Fish Diversity of Tamakoshi River and its Major Tributary Singati River, Dolakha, Nepal

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A dissertation submitted

In partial fulfilment of the requirements for the award of the degree of Master of Science in Zoology with special paper Fish Biology and Aquaculture

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Declaration

I hereby declare that the work presented in this dissertation “Fish Diversity of Tamakoshi River and its major Tributary Singati River, Dolakha, Nepal” has been done by myself, and has not been submitted elsewhere for the award of any degree. All sources of information have been specifically acknowledged by reference to the author(s) or institution(s).

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Recommendation

This is to recommend that the dissertation entitled "Fish Diversity of Tamakoshi River and its major Tributary Singati River, Dolakha, Nepal" has been carried out by Sangam Thapa Magar for the partial fulfilment of Master's Degree of Science in Zoology with special paper Fish Biology and Aquaculture. This is his original work and has been carried out under my supervision. To the best of my knowledge, this dissertation work has not been submitted for any other degree in any institutions.

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On the recommendation of supervisor "Asst. Prof. Santoshi Shrestha" this dissertation submitted by Sangam Thapa Magar entitled "Fish Diversity of Tamakoshi River and its major Tributary Singati River, Dolakha, Nepal" is approved for the examination in partial fulfilment of the requirements for Master's Degree of Science in Zoology with special paper Fish Biology and Aquaculture.

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Certificate of Acceptance

This dissertation work submitted by Sangam Thapa Magar entitled "Fish Diversity of Tamakoshi River and its major Tributary Singati River, Dolakha, Nepal" has been accepted as a partial fulfilment for the requirements of Master's Degree of Science in Zoology with special paper Fish Biology and Aquaculture.

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Sangam Thapa Magar

Abstract

The current study examines fish diversity, abundance and its relation with water quality in the Tamakoshi and Singati Rivers over three seasons: Post-Monsoon, winter, and Pre-Monsoon from 2023 to 2024. This study also focuses the identification of spawning grounds, and the social status of local fishermen. Nine sampling stations were selected along in two river system and fish samples were collected using cast net (5mm mesh size) with the help of local fishermen. A total of 7 species belonging to 2 Orders, 3 Families, and 6 Genera were recorded with 536 individuals catch. The Order Cyprinidae was recorded to be the most dominant family followed by the Sisoridae and Psilorhynchidae. *Psilorhynchus pseudecheneis* was the most dominant (31.16%) species, followed *by Schizothorax progastus* (21.26%), and *Schizothorax richardsonii* (15.29%). Station TR5 had the highest Shannon Weiner's diversity index (H'= 1.881), while Station TR1 had the lowest (H'= 1.36). The maximum Margalef's richness (d= 1.731) was observed at station SR4, whereas the minimum (d= 0.8867) was at station TR1. Similarly, the highest Pielou's evenness Index (J= 0.9906) was recorded at station TR3 and the lowest (J= 0.7733) at station SR4. The fish assemblage structure was positively correlated with environmental factors like water temperature, pH, dissolved oxygen, velocity, total dissolved solids, and hardness. Additionally, the identification of spawning grounds also reflects the conservation initiatives for fish diversity and habitats.

शोध सारांश

यो अध्ययन तामाकोशी र सिङ्गटी नदीमा माछाको विविधता, प्रचुरता, उत्पादन स्थल र तिनीहरूको बासस्थान रोजाइको मूल्याङ्कन गर्न केन्द्रित छ। अध्ययन तीन ऋतुहरू— Post-monsoon (अगस्ट–अक्टोबर २०२३), Winter (नोभेम्बर–डिसेम्बर २०२३), र Pre-monsoon (मार्च–अप्रिल २०२४) मा गरिएको थियो। अध्ययनका लागि ९ वटा station छनोट गरियो। स्थानीय माछा मार्ने व्यक्तिहरूको सहयोगमा ५×५ मि.मि. Cast net प्रयोग गरी माछा सङ्कलन गरियो। यस अध्ययन अवधिमा २ वटा Order, ३ वटा Family, र ६ Genus अन्तर्गत पर्ने ७ वटा Species पहिचान गरिए। कुल ५३६ वटा माछा सङ्कलन गरियो, जसमा Cyprinidae Family का माछाहरू सबैभन्दा बढी (६०%) पाइए भने त्यसपछि Sisoridae ३१% र Psilorhynchidae ९% पाइए। माछा प्रजातिहरू मध्ये *Psilorhynchus pseudecheneis* सबैभन्दा बढी (३१.१६%) पाइयो, त्यसपछि *Schizothorax progastus* (२१.२६%) र *Schizothorax richardsonii* (१५.२९%) क्रमशः दोस्रो र तेस्रो स्थानमा रहे। स्टेसन TR5 मा सबैभन्दा बढी Shannon-Weiner’s diversity index (H' = 1.881) पाइयो भने Margalef’s richness सबैभन्दा बढी (d = 1.731) स्टेसन SR4 मा थियो। त्यसै गरि, Pielou’s evenness सबैभन्दा बढी (J = 0.9906) स्टेसन TR3 मा थियो। माछाको फैलावट ढाँचामा नदीको पानीको Temp, pH, DO, Velocity, TDS र Hardness जस्ता वातावरणीय कारकहरूको महत्त्वपूर्ण भूमिका रहेको पाइयो। यी कारकहरूले माछा समुदायको बनावटमा पर्ने प्रभावलाई Redundancy Analysis (RDA) विधिबाट विश्लेषण गरिएको छ। साथै, स्थानीय समुदायद्वारा अत्यधिक रूपमा गरिने मौसमी माछा मार्ने कार्य, विद्युतीय माछा मार्ने प्रविधि, प्लास्टिक प्रदूषण, विष्फोटक प्रविधिको प्रयोग, अन्य प्रदूषण स्रोतहरू, र घरेलु फोहोरजस्ता समस्याहरूले माछाका बासस्थानलाई खतरा उत्पन्न गरेको छ। तसर्थ, यस्ता जोखिम न्यूनीकरणका उपायहरू अपनाउन जरुरी छ।

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Abbreviated form	Details of abbreviations
APHA	American Public Health Association
CCA	Canonical Correspondence Analysis
DCA	Detrended Correspondence Analysis
DO	Dissolved Oxygen
EDTA	Ethylenediaminetetraacetic Acid
IUCN	International Union for Conservation of Nature
LC	Least Concern
m/s	Meter per second
masl.	Meter above sea level
mg/L	Milligrams per liter
ppm	Parts per million
RDA	Redundancy Analysis
TDS	Total Dissolved Solids
VN	Vulnerable

1. Introduction

1.1 Background

Freshwater ecosystems are vital components of the global biodiversity landscape, despite covering less than 1% of the Earth's surface (Tickner et al., 2020), these habitats support an proportion of the planet's biodiversity, with freshwater environments home for approximately 51% of all known fish species and roughly one-third of all vertebrate species (WWF, 2024). River ecosystems, encompassing ecological, social, and economic processes, interconnect organisms, including humans, and are crucial for maintaining biodiversity (Allan & Flecker, 1993). Biodiversity, with its various levels and values, contributes to ecological balance, supporting various functional processes that sustain ecosystem health (Cardinale et al., 2012). Fish are the most prominent vertebrate group in aquatic habitats, contributing to ecosystem functions such as nutrient cycling, trophic interactions, and biomass regulation (Allan & Castillo, 2007). They are also crucial indicators of aquatic ecosystem health, as changes in their diversity and abundance often reflect alterations in water quality, habitat integrity, and overall ecosystem stability (Arthington et al., 2010).

Fish diversity is a fundamental component of riverine ecosystems, as different species occupy specific ecological niches, contributing to energy transfer and ecosystem functioning (Winemiller & Rose, 1992). As of April 2025, Eschmeyer's Catalog of Fishes documents 37,167 valid fish species globally, with 18,932 identified as freshwater species (Fricke et al., 2025). Fish serve as indicators of water quality, showcasing high biodiversity and thriving in diverse environments (Hussain, 2016) where the hydrological factors, such as rainfall, influence fish assemblages (Kehat & Wyndham, 1972; Poff and Allen, 1995). High flow plays a vital role in maintaining ecosystem function (Cummins & Spengler, 1978; Resh et al., 1988) and the increased flow enhances fish density and diversity (Matono et al., 2012), while low stream conditions negatively affect fish structure (Gehrke et al., 1999; Pegg & Pierce, 2002; Sagawa et al., 2007). Additionally, fish distribution and community structure are influenced by food availability, breeding areas, water conditions, and habitat characteristics (Harris, 1995). Kollaus and Bonner (2012) identified vegetation, depth, and velocity as key factors shaping fish distribution.

Nepal's rich freshwater resources, spanning various altitudes, support a wide variety of fish (Khatri et al., 2020). Over 6,000 rivers and streams Sapta Koshi, Sapta Gandaki, Karnali, and Mahakali are four major river systems originating from the Himalayas, drain approximately 70% of Nepal, with some tributaries extending into Tibet (Bhandari et al., 2018; Bricker et al., 2014). The Koshi River, one of the largest tributaries of the Ganges, drains an area of 69,300 square kilometers up to its confluence in India (Agrawal et al., 2014), though according to Dikshit (2009) this extends to 71,500 square kilometers across three countries.

The water bodies of Nepal hosts 236 freshwater native fish species belonging to 15 Orders, 40 Families, and 120 Genera (Shrestha, 2019). The Koshi River system is the most significant source of capture fisheries in Nepal in context of species diversity, abundance with high fish yield relying it for livelihoods (Gurung et al., 2016a; Paudel et al., 2016) with 211 species of fishes are inhabiting in Koshi river system (Shrestha and Thapa, 2020) while Thapa (2008) reported 92 species, Limbu and Subba (2011) listed 81 species and Gurung et al., (2016b) compiled 135 native fish species along with seven exotic species. The major tributaries of Saptakoshi River system; Tamakoshi, Likhu, Bhotekoshi, Dudhkoshi, Arun, Indrawati and Sunkoshi are potential for new species discoveries (Edds and Ng, 2007) as example *Psilorhynchus pseudochenesis* is reported from Dudhkoshi river by Menon and Dutta in 1964.

Fish habitats in the Koshi River are shaped by water quality, substrate type, vegetation, and hydrological regimes, forming microhabitats essential for different fish life stages (ICIMOD, 2019). Habitats range from shallow, vegetated areas for juveniles to deeper, faster-flowing waters for adults (Gurung & Bajracharya, 2020). Freshwater fish in the Koshi River sustain themselves on aquatic invertebrates, algae, and smaller fish, contributing to ecological balance and productivity (Rai, 2019). The river's floodplains and tributaries provide crucial spawning grounds, ensuring successful fish reproduction (Bhattarai, 2019). Fish diversity across Nepalese rivers is influenced by natural factors like altitude and flow, and anthropogenic activities such as pollution and dam construction (Katuwal et al., 2018). Climate change alters habitat conditions like water temperature and flow patterns, impacting species distributions and breeding cycles (Gurung & Bajracharya, 2020). Field studies indicate pre-monsoon and monsoon seasons offer ideal spawning conditions due to higher water flow and increased nutrients (Rana & Bhattarai, 2020).

Despite Nepal's abundant water resources, knowledge gaps and lack of organization hinder fish diversity research most studies focus on specific major river sections, while research on tributaries, wetlands and marshy plains remains limited (Jha & Shrestha, 2000). Inadequate systematic studies and missing voucher specimens obstruct accurate taxonomic assessments and conservation efforts (Dayrat, 2005). Freshwater fish, often overlooked in conservation, are declining due to habitat destruction, urbanization, and anthropogenic threats (Shrestha et al., 2009). The anthropogenic activities such as sand mining, water diversion, hydropower dam construction, dynamiting, electro-fishing, pollution, and pesticides contribute to native fish population declines (ADB, 2018; Gurung, 2012). Infrastructure projects like hydropower development hinder fish migration, degrade water quality, and disrupt ecosystems (Schilt, 2007; Simonov et al., 2015).

1.2 Statement of problem

Freshwater ecosystems in Nepal are under mounting pressure from rapid infrastructural development, including hydropower projects, sand and gravel extraction, and other anthropogenic disturbances (Gurung, 2012). The Tamakoshi River and its major tributary, the Singati River, in Dolakha district are vital watercourses that sustain unique fish populations and support local livelihoods. Despite their ecological and socio-economic importance, there is a notable gap in the comprehensive documentation of fish diversity in these rivers. This knowledge deficit hampers effective conservation and sustainable management practices. Local reports and recent field observations suggest that fish catches in the Singati River have declined significantly in both quantity and species variety since the advent of hydropower development in the region. For example, species such as the common snow trout (*Schizothorax richardsonii*), an important indigenous species with significant cultural and commercial value appear to be particularly vulnerable (Jha et al., 2015). The lack of detailed species-level data hinders the development of effective conservation strategies and sustainable management practices. Consequently, there is a critical need to conduct a systematic evaluation that not only identifies and quantifies the fish species present but also monitors key water quality parameters. Such an assessment will bridge the existing data gap, providing a scientific basis for mitigating adverse environmental impacts and informing policy decisions.

1.3 Objectives

1.3.1 General objective

- To explore fish diversity of Tamakoshi and its major tributary Singati River within the Gaurishankar Conservation Area, Dolakha Nepal.

1.3.2 Specific objectives

- To assess the distribution and abundance of fish.
- To study water quality parameters of Tamakoshi and Singati River.
- To analyze the relationship between water quality parameters with fish species.
- To identify spawning grounds and socioeconomic status of local fishermen.

1.4 Significance of the study

Overall, the study has significantly advanced our understanding of aquatic biodiversity in the Tamakoshi and Singati rivers within the Gaurishankar Conservation Area (GCA) by expanding the fish species profile through detailed documentation of both diversity and seasonal distribution. Moreover, the analysis of physicochemical parameters has revealed the specific environmental conditions that support the survival of certain fish species in these river systems.

2. Literature review

Nepal's freshwater ecosystems are renowned for their exceptional biodiversity despite the country's limited geographic area. The altitudinal gradient from the lowland Terai to the high Himalayas creates a range of habitats that support a rich assemblage of fish species. Shrestha (2019) identified 236 native species while Rajbanshi (2012) documented 230 species distributed among 11 orders, 32 families, and 99 genera. Shrestha et al., Over the years, various studies have estimated that the total number of freshwater fish species in the country ranges from 220 to 255 (Shrestha, 2011; Rajbanshi, 2012; Shrestha, 2019; Khatri et al., 2020).

Shrestha et al., (2009) conducted a study in the Tamor River revealed the presence of 30 fish species with 2 orders (Cyprinifomes and Siluriformes) and five families (Cyprinidae, Cobitidae, Balitoridae, Psilorhynchidae and Sisoridae) of which *Psilorhynchoides pseudecheneis*, an endemic fish of Nepal, was notably common and found in all stations with dominancy of family Cyprinidae with 61%. The water quality parameters were also found within the optimal range for supporting cold water fish species (water temperature (16.0-19.0 °C), dissolved oxygen (9.7-10 ppm), pH (7.3-7.5), alkalinity (17.1 mg/l), total hardness (28.5-34.2 mg/l), carbon dioxide (5 mg/l), and conductivity (37.7-56.7 μs/cm) emphasizing the threats that arose from hydropower projects and other anthropogenic activities.

Yadav's (2017), a study conducted along the Koshi River revealed the presence of 22 fish species belonging to six orders: Anguilliformes (1.73%), Clupeiformes (1.73%), Cypriniformes (48.95%), Siluriformes (35.41%), Synbranchiformes (3.47%), Perciformes (2.08%), Anguilliformes (1.73%), and Clupeiformes (1.73%). This diversity was observed from a total catch of 288 fish, representing 10 families and 17 genera where dominant order was Cypriniformes, with a significant proportion of the catch (48.95%), while the most abundant family was Cyprinidae.

Limbu et al. (2018) recorded sixteen species from Dewmai Khola, belonging to 3 orders, 6 families, and 11 genera, with Cypriniformes being the dominant order, comprising 82% of the total catch. Limbu and Prasad (2020) recorded eight species from one order, two families, and three genera from Nuwa River where Nemacheilids dominated, making up 62.5% of the species, and Cyprinids comprised 37.5%. The study found *Schizothorax plagiostomus* to be the most dominant species. Environmental variables included dissolved oxygen (6 to 11.5 mg/L), pH (7 to 9), and water temperatures (8°C to 24°C). The Shannon-Weiner diversity index peaked at 1.69 in January and dropped to 1.43 in July. The study also highlights the concerns about the disappearance of fish species like *Aanguilla*, *Catla*, and *Semiplotus* due to irrigation, hydropower expansion, and water mills.

Joshi and Joshi (2020) recorded 23 fish species in the Mahakali River, belonging to 4 orders, 7 families, and 16 genera. Cypriniformes was the most dominant order, making up 83% of the species, followed by Siluriformes (9%), and both Synbranchiformes and Perciformes (4% each). Among families, Cyprinidae had the highest number with 15 species. Other families such as Balitoridae and Sisoridae had 2 species each, while Psilorhynchidae, Cobitidae, Mastacembelidae, and Channidae were each represented by a single species.

Ghimire and Koju (2021) documented 19 species across five orders, eight families, and 15 genera from Kamala River. Water temperature ranged from 26°C to 27°C, and pH levels varied from 7.2 to 8.31. Total dissolved solids varied (41-187 ppm) with nitrate, phosphate, and ammonia levels differing across sites. Fish taxa richness ranged from 5 to 13, the Shannon diversity index from 0.66 to 2.26, and the evenness index from 0.36 to 0.881. The study highlighted significant responses of fish species to environmental gradients like nitrate levels, TDS, and EC, with Nemacheilidae and Mastacembelidae showing similar environmental responses.

Rajbanshi et al. (2021) conducted a study on the Ratuwa River's ichthyofauna, collected a total of 3,447 specimens across 4 Orders, 14 Families, and 36 Species. Cypriniformes was the most diverse order, followed by Siluriformes, Synbranchiformes, and Anabantiformes. Significant spatial variations in species richness and abundance were observed, with a peak in richness at midstream sites but a decrease downstream. Dominant species included *Barilius bendelisis, Schistura multifasciatus, Garra annandalei, Brachydanio rerio, Aspidoparia morar,* and *Schistura scaturigina*.

Gurung et al. (2024) conducted a study of the River Kankai's fish community, a total of 8,331 fish representing 94 species across 12 Orders, 29 Families, and 60 Genera were sampled over a year. Cypriniformes, Siluriformes, and Anabantiformes were the dominant orders, constituting 86.17% of the species, with Cyprinidae being the most species-rich family. The study observed the highest fish abundance and diversity during the monsoon months of July and August, reflecting the seasonal spawning patterns influenced by increased rainfall and water temperature.

A total of 11 fish species across 7 Genera, 3 Families, and 2 Orders were reported by Shrestha et al. (2021) in the Lohore River, with Cypriniformes being the most dominant, comprising 81.81% of the species. The Cyprinidae family was the most dominant with *Naziritor chelynoides, Puntius gelius, Schizothorax plagiostomus,* and *Schistura sovana* as the dominant species. In context of diversity indices the highest Shannon-Weiner's diversity index (2.29) was recorded in summer with the Simpson Dominance Index (0.88) and Evenness (0.86) while the dissolved oxygen, water temperature, and water velocity were found key environmental factors influencing fish community structure highlighting the significant role of water parameters in shaping fish diversity and distribution.

Adhikari et al. (2021) recorded 1,772 fish individuals from the Mechi River, identifying 33 species belonging to 4 Orders, 8 Families, and 16 Genera. The study also highlighted Cyprinidae and Cobitidae as the dominant families, with *Schistura devdevi, Brachydanio rerio, Puntius sophore, Barilius barila, Schistura beveani,* and *Puntius terio* being the most abundant species. The water quality also found within the desirable level that favors the habitat for fish (Water temperature; 16°C to 27°C, Velocity; 0.74 m/s to 2.12 m/s, pH; 7.1 to 7.6, DO; 6.21 mg/L to 9.3 mg/L, Free CO_2; 36.28 mg/L to 54.14 mg/L) with no significant difference ($p>0.05$).

In context of western region of Nepal Saund et al. (2012) studied fish diversity of the Mahakali River recorded 24 fish species belonging to three orders, four families, and 13 genera with dominancy of *Tor tor, Labeo pangusia,* and *Schizothorax sinuatus*. Environmental conditions were favorable for fish survival with water temperatures averaging between 20.5°C and 22.63°C, pH ranging from 6.93 to 7.20, and dissolved oxygen levels from 8.58 to 11.85 mg/L. The study highlighted concerns about the Pancheshwar Multipurpose Project's potential to alter habitats and block migratory routes, emphasizing the need for environmental management strategies. Chaudhari et al. (2020) studied fish diversity in the lower West Rapti River and recorded 42 fish species from 5 orders, 14 families, and 25 genera, with *Cabdio morar* being the dominant species. Fish abundance varied across three sampling stations, with the highest catches in winter and spring. Water quality parameters measured at the sampling stations included pH (6.5-8.5), DO (5.0-8.0 mg/L), and temperature (20°C- 28°C). This study also compared the data with previous studies and highlighted more richness with ecological significance of the river for local communities reliant on agriculture and fishing. Chapagain et al. (2021) studied on the ichthyofaunal diversity in Mardi Stream, recorded 10 species, 3 orders, 3 families, and 9 genera from 1,850 individual fish dominated by Cypriniformes (92.6%) and also hosted home to vulnerable species like *Schizothorax richardsonii* and *Naziritor chelynoides*. The study highlighted the seasonal variations with the highest diversity and abundance in summer and the lowest in spring. Fish richness was significantly correlated with pH, dissolved oxygen, water temperature, and velocity with desirable range of water quality parameters (Water temperature; 12°C to 25°C, pH; 8.1 to 9.5, DO 8.1 to 10.4 mg/L, and Water velocity 0.52 m/s to 1.8 m/s).

A study conducted by Shrestha et al. (2023) on the Dudhkoshi River in eastern Nepal found 22 fish species across 13 genera, 8 families, and 3 orders, totaling 1,265 individuals. Species richness was higher during the pre-monsoon season compared to the post-monsoon. The most abundant species were *Schizothorax richardsonii* (15.57%), *Schizothorax progastus* (11.15%), *Labeo dyocheilus* (10.12%), and *Barilius bendelisis* (8.85%). The highest average Shannon diversity index was recorded in pre-monsoon 2022 (1.74±0.199), along with the highest Simpson's index of diversity (0.77±0.221). Margalef's richness index peaked in pre-monsoon 2022 (1.93±0.342), and Pielou's evenness index was highest in pre-monsoon 2021 and 2022 (0.95±0.009 and 0.95±0.253, respectively). Species accumulation curves indicated that sampling efforts, particularly in pre-monsoon 2022, were sufficient, suggesting the potential for discovering more species with increased efforts.

Chaudhari (2024) studied how irrigation dams affect fish in Budhikhola using four sampling stations over nine months. The river had 41 fish species from 6 orders and 13 families, with Cyprinidae being the most common. Species like *Barilius barna*, *Chanda nama*, and *Chagunius chagunio* were notable. However, the construction of irrigation dams has led to significant ecological disruptions, such as habitat degradation, reduced water depth, siltation, and the loss of key fish species. These changes, coupled with seasonal variations in catch rates and spatial differences between upstream and downstream areas, reflect the intricate relationship between habitat modifications and fish community dynamics. Despite a high Shannon-Weiner's Diversity Index (H' = 3.57) and evenness value (E = 0.96), indicating a relatively balanced community, the study underscores the urgent need for targeted conservation and management strategies to address the adverse impacts of damming and other human activities.

Hydropower projects in Nepal, such as those on the Tamakoshi and Marshyangdi Rivers, have been documented to disrupt migratory pathways for large, migratory species like *Tor putitora* (Golden Mahseer). Shrestha and Amatya (2022) reported that alterations in flow regimes—induced by dam construction—result in fragmented habitats that reduce spawning success. For instance, local fishermen have observed that the Tamakoshi River has experienced a 30–50% decline in overall fish abundance since 2010 due to habitat fragmentation caused by damming (The Himalayan Times, 2021). Similar concerns have been raised for other rivers, where altered environmental flows compromise the availability of critical spawning and feeding habitats. In addition to hydropower impacts, destructive fishing practices are significantly depleting endemic fish stocks in several river systems. In the Ratuwa and Kankai Rivers, the use of electrofishing and poisonous herbs has led to a 30–50% reduction in fish populations over the past decade. The Kankai River, which is known to host up to 94 species (including six IUCN Near Threatened taxa), is particularly vulnerable to overexploitation. The unregulated use of fry nets and indiscriminate fishing methods have critically diminished fish abundance and diversity in this system, posing long-term risks for endemic species (Limbu et al., 2016).

3. Materials and Methods

3.1 Materials

pH meter-(Champ®, HI 98106), DO meter-(DO meter-DO 9100) , Standard Digital thermometer, TDS meter, GPS device (Garmin etrex 10), Cast net (mesh size 5mm), Field Guide book, Sampling box, Formalin , Measuring scale, Measuring tape, Rope, Camera, Buffer solution, Chemicals (NaOH, HCl, EDTA, etc.) for titration.

3.2 Study area

The study was conducted in the Tamakoshi and Singati Rivers of Dolakha district, Nepal. The Tamakoshi River is a tributary of the Sapta Koshi river system, originates from the Rongshar Chu and Lapchi Gang rivers close to the Nepal-Tibet border (Sharma, 1977). The study area covered a 27 km stretch from the Khopachagu Singati River to the Chyadu Tamakoshi confluence in the Tamakoshi River. The Singati River is a small but ecologically important tributary located in the Dolakha District, Nepal. This river flows through rugged hilly terrain before joining a larger watercourse in the Tamakoshi system. Singati generally lies in the region around approximately 27°.45' N latitude and 86°.90' E longitude, a zone characteristic of Dolakha's mid-hill areas. In this region, the river benefits from the fresh meltwater from nearby glaciers and seasonal rainfall, which help maintain its flow and water quality. The Singati plays a crucial role in contributing to the overall water balance and ecological integrity of the Tamakoshi River basin.

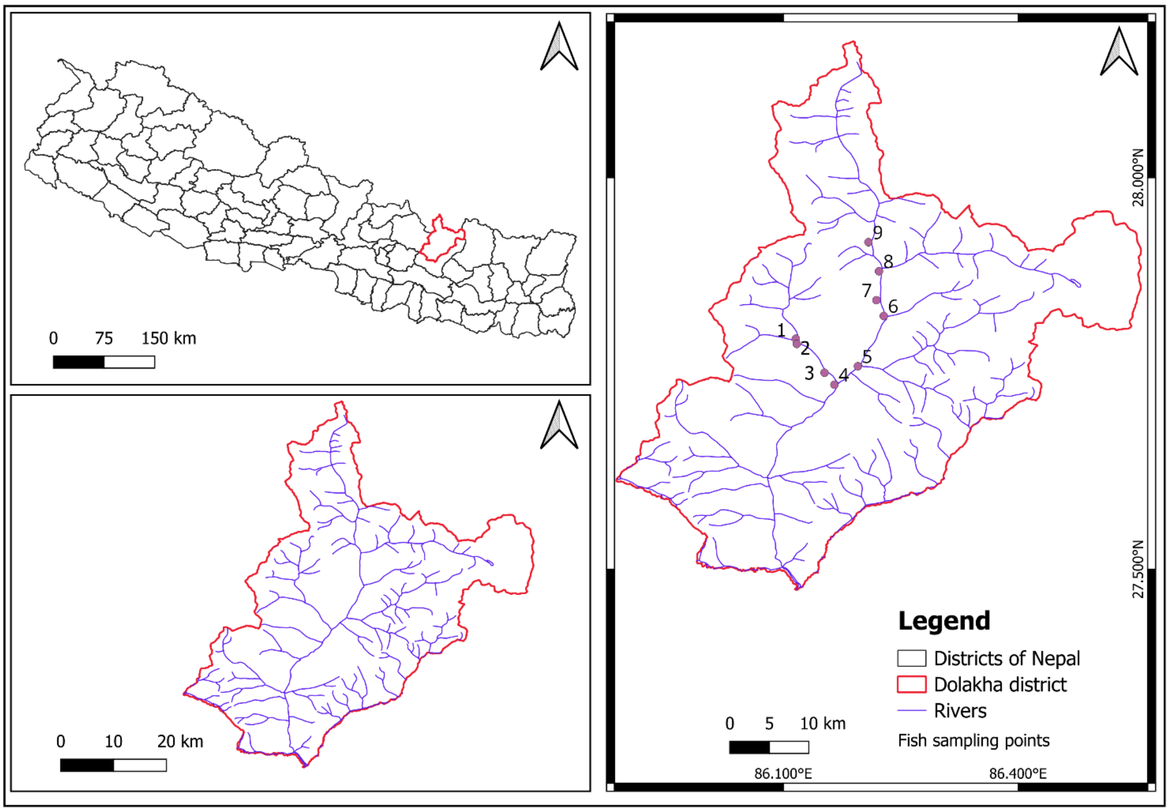


Figure 1: Map of the study area

3.3 Sampling stations

Altogether nine sampling stations were chosen based on river accessibility, habitat heterogeneity, and confluences in alignment with the study objectives. Of these stations, four were located in the Singati River (SR1 to SR4), and the other five in the Tamakoshi River (TR1 to TR5).

Station 1: Khopachagu Singati River (SR1)

It is located at the confluence of the Singati River and Sagu Khola in Khopachagu village, this station lies at an elevation of 1,276 masl (27°.79'09"N, 86°.11'60"E). The riverbed comprises pebbles, boulders, and gravel.

Station 2: Upstream of Singati Hydropower (SR2)

The station 2 lies upstream of the Singati Hydropower Project at an elevation of 1,270 masl (27.78'76"N, 86.11'72"E). The river bed consists of pebbles, boulders, gravel, and mud. Notably, the Singati Hydropower reservoir is built at this location.

Station 3: Downstream of Singati Hydropower (SR3)

This site situated downstream of the Singati Hydropower Project, this station lies at an elevation of 984 masl (27°.74'29"N, 86°.15'26"E). The river bed includes pebbles, boulders, gravel, and sand. The Singati 132 KV substation is located in this site.

Station 4: Singati-Tamakoshi Confluence (SR4)

The SR4 site located at the confluence of the Singati and Tamakoshi River near singati Bazar at an elevation of 995 masl (27°.73'54"N, 86°.16'53"E). The riverbed is composed of pebbles, boulders, gravel, and mud and significantly affected by anthropogenic activities.

Station 5: Tallo-Khare-Tamakoshi Confluence (TR1)

This station was designated in Tamakoshi River at the confluence of the Tallo Khare Khola and Tamakoshi River, with an elevation of 1,000 masl (27°.75'89"N, 86°.19'52"E). The riverbed comprises pebbles, boulders, gravel, mud, and sand. The Tallo Khare Khola Hydropower Project (TKKHEP) power station is situated at this location.

Station 6: Siprin khola-Tamakoshi Confluence (TR2)

This station is located at the confluence of the Siprin khola and Tamakoshi River, at an elevation of 1,137 masl (27°.82'32"N, 86°.22'83"E). The riverbed includes pebbles, boulders, gravel, mud, and sand. The Siprinkhola Hydropower Station is located here.

Station 7: Syalu-Tamakoshi Confluence (TR3)

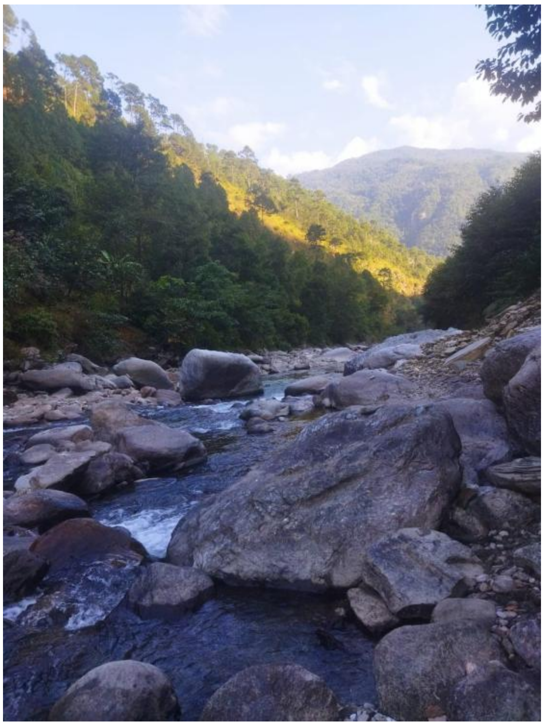
The site TR3 lies at the confluence of the Gongar Khola and Tamakoshi River at an elevation of 1,284 masl (27°.84'50"N, 86°.21'89"E). The riverbed comprises pebbles, boulders, gravel, mud, and sand.

Station 8: Simighaun-Tamakoshi Confluence (TR4)

It is situated at the confluence of the Rolwaling Kosi and Tamakoshi River in Simighaun, at an elevation of 1,440 masl (27°.88'17"N, 86°.22'22"E). The riverbed consists of pebbles, boulders, gravel, mud, and sand.

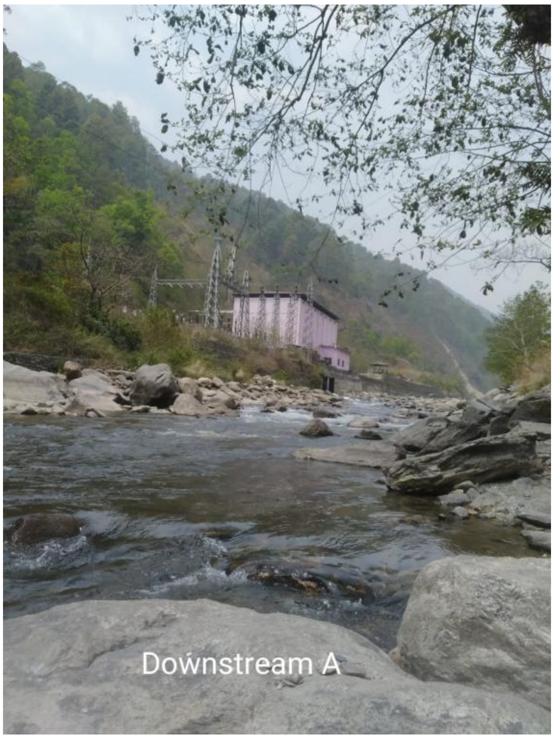
Station 9: Chyadu-Tamakoshi Confluence (TR5)

This station is situated downstream of the Upper Tamakoshi headworks diversion dam, with an elevation of 1,948 meters above sea level (27°.90'38"N, 86°.20'87"E). The river bed is mixed of muddy and sandy type with pebbles, boulders and gravels.



Station 1

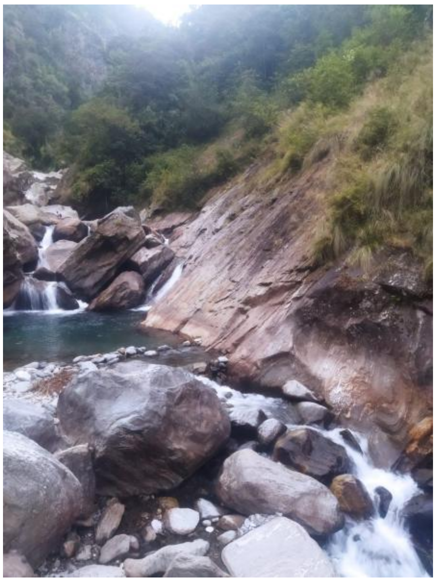
Station 2



Station 3

Station 4

Station 5



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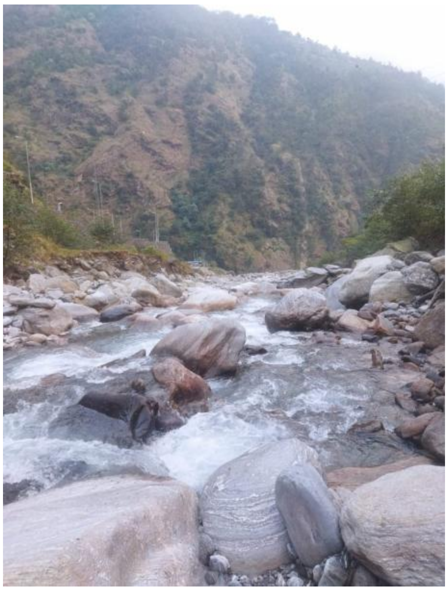

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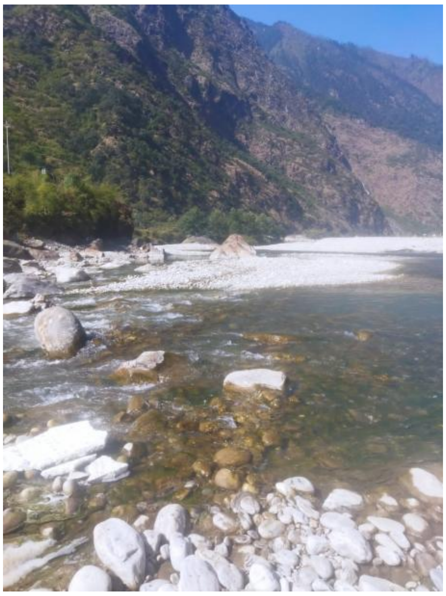

Station 8

Station 9

3.4 Sampling method

3.4.1 Sample collection and preservation

The fish survey was conducted from October 2023 to March 2024 covering three distinct seasons: post-monsoon, winter and pre-monsoon. Sampling was done using cast net (mesh size 5 mm) throwing twenty hauls in each station by the help of local fishermen. Sampling was done in the early morning between 6 am to 8 am to ensure consistent conditions. During each sampling event, a 500-meter stretch of the river, including both upstream and downstream areas from the station, was covered. The collected samples were counted and preliminary identification was done. Some voucher samples were preserved in Formaldehyde for further analysis. The rest of fish were released back into the river after necessary investigations.

3.4.2 Identification and deposition

The fish species collected from the sampling stations were identified in the field using standard keys Shrestha (1981/1994), Shrestha (2019), and Jayaram (1981), which provide comprehensive keys and descriptions for the accurate identification of fish species in Nepal's rivers and streams. During the study, the measurements were also taken such as Total length (cm), Fork length (cm), Standard length (cm), and Weight (g) and their morphological characteristics were noted. The conservation status was accessed from IUCN Red list of threatened species 2019. Then, the voucher samples were deposited in Central Department of Zoology museum of Tribhuvan University (CDZMTU).

3.5 Physicochemical parameters of water

Water samples of the Tamakoshi and Singati Rivers were collected along with fish sampling. The Physical parameters (temperature, TDS, and velocity) and the chemical parameters pH and DO were analyzed immediately in the field whereas one liter of water sample was collected in HDPE bottle to analyze the water hardness in the laboratory of Central Department of Zoology, TU, Kirtipur, Kathmandu followed by the standard method of APHA (1998) and Trivedy & Goel (1986).

3.5.1 Physical parameters of water

3.5.1.1 Water temperature

The temperature was measured by dipping the bulb of a standard mercury thermometer into the water.

3.5.1.2 Water velocity

The water velocity was measured using the float method, in which a plastic bottle was used as the float. A 10-meter stretch of the river was measured using a measuring tape, and the initial and final points of this section were marked. The plastic bottle was then released at the initial point, parallel to the flow of the river, and the time it took to reach the final point was recorded using a stopwatch. The velocity (in m/s) was then calculated based on this time.

$$v = d/t$$

where,

d = Distance marked along the river stretch.

T = Time taken

3.5.2.3 Total dissolved solids (TDS)

Total dissolved solids (TDS) refer to the combined content of all inorganic and organic substances dissolved in water. This includes irons, minerals, salts and some organic matters. TDS is usually measured in parts per million (ppm) or milligrams per liter (mg/L) and helps assess water quality for various uses. In this study, TDS was measured using a digital TDS meter.

3.5.2 Chemical parameters of water

3.5.2.1 Dissolved oxygen (DO)

The DO meter (DO 9100) was used to measure the dissolved oxygen levels at each sampling station throughout the study period.

3.5.2.2 Hydrogen ion concentration (pH)

A pH meter (Champ®, HI 98106) was used to measure the hydrogen ion concentration of water at each sampling station throughout the study period.

3.5.2.3 Hardness

A 50 ml water sample was taken in a flask, and 1 ml of ammonia buffer was added. Then, 5–6 drops of Eriochrome Black T indicator were added. The sample was titrated with 0.02 N EDTA solution until the color changed from wine red to blue, indicating the end point. The hardness was then calculated based on the titration result. Total hardness of water as $CaCO_3$ (mg/L) = (ml of EDTA used × 1000) / V

where,

V = Volume of water sample used.

3.6 Diversity indices

The diversity indices for different seasons and stations were analyzed using the Shannon-Wiener's diversity index, Margalef's richness index, and Pielou's evenness index

3.6.1 Species diversity index

The Shannon-Wiener's diversity index (Shannon and Wiener, 1949) was used to estimate species diversity in a community and denoted as H'

$H' = -\sum (Pi) \times \ln (Pi)$.

where,

Pi= ni/N

ni = The number of individuals in each species.

N = Total number of persons in the sample.

ln =logarithm of base e.

3.6.2 Species richness index (d)

The richness of species was calculated using Margalef's species richness index (Margalef, 1968) and denoted as d.

Margalef's species richness (d) =S-1/ lnN

where,

S = Total number of species

N = Total number of individuals

3.6.3 Evenness index

To assess the species distribution of species among sample sites and seasons, Pielou's evenness index (Pielou, 1966) was used. It is denoted by J and calculated as,

Pielou's species evenness (J) = H'/ lnS

where,

H' = Shannon- Wiener's diversity index.

S = Total number of species in the station.

3.7 Statistical analysis

Statistical analyses were conducted using R software, where calculations were performed to determine the Shannon-Weiner diversity index, species richness, and evenness across different seasons and sites. As the dataset followed a linear trend where the lengths of the axes and the eigenvalues from the DCA indicated that the relationships in data were best described using a linear model Redundancy Analysis (RDA). RDA was used to analyze how species numbers change with different sampling sites, seasons, and environmental factors.

3.8 Identification of spawning grounds and socioeconomic status

To identify fish spawning grounds in the study area, the physical characteristics of the river such as water depth, flow velocity, temperature, dissolved oxygen, and substrate type (e.g., gravel, sand) were observed, as these factors significantly influence fish spawning behavior (Jha et al., 2006; Shrestha, 1990). Spawning grounds were typically found in shallow, fast-flowing sections of the river with clean and coarse substrates, particularly gravel beds, which provide suitable conditions for egg deposition and oxygenation (Cowx & Welcomme, 1998). In addition, traditional ecological knowledge was gathered by interviewing local fishers and communities, who provided valuable insights on fish aggregation and breeding areas based on long-term observations (Gurung et al., 2013).

To evaluate the socioeconomic status of local fishermen, a semi-structured interviews was used. The survey collected data on type, age, education level, primary and secondary occupations, access to markets, fishing equipment ownership, perception of declining fish population, and fishing dependency. Questions were also included on awareness of fish conservation, perception of environmental changes, and involvement in local management or cooperative groups. The data were analyzed using descriptive statistics and categorized based on standard livelihood indicators (Allison & Ellis, 2001; Béné, 2003).

4. Results

4.1 Fish diversity in the Tamakoshi river and Singati river

The Tamakoshi and Singati Rivers are habitats for various types of freshwater fish. A total of seven different fish species were found during the study period, belonging to 2 orders, 3 families, and 6 genera (Table 1). Among the total species, *Psilorhynchus pseudocheneis, Schizothorax progastus, and Schizothorax richardsonii* were the dominant species. Of the seven indigenous species, five were classified as Vulnerable (VN), and two were classified as Least Concern (LC). The conservation status was adopted from the IUCN Red List (2019).

Table 1: The Systematic position of fishes with their local name and conservation status

Order	Family	Name of Species	Local name	Conservation Status
Cypriniformes	Cyprinidae	*Schizothorax progastus* (McClelland, 1839)	Chuche Asla	VN
Cypriniformes	Cyprinidae	*Schizothorax richardsonii* (Gray, 1832)	Buche Asla	VN
Cypriniformes	Cyprinidae	*Naziritor chelynoides* (McClelland, 1839)	Halundae	VN
Cypriniformes	Cyprinidae	*Garra gotyla* (Gray, 1830)	Buduna	LC
Cypriniformes	Cyprinidae	*Neolissochilus hexagonolepis* (McClelland, 1839)	Katlae	VN
Cypriniformes	Psilorhynchidae	*Psilorhynchus pseudecheneis* (Menon & Datta, 1964)	Titae	VN
Siluriformes	Sisoridae	*Pseudecheneis sulcata* (McClelland, 1839)	Kabre	LC

Schizothorax Progastus

Neolissochilus hexagonolepis

Psilorhynchus pseudecheneis

Schizothorax richardsonii

Pseudecheneis sulcata

Garra gotyla

Naziritor chelynoides

4.1.1 Order-wise composition

The collected fish samples were fall under two orders Cypriniformes with 6 species (86%), and Siluriformes with only one species (14%) (Figure 2).

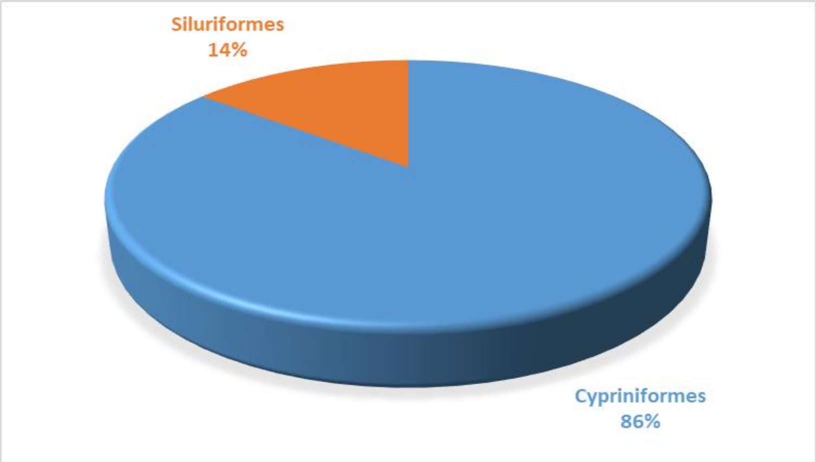

Figure 2: Order-wise composition of fishes

4.1.2 Family-wise composition

A total of three families have been recorded: Cyprinidae, Sisoridae, and Psilorhynchidae. Cyprinidae constituted 72% (n= 5), followed by Psilorhynchidae and Sisoridae 14% each with one species (Figure 3).

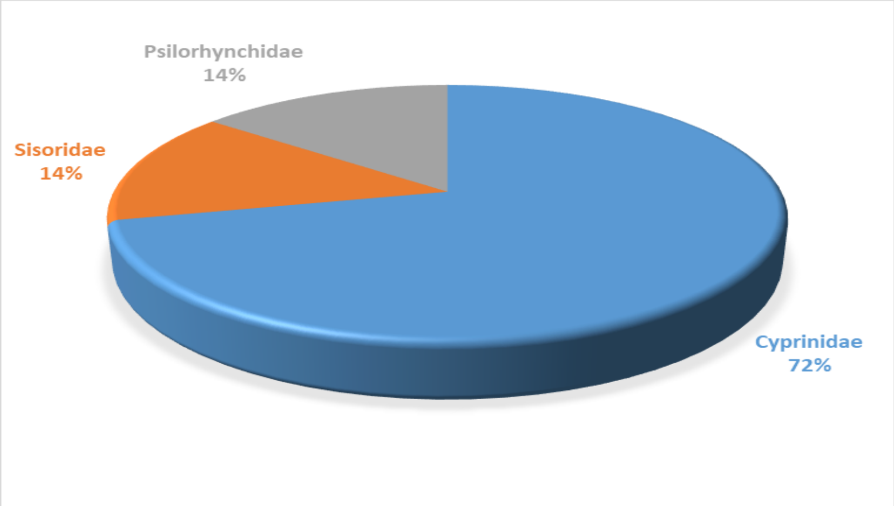

Figure 3: Family-wise composition of fishes

4.1.3 Distribution pattern and frequency occurrence

Among 7 fish species, a higher number of total catch was *Psilorhynchus pseudocheneis* (167) followed by *Schizothorax progastus* (114) and *Schizothorax richardsonii* (82). The catch frequency showed the dominancy of *Psilorhynchus pseudocheneis* with 31.16% followed by *Schizothorax progastus* (21.26%) and *Schizothorax richardsonii* (15.29%), respectively (Table 2).

Table 2: Distribution and frequency occurrence of fishes

		Station Number										Frequency (%)
S.N.	**Name of species**	**SR1**	**SR 2**	**SR 3**	**SR 4**	**TR1**	**TR2**	**TR 3**	**TR4**	**TR 5**	**Total**	
1	*Schizothorax progastus*	18	11	9	7	20	11	6	23	9	114	21.26
2	*Schizothorax richardsonii*	20	11	6	3	12	1	6	16	7	82	15.29
3	*Naziritor chelynoides*	3	2	0	10	12	9	0	10	3	49	9.15
4	*Garra gotyla*	0	5	0	1	0	0	8	6	8	28	5.22
5	*Neolissochilus hexagonolepis*	8	6	9	3	10	0	0	4	10	50	9.32
6	*Psilorhynchus pseudecheneis*	16	17	24	7	50	14	8	27	4	167	31.16
7	*Pseudecheneis sulcata*	5	0	11	1	0	7	8	6	8	46	8.59
Total Number		70	52	59	32	104	42	36	92	49	536	100

4.2 Physicochemical parameters

4.2.1 Water temperature

The water temperature varied from 17.2℃ in Chyadu-Tamakoshi Confluence (TR5) to 24℃ at Downstream Singati Hydropower (SR3) in Pre-monsoon. In winter, it varied from 14.1℃ to 20.2℃. The lowest was at the Khopachagu-Singati Confluence (SR1) and the highest was at the Shyalu-Tamakoshi Confluence (TR2). In Post-Monsoon, It varied from 15.4℃ to 22.3℃. The lowest was at the Singati-Tamakoshi Confluence (SR4) and the highest was at the Downstream Singati Hydropower (SR3) (Figure 4).

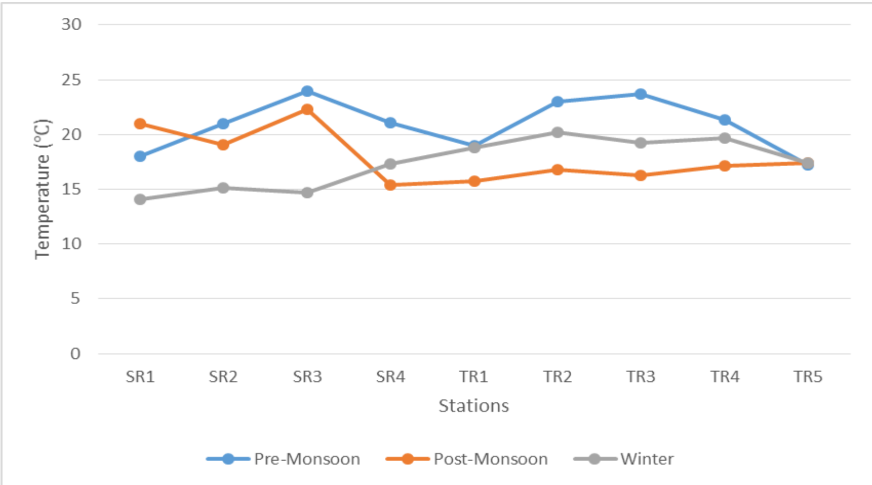

Figure 4: Variation of water temperature at Singati and Tamakoshi rivers across seasons

4.2.2 Water Velocity

The velocity was recorded in each season from all stations. During the study period, Velocity was ranged from 0.3-1.36 m/s. The velocity was found highest (1.36 m/s) in Winter at the Simighaun-Tamakoshi Confluence (TR4) and lowest value (0.3 m/s) at the Khopachagu-Singati Confluence (SR1) in Pre-monsoon (Figure 5).

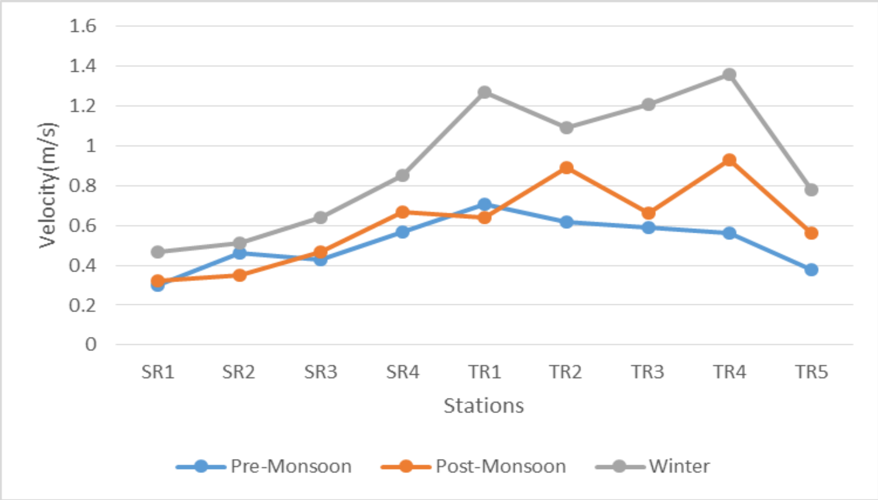

Figure 5: Variation of water velocity at Singati and Tamakoshi rivers across seasons

4.2.3 Dissolved oxygen

The DO was recorded in each season from all stations. DO was ranged from 6.7-16.8 mg/l during study. The concentration of dissolved oxygen was found highest (16.8 mg/l) in Post-monsoon at the Simighaun-Tamakoshi Confluence (TR4) and lowest value (6.7 mg/l) at the Downstream Singati Hydropower (SR3) in Pre-monsoon (Figure 6).

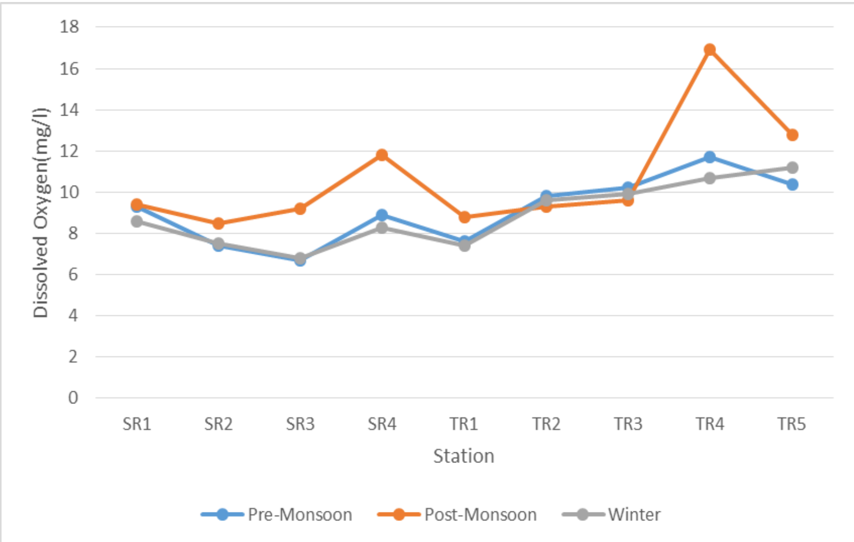

Figure 6: Variation of dissolved oxygen at Singati and Tamakoshi rivers across seasons

4.2.4 Hydrogen ion concentration (pH)

In Pre-monsoon, the pH of the water varied from 6.7 to 7.6. The lowest pH was recorded at the Siprinkhola-Tamakoshi Confluence (TR2) and the highest at the Simighaun-Tamakoshi Confluence (TR4). In winter, it varied from 6.4 to 7.8. The lowest was at the Syalu-Tamakoshi Confluence (TR3) and the highest was at the Singati-Tamakoshi

Confluence (SR4). In Post-monsoon, it varied from 6.5 to 8.1. The lowest was at the Siprinkhola-Tamakoshi Confluence (TR2) and the highest was at the Singati-Tamakoshi Confluence (SR4) (Figure 7).

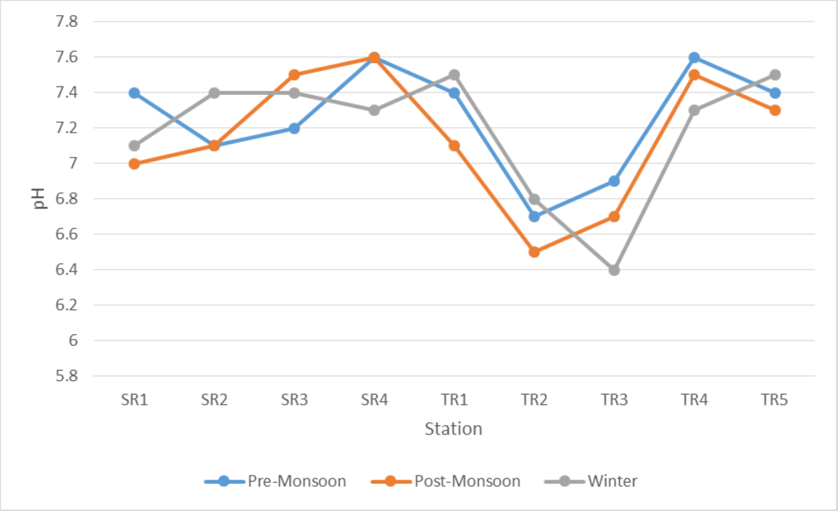

Figure 7: Variation of water pH at Singati and Tamakoshi rivers across seasons

4.2.5 Total hardness

The total hardness was recorded in each season from all stations. During the study period, Total hardness was ranged from 47.3-58.9 mg/l. The hardness was found highest (58.9 mg/l) at the Siprinkhola-Tamakoshi Confluence (TR2) in winter and lowest value (47.3 mg/l) at the Khopachagu-Singati Confluence (SR1) in Pre-monsoon (Figure 8).

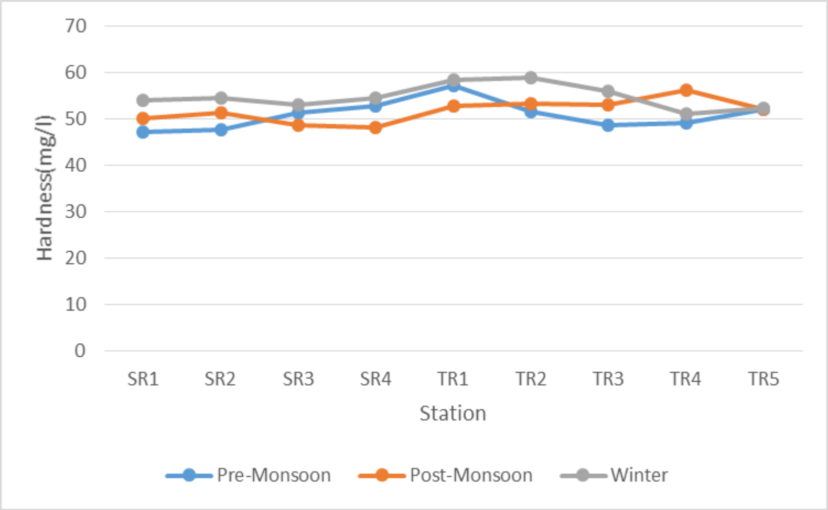

Figure 8: Variation of total hardness at Singati and Tamakoshi rivers across seasons

4.2.6 Total dissolved solids

The TDS was recorded in each season from all the stations. During the study period, TDS was ranged from 19-47 ppm. The highest TDS was at the Singati-Tamakoshi Confluence (SR4) in winter and the lowest was at the Syalu-Tamakoshi Confluence (TR3) in Pre-monsoon (Figure 9).

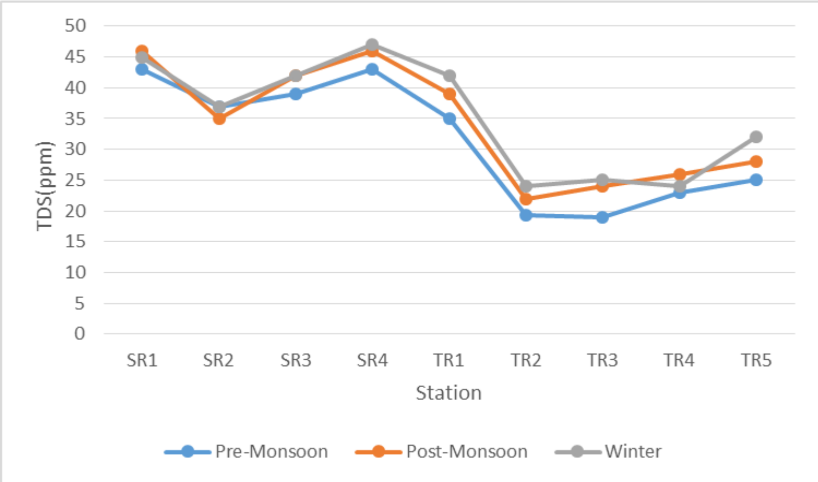

Figure 9: Variation of water total dissolved solids at Singati and Tamakoshi rivers across seasons

4.3 Diversity indices

The station wise diversity indices, including Shannon-Wiener's diversity, Margalef's richness, and Pielou's evenness, are presented station-wise in Table 5 (Appendix 2). The highest number of fish species (7) was recorded at stations SR4, TR4, and TR5 whereas the lowest number (5) was recorded at stations SR3, TR2, and TR3. The value of highest Shannon Weiner's diversity index was found at station TR5 and the lowest was at station TR1. The maximum Margalef's richness value was observed at stations SR4, whereas the minimum was found at stations TR1. Similarly, the highest Pielou's evenness index was recorded at station TR5 and the lowest at station SR4 (Figure 10, Appendix 3).

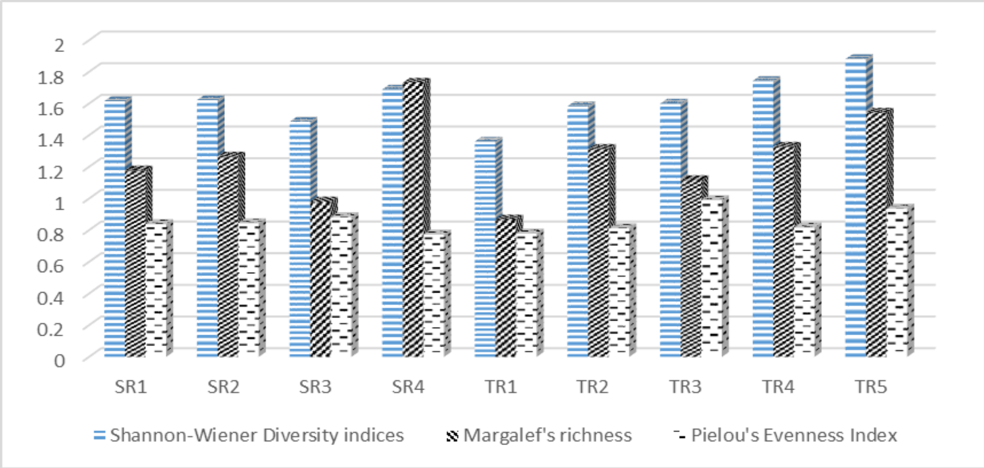

Figure 10: Station-wise diversity indices in different stations of Tamakoshi and Singati river

The season wise Shannon-Wiener's diversity, Margalef's richness, and Pielou's evenness, at Singati River are presented in Figure 11 (Appendix 3). During post monsoon, the Shannon–Wiener diversity index reached its highest value at 1.817, while the pre monsoon recorded the lowest value (1.704). Similarly, Pielou's evenness was at its peak in post monsoon (0.881) and dipped to its minimum in the pre monsoon period (0.786). In contrast, Margalef's richness was greatest at post monsoon and winter with the value1.534 but was at its lowest during pre monsoon with a value of 1.504.

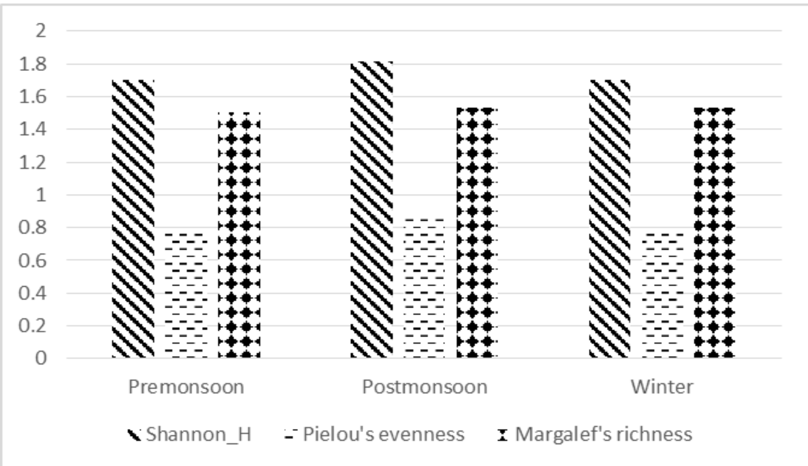

Figure 11: Season-wise diversity indices at Singati river

Likewise, in the Tamakoshi River, Shannon-Wiener's diversity was highest (1.804) during the pre-monsoon and lowest (1.735) during the post-monsoon. Margalef's richness peaked during the pre-monsoon at a value of 1.398 and dropped to its lowest at 1.19

during winter. Pielou's evenness was highest during the pre-monsoon at 0.868 and lowest during the post-monsoon at 0.81 (Figure 12).

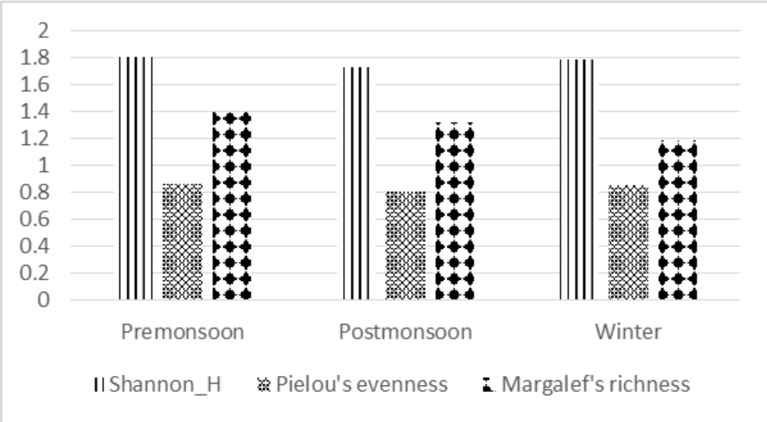

Figure 12: Season-wise diversity indices at Tamakoshi river

4.4 Relationship between environmental variables with fish species

The Redundancy Analysis (RDA) biplot (Figure 13) illustrates the relationships between environmental variables and fish species composition in the Singati River. In the Singati River the RDA results indicated that temperature and hardness were strongly and positively inter-correlated, while pH, water velocity, dissolved oxygen (DO), and total dissolved solids (TDS) varied inversely with these factors. In the ordination diagram, fish species such as *Schizothorax progastus, Psilorhynchus pseudecheneis,* and *Pseudecheneis sulcata* were positioned in a way that reflects a close link with higher temperature while velocity and DO were negatively related. In contrast, species like *Garra gotyla* was found in areas of the plot corresponding to elevated hardness but lower TDS. Additionally, *Naziritor chelynoides* and *Schizothorax richardsonii* were aligned with higher velocity and DO values, yet showed negative correlations with temperature. Notably, *Neolissochilus hexagonolepis* appeared to favor higher TDS and pH while avoiding elevated hardness. The Redundancy Analysis (RDA) biplot for the Tamakoshi River showed somewhat difference to that of the Singati River. In Tamakoshi River *Psilorhynchus pseudecheneis* and *Naziritor chelynoides* were associated with water velocity, whereas *Schizothorax progastus* was associated to temperature, while *Neolissochilus hexagonolepis* was more closely associated with velocity and temperature (Figure 14).

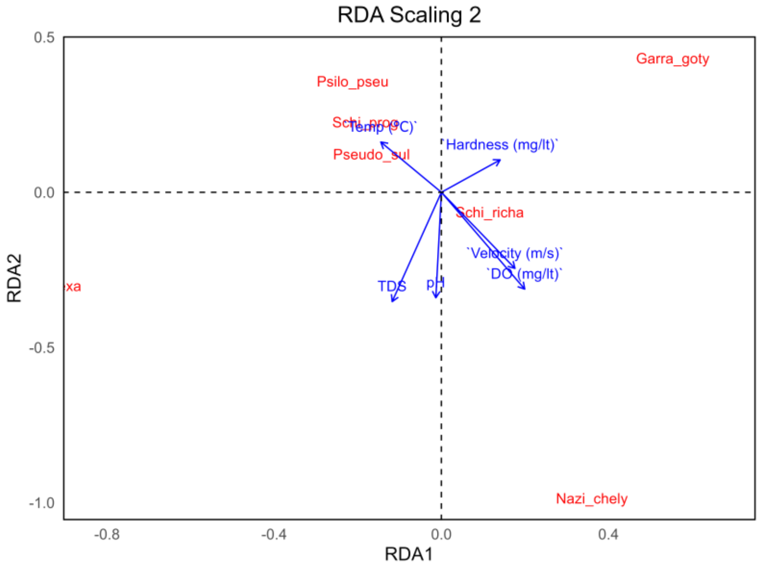

Figure 13: RDA analysis of species abundance with environmental variables at Singati River

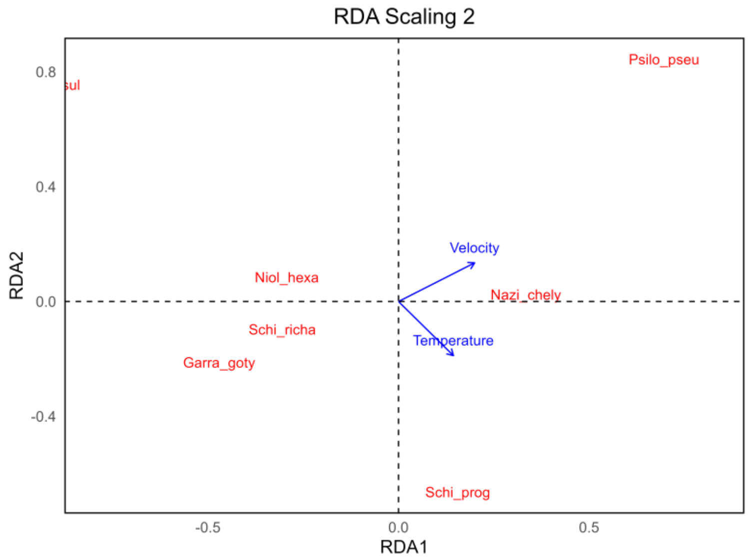

Figure 14: RDA analysis of species abundance with environmental variables at Tamakoshi River

Abbreviations: *Garra_goty* = *Garra gotyla*, *Neol_hexa* = *Neolissochilus hexagonolepis*, *Psil_pseu* = *Psilorhynchus pseudecheneis*, *Schi_prog* = *Schizothorax progastus*, *Nazi_chely* = *Naziritor chelynoides*, *Pseu_sul* = *Pseudecheneis sulcata*, *Schi_rich* = *Schizothorax richardsonii.*

4.5 Spawning grounds

Spawning grounds are specific areas where fish reproduce and lay their eggs. These areas are critical for the survival of fish populations. The observation during study period and the perception of the local fishermen in questionnaire survey, four spawning grounds were identified near stations SR3, TR1, TR2, and TR4 (Table 3, Figure 15).

Table 3: Spawning ground in Singati and Tamakoshi Rivers

Spawning ground	Latitude	Longitude	Near station	River bed
1	27°.76'94"N	86°.20'24"E	SR3	Pebbles, gravel, mud, sand, stagnant water
2	27°.88'14"N	86°.22'27"E	TR1	Pebbles, sand, stagnant water, gravel
3	27°.75'06"N	86°.15'30"E	TR2	Pebbles, sand, stagnant water, gravel
4	27°.78'76"N	86°.11'87"E	TR4	Pebbles, sand, stagnant water, gravel

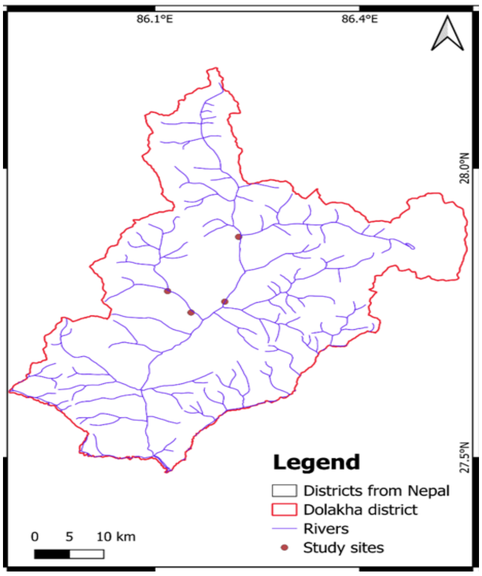

Figure 15: Map showing spawning ground with red dots

4.6 Socio-economic status of local fishermen

The aquatic ecosystems of the Tamakoshi River and its major tributaries Singati River played a crucial role in supporting fish biodiversity and sustaining local livelihoods.

4.6.1 Fishing dependency and socioeconomic status

Twelve fishermen were interviewed during the study period, out of which 5 were completely dependent on fishing for their livelihood, four of them fished solely for food, as they were engaged in farming and do labor for a livelihood whereas three of them were occasional fishermen who only fished seasonally or needed an extra source of income.

4.6.2 Age and education level of fishermen

Out of the 12 fishermen surveyed, 7 were over 50 years old, 3 fell in the 40–49 age group, and the remaining 2 were under 39 years. This study reflected that the literacy rate of fishermen was low as 67% had education above school level (10^{th} class) while 33 % had completed hardly class 5. The perception regarding conservation and awareness as well as the literacy rate highlighted the lack of conservation awareness of natural resources as well as sustainable fishing regulations and conservation measures.

4.6.3 Fish population decline and fishing practices

The knowledge and cause of the declination of fishes was questioned to respondents. According to them the main source of declination was the construction of hydropower dam (75%) followed by overfishing (25%) (Figure 16). During the study period, there was not seen any problems of plastic pollution except in Singati bazar (SR4). The recent field surveys and interactions with local fishermen found a significant decline in fish populations. According to them the abundance and diversity of fishes were high before the construction of dam so the livelihood was dependent upon fishing at that time but in recent days, the number and variety of fish species have decreased dramatically due to the obstruction of the fish path. However there were fish ladders in dam but they are not functional as low water flow and fish ladder seems like barren area.

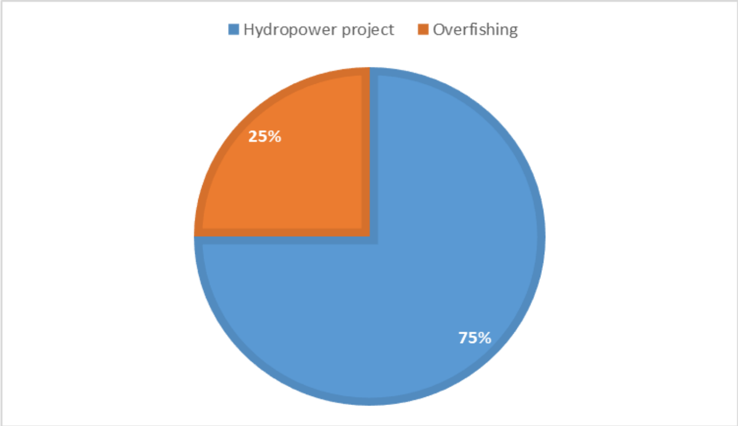

Figure 16: Perception (%) of declining fish population

A major concern raised by the fishermen was the continued use of illegal and destructive fishing methods, which have further contributed to the decline in fish populations. Capturing brood stocks was main destructive fishing practices found during study period which is followed by use of small mesh size, electrofishing and bombarding (Figure 17).

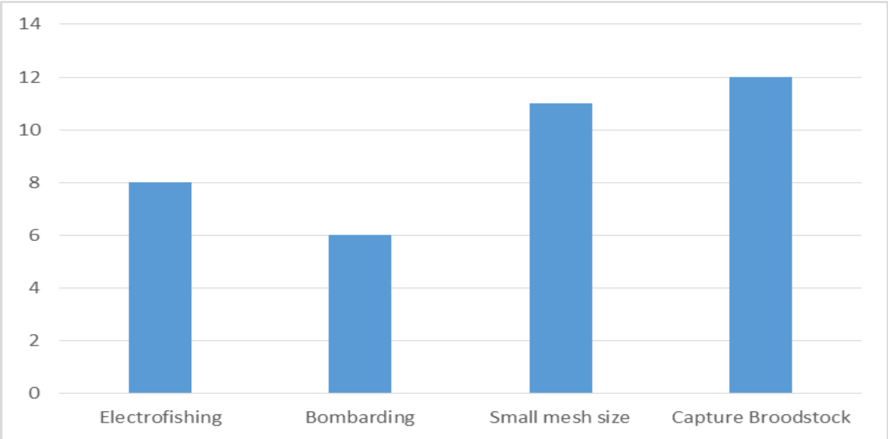

Figure 17: Destructive fishing practices

5. Discussion

The present study in the Tamakoshi and Singati Rivers recorded only seven indigenous fish species, representing two orders, three families, and six genera. In our sampling, the dominant species were *Psilorhynchus pseudecheneis, Schizothorax progastus,* and *Schizothorax richardsonii,* which together accounted for nearly 68% of all catches. In particular, *Psilorhynchus pseudecheneis* contributed 31.16% of the total catch, followed by *Schizothorax progastus* (21.26%) and *Schizothorax richardsonii* (15.29%). Notably, of these seven species, five are listed as Vulnerable and only two as Least Concern according to the IUCN Red List (2019).

The lower fish species richness recorded in the Tamakoshi and Singati Rivers was low as compared to the Tamor River (Shrestha et al., 2009), Yadav (2017) 22 species in the Koshi River, Limbu and Subba (2018) 16 species from Dewmai Khola, and Joshi and Joshi (2020) 23 species in the Mahakali River, may be due not only to ecological or human impacts but also to the sampling sites and sampling method used (Yu et al., 2024). The difference in species richness may be due to several reasons as one possible factor is the use of cast nets as the primary sampling gear may have contributed to an underrepresentation of benthic and cryptic species particularly those inhabiting fast-flowing riffles and rocky substrates. In this study, cast nets were used to sampling, which are effective for catching surface and mid-water fish but are less effective for bottom-dwelling species like those from the Cobitidae and Balitoridae families. These fish often live in fast-flowing, rocky habitats and are difficult to catch without methods like electrofishing or hand nets, which were likely used in the Tamor River study. This suggests that some species may have been missed in our survey due to gear limitations. Therefore, the lower diversity in our findings should be viewed with caution, as it may reflect both habitat disturbance and sampling bias. As a result, many sensitive species may be excluded, leading to a dominance of more tolerant fish species. Therefore, although sampling bias may have influenced species detection to some extent, the cumulative impacts of habitat alteration and flow regulation are likely the primary drivers of reduced fish diversity in the Tamakoshi system.

The aquatic ecosystem of the Tamakoshi and Singati Rivers, like many Himalayan systems, is defined not only by its fish diversity but also by its physicochemical characteristics. In this study, water temperature, velocity, dissolved oxygen (DO), pH, total dissolved solids (TDS), and total hardness were monitored across three seasons. In the pre-monsoon period, water temperature ranged from 17.2 °C at the Chyadu-Tamakoshi Confluence (TR5) to 24 °C at the Downstream Singati Hydropower (SR3). Winter temperatures were lower, varying between 14.1 °C at the Khopachagu-Singati Confluence (SR1) and 20.2 °C at the Shyalu-Tamakoshi Confluence (TR2), while post-monsoon values ranged from 15.4 °C to 22.3 °C. These seasonal temperature shifts are similar to trends reported by Bhandari and Shah (2016) in the Saptakoshi River, where temperature played a critical role in shaping fish communities. Temperature, as has been emphasized by Buisson et al. (2008) and Fisher and Willis (2000), not only influences metabolic rates and breeding cycles but also affects water chemistry parameters such as alkalinity and DO. The findings, with lower temperatures during winter, suggest that the thermal regime in the Tamakoshi system is conducive to supporting cold-water fish species during most seasons, though seasonal fluctuations may impact reproduction and growth as noted by Gillooly et al. (2001) and Mann (1991).

Flow velocity in present study varied from 0.3 to 1.36 m/s. The highest velocity was observed at the Simighaun-Tamakoshi Confluence (TR4) during winter, while the lowest was at the Khopachagu-Singati Confluence (SR1) in the pre-monsoon season. This range is comparable to velocities reported in other Himalayan rivers, where fast flows in steep-gradient reaches help dilute pollutants and maintain higher DO through enhanced aeration—a mechanism described by Negi and Joshi (2004) and supported by Gurung et al. (2019). In contrast, reduced velocities in modified channels often lead to pollutant buildup and lower DO, underscoring the importance of maintaining natural flow regimes.

Dissolved oxygen levels in present study ranged from 6.7 to 16.8 mg/l, with the highest value recorded at Station 8 in the post-monsoon season and the lowest at the Downstream Singati Hydropower (SR3) during pre-monsoon. These DO values are generally above the 5 mg/l threshold considered necessary for supporting diverse fish communities, a point stressed by Adhikari et al. (2019) and Thapa et al. (2020). However, the localized low DO near hydropower installations is a concern, as it can indicate potential stress on fish populations and reduced habitat suitability, a pattern similarly reported in studies of the Bagmati and Narayani systems (Baniya et al., 2019; Sah et al.,2000).

The pH of the water during the study was relatively stable, ranging from 6.7 to 7.6 in pre-monsoon, 6.4 to 7.8 in winter, and 6.5 to 8.1 in post-monsoon. Such values, within the neutral to slightly alkaline range, are typical for many Nepal’s rivers (Regmi et al., 2017) and are favorable for most aquatic organisms. Even though minor variations were observed between stations, the overall pH conditions in the Tamakoshi system appear similar to those reported in the Koshi and Karnali rivers (Sharma et al., 2012; Shrestha & Shrestha, 2010).

Total dissolved solids (TDS) ranged from 19 to 47 ppm across all stations, with the highest values recorded at the Singati-Tamakoshi Confluence (SR4) during winter. These low TDS levels indicate minimal mineral or pollutant loading, a finding consistent with studies on relatively pristine Himalayan streams where TDS typically remains within drinking water guidelines (Kannel et al., 2007). Total hardness values varied from 47.3 to 58.9 mg/l, with the maximum recorded at the Siprinkhola-Tamakoshi Confluence (TR2) during winter and the lowest at the Khopachagu-Singati Confluence (SR1) during pre-monsoon. Although hardness in some Nepalese water sources, such as the Marshyangdi, has been reported to reach much higher values (Tamrakar & Shakya, 2013; Shrestha & Shrestha, 2011), the relatively low hardness in our study suggests a low mineral load, likely due to the geology of the catchment.

When these water-quality parameters are compared with related studies in other Nepali river systems, a common pattern emerges. For instance, Bhandari and Shah (2016) highlighted that maintaining excellent water quality including optimal pH, temperature, and DO is essential for supporting diverse fish communities. Similarly, research on the Koshi and Bagmati rivers indicates that natural seasonal variations in these parameters are critical in sustaining high fish diversity (Gurung & Bajracharya, 2020; Rai, 2019). However, the localized deviations observed in the Tamakoshi system such as reduced DO near hydropower sites or slight pH variations at certain confluences point to the potential impacts of infrastructural modifications on water quality and, by extension, fish diversity.

The stations SR4, TR4, and TR5 recorded the highest number of species (7), along with the highest Shannon–Weiner diversity and Pielou’s evenness indices, while stations SR3, TR2, and TR3 exhibited lower species numbers (5) and diversity values. This spatial heterogeneity is comparable to patterns reported by Joshi and Joshi (2020) in the Mahakali River, where local variations in factors such as flow, substrate, and riparian vegetation significantly influenced fish community structure. Seasonally, diversity indices was highest during post-monsoon (H': 1.817 and j: 0.881) and dipped in the pre-monsoon (H': 1.704 and j: 0.786, respectively) at singati river. Margalef’s richness was highest during the post-monsoon and winter (1.534) and lowest in pre monsoon (1.504). These seasonal trends likely reflect changes in hydrological conditions and habitat availability, as higher flows during certain seasons can enhance habitat heterogeneity and promote greater species diversity, a pattern noted by Poff and Allen (1995) and later supported by studies such as those by Pegg and Pierce (2002).

The observation during study period identified the some spawning areas near stations SR3, TR1, TR2, and TR4. The identification of these spawning grounds aligns with findings from other studies in the region. For instance, Shrestha (1999) highlighted the Nepal's aquatic ecosystems offer excellent habitats for many native fish species, many of which rely on specific spawning grounds for reproduction, a study by the Asian Development Bank (2019) underlined that the construction of dams in Nepalese river basins has led to a decline in fish populations by altering water quality and damaging spawning grounds. A news on Himalayan News (2021) and local fishermen perception also identified that the Tamakoshi River is experiencing a marked decline in fish populations as the abundance of fishes before some years were declining now a day. The main causes were use of illegal electrofishing and overfishing.

There are so many hydro powers in Tamakoshi River and its tributaries. The Environmental Impact Assessment (EIA) for the Tamakoshi 3 Hydroelectric Project conducted by SWECO Norge AS (2009) highlighted that damming obstructs migratory pathways, transforms riverine habitats into reservoir environments, and disrupts natural spawning and nursery areas. Such hydropeaking operations, where large volumes of water are abruptly released, not only reduce instream flows during critical periods but also create dangerous conditions for fishermen, as recounted by local fishers who expressed concern over being swept away during sudden water releases. Hydropower projects often reduce instream flow during dry seasons, fragment aquatic habitats, and alter key environmental variables such as dissolved oxygen levels and sediment transport. These changes can severely disrupt fish migration routes, degrade spawning grounds, and reduce overall habitat suitability (FAO, 2001).

The findings of this study show that although the overall water quality in the Tamakoshi and Singati Rivers generally falls within the acceptable range for supporting fish life, there are signs of local environmental stress, particularly near hydropower sites. These impacts, combined with overfishing and harmful fishing methods, have contributed to a noticeable drop in both the number and variety of fish. This trend is reflected not only in the scientific data and diversity measurements but also in the observations shared by local fishermen, who report lower catches and changes in river conditions. Addressing these challenges requires a coordinated approach that includes better regulation of hydropower operations, such as ensuring effective fish passages and maintaining adequate water flow, along with promoting responsible fishing and conducting more detailed studies to inform conservation plans. Taking these steps is vital for maintaining healthy aquatic ecosystems and supporting the communities that rely on these rivers for their livelihoods.

6. Conclusion and recommendations

6.1 Conclusion

The study of fish diversity in the Tamakoshi River and its major tributaries reveals notable ecological and environmental concerns. Conducted over three seasons, the survey recorded seven fish species from a total of 536 individuals, indicating relatively low species richness. Dominant species included *Schizothorax progastus*, *Schizothorax richardsonii*, and *Psilorhynchus pseudecheneis*, while other species such as *Garra gotyla*, *Pseudecheneis sulcata*, *Naziritor chelynoides*, and *Neolissochilus hexagonolepis* were found in much smaller numbers. Variations in environmental parameters, such as temperature, dissolved oxygen, and water velocity significantly influenced fish distribution and abundance. The study also points to multiple stressors contributing to fish decline, including physical habitat alterations, seasonal changes in river flow, and unsustainable fishing practices such as the use of destructive or illegal gear. These combined impacts have likely led to the decline of sensitive species and the dominance of a few tolerant ones.

6.2 Recommendations

Based on field visits and interaction with local people, the following recommendations could be made:

- An intensive survey and regular monitoring of fish should be conducted by the government and other concerned agencies.
- Some of the breeding and spawning grounds were observed during the study so it is necessary to conserve that area to maintain the diversity.
- Illegal fishing practices were also practiced in GCA so it should be strictly prohibited and punished.
- Public awareness programs for local fishers should be conducted in terms of the importance of fish diversity and the adverse impacts due to its loss.
- Develop alternative livelihood opportunities such as eco-tourism, and community-based conservation programs to reduce overfishing pressure.

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Appendices

Appendix 1

Table 4: Physico-chemical parameters during different season at different stations

Station	Post-monsoon						Winter						Pre-monsoon					
	Temp	Velo	DO	pH	TDS	HN	Temp	Velo	DO	pH	TDS	HN	Temp	Velo	DO	pH	TDS	HN
1	21	0.32	9.4	7	46	50.2	14.1	0.47	8.6	7.1	45	54.2	18	0.3	9.3	7.4	43	47.3
2	19.1	0.35	8.5	7.1	35	51.4	15.1	0.51	7.5	7.4	37	54.7	21	0.46	7.4	7.1	37	47.7
3	22.3	0.47	9.2	7.5	42	48.7	14.7	0.64	6.8	7.4	42	53.1	24	0.43	6.7	7.2	39	51.4
4	15.4	0.67	11.8	7.6	46	48.3	17.3	0.85	8.3	7.3	47	54.6	21.1	0.57	8.9	7.6	43	52.9
5	15.7	0.64	8.8	7.1	39	52.8	18.8	1.27	7.4	7.5	42	58.4	19	0.71	7.6	7.4	35	57.3
6	16.8	0.89	9.3	6.5	22	53.4	20.2	1.09	9.6	6.8	24	58.9	23	0.62	9.8	6.7	19.3	51.8
7	16.3	0.66	9.6	6.7	24	53.1	19.2	1.21	9.9	6.4	25	56.1	23.7	0.59	10	6.9	19	48.7
8	17.1	0.93	16.9	7.5	26	56.2	19.7	1.36	11	7.3	24	51.3	21.3	0.56	12	7.6	23	49.3
9	17.4	0.56	12.8	7.3	28	52.2	17.4	0.78	11	7.5	32	52.5	17.2	0.38	10	7.4	25	52.2

Appendix 2

Table 5: Station-wise value of diversity indices

Station Number	**Shannon Wiener's (H')**	**Margalef's richness (d)**	**Pielou's evenness (j)**
SR1	1.616	1.177	0.8387
SR2	1.623	1.265	0.8442
SR3	1.486	0.981	0.8831
SR4	1.689	1.731	0.7733
TR1	1.36	0.8667	0.7792
TR2	1.584	1.313	0.8125
TR3	1.60	1.116	0.9906
TR4	1.744	1.327	0.8173
TR5	1.881	1.542	0.9371

Appendix 3

Table 6: Season-wise value of diversity indices at Tamakoshi River

Diversity indices	**Season**	**Pre-Monsoon**	**Post-monsoon**	**Winter**
Shannon_(H')		1.804	1.735	1.793
Pielou's evenness (j)		0.868	0.81	0.859
Margalef's richness (d)		1.398	1.318	1.19

Table 7: Season-wise value of diversity indices at Singati River

Diversity indices	**Season**	**Pre-Monsoon**	**Post-monsoon**	**Winter**
Shannon_(H')		1.704	1.817	1.706
Pielou's evenness (j)		0.786	0.881	0.787
Margalef's richness (d)		1.504	1.534	1.534

Appendix 4

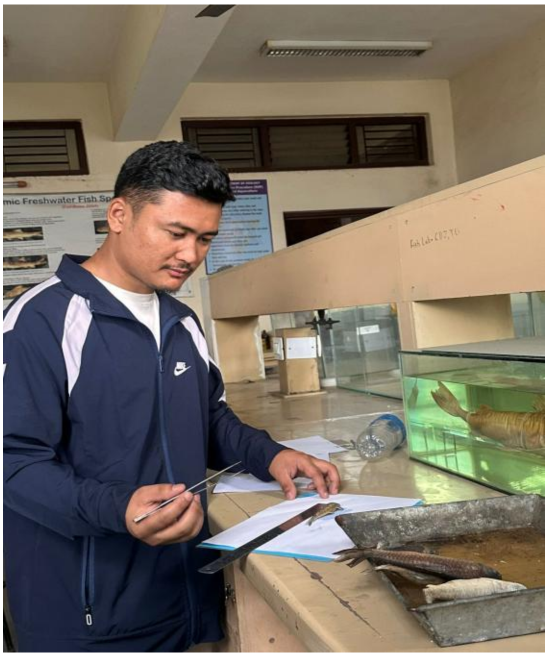
Table 8: Socio-economic status of local fishermen

Survey Parameters	**Responses**
Total Respondents	12
Fishing Dependency	Full-time: 5(42%) Subsistence: 4(33%) Occasional: 3(25%)
Alternative Livelihoods	Labor work & agriculture (Subsistence & Occasional fishermen)
Age Distribution	>50years: 7(58%) 40–49years: 3(25%) <39 years: 2 (17%)
Educational Background	Above 10th standard: 4 (33%) Below 5th standard: 8 (67%)
Fishing Experience	More than 10 years: 8 (67%)
Perception of Fish Population Decline	12 (100%) – All reported worsening fish availability
Main Cause of Decline	Hydropower Project: 9 (75%) Overfishing: 3 (25%)
Use of Harmful Fishing Methods	11 (92%) – Reported electrofishing, explosives, and small-mesh nets
Broodfish Release Practices	12 (100%) – None of the fishermen release broodfish

Photographs

Photoplate 1

Fisherman using cast net



Measuring fish at lab

Noting water quality data

Local using Hook