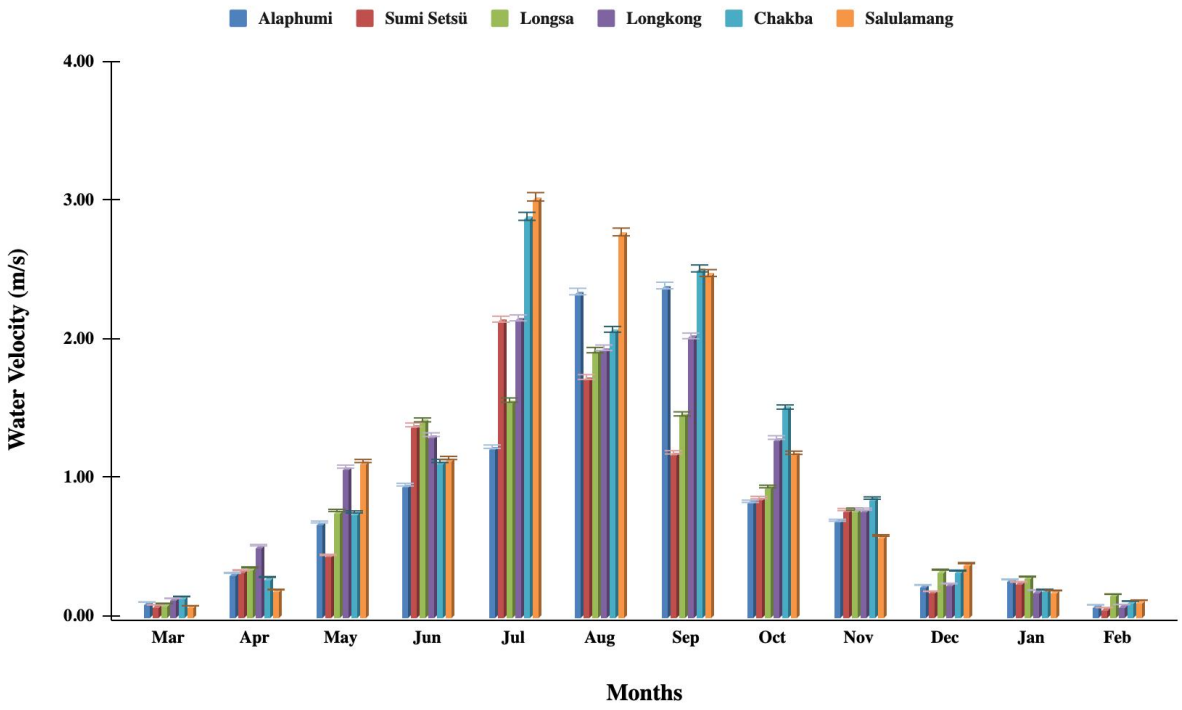

Figure 2.12: Monthly observations of water velocity in the Dikhu River

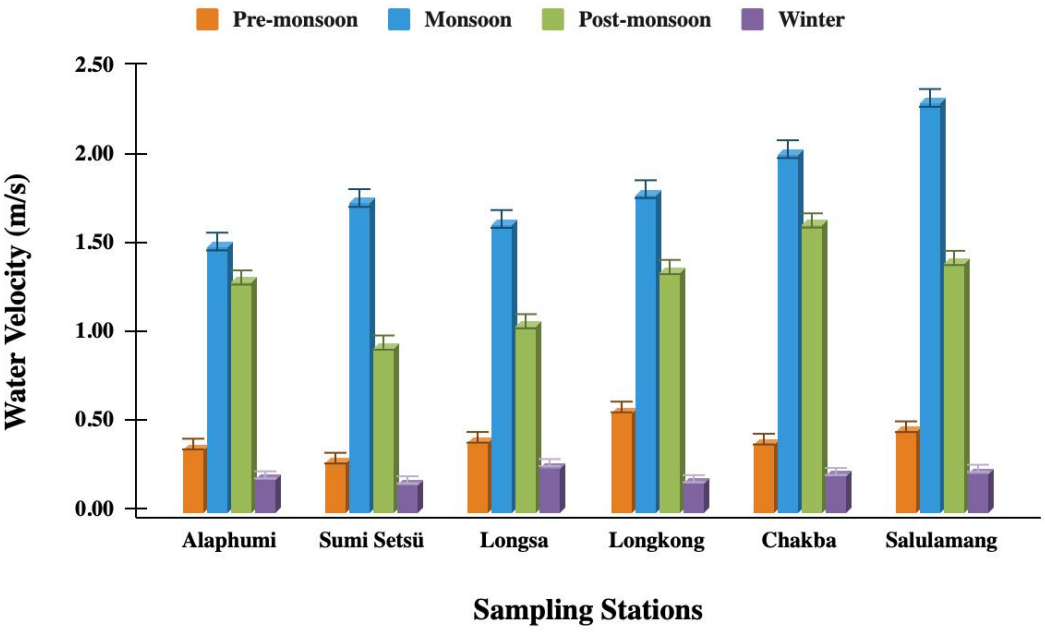

Figure 2.13: Seasonal observations of water velocity in the Dikhu River

2.3.1.4 pH

The mean pH values ranged from 7.07 at Chakba to 8.17 at Salulamang, yielding an annual mean of 7.58 ± 0.33. Seasonal variation in pH was relatively minimal, with the highest mean value recorded in winter (7.80 ± 0.19), followed by pre-monsoon (7.61 ± 0.25), post-monsoon (7.52 ± 0.23), and the lowest value in the monsoon season at 7.37 ± 0.16, across all stations. Details are provided in Table 2.5 and Figures 2.14 - 2.15.

Station 1 (Alaphumi) revealed pH readings between 7.67 and 8.13, with seasonal means lowest in the monsoon (7.38 ± 0.13) and highest in the pre-monsoon (7.97 ± 0.26).

At station 2 (Longsa), pH varied from 7.13 to 7.97. The lowest mean fell in the monsoon (7.27 ± 0.12) and the highest in winter (7.83 ± 0.06).

The pH values for station 3 in Longsa village ranged from 7.30 to 7.90. The post-monsoon season was found to show the lowest values of 7.37 ± 0.12, while the pre-monsoon season recorded the highest peak at 7.61 ± 0.28.

Station 4 (Longkong) recorded values from 7.17 to 8.10, peaking in winter (8.07 ± 0.03) and the minimum recorded values in the pre-monsoon (7.22 ± 0.04).

At station 5 (Chakba), values spanned from 7.07 to 8.03; the monsoon mean was the lowest (7.13 ± 0.07) and the pre-monsoon the highest (7.74 ± 0.34).

In station 6 (Salulamang), the pH values ranged from 7.13 to 8.17, with the winter period recording the peak values at 7.88 ± 0.32 and the monsoon recording the lowest values at 7.36 ± 0.05.

Table 2.5: Mean pH with its corresponding standard deviation values recorded at six stations along the Dikhu River.

pH					
Stations	**Mean Range**	**Seasons**			
		Pre-monsoon Mean ± SD	**Monsoon Mean ± SD**	**Post-monsoon Mean ± SD**	**Winter Mean ± SD**
Alaphumi	7.23	7.97 ± 0.26	7.38 ± 0.13	7.30 ± 0.06	7.81 ± 0.25
	8.13	7.67 - 8.13	7.30 - 7.53	7.23 - 7.33	7.63 - 8.10
Sumi Setsü	7.13	7.54 ± 0.37	7.27 ± 0.12	7.30 ± 0.15	7.83 ± 0.06
	7.97	7.27 - 7.97	7.13 - 7.33	7.13 - 7.43	7.77 - 7.87
Longsa	7.27	7.61 ± 0.28	7.53 ± 0.21	7.37 ± 0.12	7.70 ± 0.24
	7.90	7.30 - 7.83	7.30 - 7.70	7.27 - 7.50	7.43 - 7.90
Longkong	7.17	7.22 ± 0.04	7.53 ± 0.35	7.68 ± 0.40	8.07 ± 0.03
	8.10	7.20 - 7.27	7.17 - 7.87	7.27 - 8.07	8.03 - 8.10
Chakba	7.07	7.74 ± 0.34	7.13 ± 0.07	7.70 ± 0.29	7.50 ± 0.47
	8.03	7.37 - 8.03	7.07 - 7.20	7.50 - 8.03	7.17 - 8.03
Salulamang	7.13	7.58 ± 0.49	7.36 ± 0.05	7.80 ± 0.43	7.88 ± 0.32
	8.17	7.13 - 8.10	7.30 - 7.40	7.30 - 8.07	7.53 - 8.17

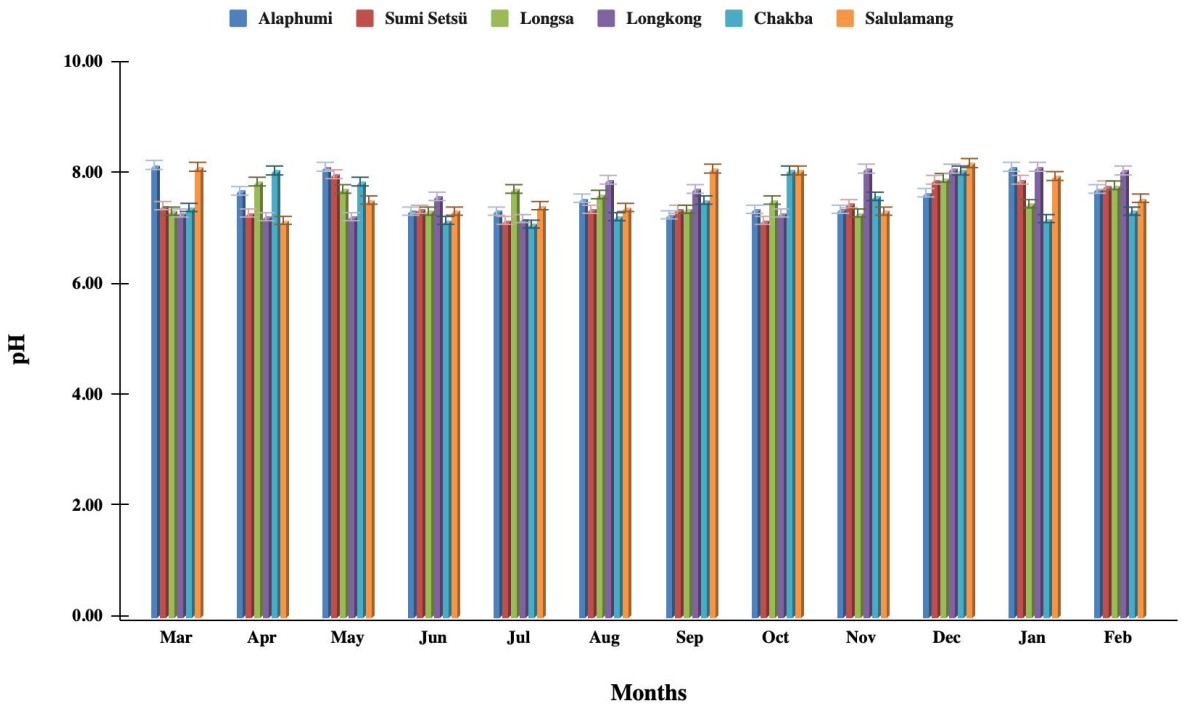

Figure 2.14: Monthly observations of pH in the Dikhu River

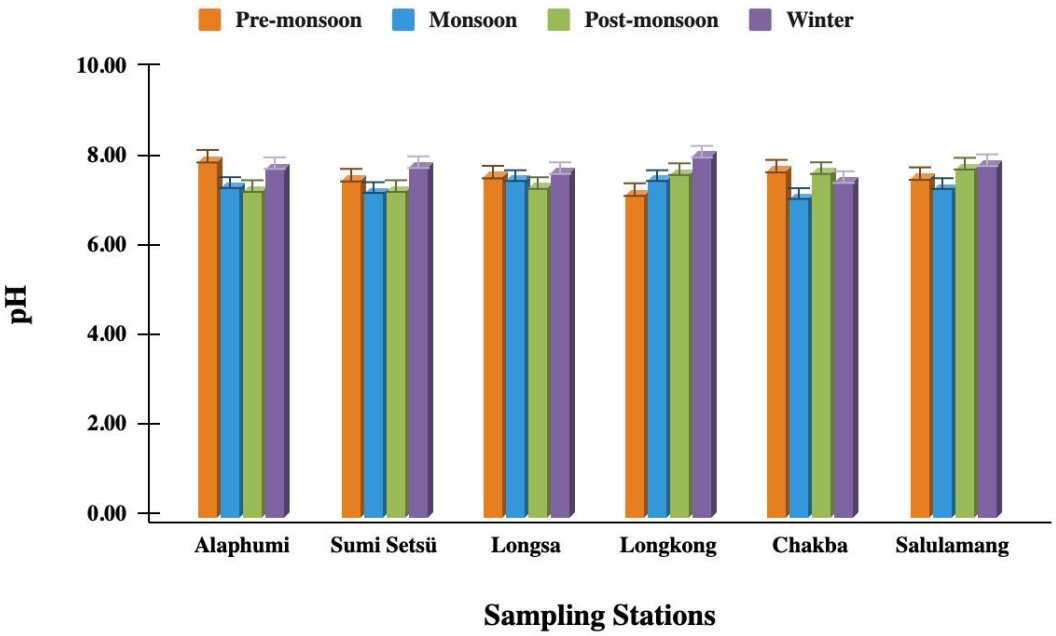

Figure 2.15: Seasonal observations of pH in the Dikhu River

2.3.1.5 Dissolved oxygen

The mean dissolved oxygen (DO) ranged from 5.57 mg/L at Alaphumi to 11.37 mg/L at Longkong, with an overall annual mean of 8.07 ± 1.47 mg/L. The highest average dissolved oxygen (DO) concentration was observed in winter at 9.93 ± 0.43 mg/L, reflecting increased oxygen availability during colder months. The average values for the pre-monsoon and post-monsoon seasons were 8.04 ± 0.67 mg/L and 7.73 ± 0.33 mg/L, respectively. The lowest DO concentration was recorded during the monsoon season at 6.56 ± 0.45 mg/L. Seasonal variations in DO are presented in Table 2.6 and illustrated in Figures 2.16 and 2.17.

Dissolved oxygen at site 1 (Alaphumi) ranged from 5.57 to 11.23 mg/L. The winter season displayed the highest mean (10.08 ± 1.01 mg/L), the monsoon the lowest (6.29 ± 0.93 mg/L).

At Sumi Setsü (station 2), DO ranged from 5.83 to 10.97 mg/L, with a monsoon low of 6.39 ± 0.74 mg/L and a winter high of 9.87 ± 1.01 mg/L.

Station 3 (Longsa) ranged between 5.63 and 10.87 mg/L; the winter mean was highest (10.40 ± 0.57 mg/L) and the monsoon was the lowest (5.88 ± 0.39 mg/L).

In station 4 (Longkong), the observed DO levels varied from 6.47 to 11.37 mg/L. The monsoon were found to record a low value of 6.97 ± 0.44 mg/L, whereas the winter season noted the highest value of 10.32 ± 1.23 mg/L.

The DO values at station 5 (Chakba) varied between 6.33 and 9.83 mg/L. The minimum mean value was recorded during the monsoon season at 6.87 ± 0.57 mg/L, while the maximum value of 9.26 ± 0.64 mg/L was recorded in winter.

At station 6, dissolved oxygen ranged from 6.73 to 10.87 mg/L, peaking in winter (9.66 ± 1.20 mg/L) and lowest recorded in the monsoon (6.97 ± 0.38 mg/L).

Table 2.6: Mean dissolved oxygen with its corresponding standard deviation values recorded at six stations along the Dikhu River.

Dissolved Oxygen (mg/L)					
Stations	**Mean Range**	**Seasons**			
		Pre-monsoon Mean ± SD	**Monsoon Mean ± SD**	**Post-monsoon Mean ± SD**	**Winter Mean ± SD**
Alaphumi	5.57	7.48 ± 0.62	6.29 ± 0.93	7.91 ± 0.88	10.08 ± 1.01
	11.23	6.77 - 7.93	5.57 - 7.33	6.97 - 8.70	9.37 - 11.23
Sumi Setsü	5.83	7.94 ± 0.42	6.39 ± 0.74	7.73 ± 1.05	9.87 ± 1.01
	10.97	7.57 - 8.40	5.83 - 7.23	6.73 - 8.83	8.97 - 10.97
Longsa	5.63	7.54 ± 0.59	5.88 ± 0.39	7.19 ± 0.24	10.40 ± 0.57
	10.87	6.90 - 8.07	5.63 - 6.33	7.03 - 7.47	9.77 - 10.87
Longkong	6.47	8.98 ± 1.12	6.97 ± 0.44	8.17 ± 0.48	10.32 ± 1.23
	11.37	7.73 - 9.90	6.47 - 7.30	7.63 - 8.57	8.97 - 11.37
Chakba	6.33	7.56 ± 0.52	6.87 ± 0.57	7.81 ± 1.20	9.26 ± 0.64
	9.83	7.03 - 8.07	6.33 - 7.47	6.90 - 9.17	8.57 - 9.83
Salulamang	6.73	8.77 ± 1.58	6.97 ± 0.38	7.57 ± 0.54	9.66 ± 1.20
	10.87	7.20 - 10.37	6.73 - 7.40	6.97 - 8.00	8.47 - 10.87

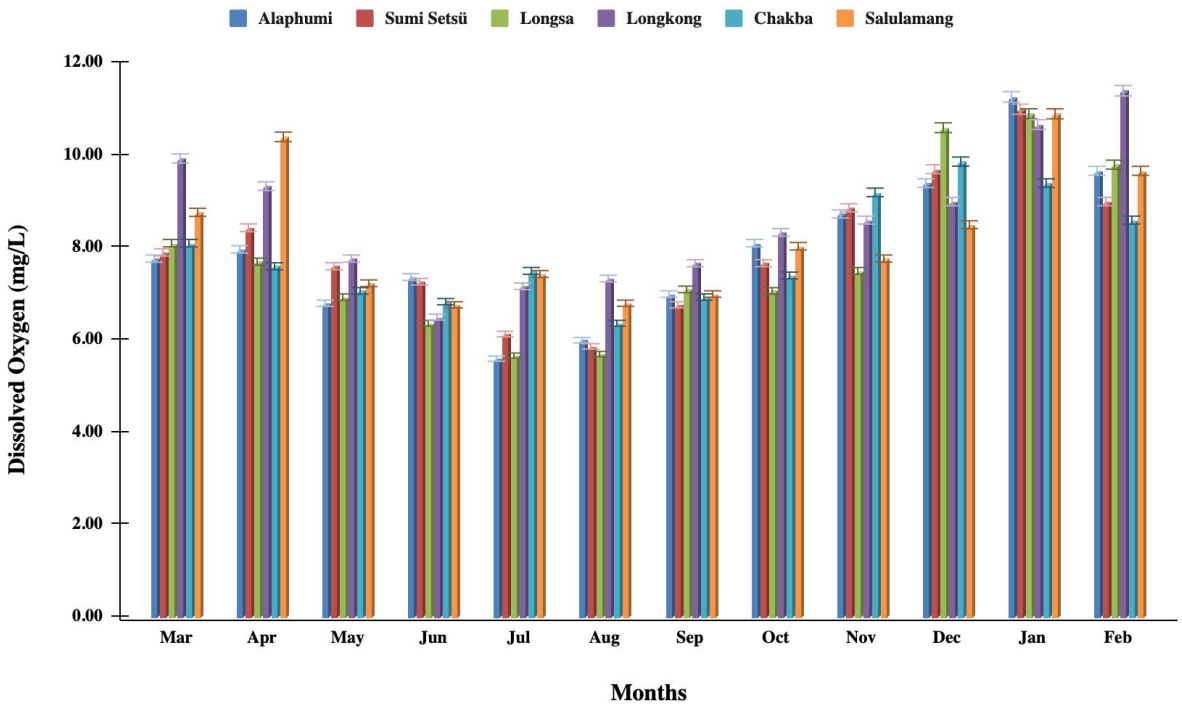

Figure 2.16: Monthly observations of dissolved oxygen (DO) in the Dikhu River

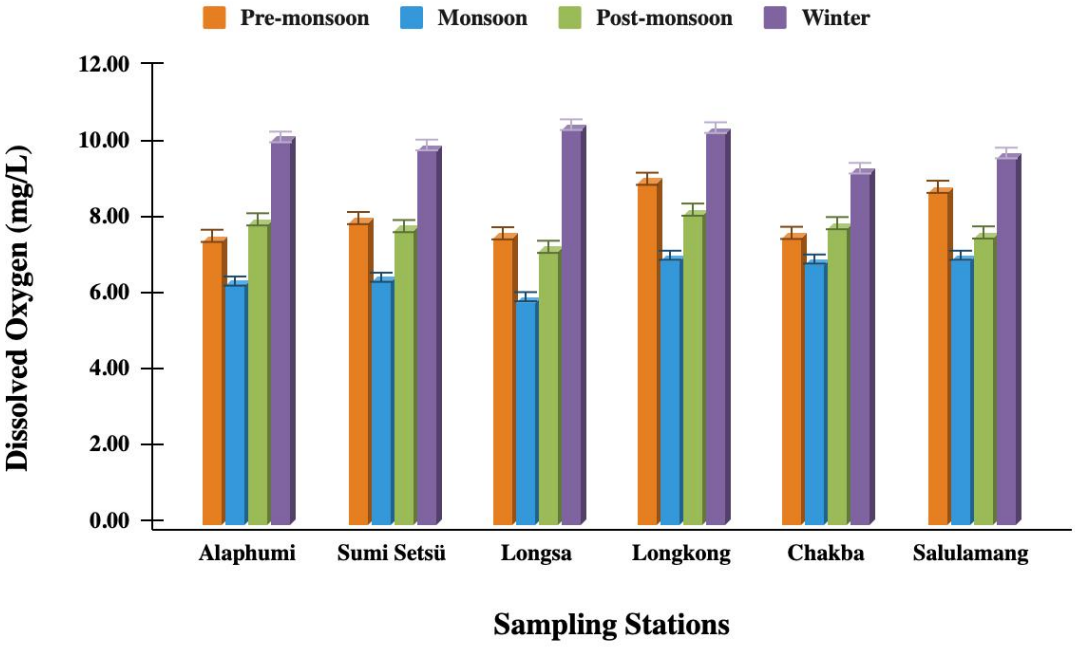

Figure 2.17: Seasonal observations of dissolved oxygen (DO) in the Dikhu River

2.3.1.6 Total alkalinity

The total alkalinity mean values ranged from 36.23 mg/L at Sumi Setsü to 77.83 mg/L at Longkong, with an annual mean value of 55.99 ± 10.97 mg/L. In seasonal variation, the highest mean value was observed in winter (68.90 ± 4.22 mg/L), followed by pre-monsoon (58.62 ± 2.50 mg/L) and post-monsoon (53.88 ± 6.86 mg/L), while the lowest value was noted during the monsoon period (42.55 ± 2.53 mg/L). Results are presented in Table 2.7 and Figures 2.18 and 2.19.

The mean total alkalinity at sampling station 1 (Alaphumi) ranged between 38.23 mg/L to 74.40 mg/L The value was significantly lower contrasted with the monsoon season (40.44 ± 2.11 mg/L) and significantly higher when compared with winter season (71.31 ± 2.81 mg/L).

The mean total alkalinity value at sampling station 2 (Sumi Setsü) ranged from 36.23 mg/L to 71.53 mg/L with the lowest seasonal mean value of 39.30 ± 2.91 mg/L in monsoon season and the highest mean value of 70.30 ± 1.32 mg/L during winter.

The mean total alkalinity at sampling station 3 (Longsa) ranged from 39.27 mg/L to 67.87 mg/L wherein the lowest average for the season was observed during monsoon with 41.48 ± 2.31 mg/L, and the seasonal mean peaking in winter with 66.01 ± 1.94 mg/L.

The mean total alkalinity for sampling station 4 (Longkong) ranged between 41.13 mg/L to 77.83 mg/L with a monsoon season low seasonal average of 44.68 ± 3.52 mg/L and a winter season high seasonal average of 75.52 ± 2.54 mg/L were recorded.

The mean total alkalinity at sampling station 5 (Chakba) ranged between 39.17 mg/L to 69.90 mg/L with the monsoon season exhibiting the lowest mean value of 43.68 ± 5.14 mg/L and the highest recorded in the post-monsoon (63.02 ± 5.48 mg/L).

The mean total Alkalinity at station 6 (Salulamang), ranged between 43.13 mg/L to 67.83 mg/L, in terms of average seasonal, it was 45.73 ± 3.54 mg/L during monsoon which was the lowest among all the seasons and 65.64 ± 2.23 mg/L in winter season was the highest.

Table 2.7: Mean total alkalinity with its corresponding standard deviation values recorded at six stations along the Dikhu River.

Total Alkalinity (mg/L)					
Stations	**Mean Range**	**Seasons**			
		Pre-monsoon Mean ± SD	**Monsoon Mean ± SD**	**Post-monsoon Mean ± SD**	**Winter Mean ± SD**
Alaphumi	38.23	60.10 ± 3.34	40.44 ± 2.11	46.18 ± 7.15	71.31 ± 2.81
	74.40	56.43 - 62.97	38.23 - 42.43	39.30 - 53.57	68.90 - 74.40
Sumi Setsü	36.23	62.03 ± 5.12	39.30 ± 2.91	50.63 ± 11.71	70.30 ± 1.32
	71.53	56.47 - 66.53	36.23 - 42.03	37.73 - 60.60	68.90 - 71.53
Longsa	39.27	55.24 ± 5.08	41.48 ± 2.31	51.61 ± 2.28	66.01 ± 1.94
	67.87	49.57 - 59.37	39.27 - 43.87	49.37 - 53.93	64.00 - 67.87
Longkong	41.13	59.14 ± 2.70	44.68 ± 3.52	61.74 ± 4.45	75.52 ± 2.54
	77.83	56.40 - 61.80	41.13 - 48.17	56.63 - 64.80	72.80 - 77.83
Chakba	39.17	56.27 ± 1.23	43.68 ± 5.14	63.02 ± 5.48	64.61 ± 6.04
	69.90	55.37 - 57.67	39.17 - 49.27	58.87 - 69.23	58.03 - 69.90
Salulamang	43.13	58.96 ± 2.43	45.73 ± 3.54	50.07 ± 2.83	65.64 ± 2.23
	67.83	56.40 - 61.23	43.13 - 49.77	47.23 - 52.90	63.37 - 67.83

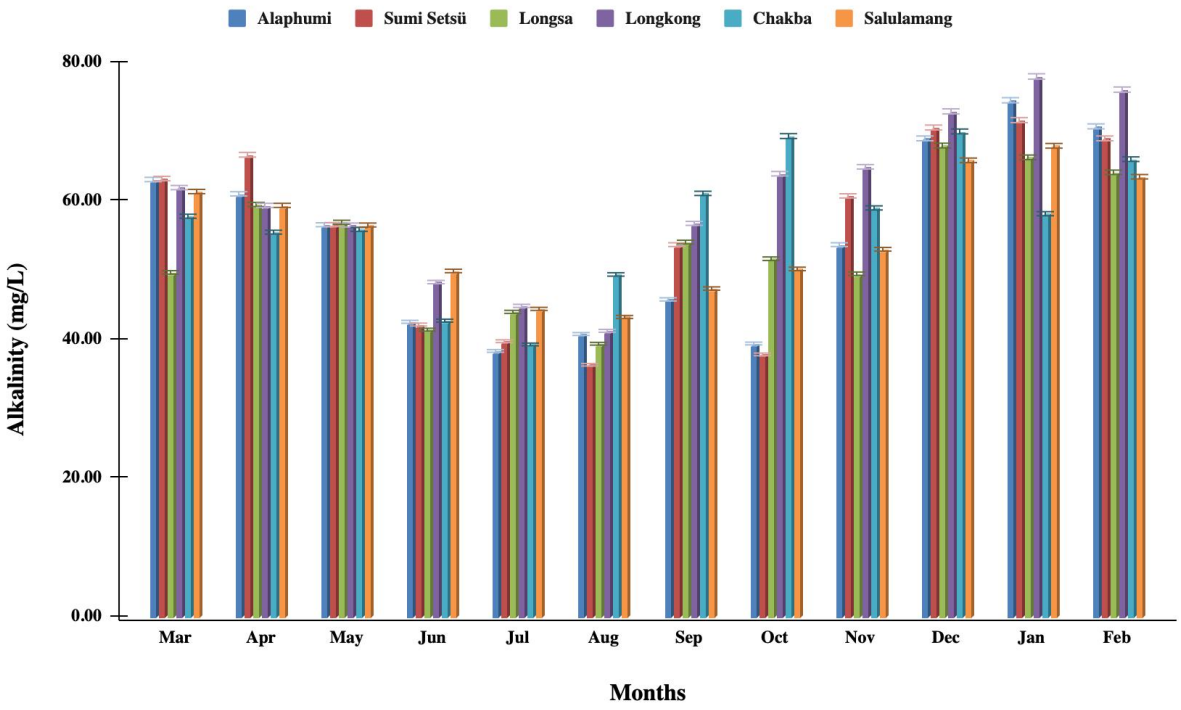

Figure 2.18: Monthly observations of total alkalinity in the Dikhu River

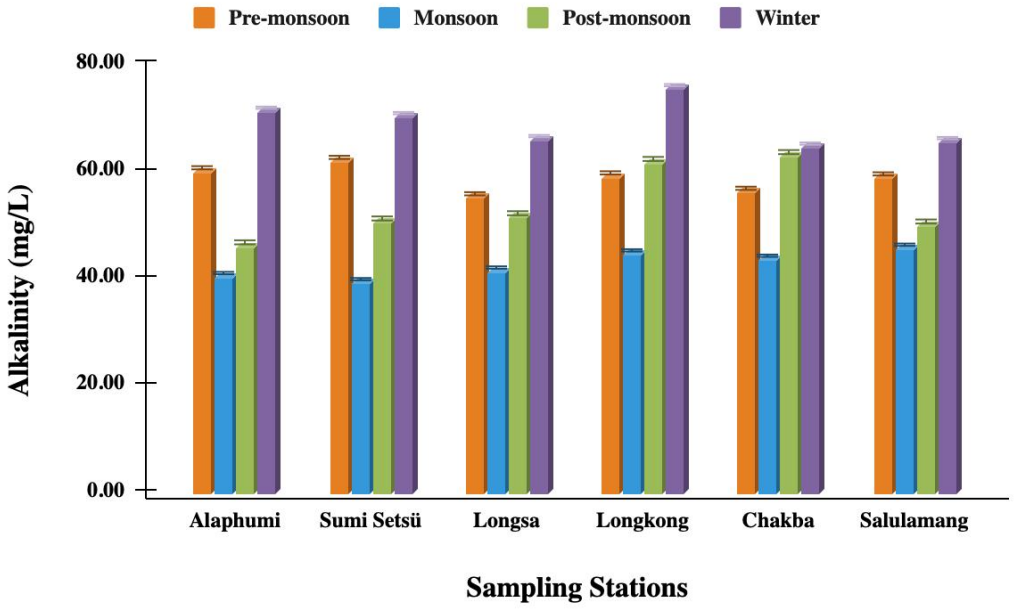

Figure 2.19: Seasonal observations of total alkalinity in the Dikhu River

2.3.1.7 Total hardness

The mean total hardness of the water samples varied from 31.97 mg/L at Longsa to a maximum of 92.10 mg/L at Salulamang, reflecting notable spatial variation across the sampling stations. The annual total hardness was measured at 57.32 ± 16.23 mg/L. By season, it was highest in winter (78.48 ± 5.99 mg/L), then the pre-monsoon (61.13 ± 6.61 mg/L), then the post-monsoon (49.25 ± 3.96 mg/L), and lowest in the monsoon (40.43 ± 3.95 mg/L). Table 2.8 and Figures 2.20 and 2.21 summarise these results.

At sampling station 1 (Alaphumi), total hardness ranged from 33.93 to 86.43 mg/L. The highest mean value was recorded during winter (79.44 ± 6.95 mg/L), while the lowest value occurred in the monsoon months (41.37 ± 9.04 mg/L).

Station 2 (Sumi Setsü) ranged from 39.20 to 79.97 mg/L, recording peak values in winter (75.11 ± 5.98 mg/L) and minimum values in monsoon (40.41 ± 1.29 mg/L).

The average total hardness varied from 31.97 to 86.00 mg/L at the Longsa sampling station 3 with significant seasonal variations. The mean value of 33.71 ± 1.86 mg/L was documented in the monsoon season, whereas the mean value of 67.98 ± 18.85 mg/L was noted in the winter season.

Station 4 (Longkong) varied between 36.77 and 90.07 mg/L, from a monsoon minimum of 39.19 ± 2.35 mg/L to a winter maximum of 83.49 ± 9.60 mg/L.

At station 5 (Chakba), hardness ranged from 40.63 to 88.03 mg/L, with the lowest value in the monsoon (42.28 ± 2.48 mg/L) and the highest value in winter (82.19 ± 8.37 mg/L).

Station 6 (Salulamang) varied from 43.47 to 92.10 mg/L, with a monsoon low of 45.63 ± 2.05 mg/L and a winter high of 82.69 ± 8.29 mg/L.

Table 2.8: Mean total hardness with its corresponding standard deviation values recorded at six stations along the Dikhu River.

Total Hardness (mg/L)					
Stations	**Mean Range**	**Seasons**			
		Pre-monsoon Mean ± SD	**Monsoon Mean ± SD**	**Post-monsoon Mean ± SD**	**Winter Mean ± SD**
Alaphumi	33.93	71.70 ± 5.06	41.37 ± 9.04	52.47 ± 6.80	79.44 ± 6.95
	86.43	66.30 - 76.33	33.93 - 51.43	44.87 - 57.97	72.53 - 86.43
Sumi Setsü	39.20	64.13 ± 4.48	40.41 ± 1.29	47.96 ± 4.47	75.11 ± 5.98
	79.97	59.67 - 68.63	39.20 - 41.77	43.83 - 52.7	68.43 - 79.97
Longsa	31.97	54.62 ± 8.84	33.71 ± 1.86	42.07 ± 6.56	67.98 ± 18.85
	86.00	45.43 - 63.07	31.97 - 35.67	36.57 - 49.33	48.40 - 86.00
Longkong	36.77	59.34 ± 10.00	39.19 ± 2.35	49.26 ± 4.32	83.49 ± 9.60
	90.07	48.47 - 68.13	36.77 - 41.47	46.07 - 54.17	72.47 - 90.07
Chakba	40.63	54.11 ± 6.65	42.28 ± 2.48	51.12 ± 2.93	82.19 ± 8.37
	88.03	48.43 - 61.43	40.63 - 45.13	48.67 - 54.37	72.60 - 88.03
Salulamang	43.47	62.87 ± 4.55	45.63 ± 2.05	52.61 ± 2.37	82.69 ± 8.29
	92.10	59.23 - 67.97	43.47 - 47.53	50.43 - 55.13	76.47 - 92.10

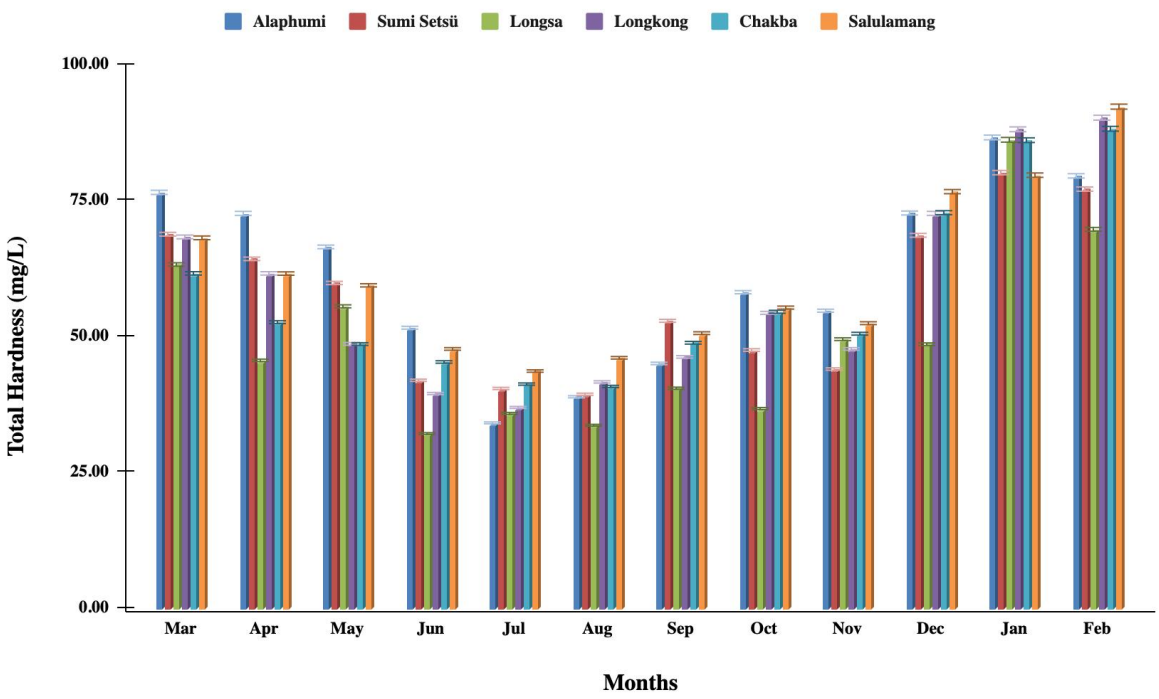

Figure 2.20: Monthly observations of total hardness in the Dikhu River

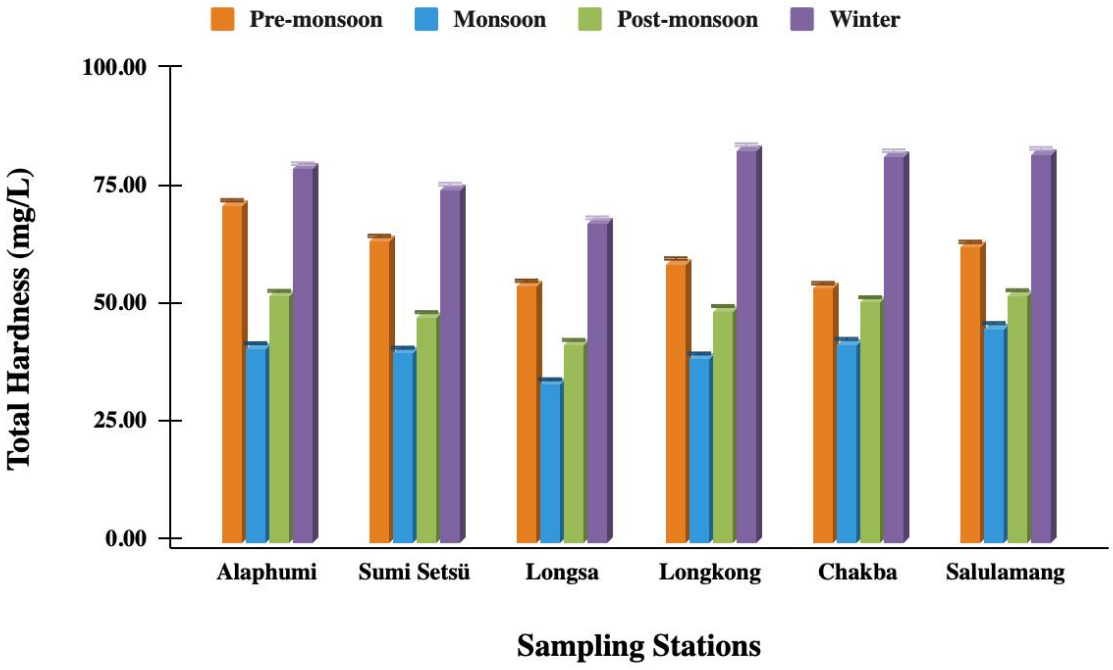

Figure 2.21: Seasonal observations of total hardness in the Dikhu River

2.3.1.8 Total dissolved solids

The mean total dissolved solids (TDS) fluctuated from a minimum of 35.67 mg/L at Sumi Setsü to a maximum of 94.67 mg/L at Alaphumi, revealing considerable spatial differences among the sampling sites. The pooled TDS data for a year varied from 63.40 ± 15.51 mg/L. It peaked in the monsoon (80.74 ± 6.50 mg/L), followed by the pre-monsoon (71.19 ± 6.71 mg/L) and post-monsoon (56.28 ± 3.67 mg/L), and was lowest in winter (45.39 ± 2.91 mg/L). A detailed summary of the data is presented in Table 2.9 and Figures 2.22 and 2.23.

Station 1 (Alaphumi) ranged from 44.67 to 94.67 mg/L, highest in the monsoon (87.89 ± 5.93 mg/L) and lowest in winter (49.11 ± 4.34 mg/L).

At station 2 (Sumi Setsü), TDS varied between 35.67 and 77.67 mg/L, reaching 70.44 ± 7.52 mg/L in the monsoon and falling to 41.67 ± 5.29 mg/L in winter.

Station 3 (Longsa) ranged from 38.33 to 87.00 mg/L. The seasonal mean was lowest in winter (42.56 ± 4.17 mg/L) and the highest was 81.11 ± 6.80 mg/L [the original lists this peak as winter too; please confirm the season, since every other station peaks in the monsoon].

Site 4 (Longkong) exhibited a TDS concentration varying from 40.33 to 90.33 mg/L. The minimum value is a seasonal average of 45.00 ± 6.43 mg/L in winter, while the maximum value is 82.56 ± 11.24 mg/L in the monsoon.

At station 5 (Chakba), TDS ranged from 36.67 to 84.33 mg/L, lowest in winter (47.78 ± 9.63 mg/L) and highest in the monsoon (76.22 ± 7.57 mg/L).

Station 6 (Salulamang) ranged from 42.33 to 93.33 mg/L, peaking in the monsoon (86.22 ± 6.85 mg/L) and lowest in winter (46.22 ± 4.62 mg/L).

Table 2.9: Mean total dissolved solids with its corresponding standard deviation values recorded at six stations along the Dikhu River.

TDS (mg/L)					
Stations	**Mean Range**	**Seasons**			
		Pre-monsoon Mean ± SD	**Monsoon Mean ± SD**	**Post-monsoon Mean ± SD**	**Winter Mean ± SD**
Alaphumi	44.67	59.44 ± 4.17	87.89 ± 5.93	81.78 ± 5.17	49.11 ± 4.34
	94.67	55.33 - 63.67	83.67 - 94.67	78.00 - 87.67	44.67 - 53.33
Sumi Setsü	35.67	51.89 ± 3.67	70.44 ± 7.52	64.22 ± 4.67	41.67 ± 5.29
	77.67	48.33 - 55.67	62.67 - 77.67	59.67 - 69.00	35.67 - 45.67
Longsa	38.33	60.56 ± 7.73	81.11 ± 6.80	69.00 ± 6.43	42.56 ± 4.17
	87.00	51.67 - 65.67	73.67 - 87.00	61.67 - 73.67	38.33 - 46.67
Longkong	40.33	58.22 ± 5.21	82.56 ± 11.24	76.89 ± 3.69	45.00 ± 6.43
	90.33	52.67 - 63.00	69.67 - 90.33	73.00 - 80.33	40.33 - 52.33
Chakba	36.67	52.44 ± 9.70	76.22 ± 7.57	66.78 ± 3.86	47.78 ± 9.63
	84.33	42.33 - 61.67	69.33 - 84.33	62.67 - 70.33	36.67 - 53.67
Salulamang	42.33	55.11 ± 8.88	86.22 ± 6.85	68.44 ± 9.65	46.22 ± 4.62
	93.33	49.33 - 65.33	79.67 - 93.33	57.33 - 74.67	42.33 - 51.33

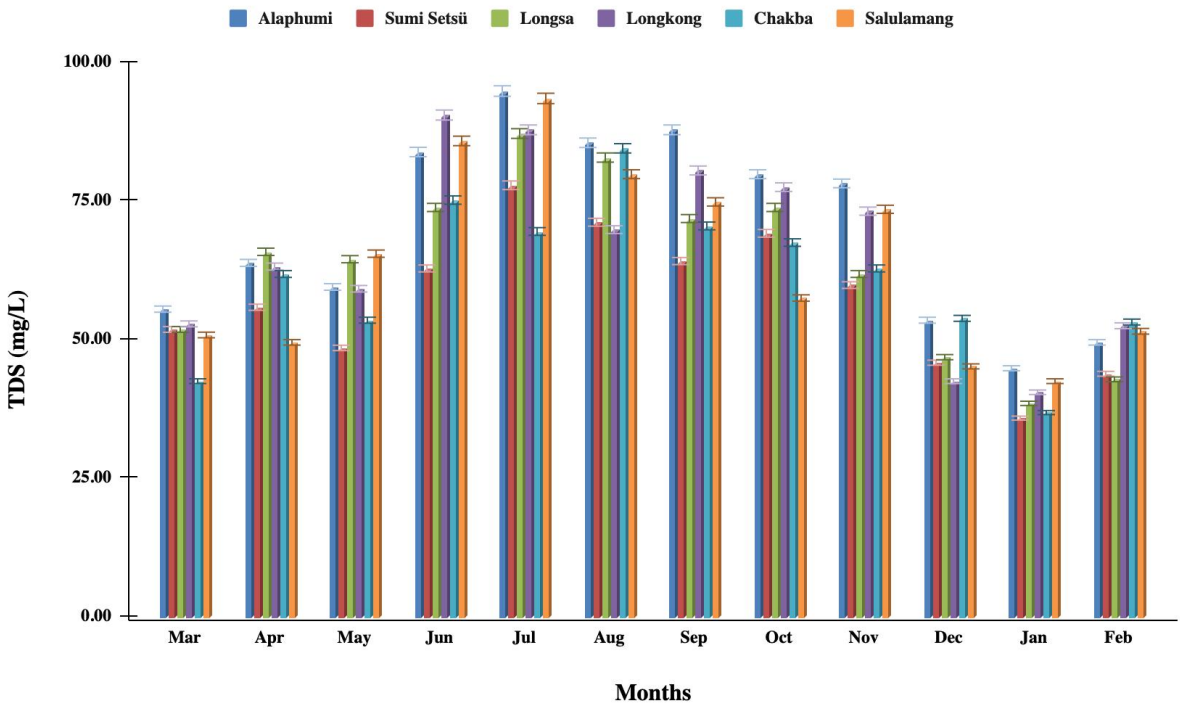

Figure 2.22: Monthly observations of total dissolved solids in the Dikhu River

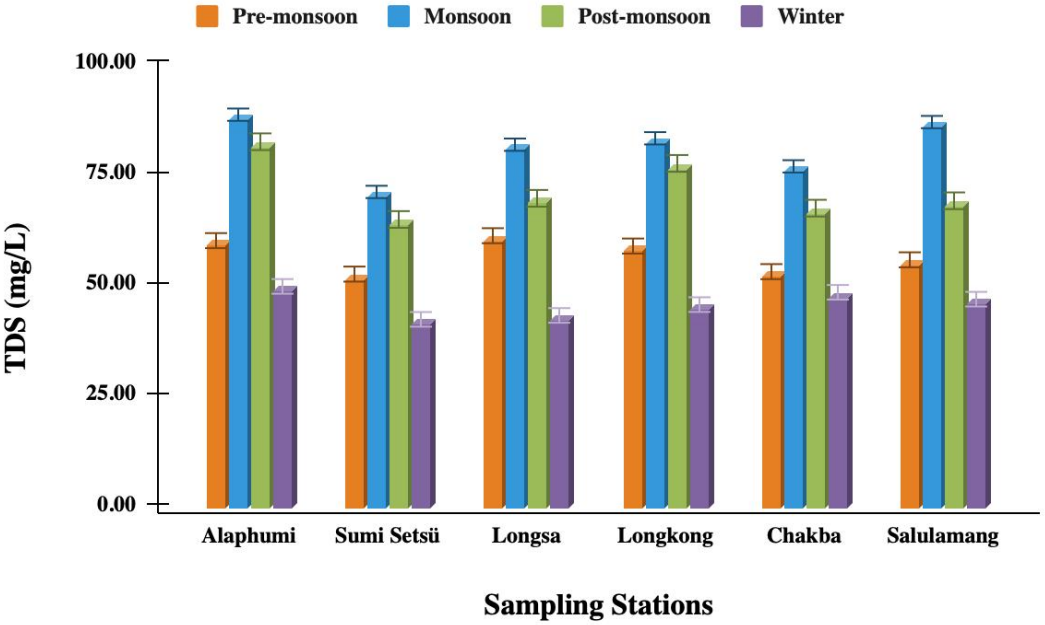

Figure 2.23: Seasonal observations of total dissolved solids in the Dikhu River

Table 2.10: Permissible limits for water quality parameters based on BIS (2003), ICMR (1975) and WHO (2004)

Water Parameter	BIS/ICMR/WHO Standard
pH	6.5-8.5
TDS	500
TH	300
TA	120
DO	5-7 or above 5

2.4 Discussion

Analyzing physico-chemical parameters is vital for maintaining the integrity of river ecosystems, maintaining water safety for human needs, and preserving biodiversity. Monitoring of physico-chemical characteristics of the Dikhu River is essential for adapting to environmental changes and mitigating the impacts of human activities on freshwater resources (Majeed *et al.,* 2022).

Rising air temperatures elevate river water temperatures, thereby altering thermal regimes and impacting water quality, aquatic species distribution, and overall ecosystem health (Pletterbauer *et al.,* 2018). Water temperature is a critical ecological factor that largely governs the growth and distribution of aquatic flora and fauna (Beechie *et al.,* 2013). It is also shaping the river ecosystems by influencing biological processes, chemical dynamics, and overall water quality. Effective management of river systems, therefore, necessitates continuous monitoring and a thorough understanding of temperature variations to safeguard ecological integrity (Johnson *et al.,* 2024). The strong correlation between air and water temperatures plays a crucial role in determining water quality and significantly influences the viability and behavior of aquatic organisms (Stumm and Morgan, 1995). Mean air temperature in the Dikhu River ranged from 15°C to 31.67°C, while water temperatures varied between 10.33°C to 26.67°C. The temperatures recorded fall within the optimal range for freshwater ecosystems, supporting essential physiological processes of aquatic organisms (Wetzel, 2001). Seasonal analysis revealed that the highest air and water temperatures occurred during the monsoon season, with an average of 27.81 ± 0.99°C and 23.30 ± 1.02°C, respectively whereas the least values were noted during winter season, at 18.38 ± 1.20°C and 13.44 ± 1.22°C respectively. These values are in accordance with those proposed for the protection of aquatic life by the World Health Organization (WHO, 2017) and United States Environmental Protection Agency (USEPA, 2012). These seasonal thermal differences are characteristic for lotic systems and are vital for the promotion of biological production and seasonal movement of fish. Similar seasonal findings were also reported by Longchar et al. (2025) and Pukhrambam and Ao (2024) in the Dikhu River and Ahmed et al. (2024) in the Northwest Himalayan region of India, where maximum values of air and water temperatures were recorded in the summer and

lowest values during winter months, typical of the hot summers and cold winters of this region.

Adequate water velocity is essential for habitat diversity, sediment transport, oxygenation, and supporting migratory fish species (Bunn and Arthington, 2002; Gordon *et al.,* 2004; Allan and Castillo, 2007). The recorded water velocity in the Dikhu River ranged from 0.06 to 3.02 m/s, indicative of a typical lotic environment. Higher mean velocities observed during the monsoon (1.83 ± 0.29 m/s) correspond with increased discharge due to rainfall, while reduced flow in winter (0.20 ± 0.04 m/s) reflects seasonal water scarcity. Similar seasonal patterns were reported by Longchar et al. (2017) in the Dikhu River, Nagaland, and Chakravarty and Gupta (2021) in the Jatinga River, Assam.

pH is a critical parameter in river systems, influencing both chemical and biological processes. Most aquatic organisms are adapted to a narrow pH range, and deviations can be harmful or even fatal to fish, including other aquatic species. Maintaining a stable pH is essential for sustaining biodiversity, supporting ecosystem services such as water purification, and ensuring overall river health. Water pH, reflecting its acidity or alkalinity, serves as a key indicator of habitat suitability for aquatic life (Hamid *et al.*, 2020; Saalidong *et al.*, 2022; Dewangan *et al.*, 2023). Observed alkaline pH levels are often attributed to substantial anthropogenic loads and human settlements along riparian regions, particularly at downstream sites (Ahmed *et al.*, 2024). In a study by Bouslah et al. (2017), experimental water bodies recorded approximately neutral to slightly alkaline pH values. The normal observed pH range in surface waters is typically 6.5 - 8.5, with the optimum range for irrigation and fish culture being 6.5 to 8.0 (DoE, 1997). Parker et al. (1992) emphasized the influence of water acidity on spatial distribution of fish and aquatic invertebrates, highlighting its role in shaping freshwater ecosystems. In this investigation, mean pH values across the sampling sites ranged from 7.07 to 8.17, indicating mildly alkaline conditions that fall within the permissible limits prescribed by BIS (2003), ICMR (1975), and WHO (2004) as represented in Table 2.10, and are considered suitable for freshwater fish culture (Boyd and Tucker, 1998). Seasonal analysis further revealed slightly higher pH during winter and post-monsoon, likely due to reduced dilution and increased biological activity. These observations are consistent with findings by

Longchar et al. (2023) on the Dikhu River, where pH values remained mildly basic and within permissible limits (6.6 - 8.5). Similar alkaline pH trends were also reported by Sarmah et al. (2020), Pukhrambam and Ao (2024), and Longchar et al. (2025) in the Dikhu River, supporting the overall pattern recorded in this study. Dissolved oxygen (DO) is an essential parameter of river ecosystems, a central indicator of both ecological integrity and pollution stress. Aquatic organisms, from fish and invertebrates to aerobic microbes, rely on DO for respiration, and it also serves as an important factor for countless biochemical reactions happening below the surface (Csábrági *et al.,* 2019; Ice *et al.,* 2021). In the current study, DO concentrations spanned from 5.57 mg/L - 11.37 mg/L. These values not only support vibrant aquatic habitats but also surpass the recommended minimums set by BIS (2003), ICMR (1975), and WHO (2004), pointing toward commendable water quality. Boyd (2015) suggests that DO levels in the 6 - 9 mg/L range are optimal for fish survival, though some species show resilience outside these bounds. Overall, the observed DO concentrations reflect a healthy aquatic environment, conducive to both biological diversity and ecosystem function. During winter, dissolved oxygen levels were notably higher (9.93 ± 0.43 mg/L). In contrast, the lowest mean concentrations appeared in the monsoon season at 6.56 ± 0.45 mg/L. This trend can be attributed to lower temperatures, reduced microbial activity, and enhanced oxygen solubility during colder periods (Gupta *et al.,* 2017). Similar findings were made by Longchar et al. (2023) in the Dikhu River, with a peak of 11.06 ± 0.88 mg/L during winter and a low of 6.58 ± 1.04 mg/L during summer, attributed to reduced oxygen solubility at higher temperatures, elevated organic decomposition, and higher metabolic activity in aquatic organisms during summer. These results align with earlier studies in the region (Temjen and Singh, 2018; Lkr *et al.*, 2020; Semy and Singh, 2021; Pukhrambam and Ao, 2024), which highlighted lower DO concentrations in summer attributing to higher temperatures, algal blooms, and reduced water depth, while higher DO levels recorded in winter were associated with lower water temperatures (Temjen and Singh, 2018).

Total alkalinity (TA) refers to the acid-neutralizing capacity of water, primarily derived from the presence of carbonates, bicarbonates, and hydroxides originating from limestone, salts, dissolved rocks, and sediments, enabling aquatic environments

to resist changes in pH levels (Neal, 2001; Kumar *et al.*, 2012; Mir *et al.*, 2023). In the present study, TA levels ranged from 36.23 mg/L to 77.83 mg/L, indicating a moderate buffering capacity and falling within the desirable standard permissible limits of BIS (2003) and WHO (2004). These values suggest that the water is suitable for aquatic life and fish production (Bhatnagar and Devi, 2013). Total alkalinity (TA) exhibited clear seasonal variation, showing the maximum mean values in winter (68.90 ± 4.22 mg/L), and the lowest during the monsoon season (42.55 ± 2.53 mg/L). Total alkalinity was highest during winter and post-monsoon seasons, likely due to mineral dissolution resulting from reduced flow and limited dilution, whereas a decline during the monsoon could be attributed to increased freshwater influx, consequent dilution, and precipitation effects (Chatterjee and Raziuddin, 2002; Chakravarty and Gupta, 2021). A similar trend was observed by Longchar et al. (2023) in the Dikhu River, where TA values peaked during winter (91.2 ± 1.9 mg/L) and decreased with the onset of the rainy season across all sampling sites. In the current study, higher TA values during winter were also attributed to the use of liming and other chemicals for fishing activities, particularly during the dry season when water levels are low. These findings are consistent with previous studies conducted by Temjen and Singh (2018), Semy and Singh (2021), and Pukhrambam and Ao (2024) and Lemla et al. (2025).

Total hardness (TH) depends on the concentration of soluble salts of bivalent ions, primarily calcium and magnesium bicarbonates, chlorides, and sulphates, although other ions such as manganese, strontium, and iron also contribute (USEPA, 2000). Sawyer and McCarty (1967) established a classification system for river water hardness: soft (<75 mg/L), moderately hard (75 - 150 mg/L), hard (150 - 300 mg/L), and very hard (>300 mg/L). In this study, total hardness (TH) ranged from 31.97 mg/L to 92.10 mg/L, placing the water samples predominantly in the soft to moderately hard categories. Seasonal data analysis indicated that the mean total hardness reached its highest value in winter (78.48 ± 5.99 mg/L), while the lowest mean occurred during the monsoon season (40.43 ± 3.95 mg/L). The overall values remained within the acceptable limits given by BIS (2003), ICMR (1975), and WHO (2004) standards indicating favorable conditions for aquatic life. Boyd and Tucker (1998), along with Bhatnagar and Devi (2013), suggests that hardness levels actually

benefit aquatic organisms, aiding crucial metabolic processes. Typically, higher hardness values appear in winter likely because reduced water flow and increased evaporation lead to greater concentration of minerals. In contrast, during the monsoon, heavy rainfall dilutes the water, resulting in lower hardness levels. These observations had similar outcomes made by Longchar et al. (2023) and Pukhrambam and Ao (2024) in the Dikhu River, where the highest observed levels of total hardness were in the winter season. The elevated hardness during winter may be due to the influx of bicarbonates and reduced dilution, while the decreased values during the rainy season likely result from the high rate of precipitation diluting the river system (Temjen and Singh, 2018).

Total dissolved solids (TDS) represent the concentration of dissolved organic and inorganic ions present in a given volume of water. TDS is widely recognized as a key indicator for assessing the overall composition, cleanliness, and integrity of water (Dar *et al.,* 2019). By measuring the amount of dissolved particles, TDS provides valuable insight into the general quality or salinity of a water sample (Lkr *et al.,* 2020). Total dissolved solids (TDS) concentrations ranged from 35.67 to 94.67 mg/L, remaining well within the BIS (2003)/ICMR (1975) limit of 500 mg/L, indicating good water quality (Boyd and Tucker, 1998). Seasonal trends revealed the highest TDS levels during monsoon (80.74 ± 6.50 mg/L), while concentrations were found to be minimal during the winter season (45.39 ± 2.91 mg/L). Higher TDS may result from agricultural runoff, organic matter deposition, and mineral leaching from the catchment (Moniruzzaman *et al.,* 2009; Sharma and Ravichandran, 2021). In certain sections of the riverbank, wet rice and shifting cultivation were observed. The elevated levels of electrical conductivity, total dissolved solids, and total alkalinity may be attributed to riverine jhum cultivation, agricultural runoff, and the deposition of organic matter and nutrients from rich riparian vegetation (Chakravarty and Gupta, 2021). Jindal and Sharma (2011) and Singh et al. (2020) opinionated that agricultural runoff carrying organic matter and nutrients in the water body might be responsible for high EC and TDS in water. Earlier work on the Dikhu reports the same pattern and points to a clear cause for the monsoon peak in TDS with runoff from neighbouring land carrying colloidal particles, dissolved ions, and sediment from agricultural fields into the river, and effluent from nearby mining sites mixes in as

well. The warmer water temperatures during the monsoon also speed the breakdown of organic matter, which results in higher TDS values (Sarmah *et al.,* 2020; Longchar *et al.,* 2023; Pukhrambam and Ao, 2024). Other preliminary studies on different rivers in Nagaland also documented similar findings (Temjen and Singh, 2018; Lkr *et al.,* 2020; Semy and Singh, 2021; Ahmed *et al.,* 2024; Lemla *et al.,* 2025).

The physico-chemical values recorded across all sampling seasons in the study area remained within permissible thresholds for freshwater ecosystems as per BIS, ICMR and WHO guidelines. Seasonal fluctuation and anthropogenic pressure both influence the water characteristics on the surveyed river, which makes periodic monitoring and coordinated management a practical necessity for maintaining its ecological condition over time.

CHAPTER 3

Ichthyofaunal diversity and traditional fishing practices in the Dikhu River

CONTENTS

3.1 Introduction

3.2 Materials and methods

3.3 Results

3.4 Discussion

Parts of this chapter have been published in WOS/SCOPUS indexed research journal

3.1 Introduction

India is globally recognized as one of the mega biodiversity countries due to its exceptional variety of species across diverse ecosystems (Mittermeier *et al.*, 1998). Northeast India is believed to be one of the established and recognized biodiversity hotspots in the world. Both the topography and the tectonic history of the region are responsible for a significant portion of the abundant flora and fauna in the region (Kottelat *et al.,* 1996; Pawar *et al.,* 2006; Vishwanath *et al.,* 2007). According to Chitale et al. (2014), the Western Ghats, the Himalayan belt, and the Indo-Burma region are all known to harbour rich biodiversity.

Nagaland lies in the northeastern region of India, bordered by Assam to the north and west, Arunachal Pradesh to the northeast, Manipur to the south, and Myanmar to the east (Kosygin *et al.,* 1998). According to Ao et al. (2008), the region is drained by three major river systems: the Brahmaputra and the Barak, both of which originated in India, and the Chindwin, which originates in the Indo-Burmese region, Myanmar.

The Dikhu runs through the central part of the state and is one of its major rivers. With its swift water flow and rocky terrain, it is suitable for a wide variety of native fish. These rivers are now increasingly threatened by overfishing, habitat destruction, pollution, and deforestation, the latter being the primary cause of soil erosion and siltation further downstream (Kosygin e*t al.,* 1998; Béné, 2003). Such threats may jeopardise aquatic biodiversity and emphasise the urgency of research and conservation efforts in environmentally protected areas. Data and reports on fish diversity in this region remains unexplored and limited. A limited number of studies have been conducted by Hora (1936), Menon (1954), Jayaram (1999), Vishwanath et al. (2007), Vishwanath (2021), Acharjee et al. (2012), Rongsenkumzuk et al. (2019), and Ezung et al. (2020b). Specific studies on the Dikhu River are relatively recent, including those by Konyak and Limatemjen (2022), Pukhrambam and Bendang (2024) and Kechu and Pankaj (2025). In freshwater ecosystems, the reaction of fish assemblages to natural habitats and man-made stressors can affect their fish composition and structure, which can act as health indicators (Pinder *et al.,* 2019). However, the absence of baseline data and taxonomic clarity can hinder effective management (Nautiyal, 2014).

The Shannon-Wiener index, Simpson index, and evenness index are common quantitative measures of community structure and species diversity in ecological studies (Chiarucci *et al.,* 2011). Biodiversity is the presence of species strength and its relative abundance in a community (Peet, 1974; Zerbe and Kreyer, 2006; Jewel *et al.,* 2018). A loss of species richness, or a shift toward tolerant species as dominants, can be an early sign of degradation from deforestation, sedimentation, agricultural runoff, and climate change (Dahanukar *et al.,* 2011). Pukhrambam and Bendang (2024) reported substantial changes in the diversity and structure of the hill-stream fish population in the Dikhu River under these pressures. These indices help assess the health and stability of fish communities and set conservation priorities. Such a situation requires a periodic reassessment of indigenous ecological knowledge as pivotal plans for the protection and restoration of habitats. To preserve the ichthyofaunal legacy of Nagaland, active participation from the local communities through sustainable practices and ex situ conservation efforts is necessary (Pukhrambam and Bendang 2024). Regular monitoring and updated species data reveal that the conservation measures are mostly inadequate (Nautiyal, 2014).

In Nagaland, the traditional fishing practices, particularly among the tribal communities, are laden with cultural knowledge. These small-scale fisheries rely on sustainable, locally adapted techniques passed down through generations. The methods and materials used, often biodegradable and eco-friendly, are shaped by environmental factors such as river morphology, seasonality, fish behavior, and available natural resources (Sinha, 1994). However, traditional fishing is declining owing to environmental degradation, overfishing, and the growing dominance of modern fishing technologies (Imchen and Joglekar, 2017). Globally, small-scale fisheries support approximately 4% of the population which are crucial for food security and cultural identity, particularly in marginalized regions (Kurien, 1998; FAO, 2002; Johnson, 2006). Yet, these practices face challenges including poverty, weak governance, and limited market access (Béné, 2003; Cochrane and Garcia, 2009). Documentation of indigenous fishing knowledge in Nagaland remains limited compared to other northeastern states. The oral transmission of these practices through stories and traditions risks being lost unless systematic efforts are made to preserve and study them (Kirby, 2004; Kittinger *et al.*, 2013; Béné *et al.*, 2016;

Kechu and Pankaj, 2025). Understanding the ecological, social, and economic implications of traditional fishing is essential for developing inclusive and sustainable fisheries policies.

Although the Dikhu River plays a significant ecological and cultural role in Nagaland, there is a notable gap in research concerning its fish diversity and habitat ecology. This study aims to fill that gap by identifying the current ichthyofaunal diversity in the Dikhu River, and documenting and analyzing traditional fishing knowledge, including gear construction and technique execution, among the Ao and Sumi tribes. The research also seeks to evaluate the viability and sustainability of these indigenous methods, contributing to broader efforts in biodiversity conservation and community-based resource management in the region.

3.2 Materials and Methods

3.2.1 Study area

The Dikhu River, a tributary of the Brahmaputra River, was selected as the study site for ichthyofaunal assessment. Six sampling stations were selected along the river: Alaphumi, Sumi Setsü, Longsa, Longkong, Chakba, and Salulamang. The study was conducted over a twelve-month period, from March 2019 to February 2020. The geographic coordinates of each sampling site were obtained using a handheld Garmin eTrex 10 GPS device. The Dikhu River originates in the Naruto Hills of Zunheboto district, traverses through Zunheboto and Mokokchung in Nagaland, and joins the Brahmaputra near Naginimora, Assam. Spanning about 170 km, it sustains diverse aquatic habitats, fed by two main tributaries, the Yangyu from Tuensang district and the Nanung from the Langpangkong range in Mokokchung district (Ao *et al.,* 2008).

3.2.2 Fish sampling

Fish specimens were collected on a monthly basis from six selected locations along the Dikhu River; Alaphumi, Sumi Setsü, Longsa, Longkong, Chakba, and Salulamang. Sampling employed a range of fishing methods, including cast nets, gill nets, scoop nets, hooks and lines, as well as locally sourced traditional traps. At each station, the collected fish were photographed and their measurements recorded. Surplus sampled individuals were released into the river, while representative individuals were preserved in 10% formalin prior to laboratory study (American Fisheries Society *et al.,* 2004). Species identification was conducted using diagnostic keys provided by Talwar and Jhingran (1991), Menon (1999),Vishwanath et al. (2007) and Jayaram (2010), with taxonomic nomenclature updated according to the Catalog of Fishes (Fricke *et al.*, 2021).

Specimens of *Garra birostris* were specifically collected from the Dikhu River. These were initially fixed in 10% formalin to preserve morphological integrity and later transferred to 70% ethanol for long-term storage (American Fisheries Society *et al.,* 2004). Morphometric measurements were taken using digital calipers to the nearest 0.1 mm, from the first non-zero digit to the last decimal place. Morphometric and meristic analyses followed the methodologies of Kottelat (2000) and Nebeshwar and Vishwanath (2013), while gular disc terminology adhered to Kottelat (2020).

Meristic counts were performed under a Leica M205A stereo-zoom microscope for high accuracy. All voucher specimens have been preserved in the Nagaland University Fish Museum (NUFM), Nagaland.

3.2.3 Species diversity

To quantify species richness and evenness within the fish community, three diversity indices that are Shannon-Wiener diversity index (H′), Simpson's diversity index (1-D), and Evenness index (e^H/S) were calculated across different sites and seasons. Calculations were performed using PAST (Paleontological Statistics) software, a widely recognized statistical package for ecological and palaeontological data analysis (Hammer and Harper, 2001).

The relative abundance (percentage of catch) of fish species across these six different sampling stations were analysed by the following formula.

Number of samples of particular fish species x 100 / Total number of samples

3.2.4 Sampling framework for traditional fishing techniques

To document traditional fishing methods, a survey was conducted in the Dikhu River area from April 2018 to February 2020. Data were collected from 119 informants across 10 randomly selected villages in Mokokchung and Zunheboto districts. The respondents included village heads, council members, traditional knowledge holders, fishermen, fisherwomen, and other community members spanning various age groups. Of the total informants, 11 were classified as older adults (>65 years), 41 as middle-aged (45 - 65 years), and 67 as younger adults (25 - 45 years).

Primary information was collected through personal interviews, focus group discussions, and field observations using a structured questionnaire designed to obtain detailed information efficiently. In addition to documenting fishing strategies such as the types of gear and techniques employed, the survey also recorded the respondent local ecological knowledge related to the fishery (Gurumayum and Choudhury, 2009). To complement the primary findings and provide historical and cultural context, secondary data were sourced from scientific literature, published studies, historical documents, books, and financial reports from relevant governmental agencies. This integrated approach facilitated a comprehensive understanding of traditional fishing practices by combining both primary and secondary sources of information.

3.2.5 Statistical analysis

For data conversion and preliminary analysis, Microsoft Excel 2007 was utilized, while further statistical analyses were performed using PAST (Paleontological Statistics) software (Hammer and Harper, 2001). Canonical Correspondence Analysis (CCA) was employed to explore and visualize the relationships between fish species distribution, seasonal variation, and key physicochemical parameters of the water. This multivariate technique enabled the identification of patterns and ecological gradients influencing species assemblages across different seasons. Additionally, the Bray-Curtis similarity index was implemented to measure the degree of similarity and dissimilarity in fish species composition across the various study sites and seasonal periods. This approach provided insights into species contributions to observed differences, allowing for a more nuanced understanding of spatial-temporal differences in the fish community structure.

Table 3.1. Comprehensive overview of fish diversity in the Dikhu River, Nagaland: conservation status, population trends and economic significance.

Sl. No.	Systematic position	Local name (Ao)	Common name	IUCN Status	Population Trends	Economic value	Specimen number
Order: Anguilliformes Family: Anguillidae							
1	*Anguilla bengalensis* (Gray, 1831)	Angulang	Indian Mottled Eel	NT	Unknown	Fd	NUFM 1390
Order: Cypriniformes Family: Cyprinidae Subfamily: Barbinae							
2	*Neolissochilus hexagonolepis* (McClelland, 1839)	Seben	Katli or Chocolate mahseer	NT	Decreasing	Fd, Sp	NUFM 1279
3	*Tor putitora* (Hamilton, 1822)	Tzünger	Golden mahseer	EN	Decreasing	Fd, Sp	NUFM 1285
4	*Pethia conchonius* (Hamilton, 1822)	Tzünger	Rosy barb	LC	Unknown	Fd, Or	NUFM 1289
Subfamily: Danioninae							
5	*Opsarius bendelisis* (Hamilton, 1807)	Tawa	Indian hill trout	LC	Stable	Fd, Or	NUFM 1310
6	*Opsarius tileo* (Hamilton, 1822)	Tawa	Tileo baril	LC	Unknown	Fd, Or	NUFM 1316
7	*Opsarius barna* (Hamilton, 1822)	Tawa	Barna Baril	LC	Stable	Fd, Or	NUFM 1317
8	*Danio dangila* (Hamilton, 1822)	Zer	Dangila Danio	LC	Decreasing	Fd, Or	NUFM 1325
9	*Danio rerio* (Hamilton, 1822)	Zer	Zebra fish	LC	Decreasing	Fd, Or	NUFM 1329
10	*Danio assamila* (Kullander, 2015)	Zer	Not accessed	NA	NA	Fd, Or	NUFM 1332
11	*Devario aequipinnatus* (McClelland, 1839)	Zer	Giant danio	LC	Unknown	Fd, Or	NUFM 1319
Subfamily: Labeoninae							
12	*Tariqilabeo latius* (Hamilton, 1822)	Anget	GangeticLatia	LC	Unknown	Fd	NUFM 1295
13	*Garra lissorhynchus* (McClelland, 1842)	Anget	Khasi garra	LC	Unknown	Fd, Or	NUFM 1296
14	*Garra birostris* (Nebeshwar and Vishwanath, 2013)	Anget	Not accessed	NA	NA	Fd, Or	NUFM 1302
15	*Garra naganensis* (Hora, 1921)	Anget	Naga garra	LC	Unknown	Fd, Or	NUFM 1304
Family: Psilorhynchidae							
16	*Psilorhynchus homaloptera* (Hora and Mukherji, 1935)	Mernngo	Homaloptera minnow	LC	Unknown	Or	NUFM 1347

17	*Psilorhynchus arunachalensis* (Nebeshwar, Bagra and Das, 2007)	Mernngo	Not accessed	DD	Unknown	Or	NUFM 1353
Family: Botiidae							
18	*Botia rostrata* (Günther, 1868)	Nga-medaktsü	Gangetic loach	VU	Decreasing	Or	NUFM 1356
Family: Nemacheilidae							
19	*Paracanthocobitis botia* (Hamilton, 1822)	Sangsert	Mottled loach	LC	Decreasing	Or	NUFM 1335
20	*Schistura savona* (Hamilton, 1822)	Retong	*Half-banded Loach*	LC	Unknown	Or	NUFM 1341
Order: Siluriformes Family: Siluridae							
21	*Pterocryptis indica* (Datta, Barman and Jayaram, 1987)	Lorng	Siluras Catfish	DD	Unknown	Fd	NUFM 1360
Family: Bagridae							
22	*Olyra longicaudata* (McClelland, 1842)	Nenak	Torrent Catfish	LC	Unknown	Or	NUFM 1357
Family: Amblycipitidae							
23	*Amblyceps apangi* (Nath and Dey, 1989)	Nenak	Indian Torrent Catfish	LC	Unknown	Or	NUFM 1368
Family: Sisoridae							
24	*Glyptothorax indicus* (Talwar, 1991)	Jangmu	Catfish	LC	Unknown	Or	NUFM 1366
Order: Anabantiformes Family: Channidae							
25	*Channa melanostigma* (Geetakumari and Vishwanath, 2011)	Alopungo	snakehead	NA	NA	Fd, Or	NUFM 1374
Family: Badidae							
26	*Badis badis* (Hamilton, 1822)	Akngo	Badis	LC	Unknown	Or	NUFM 1379
Order: Beloniformes Family: Belonidae							
27	*Xenentodon cancila* (Hamilton, 1822)	Jokli	Freshwater Garfish	LC	Unknown	Or	NUFM 1385
Order: Synbranchiformes Family: Mastacembelidae							
28	*Mastacembelus armatus* (Lacepède, 1800)	Merü	Spiny Eel	LC	Stable	Fd, Or	NUFM 1388

*DD, Data deficient; LC, Least concern; NT, Near threatened; VU, Vulnerable; EN, Endangered; NA, Not accessed; Fd, Food; Sp, Sport; Or, Ornamental

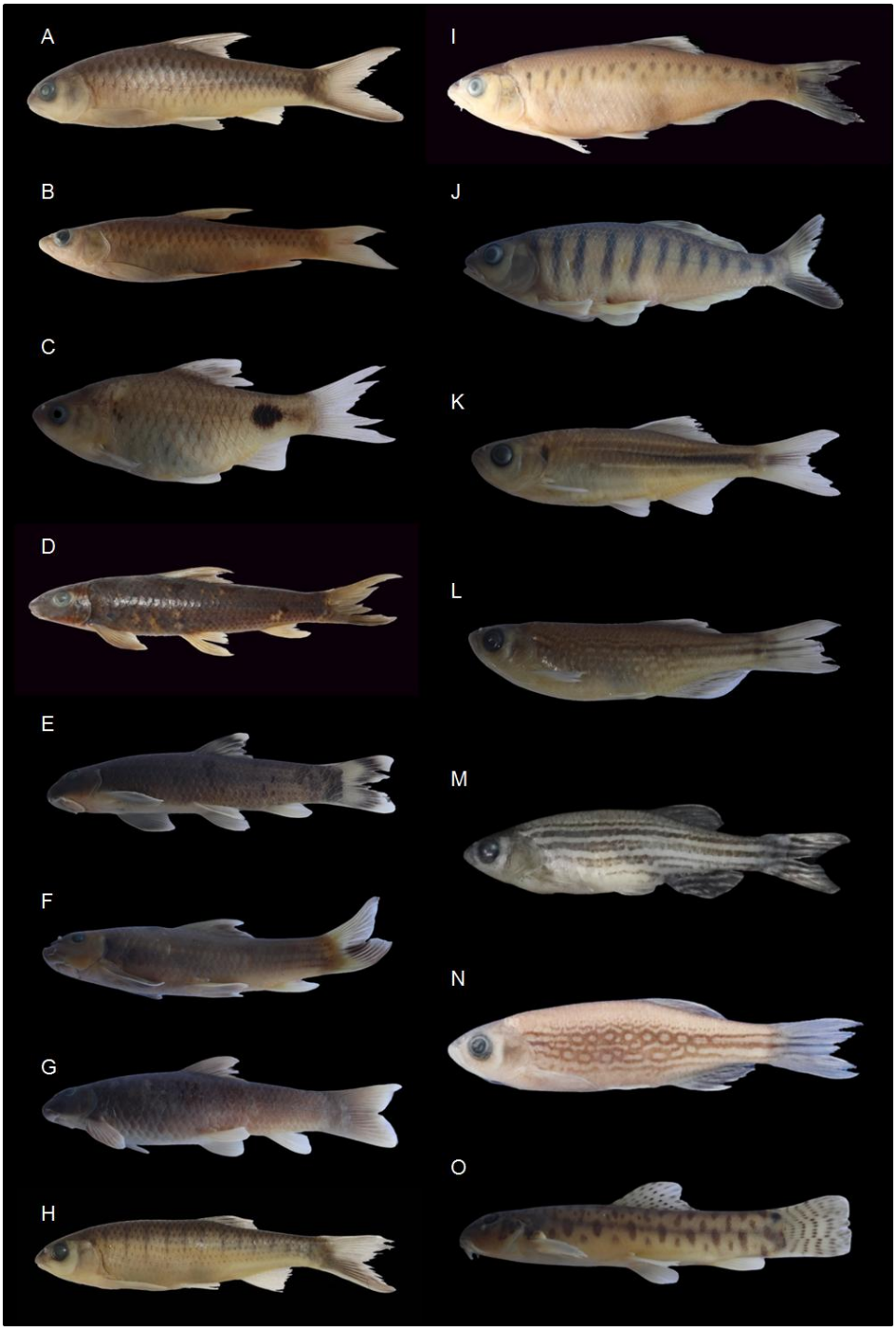

Figure 3.1. Comprehensive catalog of fish species recorded in the Dikhu River, Nagaland. A - *Neolissochilus hexagonolepis*, B - *Tor putitora*, C - *Pethia conchonius*, D - *Tariqilabeo latius*, E - *Garra lissorhynchus*, F - *Garra birostris*, G - *Garra naganensis*, H - *Opsarius bendelisis*, I - *Opsarius tileo*, J - *Opsarius barna*, K - *Devario aequipinnatus*, L - *Danio dangila*, M - *Danio rerio*, N - *Danio assamila* , O - *Paracanthocobitis botia*

Figure 3.2. Comprehensive catalog of fish species recorded in the Dikhu River, Nagaland. Cont. A - *Schistura savona*, B - *Psilorhynchus homaloptera*, C - *Psilorhynchus balitora*, D - *Botia rostrata*, E - *Olyra longicaudata*, F - *Pterocryptis indica*, G - *Glyptothorax indicus*, H - *Amblyceps apangi*, I - *Channa melanostigma*, J - *Badis badis*, K - *Xenentodon cancila*, L - *Mastacembelus armatus*

3.3 Results

3.3.1 Ichthyofaunal diversity and catch composition

3.3.1.1 Species composition

The fish species composition of the Dikhu River revealed a rich and diverse fish community, with 28 species identified across 6 orders, 13 families, and 3 subfamilies. A comprehensive checklist of these species, categorized by their IUCN conservation status (IUCN, 2024) and population trends, is presented in Table 3.1. Notably, the order Cypriniformes emerged as the most dominant group, comprising 67.9% of the total catch, followed by Siluriformes (14.3%) and Anabantiformes (7.1%). In contrast, the orders Beloniformes, Synbranchiformes, and Anguilliformes were least represented, collectively contributing only 10.7%. Among families, Cyprinidae was the most diverse, represented by 14 species (50 %), while genera such as *Garra, Opsarius,* and *Danio* were the most common, each contributing three species. According to the IUCN Red List (IUCN, 2024), a majority (71.4%) of species fell under the Least Concern (LC) category, but concerningly, 7.1% were classified as Near Threatened (NT), 3.6% as Vulnerable (VU), and 3.6% as Endangered (EN). Additionally, 10.7% had not yet been assessed (NA), and 3.6% were listed as Data Deficient (DD), highlighting critical gaps in conservation knowledge. The population trends of these species, as reported by the IUCN, further underscored conservation concerns: 57.1% of species had unknown population trends, 21.4% showed declining populations, 10.7% were stable, and 10.7% were yet to be assessed. Assessing the species based on their economic value revealed that 46.4% were valued for both food and ornamental purposes, 35.7% served primarily ornamental roles, 10.7% were utilized for food, and 7.1% were important for both food and sport fishing. Figures 3.1 to 3.7 provide a detailed representation of the data.

3.3.1.2 Record of *Garra birostris* in Nagaland from the Dikhu River

The present study reports the first site record of *Garra birostris* in Nagaland from the Dikhu River, expanding the known geographical range of this species, initially described from the Brahmaputra River system in Northeast India by Nebeshwar and Vishwanath (2013). During the field surveys, five specimens of *G. birostris* were collected, marking a significant addition to the ichthyofaunal diversity of Nagaland.

Morphological examination confirmed the identity of the specimens as *Garra birostris*, exhibiting the distinctive features of the species, notably a prominently bilobed proboscis bearing large, tri- to tetra-cuspid acanthoid tubercles on each lobe, consistent with the description by Nebeshwar and Vishwanath (2017). This species is closely related to *Garra biloborostris* (Roni and Vishwanath, 2017) and *Garra chathensis* (Ezung *et al.,* 2020a), all members of the proboscis species-group. However, the presence of large tri- or tetra-cuspid acanthoid tubercles in *G. birostris*, as opposed to three acanthoid tubercles in *G. biloborostris* and bicuspid tubercles in *G. chathensis*, serves as a key diagnostic feature distinguishing it from its congeners. Figure 3.8 represents the diagrammatic view of *Garra birostris*, highlighting its distinctive morphological traits.

The specimens sampled from the Dikhu River also shared several diagnostic traits described in the original species description, including a moderately large and depressed head, two pairs of barbels (rostral and maxillary), a distinctively structured proboscis sharply delineated from the depressed rostral surface, pectoral fin with i14 - 15 rays, pelvic fin with i8 rays reaching beyond the midpoint to the anal-fin origin, 10 or 11 predorsal scales, and transverse scale rows arranged as 4½|1|3½. Additional features, such as a relatively smaller adhesive disc (26.4 - 43.3% HL), a black spot at the upper angle of the gill opening, a longer snout (51.2 - 58.3% HL), and a narrower interorbital distance (37.9 - 43.5% HL), were consistent with the original description. However, marginal differences were evident in our specimens, notably in the fin formulae, a reduced dorsal fin ray count of ii8½ (vs. iii8½) and anal fin rays of ii5½ (vs. iii5½). These variations likely reflect adaptations to local adaptations to the distinct habitat conditions, such as variations in the physico-chemical properties of the water and climatic factors unique to the Dikhu River ecosystem. Detailed meristic and morphometric data for the specimens are provided in Table 3.2.

3.3.1.3 Relative abundance

The relative abundance of small native fish species, including *Devario aequipinnatus* (15.55%), *Opsarius bendelisis* (11.39%), *Garra naganensis* (9.52%), *Amblyceps apangi* (7.73%), and *Schistura savona* (6.61%), was notably high across the study sites, underscoring their dominance and ecological significance within the river ecosystem. These species form an integral part of the aquatic community,

contributing to the overall health and resilience of the Dikhu River system. Among species of conservation concern, *Neolissochilus hexagonolepis* (NT) exhibited a comparatively high relative abundance (4.31%), offering a glimmer of hope for its population stability in the face of ongoing natural and anthropogenic pressures in the region. However, the alarmingly low relative abundance of *Tor putitora* (EN) at 0.62%, *Anguilla bengalensis* (NT) at 0.16%, and *Botia rostrata* (VU) at 0.08% raises serious conservation concerns, signaling potential declines in their populations and highlighting the urgent demand for conservation interventions. Other species, including *Schistura savona* (6.61%), *Psilorhynchus homaloptera* (5.91%), *Pterocryptis indica* (5.71%), and *Pethia conchonius* (5.25%), demonstrated moderate relative abundance, further illustrating the diversity and complexity of the riverine fish community. Notably, *Tariqilabeo latius* and *Botia rostrata* exhibited the lowest relative abundance values, each contributing a mere 0.08% to the total catch, reflecting their rarity and possible vulnerability within the studied ecosystem. Seasonal patterns were also evident, with the highest catches recorded during the post-monsoon and pre-monsoon seasons, underscoring the influence of seasonal hydrological dynamics on fish populations and catch composition. Figure 3.9 highlights the distribution pattern of relative occurrence of each species. The results reveal a rich and diverse fish community in the Dikhu River, while also exposing the vulnerability of some species, calling for targeted conservation strategies.

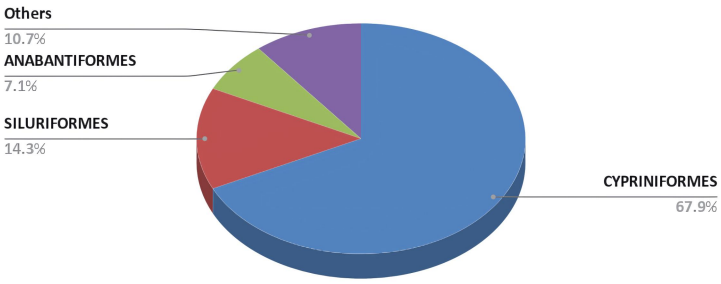

Figure 3.3: Percentage distribution of fish species by order group

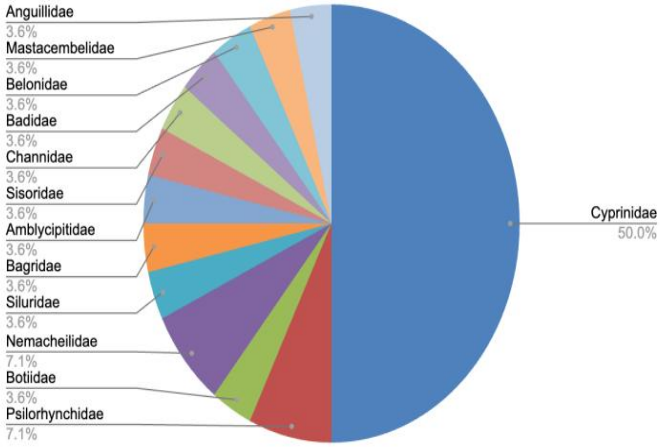

Figure 3.4: Percentage distribution of fish species by family distribution

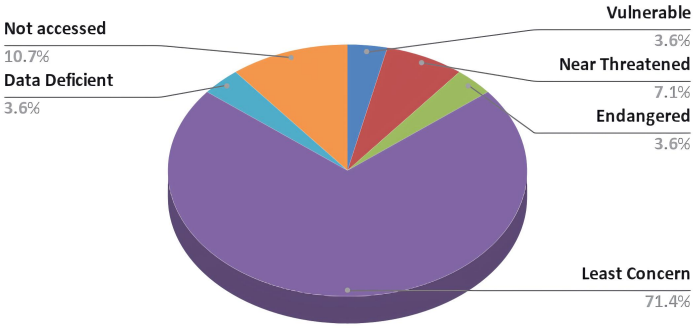

Figure 3.5: Percentage distribution from IUCN conservation status

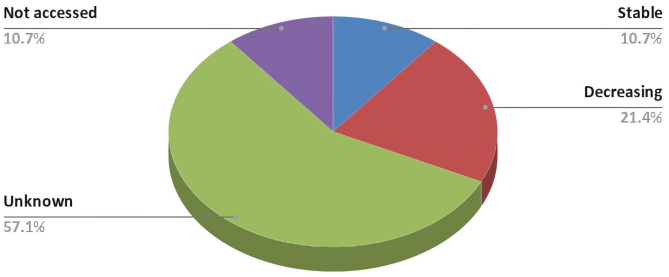

Figure 3.6: Percentage distribution of fish species by population trend

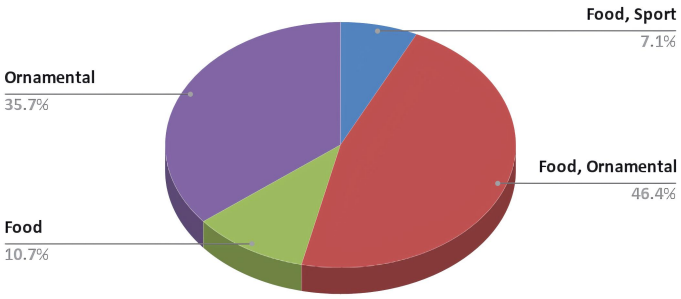

Figure 3.7: Percentage distribution of fish species by economic value.

Figure 3.8: *Garra birostris*, NUFM 1302, 113.1 mm SL, Dikhu River in Nagaland: a- lateral view, b- dorsal head view, and c - ventral view

Table 3.2: Morphometric and meristic profiles of *Garra birostris* from the Dikhu River.

Morphometric traits	**Dikhu River (n = 05)**		
	Range	**Mean**	**SD**
Standard length (mm)	113.1-138.7		
In percent of standard length			
Head length	23.3-25.3	24.4	0.7
Body depth at dorsal fin origin	20.1-24.9	22.7	1.7
Predorsal length	44.5-47.4	46.1	1.1
Preanus length	67.4-72.8	69.4	2.0
Preanal length	75.1-78.2	76.1	1.2
Prepectoral length	19.9-23.1	21.7	1.5
Prepelvic length	49.1-52.3	50.5	1.2
Dorsal-fin base length	17.1-20.1	18.8	1.1
Dorsal-fin length	24.1-27.7	25.3	1.4
Pectoral-fin length	19.3-23.7	21.9	1.6
Pelvic-fin length	20.1-23.1	21.7	1.2
Anal-fin base length	7.1-10.0	8.3	1.1
Anal-fin length	20.3-22.0	21.1	0.8
Vent to anal distance	5.4-7.1	6.4	0.6
Caudal peduncle length	15.2-17.2	15.9	0.7
Caudal peduncle depth	12.3-14.1	13.1	0.6
Caudal fin length (upper lobe)	24.4-28.1	26.6	1.5
Disc length	6.3-10.5	8.4	1.6
Disc width	9.8-13.8	12.2	1.4
Pulvinus length	3. 1-6.3	5.5	1.3
Pulvinus Width	5. 7-9.1	8.1	1.3
In percent of head length			
Head depth at occiput	67.4-72.1	69.9	1.8
Snout length	51.2-58.3	53.8	3.2

Interorbital width	37.9-43.5	41.1	2.1
Eye diameter	16.1-19.5	17.8	1.5
Disc length	26.4-43.3	34.5	6.6
Disc width	41.1-56.9	50.1	6.1
Pulvinus length	13.2-26.2	22.7	5.3
Pulvinus width	23.6-36.3	33.2	5.3
Meristic counts	**N = 05**		
Dorsal-fin rays	ii8½		
Pectoral-fin rays	i14-15		
Pelvic-fin rays	i8		
Anal-fin rays	ii5½		
Pre-dorsal scales	10-11		
Lateral line scales	33-34		
Transverse scales	4½|1|3½		
Circumpeduncular scale rows	16		

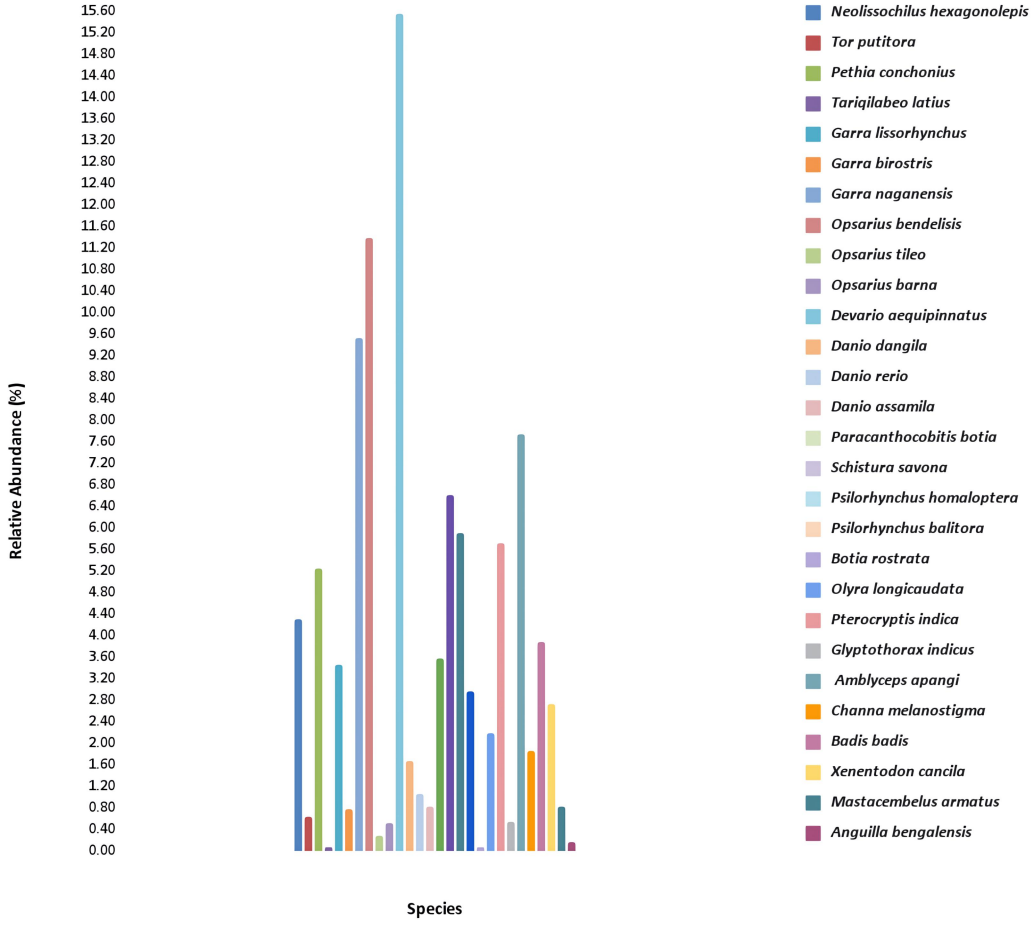

Figure 3.9: Relative abundance percentage distribution for each fish species

3.3.2 Diversity Index

3.3.2.1 Diversity indices of fish communities across different sampling sites

The analysis of site-wise variation in fish community diversity indices across the six sampling sites revealed notable spatial differences in species richness, abundance, and diversity metrics as shown in Table 3.3. The number of taxa (S) ranged from 21 to 28, highest at Site 4 (S = 28) and Site 6 (S = 27) and lowest at Sites 1 and 2 (S = 21). Abundance also varied, with Site 4 comprising the most individuals (n = 526), pointing to a relatively dense fish population, and Site 1 with the lowest individuals (n = 340).

The Shannon-Wiener index (H′), which combines richness and evenness, ranged from 2.551 at Site 1 to 2.984 at Site 4, indicating Site 4 had the most diverse and even community. Simpson's dominance index (1-D) ranged from 0.892 at Site 1 to 0.939 at Site 4, again the highest at Site 4. Evenness was similar across sites, highest at Site 5 (0.723) and lowest at Site 6 (0.608). Overall, Site 4 was notable for having the highest richness (S = 28), abundance (n = 526), and diversity values (H′ = 2.984; 1-D = 0.939). Figure 3.10 represents the diversity indices for fish communities at six different sites in the Dikhu River.

Table 3.3: Site-wise variation in fish community diversity indices.

Diversity indices	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Taxa (S)	21	21	22	28	26	27
Individuals	340	364	430	526	404	509
Shannon - Wiener diversity index (H')	2.551	2.689	2.681	2.984	2.934	2.798
Simpson's dominance index (1-D)	0.892	0.919	0.913	0.939	0.935	0.920
Evenness (e^H/S)	0.610	0.701	0.664	0.706	0.723	0.608

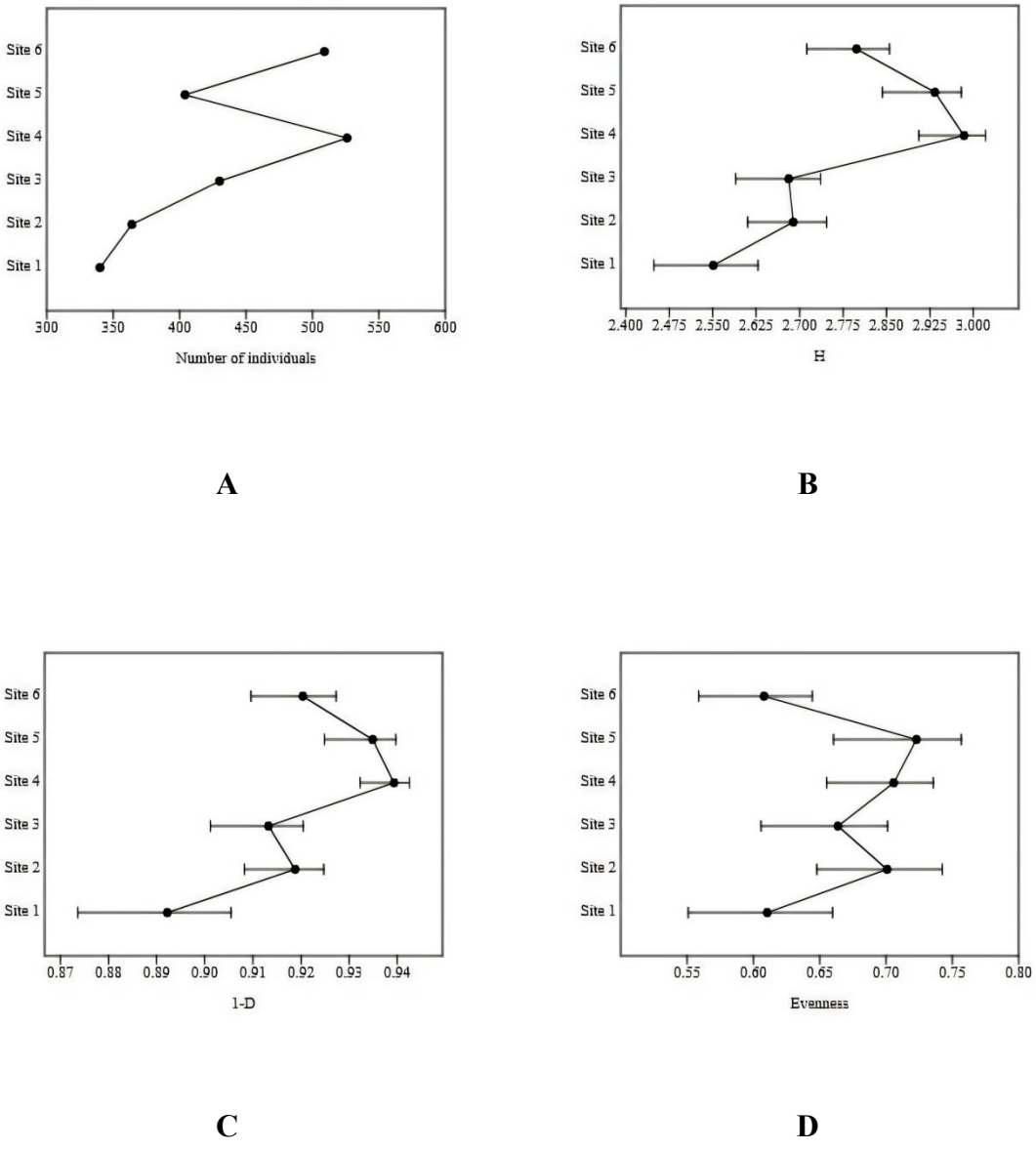

Figure 3.10: Graphical representation of diversity indices for the fish assemblage at six sampling sites in the Dikhu River. A; Number of individuals, B; Shannon-Wiener diversity index (H'), C; Simpson's dominance index (1-D) and D; Evenness index

3.3.2.2 Diversity indices of fish communities across different seasons and sites

The analysis of fish community diversity across different sites and seasons in the Dikhu River revealed distinct spatial and temporal patterns as represented in Table 3.4. Each site exhibited seasonal variation in species richness (S), abundance and diversity indices.

Species richness at Site 1 ranged from 12 taxa during the monsoon to 17 taxa before the monsoon. The maximum number of individuals was recorded in pre-monsoon (116) and the minimum in the monsoon season (51). The Shannon-Wiener diversity index (H') ranged from 2.10 during the monsoon to 2.519 before the monsoon, showing a difference in diversity. Simpson's dominance index (1-D) showed a similar pattern with the highest value (0.895) after the monsoon and the lowest (0.841) during the monsoon. The evenness index also changed moderately, with the highest value (0.787) after the monsoon and the lowest (0.681) during the monsoon season. These results indicate that monsoonal flows have a strong influence on community structure, probably due to changes in water flow. Figure 3.11 depicts the seasonal trends in fish diversity at Site 1 (Alaphumi) in graphical form.

Site 2 exhibited relatively stable species richness across seasons, ranging from 13 taxa in monsoon to 18 taxa in pre-monsoon. Fish abundance peaked in pre-monsoon (113 individuals) and declined during winter (59 individuals). Diversity indices were highest in winter (H' = 2.560; 1-D = 0.906), suggesting a well-balanced community despite lower abundance. Evenness peaked in post-monsoon (0.796), indicating a more equitable distribution of individuals among species, while the lowest evenness (0.710) occurred in pre-monsoon. Figure 3.12 presents a graphical depiction of seasonal changes in fish diversity at Site 2 (Sumi Setsü).

At Site 3, species richness was relatively consistent across seasons, ranging from 13 to 18 taxa. Fish abundance was highest in post-monsoon (160 individuals) and lowest in monsoon (73 individuals). Diversity indices peaked in pre-monsoon (H' = 2.657; 1-D = 0.918), while the lowest values were observed in monsoon (H' = 2.287; 1-D = 0.874). Evenness was highest in pre-monsoon (0.792) and lowest in winter (0.654), indicating a moderate seasonal variation in community structure. Figure 3.13 represents a graph showing seasonal changes in fish diversity at Site 3 (Longsa).

Site 4 consistently supported the highest diversity and abundance across seasons. Species richness ranged from 18 taxa in monsoon to 24 taxa in post-monsoon, while individual abundance peaked in post-monsoon (199) and pre-monsoon (160). Diversity indices were highest in post-monsoon (H' = 2.935; 1-D = 0.940), reflecting a highly diverse and stable community. Evenness also remained high across seasons, peaking at 0.784 in post-monsoon. Figure 3.14 depicts the seasonal patterns of fish diversity at Site 4 (Longkong) in graphical form.

Site 5 exhibited moderate seasonal fluctuations, with species richness ranging from 19 taxa in winter to 21 taxa in pre- and post-monsoon. Fish abundance was highest in post-monsoon (134) and pre-monsoon (130). Diversity indices peaked in pre-monsoon (H' = 2.835; 1-D = 0.934), while winter recorded the lowest values (H' = 2.545; 1-D = 0.898). Evenness was highest in pre-monsoon (0.811), indicating a relatively balanced community structure during this season. Figure 3.15 presents seasonal patterns in fish assemblage diversity at Site 5 (Chakba).

At Site 6, species richness ranged from 15 taxa in monsoon to 23 taxa in pre-monsoon. Fish abundance peaked in post-monsoon (179) and pre-monsoon (161), while the lowest abundance (69) was observed in monsoon. Diversity indices were highest in post-monsoon (H' = 2.747; 1-D = 0.921) and lowest in monsoon (H' = 2.248; 1-D = 0.849), reflecting a decline in community diversity during periods of increased hydrological flow. Evenness followed a similar trend, with the highest value (0.743) in post-monsoon and the lowest (0.631) in monsoon. Figure 3.16 depicts seasonal fluctuations in fish assemblage diversity at Site 6 (Salulamang).

In summary, the observed data reveal a clear seasonal pattern across all sites, with diversity generally highest during pre- and post-monsoon periods, and reduced during monsoon, likely due to increased flow regimes and habitat disturbance.

Table 3.4: Site-specific and seasonal variations of fish community diversity in the Dikhu River.

Seasons	Taxa (S)	Individuals	Shannon - Wiener diversity index (H')	Simpson's dominance index (1-D)	Evenness (e^H/S)
Site 1 (Alaphumi)					
Pre-monsoon	17	116	2.519	0.889	0.730
Monsoon	12	51	2.100	0.841	0.681
Post-monsoon	15	108	2.469	0.895	0.787
Winter	13	65	2.210	0.859	0.701
Site 2 (Sumi Setsü)					
Pre-monsoon	18	113	2.548	0.904	0.710
Monsoon	13	81	2.257	0.863	0.735
Post-monsoon	15	111	2.480	0.899	0.796
Winter	17	59	2.560	0.906	0.761
Site 3 (Longsa)					
Pre-monsoon	18	118	2.657	0.918	0.792
Monsoon	13	73	2.287	0.874	0.757
Post-monsoon	17	160	2.531	0.903	0.739
Winter	18	79	2.465	0.882	0.654
Site 4 (Longkong)					
Pre-monsoon	22	160	2.838	0.933	0.777
Monsoon	18	65	2.593	0.902	0.743
Post-monsoon	24	199	2.935	0.940	0.784
Winter	20	102	2.625	0.903	0.690

Site 5 (Chakba)					
Pre-monsoon	21	130	2.835	0.934	0.811
Monsoon	19	68	2.672	0.911	0.762
Post-monsoon	21	134	2.804	0.930	0.786
Winter	19	72	2.545	0.898	0.671
Site 6 (Salulamang)					
Pre-monsoon	23	161	2.705	0.913	0.650
Monsoon	15	69	2.248	0.849	0.631
Post-monsoon	21	179	2.747	0.921	0.743
Winter	18	100	2.425	0.881	0.628

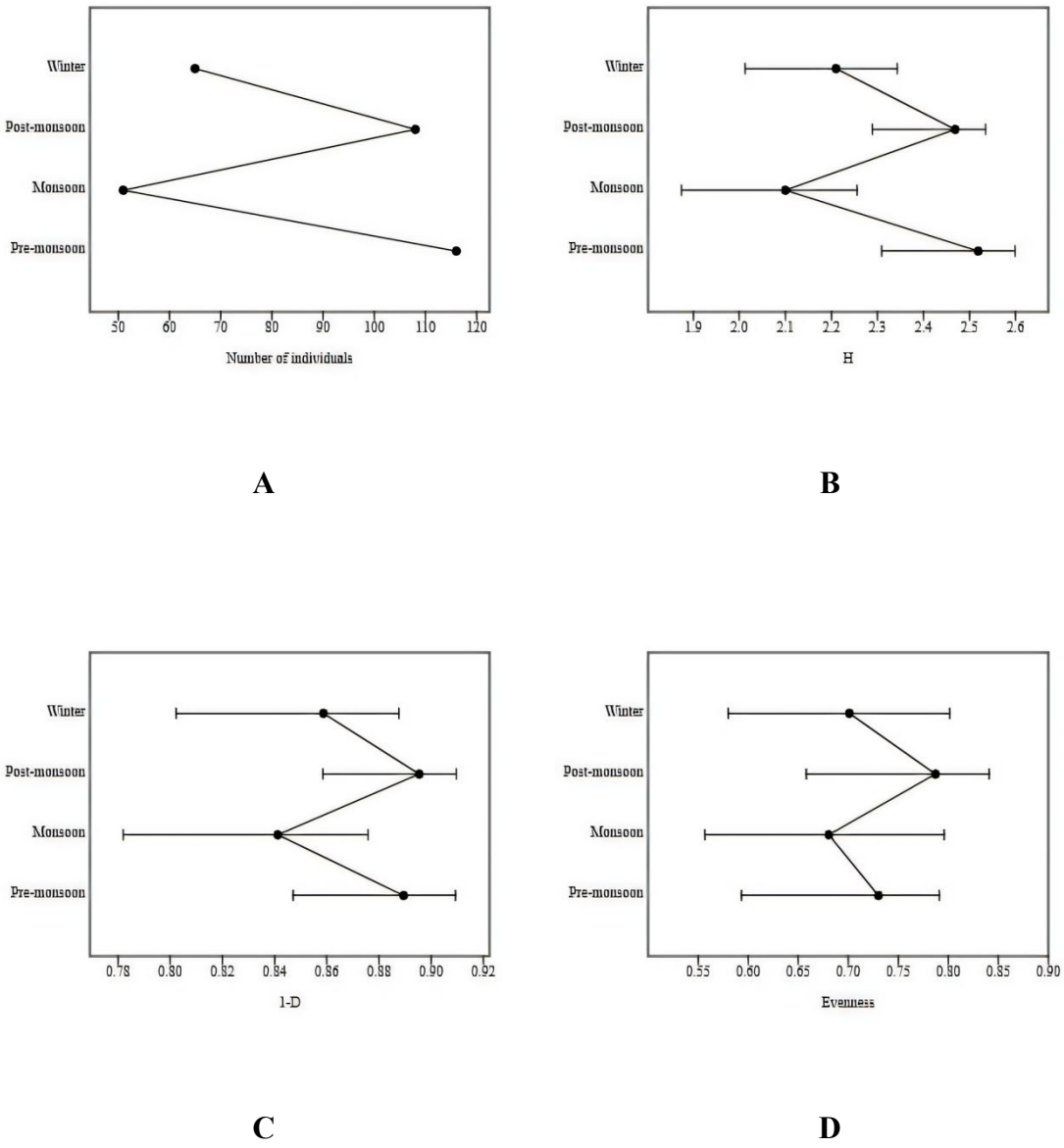

Figure 3.11: Graphical representation of seasonal variation in fish assemblage diversity at Site 1 (Alaphumi). A; Number of individuals, B; Shannon-Wiener diversity index (H'), C; Simpson's dominance index (1-D) and D; Evenness index

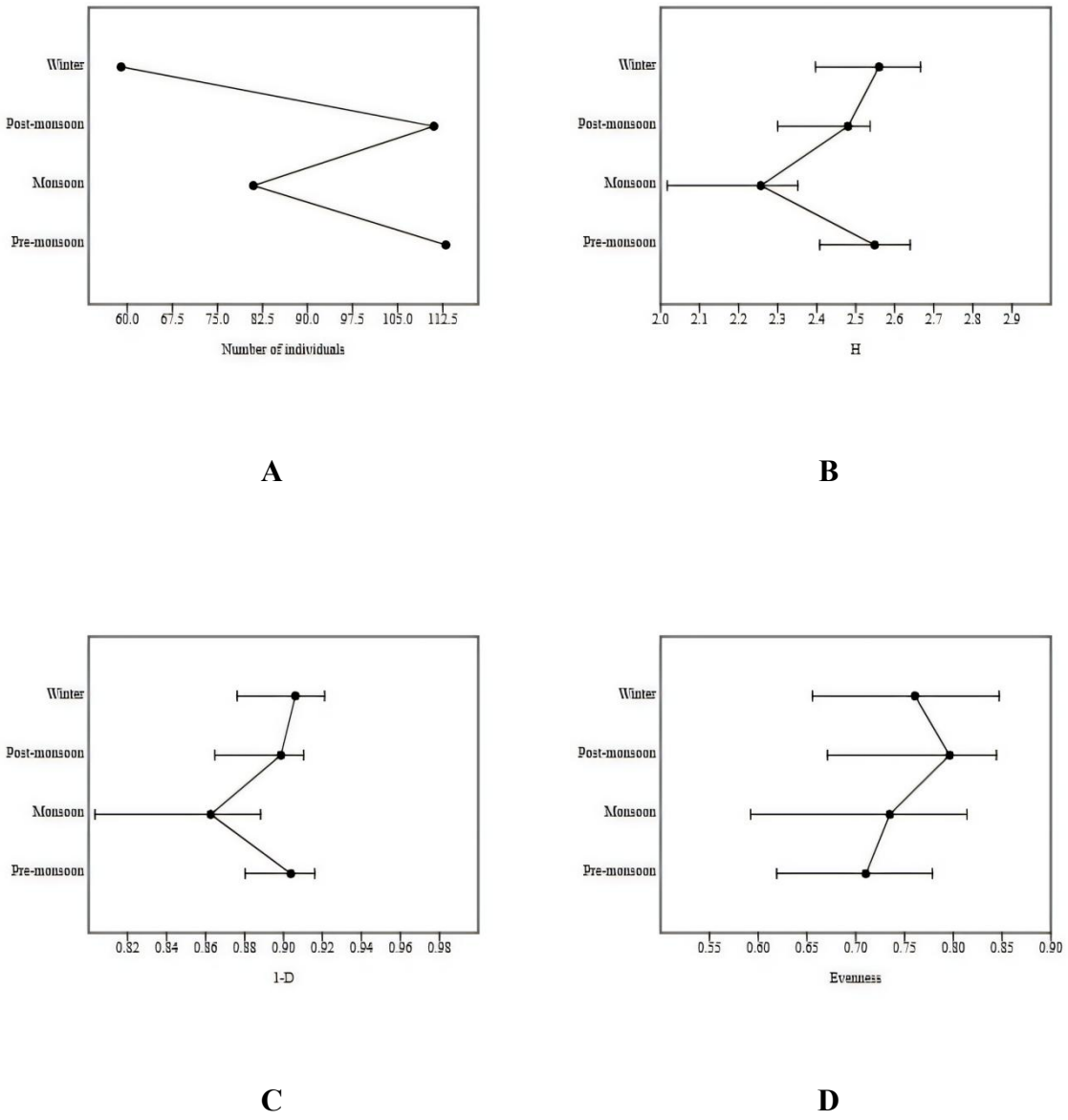

Figure 3.12: Graphical representation of seasonal variation in fish assemblage diversity at Site 2 (Sumi Setsü). A; Number of individuals, B; Shannon-Wiener diversity index (H'), C; Simpson's dominance index (1-D) and D; Evenness index

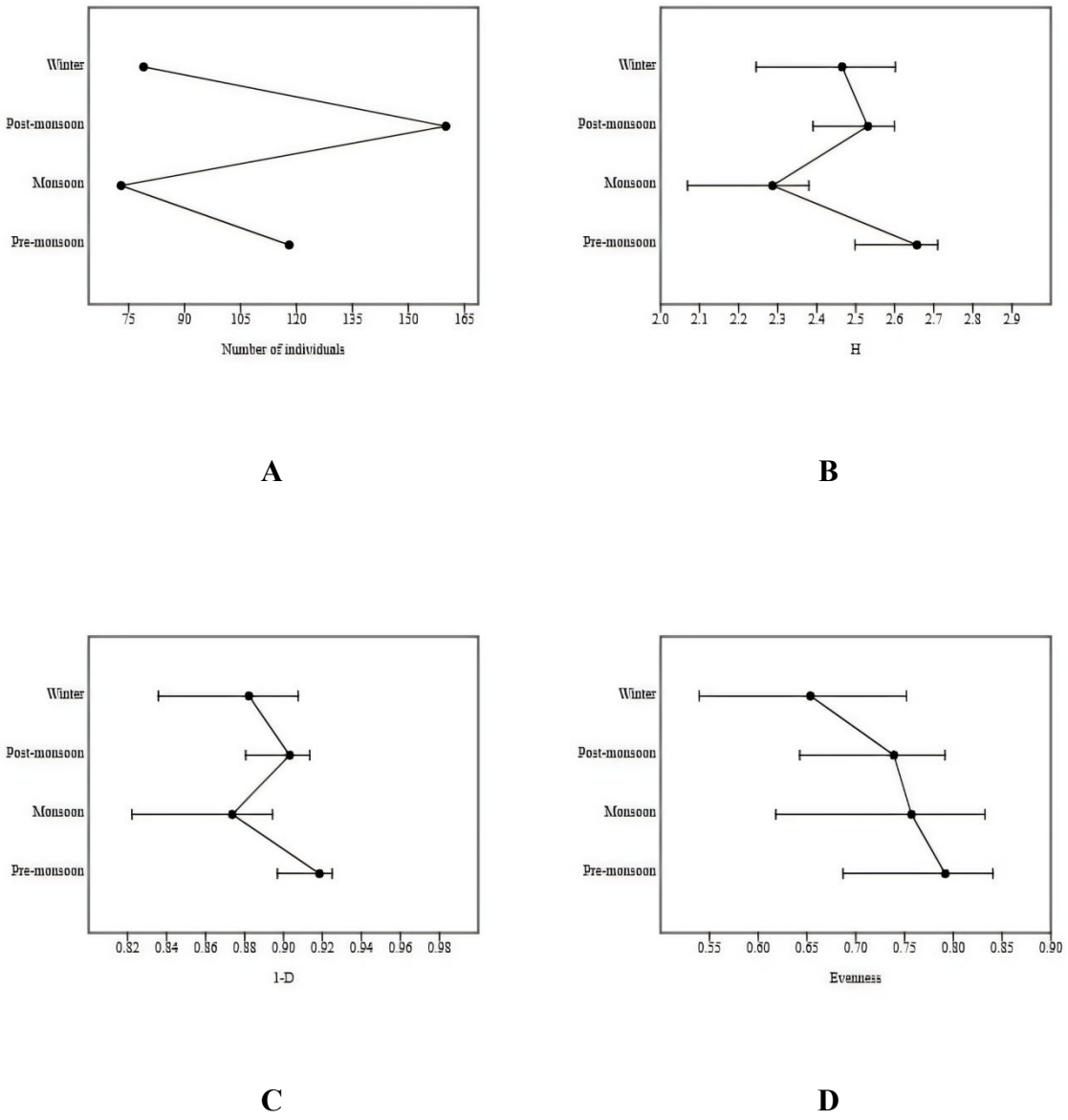

Figure 3.13: Graphical representation of seasonal variation in fish assemblage diversity at Site 3 (Longsa). A; Number of individuals, B; Shannon-Wiener diversity index (H'), C; Simpson's dominance index (1-D) and D; Evenness index

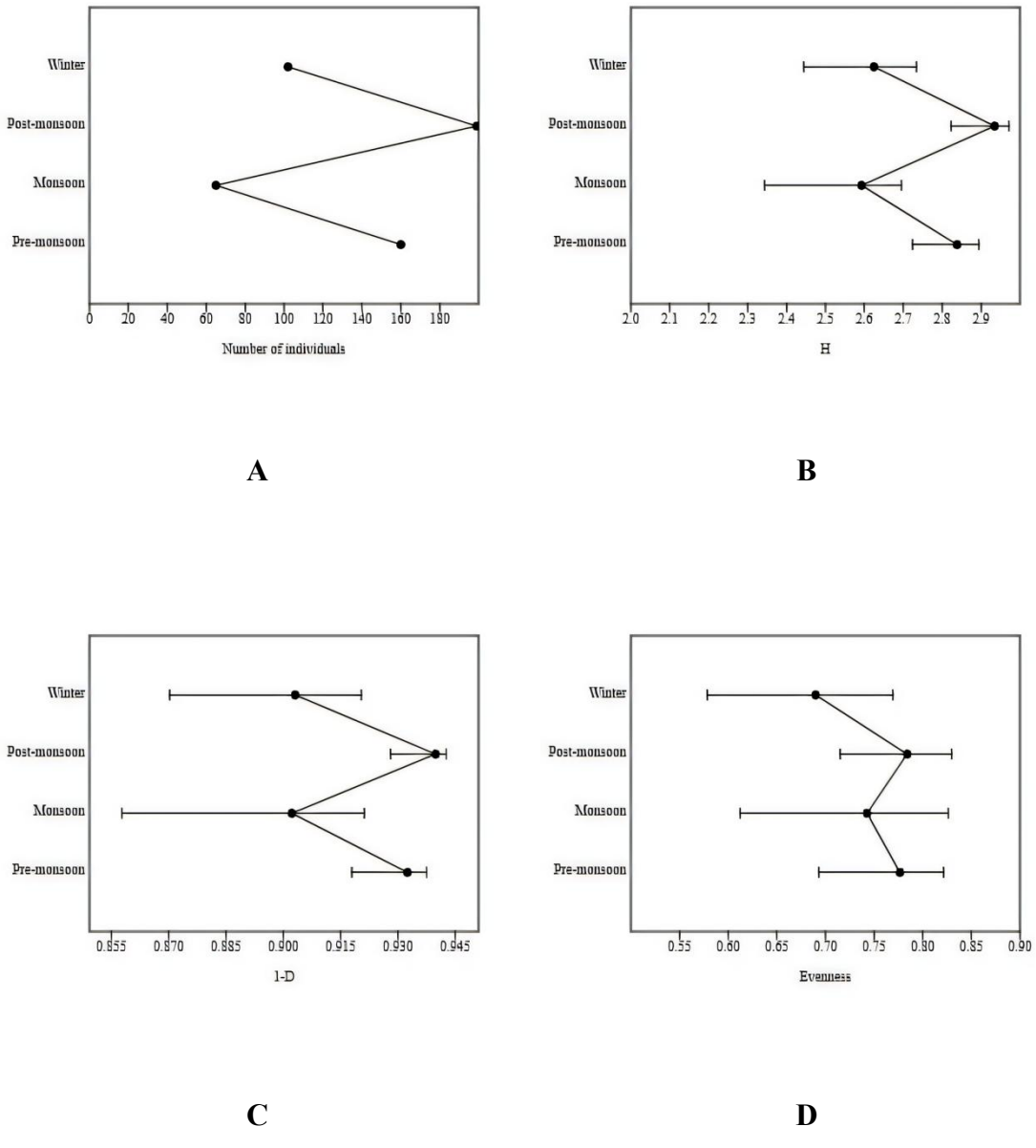

Figure 3.14: Graphical representation of seasonal variation in fish assemblage diversity at Site 4 (Longkong). A; Number of individuals, B; Shannon-Wiener diversity index (H'), C; Simpson's dominance index (1-D) and D; Evenness index

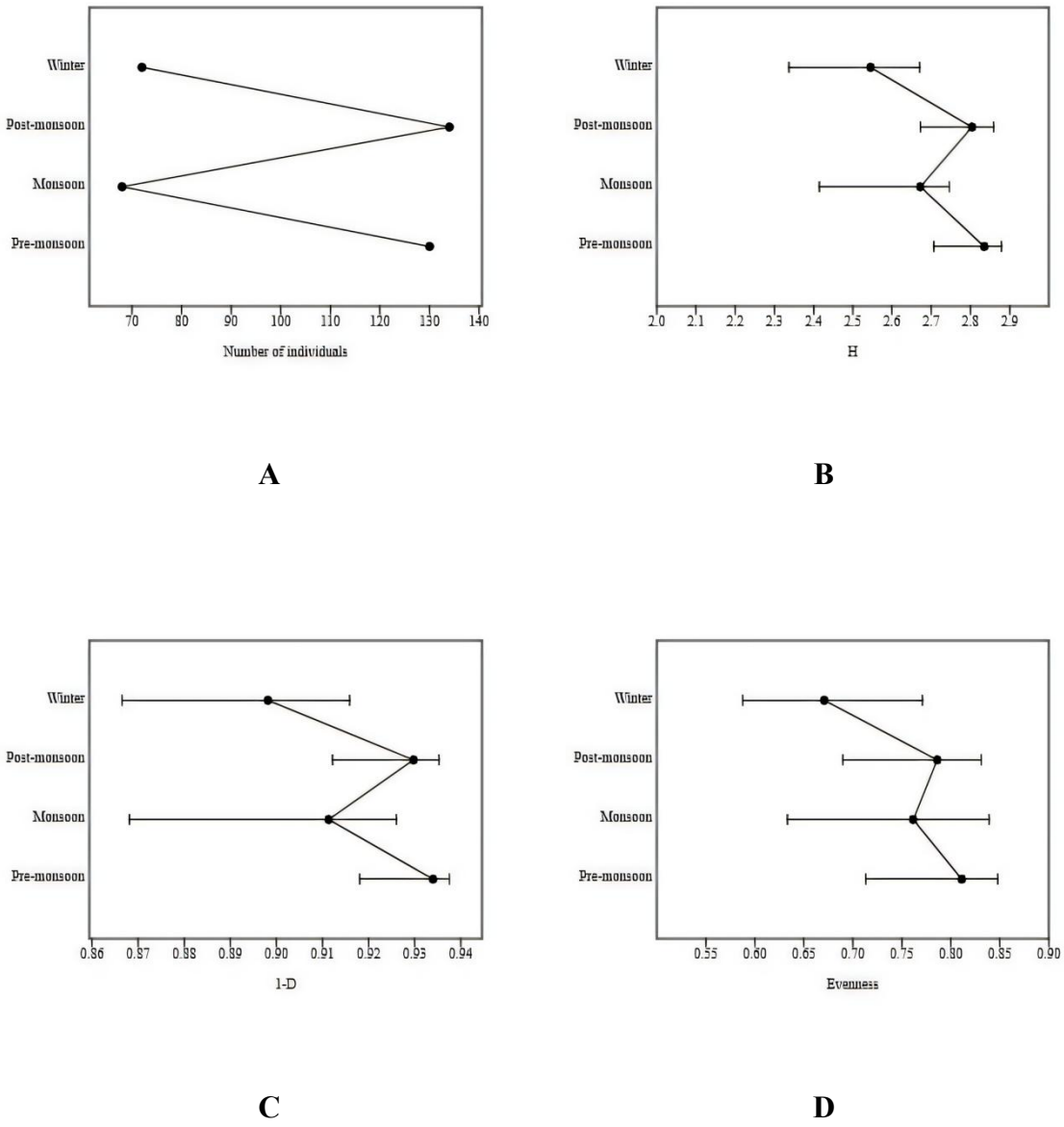

Figure 3.15: Graphical representation of seasonal variation in fish assemblage diversity at Site 5 (Chakba). A; Number of individuals, B; Shannon-Wiener diversity index (H'), C; Simpson's dominance index (1-D) and D; Evenness index

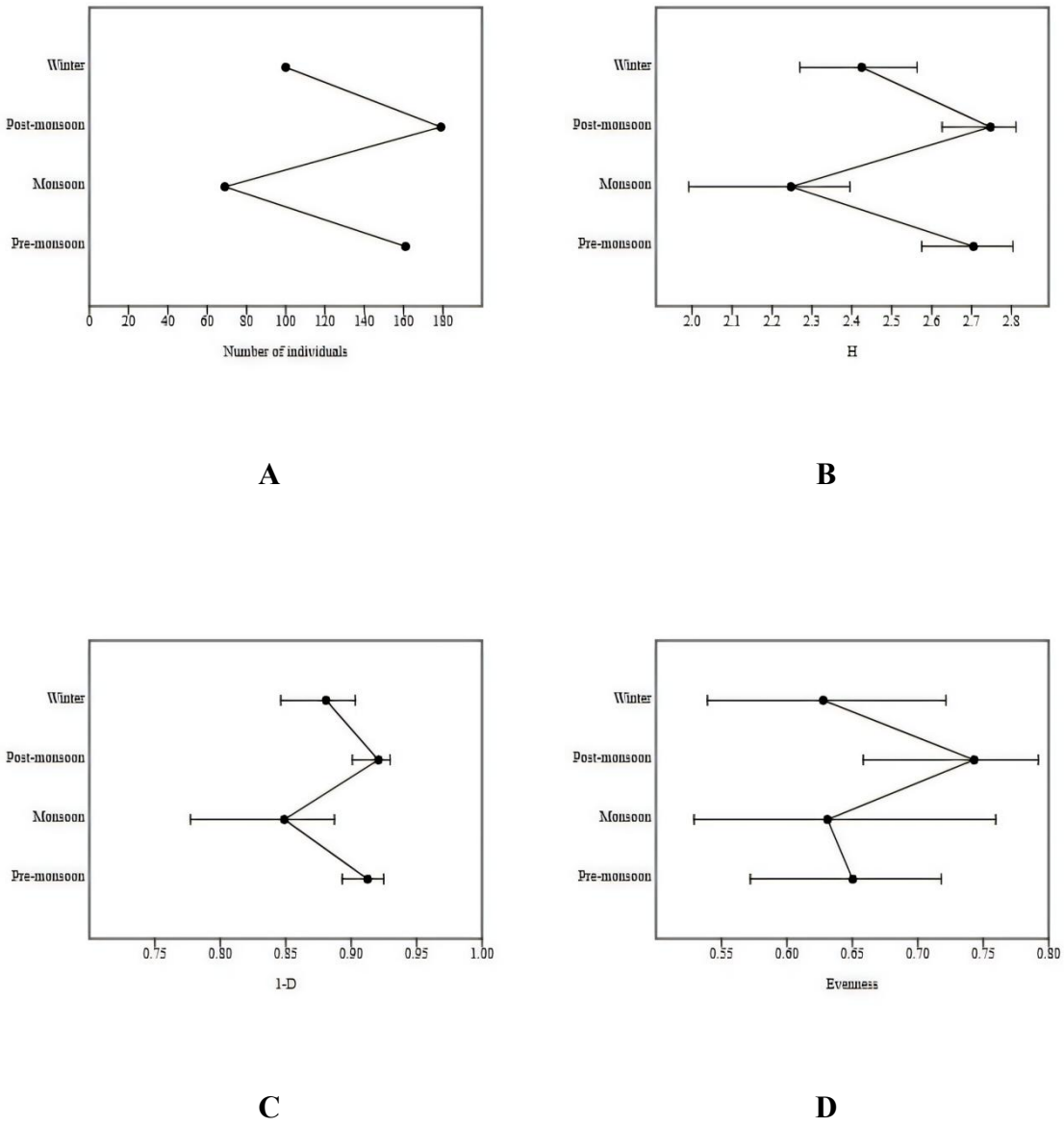

Figure 3.16: Graphical representation of seasonal variation in fish assemblage diversity at Site 6 (Salulamang). A; Number of individuals, B; Shannon-Wiener diversity index (H'), C; Simpson's dominance index (1-D) and D; Evenness index

3.3.2.3 Seasonal trends in overall fish diversity indices

The analysis of fish diversity indices across all seasons in the Dikhu River revealed distinct temporal patterns, reflecting the dynamic nature of the riverine ecosystem as represented in Table 3.5. The maximum number of species richness across seasons was recorded in the post-monsoon period (26 taxa), followed by the pre-monsoon period (25 taxa). Monsoon season had the least species richness (21 taxa), probably due to increased water flow and sediment.

The fish population was increased significantly in post-monsoon (891) and pre-monsoon (798) seasons. However, in the monsoon, the fish population was reduced significantly (407), and winter was moderate (477). This means that the post-monsoon period is generally tied to restoring fish populations after the disruptions of the monsoon season on community structure.

The diversity trends were similar for both the Shannon-Wiener diversity index (H') and the Simpson's dominance index (1-D). The highest diversity was recorded during post-monsoon (2.912) and pre-monsoon (2.842), indicating a more complex and stable fish community structure than experienced during the monsoon (H' = 2.497) and winter (H' = 2.613) periods, when habitat loss and/or ecological stress are likely factors contributing to high total densities of fishes due to reduced habitat and community population density.

Simpson's (1-D) also showed significant seasonal changes, as with the other indices. The dominance was highest in post-monsoon (0.936) and pre-monsoon (0.930) and lowest in monsoon (0.892), further indicating the destabilising effect of monsoon discharge on fish assemblages.

The post-monsoon (0.707) and the pre-monsoon (0.686) demonstrated higher evenness levels than the monsoon (0.579) and the winter (0.593). This shows that the communities are more evenly structured after the ecological recovery period than during the monsoon, when some species may be more abundant. Seasonal variation in fish assemblage diversity across all sampling sites is represented in Figure 3.17.

Overall, these seasonal dynamics highlight the resilience and adaptability of fish communities in the Dikhu River, with diversity peaking in post-monsoon and pre-monsoon seasons, and declining during monsoon and winter. The patterns emphasize the critical role of hydrological cycles in shaping community structure and

highlighting the importance of conservation strategies for sustaining riverine biodiversity.

Table 3.5. Seasonal dynamics of fish diversity indices in the Dikhu River

Diversity indices	Pre-monsoon	Monsoon	Post-monsoon	Winter
Taxa (S)	25	21	26	23
Individuals	798	407	891	477
Shannon - Wiener diversity index (H')	2.842	2.497	2.912	2.613
Simpson's dominance index (1-D)	0.930	0.892	0.936	0.901
Evenness (e^H/S)	0.686	0.579	0.707	0.593

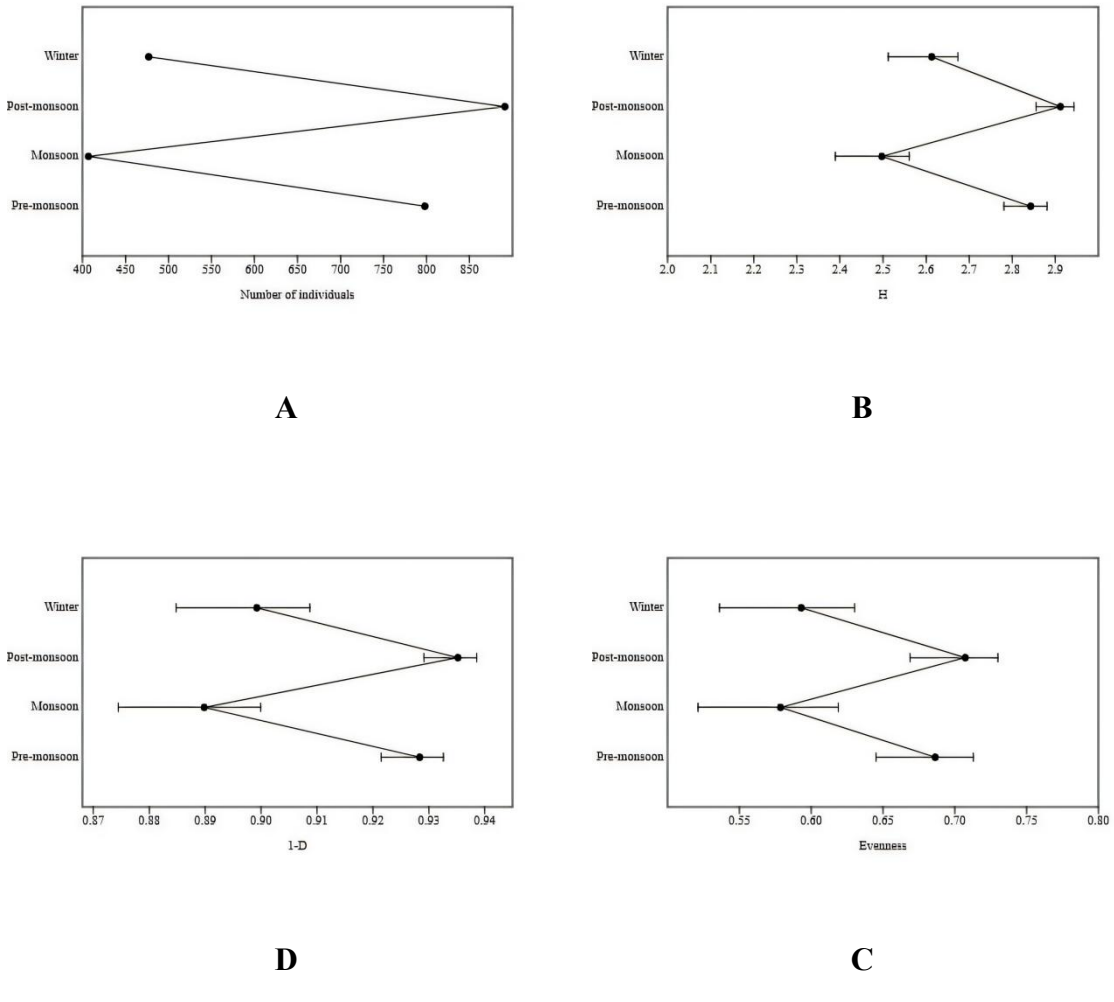

Figure 3.17: Graphical representation of seasonal variation in fish assemblage diversity across all stations combined in the Dikhu River. A; Number of individuals, B; Shannon-Wiener diversity index (H'), C; Simpson's dominance index (1-D) and D; Evenness index

3.3.2.4 Fish community structure in the Dikhu River: CCA and Bray-Curtis analysis

The Canonical Correspondence Analysis (CCA) revealed distinct patterns in the fish community structure of the Dikhu River in relation to seasonal and physicochemical variables. Analysis of eight environmental parameters revealed clear species separation along two axes. In particular, three of the species studied (i.e. *Botia rostrata*, *Tor putitora*, and *Garra naganensis*) were positively correlated with environmental factors that comprise Axis 2 (air temperature, water temperature, and TDS). Conversely, *Schistura savona* and *Glyptothorax indicus* were negatively correlated and indicative of a preference for cooler water (i.e. lower velocity) conditions typical during winter and pre-monsoon seasons along Axis 1. Furthermore, a seasonal pattern existed with respect to clustering between pre-monsoon and winter (e.g. *Opsarius barna, Opsarius bendelisis,* and *Garra birostris*) at the negative end of Axis 1 and post-monsoon and monsoon (e.g. *Channa melanostigma, Psilorhynchus homaloptera*, and *Danio dangila*) at the positive end. Additionally, the environmental factors pH, dissolved oxygen (DO), alkalinity, and velocity projected at strong vectors, indicating that these variables significantly influenced community composition. The remaining species were clustered near the origin; therefore, there was little distinction between the various environmental parameters associated with these species. The Canonical Correspondence Analysis (CCA) triplot illustrating the relationships among fish species abundance, environmental variables, and seasonal variations is presented in Figure 3.18.

To determine the similarity percentage of fish assemblages between the sites, Bray-Curtis similarity analysis was performed. The results reveal distinct patterns of community similarity across the surveyed sites in the Dikhu River. Two main clusters emerged, reflecting distinct ecological affinities among the sites. The first major cluster comprised four stations; Longsa, Chakba, Longkong, and Alaphumi. Within this group, Longsa and Chakba formed the closest pair, exhibiting a notably high similarity (approximately 0.75), suggesting a strong overlap in species composition and relative abundance. Longkong was subsequently linked to this pair, followed closely by Alaphumi, indicating that these sites share a common ecological structure, likely shaped by similar habitat conditions or environmental influences. In

contrast, the second cluster included Salulamang and Sumi Setsü, which formed a distinct subgroup with considerable dissimilarity from the first cluster. Their separation underscores notable differences in fish assemblage structure, potentially due to varying habitat types and hydrological regimes. Figure 3.19 represents dendrogram from cluster analysis of sampling sites, illustrating fish assemblage composition patterns using Bray-Curtis similarity.

Bray-Curtis similarity analysis of seasonal fish assemblages revealed two distinct clusters, reflecting temporal shifts in community structure within the Dikhu River. Pre-monsoon and Post-monsoon seasons formed the closest cluster (similarity ~0.85), suggesting a continuity in ecological conditions that support comparable fish communities. In contrast, Monsoon and Winter formed a separate group, suggesting a shared response to conditions like flooding during the monsoon and cold, low water level in winter. These seasonal patterns highlight how fish communities adapt to changing river conditions, emphasizing the importance of understanding seasonal shifts for effective biodiversity management. Figure 3.20 depicts seasonal variations of fish diversity, generated through Bray-Curtis similarity analysis.

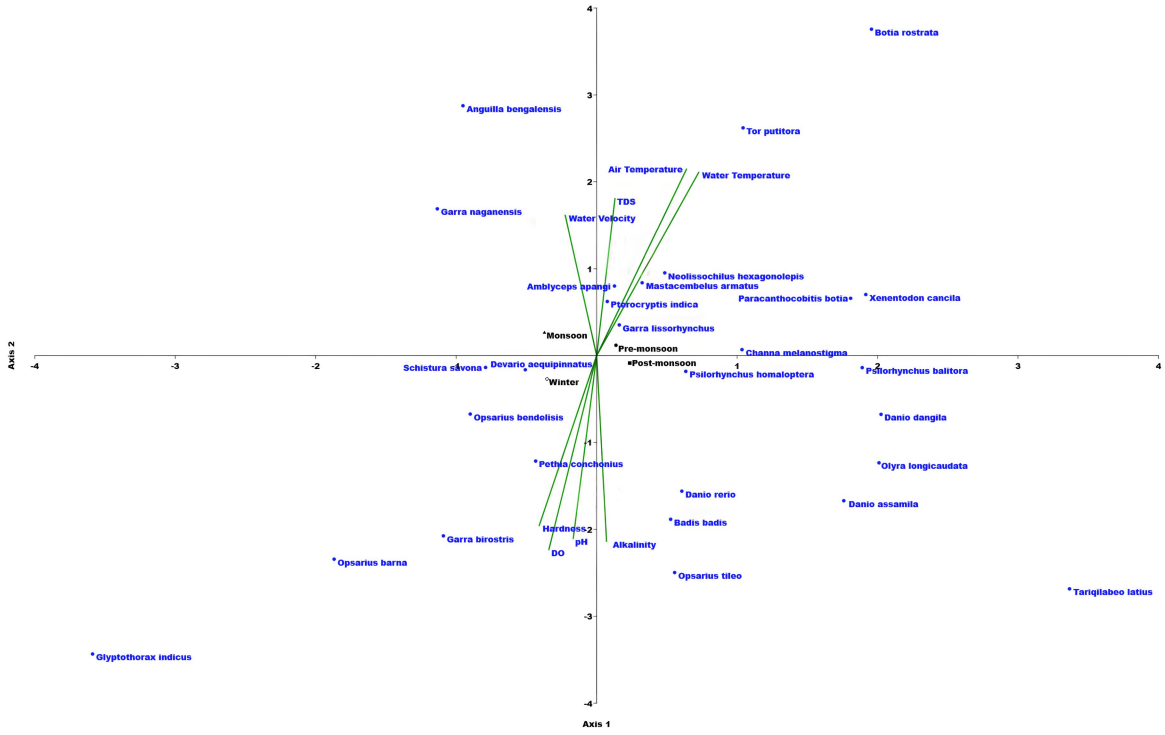

Figure 3.18: Canonical correspondence analysis (CCA) ordination triplot depicting relationships between fish species abundance, environmental variables, and seasonal variations in the Dikhu River

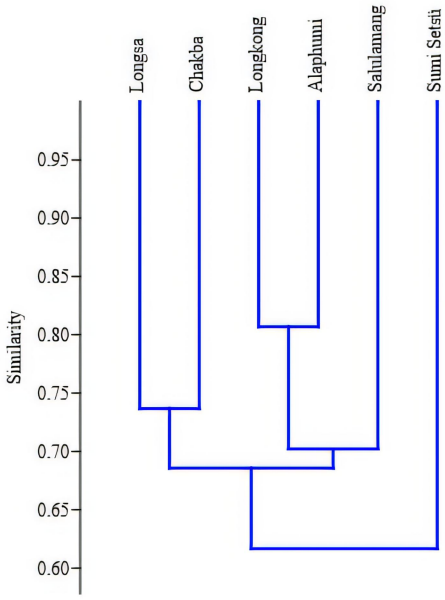

Figure 3.19: Dendrogram cluster analysis of sampling sites based on fish assemblage composition using Bray-Curtis similarity

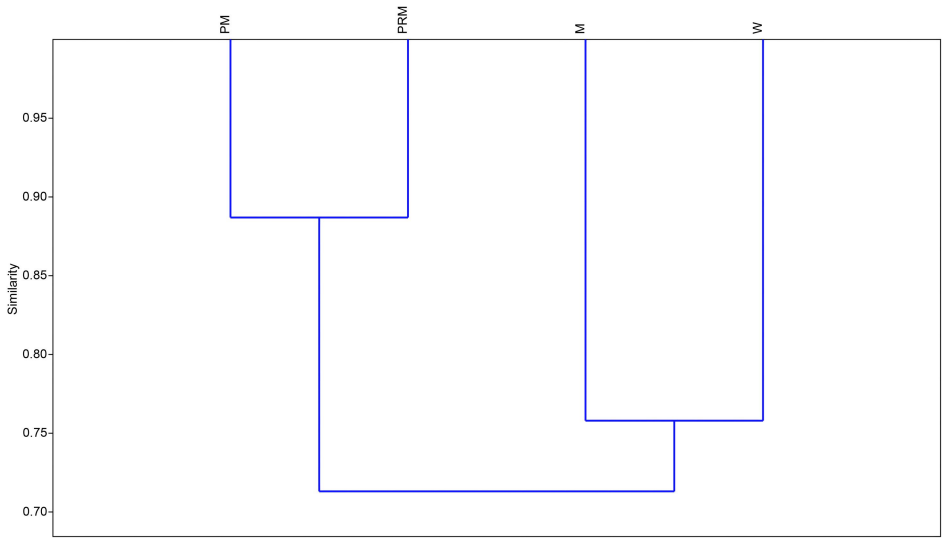

Figure 3.20: Dendrogram of seasonal clusters (PM; Post-monsoon, PRM; Pre-monsoon, M; Monsoon, W; Winter) based on Bray-Curtis similarity matrix reflecting fish community structure

3.3.3 Traditional fishing techniques

The Ao and Sumi tribes of Nagaland, drawing from generations of indigenous knowledge, primarily rely on traditional fishing techniques for their subsistence, reflecting a profound bond with the river and its resources. Different traditional gears and techniques are presented in Table 3.6 and Figure 3.21 respectively.

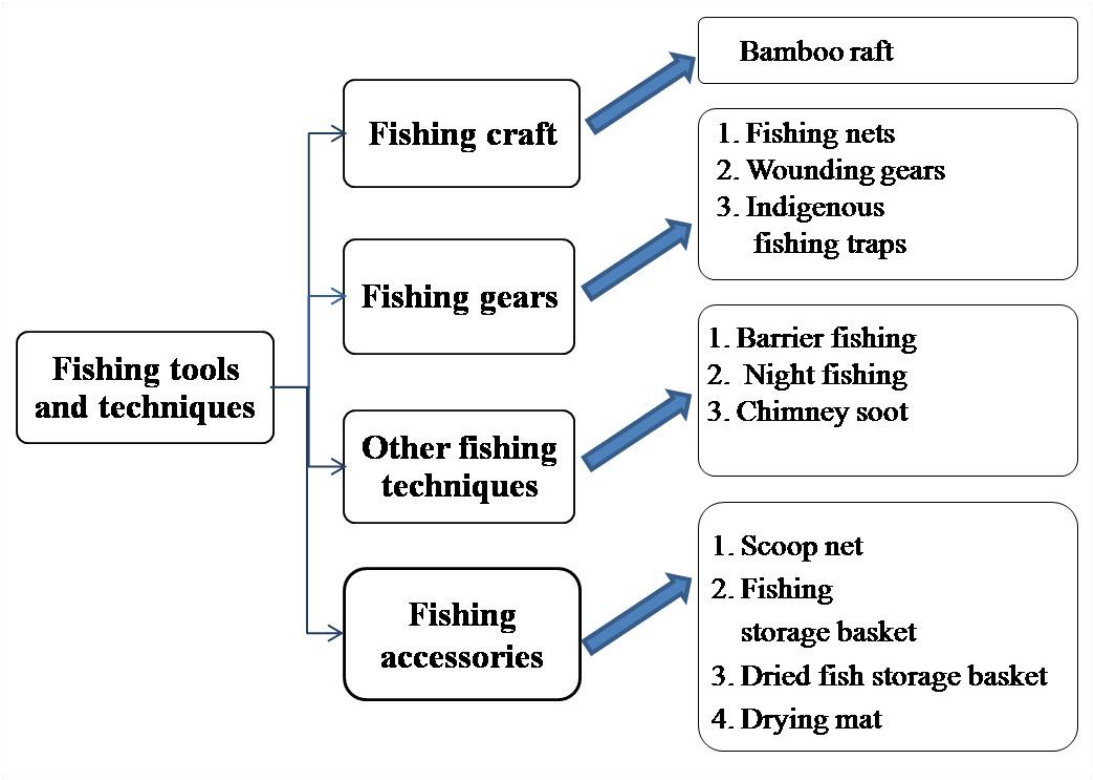

Figure 3.21: Flow diagram representing different fishing techniques practiced by Ao and Sumi tribes of Nagaland

Table 3.6: Traditional fish-catching gears / accessories practiced by Ao and Sumi tribes in Dikhu River, Nagaland, India.

Fishing gears/ accessories used	**Local name (Ao)**	**Local name (Sumi)**	**Use in season**	**Longevity (years)**	**Material used in fabrication**	**Fishing efforts**
Fishing nets						
Gill net	Fasi jal	Akhame	Post and pre-monsoon in shallow water	3-5 yrs	Nylon/polyester	Two or more
Cast net	Zütsük	-	Whole season	5-6 yrs	Cotton/nylon, iron, or stone weights	Single
wounding/ Impaling gears						
Hooks and lines	Porki/ Bulchi	Porki/ Bulchi	Summer months	3-5 yrs	Sharp iron hook, nylon twine, bamboo/wooden pole	Single
Harpoon	Anguakatsü,	-	Whole season depending on visibility	3-5 yrs	Barbed iron, bamboo /wooden pole, ropes/rubber	Single
Fishing Spear	-	Angu	Summer months	3-5 yrs	Wooden stick/sharp iron tip	Single

Indigenous fish traps						
Tubular-shaped trap	Talu-Tatu kago	Kitsakhu	Shallow waters in summer months	2-3 yrs	Bamboo splits, nylon thread/cane Strings	Single
Funnel-shaped trap	Mashiba,	Mushohe	Monsoon months in rivers and paddy fields	1-3 yrs	Bamboo splits	Single
Conical-shaped trap	Shiba	Akhu	Summer months in mild water current	2-3 yrs	Bamboo splits	Single
Fishing accessories						
Scoop net	Tsüteptsü	Akhasho	Whole season	2-3 yrs	Nylon/cotton twine, plastic/bamboo /metal ring, bamboo/wood en pole	Single
Fishing basket	Angamakang	Shibakhu	Whole season for fish storage	2-3 yrs	Bamboo strips, stings	Single
Dried fish storage basket	Tsükden	Aqhupu	Whole season	2-3 yrs	Bamboo slits/twine	Single
Fish drying mat	Makang	Aqhesu	Whole season	1-2 yrs	Bamboo splits	Single

3.3.3.1 Fishing craft

Traditional fishing crafts, particularly bamboo rafts, serve as vital modes of transportation for local fishermen, enabling them to access their preferred fishing grounds with relative ease. The bamboo raft, a hallmark of indigenous creativity, is constructed primarily from long bamboo stems, carefully selected for uniformity in length and bound tightly into a mat-like frame using bamboo strings or ropes as presented in Figure 3.22a. The typical raft is composed of 18 - 50 bamboo poles, their thicker ends aligned toward the stern, and secured with coir or jute ropes. These rafts generally span 3 - 5 m in length and 1.5 - 2.0 m in width, dimensions adjusted according to the water current and the intended use. A long bamboo pole serves as an oar, allowing the fisher to propel and steer the craft across calm waters. While labor-intensive to maneuver, these rafts are remarkably durable, often lasting one to two years, and are particularly suited for use in stagnant rivers and floodplain reservoirs. The use of such traditional crafts is not merely a matter of convenience; it embodies a deep-rooted knowledge of local materials, hydrological patterns, and the rhythms of riverine life, transmitted across generations.

3.3.3.2 Fishing gears

In this study, fishing gear refers to traditional, non-mechanized tools used for harvesting fish, reflecting the adaptability of local communities. In the Dikhu River basin, a variety of such gears such as gill nets, cast nets, traps, and hooks are employed across paddy fields, streams, and main river channels as illustrated in Figures 3.22b. 3.22c, 3.22e, 3.22f, 3.22g, 3.22h, 3.22i and 3.22j. Fishing gear selection depends on fishing skills, target species, water depth, and seasonal river conditions, reflecting the use of traditional ecological knowledge to make practical decisions that improve fishing efficiency and help maximise catches.

3.3.3.2.1 Fishing nets

Gill nets

The multitude of purposes for which gill nets are utilised is evident by their frequent use throughout the region in paddy and aquatic riverine systems. The mesh size is important because it determines which fish are caught. The locals prefer gill nets because they are inexpensive, easy to function, and gear maintenance is simple. The net is usually rectangular in shape and hung vertically like a wall across the water.

On the surface, a head rope is buoyed by floats to increase the net's visibility above the water surface. On the other hand, the foot rope is positioned below the surface in such a way that it is weighted with stones or mud to ensure that the net remains stable. In most cases, fishermen will leave them in place overnight after placing them across the migration routes that fish use. These poles are typically made of bamboo or wood. In other words, they are passive gear, which means that the catch is dependent on fish swimming into them as they move along their typical routes. Common catches include *Pethia sps., Garra sps., Devario spp., Neolissochilus sps., Opsarius sps.,* and various catfish.

Cast nets

Among local fishing communities along the Dikhu, cast netting is one of the most widely practised methods. The nets are cone-shaped, woven from nylon or cotton yarn. The net is cast with a wide rotational motion, spreading flat across the water surface before submerging and encircling the fish below. Typically lasting 5 to 6 years, they measure about 1.2 to 2.5 metres in diameter, with mesh sizes ranging from 20 to 40 mm. Casting a net is a skill that needs a lot of expertise and practice. Cast nets are cheap, easy to use, adaptable to shallow waters, and can be used year-round and at all hours. They are particularly effective in catching mahseer, carps and catfishes.

3.3.3.2.2 Wounding fishing gears

Hooks and lines

This gear is one of the oldest and most durable fishing techniques and is deeply anchored in Indigenous and modern practices. This method depends on understanding the feeding behaviour and preferences of target species. The gear is a long bamboo rod, plastic pole or any suitable wooden stick with a nylon or fibre thread attached at one end. The fishing line is fitted with a metallic hook of varying sizes, securely fastened to the twine. In some cases, a simple handline, without a rod, is employed. The length of the pole typically ranges from 1.5 to 3.0 meters, while the hook, usually made of iron, is sharp-edged and curved for effective entanglement. For stability and ease of operation in running waters, floats and weights may be added. Baits such as small fish, meat pieces, insects, earthworm, rice bran, flour, frogs, or crabs are used to attract fish. The fish, in attempting to swallow the bait,

becomes hooked, and is retrieved by pulling the line. This method allows for the selective targeting of species, from bottom-dwelling fish to game species like trouts, carps, and minnows. Hooks and lines are widely favored for their simplicity, low environmental impact, and accessibility making them suitable for fishers of all ages. With proper maintenance, the gear can last for 3 - 5 years, reflecting its enduring utility in both small-scale and recreational fishing contexts.

Harpoon

The harpoon is a traditional fishing gear used to impale, grapple, or wound fish, primarily targeting bottom-dwelling species. It consists of a bamboo or wooden pole (0.9 - 1.2 m) fitted with 7 - 12 sharp barbed iron rods (0.05 - 1.0 m) at the tip, connected to an elastic cord for propulsion. Operated by extending and releasing the elastic band, the harpoon is suited for shallow waters and is commonly used to capture species like carps, mahseer, and catfishes. This method reflects the ingenuity and precision of indigenous fishing practices.

Fishing spear

The fishing spear is a time-honored tool in tribal fishing traditions, featuring a long wooden pole with a sharp, pointed tip made from metal or animal bone. Used primarily for targeting larger fish, this method demands skill, patience, and extensive knowledge of the riverine environment, exemplifying the enduring connection between traditional fishers and their aquatic ecosystems.

3.3.3.2.3 Indigenous fishing traps

Tubular-shaped trap

Crafted from split bamboo bound with nylon threads or cane strings, the tubular-shaped trap (0.9 - 1.2 m length; 0.3 - 0.4 m width) is ingeniously designed with two inward-facing valves along its sides. These valves act as entry points for fish but restrict their exit, creating an efficient one-way system. Baits such as earthworms or meat pieces are often used to attract fish or shellfish. Typically set horizontally in shallow waters and secured with stones and leaves for camouflage, the trap is left for a day or overnight along the water current. Fish catch varies depending on the season and species availability. These traps, made from readily available, eco-friendly materials, are cost-effective and reflect the ingenuity of local fishing communities.

Funnel-shaped trap

The funnel-shaped trap, woven from bamboo splits (0.9 - 1.6 m length; 0.15 - 0.3 m mouth diameter), features a wide conical opening that gradually narrows into a tubular cod-end. Simple yet effective, it requires only one or two operators. Typically positioned against the water current, whether at river mouths or in waterlogged paddy fields during the monsoon, the trap guides fish such as *Opsarius sps., Puntius sps., Clarias batrachus, Channa sps., Mastacembelus armatus,* and prawns into its narrowing end. The design includes detachable ropes for easy retrieval of fish. During the summer, when water levels rise, these traps are set across small water gaps, forming a passive yet reliable means of capture. Their efficiency, simplicity, and low cost underscore their enduring value in traditional fisheries.

Conical-shaped trap

This elongated, tubular trap (1.5 - 2.0 m length; 0.1 - 0.2 m mouth diameter) is crafted from split bamboo, with a triangular rim enclosing its mouth. It is typically set in rivers or adjacent paddy fields during the monsoon season and left undisturbed for a day or more. The trap is positioned against the current, passively collecting species such as *Puntius sps., Channa sps.*, and catfishes. These low-cost traps, built from locally available materials, showcase the resourcefulness of indigenous fishers who have long adapted their techniques to seasonal changes and riverine dynamics.

3.3.3.3 Other fishing techniques

3.3.3.3.1 Barrier fishing techniques

Ahet (Ao) / Apili (Sumi)

This traditional technique involves temporarily partitioning a section of a river from the main channel to create an enclosed pocket or pool. The enclosure is constructed using stones, leaves, shrubs, logs, or twigs, forming a barricade. After a few hours, water is gradually drained, and fishes, often seeking refuge among stones, are caught by hand as displayed in Figure 3.22n. Occasionally, crude plant-based toxins are introduced to stun the fish. The technique fosters a communal spirit, with 10 to 50 or more participants of varying ages working together. Catches mainly include loaches, minnows, barbs, and catfishes.

Züra (Ao) / Aku (Sumi)

In this method, an enclosure is created using bamboo, stones, or tarpaulin in a selected river section. Conical bamboo traps are strategically placed at the opening of the enclosure to intercept fish attempting to escape. Plant-based stupefying agents, typically from species such as *Juglans regia*, *Acacia pennata*, or *Schima wallichii*, are applied to stun the fish, which are then collected using scoop nets, baskets, or by hand as presented in Figure 3.22o.

Tzüyok (Ao) / Aichivu (Sumi)

Tzüyok, meaning "to set free water" in the Ao dialect, is an ancient, community-based fishing tradition passed down through generations. Rooted in cultural beliefs, it is often performed as a prayer to ward off misfortune or illness, blending spiritual reverence with practical fishing. On an appointed day, the village council decides the construction site, date, and requirements. The communal effort may involve 20 - 100 people, depending on the scale. Barriers are constructed across fish migration routes using rocks, bamboo, and wood, allowing fish to accumulate over days before harvesting as depicted in Figure 3.23a. Traditional plant-based piscicides (*Schima wallichii*, *Acacia pennata*, *Juglans regia*) are sometimes used to stupefy fish as illustrated in Figure 3.23d. The catch is harvested using spears, cast nets, daos (traditional machetes), scoop nets, or handpicking. The fish are then equitably shared among the community, reinforcing social bonds.

3.3.3.3.2 Night fishing

Night fishing is a widespread practice, especially during the summer months. It typically involves groups of three or more fishers operating under clear skies and calm waters. By using fish-aggregating devices such as lanterns or battery torches for illumination, fish are lured toward the light and then captured with spears, harpoons, or cast nets.

3.3.3.3.3 Chimney soot fishing

An age-old technique, chimney soot fishing involves mixing mud and soot in equal proportions and dispersing it into water bodies. The mixture temporarily blinds the fish, making them vulnerable to capture using scoop nets or baskets, as illustrated in Figure 3.23b. This reliable method demonstrates the ingenuity of traditional fishing knowledge passed down through generations.

3.3.3.4 Fishing accessories

Scoop net

Scoop nets, an integral part of traditional fishing practices, are designed in various shapes, rectangular, triangular, or circular, based on local utility. The frame is constructed from a metal ring or indigenous materials such as bamboo or jute, onto which a net of fine mesh (nylon, cotton, or mosquito net) is affixed as illustrated in Figure 3.22d. The nets are fitted to a wooden or metal handle for easy use, and are a common sight in the shallow waters of the region. It is simple, accessible, and used year-round by men, women, and even children, they allow fishers to catch minnows, prawns, *Barilius*, *Channa* spp., and other small fish, depending on the mesh size (1 - 15 mm). These nets can typically last for 2 to 3 years.

Fishing storage basket

This basket is crafted from interwoven bamboo strips, is designed in a shape reminiscent of a traditional earthen pot and serves as a convenient fish storage container during fishing as depicted in Figure 3.22k. Typically worn around the waist using a string or rope, it allows fishers to store their catch, small fishes, crabs, and frogs, while engaged in fishing. Beyond utility, this basket holds cultural significance, connecting generations through its continued use and reflecting the symbiotic relationship between humans and their rivers.

Dried fish storage basket

Another important indigenous innovation, the dried fish storage basket, is woven from split bamboo, as shown in Figure 3.22l. After fish are smoked over fire or sun-dried, they are stored in these baskets for long-term preservation. With proper care, these baskets can last for 2 - 3 years or more, embodying a low-cost, eco-friendly solution for fish storage that supports food security in rural communities.

Fish drying mat

The fish drying mat, woven from interlocking bamboo strips, is an essential accessory for preserving fish. These mats, varying in size depending on local needs, are used for sun-drying or smoking fish in both raw and cooked forms, as depicted in Figure 3.22m. Beyond functionality, they symbolize the resourcefulness and deep-rooted connection of fishing communities to their natural environment, sustaining livelihoods and cultural heritage.

3.3.3.5 Detrimental fishing

Dynamite fishing

Dynamite fishing, though illegal and destructive, is still practiced in certain regions by local communities who produce blast sticks using gunpowder, packed into elongated, cylindrical paper tubes as shown in Figure 3.23c. These improvised explosives, sold in bundles of three at prices ranging from ₹350 to ₹500 or more depending on location, are ignited using a lighter and thrown into the water from a safe distance. Upon detonation, the explosion stuns or kills fish, which are subsequently retrieved by hand from the water surface. This technique is particularly effective for capturing species such as large minnows and carps, especially in areas where rocky or unstable substrates hinder the use of conventional nets or other fishing gear. However, the indiscriminate destruction caused by such practices poses grave threats to aquatic ecosystems, depleting fish stocks, damaging riverbeds, and endangering non-target species.

Use of chemicals in fishing

Another harmful practice involves the application of synthetic chemicals, such as lime, bleaching powder, or pesticides, to water bodies to stupefy fish for easier capture. While such approaches could result in immediate results, they exert detrimental impacts on aquatic biodiversity, contaminating ecosystems and disrupting delicate ecological balances.

Electric fishing

Electric fishing, though often justified for scientific research or population management, has seen a concerning rise in informal use across various regions. This method operates by transmitting an electric current into the water through a metal wire or plate powered by a charged battery, momentarily stunning fish as depicted in Figure 3.23e. The immobilized fish are then collected using scoop nets, baskets, or by hand while they remain in shock for a brief period. Although this technique offers advantages, being cost-effective and capable of capturing live specimens, its unchecked use, particularly in fragile riverine ecosystems, can result in significant ecological damage, altering fish behavior, and threatening long-term sustainability.

Figure 3.22: Traditional fishing crafts / gears / accessories. (a) Bamboo raft; (b) Gill net; (c) Cast net; (d) Scoop net; (e) Hooks and lines; (f) Tubular-shaped trap; (g) Funnel-shaped trap; (h) Conical-shaped trap; (i) Tip of harpoon; (j) Harpoon; (k) Fishing basket; (l) Dried fish storage basket; (m) Fish drying mat; (n) Ahet (Ao) / Apili (Sumi) fishing; and (o) Züra (Ao) / Aku (Sumi) fishing

Figure 3.23: Miscellaneous fishing techniques practiced by Ao and Sumi tribes. (a) Tzüyok (Ao)/ Aichivu (Sumi) fishing; (b) Chimney soot used in fishing; (c) Blast stick; (d) *Juglans regia* and (e) Electrical fishing equipment

3.4 Discussion

Freshwater fish represents one of the most threatened taxonomic groups globally (Darwall and Vie, 2005), largely due to their heightened sensitivity to both quantitative and qualitative alterations in aquatic habitats (Lafaille *et al.,* 2005). The dominance of cypriniformes in the fish assemblages of the Dikhu River aligns with findings from other river systems across Northeast India (Ahmed *et al.,* 2023; Chetry *et al.,* 2023; Singh *et al.,* 2024). This pattern can be attributed to the cypriniformes remarkable evolutionary adaptations to these specific freshwater environments. Their capacity to endure variable water conditions, combined with diverse feeding habits, confers a competitive advantage over other species in these dynamic ecosystems. Furthermore, their reproductive strategies and efficient utilization of available resources underpin their success in Indian rivers, reinforcing their critical role in the ecological fabric of these freshwater systems (Mondal and Bhat, 2020).

Where fish settle along a river is the product of abiotic, biotic, and evolutionary factors acting together to set the ecological character of a particular habitat (Pelicice *et al.,* 2015; Bose *et al.,* 2019; Satpathy e*t al.,* 2021; Alam *et al.,* 2024). Against that backdrop, at least 21% of the species recorded from the Dikhu River appear to be declining, a sign of the environmental stress and human pressure that make these systems easier to degrade (Nel *et al.,* 2009; Goswami, 2012; Kechu *et al.,* 2021). When biodiversity is lost, the freshwater ecosystem suffers, as well as the fisheries and cultural practices that are built around these fish. A few species are already at real risk despite the general abundance in the region. *Botia rostrata* is listed as vulnerable and *Tor putitora* as endangered, while *Anguilla bengalensis* and *Neolissochilus hexagonolepis* are near threatened. *Anguilla bengalensis* was rarely observed during the study, which fits its elusive nature: it shelters in the hollows of large boulders, and those were scarce at the sites surveyed. Its tough and slippery body also makes it even more difficult to be taken in a cast net as reported from Arunachal Pradesh (Taro *et al.,* 2022). The scarcity of this species serves as a warning, indicating an immediate need for targeted protection.

According to Nebeshwar and Vishwanath (2017), the genus *Garra* exhibits a remarkable degree of morphological diversity, particularly with regard to the shape of its snout. In the present study, specimens of *Garra birostris* collected from the

study area displayed the distinctive features of the 'proboscis species-group', notably a bi-lobed proboscis with a prominent transverse lobe, in line with descriptions by Nebeshwar and Vishwanath (2017). *Garra birostris*, a rheophilic cyprinid, closest congeners consist of *Garra biloborostris* (Roni and Vishwanath, 2017) and *Garra chathensis* (Ezung *et al.,* 2020a), share the presence of a pronounced bilobed proboscis, a hallmark of this group. However, these species are reliably distinguished by the morphology of the acanthoid tubercles; *G. birostris* possesses large tri- or tetra-cuspid acanthoid tubercles on each lobe, *G. biloborostris* has three per lobe, while *G. chathensis* bears large bicuspid acanthoid tubercles. The identification of *G. birostris* in the present study was confirmed by the presence of tri- to tetra-cuspid acanthoid tubercles on each lobe, along with a characteristic black spot at the upper angle of the gill opening. Intriguingly, minor variations from the original species description were noted, including a reduced dorsal fin ray count of ii8½ (vs. iii8½) and anal fin rays of ii5½ (vs. iii5½). These subtle morphological differences may reflect the influence of localized habitat conditions, such as variations in water physico-chemical parameters and climatic factors, suggesting the species remarkable adaptive plasticity in response to its environment.

The fish community was dominated by *Devario aequipinnatus* (15.55%), *Opsarius bendelisis* (11.39%), *Garra naganensis* (9.52%), *Amblyceps apangi* (7.73%), and *Schistura savona* (6.61%), as reflected by their relative abundance. Similar patterns were observed in the hill streams of Karbi Anglong district, Assam, where *Devario aequipinnatus* (5.09%), *Opsarius bendelisis* (4.65%), and *Schistura skimaiensis* (4.22%) were reported as the most abundant species (Valentina *et al.,* 2015). Notably, fishing yield peaked during the post-monsoon season, likely due to the receding water levels concentrating fish populations and thereby enhancing catchability. This seasonal dynamic reflects the fragile balance between natural hydrological processes and the survival strategies of riverine species, suggesting the need for urgency of safeguarding such vulnerable ecosystems.

The Shannon-Wiener diversity index classifies communities based on diversity values; indices below 1 suggest stressed and polluted environments, values between 1 and 2 indicate moderate ecological balance, and values above 3 reflect a stable, thriving ecosystem conducive to species survival (Stub *et al.,* 1970). Consistent with

these thresholds, the present study recorded the highest fish diversity during the post-monsoon season, while minimum diversity was recorded in the monsoon. Similar seasonal patterns were reported by Dey and Sarma (2018) in the Manas River, where the overall Shannon-Wiener diversity index reached 3.86. Satpathy et al. (2021), also documented comparable findings in the Subansiri River of Arunachal Pradesh, with an H' value of 2.76. The Simpson index, known for its sensitivity to dominant species and lower sensitivity to overall species richness (Islam and Yasmin, 2018), further emphasized the dominance of certain species within the Dikhu River community. Evenness values across seasons indicated a relatively equitable distribution of species: the highest evenness was recorded in the post-monsoon season (0.707), while the lowest occurred during the monsoon (0.579). These findings align closely with the evenness indices reported by Kumar et al. (2020) in the Ghaghara River, which ranged from 0.754 to 0.847. Every sampling site reached its highest point of species richness and ichthyofaunal diversity during the post-monsoon season. The likely reason is the monsoon itself brings in heavy rain and flooding, mixing the river water from different sources and helping fish disperse, and also migratory fish moving up into the Dikhu River from larger rivers to spawn and breed probably adds to the count as well.

The CCA plot brings out how closely fish abundance in the Dikhu tracks the seasonal shift in environmental conditions, and the relationship exhibits considerable complexity. During the pre-monsoon and winter seasons, characterized by cooler water temperatures and high dissolved oxygen levels, *Schistura savona* and *Glyptothorax indicus* emerged as the predominant species, distinctly favouring these conditions. This interprets how the seasonal shifts can predict where particular fish thrive. The pattern reverses for other species like *Tor putitora, Botia rostrata,* and *Garra naganensis* correlate positively with higher air and water temperatures and high total dissolved solids, and their abundance is notable mainly in the monsoon and post-monsoon seasons. *Neolissochilus hexagonolepis* is an exception to both, positioned centrally in the ordination plot, indicating its status as a widely distributed species, showing its adaptability to various habitats rather than being confined to a specific location. Work from other parts of Northeast India is consistent with the findings reported here. Turbidity, dissolved oxygen, water temperature, and pH were

the key determinants of fish community composition on the Kameng River, with Neolissochilus hexagonolepis recorded as the most abundant cyprinid across sampling sites (Dey *et al.,* 2021). Studies in the Diyung River found that Tor putitora and Schistura fasciata were concentrated in sections with high dissolved oxygen and swift waters, further supporting the idea that hydrological conditions are central to how fish communities are organised in hill-stream systems (Ahmed *et al.,* 2023).

The Bray-Curtis cluster analysis provides a different perspective on the same findings, revealing distinct spatial and seasonal shifts in community structure across the Dikhu. As previously discussed, the composition of the assemblage varies based on both location and the time of year. The strong similarity (~0.89) between pre-monsoon and post-monsoon seasons shows that the fish community consistently adapts to the progressive change of the environment. However, the monsoon and winter are lumped together, suggesting that extreme situations such as flooding and cold water can result in less diversified fish communities. The index was quite high between the stations of Longsa and Chakba (~0.75) suggesting that the two stations might have comparable ecology, which could be due to similar habitat characteristics or environmental conditions. Similarly, the clustering of Longkong and Alaphumi with the other stations shows that all four stations have similar ecological circumstances and can support their habitats. Other studies of rivers in Northeast India have shown similar seasonal tendencies. For example, Dey et al. (2021) documented pronounced seasonal variations in fish assemblages in the Kameng River, attributing the shifts to changing physicochemical conditions and habitat variability. Similarly, Baidya (2022) observed that fish diversity in the Chathe River was closely linked to seasonal changes in phytoplankton abundance and water quality. Furthermore, Kundu et al. (2014) highlighted that in interconnected rivers of eastern India, seasonal shifts in fish assemblages were influenced by variations in dissolved oxygen, temperature, and nutrient levels. Variations in findings across studies often reflect from varying locations, survey times, and sampling methods, reflecting the complex nature of aquatic ecosystems.

Field surveys and conversations with local communities revealed a growing unease about the declining fish diversity in the Dikhu River. During the study period, villagers were advised through awareness programs to refrain from destructive fishing practices, particularly the use of dynamite, lime, bleaching powder, and other harmful methods, which, despite offering quick returns, disrupt the ecological balance of the river.

Fish is a staple protein in Nagaland and is consumed either smoked, sun-dried, or cooked with local seasonings and herbs. Fishing is also woven into Naga cultural, religious, and social life. The Ao and Sumi still fish with traditional gear and techniques, and the practice matters to foster community bonds and cultural continuity and not just for sustenance.

These practices closely mirror those recorded in the Nagaon district of Assam (Sarkar and Ponniah, 2006). Seasonal variations influence fishing techniques, with hooks and lines predominantly used in summer when water depths favor the capture of larger species. Community fishing events, including impoundment and barricade fishing, remain a cherished tradition among Ao, Sumi, and other Naga tribes, fostering collective responsibility and cultural continuity.

However, the decline in fish populations and diversity, largely driven by destructive practices has raised growing concerns among local communities. In response, the Ao and Sumi tribes have initiated bans on harmful fishing methods across several stretches of the Dikhu River, demonstrating a commendable commitment to conserving aquatic biodiversity. The continued use of plant-based ichthyotoxin, a method also documented in indigenous cultures worldwide (Van Andel, 2000), persists in some areas of Nagaland.

An improvement in catches, livelihoods, and biodiversity could be achieved by combining indigenous gear with modern technology, provided that the conditions are favorable. This would be preferable to the alternative of trading one off against the others.

Fish matter in this region both ecologically and culturally, yet fish diversity remains understudied. As pressure on the environment grows, taxonomy, genetic studies, and traditional knowledge all require more attention. Closing those gaps is what will make conservation work. Understanding how species interact and how climate

change and pollution affect them, supporting sustainable fisheries, food security, and cultural continuity, will add more knowledge to the scientific database.

CHAPTER 4

Bionomic features of *Neolissochilus hexagonolepis*

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4.1 Introduction

4.2 Materials and methods

4.3 Results

4.4 Discussion

Parts of this chapter have been published in WOS/SCOPUS indexed research journal

4.1 Introduction

Neolissochilus, a genus under the family cyprinidae, holds substantial biological, ecological, and cultural significance and is renowned as an endemic game fish in South Asia (Kottelat, 2013). This genus has been reported across several Asian countries, including India, China, Bhutan, Nepal, Pakistan, Bangladesh, Myanmar, Indonesia, Malaysia, Vietnam, Thailand, and the Malay Archipelago. Among the species within this genus, *Neolissochilus hexagonolepis*, commonly referred to as the chocolate mahseer, stands out as a flagship species inhabiting the river systems of South and Southeast Asia, particularly in India, Nepal, Bhutan, and surrounding regions (Laskar and Das, 2016). Within India, the genus *Neolissochilus* is widespread across the major river systems and does particularly well in the coldwater streams of the Himalayan foothills and the hill streams of the Northeastern states, more specifically Meghalaya, Assam, Arunachal Pradesh, Sikkim, Manipur, Nagaland, Mizoram, and Tripura, which together make up the Northeast region of India (Vishwanath, 2021; Debnath *et al.,* 2024b).

Neolissochilus genus are cyprinids with moderately large scales and a streamlined and elongated body for life in fast, clear mountain rivers. Because the genus is ecologically important and sensitive to human disturbance, it has become a focus for freshwater conservation and ecosystem management (Kottelat, 2013). They live at high altitude, where oxygen-rich water and rocky beds are suitable for feeding and growth. The majority of its diet consists of plants, algae, and debris; however, at certain juvenile stages, it can become omnivorous and consume insects and small fish. This degree of adaptability allows it to survive in a wide variety of environments. These are strong swimmers; a deep, laterally compressed body and sensitive barbels help them feed and hold position in swift water. In many regions it holds cultural and economic value, and also conserving it helps monitor the health of a river system, making it a well-known target for regional conservation (Sarkar *et al.,* 2015). It also sits at an important point in the river food chain as prey for larger carnivores, helping keep the predator-prey balance.

N. hexagonolepis serves as an indicator species, where its presence, abundance, and physiological condition give measurable information on water quality and pollution levels in a given reach (Panja *et al.,* 2021; Sarma *et al.,* 2022). The same sensitivity

that makes it ecologically informative also makes it susceptible to progressive habitat degradation and sustained human pressure, which have contributed to its recognition as a conservation priority. In the Dikhu catchment specifically, the most direct threats are pollution from agricultural runoff and mining activity, use of destructive fishing techniques, and the removal of riparian vegetation through deforestation, each of which degrades the fast-flowing, oxygen-rich conditions the species depends on.

One of the major factors, like the development of hydropower in riverine ecosystems, has brought about disruption to migratory routes for fish and have degraded the overall ecological quality of water, thus leading to declining fish populations (Dash *et al.,* 2021a). The IUCN currently lists *N. hexagonolepis* as 'Near Threatened,' a designation reflecting documented population decline across much of its range and the species limited tolerance for degraded water conditions (Arunachalam, 2010). Population losses have been attributed to several converging pressures: the destruction and fragmentation of riverine habitat, the use of electrofishing and piscicides that kill indiscriminately across life stages, escalating agricultural and industrial pollution that reduces dissolved oxygen and raises turbidity, and overharvesting fishing that targets fish before they reach reproductive maturity (Kechu *et al.,* 2023b; Debnath *et al.,* 2024b; Abass *et al.,* 2024). The fish is valuable economically and culturally as well as ecologically, as indigenous tribes have long used and managed it, and it carries real meaning for local identity. River fragmentation and deforestation have also disrupted the conditions it needs to reproduce and survive. Sustained conservation is what will keep it from sliding toward extinction, and protecting its habitat alongside developing sustainable fisheries would benefit both the species and the communities tied to it (Kottelat, 2013).

Taxonomists use meristic and morphometric methods to describe and classify species precisely. These measurements dictate population and growth structure and the sources of variation between fish, which feeds into sustainable management (Zargar *et al.,* 2012; Mir *et al.,* 2013). Morphometrics can also expose sexual dimorphism in *N. hexagonolepis*, important for understanding how it breeds and how to protect it (Laskar *et al.,* 2013b). Meristic traits, including fin rays, scales, and gill rakers,

remain especially important for distinguishing *N. hexagonolepis* from closely related mahseer species in shared habitats. Specific characteristics like lateral line scale counts and fin ray numbers serve as key diagnostic markers (Brraich and Akhter, 2015). When combined, morphometric and meristic data offer a comprehensive picture of how *N. hexagonolepis* responds to environmental pressures, helping to identify habitat-specific adaptations and historical population patterns (Douglas *et al.,* 2001; Dwivedi and Dubey, 2013; Hernandez *et al.,* 2022).

The length-weight relationship (LWR) is a key tool in fisheries biology, offering valuable insights into a species growth pattern whether it grows proportionally (isometric) or disproportionately (allometric) (Froese, 2006). A well established LWR not only reflects the overall health and condition of fish populations but also provides clues about the quality of their surrounding habitats. When LWR values deviate from expected norms, they can signal underlying environmental stressors, such as pollution, habitat degradation, or overfishing. This makes LWR an important indicator for assessing ecosystem health and guiding conservation and fishery management decisions (Mortuza and Rahman, 2006; Hossain, 2010; Jisr *et al.*, 2018; Subba *et al.,* 2018).

The condition factor (K) serves as an important indicator of a species overall health and nutritional status. Higher K values generally reflect good environmental conditions and healthy growth, whereas lower values may point to stress, poor nutrition, or habitat degradation. For *N. hexagonolepis*, condition factor assessments can provide early warnings of changes in environmental quality, food availability, and the impacts of anthropogenic stressors such as pollution and overfishing (Le Cren, 1951). Condition factors are also widely used to assess differences between species or within populations and to monitor fish health in aquaculture settings (Araneda *et al.,* 2008; Abdoli *et al.,* 2009; Ozcan and Altun, 2015). These metrics offer insight into the environmental and physiological conditions that influence fish well-being and reproductive success (Das *et al.,* 2017). When interpreted alongside length-weight relationship data, condition factors can support the development of predictive models for fishery management and environmental monitoring (Teubner *et al.,* 2015).

Given the limited information on the biology, distribution, and morphological variation of *N. hexagonolepis* in Nagaland, this study seeks to examine its morphometric traits, length-weight relationship, and condition factor in the Dikhu River. The findings aim to provide essential baseline data that can inform future conservation and management efforts for this ecologically important and culturally valued species.

4.2 Materials and Methods

This study was conducted to investigate the bionomic characteristics of *Neolissochilus hexagonolepis* (chocolate mahseer) from the Dikhu River in Nagaland, India. The primary objectives were to assess sample collection techniques, morphometric and meristic traits, as well as to analyze the length-weight relationship (LWR) and condition factor of the species

4.2.1 *Sample collection*

Fish specimens were collected monthly over the course of a year, from March 2019 to February 2020, from various accessible sites along the Dikhu River in the Mokokchung and Zunheboto districts of Nagaland. Sampling locations were carefully selected to cover a broad stretch of the river, from its upper to lower reaches, ensuring the collected specimens reflected the natural diversity of the fish population. To achieve a representative and diverse sample, a combination of traditional fishing techniques and gears like nets, fishing rods and lines were carried out with the assistance of local fishermen. Immediately after capture, specimens were preserved in 10% buffered formalin to maintain their morphological integrity for accurate laboratory analysis (American Fisheries Society *et al.,* 2004).

4.2.2 *Morphometric and meristic measurements*

Morphometric and meristic methods were employed to examine the morphological traits and growth patterns of *N. hexagonolepis*, contributing to a deeper understanding of its biology and ecological adaptation. Measurement procedures followed standardized methods described by Hubbs and Lagler (1964), Jayaram (1981), and Rainboth (1985). Tools used included a graduated measuring tape (mm precision), vernier caliper, and a Ionix portable electronic balance (measuring in grams with 0.01 accuracy). A total of 27 morphometric traits and 10 meristic characters were recorded. Linear regression analysis was performed using the least squares method, following the equation:

$$\mathbf{Y = a + bX}$$

Where,

Y = dependent variable,

X = independent variable,

a = constant variable,

b = slope of the regression line

The correlation coefficient (r) with respect to total length (TL) was calculated to examine the strength and direction of relationships between variables.

4.2.3 *Length-Weight Relationship (LWR)*

The Length-weight relationship (LWR) offers an important approach for studying the growth pattern of a fish species. In this study, the LWR was analyzed using the equation proposed by Le Cren (1951):

$$\mathbf{W = aL^b}$$

Where,

W = weight of the fish (g),

L = total length (cm),

a = constant,

b = exponent of the regression curve which indicates the growth pattern

To analyze the LWR, the total length and weight data were logarithmically transformed: The equation is expressed in logarithmic form transformed by Tesch (1971):

$$\mathbf{Log\ W = Log\ a + b\ Log\ L}$$

Where,

Log W = dependent variable,

Log L = independent variable,

a = constant (initial growth),

b = slope or growth coefficient

Log-transformed total length (TL) and weight (W) data were used to determine the correlation coefficient (r) and the coefficient of determination (r^2). These metrics helped assess the linearity and strength of the LWR.

4.2.4 *Condition factor (K)*

The condition factor is widely used to assess the general health of the fish. The condition factor was calculated using Fulton's (1904) formula:

$$\mathbf{K = 100*W/ L^3}$$

Where,

W = weight of the fish (g),

L = total length (cm),

100 = scaling factor to bring K close to unity (100)

4.2.5 *Statistical Analysis*

Descriptive statistics, including mean and standard deviation, were computed for all morphometric and meristic traits. Regression analysis was applied to examine the relationship between length and weight. The significance of the LWR and condition factor was tested using Student's t-test, with statistical significance set at $p < 0.05$. All statistical analyses were carried out using Microsoft Excel 2007. Data were organized into spreadsheets where regression models, correlation coefficients, and condition factors were computed. This analytical approach facilitated a comprehensive understanding of the growth dynamics and health condition of *Neolissochilus hexagonolepis* within its natural habitat.

4.3 Results

4.3.1 Systematic position of *Neolissochilus hexagonolepis*

Kingdom: Animalia

Phylum: Chordata

Class: Actinopterygii

Order: Cypriniformes

Family: Cyprinidae

Genus: *Neolissochilus*

Species: *hexagonolepis*

Current status: Valid as *Neolissochilus hexagonolepis* (McClelland 1839)

Figure 4.1: Material examined; *N. hexagonolepis* NUFM/NUFM 1279-1280, 2exs., 11.3 - 14.2 cm SL, Dikhu River at Lonkong village, Mokokchung district, April, 2019

4.3.2 *Coloration*

The species displays a striking coloration pattern, with olive-green tones on the dorsal region and silvery-white hues on the ventral side as depicted in Figure 4.1. Scales located above the lateral line exhibit a coppery coloration near the margins. The sides of the head are highlighted with golden reflections. In larger individuals, the dorsal surface, head, fin bases, and scales appear blackish-grey, while the opercular plates, fins, and scale tips are tinged with yellow.

4.3.3 *Tuberculation*

Small and not very prominent tubercles are present on the snout, especially along the lateral surfaces and the cheeks, extending beneath the eyes but less developed than in other related species.

4.3.4 *Morphometric Description*

The body is deep anteriorly and gradually tapers toward the posterior, with a strongly compressed caudal peduncle. The head is broad with a blunt snout, and the mouth is subterminal to inferior in position. The lower lip lacks both fleshy lobes and notches, and the postlabial groove is medially interrupted. Lips are thick, and two pairs of barbels are present; one rostral and one maxillary. The eyes are positioned in the upper half of the head, and the infraorbital bone is notably broad. The dorsal fin originates approximately midway between the tip of the snout and the base of the caudal fin, with the last unbranched ray being osseous and unsegmented. Scales are large and well-developed. Specimens of *N. hexagonolepis* examined ranged from 10.6 to 21.3 cm in standard length (SL). Body moderately deep-bodied and laterally flattened, with a body depth at dorsal-fin insertion varying from 24.03 - 32.02% SL (mean 28.48 ± 1.83). Snout is relatively short, ranging from 4.23 - 5.63% SL (mean 4.85 ± 0.41). Dorsal fin is high and well-developed, with height ranging from 24.65 - 33.86% SL (mean 29.02 ± 2.45) and dorsal-fin base length ranging from 13.18 - 17.14% SL (mean 15.27 ± 0.88). Pectoral fins are moderately long (18.78 - 26.85% SL, mean 21.46 ± 1.53), with narrow bases (3.33 - 5.31% SL, mean 4.26 ± 0.53). Pelvic fins are shorter, measuring 16.90 - 20.83% SL (mean 18.89 ± 1.16). Anal fin height ranged from 17.37 - 22.83% SL (mean 19.34 ± 1.52), with base length 6.20 - 8.43% SL (mean 7.34 ± 0.51). Caudal fin elongate, comprising 27.53 - 35.40% SL (mean 31.07 ± 1.92). The caudal peduncle ranged in length from 17.24 - 20.83% SL (mean 18.81 ± 0.93), with depth at the narrowest point 11.27 - 13.48% SL (mean 12.15 ± 0.52). Predorsal distance ranged from 46.03 - 51.75% SL (mean 48.56 ± 1.56), postdorsal distance ranged from 31.48 - 42.98% SL (mean 36.73 ± 2.59), and prepectoral distance from 21.13 - 34.26% SL (mean 24.94 ± 2.48). Prepelvic and preanal distances were 46.01 - 53.10% SL (mean 49.97 ± 2.11) and 70.22 - 79.58% SL (mean 74.76 ± 2.24), respectively. Preanus length ranged from 63.33 - 77.36% SL (mean 72.66 ± 3.05). Distance between pectoral and pelvic fins ranged from 22.73 - 29.37% SL (mean 26.28 ± 1.67), and between pelvic and anal fins from 23.58 - 27.70% SL (mean 25.38 ± 1.16).

Head length ranged from 2.6 - 4.9 cm. Relative to head length (HL), head height at occiput ranged from 57.89 - 81.82% HL (mean 72.77 ± 4.71). Eye diameter was

moderate, 15.79 - 29.03% HL (mean 20.63 ± 2.48), and snout length was 16.13 - 21.43% HL (mean 18.78 ± 1.55). Interorbital width varied between 23.68 - 44.44% HL (mean 34.93 ± 3.77), preorbital distance between 28.57 - 35.56% HL (mean 31.96 ± 1.71), and postorbital distance from 45.16 - 53.13% HL (mean 48.91 ± 2.24). Data are represented in Table 4.1 and visual representation in Figure 4.2.

4.3.5 ***Meristic observations***

The meristic characteristics of *N. hexagonolepis* were documented as follows: lateral line scales ranged from 25 to 29; upper transverse scale rows above the lateral line ranged from 4 to 4.5 and lower transverse scale rows ranged from 3 to 3.5. Fin ray counts included dorsal fin rays (iv/9), pelvic fin rays (i/8), pectoral fin rays (i/14-16), anal fin rays (ii-iii/5), and caudal fin rays (19). Additionally, the number of predorsal scales ranged from 9 to 10, while the number of circumpeduncular scales was consistently 12.

Table 4.1: Morphometric measurements of *N. hexagonolepis*

Morphometric measurements	Range	Mean	SD
%SL			
Standard length	10.6 - 21.3 (cm)		
Body depth at dorsal-fin insertion	24.03 - 32.02	28.48	1.83
Snout length	4.23 - 5.63	4.85	0.41
Dorsal fin height	24.65 - 33.86	29.02	2.45
Dorsal fin base length	13.18 - 17.14	15.27	0.88
Pectoral fin height	18.78 - 26.85	21.46	1.53
Pectoral fin base length	3.33 - 5.31	4.26	0.53
Pelvic fin height	16.90 - 20.83	18.89	1.16
Anal fin height	17.37 - 22.83	19.34	1.52
Anal fin base length	6.20 - 8.43	7.34	0.51
Caudal fin length	27.53 - 35.40	31.07	1.92
Length of caudal peduncle	17.24 - 20.83	18.81	0.93
Depth of caudal peduncle	11.27 - 13.48	12.15	0.52
Predorsal distance	46.03 - 51.75	48.56	1.56
Postdorsal distance	31.48 - 42.98	36.73	2.59
Prepectoral distance	21.13 - 34.26	24.94	2.48
Prepelvic distance	46.01 - 53.10	49.97	2.11
Preanal distance	70.22 - 79.58	74.76	2.24
Preanus length	63.33 - 77.36	72.66	3.05
Distance between pectoral and pelvic fins	22.73 - 29.37	26.28	1.67
Distance between pelvic and anal fins	23.58 - 27.70	25.38	1.16
% HL			
Head length	2.6 - 4.9		
Head height at occiput	57.89 - 81.82	72.77	4.71
Eye diameter	15.79 - 29.03	20.63	2.48
Snout length	16.13 - 21.43	18.78	1.55
Interorbital distance	23.68 - 44.44	34.93	3.77
Preorbital distance	28.57 - 35.56	31.96	1.71
Postorbital distance	45.16 - 53.13	48.91	2.24

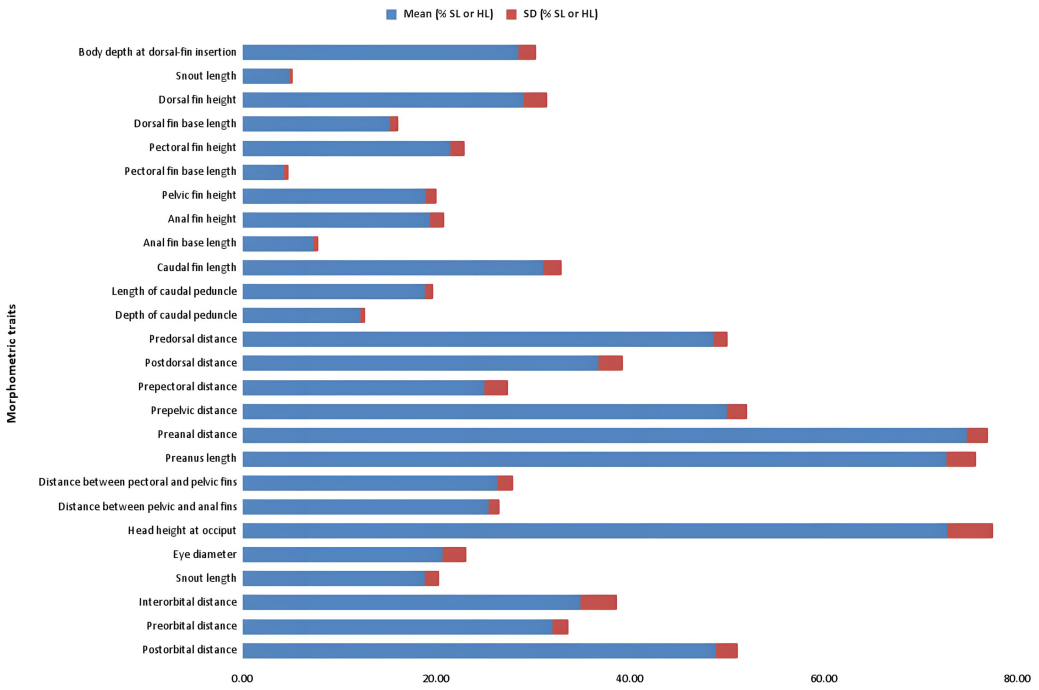

Figure 4.2: Percentage distribution of morphometric traits relative to standard length (SL) and head length (HL) presented as mean ± SD

4.3.6 *Morphometric values in proportion to total length*

In the present study, a total of 53 specimens of *N. hexagonolepis* were collected from the Dikhu River and examined for various morphometric characteristics. The total length of the specimens ranged from 14.0 to 33.8 cm, while their body weight varied between 28.63 and 288.68 g. Among the measured traits, standard length (SL) exhibited the highest rate of growth, with a regression slope ('b') value of 0.8125, whereas eye diameter (ED) showed the lowest growth rate, with a 'b' value of 0.0205. These observations suggest that the rate increase in standard length was greater when compared to all other morphometric traits as shown in Table 4.2. Furthermore, the correlation coefficient ('r') for each morphometric variable in relation to total length ranged from 0.7769 to 0.9968, reflecting a strong positive correlation. Overall, the findings confirm that all external morphometric traits exhibit positive relationships with total length, indicating a proportional increase in these parameters as the fish grows in length.

4.3.7 *Length-weight relationship and condition factor*

The calculated exponent values ('b') for *N. hexagonolepis* were 3.015 for males, 2.807 for females, and 2.868 for the combined sexes. These observations reveal positive allometric growth in males, while females and the pooled group displayed negative allometric growth patterns. The length-weight relationship (LWR) demonstrated a strong correlation in all three groups, supported by high values of the correlation coefficient ('r') and the coefficient of determination ('r²'), which ranged from $r = 0.970$ to 0.981 and $r^2 = 0.941$ to 0.961, thereby confirming the robustness of the regression models and depicted in Figures 4.3, 4.4, and 4.5. In addition, the estimated condition factor (K) values for males, females, and pooled samples were 1.14, 1.10, and 1.13, respectively, all exceeding the threshold value of 1, indicating that the individuals in all groups were in good health and well-adapted to their natural habitat and is tabulated in Table 4.3.

Table 4.2. Regression equation and correlation coefficient of different morphometric characters in relation to total length in *N. hexagonolepis* from Dikhu River, Nagaland

Morphometric count	Range	Mean±SE	Regression Equation Log Y = a + b Log X	Correlation coefficient 'r'
Total length (cm)	14.0-27.2	17.652±0.418		
Standard length	10.6-21.3	13.337±0.339	Y= -1.0295 + 0.8125	0.9968
Body depth at dorsal-fin insertion	2.8-5.7	3.789±0.865	Y= -0.1054 + 0.2197	0.9641
Lateral head length	2.6-4.9	3.411±0.065	Y= 0.7572 + 0.1500	0.9596
Head height at occiput	2.0-3.9	2.489±0.057	Y= 0.1729 + 0.1308	0.9546
Eye diameter	0.6-0.9	0.696±0.011	Y= 0.3345 + 0.0205	0.7769
Interorbital distance	0.9-2.0	1.204±0.035	Y= -0.2602 + 0.0827	0.9731
Preorbital distance	0.8-1.6	1.096±0.026	Y= 0.0709 + 0.0580	0.9429
Postorbital distance	1.2-2.6	1.670±0.035	Y= 0.3188 + 0.0765	0.9225
Snout length	0.5-0.9	0.644±0.016	Y= 0.0335 + 0.0346	0.9220
Dorsal fin height	2.8-5.7	3.833±0.080	Y= 0.6854 + 0.1787	0.9436
Dorsal fin base length	1.6-3.1	2.037±0.054	Y= -0.2118 + 0.1269	0.9715
Pectoral fin height	2.2-4.2	2.844±0.065	Y= 0.2332 + 0.1479	0.9552
Pectoral fin base length	0.4-0.9	0.570±0.017	Y= -0.0870 + 0.0373	0.9093
Pelvic fin height	1.9-3.6	2.504±0.056	Y= 0.2184 + 0.1297	0.9716
Anal fin height	1.9-4.5	2.581±0.071	Y= -0.2481 + 0.1605	0.9462
Anal fin base length	0.7-1.7	0.985±0.029	Y= -0.2358 + 0.0690	0.9711
Caudal fin length	3.3-6.3	4.119±0.094	Y= 0.2568 + 0.2186	0.9705
Length of caudal peduncle	1.9-3.9	2.504±0.062	Y= -0.0295 + 0.1432	0.9657
Depth of caudal peduncle	1.3-2.5	1.622±0.043	Y= -0.1879 + 0.1024	0.9852
Predorsal distance	5.1-10.0	6.452±0.150	Y= 0.1201 + 0.3578	0.9877
Postdorsal distance	3.4-8.0	4.885±0.121	Y= 0.0305 + 0.2751	0.9504
Prepectoral distance	2.5-4.5	3.281±0.062	Y= 0.9098 + 0.1343	0.9068
Prepelvic distance	5.2-9.8	6.633±0.151	Y= 0.3436 + 0.3561	0.9848
Preanal distance	8.0-15.3	9.941±0.235	Y= 0.0606 + 0.5589	0.9894
Preanus length	7.3-15.0	9.674±0.239	Y= -0.1714 + 0.5584	0.9835
Distance between pectoral and pelvic fins	2.6-5.4	3.507±0.093	Y= -0.3547 + 0.2183	0.9687
Distance between pelvic and anal fins	2.5-5.9	3.393±0.093	Y= -0.4915 + 0.2193	0.9785

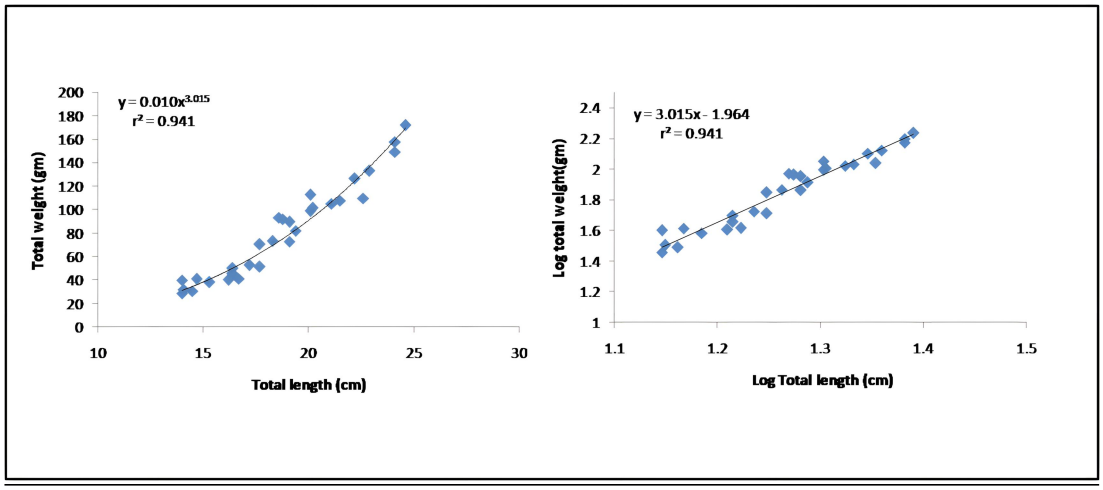

Figure 4.3: Length-weight relationships of *N. hexagonolepis* in parabolic and log form (Male)

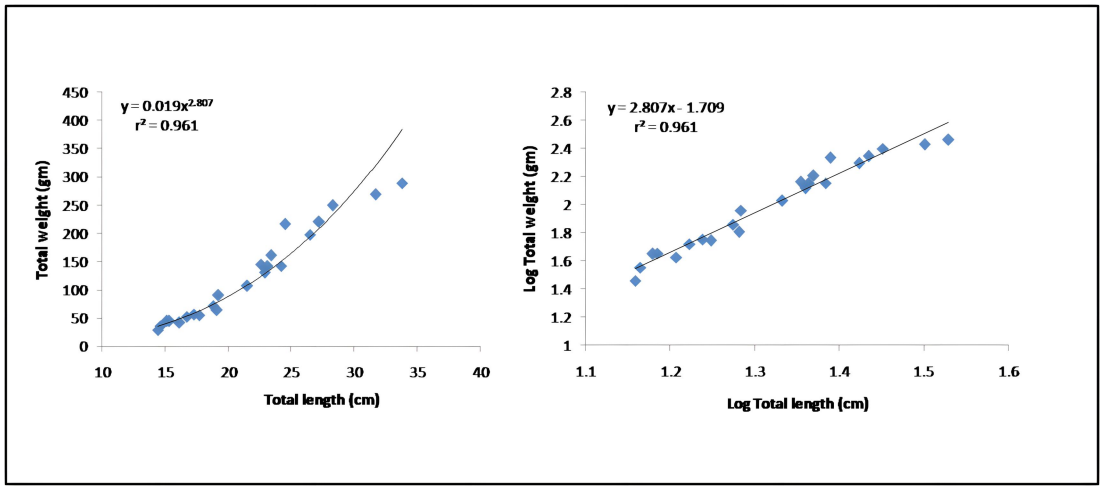

Figure 4.4: Length-weight relationships of *N. hexagonolepis* in parabolic and log form (Female)

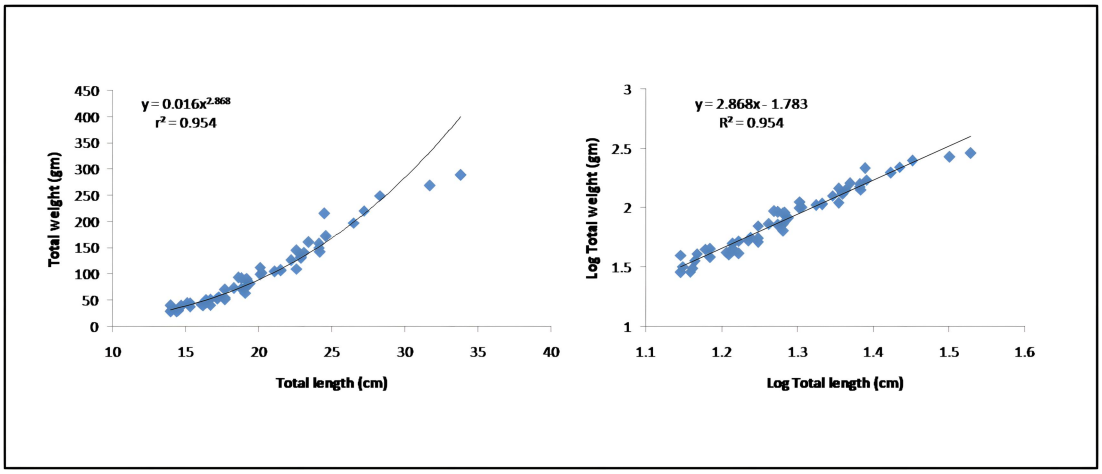

Figure 4.5: Length-weight relationships of *N. hexagonolepis* in parabolic and log form (Pooled)

Table 4.3: Assessment of length-weight relationship and condition factor of *N. hexagonolepis* in the Dikhu River

Sex	n	Length (cm)		Weight (gm)		a	b	r	r^2	K	t-test	p-value
		Range	Mean± SD	Range	Mean± SD							
Male	30	14.0-24.6	18.723± 3.188	28.63-172.10	81.320± 40.696	0.010	3.015	0.970	0.941	1.14	5.17E-10	p<0.05 S
Female	23	14.4-33.8	21.688± 5.497	28.76-288.68	124.146 ± 81.909	0.019	2.807	0.981	0.961	1.10	1.79E-06	p<0.05 S
Pooled	53	14.0-33.8	19.919± 4.511	28.63-288.68	99.905± 64.971	0.016	2.868	0.977	0.954	1.13	3.99E-13	p<0.05 S

n: sample size; SD: standard deviation; a: constant; b: exponent of the regression curve; r: correlation coefficient; r^2: coefficient of determination; K: condition factor; S: significance at 5 % level ($p<0.05$).

4.4 Discussion

The morphometric characteristics of *N. hexagonolepis* depicted in the present analysis reflect a streamlined and elongated body shape, which is well-adapted for life in riverine environments with moderate to strong currents. Elevated values for preanal, predorsal, and prepelvic distances suggest a well-extended trunk region, facilitating efficient, sustained swimming and enhanced locomotive performance essential for navigating fast-flowing waters (Jayaram, 2010). The relatively large caudal and dorsal fins further support high propulsion efficiency, a common feature in rheophilic species. Such morphological adaptations are comparable to those seen in other fast-water cyprinids like *Tor putitora* and *Acrossocheilus sps.* (Lindsey, 1978; Rainboth, 1996).

The biometry of chocolate mahseer across various geographic locations has been documented by several ichthyologists. Kar and Barbhuiya (2010), studying populations from the Barak River, documented strong positive correlations among all morphometric parameters, indicating that these grow proportionally with body length. Similarly, Laskar et al. (2013b) found that the highest growth rate occurred in total length (b = 1.3082), while the head height at eye showed the lowest (b = 0.0366). Mehmood et al. (2021) recorded the highest growth in standard length (0.976) and fork length (0.977) in *Tor putitora* from the Rajouri River, while Bansal (2021) noted the lowest correlation in eye diameter (r = 0.67) in *T. putitora* from the Ujh River. Comparable patterns were reported by Suyani et al. (2021) for *Odonus niger*, where standard length showed the highest correlation (r = 0.91) with total length, while eye diameter exhibited the lowest (r = 0.28). These findings are in agreement with the studies by Gonzalez-Martinez et al. (2020) and Masood et al. (2022), which documented pronounced linear relationships linking body length with other morphometric parameters in *Dormitator latifrons* and *Alepes vari*, respectively.

Meristic traits, being genetically fixed and less influenced by environmental factors, are independent of morphometric traits. Observed meristic counts in the present study aligned closely with findings from Arunachalam et al. (2017) for populations in the Western Ghats. However, minor deviations from Laskar et al. (2013b) were noted, such as differing pectoral (ii+14) and dorsal (ii+10) fin ray counts in *N. hexagonolepis* from Arunachal Pradesh. Geographical isolation and habitat

variability may contribute to these phenotypic differences, which can be useful for future stock delineation and management purposes. Overall, the morphometric and meristic data from the Dikhu River population indicated negligible variation, suggesting population stability and offering a valuable baseline for conservation and resource management strategies.

The length-weight relationship (LWR) provides essential insights into the growth dynamics and physiological condition of fish populations. In *N. hexagonolepis*, LWR analysis helps determine whether the fish exhibit isometric growth (where length and weight increase proportionally) or allometric growth (where one parameter grows disproportionately). A study from three rivers (Amlayee River, Khri River and Umran River) in Meghalaya reported 'b' values ranging from 1.10 to 2.59, indicating a mix of isometric and allometric growth patterns depending on environmental conditions (Jyrwa *et al.,* 2015). In contrast, fingerlings from the Ghish River, Darjeeling Himalaya, showed near-isometric growth, with 'b' values ranging from 2.893 to 2.926 and a condition factor (K) of 0.841 - 0.850, indicating good health in early life stages (Nur *et al.,* 2022). Subba et al. (2018) reported a 'b' value of 2.962 and a condition factor of 1.29 ± 0.49 in the Tamor River population in Nepal, reflecting overall well-being. In the present study, LWR analysis across all sample groups (males, females, and combined sexes) revealed a strong positive correlation. Nur et al. (2022) reported similar findings for fingerlings of *N. hexagonolepis*, with highly significant correlations ($p < 0.001$) and high r^2 values (0.974 - 0.976). Goel et al. (2011) suggested that r-values exceeding 0.9 indicate a strong length-weight relationship. Likewise, Subba et al. (2018) observed higher 'b' values in males than in females, a trend also noted by Ezung and Pankaj (2022) in *Garra langlungensis* from the Langlung River, Nagaland. Jyrwa and Bhuyan (2017) explained the higher male capture rates by suggesting that females may inhabit deeper river sections, making them less accessible during sampling. In our analysis, the exponent 'b' values in all groups deviated from the cube law, reflecting both positive and negative allometric growth. Such variations, typically ranging between 2.5 to 3.5, are influenced by factors such as habitat conditions, reproductive status, seasonal changes, and overall fish health (Froese, 2006).

The condition factor (K) is an important indicator of fish fitness, reflecting the complex interplay between biotic and abiotic environmental factors. K-value above 1 generally implies a healthy fish population in its natural habitat (Froese, 2006). Multiple studies, including those by Kar et al. (2005), Jyrwa et al. (2015), and Subba et al. (2018), have reported K-values greater than 1, suggesting favorable environmental conditions for *N. hexagonolepis* in those regions.

However, recent reports indicate a decline in chocolate mahseer populations and a reduction in overall fish diversity, attributed to overexploitation, habitat degradation, destructive fishing practices, pollution, and temperature fluctuations (Sarkar *et al.,* 2015; Dash *et al.,* 2023; Debnath *et al.,* 2024a). These concerns necessitate urgent and effective conservation strategies. Comprehensive taxonomic and biometric studies are essential for resolving species-level ambiguities and for facilitating sustainable management practices. Monitoring morphometric traits, growth patterns, gonadal development, and overall health can inform adaptive management strategies and conservation planning.

The significant correlations observed between standard length, snout length, and head length relative to total length indicate a well-defined growth relationship in *N. hexagonolepis*. The length-weight relationship showed strong significance, and the condition factor values support the general well-being of the studied population. These findings provide foundational data for the development of targeted fisheries management and conservation strategies in the riverine ecosystems of Nagaland.

CHAPTER 5

Breeding and larval development of *Neolissochilus hexagonolepis*

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5.1 Introduction

5.2 Materials and methods

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5.1 Introduction

Neolissochilus hexagonolepis, widely known as the chocolate mahseer, is a culturally celebrated and ecologically significant coldwater cyprinid native to the upland rivers and streams of Northeast India. As the state fish of both Nagaland and Sikkim, it serves not only as an emblem of aquatic biodiversity but also as a flagship species for regional conservation and aquaculture efforts (Debnath *et al.*, 2024b). Despite its cultural and ecological prominence, wild populations of *N. hexagonolepis* are undergoing a significant decline, attributed to overexploitation, habitat degradation, and low stock of wild populations (Mahapatra and Vinod, 2011; Subba *et al.,* 2020).

To enable science-based conservation and the development of aquaculture, a thorough understanding of the reproductive biology of this species and early ontogeny is crucial. Key reproductive indicators such as sex ratio, sexual dimorphism, gonadosomatic index (GSI), fecundity, fertilization and hatching success, larval survival rate, and embryonic development trajectories provide foundational data for assessing breeding performance, improving hatchery operations and restocking efforts (Laskar *et al.*, 2013a; Pinder *et al.,* 2019; Sharma *et al.,* 2024). Accurate understanding of reproductive traits, such as gonadosomatic index (GSI) trends, fecundity, and sex ratio patterns is key to establishing effective conservation strategies (Lowerre-Barbieri *et al.,* 2023; Manas *et al.,* 2025). As a key indicator species in the coldwater ecosystems of the northeastern Himalayas, the chocolate mahseer plays a vital ecological role and holds significant socio-economic importance, particularly in recreational fisheries and aquaculture. While many cyprinid fishes are known to show sexual dimorphism such as the development of breeding tubercles and changes in coloration these characteristics remain largely unexplored in *Neolissochilus hexagonolepis* (Laskar *et al.,* 2013b).

Earlier studies have described *N. hexagonolepis* as a seasonal spawner, with peak reproductive activity typically occurring during the monsoon season, particularly between July and August (Mahapatra and Vinod, 2011). Research conducted in Tamor River, Nepal, further supports this findings and reveals a female-skewed sex ratio and a prolonged breeding season extending from May to November, with peak spawning in July (Subba and Mahaseth, 2015; Subba *et al.,* 2018).

Studies have classified *N. hexagonolepis* as a seasonal spawner, with peak breeding activity aligning with the monsoon period, particularly from July to August (Mahapatra and Vinod, 2011; Subba *et al.,* 2020). Studies conducted in the Tamor River, Nepal, have indicated a female-biased sex ratio and an extended breeding season from May to November, peaking in July (Subba and Mahaseth, 2015; Subba *et al.*, 2018). Histological evaluations reveal asynchronous oocyte development, suggesting multiple spawning events within a season (Jyrwa and Bhuyan, 2017). Such reproductive flexibility underscores the need for habitat protection during critical reproductive windows. Further studies in Meghalaya indicated that *N. hexagonolepis* begins maturing in May, with peak reproductive activity occurring between July and September (Mahapatra and Vinod, 2011). Supporting this, Joshi et al. (2002) and Azuadi et al. (2013) highlighted high GSI values and the presence of viable eggs and larvae during these months. Although *N. hexagonolepis* has traditionally been considered a seasonal spawner, evidence suggests its reproductive cycle may be more flexible, with spawning potentially occurring from January to September (Nautiyal, 2014).

This species is also known for its ecological adaptability and striking physical features, including a coppery-golden hue and distinctive hexagonal scales. Functioning as both predator and prey, the chocolate mahseer contributes significantly to the trophic dynamics of its native freshwater ecosystems. However, populations of *N. hexagonolepis* are facing growing threats from human-induced pressure such as habitat fragmentation, pollution, and changes in hydrological regimes driven by climate change (Sharma *et al.,* 2019). These factors, coupled with the species inherent reproductive constraints such as delayed sexual maturity and low fecundity have led to its classification as "Near Threatened" (Ingram, 2005; Nautiyal, 2014; Pinder *et al.,* 2019; Dash *et al.,* 2021b; Pandey and Radhakrishnan, 2022; Debnath *et al.,* 2024b; Pongsanarm *et al.,* 2025). To address these concerns, various conservation measures have been implemented, including the enforcement of closed fishing seasons and the promotion of captive breeding programs using both wild-caught and hatchery-reared brooders (Sarma *et al.,* 2016; Akhtar *et al.,* 2018). However, successful breeding and stock enhancement require detailed insights into

reproductive physiology, age and size at sexual maturity, breeding behavior, sex ratio, and gonadal seasonality (Joshi *et al.,* 2018).

Fish embryogenesis typically progresses through stages including zygote, cleavage, morula, blastula, gastrula, organogenesis, and hatching (Faustino *et al.*, 2010). Comprehensive studies on these phases offer critical insight into nutritional needs and environmental thresholds during early development (Borçato *et al.*, 2004). Moreover, comparative studies on gonadal morphology and seasonal cycles are needed to fully characterize reproductive strategies in this species (Moyle and Cech, 2004).

The present study aims to bridge the gap by investigating the reproductive characteristics, GSI, fecundity, sex ratio, embryogenesis, larval growth dynamics, embryonic development, deformity incidence, and survival rates of *N. hexagonolepis* under agro climatic conditions of Nagaland. The outcomes are intended to inform hatchery management protocols and enhance the long-term sustainability of this threatened species. The objective is to support data-driven conservation and management interventions for this ecologically and culturally important freshwater species.

Figure 5.1: Mapping location of Mahseer hatchery farm at Süteplenden and Dikhu River, Mokokchung

5.2 Materials and methods

5.2.1 Study site

The study for fish breeding and larval development was conducted at the mahseer hatchery in Süteplendon, Longkong village, Mokokchung district, Nagaland. The site is geographically positioned at 26° 23 '39"N and 94° 38' 22"E with an altitude of 816 m, approximately 27 km from Mokokchung town, Nagaland. Collection of samples for brooders and other analysis was done in Dikhu River with geographical coordinates at 26° 22 '43"N and 94° 39' 39"E with an altitude of 442 m. Mapping of the study sites are represented in Figure 5.1.

5.2.2 Broodstock management and feeding

Chocolate mahseer were obtained from the Dikhu River and transported to the mahseer hatchery in Süteplendon, Mokokchung, village transported to the hatchery, and reared in ponds for growth and maturation. The brooders were fed with a pelleted diet, fruits like mulberry, *Azolla filiculoides* (mosquito fern) and insects.

5.2.3 Water analysis in experimental pond

Dissolved oxygen and total hardness were determined using a compact water analysis kit (Aquamerck 1.11151.0001). The pH and total dissolved solids (TDS) of water samples was measured with a portable digital pH meter and TDS meter. Air and water temperatures were monitored with a thermometer. Total alkalinity was assessed using the titration method as per APHA (2005) guidelines.

5.2.4 Sexual dimorphism during spawning period

Sexual dimorphism was most evident during breeding season. Males and females were sexually characterized during its peak spawning period with characteristics such as abdominal bulging, colouration, fin morphology and releasing of eggs and milt with slight pressure on the abdomen.

5.2.5 Sex ratio

The monthly sex ratio of *Neolissochilus hexagonolepis* was analyzed based on the percentage of males and females in wild populations. Fish specimens were obtained at regular monthly intervals between March 2019 and February 2020 from multiple sampling sites along the Dikhu River. The homogeneity of the sex ratio was assessed using the Chi-square test given by Snedecor and Cochran (1967) to determine

deviations from the expected 1:1 ratio. The Chi-square value was calculated using the formula:

Chi-square (χ^2) = $(O - E)^2/E$

where *O* is the observed frequency and *E* is the expected frequency.

Additionally, Sokal and Rohlf (1973) provided a specific formula for two-class Chi-square calculations:

Chi-square (χ^2) = $\Sigma(O_i^2/E_i) - n$

where O_i represents the observed frequency, E_i the expected frequency, and *n* the total sample size.

***5.2.6 Gonado somatic index** (GSI)*

The GSI was used to assess the reproductive condition of both male and female *N. hexagonolepis* throughout the season. The GSI provides an indication of the relative size of the gonads compared to the overall body size, which is directly related to the fish readiness for spawning. For the GSI study, fish were collected from both the wild and hatchery from the same agroclimatic condition between March 2019 and February 2020. To analyze seasonal variations, the months were categorized into four seasons: pre-monsoon (March-May 2019), monsoon (July-August 2019), post-monsoon (September-November 2019), and winter (December 2019-February 2020). The Gonado-Somatic Index was calculated using Nikolsky's (1963) method with the following formula:

GSI = Gonad weight / Total body weight * 100

5.2.7 Fecundity

Observations on fish maturity were taken from both wild and hatchery from the same agroclimatic condition. Fecundity studies included 10 mature females, measuring 23.7 - 33.8 cm in length and 200.19 - 288.68 g in weight. The ovarian weight was recorded, and three 1 g subsamples were collected from different sections. Eggs were washed, separated, air-dried, and fecundity was determined as the mean of the subsamples. The relationship between fecundity and biometric traits was assessed using $\log_{10}$-transformed linear regression. Fecundity was estimated using the approach proposed by Bagenal (1967).

F = W * (N1 +N2 +N3) / W1 +W2 +W3

W is gonad weight, N is number of eggs per sub set and w weight of eggs per sub set

5.2.8 Egg diameter

The ova diameter study followed the method of Qasim and Qayyum (1962). Mature ova of *Neolissochilus hexagonolepis* were measured using a vernier caliper, with 50 randomly selected eggs from different brooders analyzed to ensure representative data.

5.2.9 Acclimation

The study was conducted during the natural spawning season of *Neolissochilus hexagonolepis* from September 2021 to December 2022. Brooders reared in ponds were selected based on easily external morphological characteristics. Ovulation in females was confirmed when eggs were released from the genital pore after gentle pressure was applied to the abdomen. The eggs were then carefully stripped into clean trays, while milt was collected from males and combined using the dry stripping method described by Joshi et al. (2002). Fertilization was carried out by gently mixing the eggs and milt with a feather, a traditional practice that ensures uniform mixing. The fertilized eggs were then rinsed with freshwater to remove any residual milt or clots and spread carefully in fiber-reinforced plastic (FRP) hatching trays. A continuous flow of clean water was maintained in the trays to create optimal conditions for incubation.

Reproductive performance was assessed through key indicators such as fertilization rate, hatching success, larval survival, and the occurrence of deformities. A total of 200 eggs per breeder were randomly selected, with three replicates per treatment (Azuadi *et al.,* 2013). A particular development stage was determined when >50% of all specimens reached that stage. Larval deformities were assessed by identifying abnormalities, including head malformations, curved tails, distorted notochords, and bloated body structures. The Reproductive metrics were calculated using standard formulas following Azuadi et al. (2013).

$$\text{Fertilization rate (\%)} = \frac{\text{Number of fertilized eggs}}{\text{Total number eggs in a group}} \times 100$$

$$\text{Hatching rate (\%)} = \frac{\text{Number of hatched larvae}}{\text{Total number fertilized eggs in a group}} \times 100$$

$$\text{Survival rate (\%)} = \frac{\text{Number of surviving larvae till 10 days after hatching}}{\text{Total number of larvae post hatching}} \times 100$$

$$\text{Percentage of normal larvae (\%)} = \frac{\text{Number of normal larvae}}{\text{Total larvae observed}} \times 100$$

$$\text{Percentage of deformed larvae (\%)} = \frac{\text{Number of deformed larvae}}{\text{Total larvae observed}} \times 100$$

5.2.10 Egg and larval development

The duration of each embryonic stage, from fertilization to hatching, was systematically recorded. Egg development was documented using a CZM6 stereo zoom microscope (2× magnification, 34.5 mm working distance) equipped with a digital eyepiece camera (Dino-eye), with total length measurements and morphological changes observed at hourly intervals for the first 48 hours, followed by daily monitoring until yolk sac absorption was complete (Qasim and Qayyum, 1962; Kunal *et al.,* 2018).

Freshly hatched larvae were examined for key developmental milestones, including yolk sac absorption, fin formation, pigmentation, and feeding behavior. Morphological descriptions of the larvae were prepared based on observed structural changes, following Sarma et al. (2015). Once exogenous feeding commenced, hatchlings were initially fed with Artemia, goat liver, or chicken liver until 14 days after hatching (DAH), after which they were transitioned to artificial pellet feed. Larvae were maintained under controlled rearing conditions, and survival rates were assessed. Images of the experimental ponds were taken using a Canon EOS 3000D camera.

5.2.11 Statistical analysis

Microsoft Excel 2007 was used for data sorting and preliminary analysis. Logarithmic regression techniques were applied to assess the relationship between fecundity and biometric traits, such as total length, body weight, and gonad weight. Regression equations were developed to quantify the linear relationships, and the coefficient of determination (r^2) was used to determine the fit of the models. The sex ratio was analysed using Chi-square test. Sex-specific data for males and females were analyzed separately using one-way analysis of variance (one-way ANOVA) across seasons with GraphPad Prism version 5.

5.3 Results

5.3.1 Water quality

The water parameters fall within suitable ranges for fish rearing, ensuring optimal growth and metabolic function. The air and water temperatures fell within the species natural breeding range, and the pH was ideal for maintaining physiological processes. The dissolved oxygen levels varied between 4.97 and 6.17 mg/L was found to be adequate. The total dissolved solids (26.33 - 28.33 mg/L), total hardness (30 - 40 mg/L), and total alkalinity (18.57 - 21.37 mg/L) remained within recommended thresholds for freshwater aquaculture, indicating low mineral content and soft water conditions typical of hill stream habitats. The water variables are tabulated in Table 5.1.

Table 5.1: Water quality metrics in the study pond

Parameters	**Range**
Air temperature	27 - 29 °C
Water temperature	22 - 24 °C
pH	7 - 7.5
Dissolved oxygen	4.97 - 6.17 mg/L
Total dissolved solids	26.33 -28.33 mg/L
Total hardness	30 - 40 mg/L
Total alkalinity	18.57 - 21.37 mg/L

5.3.2 Sexual dimorphism

Sexual dimorphism was evident in *N. hexagonolepis* during the breeding season. Males developed tubercles on the operculum with gradual deepening of colour. They also release oozing milt with slight pressure on the abdomen. While females exhibited a rounded, soft abdomen due to ovarian development, less vibrant coloration, and pink, swollen vents that release eggs during peak spawning.

5.3.3 Sex ratio

The mahseer spawning season occurs from May to September, with female individuals typically larger than male counterparts. The sex ratio of *N. hexagonolepis* was assessed from 111 specimens, consisting of 78 males and 33 females, resulting in a male-to-female ratio of 1:0.42. Wild populations exhibited a higher proportion of males. A Chi-square test ($\chi^2 = 18.24$) indicated that this deviation from the expected 1:1 ratio was statistically non-significant at $p > 0.05$. Monthly data consistently showed male dominance throughout the study period, with significant deviations observed only in November, where the sex ratio was statistically significant as shown in Table 5.2. The findings of this study suggest that male dominance is common, there may be seasonal fluctuations in the sex ratio, potentially influenced by environmental or biological factors.

Table 5.2: Sex ratio assessment and chi-square analysis of *N. hexagonolepis* in the Dikhu River

Months	No. of males	No. of females	Size group range			Sex ratio (M:F)	Chi-square (χ^2)	P value ($p < 0.05$)
			Sex	Length (cm)	Weight (gm)			
January	2	1	Male	12.7 13.1	17.41 20.91	1:0.50	0.34	Non-significant
			Female	16.7 16.7	52.41 52.41			
February	4	2	Male	14.3 19.2	26.06 79.52	1:0.50	0.66	Non-significant
			Female	14.6 19.4	35.63 81.95			
March	7	4	Male	11.8 13.5	15.03 23.61	1:0.57	0.83	Non-significant
			Female	13.4 26.3	26.27 209.67			
April	14	7	Male	12.1 20.2	18.15 101.64	1:0.50	2.34	Non-significant
			Female	13.2 24.2	26.33 142.12			
May	10	3	Male	11.5 18.8	11.99 71.98	1:0.30	3.76	Non-significant
			Female	15.1 23.1	44.59 141.70			
June	5	3	Male	14.7 24.1	41.05 157.79	1:0.60	0.5	Non-significant
			Female	22.6 27.2	145.3 220.61			
July	3	1	Male	22.9 27.6	132.97 160.68	1:0.33	1	Non-significant
			Female	31.8 31.8	266.51 266.51			
August	4	1	Male	18.6 24.6	93.39 172.10	1:0.25	1.8	Non-significant
			Female	33.8 33.8	288.68 288.68			

September	8	5	Male	13.3 22.2	24.34 126.35	1:0.62	0.7	Non-significant
			Female	12.1 17.3	20.53 76.45			
October	5	1	Male	14 22.5	28.63 104.46	1:0.20	2.66	Non-significant
			Female	14.4 14.4	28.76 28.76			
November	13	4	Male	11.6 22.1	13.81 73.93	1:0.30	4.76	Significant
			Female	12.5 18.8	18.17 91.98			
December	3	1	Male	17.7 18.3	51.46 76.21	1:0.33	1	Non-significant
			Female	17.7 17.7	44.99 44.99			
Stock	78	33	Male	11.5 24.6	11.99 172.10	1:0.42	18.24	Non-significant
			Female	12.1 33.8	20.53 288.68			

5.3.4 Gonadosomatic index

The gonadosomatic index (GSI) of females ranged from a minimum of 0.38% in October (19.1 cm TL, 63.98 g) to a maximum of 10.13% in July (32.6 cm TL, 319.57 g). This indicates that the reproductive activity of *Neolissocheilus hexagonolepis* peaks during the monsoon months (July-August) is at its highest and at its lowest during the post-monsoon months (October). For males, the minimum GSI percentage recorded was 0.29% in January for a fish with a total length of 14.5 cm and a weight of 27.81 g, while the maximum GSI percentage recorded was 3.77% in August for a fish with a total length of 28.9 cm and a weight of 263.61 g. This indicates that male reproductive activity is comparatively low during the post-monsoon and winter months (October-January), with a marked increase observed during the monsoon season (July-August), aligning closely with the reproductive peak observed in females. The data is illustrated in Figure 5.2.

Reproductive activity followed a clear seasonal cycle. In females, GSI was highest in July (7.84 ± 2.02), marking peak gonadal maturation during the monsoon as the fish entered their main reproductive phase, most likely during the period leading up to spawning. Males peaked a little later, in August (3.37 ± 0.37), as testicular development caught up and the two sexes came into reproductive synchronisation. During the months following the monsoon and into the subsequent winter, after the breeding period had concluded, GSI declined sharply in both sexes. It reached its lowest in females in October (0.79 ± 0.36) and in males in January (0.80 ± 0.52), a post-spawning phase marked by gonadal regression and reduced reproductive activity. Values then climbed again through the pre-spawning months of March to May, signalling the start of a new round of gonadal maturation. This is the standard pattern for a seasonal breeder where factors such as rainfall, temperature, and food availability worked together, providing favourable conditions for spawning. The GSI was maximum in both sexes during the peak breeding period of the monsoon in females (6.18 ± 1.98) and males (2.76 ± 0.54).

The one-way ANOVA for males shows that the monsoon season is significantly different from winter season, while pre-monsoon also differs from winter, but post-monsoon does not show any remarkable differences from other months. The one-way ANOVA for females shows that the monsoon season is significantly different from

post-monsoon and winter, while the other months do not show significant differences as shown in Figures 5.3 and 5.4.

Overall, females consistently show higher GSI values than males across all seasons, reflecting their greater investment in reproductive effort. Males exhibit a steadier trend with less fluctuation, suggesting that they may remain reproductively active for a longer period compared to females. The monsoon marks peak spawning, the pre-monsoon period involves gonadal preparation, and the post-monsoon and winter signify reproductive regression with low gonadal activity. This pattern is typical of seasonal breeders, aligning reproductive cycles with environmental factors to optimize offspring survival.

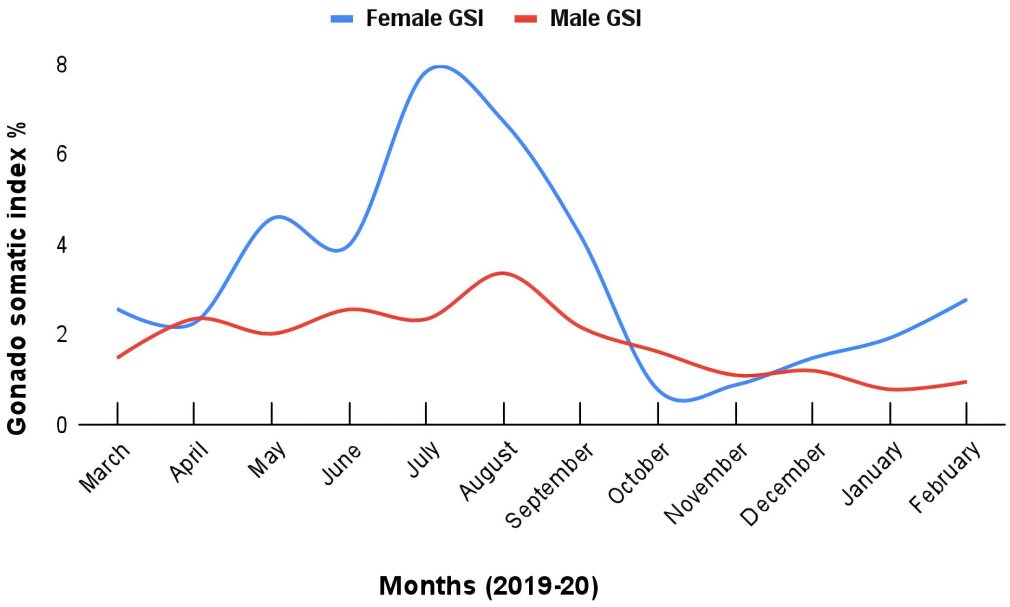

Figure 5.2: Monthly variations in gonadosomatic Index (GSI) of male and female *N. hexagonolepis*

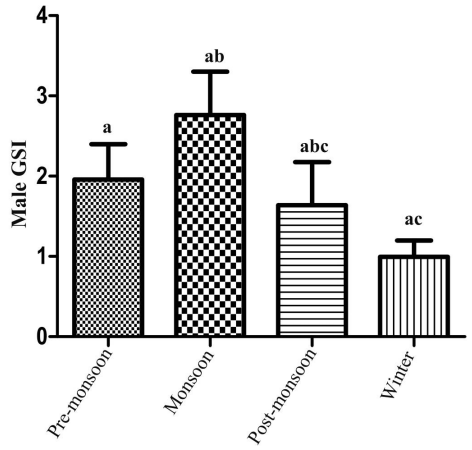

Figure 5.3: Seasonal variation in average GSI of male *N. hexagonolepis*. Distinct superscripts denote statistically significant differences between groups ($p < 0.001$), while identical superscripts indicate no significant difference ($p > 0.05$)

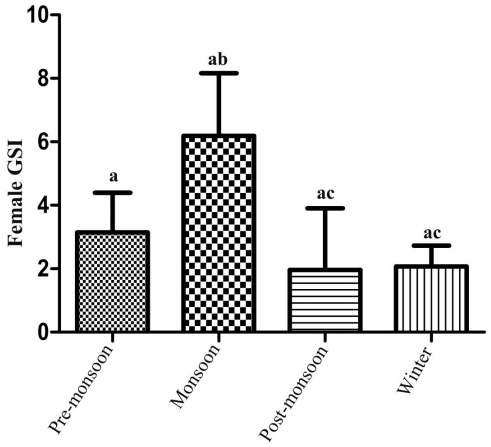

Figure 5.4: Seasonal variation in average GSI of female *N. hexagonolepis*. Distinct superscripts denote statistically significant differences between groups ($p < 0.001$), while identical superscripts indicate no significant difference ($p > 0.05$)

Table 5.3: Seasonal trends in gonadosomatic index (GSI) of female and male *N. hexagonolepis*

Season Variation	Length range (cm)	Weight range (g)	Female Mean ± SD	Male Mean ± SD
Pre monsoon	F 19.2 - 28.8 M14.8 - 28.8	F 90.76 - 232.25 M 32.09 - 224.74	3.14 ± 1.25[a]	1.96 ± 0.44[a]
Monsoon	F 18.9 - 33.8 M 16.4 - 31.7	F 101.98 - 319.57 M 69.96 - 268.65	6.18 ± 1.98[ab]	2.76 ± 0.54[ab]
Post monsoon	F 17.3 - 30.6 M 14.4 - 27.9	F 55.46 - 257.43 M 37.42 - 180.58	1.96 ± 1.94[ac]	1.64 ± 0.53[abc]
Winter	F 15.1 - 24.9 M 14.3 - 21.5	F 69.25 - 145.3 M 26.06 - 96.86	2.07 ± 0.66[ac]	0.99 ± 0.21[ac]

5.3.5 Fecundity

The fecundity of *Neolissochilus hexagonolepis* ranged from 4,650 to 10,754 eggs, with an average of 7,566 ± 1964.15 eggs. The total length varied between 23.7 cm and 33.8 cm, with a mean of 28.77 ± 3.82 cm, while the total weight ranged from 148.65 g to 319.57 g, with a mean of 241.33 ± 50.47 g.

The present study examined the relationships between absolute fecundity and key biological parameters, including total length (TL), total weight (TW), and gonadal weight (GW) of *Neolissochilus hexagonolepis*. Correlation and regression analyses were conducted to determine the strength of these relationships. Fecundity showed a moderate correlation with total length ($r = 0.712$, $r^2 = 0.507$), a stronger correlation with total weight ($r = 0.876$, $r^2 = 0.767$), and the highest correlation with gonad weight ($r = 0.909$, $r^2 = 0.827$), confirming ovarian mass as the most reliable predictor of egg production. A moderate correlation was observed between TL and GW ($r = 0.632$, $r^2 = 0.399$). While the strong TW-GW correlation ($r = 0.883$, $r^2 = 0.779$), reinforces TW as a better predictor of fecundity than TL. The scatter plot indicated a linear relationship between fecundity and body parameters, with fecundity most strongly linked to ovary weight. The data are represented from Figure 5.5 to Figure 5.10.

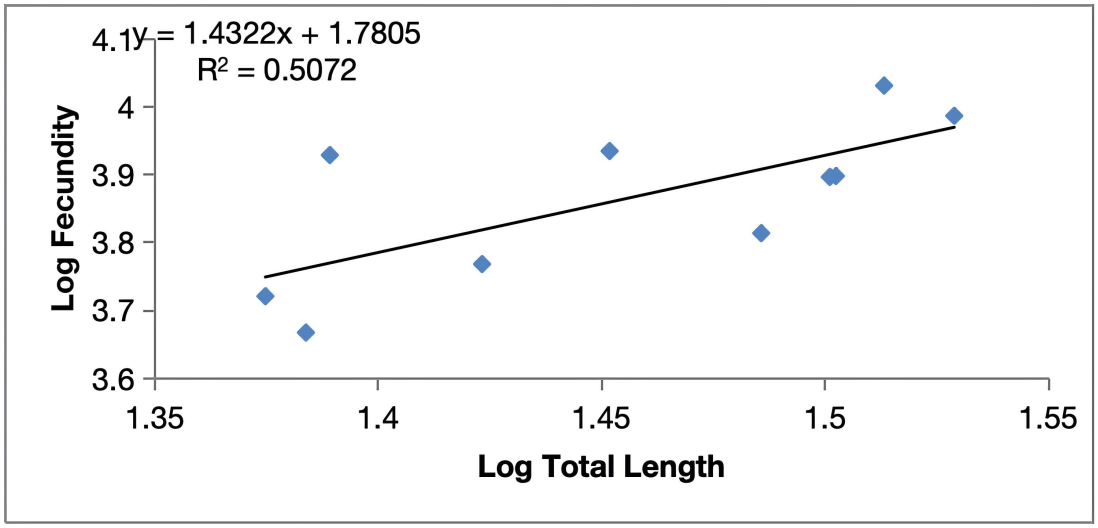

Figure 5.5: Correlation between fecundity and total length

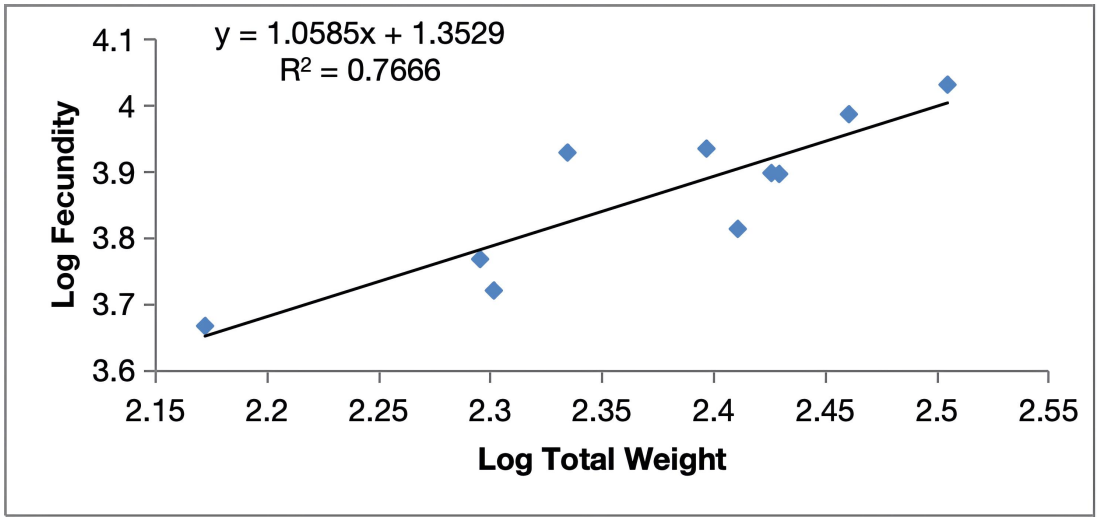

Figure 5.6: Correlation between fecundity and total weight

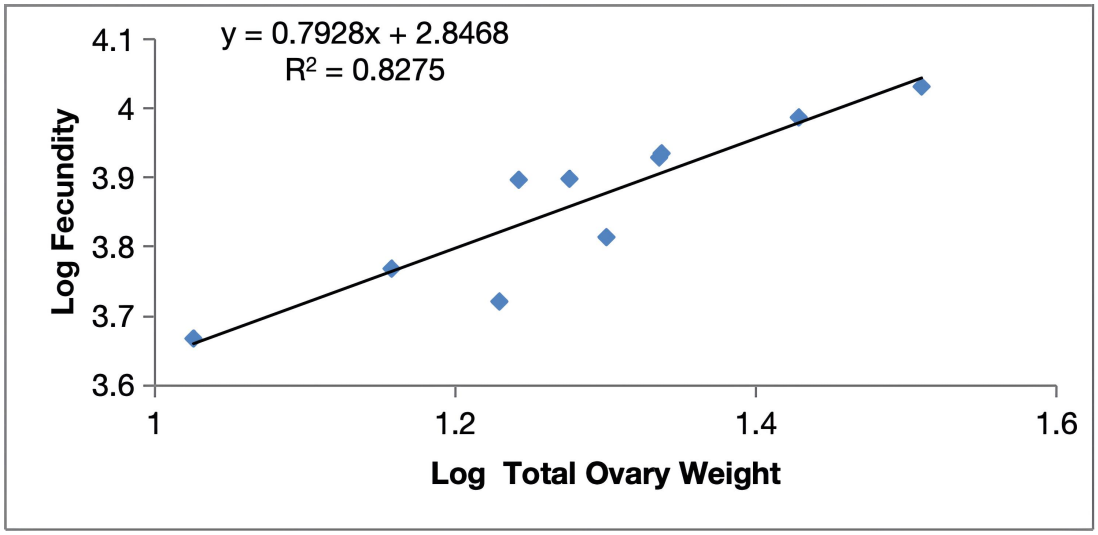

Figure 5.7: Correlation between fecundity and total ovary weight

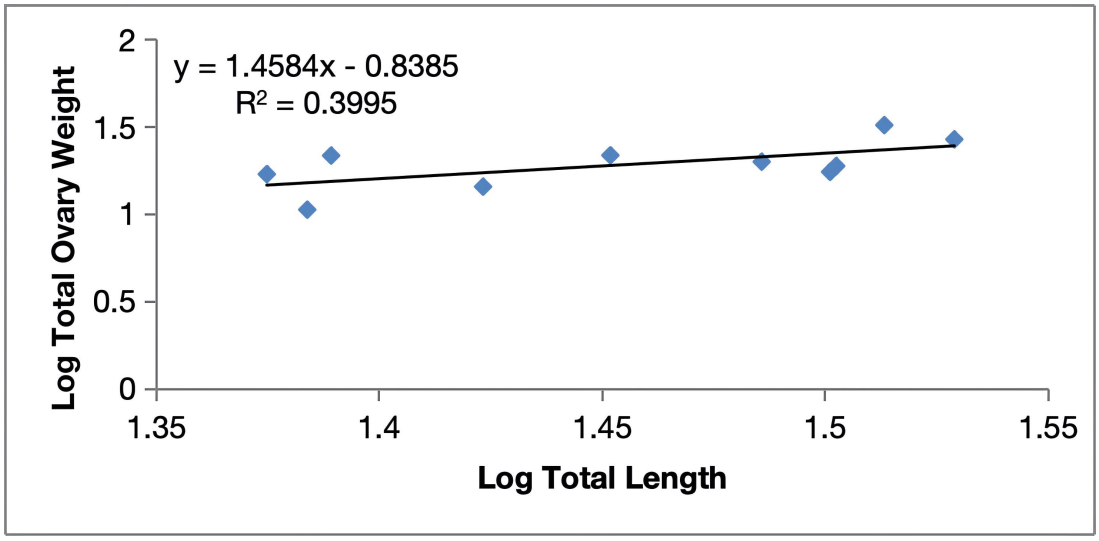

Figure 5.8: Correlation between total ovary weight and total length

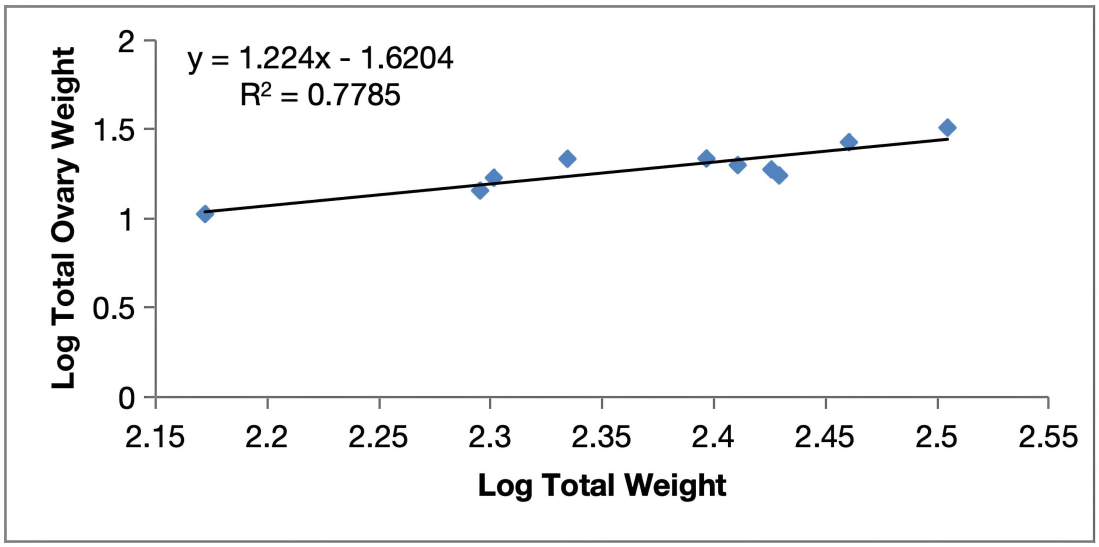

Figure 5.9: Correlation between total ovary weight and total weight

Figure 5.10: Developing male and female gonads

5.3.6 Egg diameter

The egg diameter ranged from 2.2 mm to 3.0 mm, with a mean of 2.564 ± 0.23 mm based on a sample of 50 eggs.

5.3.7 Reproductive metrics

The data represents fertilization, hatching, and survival rates of *Neolissochilus hexagonolepis* based on three trials, each with a total sample size of 200 fertilized eggs. The fertilization rate averaged 89.33% ± 5.03, indicating high fertilization success. The hatching rate was 79.33% ± 5.86, showing that a substantial proportion of fertilized eggs develop into hatchlings. The survival rate of hatchlings averaged 70% ± 5.29, reflecting the expected outcome recorded during initial larval development and are illustrated in Figure 5.11. The declining trend from fertilization to survival reflects natural losses at each developmental stage, which is typical in fish breeding and larval rearing. The relatively low variability among all three rates suggest consistency in the results, implying stable environmental and biological conditions during the study.

The percentage of normal larvae across all samples averaged 85.1% ± 6.37, indicating that the majority of hatchlings exhibited normal morphological development. In contrast, deformed larvae accounted for 16.83% ± 7.91, showing relatively high variability among samples as graphically presented in Figure 5.12. The data shows that *N. hexagonolepis* exhibits a high rate of normal larvae with moderate variability in deformity rates.

The coefficient of variation (CV%) for fertilization (5.63%), hatching (7.39%), and survival (7.56%) remained within a stable range, indicating successful reproductive performance. The normal larvae percentage (7.48%) was also fairly consistent, suggesting optimal hatchery conditions. However, the high variability in deformity rates (47.01%) highlights the potential influence of environmental stressors, genetic factors, or incubation conditions. A statistically significant difference ($p < 0.05$) was observed among the measured rates, suggesting that fertilization rates were significantly higher than hatching and survival rates, which declined progressively. Variability in hatching and survival rates may be attributed to environmental conditions, egg quality, or larval viability. The data are presented in Table 5.4.

Overall, the findings indicate that *N. hexagonolepis* exhibits high reproductive

success, with fertilization and hatching rates exceeding 75%. However, the survival rate of 70% suggests the need for further optimization in hatchery conditions, including improved water quality, feeding strategies, and disease management, to enhance larval survival and minimize deformities.

Table 5.4: Reproductive performance and larval development metrics of *N. hexagonolepis*

Parameter	Sample Size (N)	Rates (% ± SD)	Coefficient of Variation (CV%)	Significance ($p < 0.05$)
Fertilization rate	200	89.33 ± 5.03	5.63%	S
Hatching rate	200	79.33 ± 5.86	7.39%	S
Survival rate	200	70 ± 5.29	7.56%	S
Normal larvae	200	85.1 ± 6.37	7.48%	S
Deformed larvae	200	16.83 ± 7.91	47.01%	S

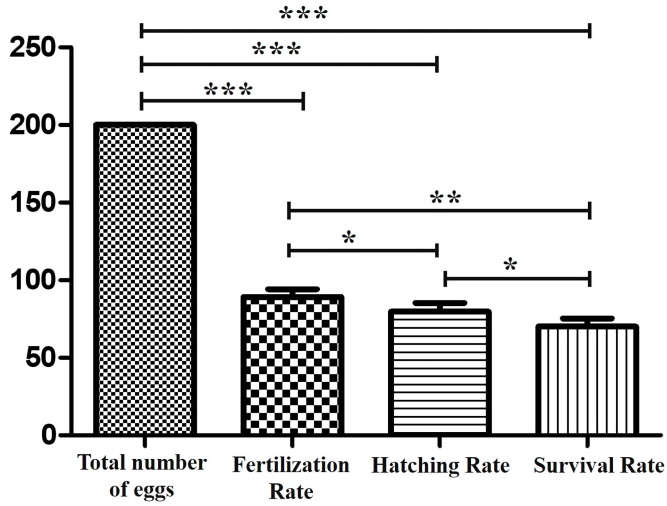

Figure 5.11: Comparative analysis of fertilization, hatching, and survival rates in *N. hexagonolepis*. The asterisks indicate the level of statistical significance between groups. Fertilization and hatching rates, as well as hatching and survival rates, showed significant differences (*p < 0.05), while fertilization and survival rates differed strongly (**p < 0.01)

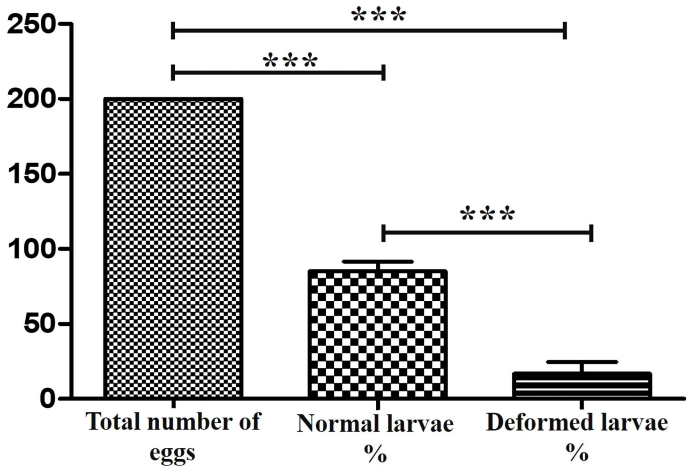

Figure 5.12: Percentage composition of normal and deformed larvae in *N. hexagonolepis*. Asterisks denote levels of statistical significance. The normal larvae and deformed larvae showed a highly significant difference (***p < 0.001)

5.3.8 Egg and larval development

5.3.8.1 Embryonic stage

Fertilized phase: The fertilized eggs were translucent, spherical, and golden in colour, with diameters ranging from 2.2 - 3.0 mm with an average of 2.61 ± 0.23 mm for 50 egg count. In contrast, unfertilized eggs appeared opaque and whitish. Fertilization occurs immediately when the milt is mixed with the eggs, resulting in the formation of the zygote at the one-cell stage at 1-2 hours after fertilization (HAF), accompanied by the swelling of the chorion. Various stages of development are presented in Table 5.5.

Cleavage phase: Cytoplasmic division follows a discoidal cleavage pattern, with the first cleavage occurring 2 h 30 min after fertilization, forming two blastomeres. Subsequent divisions progress sequentially, reaching the 4, 8, 16, and 32-cell stages at regular intervals. The cleavages do not fully separate the blastodisc, keeping the blastomeres or specific subsets at each stage interconnected by cytoplasmic bridges.

Morula phase: The morula stage occurs between 9 h 30 min - 10 h 15 min after fertilization is characterized by the compaction of blastomeres into a dense mass, undergoing successive cleavages without a notable increase in size, while the blastodisc remains structurally distinct from the yolk.

Blastula phase: The blastula stage occurred at 10 h - 13 h 50 min after fertilization, marked by cellular flattening, a layered blastoderm, and loss of synchrony in cell division. The number of oil droplets decreased, and the blastodisc assumed a ball-like structure. Key processes at this stage involved the development of the yolk cytoplasmic layer and the initiation of epiboly, which progressed into gastrulation.

Gastrula phase: The gastrula stage occurs at 15 h 15 min - 35 HAF which is characterized by blastoderm extension. Epiboly continues to progress, accompanied by morphogenetic cell movements that establish the primary germ layers and define the developmental axis.

Somite formation phase: This stage occurs between 35 - 55 HAF, characterized by somite formation, the emergence of the notochord and heart primordium, the onset of body movements, and a more prominent tail bud.

Pharyngula phase: This stage occurs between 50 - 80 HAF, marked by progressing somite differentiation, body axis elongation, and the development of a well-defined

head and tail. The circulatory system becomes active with a rhythmic heartbeat, and pigment cells begin to emerge.

Hatching phase: Hatching occurred between 72 - 105 HAF, characterized by vigorous twitching as the embryo ruptured the chorion. The tail gradually detached from the yolk mass, and early twitching movements coincided with further head development. Egg developmental stages are illustrated in Figures 5.13 and 5.14.

5.3.8.2 Larval and post larval stages

The newly hatched larvae possessed a large, elongated, bilobed yolk sac measuring 5.7 - 5.9 mm with an average of 5.81 ± 0.01 mm. Hatchlings had a transparent, silverish, compressed body ranging between 8.2 - 8.5 mm with an average of 8.34 ± 0.019 mm, had unpigmented eyes, lacked a functional mouth and fins, and were incapable of swimming. The different larval stages are depicted in Figure 5.15.

At 1 DAH, larvae measured 8.7 - 8.9 mm in length, with an average of 8.80 ± 0.01 mm, while the yolk sac length averaged 5.60 ± 0.01 mm. The eyes remained unpigmented as blood vessels became visible, with reddish-orange blood corpuscles indicating hemoglobin development. The yolk sac progressively elongated and reduced in size, while the mouth and fins remained underdeveloped.

By 5 DAH, larvae measured 10.6 - 10.8 mm in length, with an average of 10.70 ± 0.01 mm. The yolk sac became slender and slightly elongated, averaging 5.70 ± 0.01 mm. Eye pigmentation developed, and melanin deposits appeared along the body. The mouth remained invaginated and unopened.

The larvae at 7 DAH measured 10.9 - 11.1 mm (mean 10.99 ± 0.01 mm), with intensified body pigmentation. The swim bladder was fully developed, and fin formation became prominent. The upper and lower jaws showed significant development, and the heart was fully formed.

The larval stage at 21 DAH, attains a length of 15.6 - 15.8 mm, averaging 15.69 ± 0.01 mm. Fin development is well-defined, with black blotches emerging on the caudal and post-anal regions. Larvae demonstrate enhanced locomotor activity, and the yolk sac is completely absorbed.

At 50 DAH, post-larvae measure between 2.3 - 2.9 cm, with an average length of 2.64 ± 0.03 cm. This stage is marked by active feeding behavior and advanced morphological development, including well-formed fins, distinct pigmentation

patterns, and enhanced swimming proficiency, indicating the transition to the fingerling stage.

At 90 DAH, post-larvae measure 5.7 - 6.8 cm, with an average length of 6.25 ± 0.06 cm. Body scales are fully developed, covering the entire body, while the coloration transitions to a silvery-white hue with fine dark pigmentation on the scales. The lateral line is distinctly formed, marking further morphological advancement.

5.3.9 Assessment of egg and Larval Deformities

Malformations in the developing larvae were systematically categorized into distinct types, including egg coagulation, blister formation, lordosis (spinal curvature), and edema (abnormal fluid accumulation). These abnormalities, indicative of developmental impairments, are visually represented in Figures 5.16 to 5.17, providing a detailed overview of structural anomalies observed during early ontogeny.

Table 5.5: Early developmental stages of chocolate mahseer (*N. hexagonolepis*)

Developmental Phases	Time taken / length variation	Summary
Embryonic stage		
Fertilized egg	0 h	Post-fertilization hardening
1- cell stage (zygotic stage)	1:30 h	One-cell stage development
cleavage phase	2:30 - 9 h	Blastodisc segmentation and cytoplasmic bridge formation
Morula phase	9:30 - 10:15 h	Dense blastomere clustering with continued cleavage
Blastula phase	10 - 13:50 h	Yolk cytoplasmic layer formation and epiboly initiation
Gastrula phase	15:15 - 35 h	Blastoderm extension and progressive epiboly
Somite formation phase	35 - 55 h	Somite differentiation and notochord formation lead to axial structure development and segmentation of the embryonic body.
Pharyngula phase	50 - 80 h	Completion of head and tail morphogenesis accompanied by circulatory system activation
Hatching phase	72 - 105 h	Chorion rupture, tail detachment, and early twitching movements
Larval and post-larval stages		
Hatched larvae	8.7 - 8.9 mm	Characterized by a large yolk sac, absence of pigmentation in the eyes, and underdeveloped mouth and fins
1 day old (post-hatching)	8.7 - 8.9 mm	Visibility of blood vessels
5 days old (post-hatching)	10.6 - 10.8 mm	Yolk sac elongation, eye pigmentation onset, and melanin deposition along the body.
7 days old (post-hatching)	10.9 - 11.1 mm	Presence of swim bladder, fin differentiation, and jaw development
21 days old (post-hatching)	15.6 - 15.8 mm	Complete yolk sac absorption and increased motility
50 day old post larvae	2.3 - 2.9 cm	Well-developed fins and Progression towards fingerling characteristics
90 day old fingerling	5.7 - 6.8 cm	Completion of scale development and Formation of a distinct lateral line

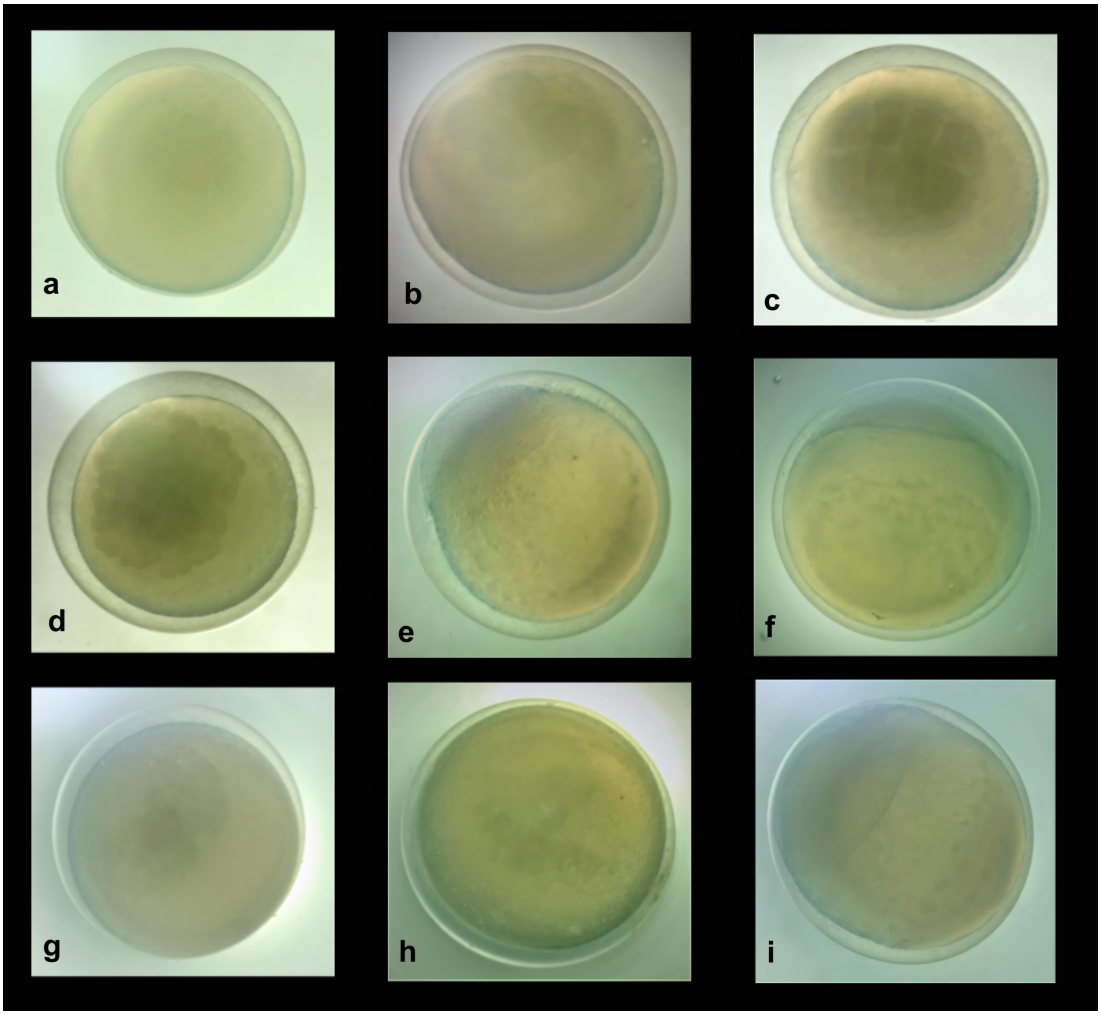

Figure 5.13: a) Fertilized egg b) 4 cell stage at 3 h c) 8 cell stage at 3:35 h d) 32 cell stage at 4:45 h e) Morula stage f) Oblong stage (Blastula phase) g) Sphere stage (Blastula phase phase) h) Dome stage (Blastula phase i) epiboly 30%

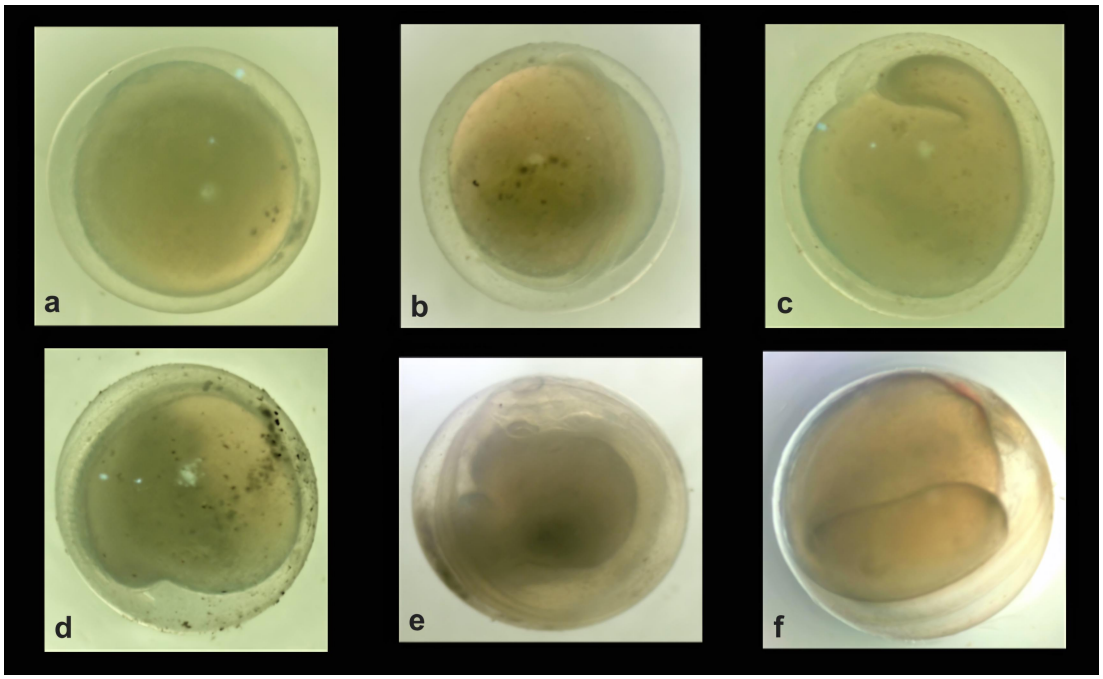

Figure 5.14: a) Germ ring (Gastrula stage) b) Bud stage (Gastrula stage) c) and d) Somite formation e) Pharyngula phase f) Right before hatching

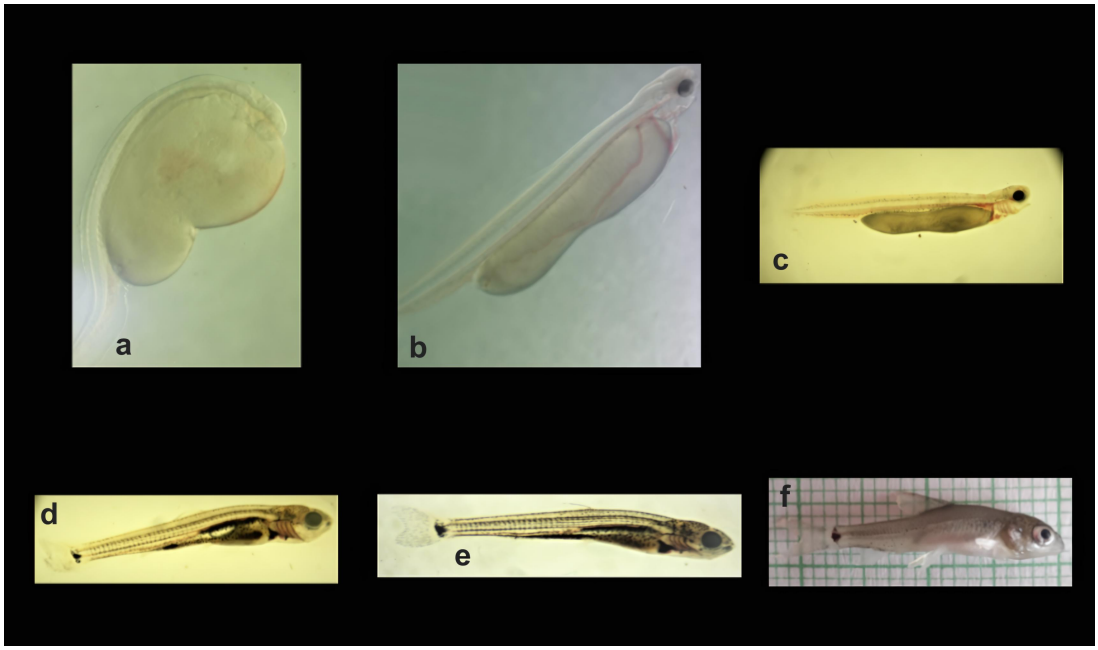

Figure 5.15: a) 72 h after fertilization hatched larvae b) 1 day old larvae, 8.7 mm c) 5 days old larvae, 10.7 mm d) 7 days old larvae, 10.9 mm e) 21 days old larvae, 15.7 mm f) 50 days old larvae, 2.4 mm

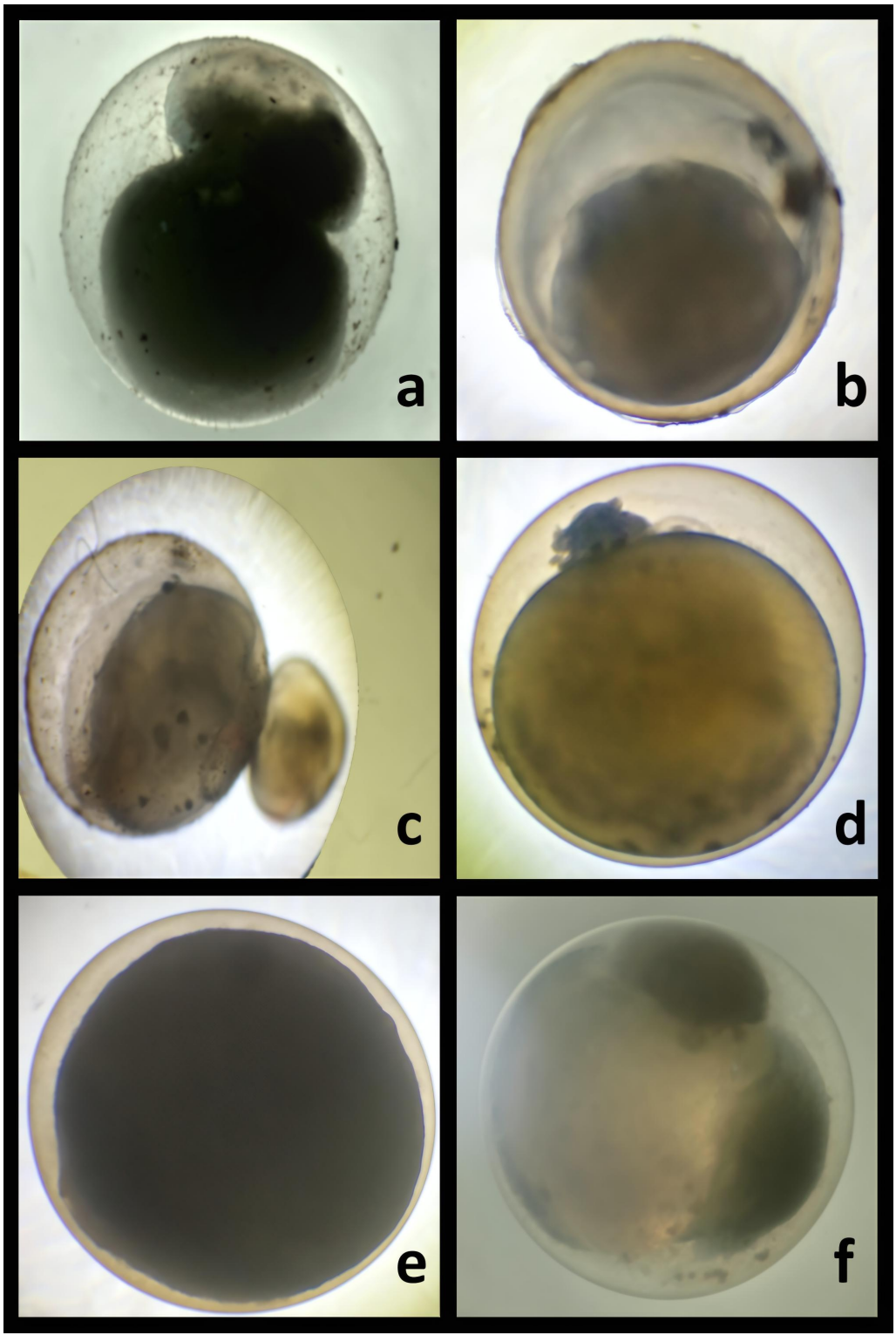

Figure 5.16: a-b) Yolk sac edema c-d) Appearance of blister e-f) Coagulation of egg

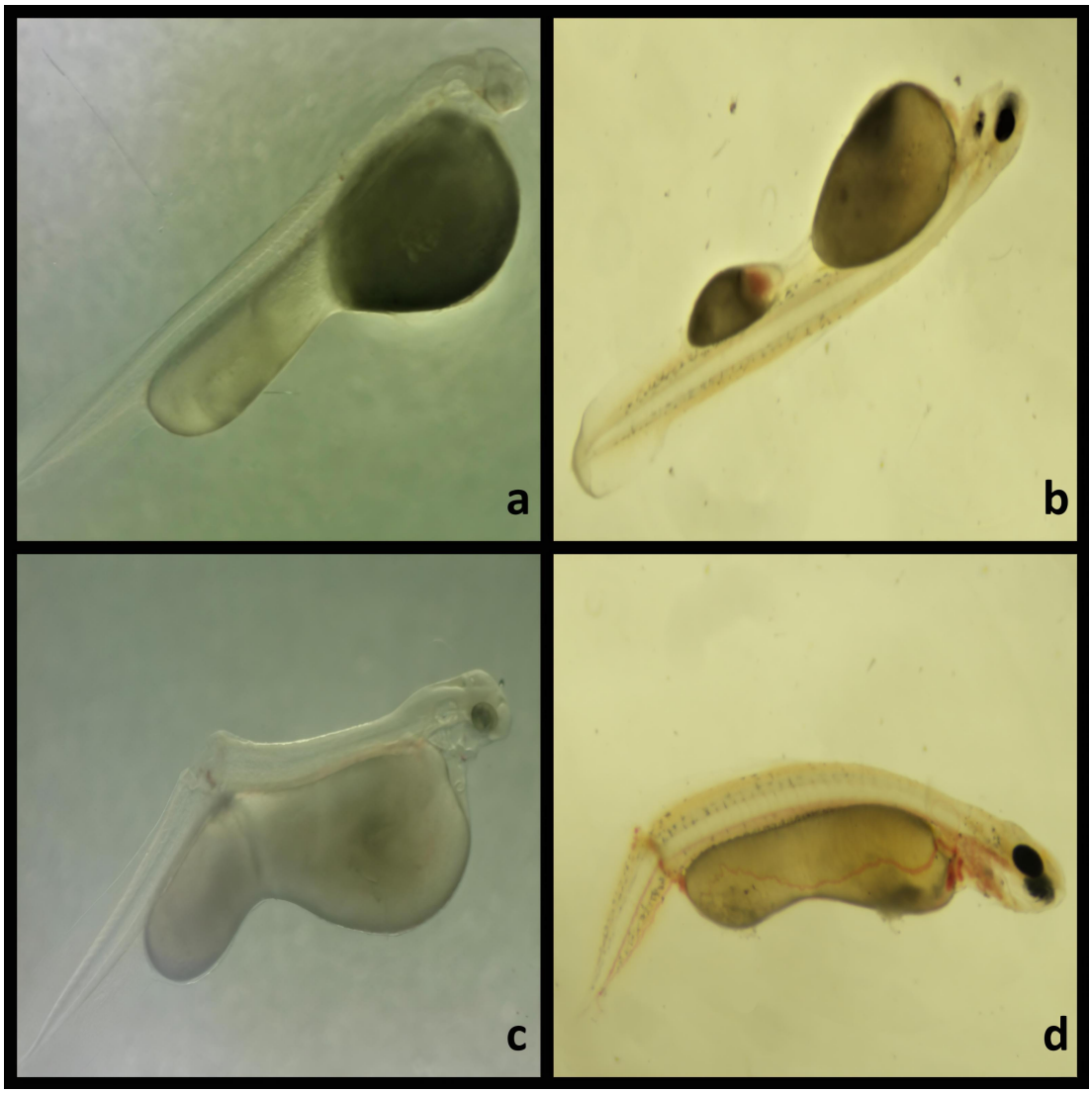

Figure 5.17: a-b) Edema on newly hatched larvae c-d) Spinal deformities

Figure 5.18: Experimental pond

Figure 5.19: Panoramic view of experimental pond

Figure 5.20: Overview of the hatchery farm

Figure 5.21: Mulberry trees overlying the pond

Figure 5.22: Azolla fern

Figure 5.23: Mahseer feeding on insects

Figure 5.24: Capturing of fishes for breeding

Figure 5.25: Artificial stripping of eggs from female brooder

Figure 5.26: Mixing of eggs and milt for fertilization

Figure 5.27: Incubation of fertilized eggs in hatching trays

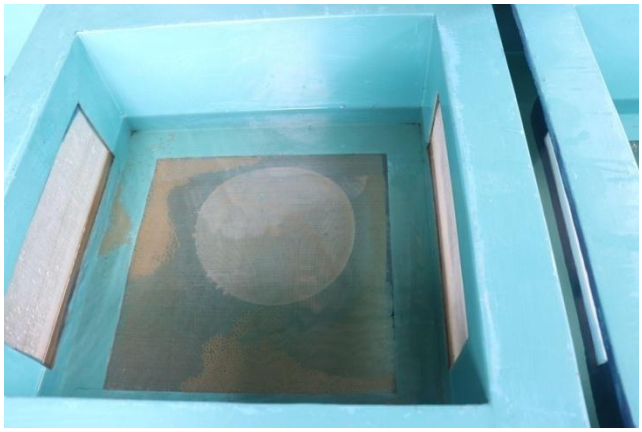

Figure 5.28: Eggs in hatching trays

Figure 5.29: Manual removal of unfertilized eggs

5.4 Discussion

Optimal water quality is a critical determinant of successful breeding and larval rearing in *Neolissochilus hexagonolepis* (commonly known as copper or chocolate mahseer). Even minor deviations from ideal parameters can significantly compromise reproductive efficiency and early developmental stages (Dash *et al.,* 2021b). Environmental variables such as temperature and photoperiod are integral to the regulation of reproductive cycles, with spawning closely associated with the monsoonal period. This synchrony suggests that increased water flow and temperature fluctuations may serve as natural spawning triggers (Subba and Mahaseth, 2015). A dissolved oxygen concentration greater than 6 mg/L is crucial for sustaining high egg viability and robust larval survival. Hypoxic conditions have been shown to result in substantial embryonic mortality, with experimental data indicating 40 - 60% mortality within just 24 hours of exposure (Lemos *et al.,* 2018). Similarly, temperature plays a pivotal role, with an optimal range of 24 - 26°C identified for successful spawning induction and larval growth. Temperatures below 22°C or above 28°C are linked to lower fertilization success (35 - 50% decrease) and increased occurrences of larval deformities (Tropea *et al.,* 2015). Stability in pH levels, ideally between 6.8 and 7.5, is essential for ensuring proper chorion expansion during egg hydration, as well as preventing osmoregulatory stress that could compromise larval viability (Slembrouck *et al.,* 2012). Studies by Dash et al. (2021b) further confirmed that 23 - 25°C is optimal for egg incubation and larval growth. Water temperatures beyond 31°C in hill stream environments, may induce thermal stress, ultimately impairing reproductive performance in this cold-water-adapted species (Majhi *et al.,* 2013). Environmental contamination of surface and groundwater from natural and human-related sources have been recognized as a growing threat to aquatic biodiversity and human health globally (Akhtar *et al.,* 2021). Given these sensitivities, it is imperative to adopt both in situ and ex situ conservation strategies tailored to the species ecological requirements.

This study observed moderate but consistent sexual dimorphism in *N. hexagonolepis*, aligning with patterns found in other mahseer species. Adult males were generally more streamlined, with lower body depth ratios, and exhibited elongated pectoral fins, traits possibly linked to mating behaviors (Urquhart and Koetsier, 2011).

Additionally, breeding males developed small but distinguishable tubercles on the snout and operculum, reflecting traits in *T. putitora* (Langer *et al*., 2001). The Tor species *T. remadevii* is known for its striking golden nuptial coloration (Pinder at al., 2018) whereas *N. hexagonolepis* exhibits a mild intensification of its coppery opercular sheen during the breeding season. This interspecific variation in dimorphism likely reflects adaptations to diverse habitats or reproductive strategies. Juveniles showed no significant sexual dimorphism, supporting the findings of Laskar et al. (2013b), who proposed that secondary sexual characteristics in mahseers emerge only at sexual maturity. Observations of brighter coloration in males and distended abdomens in females during the breeding season mirror previous biometric studies (Laskar *et al.,* 2013b; Sharma and Mahapatra, 2018).

Some scientific studies have demonstrated notable geographical variations in the sex ratio of *N. hexagonolepis* populations. For instance, investigations carried out in the Tamor River, Nepal, revealed a female-biased sex ratio of approximately 1:1.2 (male to female), implying a relatively higher abundance of females in that habitat. This imbalance in sex ratio may be attributed to factors such as asynchronous spawning migrations and sex-specific behavioral segregation during feeding periods (Subba and Mahaseth, 2015). Conversely, contrasting findings were reported from Meghalaya, India, where the sex ratio was skewed towards males, with one female corresponding to approximately 1.26 males. This male-biased ratio suggests potential regional disparities that may be influenced by ecological variables, reproductive timing, or variations in sampling techniques (Mahapatra and Vinod, 2011). In relation to these findings, the present study observed a more pronounced male dominance, with a recorded sex ratio of 1:0.42 (male to female) in wild populations. This trend highlights how environmental and biological factors can shape sex ratio patterns and may also point to differences in reproductive strategies or habitat use between males and females.

In the present study, the GSI confirmed an extended breeding season for *N. hexagonolepis*, extending from May to September, with peak activity during July and August. This trend mirrors observations in *T. putitora* (Sharma *et al.,* 2024) and emphasizes the role of monsoon cues indicating reproductive readiness during the monsoon period. These findings validate regional studies that emphasize the role of

environmental factors in modulating reproductive cycles (Mahapatra and Vinod, 2011). According to Subba et al. (2024), the male GSI values per month ranged between 0.17 ± 0.05% and 3.27 ± 1.68%, while female values spanned more widely, from 0.13 ± 0.07% to 10.57 ± 4.56%, which corresponds closely with my current findings. GSI values in females were highest during the monsoon and lowest in post monsoon, consistent with seasonal ovarian regression. This trend is similar to that reported for *T. putitora* in Bhimtal Lake (Sharma *et al*., 2024), suggesting a shared pattern of reproductive synchrony across species. Histological examinations revealed the presence of post-ovulatory follicles alongside developing vitellogenic oocytes, indicating that *N. hexagonolepis* is a multiple spawner, releasing eggs over an extended period rather than in a single spawning event (Jyrwa and Bhuyan, 2017).

Fecundity is an important indicator of a species reproductive capacity and is influenced by factors such as body size and health (Subba *et al.,* 2020). Fecundity in females exhibited considerable variation, ranging from 4,650 to 10,754 eggs per female, and demonstrated a high positive correlation with ovary weight (r = 0.909), highlighting the direct influence of gonadal mass on reproductive output. These values align with those previously documented by Mahapatra et al. (2004), thereby affirming the species consistent reproductive potential under hatchery conditions. Furthermore, fecundity showed a significant positive correlation with total body weight (r = 0.7666) was also observed, underscoring the biological trend that larger females contribute more substantially to egg production, a pattern similarly noted by Subba and Mahaseth (2015). Despite existing efforts, comprehensive research that integrates multiple perspectives on reproductive biology in relation to localized environmental conditions remains limited.

In the present study, the diameter of fertilized eggs of *N. hexagonolepis* ranged between 2.8 to 3.1 mm, aligning closely with the findings reported by De Silva et al. (2004), who observed a size range of 2.0 - 3.08 mm in the same species. The consistency in egg dimensions reported across various studies highlights the species-specific nature of egg size in *N. hexagonolepis*, suggesting that both genetic makeup and environmental conditions whether in the wild or under hatchery settings play a role in shaping this trait. The water-hardened eggs measured 2.2 - 3.0 mm in diameter, with an incubation period of 72 - 105 hours after fertilization (HAF). These

observations are in line with reports from other mahseer species, such as *Tor tambroides*, which shows similar egg sizes and hatching duration (Azaudi *et al.,* 2013). Together, these findings deepen our understanding of the early developmental biology of this species and provide a useful foundation for refining hatchery practices to improve larval survival and overall reproductive success.

In this investigation, *N. hexagonolepis* showed strong reproductive performance under hatchery conditions, with fertilization and hatching rates of 89.33% and 79.33%, respectively. These results are consistent with earlier work by Mahapatra and Vinod (2011), who reported fertilization rates of 80 - 85% using the dry stripping method in captive breeding programs in Meghalaya. Comparable trends are also seen in other mahseer, such as *Tor tambroides*, where fertilization and hatching rates have ranged from 80.1% - 99.9% and 55% - 96.4%, respectively (Azaudi *et al.,* 2013). Such comparisons highlight the considerable reproductive potential of mahseer species when bred under optimal conditions. Hormonal induction has further enhanced breeding success, with synthetic hormones like ovaprim and gonopro-FH yielding promising results in *N. hexagonolepis*, as reported by Sharma et al. (2016) and Jyrwa and Bhuyan (2017). These findings collectively reinforce the effectiveness of controlled breeding approaches in enhancing reproductive success in this valuable species. Furthermore, the application of ovatide has yielded high success rates, with Azaudi et al. (2013) reporting a 91% fertilization rate in the related species *Tor tambroides*, suggesting potential applicability for *N. hexagonolepis* in the future. The observed deformity rate of 16.83% in this study underscores the need for further investigation into the environmental and genetic factors influencing embryonic development. Despite progress in breeding techniques, comprehensive evaluations of reproductive parameters under region-specific hatchery conditions remain limited. Adapting protocols to local environmental contexts and validating the efficacy of different hormonal inducers can be essential for enhancing breeding success in the future.

Embryonic development in *N. hexagonolepis* adheres to the common ontogenetic mechanisms documented in most teleosts, proceeding sequentially through the morula, blastula, gastrula, and pharyngula stages before culminating in the hatching process (Hubbs and Blaxter, 1986). The embryonic development in fishes initiates

post-fertilization and encompasses a series of intricate morphological events and cellular movements that ultimately result in the hatching of larvae into the external environment (Solnica-Krezel, 2005; Da Rocha Perini *et al*., 2010). During the morula stage, a dome-shaped blastoderm is established in *N. hexagonolepis* through the aggregation of embryonic cells arranged in layers. Subsequently, in the blastula stage, the blastoderm cells undergo migration towards the equator of the blastodisc, leading to the formation of the blastocoel, a phenomenon also observed in *Tor putitora* (Sarma *et al*., 2016). In the present investigation, the gastrula stage commences with epibolic movements, resulting in the formation of a germ ring observed between 15 and 35 hours after fertilization (HAF), while the gastrula stage in *T. putitora* was observed at 32 hours post-fertilization (Sarma *et al*., 2016), and in *T. khudree*, the gastrula stage is observed at 18 HAF at a water temperature of 20 - 23 °C (Oliver *et al.,* 2007), corresponding to similar findings. At around 36 hours post-fertilization, during the segmentation stage, key morphogenetic movements begin, somites form, the first organ rudiments appear, the tail bud becomes more prominent, and the embryo elongates. In the pharyngula period, the embryo is clearly bilaterally organized, with a well-developed notochord and a complete set of somites that extend to the end of the post-anal tail, similar to observations in golden mahseer (Sarma *et al*., 2016). Hatching occurred between 72 and 105 hours, with hatchlings measuring about 8.7 - 8.9 mm. By 90 days post-hatch, they reached an average length of 6.25 cm. These results are in alignment with prior findings documented in *Tor putitora* (Kunal *et al*., 2018).

The hatchlings presented unpigmented eyes and were devoid of distinct mouths and fins, as reported in other species of mahseer (De Silva *et al*., 2004), consistent with findings in this study. Comparative studies on two indigenous Malaysian mahseers, *Tor douronensis* and *Tor tambroides*, reported hatching times of 68 - 82 and 69 - 90 h post fertilization respectively at 26 - 30 °C (Ingram *et al*., 2005). Complete yolk sac absorption occurred within 16 days post-hatching, by which juncture the larvae attained a total length of approximately 14.32 mm and commenced exogenous feeding, as reported by Akhtar et al. (2015), while in another study, complete yolk sac absorption took place after 21 days post-hatching, possibly due to different agro-climatic conditions. The completion of embryonic development within this

timeframe reflects the adaptation of this species to specific thermal regimes. Temperature exerts a pivotal role in the early developmental stages of *N. hexagonolepis*. Optimal hatching and larval viability were recorded at 23 °C, supporting the findings of Dash et al. (2021b), who emphasized the sensitivity of this species to thermal conditions during embryogenesis. This emphasizes the necessity for temperature optimization in hatchery operations to enhance larval performance and survival rates. Larval development of a new hybrid Malaysian mahseer showed the post-larval stage of this hybrid was short and completed by 23 - 25 DAH when the scales fully covered its body (Ismail *et al*., 2020), with similar findings in this study. The critical nature of the larval stage, characterized by high mortality rates, underscores the importance of understanding developmental biology for effective aquaculture and conservation efforts (Conides and Glamuzina, 2001). The successful transition from endogenous to exogenous feeding, coupled with the development of functional anatomical structures, is essential for larval survival. Insights from the developmental timeline and morphology of *N. hexagonolepis* can improve rearing protocols by informing suitable feeding practices and optimal environmental conditions (Rønnestad *et al*., 2013).

Skeletal deformities in fish have been closely associated with deteriorating water quality conditions (Sindermann, 1979). A range of morphological abnormalities, including lordosis (Sun *et al.,* 2009) and fin deformities (Almeida *et al.,* 2008), have been documented across various species. In recent years, such abnormalities have gained importance as biomarkers for environmental stress and pollution (Yap *et al.,* 2009). Specific deformities such as split fins, gill malformations, and lower jaw protrusions have been significantly correlated with poor water quality parameters, notably low dissolved oxygen levels and elevated concentrations of ammonium, lead, and zinc. The resilience of tilapia in polluted habitats, coupled with their expression of these deformities, highlights their potential utility as bioindicators of non-specific source pollution in freshwater ecosystems (Sun *et al.,* 2009).

The present study emphasises the critical conservation and aquaculture potential of *N. hexagonolepis*, a species increasingly threatened by overexploitation, habitat degradation, and environmental perturbations. The reproductive biology of *N. hexagonolepis* serves as a cornerstone for both i*n situ* and *ex situ* conservation

strategies. The successful use of induced breeding techniques, such as the stripping method, under local environmental conditions shows the possibility of propagation in hatchery conditions. However, future research can be directed towards assessment of artificial propagation techniques such as hormonal induction, effects of climate variability on reproductive phenology and maintenance of genetic health in wild and captive populations. There is a need for the integration of hatchery initiatives with river habitat restoration, as suggested in the broader conservation frameworks (Gupta *et al.,* 2017). In particular, protection of key spawning habitats during peak breeding season and implementation of region-based management plans will be critical for the recovery of *N. hexagonolepis* populations (Sharma *et al.,* 2019). Approaches such as ecosystem-based management and intervention at the policy level (Vinod *et al.,* 2007; Sarma *et al.,* 2021) will be crucial to reverse the decline of this species' population. In conclusion, a comprehensive understanding of the reproductive behavior and ecological parameters of *N. hexagonolepis* is essential for its effective conservation and sustainable management. Future studies can investigate the effects of climate change on spawning behavior, assess the efficiency of artificial propagation methods, and evaluate the genetic integrity of wild populations to support the species resilience and ecological function within freshwater ecosystems.

CHAPTER 6

Sustainable fisheries in Nagaland: Management, conservation, and recommendations from the Dikhu River

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Parts of this chapter have been published in WOS/SCOPUS indexed research journal

6.1 Introduction

The Dikhu River is an important aquatic biodiversity lifeline of Nagaland and harbours a rich and unique assemblage of freshwater fish species with many endemics and ecological importance. However, this fragile ecosystem is under threat from increasing human pressures such as habitat degradation, overfishing, pollution and unsustainable development practices (Lakra and Sarkar, 2006). Given the rapidly escalating threats of habitat destruction, over-exploitation and invasive species combined with insufficient or inadequate management practices during the last century, this rich aquatic biodiversity is under serious threat throughout Asia (Dudgeon *et al*., 2006), where up to 230 freshwater fish species are reportedly at risk. This loss not only endangers ecological health but also the cultural and livelihood values of local communities (Sarkar and Ponniah, 2000).

In recent years, increased sand extraction and deforestation activities in the upper reaches of the river; overfishing of aquatic resources leading to decline in populations of native fish and disruption of food webs in the river system, as well as degradation of ecosystem conditions have been noticed (Kechu *et al.,* 2021). Climate change has also put further strain on fish populations by changing hydrological cycles and the temperature of water that is important for fish migrations, spawning and survival (Xenopoulos *et al.,* 2005; Reid *et al.,* 2019).

With large numbers of fish species under threat of extinction, a synthesis of scientific information and ethno-traditional knowledge is urgently needed, especially in biodiversity-rich regions such as Northeast India. This chapter will provide a broader discussion on the research findings and conservation frameworks on activities taken by the government, fishing communities and field visits to provide recommendations for the management and protection of fish communities in the Dikhu River. Long-term sustainable management of riverine fish populations involves active engagement of local stakeholders and communities (Mittermeier *et al.,* 1998; Chitale *et al.,* 2014). This study was conducted utilising primary data obtained through site visits and interactions with different members of fishing communities, village chiefs and the Department of Fisheries, and secondary data were obtained from official reports and research publications.

6.2 Legal, customary, and community approaches to fisheries management in Nagaland

The Nagaland fisheries sector is evolving through a unique blend of statutory frameworks, traditional governance, and grassroots participation. The Nagaland Fisheries Act, 1980, provides a legal basis for the sustainable use of aquatic resources. Customary laws and community-conserved areas are a testament to the enduring ecological wisdom of indigenous communities. In addition to these laws, local efforts such as self-help groups, cooperatives and involvement of NGOs which have a strong community-based approach to conservation and improving livelihoods.

6.2.1 Government initiatives and present scenario of fisheries in Nagaland

The Department of Fisheries and Aquatic Resources has taken a proactive approach to promote sustainable aquaculture and enhance fish production in the state. In the annual report, the department has highlighted its efforts for the promotion of fish production through semi-intensive and intensive aquaculture, paddy-cum-fish culture, reservoir fisheries and integrated farming. These strategies not only improve the efficient use of resources but also support the long-term sustainability of aquatic ecosystems. The state produces 11,158.90 metric tonnes of fish and about 56 million seed units annually with the help of a network of government and private hatcheries, demonstration farms and specialised Mahseer and trout facilities. It has also provided awareness centres, training institutes and farmers hostels which can build local capacity and promote community participation in sustainable fisheries.

6.2.1.1 Schemes and policy framework

The state has introduced a range of schemes and policy measures designed to boost fish production, ensure responsible use of resources, and improve the livelihoods of fishing communities.

A. State plan schemes:

● These includes provision of administrative assistance, the implementation of digital tools, awareness programs through exhibitions and melas, implementation of gender-focused budgeting in order to empower women, promotion of sport fisheries for the purpose of conservation, and the investment in infrastructure and development.

B. Schemes supported by NABARD:

● At present, NABARD is in the process of implementing cluster-based fisheries projects in seven districts of Nagaland. While, new hatcheries are also being set up to boost the production of fish seeds.

C. Central sector and centrally sponsored schemes:

● The North Eastern Council (NEC) has started the project of "Table Fish Production Farm," which is for the unexploited and remote areas for seed and table fish production, as well as generating employment in rural areas. This project is being implemented in all the districts.

● Pradhan Mantri Matsya Sampada Yojana (PMMSY) aims at the development of a fisheries sector which is environmentally sustainable, economically vibrant and socially inclusive. The organisation aims at sustainable growth, upgrading the value chain, income generation, nutrition security and establishing a strong regulatory framework.

6.2.1.2 Conservation and ecotourism linkages

The department has also turned to fishery-based ecotourism as a means of conservation and rural upliftment. These initiatives include setting up community fish reserves, promoting angling and sport fisheries, and raising public awareness. One chief example is the annual hornbill angling festival, held in December during the hornbill festival in coordination with the Anglers Association Nagaland (AAN). The event not only promotes ecological conservation but also links it to tourism and instills local pride by providing income opportunities for local communities.

6.2.1.3 Women participation

The government is aiding women by providing them with subsidies and support to undertake small-scale fish farming and other businesses through programmes like SHGs and cooperatives. Participation of women in aquaculture and fisheries are also being actively encouraged by the Department of Fisheries.

Many women have increased their diversity of income and household nutritional status through activities such as integrated farming, ornamental fish farming, aquaculture and entrepreneurial training. The required practical skill-based training in processing, preservation, value addition and marketing is provided by the government and other organisations to empower women in the community to have financial independence and a chance to uplift their livelihoods. The women

community are also actively involved in fish marketing activities in various regions of Nagaland. These initiatives help boost community participation, generate employment and promote sustainable fisheries development in the state.

6.2.1.4 Collaborative support

The state receives support for aquaculture development from the state fisheries department as well as various central and regional agencies. This organisation includes the North Eastern Council, National Bank for Agriculture and Rural Development (NABARD), Indian Council of Agricultural Research (ICAR), Ministry of Agriculture (Government of India) and National Cooperative Development Corporation (NCDC), providing financial assistance and technical support for strengthening the sector. Some other central agencies also provide research and seed production technology, capacity building and extension services to the fish farmers of the state. These institutes are the ICAR Research Complex for North Eastern Hill Region and the ICAR-Central Institute of Freshwater Aquaculture. The ministry also implements numerous Centrally Sponsored Schemes, including PMMSY for assisting in the construction of ponds, hatchery development, fish seed distribution, cold chain facilities, ornamental fisheries and production of livelihoods in rural communities. To provide financial assistance to farmers, the government has also established subsidies at low rates, credits and programmes in collaboration with banks and cooperatives.

6.2.2 Acts and Laws

The Nagaland Fisheries Act, 1980

The Nagaland Fisheries Act was introduced in 1980, which provides regulations regarding fisheries development in the state. It was formed to prohibit the use of destructive fishing ways such as poisoning, dynamiting and indiscriminate nets and also to monitor the type of gear and mesh size and to observe seasonal bans to protect breeding grounds and young ones. There is a licensing system with restrictions on the size of the catch and weight and closed seasons to allow stocks to recover. The government also tracks portions of the fish trade, like prices for sale and export, to help the regional economy. Illegal activities are monitored by the authorities, granting them the rights to penalise, act and confiscate illegal fishing gear and unauthorised practices.. It gives authority to the government to manage water resources and safeguards the livelihood of the fishing communities.

The Wildlife (Protection) Act, 1972

The Wildlife (Protection) Act of 1972 applies to Nagaland and provides the main legal basis for biodiversity conservation in the state. Wild flora and fauna inhabit the area, including freshwater fish, and activities such as hunting, trading, and any other destructive practices are prohibited.

It sets out the framework for protected areas, national parks, and wildlife sanctuaries, where species can be conserved in their natural habitat rather than only in captivity. Species are classified into categories according to how vulnerable they are, and those with the highest level, covering the most endangered species, receive the strongest legal protection and severe penalties. Poaching, illegal trade, and possession of wildlife or wildlife products without the proper permits are all offenses under the Act, with penalties ranging from substantial fines to imprisonment, and the 2003 amendment tightened these provisions further. It directed the creation of a National Board for Wildlife to advise on the formulation of conservation policies. Conversely, implementing these laws in more isolated areas of the country is notoriously challenging. Even with these challenges, the Act remains the most pivotal legal instrument for wildlife conservation and environmentally sustainable resource management.

The Biological Diversity Act, 2002

India enacted the Biological Diversity Act, 2002, to implement the UN Convention on Biological Diversity (1992). The goal is to conserve biodiversity in a sustainable manner and to share equitably in the benefits that arise from the use of resources that they have traditionally developed and conserved.

The Act was implemented through the National Biodiversity Authority (NBA), local Biodiversity Management Committees (BMCs) and State Biodiversity Boards (SBBs). Together they control access to biological resources and fund grassroots conservation initiatives.

The Act empowers the central government to determine threatened species, regulate their use and establish databases. The offences are cognisable and non-bailable by the National Green Tribunal (NGT), as stated above. Recognising customary practices, facilitating approved trade and supporting collaborative research, and protecting farmers, livestock keepers and traditional healers are ways of providing

protection of traditional knowledge. It involves balancing biodiversity conservation, social justice, and community rights.

Customary Law and Community-Conserved Areas in Nagaland

Historically, Community Conserved Areas (CCAs) were established in the 1800s to combat deforestation and loss of wildlife. CCAs are defined as natural and modified ecosystems containing significant biodiversity values and ecological services and that are voluntarily conserved by indigenous and local communities through customary laws or other effective means (Hockings *et al.,* 2004). These areas prove that they are dedicated to preserving ecosystems and cultural heritage amid socio-economic shifts and ecological stresses due to overhunting, poaching and shifting cultivation.

This grassroots conservation ethos aligns with Article 371(A) of the Indian Constitution, which guarantees Naga customary practices, legal frameworks, and land ownership rights. This document points out the need for proper management of the forests and aquatic habitats and respect for the rights of indigenous people. Article 48A and Article 51A of the Constitution provide duties of the state and duties of the people to protect and improve the environment, including forests, animals and natural resources. The Supreme Court of India has reaffirmed that natural resources belong to the people, and any violation of ecological integrity can be a violation of the fundamental right to life under Article 21.

Traditional ecological knowledge underpins rural livelihoods and helps to conserve the genetic diversity on which agriculture, medicine and the health of ecosystems depend. The focus of conservation efforts should prioritise the protection of biodiversity hotspots, ensuring the active involvement of local communities and the promotion of alternative livelihoods. Additionally, ex-situ conservation through gene banks, along with the scientific validation of traditional health practices, plays a crucial role in both the conservation and responsible utilisation of local knowledge.

6.2.3 Community participation in fisheries

Self-Help Groups (SHGs)

Since 1999-2000, self-help groups have been initiated in Nagaland as part of rural development initiatives with active promotion for women and youth empowerment. As of January 2020, the total number of SHGs in the state was 9175. The Nagaland State Rural Livelihoods Mission (NSRLM) provides these groups with financial and

technical support to earn income through activities such as processing, marketing, fish farming, etc. The state Department of Fisheries has also developed training programmes that can build capacity in value addition and entrepreneurship (Tuithung *et al*., 2023).

Fishermen Cooperative Societies

There are around 413 fishery cooperatives registered in Nagaland (State Cooperative Database, Nagaland). They work with local Panchayati Raj institutions to encourage collective fisheries development, enhance market access and promote development across the sector.

NGOs and Non-Profit Organisations

Various non-governmental organisations (NGOs) have been helping state agencies, local communities and individual stakeholders with the aim of conserving indigenous fish and supporting sustainable aquaculture and fisheries-based activities.

Anglers Association Nagaland (AAN)

This is a registered non-profit organisation dedicated to freshwater angling as a sustainable recreational activity and to fish conservation. It runs awareness programmes and promotes responsible fishing tourism. It collaborates with government agencies and other NGOs to back up conservation efforts.

6.3 Major threats

Indiscriminate fishing

The unsustainable and indiscriminate fishing techniques have negative effects on fish stocks and disturb ecological balance and threaten aquatic ecosystems. Apart from the destructive techniques like dynamite, the use of chemical agents like lime, bleaching powder, herbicides, insecticides and overfishing can lead to mass mortality of juvenile and adult fish, thus reducing natural populations and affecting reproductive capacity (Betts *et al*., 2020; Kechu *et al*., 2021).

Pollution

Human activities that degrade water quality pose direct threats to fish populations and weaken the overall health of river ecosystems. Pollutants such as untreated industrial effluents, agricultural runoff and domestic waste not only pollute water but also destroy fish habitats, making survival more and more difficult. Research on the Dzuna River in Jotsoma village, Nagaland, observed that the fish diversity was lower

in downstream sections, where pollution levels were higher, compared to the less impacted upstream areas (Konyak *et al*., 2023).

Degradation/habitat fragmentation

Pollution from natural and anthropogenic sources contributes to ecological degradation and the loss of biodiversity in the river systems. The ecological degradation occurs mostly due to overexploitation, sand mining, industrialisation and aggressive fishing methods. Diversions of water resources, habitat loss and modification in hydropower dams have affected the overall habitat ecology and population. It poses a serious threat by creating a barrier for fish migration, breeding, feeding and mass mortality of fries and fingerlings due to irregular discharge of water from dams and habitat loss (Goswami, 2018). The Dhansiri River, a major river in Nagaland, is similarly under pressure from habitat loss and environmental degradation, which may negatively affect its fish populations and overall aquatic biodiversity (Acharjee *et al*., 2012).

Invasion of exotic species

The indigenous group of fishes is always a threat when exotic species are introduced in the same water body, as they compete for food and shelter. This inception can bring about parasitic diseases and genetic dilution in the form of hybridisation to the native fishes, resulting in loss of diversity and natural habitat of the ecosystem (Singh *et al*., 2013). One example is the predominance of Indian major carps, particularly *Catla catla*, in Doyang Reservoir can largely be attributed to deliberate stocking practices (Odyuo and Nagesh, 2012). The introduction of these species into the reservoir has significantly influenced the fish community structure, favouring the proliferation of stocked species over naturally occurring ones.

Effects of climate change

The fish community can be affected by environmental problems due to the monsoon patterns influenced by climatic changes (Nel *et al*., 2009). The effects of climate change can be adverse on the riverine ecosystem by disrupting the food chain, changing the flow dynamics of streams and rivers and changing temperatures. The life cycle of many native species, gross productivity and modifications in the feeding and breeding habitats of endemic species populations impact their spawning nature (Singh, 2015). The consequences of climate change in the Eastern Himalayan fragments can result in possible flooding in north-eastern parts of India such as

Assam, Arunachal Pradesh and Sikkim. Furthermore, this can lead to the formation of lakes which flow uncontrollably downstream, causing anything on the way to be washed away. In this way, the fish communities that are rheophilic in nature are threatened to become extinct, which can pose a serious threat (Das, 2010). The adverse natural disasters, like erosion, floods, irregular changes in river course, earthquakes, cloudbursts, etc., are also factors contributing to a deteriorating fish population (Goswami *et al.,* 2012). Arunachal Pradesh ranks second in India in terms of high-altitude wetlands, accounting for about 7.6% of the total in the state, bearing rich biodiversity of flora and fauna and playing a significant role in maintaining ecological tranquillity. Unfortunately, the assessment report predicted by the Indian Network for Climate Change Assessment (INCCA) states that the surface air temperature is estimated to rise from 0.9° ± 0.6°C to 2.6° ± 0.7°C by the 2030s and subsequently by the 2080s is projected to increase to 2.8° - 5°C in due course of time (Deka *et al*., 2013).

6.4 Conservation efforts in Dikhu River, Nagaland

Sustaining biodiversity through community fishing

Community fishing is an age-old tradition in the tribal villages along the Dikhu River, deeply woven into their cultural and spiritual beliefs. It's not just a means of livelihood; it is a time of unity when communities come together not only to fish but also to bond and seek divine intervention from God. This practice is often the responsibility of village councils and elders. Usually men from the village come together to select the site and construct the barricades using locally available materials such as bamboo, rocks and twigs, often before the monsoon or sowing season. The fish traps are not permanent and are placed in spots along the migratory paths where the fish will congregate to be harvested, and the process can take a few days.

Community fishing uses traditional plants such as *Schima wallichii, Acacia pennata* and *Juglans regia* to stun fish to facilitate their capture using spears, nets, or indigenous traps. The catch is shared fairly among community members. Community fishing protects ecological knowledge, cultural identity, and food security. Biodiversity loss in Northeast India, with the help of community support, can aid in river management for long-term aquatic ecosystem protection and restoration (Kechu and Pankaj, 2023a).

The Tzüla (Dikhu) Green Zone initiative

The Tzüla (Dikhu) Green Zone Project, initiated in 2010 by the villages of Longsa and Ungma in the Mokokchung district, is a positive example of conservation by the community. Managed by village councils and youth unions, it protects nearly 16.8 km² of forest and river habitats. The Dikhu River, locally known as "Tzüla", meaning "water" in the Ao dialect, is valued for its cultural importance and as a critical breeding site for native fishes such as trout and mahseer. The community has also imposed strict rules, including a ban on illegal fishing, with fines as high as ₹50,000. The project is an example of how local governance and collective action can restore biodiversity and conservation of cultural traditions.

Mahseer hatchery at Süteplenden (Longkong village), Mokokchung, Nagaland

The Mahseer hatchery was launched on 25 April 2018 and is situated geographically at 26° 23' 39.0" N latitude and 94° 38' 21.5" E longitude. The hatchery has been established jointly by the ICAR-Directorate of Coldwater Fisheries Research (DCFR), Bhimtal, and the Department of Fisheries and Aquatic Resources, Government of Nagaland, under the North Eastern Hill (NEH) programme and is a significant step towards sustainable coldwater aquaculture in the region. The hatchery also encourages ecotourism by supporting recreational fisheries and conservation objectives through breeding and seed production of golden and chocolate Mahseer. The project has a capacity to produce 50,000 fingerlings at present with a scope to increase it to 100,000 in the near future, promising to strengthen local livelihoods while conserving indigenous fish biodiversity.

6.5 Management policies and recommendations for sustainable fisheries

A scientific approach and sincere engagement with communities are crucial for sustainable fishery resources in ecologically sensitive hill regions like Nagaland. Here are a few recommendations (Singh, 2015; Shahi et al., 2018; Singh, 2018).

1. Resource mapping and assessment: Systematic surveys should identify areas suited to aquaculture development and map biodiversity hotspots that need protection. At present, most management decisions are made without this baseline data.

2. Stock enhancement through ranching: Seed ranch programmes need to be developed specifically for endemic wild species whose populations have declined. Priority should be given to the most vulnerable species that are endangered.

3. Improving regulatory frameworks: Harmful practices like poisoning, dynamite

fishing, and electro-fishing remain active threats in many parts of Nagaland. But stringent legislation alone is not enough without enforcement at the local level.

4. Technology-based hatcheries and ecotourism: Technology-equipped hatcheries can support recreational fisheries, but they can also create income streams through ecotourism.

5. Seasonal fishing bans: Commercial fishing during breeding seasons depletes the very stocks that sustain long-term catches. A closed season gives fish population time to recover before the next harvest cycle.

6. Species-specific feed development: Live and formulated feeds suited to indigenous species would take pressure off wild stocks. It remains one of the wider gaps in the field.

7. Community capacity building: Fisheries management requires local awareness, training and support to encourage active local participation.

8. Habitat preservation: Water quality and the ecological habitat are lost when riparian zones are deforested or mined. Land-use restrictions near riverbanks are necessary for recovery and restoration.

9. Genomics research and health management Genomic tools can improve the breeding programmes and disease resistance in aquaculture. This research is largely lacking in the indigenous species of Nagaland and needs investment.

10. Eco-monitoring and climate resilience: Only through long-term biological monitoring can we detect gradual environmental changes before they become a crisis.

11. Protection of ecologically important habitats: Breeding and feeding grounds should be officially recognised as protected areas or community fish sanctuaries. It works best when local communities set the boundaries and monitor the rules to protect the natural resources.

12. Gear and mesh size regulations: Standardised gear and minimum mesh sizes reduce the harvest of juveniles before they reach reproductive stage. Without these regulations, pressure accumulates at the base of the population rather than at the top.

13. Collaborative conservation campaigns: Government agencies, NGOs, and local stakeholders need to join efforts in promoting sustainable conservation.

The Dikhu River holds a large share of aquatic biodiversity in the region, and it is under growing pressure from human activity and a changing climate. However, traditional governance and community efforts such as the Tzüla Green Zone,

together with state programmes like hatcheries and fishing regulations, show that sustainable management can work here. The real constraint is how little has been documented; protecting the river will take much more knowledge of its habitats and fish than currently exists and a far better grasp of how the river system works. Community-based conservation works best when local knowledge and scientific understanding reinforce each other. Habitat protection, restocking, legal enforcement, and ecotourism must function as an integrated approach to keep the river healthy while supporting dependent communities.

CHAPTER 7

Summary and conclusion

The Dikhu River is an important freshwater river in Nagaland. It represents a crucial lifeline for the local residents and wildlife depending on it. It also extends through culturally rich and vibrant villages of Nagaland and supports the livelihoods, traditions, and day-to-day lives of local inhabitants. The present study provides an overview of the water quality, fish diversity, traditional fishing practices and the conservation measures being carried out to protect this valuable ecosystem of the Dikhu River. The species investigated, *Neolissochilus hexagonolepis*, has received special importance due to its commercial and cultural significance in the region. The research sheds light on its natural ecology and captive reproduction that can be important for its protection in the future.

Variations in the physico-chemical characteristics during the course of the study revealed the impact of environmental shifts on the water quality of the river studied. The measurements showed that air temperature (31.67°C), water temperature (26.67°C), flow velocity (3.02 m/s), and total dissolved solids were high (94.67 mg/L) during monsoon season, implying the major impact of runoff and catchment systems. While the winter season showed the maximum values of dissolved oxygen (11.37 mg/L), alkalinity (77.83 mg/L) and hardness (92.10 mg/L) because of the low flow of water and higher concentrations of solutes. From all the observed parameters, it suggests that the variables are within the permissible limits for fresh water ecosystems: pH (6.5 - 8.5), DO (>5 mg/L), TDS (<500 mg/L), TH (<300 mg/L), and TA (<120 mg/L) as per BIS, ICMR and WHO guidelines.

Hence, to continue the preservation of ecological stability in the river ecosystem, it is important to keep a routine check and integrated management of natural resources. There is a need for a regular monitoring system and integrative management of riverine resources to preserve ecological stability along the river. The findings provide baseline data for sustainable policy recommendations that will help in promoting fisheries and biodiversity conservation, along with livelihood support for people dependent on the Dikhu River.

The study site had a fairly diverse fish community (28 species distributed across 6 orders and 13 families), dominated by the cypriniformes with 19 species. The post-monsoon ($H' = 2.912$; Simpson's 1-D = 0.936; evenness = 0.707) was the most diverse season, with species richness ranging between 21 at Alaphumi and Sumi Setsü to a peak of 28 species identified at Longkong during the study period. Among

the listed species, *Devario aequipinnatus, Opsarius bendelisis, Garra naganensis, Amblyceps apangi,* and *Schistura savona* were the most dominating. The data also recorded the first taxonomical documenation of *Garra birostris* from this river.

During field investigation, economically important but threatened category species, viz., *Tor putitora* (Endangered) and *Neolissochilus hexagonolepis* (Near Threatened), were recorded from the study site, marking the importance of both fisheries and biodiversity conservation in this region. The species listed and identified are categorized mostly under the "Least Concern" category, but the occurrence of threatened and data-deficient taxa, accompanied by the segregation of community composition in seasonal variations, mirrors the ecological sensitivity of the river ecosystems. Studies reveal that the Dikhu River supports a broadly stable fish community but is susceptible to environmental pressures and needs attention to biodiversity conservation and habitat restoration.

The cluster analysis (Bray-Curtis) showed two distinct groups based on site segregation: Longsa, Chakba, Longkong and Alaphumi as one group and Salulamang and Sumi Setsü as another group. Species like *Botia rostrata, Tor putitora,* and *Garra naganensis* were found to be associated with higher TDS levels and warmer waters, while *Schistura savona* and *Glyptothorax indicus* were more associated with cooler, reduced water flow conditions during the winter and pre-monsoon periods. Studies on the seasonal variation also showed overlap between pre-monsoon and post-monsoon fish communities, while monsoon and winter seasons indicated separate cluster groups which may be likely influenced by floods and reduced water flow. In conclusion, the spatial and seasonal analyses play a vital role in shaping the fish communities of the Dikhu River. These findings may serve as a significant foundation for the development of management strategies that are site- and season-specific for the purpose of future biodiversity conservation.

The documentation of Ao and Sumi provides evidence that the locals practice fishing practices along the Dikhu River and so far the types of gear recorded were four accessories, one fishing craft, and three fishing techniques. Most of the traditional gears were handcrafted with locally available and eco-friendly materials such as bamboo, wood, and cotton twine. Even so, the use of destructive practices such as dynamite and chemicals in fishing continues to be a concern for the preservation of

traditional knowledge and stricter regulation for the sustainable management of biodiversity resources.

Based on 53 specimens of *N. hexagonolepis* studied from the Dikhu River, the total length range is from 14.0 to 33.8 cm, and the weight range is from 28.63 to 288.68 g. From the given data, an assessment of morphometric and meristic characteristics, the length-weight relationship, and the condition factor was carried out. The morphometric traits expressed as percentages of the standard length (SL) showed significant variation, especially in the height of the dorsal fin (24.65 - 33.86% SL), length of the caudal fin (27.53 - 35.40% SL) and body depth (24.03 - 32.02% SL). The eye diameter relative to the head length ranged from 15.79 to 29.03%. Meristic counts were largely consistent with earlier reports from the Himalayan and North-Eastern regions of India.

Growth analyses showed the highest growth rate for standard length (b = 0.8125) and the lowest for eye diameter (b = 0.0205). Strong positive correlations (r = 0.7769 - 0.9968) between morphometric traits and total length confirmed that body features increase proportionally to fish growth. The length-weight relationship showed positive allometry in males (b = 3.015) and negative allometry in females (b = 2.807) and the pooled sample (b = 2.868). Such differences are likely to reflect ecological factors, including food availability, habitat conditions and seasonal variability. The correlation values for LWR were high (r = 0.970-0.981) for all groups, indicating a satisfactory statistical fit.

The condition factor values greater than 1 in all groups (1.10 - 1.14) confirm that the species is in good physiological health and compatible with the riverine environment. The results in general show that N. hexagonolepis in the Dikhu River shows distinct morphological traits and good condition factors which indicate a healthy habitat. These baseline insights strengthen the case for its conservation and provide a biological rationale for the initiation of captive propagation trials to support both aquaculture and long-term management efforts.

The hatchery study led to successful captive breeding of *N. hexagonolepis* and provided valuable data on its reproductive biology, early growth and survival using wild broodstock obtained from the Dikhu River. Sexual dimorphism was observed during the breeding season, with males releasing milt under gentle pressure on the abdomen and females having a more rounded soft abdomen due to ovarian

development, subdued colouration and pinkish swollen vents that released eggs at peak spawning. A male-biased sex ratio (1:0.42) and a clear spawning peak during monsoon were recorded. Fecundity ranged from 4,650 to 10,754 eggs per female (mean 7,566 ± 1964.15) and was highly correlated with ovary weight (r = 0.909). Fertilisation and hatching rates were quite high at 89.33% and 79.33%, respectively, while larval survival was 70% despite a deformity rate of 16.83%. Growth was similar to hatchlings measuring 8.7 - 8.9 mm at emergence and growing to juveniles measuring 6.25 cm at 90 days, demonstrating the species' ability to adapt to captive conditions. This study helps connect wild *N. hexagonolepis* populations with aquaculture possibilities, giving us a baseline for saving this vulnerable hill-stream fish in the long run.

The Dikhu River is rich in ecology and culture and has been sustained over generations through combined efforts of local governance and community efforts. The Tzüla Green Zone project and similar local initiatives have led to a positive impact on biodiversity conservation. But in recent times, activities such as habitat degradation, usage of harsh chemicals, and overfishing are putting anthropogenic pressure on the riverine resources. Hence, monitoring and active implementation of legal frameworks, empowering local communities for conservation efforts, and encouraging sustainable fishing methods can help restore its natural resources.

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Questionnaire for community perspectives on fisheries and conservation
Title of study:
Researcher:

Section 1: Basic information

Sl. No.	Information	Response
1	Name	
2	Age	
3	Gender	☐ Male ☐ Female ☐ Other
4	Village Name	
5	Tribe/Community	
6	Educational Qualification	☐ None ☐ Primary ☐ Secondary ☐ Graduate ☐ Other
7	Occupation	
8	Marital Status	☐ Single ☐ Married ☐ Widowed
9	Household size	
10	Years of fishing experience (if any)	

Section 2: Fishing practices and resource use

1. Do you or anyone in your family engage in fishing?
   ☐ Yes ☐ No
2. If yes, how often do you fish?
   ☐ Daily ☐ Weekly ☐ Occasionally ☐ Seasonally
3. What methods do you use for fishing? (You can tick more than one)
   ☐ Traditional traps (specify): _____
   ☐ Cast nets
   ☐ Gill nets
   ☐ Hook and line
   ☐ Impaling gears
   ☐ Poisoning (e.g. plant-based)
   ☐ Modern gear (specify): _____

4. What kind of fish do you mostly catch? Please list any local names.Can you specify any fish species that have declined over the years?

   ☐ Yes ☐ No

   If yes, which ones? _____

5. What do you do with the fish you catch?

   ☐ Consume at home

   ☐ Marketed

   Sale (price/Kg/species): _____

   ☐ Share with community

   ☐ Other: _____

6. Are there any rules or restrictions related to fishing in your village (e.g., closed seasons, gear ban, fishing zones)?

   ☐ Yes ☐ No

   If yes, who enforces them? ☐ Village Council ☐ Government ☐ Others

7. Any destructive methods observed?

   ☐ Chemical poisoning ☐ Dynamite ☐ Others specify:

   _____

8. Does your village impose any fines or punishments for illegal fishing?

   ☐ Yes ☐ No

   If yes, what kind of fine or punishment is given? specify:

   _____

Section 3: Ecological observations and traditional knowledge

1. Are there any particular months or seasons when fishing is especially good or poor? Why?

   _____

2. Have you noticed any changes in the river over the years? (You may tick more than one)

   ☐ Water level changes

   ☐ Increase in pollution

   ☐ Fewer fish catch

   ☐ More flooding or erosion

   ☐ Others: _____

3. Did you observe fish migration or breeding behavior (e.g., when/where certain fish gather to spawn)?

   ☐ Yes ☐ No

   If yes, please describe: _____

4. Do you know of any plants traditionally used to catch fish?

   ☐ Yes ☐ No

   If yes, which ones? _____

5. Do you know of any fish or fish parts that are used as medicine or for healing?
   ☐ Yes ☐ No
   If yes, specify fish and how it is used: _____
6. Do you use any methods to preserve fish?
   If yes, which method?
   ☐ Sun-drying ☐ Smoking ☐ Salting ☐ Fermenting ☐ Others (please specify): _____
7. Are there any sacred or protected areas in or near the river (e.g., Green Zones, fish sanctuaries)?
   ☐ Yes ☐ No
   If yes, name/location: _____

Section 4: Perceptions on *Neolissochilus hexagonolepis*

1. Are you familiar with the fish *Neolissochilus hexagonolepis* (commonly called chocolate mahseer)?
   ☐ Yes ☐ No ☐ Not sure
2. Have you noticed any changes in the population of this fish in your river over the years?
   ☐ Increased ☐ Decreased ☐ No change ☐ Not sure ☐ Other (please specify): _____
3. In your view, what are the threats faced by this fish in your area?
   ☐ Overfishing ☐ Destructive fishing ☐ River obstruction ☐ Pollution
   ☐ Not sure ☐ Other (please specify): _____
4. Does this fish hold any significance in your area?
   ☐ Food ☐ Traditions or customs ☐ Market value ☐ Fishing for fun/tourism
   ☐ Not sure
5. Would you support efforts to save this fish locally?
   ☐ Yes ☐ No ☐ Not sure

Section 5: Community perspectives on conservation and livelihoods

1. Are you aware of any government or NGO efforts to protect fish or the river?
   ☐ Yes ☐ No
   If yes, which ones? _____
2. Has your village ever been involved in conservation activities (e.g., bans, awareness activities, protected river areas)?
   ☐ Yes ☐ No
   Please describe briefly: _____

3. What are the main threats to fish in the Dikhu River according to you? (Tick all that apply)

   ☐ Overfishing

   ☐ Illegal fishing methods

   ☐ Pollution

   ☐ Dams or river blockages

   ☐ Invasive species

   ☐ Climate change

   ☐ Deforestation/siltation

4. Do you feel fishing today provides enough income or food security for your family?

   ☐ Yes ☐ No

   Please explain: _____

5. Have you received any help or support from the government to start or improve fishery activities?

   If yes, what kind of help did you receive?

   ☐ Fish seeds ☐ Nets or gear ☐ Training ☐ Pond construction ☐ Financial support ☐ Others (please specify): _____

6. What kind of support would you like from the government or researchers?

   ☐ Training or workshops

   ☐ Better fishing tools or methods

   ☐ Access to markets

   ☐ Awareness on conservation

   ☐ Hatchery/fish seed support

   ☐ Protection of traditional practices

   ☐ Other: _____

7. Are you aware of any fish or river conservation?

   ☐ Yes ☐ No

8. Are you willing to support fish and river conservation efforts in your area?

   ☐ Yes ☐ No

   If yes, how would you like to help?

   ☐ Follow village rules

   ☐ Stop harmful fishing practices

   ☐ Join community meetings or activities

   ☐ Spread awareness to others

☐ Other (please specify): _____

Section 6: For village leaders or council members

1. Does your village have specific customary laws regarding river and fishing rights?

   ☐ Yes ☐ No

   If yes, please mention briefly: _____
2. Is your community part of any fish conservation initiative or Community-Conserved Area (CCA)?

   ☐ Yes ☐ No

   If yes, name and purpose: _____
3. Are there penalties for violating fishing rules?

   ☐ Yes ☐ No

   If yes, what kind? ☐ Fine ☐ Confiscation ☐ Social Sanction

   What are the biggest challenges in enforcing conservation practices in your area?

List of paper publications

1. **Kechu, M.,** and Pankaj, P. P. (2025). Checklist on the ichthyofaunal resources and conservation status of Dikhu River, Nagaland, India. *Journal of Threatened Taxa*, *17*(2), 26504-26514.
2. **Kechu, M.,** and Pankaj, P. P. (2023a). Traditional fishing methods practiced by Ao and Sumi tribes in Dikhu River of Nagaland, *Indian Journal of Fisheries*, *11*(2), Article 112202.
3. **Kechu, M.,** Ezung, S., and Pankaj, P. P. (2023b). Bionomics, length-weight relationship and condition factor of chocolate mahseer, Neolissochilus hexagonolepis, from Dikhu River, Nagaland. *Journal of Environmental Biology*, *44*, 706-712.
4. **Kechu, M.,** Ezung, S., Longkumer, S., Jamir, A., and Pankaj, P. P. (2021). Progress and prospects for sustainable production and conservation of threatened coldwater fishes of North-East India with special reference to Nagaland State. *Journal of Experimental Zoology India*, 24, 27-33.
5. Ezung, S., **Kechu, M.,** Longkumer, S., Jamir, A., and Pankaj, P. P. (2020). A review on the ichthyofauna of Nagaland, North-East India. *World News of Natural Sciences, 30*(2), 104-116.
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COMMUNICATION

Checklist on the ichthyofaunal resources and conservation status of Dikhu River, Nagaland, India

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Abstract: Dikhu River constitutes one of the major perennial rivers of Nagaland and due to its pristine beauty aids as a tourism spot. From the present study, ichthyofaunal diversity accounted for a total of 28 fish species belonging to 6 orders, 13 families, and 3 subfamilies. From the investigation, order Cypriniformes (67.9%) was found to be the most dominant, followed by Siluriformes (14.3%) and Anabantiformes (7.1%) while order Beloniformes, Synbranchiformes and Anguilliformes was found to be the least common with 10.7% in total. The IUCN red list of threatened species shows 71.4% are Least Concern, 7.1% Near Threatened, 3.6% Vulnerable, 3.6% Endangered, 10.7% Not Accessed and 3.6% Data Deficient. IUCN population status data shows that 57.1% are unknown, 10.7% stable, 10.7% not accessed, and 21.4% with decreasing population trends. Diversity indices (Shannon, Simpson, and Evenness) indices ranged 2.497–2.912, 0.892–0.936, and 0.820–0.908, respectively. Relative abundance determinations ranged from a high of 15.55% for *Devario aequipinnatus* to the lowest values for *Tariqilabeo latius* and *Botia rostrata* at 0.08%. Anthropogenic pressure on the Dikhu River has resulted in habitat modification and fragmentation, posing a hazard to fish diversity. Fish abundance was found to be highest in the post-monsoon season and lowest in winter. These findings are significant for academic purposes and support conservation strategies for local fish resources.

Keywords: Assessment, biodiversity, diversity index, fish species, fisheries management, ichthyofauna, Nagaland fisheries, population status, riverine habitat, threatened species.

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Funding: ICAR-National Bureau of Fish Genetic Resources, Lucknow (Project No.: G./NE/2015).

Competing interests: The authors declare no competing interests.

Author details: Metevinu Kechu is a research scholar and is actively engaged in ichthyofaunal exploration and documentation in Nagaland. Pranay Punj Pankaj is engaged in teaching fisheries as well as research and development activities on the subject in the region.

Author contributions: MK surveyed the Dikhu River of Nagaland and confirmation of the identity of the species. PPP supervised the work and interpreted the taxonomic information gathered by the Mk.

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Original Article

Traditional fishing methods practiced by Ao and Sumi tribes in Dikhu River of Nagaland, India

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Kechu M, Pankaj PP (2023) Traditional fishing methods practiced by Ao and Sumi tribes in Dikhu River of Nagaland, India. Journal of Fisheries 11(2): 112202. DOI: 10.17017/j.fish.458

Abstract
Traditional fishing knowledge dates back to the early fish catching techniques passed down from forefathers in most of the Naga communities, Nagaland. Traditional fishing is mainly practiced for household consumption and is considered less intensive than industrial fishing practices, which can negatively impact riverine sustainability. However, there is a risk of loss of traditional knowledge in recent times. Hence, an effort was made to comprehend and document the indigenous traditional knowledge associated with fishing practices utilized by the Ao and Sumi tribal communities residing along the banks of Dikhu River. The diverse array of traditional fishing equipment and techniques employed has been categorised based on their specific functions, resulting in the documentation of three types of fishing gears, four fishing accessories, one fishing craft and three other types of fishing techniques. However, in some regions, use of detrimental fishing like dynamites and harsh chemicals were encountered. The results indicate that local fishers continue to rely on indigenous fishing practices for sustenance, and the majority of traditional fishing gears are constructed using locally available eco-friendly materials such as bamboo, wooden poles and cotton twine. The information obtained in this study can be preserved and implemented in contributing better resource management.

Keywords: fishing craft; indigenous traditional knowledge; Naga communities; traditional fishing gears

1 | INTRODUCTION

Traditional fishing in marginal areas are considered small-scale fishing by local communities involving fishing techniques based on local fishers knowledge, traditions, resources and skills. These types of sustenance fishing are often practice in regions that are economically disadvantaged with limited infrastructure and institutional development (Kurien 1998; Johnson 2006). According to FAO (2002), around 4% of the world's population is dependent on small scale fishing that has been significantly contributing to food security, livelihoods and cultural identity in many marginal areas. However, traditional fishing in marginal areas is facing increasing threats from environmental degradation, overfishing and competition from advanced fishing technologies (Béné 2003). In order to sustain and improve the viability of traditional fishing, it is important to implement management based measures like community rights approach, ecosystem approach or protected areas to govern natural resource conservation and management measures taking into account the unique challenges faced by the native communities, such as poverty, poor governance and inadequate market areas (Cochrane and Garcia 2009).

Traditional fishing is a long-standing tradition among tribal communities in Nagaland, and certain fishing practices are still considered sacred and locally practiced. Fishing gear fabrication and execution of traditional fishing techniques can vary based on factors such as location, fishing season, fishing grounds, physicochemical characteristics of the water body, ecological morphology, work

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Bionomics, length-weight relationship and condition factor of Chocolate mahseer, *Neolissochilus hexagonolepis* from Dikhu River, Nagaland

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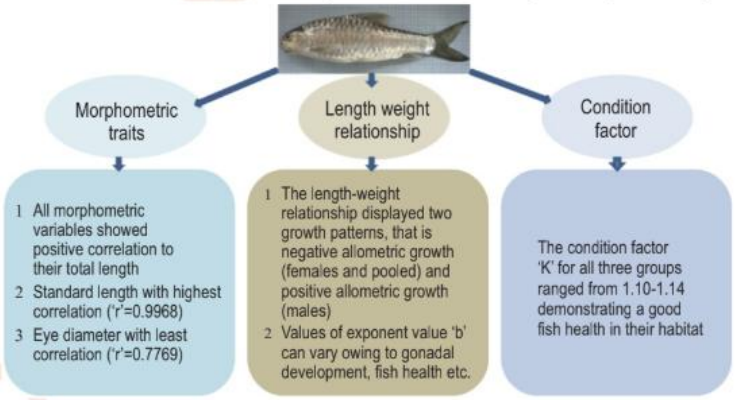
Abstract

Aim: Chocolate mahseer (*Neolissochilus hexagonolepis*) is widely distributed in the North-eastern region of India. The study aimed to evaluate the bionomic aspects of chocolate mahseer of Nagaland to validate its status.

Methodology: Fish *Neolissochilus hexagonolepis* were collected from March 2019 to February 2020 from Dikhu River, Nagaland. Regression analysis for morphometric study was conducted using the least square method. Logarithmically transformed total length and weight data were utilized to determine the correlation coefficient 'r', coefficient of determination 'r^2', and condition factor for male, female, and pooled groups.



Results: The highest correlation was seen in standard length ('r' = 0.9968), and the least correlation was observed in eye diameter ('r' = 0.7769). The length-weight relationship exhibited two growth patterns, namely negative allometric growth, which were represented by females (b = 2.807) and pooled (b = 2.868) population, whereas the population of males displayed positive allometric growth (b = 3.015). The correlation coefficient and coefficient of determination of males, females and the pooled sexes showed a positive correlation with relation to its length and weight ranging from 'r' = 0.970 - 0.981 and 'r^2' = 0.941 - 0.961, respectively. The condition factor for all the groups ranged from 1.10 - 1.14.

Interpretation: Morphometric traits like standard length, snout length, head length etc. (dependent variable) were analyzed on total length (independent variable), signifying a positive correlation among variables. Length-weight relationship displayed high significance between length and weight parameters. The condition factor for all the groups indicated general well-being of fish condition in their environment.

Key words: Chocolate mahseer, Condition factor, Length-weight relationship, Morphometric studies

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PROGRESS AND PROSPECTS FOR SUSTAINABLE PRODUCTION AND CONSERVATION OF THREATENED COLDWATER FISHES OF NORTH-EAST INDIA WITH SPECIAL REFERENCE TO NAGALAND STATE

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ABSTRACT : The geographic position of Northeast India with its captivating landscapes, climatic conditions of rivers or lakes to swift-running stream or rivulets makes it an ideal location for the existence of coldwater fishes in the region. Unfortunately, threatened coldwater fishes have declined in population because of overexploitation, destructive fishing methods, chemical toxins, and habitat fragmentation. It is highly recommended that the government and the local stakeholders adopt a more constructive technology-based approach and strengthened policies for enhancing sustainable fish production and conservation.

Key words : Northeast India, coldwater fishes, habitat fragmentation, constructive technology-based approach, sustainable fish production and conservation.

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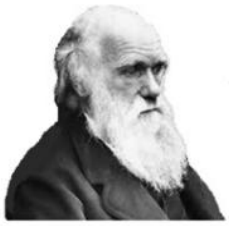
INTRODUCTION

A total number of 278 coldwater fish species consisting of 21 families and 76 genera are distributed in the peninsular plateau and the uplands of Himalayas (Singh *et al*, 2015). Coldwater fishes consist of both the exotic and the indigenous fish species. The most common indigenous coldwater fish harbours the Mahseer viz. *Tor tor* and *Tor putitora*, schizothoracines like *Schizothorax richardsonii*, *Schizothorax progastus*, *Schizothorax curvifrons* and *Schizothorax esocinus* and *Schizothorax niger*. In contrast, the exotic coldwater fish consists of exotic trouts like *Oncorhynchus mykiss* and *Salmo trutta*. Among these fishes, *Schizothorax richardsonii*, *Schizothorax progastus* and *Tor putitora* are mostly preferred for aquaculture prospects for their wide range availability and distribution. Exotic trouts like *Salmo trutta fario* and *Oncorhynchus mykiss* were first transferred from Europe in 18th century during the British colonial rule in the cold waters of the Himalayan and Peninsular rivers. These exotic species have been closely associated with angling or sport fishing by British administrators (Sehgal, 1989). Indigenous species taking into advantages of its wide distribution and consumer preferences by the local people can boost its aquaculture production in Northeast and the country by further setting research interest on its thriving culture, health management, feeding nature, and breeding biology. The ICAR-Directorate of Coldwater Fisheries Research, Bhimtal, Uttarakhand, has recently chosen five species: *Semiplotus semiplotus*, *Labeo dero*, *Labeo dyocheilus*, *Neolissocheilus hexagonolepis* and *Osteobrama belangeri*, as upcoming candidate species for aquaculture.

India's north-eastern region has diversified physiographic landscapes ranging from numerous hill streams to major perennial rivers to varied mountain terrains, making it one among the 34 biodiversity hotspots globally by Conservation International (Roach, 2005). Northeast India is home to a wide variety of native and rheophilic fishes such as loaches, minor carps, minnows, catfishes, and mahseers to barbs, making it a biota hotspot for endemic freshwater fauna and flora. It is also contributing to the economy and livelihood of many local communities. There are about 0.92 lakh ha dams, 0.4 lakh ha mini barrages and small ponds in the north-eastern region that can be used effectively and productively for the production of coldwater fisheries (Sarma *et al*, 2015).

Available online at www.worldnewsnaturalsciences.com



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A Review on the Ichthyofauna of Nagaland, North-East India

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ABSTRACT

North-East India is a region with many native freshwater fishes and is one of the ichthyofaunal hotspots of the world. According to the current study, a total of 197 valid species of fish has been reported from Nagaland, India, which consists of 10 orders, 26 families and 87 genera, from various lotic and lentic habitats. Family Cyprinidae consists of the highest record of 75 fish species and Osphronemidae, Gobidae, Scianenidae and Chacidae families with the lowest record of one fish species in each.

Keywords: North-East India, Ichthyofaunal hotspots, lotic and lentic habitat, Nagaland, Cyprinidae

1. INTRODUCTION

Northeast is known as one of the hot spots of the global biodiversity of freshwater fish that include substantial fish germplasm reserves. This region of India comprises of eight states viz: Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and Sikkim. The abundance of ichthyofaunal diversity in this region is by forming part of the Himalayas and Indo-Burma. A total of 422 species belonging to 39 families is present in the Northeast region.

Nagaland is a small hilly mountainous state, in the northwestern corner of the country. It is situated between 25º6'-27º4' N latitudes and between 93º2'-95º1' E longitudes. The state of Nagaland has many rivers and hill streams blessed by the unusual exotic fish fauna.

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SHORT COMMUNICATION

First record of *Garra birostris* Nebeshwar & Vishwanath, 2013 (Cypriniformes: Cyprinidae) from Doyang and Dikhu rivers of Brahmaputra drainage, Nagaland, India

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Abstract: *Garra birostris* is recorded for the first time from the Doyang and Dikhu tributaries of the Brahmaputra drainage, Nagaland, northeastern India. The detailed morphometric and meristic data of the specimens that forms the basis of this new record are presented.

Keywords: Freshwater fish, meristic data, northeastern India, stone suckers, taxonomy.

Members of the labeonine genus *Garra* Hamilton, 1822 are widely distributed from Sub-Saharan Africa to Borneo through the Arabian Peninsula, southern, and southeastern Asia, and southern China (Zhang & Chen 2002). The genus *Garra* is diagnosed in possessing a specialized adhesive pad or modified lower lip forming a gular disc, that displays extraordinary variations in the snout (Kottelat 2020a). They can also be distinguished by their pharyngeal teeth arranged in three rows, the origin of dorsal fin which starts slightly anterior to pelvic fins, and an anal fin originating well behind the pelvic fins (Stiassny & Getahun 2007).

Northeastern India, part of the Himalaya Biodiversity Hotspot is represented by 56 nominal species of the genus *Garra* which are distributed in the Brahmaputra, Barak, Kaladan, Karnaphuli, and Chindwin drainages, respectively (Vishwanath 2017; Roni & Vishwanath 2018; Fricke et al. 2022). Rivers in the state of Nagaland harbour 13 species of the genus *Garra*—*G. annandalei* Hora, 1921, *G. gravelyi* Annandale, 1919, *G. gotyla* Gray, 1830, *G. kempi* Hora, 1921, *G. lamta* Hamilton, 1822, *G. lissorhynchus* McClelland, 1842, *G. mcclellandi* Jerdon, 1849, *G. notata* Blyth, 1861, *G. naganensis* Hora, 1921, *G. nasuta* McClelland, 1838, *G. rupicola* McClelland, 1839, *G. chathensis* Ezung, Shangningam & Pankaj, 2020 and *G. langlungensis* Ezung, Shangningam & Pankaj, 2021 (Ezung et al. 2020a,b,c). So far, *Garra birostris*is known to occur in Arunachal Pradesh (Nebeshwar & Vishwanath 2013) and Assam (Basumatary et al. 2017)

Editor: Rajeev Raghavan, Kerala University of Fisheries and Ocean Studies, Kochi, India. **Date of publication:** 26 July 2022 (online & print)

Citation: Ezung, S., M. Kechu & P.P. Pankaj (2022). First record of *Garra birostris* Nebeshwar & Vishwanath, 2013 (Cypriniformes: Cyprinidae) from Doyang and Dikhu rivers of Brahmaputra drainage, Nagaland, India. *Journal of Threatened Taxa* 14(7): 21453–21457. https://doi.org/10.11609/jott.7075.14.7.21453-21457

Funding: (a) University Grants Commission, New Delhi; (b) Ministry of Tribal Affairs, Government of India; (c) ICAR-National Bureau of Fish Genetic Resources, Lucknow.

Competing interests: The authors declare no competing interests.

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List of paper presentation

International conferences

1. Oral presentation on *"Review on current status, threats and management prospects of Mahseer in Nagaland, India"* at the International Conference on Biodiversity: Exploration, Exploitation and Conservation for Sustainable Development (ICB-01), organized by the Department of Botany, PDUAM, Behali, Assam in association with ECO-CLUB (MoEFC, Govt. of India & ASTEC, Assam), 05th January, 2022.
2. Oral presentation *"Biometric features and conservation aspects of Neolissochilus hexagonolepis from Dikhu River, Nagaland"* at the International Conference on Environmental, Agriculture, Horticulture, and Applied Sciences for Human Welfare (ICEAHAH 2021), organized by VOICE (Voice of Indian Concern for the Environment) in collaboration with international and Indian academic institutions, 5th - 6th June, 2021.

National conferences

1. Paper presentation on *"Traditional fishing techniques documented in the Mokokchung and Zunheboto districts along the Dikhu River, Nagaland, India"* at the ICSSR-New Delhi Sponsored Two Days National Seminar on Anthropology in the 21st Century: Emerging Areas of Research in Northeast India and Its Role in National Development, organized by the Department of Anthropology, Nagaland University, Lumami, 19th - 20th March, 2024.
2. Presented on the topic "*Prospects and status of Chocolate Mahseer (Neolissochilus hexagonolepis) in Nagaland*" at the National Campaign on "System Diversification in Aquaculture" held as part of *Azadi ka Amrut Mahotsav: 75th Year of Independence Celebration*, organized by the Department of Zoology, Nagaland University in collaboration with the ICAR-National Bureau of Fish Genetic Resources (NBFGR), on 1st September, 2021.
3. Oral presentation on *"Coldwater fishery with special reference to endemic Mahseer of Nagaland, major threats and conservation prospects"* at the National e-Conference on Bioresources and Sustainable Livelihood of Rural India, organized by the Department of Botany, Nagaland University, Lumami, 28th - 29th September, 2020.
4. Presented a paper on *"Ichthyofaunal Diversity of Dikhu River, Mokokchung, Nagaland, India"* at the UGC Sponsored National Conference on "Contemporary Excitement in New Biology", organized by the Department of Zoology, Nagaland University, Lumami, held on 30th - 31st October, 2018.

International Conference
On
BIODIVERSITY:
Exploration, Exploitation And Conservation For Sustainable Development
(ICB-01)
(On Blended Mode)

Ref.: Cert/ICB01/PDUAMB/2022

Certificate of Participation

This is to certify that
Metevinu Kechu
of
Nagaland university
has participated and presented a research paper (oral) entitled

Review on current status, threats and management prospects of Mahseer in Nagaland, India

in the International Conference on Biodiversity: Exploration, Exploitation and Conservation for Sustainable Development (ICB-01), organized by the Department of Botany, Pandit Deendayal Upadhyaya Adarsha Mahavidyalaya -Behali, Assam, India in association with ECO-CLUB (MoEFC, Govt. of India and ASTEC, Assam) on 5th January, 2022.

DR. DEBOJIT BARUAH
Principal and Chairperson,
ICB-01

DR. SHAFIQUL ISLAM BHUYAN
Organizing Secretary,
ICB-01

DR. MOFIDUL ISLAM
Joint Organizing Secretary,
ICB-01

MS. HEENA AGARWAL
Joint Organizing Secretary,
ICB-01

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June 05-06, 2021

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Ms. Metevinu Kechu
Nagaland university, Lumami – 798627

as Young Scientist
"Best oral ppt presentation"

Topic: Biometric features and conservation aspects of *Neolissochilus hexagonolepis* from Dikhu river, Nagaland

Dr. Ramasamy Rajesh Kumar
Convener & Organizing Secretary
Founder - Voice Of Indian Concern for the Environment (VOICE)
Research Scientist- Institute of Nuclear-Agricultural Sciences, College of Agriculture and Biotechnology, Zhejiang University, China PR
Honorary Faculty - Novel Global Community Educational Foundation, Australia

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Co-organizing Secretary
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Donghua University, Shanghai, China PR

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Director, Phycospectrum Environmental Research Centre, Chennai, India

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University of Delhi, New Delhi, India

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DST- Inspire Faculty
BRICS Young Scientist, KGSP Fellow
Manipur Central University, Manipur, India

Dr. Kailas Deoram Ahire
Co-organizing Secretary
Assistant Professor in Environmental Science,
K.R.T. Arts, B.H. Commerce and A.M. Science (KTHM) College, Nashik, Savitribai Phule Pune University, Maharashtra, India

Indian Council of Social Science Research

NAGALAND UNIVERSITY ESTD 1994 LABOR et HONOR

ICSSR- NEW DELHI sponsored Two Days National Seminar

On

ANTHROPOLOGY IN THE 21ST CENTURY: EMERGING AREAS OF RESEARCH IN NORTHEAST INDIA AND ITS ROLE IN NATIONAL DEVELOPMENT

19th and 20th March, 2024

Organized by

Department of Anthropology, Nagaland University (A Central University)
HQRS: LUMAMI, DIST: ZUNHEBOTO, NAGALAND, PIN - 798627

Certificate of Academic Participation and Paper Presentation

This is to appreciate the participation of Mr./Ms./Dr. METEVINU KECHU of Zoology, Nagaland University in the seminar and acknowledge his/her contribution in presenting the paper. The topic of his/her presentation was Traditional fishing techniques..... DiKhu river, Nagaland, India.

Prof. M. S. Rawat
Dean, School of Sciences
Nagaland University

Prof. Somenath Bhattacharjee
Professor and Head
Department of Anthropology
Nagaland University

भाकृअनुप ICAR

NBFGR

NAGALAND UNIVERSITY ESTD 1994 LABOR et HONOR

Azadi ka Amrut Mahotsav: 75th years of Celebration of Independence

National Campaign "System Diversification in Aquaculture"

Organized by

Department of Zoology, Nagaland University

&

ICAR-National Bureau of Fish Genetic Resources

CERTIFICATE

This is to certify that **Ms. Metevinu Kechu** from **Nagaland University** has **participated** in the National Campaign on 01- September-2021 as **Presenter**. Her participation was highly appreciated.

Dr. Bendang Ao
HoD & Project Coordinator

Dr. Pranay P. Pankaj
Assistant Professor & PI

National e-Conference On
'Bioresources and Sustainable Livelihood of Rural India'
September 28-29, 2020

Organized by
Department of Botany, Nagaland University, Lumami-798627, Nagaland

Certificate of Participation

This is to certify that Ms. METEVINU KECHU has participated virtually in the National e-Conference 'Bioresources and Sustainable Livelihood of Rural India' held during September 28-29, 2020 in the Department of Botany, Nagaland University, Lumami-798627, Nagaland, India. She also presented a paper entitled 'Coldwater Fishery with Special Reference to Endemic Mahseer of Nagaland, Major Threats and Conservation Prospects ' (Abstract No. 09) in the Technical Session.

(Sangyu Yaden)
Dean, School of Sciences
Nagaland University

(Chitta Ranjan Deb)
Head, Department of Botany &
Organizing Secretary

UGC Sponsored National Conference

Contemporary Excitement in New Biology

Certificate of participation

This is to certify that Prof./Dr./Mr./Ms. Metevinu Kechu of Nagaland University participated/presented a paper (Key Note Talk/Invited Talk/Presentation Talk/Platform Talk) titled: Ichthyofaunal Diversity of Dikhu River, Mokokchung, Nagaland, India.

in the UGC Sponsored National conference on "Contemporary Excitement in New Biology" organized by the Department of Zoology, Nagaland University, Lumami, Nagaland held during 30 – 31st October 2018.

Prof. M. Indira Devi
Dean
School of Sciences

Prof. Sarat C. Yenisetti
Organising Secretary
CENB-2018

Prof. L. N. Kakati
Convener
CENB-2018

Prof. Bendang Ao
Treasurer
CENB-2018

List of training/ seminars/ workshops

1. Participated in a two-day workshop titled *"Use of e-Resources for Academic Excellence"*, organized by the Internal Quality Assurance Cell (IQAC), Nagaland University, held on 16th - 17th April, 2021.
2. Participated in a two day workshop on *"Quality enhancement in research"* organized by IQAC, Nagaland University from 22nd - 23rd March, 2021.
3. Participated in an international webinar on *"Innovations in science and technology"* organized by Department of Chemistry, Smt. Narsamma Arts, Commerce and Science college, Kiran Nagar, Mumbai on 27th February, 2021.
4. Completed 5 days online course on *"Remote Sensing and GIS Applications in Forestry and Ecology"* organized by the North Eastern Space Applications Centre (NESAC), Department of Space, Government of India, Umiam, Meghalaya, held from 1st - 5th February, 2021.
5. Attended a three day international webinar on *"Sustainable ornamental fisheries: Way forward"* organized by School of Industrial Fisheries, Cochin university of science and technology, Kochi, Kerala on 15th - 17th October, 2020.
6. Participated in a hands-on training program on *"Breeding and Seed Production of Golden Mahseer and Chocolate Mahseer"* organized by the ICAR-Directorate of Coldwater Fisheries Research (DCFR), Bhimtal, Uttarakhand, held from 27th - 31st August, 2018.
7. Completed a training program on *"Integrative Taxonomy and Systematics in Freshwater Fishes"* organized by the ICAR-National Bureau of Fish Genetic Resources (NBFGR), Lucknow, held from 5th - 10th February 2018.

नागालैण्ड **NAGALAND** विश्वविद्यालय **UNIVERSITY**

(संसद द्वारा पारित अधिनियम 1989, क्रमांक 35 के अंतर्गत स्थापित केंद्रीय विश्वविद्यालय)
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मुख्यालय : लुमामी | **Headquarters : Lumami**

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Ph.D/M.Phil. Registration Number पीएच.डी/एम.फिल. पंजीयन संख्या	**Reg. No. Ph.D./ZOO/00127/2017**
Title of Ph.D thesis /M.Phil. Dissertation पीएच.डी थीसिस/एम.फिल. शोध-प्रबंध का शीर्षक	**Studies on ichthyofaunal diversity of Dikhu River, Nagaland with special reference to conservation and developmental biology of *Neolissochilus hexagonolepis* (McClelland, 1839)**
Name & Institutional Address of the Supervisor/Joint Supervisor शोध-निर्देशक/सह शोध-निर्देशक का नाम व संस्थानिक पता	**Dr. Pranay Punj Pankaj** **Associate Professor** **Department of Zoology, Nagaland University** **HQ: Lumami-798627, Nagaland**
Name of the Department/School विभाग/संकाय का नाम	**Department of Zoology** **School of Sciences**
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(Metevinu Kechu)
(Name & Signature of the Scholar)
(शोधार्थी का नाम व हस्ताक्षर)

Dr. Pranay Punj Pankaj
Name & Signature of the Supervisor (With Seal)
शोध-निर्देशक का नाम व हस्ताक्षर (मुहर सहित)

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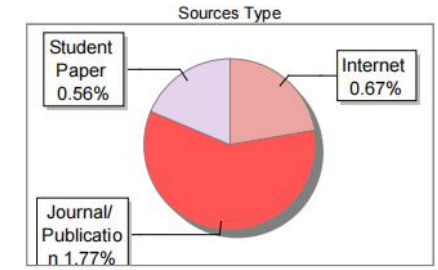

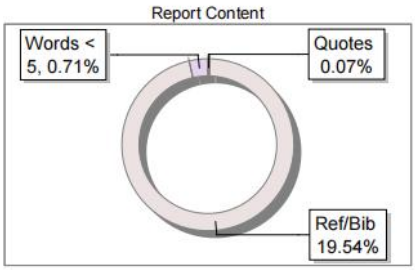

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1	dikhu river
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3	with its corresponding standard deviation
4	seasonal variation
5	monsoon season
6	traditional fishing
7	conservation efforts

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Title	Studies on ichthyofaunal diversity of Dikhu River, Nagaland with special reference to conservation and developmental biology of Neolissochilus hexagonolepis (McClelland, 1839)
Paper--Submission ID	5868761
Submitted By	pranaypunj@nagalanduniversity.ac.in
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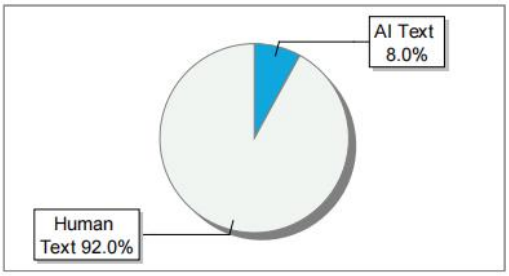

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