Spatio-Temporal Variation in Fish Assemblage in West Babai, Dang, Nepal

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A dissertation submitted

In partial fulfillment of the requirement for the award of the Degree of Master of Science in Zoology with special paper Fish Biology and Aquaculture

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Certificate of acceptance

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Recommendation

This is to recommend that the thesis entitled "Spatio-Temporal Variation in Fish Assemblage in West Babai, Dang, Nepal" has been carried out by Mr. Ram Bahadur Khadka for the partial fulfillment 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 thesis work has not been submitted for any other degree in any institutions.

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On the recommendation of supervisor "Associate Prof. Dr. Archana Prasad" this thesis submitted by Mr. Ram Bahadur Khadka entitled "Spatio-Temporal Variation in Fish Assemblage in West Babai, Dang, Nepal" is approved for the examination in partial fulfillment of the requirements for Master's Degree 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 thesis "Spatio-Temporal Variation in Fish Assemblage in West Babai, Dang, 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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Ram Bahadur Khadka

Abstract

The study focused on spatio-temporal variation in fish assemblages in West Babai River, Dang, Nepal which originates from the eastern end of Dang valley. The fish samples and water parameters were collected from March to December, 2023. In Each season, sampling stations were visited once to gather data. Samples were collected from three stations; i.e. Kalitara (I), Jaluke(II) and Purandhara(III) of Babai Gaupalika. Fish sampling was done by using cast net (1*1 cm^2), hook and line and diverting river course with the assistance of local fishermen.The collected fish samples were identified by using keys (Shrestha 2019, Jayaram 1999). A total 784 individuals were collected belonging to six Order, eight families and 15 genera. Cypriniformes exhibited highly dominant order, which contained 15 species. Beloniformes and Perciformes were less dominant, both consisting only one species. *Pethia ticto* appeared as the most abundant species, comprising 13.13% of the total catch, while *Danio rerio* was the least dominant, accounting for only 0.12%. The Shannon-Weiner diversity index was highest in summer (2.86) and at station I & II (1.87) whereas lowest in winter (1.49) and at station III (1.81). The Redundancy Analysis (RDA) ordination plot highlighted spring and summer as optimal seasons for the existing fish populion. Notably, the analysis of water quality confirmed that the Babai River in Dang, Western Nepal, provides favorable conditions for fish growth and development. This study establishes foundational data crucial for future investigations concerning fish diversity, distribution, and water quality in the Babai River region.

शोध सार

प्रस्तुत सोधकार्य दाङ जिल्लाको पूर्वी भेगबाटउत्पत्ति हुने बबई नदीमा भएको "भौतिक - रासायनिक प्यारामिटरहरु र माछाको प्रजातिको विविधताको अध्ययनमा केन्द्रीत रहेको छ । यस शोधकार्यमा माछाका नमूनाहरू र पानीका मापकहरू सन् २०२३ को मार्च देखि डिसेम्बरसम्म संकलन गरिएको थियो । नमूना संकलनका लागि प्रमुख तीन स्टेसनहरू (i) कालीटारा (ii) जलुके र (iii) पुरन्धारा (बबई गाउँपालिका क्षेत्रभित्र) मा प्रत्येक ऋतुमा एकपटक भ्रमण गरिएको थियो । नमूना संकलनका, लागि (१*१) cm^2 को हातेजाल, बल्छी र दुवालो थुन्ने बिधि, स्थानीय माझीहरूको सहयोगबाट गरिएको थियो । यसका साथै पानीका प्यारामिटरहरु पनि स्यामपलिङ स्टेसनमा मापन गरिएको थियो। संकलीत माछाका नमुनाहरू (क्षेष्ठ (२०१९),जयराम (१९९९))का काञ्जीहरुको सहायताले पहिचान गरिएको थियो। यस अध्ययनमा ६ अर्डर, ८ फ्यामिलीज र १५ जेनेराका ७८४ माछाहरू संकलन गरिएको थियो जसमध्य साइप्रिनिफर्मिसले सबैभन्दा प्रभुत्वशाली अर्डर भएको देखायो जसमा १५ प्रजाति भएको पाइयो, बेलोनीफर्मिज र पर्सिफर्मिज कम प्रभुत्वशाली रहेको पाइयो जसमा एउटामात्र प्रजाति पाइयो । यस अध्ययन अनुसार पेथिया टिक्टो प्रजातिको माछा सबैभन्दा बढी (१३.१३ %) रहेको पाइयो जबकी डेनियो रेरियो प्रजाति जम्मा संकलित नमुनामा सबै- भन्दा कम (०.१२ %) मात्र पाइयो । स्यानन उइनर विविधता सूचक सबैभन्दा बढी ग्रिष्म ऋतुमा (२.८६) पाइयो जुन स्टेसन i र ii (१.८७) । तर यो सूचक शिशिर ऋतुमा (१.४९) स्टेसन iii मा कम (१.८१) पाइयो । आर.डी.ए विश्लेषणले वसन्त र गृष्मलाई माछाका प्रजातिका लागि आदर्शतम ऋतुको रूपमा देखायो र अन्तिममा पानीको गुणस्तर विश्लेषण गर्दा दाङको पश्चिमी भेगमा पर्ने बबई नदि माछाको वृद्धिविकासका लागि उचित वातावरण युक्त नदी भएको पाइयो । यो अध्ययनले बबई नदी क्षेत्रमा भविष्यमा माछाको विविधता, वितरण र पानीको गुणस्तरको बारेमा अनुसन्धान गर्नका लागि एक मजबूत आधार तयार गरेको छ ।

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List of abbreviations

Abbreviated Form	Details of Abbreviation
APHA	American Public Health Association
CCA	Canonical Correspondence Analysis
CDZ	Central Department of Zoology
CO	Carbon Dioxide
DO	Dissolved Oxygen
EC	Electrical Conductivity
EDTA	Ethylene Diaminetetraacetic Acid
HCl	Hydrochloric Acid
MBT	Main Boundary Thrust
Mg/L	Milligram per litre
ml	Millilitre
N	Normality
pH	Hydrogen Ion Concentration
ppm	Parts per million
RDA	Redundancy Analysis
TDS	Total Dissolved Solids
µS/cm	Microsiemens per centimeter
$^{\circ}$C	Degree Celsius
S.N.	Serial Number

List of appendices

1. Introduction

1.1 Background

There are around 34300 species of fish (Froese & Pauly, 2020), making them one of the most significant and diverse groups of vertebrates. Fish are also closely linked to the welfare of humans (Leveque et al., 2008). Asian freshwater fish taxa are estimated to number 3000 (Lundberg et al., 2000), with carps (Cypriniformes) and catfishes (Siluriformes) constituting the majority of these species (Berra, 2007; Nelson et al. 2016).

The success or failure of fish collections in the waterways or springs is largely determined by the diversity of fish, the structure, and species assemblages in these waterways, springs and rivers. Within the boundaries of geographical scales, there are streams or springs (Minn, 1989, Negi and Mamgain, 2013). Since different elevations, flow rates, dissolved oxygen concentrations, and physical substrates offer different levels of food and shelter, freshwater habitats in rivers and streams are diverse (Armantrout, 1990). Fish serve as important indicators of the health of the ecosystem in these kinds of freshwater habitats, which give rise to a more varied fauna (Karr et al., 1986). When compared to temperate regions, the structure and heterogeneity of the fish community are suitably exposed in tropical locations along rivers and waterways. However, there is a lack of information regarding tropical fish communities (Nair et al. 1989, Arunachalam et al. 1997, Arunachalam and Martin et al. 2000 and Sankaranarayanan, 1999). The majority of endemic fish species are found in riverine streams, indicating a high degree of endemism in the riverine fauna (Groombridge, 1992, Kottelat and Whitten, 1997).

Numerous hydrological elements, including rainfall have been linked to the fish assemblage (Kehat and Wyndham, 1972). Poff and Allen (1995) used hydrological systems as a format to make differences in fish assemblage in lotic environments more understandable. One of the important routine processes that keeps a network and system functioning properly is a high flow (Cummins and Spengler, 1978, Resh et al. 1988). Numerous studies (Pegg and Pierce, 2002, Aarts et al. 2004, Xenopoulos and Lodge, 2006, Matono et al. 2012) have shown that an increase in current flow is correlated with an increase in fish density and diversity in the fish assemblage. The structure of the fish collection, however, is negatively impacted by low stream conditions (Gehrke et al., 1999, Pegg and Pierce 2002, Sagawa et al. 2007). Kollaus and Bonner (2012) came to the conclusion that the best explanations for fish distribution are vegetation, depth, and current velocity. Predation and competition, two biotic variables have essentially the same effects on fish networks in rivers and streams as well as lakes Jackson et al.(2001).

Abiotic versus biotic control, species consumption, channel type, disturbance history, frequency and hydrological regime are only a few of the numerous interrelated elements that affect fish assemblage change (Grossmann et al., 1998). There has been much written on how environmental factors significantly influence the distribution and abundance of fish species (Tejerina et al. 1998; Brown, 2000). The complex interaction among various ecological factors such as river size, drainage basin surface area, average yearly river discharge, temperature, depth, flow velocity, channel morphology, substrate and climate determines the pattern of fish species diversity in rivers (Welcomme, 1985, Hugueny, 1989, Oberdorff et al., 1995, 1997, Pussy and Kennard, 1996, Guegan et al., 1998, Bunn and Arthington, 2002, Arrington and Weinemiller, 2003, Postel and Richter, 2003, Poff and Zimmerman, 2010).

With her first publication of “Fishes of Nepal” Shrestha (1981) is regarded as the indigenous pioneer Ichthyologist. In it, she described 120 species of freshwater fishes from 10 Orders, 26 Families and 63 Genera. Up until recently, Nepal’s ichthyologic activity has been trending upward. 182 fish species have been reported from Nepal by Shrestha (2001), Rajbanshi (2005) enumerated 187 species of fish found in Nepal. Afterwards , Saud and Shrestha (2007) found 199 species, and Shrestha (2008) found 217 native and 15 exotic fish species . While Shrestha (2019) reported 236 indigenous and 16 exotic fish species. Notably, the Karnali River in Western Nepal provides habitat for 121 fish species (Smith et al., 1996), while the Babai River in Bardiya district is home to 40 species (Singh, 2001). Similarly G.C.et al. (2019) recorded 24 fish species from the Babai River,Dang western Nepal. Despite extensive research in the main river systems, there is still a need for further investigations into fish ecology in middle-sized rivers. As a result, this study aims to explore the fish diversity in the Babai River.

Numerous problems pose a risk to the diversity and distribution of fish structure found in rivers. Freshwater biodiversity has greater rates of impact worldwide (Dudgeon 2011, Liermann et al. 2012, Yang et al. 2016). Many species, particularly endemic fish species, are at risk due to water pollution, overexploitation boosted by various ecological changes, flow modification, destruction or degradation of natural habitats, widespread industrial installation, invasion of exotic fish species, and global climate change (Dudgeon et al. 2006, Rao et al. 2015b, Siddek et al. 2014).

This research aims to fill a critical gap in understanding spatio-temporal variation in fish assemblage in Nepal, particularly focusing on the West Babai River and identifies potential threats to aquatic ecosystems. The findings also contribute to the conservation and management of fish resources in Nepal.

1.2 Objectives:

1.2.1 General Objectives:

- The general objective is to access spatio-temporal variation in fish assemblage in West Babai, Dang, Nepal.

1.2.2 Specific Objectives:

- To assess the fish diversity using different diversity indices
- To examine physico-chemical parameters of water
- To assess the relationship between water quality parameters with fish species.

1.3 Significance of the study

- It has contributed to the diversity of fish species profile of Babai River Dang, western Nepal in accordance with different season
- The physiochemical parameters that were analyzed has shown what types of fish species can be able to survive in that particular aquatic environment.
- It has provided knowledge to the local people about the conservation needs of locally available fish fauna with their sustainable use.

1.4 Limitations of the study

- Utilizing a multi-parameter tool could have enhanced the testing of additional water parameters efficiently.

2. Literature review

2.1 Spatial variation of fish assemblage structure

Fish assemblages play a crucial role in aquatic ecosystems serving as reliable indicators of freshwater ecosystem quality due to their sensitivity to various stressors (Karr, 1981; Oberdorff et al., 2002). Numerous studies have established strong correlations between the distribution and abundance of fish species and environmental variables (Tejerina-Garro et al., 1998; Brown, 2000). At the local scale, habitat characteristics like substratum composition, pool presence, and available cover exhibit significant associations with fish assemblage structure (Ibarra and Stewart, 1989; Fischer and Paukert, 2008; Rowe et al., 2009). These abiotic factors exert both short-term and long-term influence on fish community composition (Gasith and Resh, 1999).

Critical habitat variables, including stream size (channel depth and width), discharge and F-CO_2 have been identified as significant contributors to fish assemblage composition in the Red River, USA and North Tiaoxi River, China (Koel and Peterka, 2003 ; Li et al., 2012. Similarly, conductivity, dissolved oxygen (DO), pH, alkalinity and salinity were found to strongly correlate with the fish community composition in the Kali Gandaki River Basin, Nepal and the Ganga River Basin, India (Edds, 1993; Dubey et al., 2012). Research in the Seti Gandaki River in Pokhara, Nepal, documented 30 fish species belonging to 5 orders, 9 families and 24 genera with depth, width, conductivity, DO,F-CO_2, SiO_2 and chlorides identified as key environmental variables structuring the fish assemblage (Pokharel et al., 2018).

The biodiversity and composition of fish assemblages in ecosystems are influenced by a variety of physiological and biological factors. The most well-established pattern for altering species diversity in terms of geographical distribution is the shift in species richness with altitude gradient. Fish structural variations have been documented by Rahbek (1995), Rosenzweig (1995), Lomolino, (2001), Whittaker et al. (2001), and Sanders (2013). According to Bertoni and Hued (2002), there is a negative correlation between elevation and fish species richness and there is a correlation between fish diversity and the spread of river systems in temperate and tropical climates. Accordingly, altitude declines with increasing stream size (Pouilly et al., 2006) or fish species richness decreases with rising altitude (Jaramilo-Villa et al., 2010). The reduced land area is the cause of the declining diversity of fish species at high altitudes (Lomolino, 2001). Due to the restricted land area, there is less primary food resource production and fewer vegetation niches that either directly or indirectly influence in the spread of fish assemblage structure (Rahbeck 1995, Odland and Birks 1999, Grytnes 2003, Fu et al. 2006, Rowe 2009, Wang et al. 2009, Sanders and Rahbeck 2012, Askeyev 2015).

2.2 Temporal variation of fish assemblage structure

Besides abiotic parameters, biotic factors such as predation and competition can also influence fish assemblages through direct and indirect mechanisms (Jackson et at., 2001). The interplay of these biotic and abiotic factors shapes fish community structure and dynamics in freshwater ecosystems, highlighting the importance of considering both environmental and biological factors in understanding fish assemblage patterns.

According to Buisson et al. (2008), temperature is the key element that determines how the fish assemblage structure functions in riverine systems. Alkalinity, salinity and dissolved oxygen are all directly impacted by water temperature (Fisher and Willis, 2000). Similarly, the metabolism (Gillooly et al., 2001), breeding (Mills and Mann, 1985), development and growth (Mann 1991, Wolter 2007), and behavior (Taniguchi et al., 1998) are all impacted by water temperature. Fish assemblage structure is reduced in streams and river systems at higher elevations due to thermal change in the water temperature (Jacobsen, 2008, Jaramillo-Villa et al., 2010). Season also affect fish composition distribution in streams because seasonal variations exist in environmental and physic-chemical variables (Beugly and Pyron, 2010). The dissolved oxygen in the water drops when the temperature drops throughout the winter. Summertime brings higher levels and warmer water, but it also brings decreased dissolved oxygen levels. As a result, seasonal change and fish composition are somewhat related (Li and Gelwick, 2005, Trujillo-Jimenenz et al., 2010).

The Babai River, situated in the mid-western region of Nepal, has generated attention from researchers due to its ecological significance, particularly in terms of fish diversity. The aquatic ecosystem of the Babai River plays a crucial role in sustaining a variety of fish species. Past studies, such as the work of Shrestha and Pradhan (2018), have highlighted the river's importance as a habitat for both indigenous and migratory fish species. Fish and water quality have a strong correlation, although the precise nature of this interaction is yet unknown (Chow-Fraser, 2003). In an aquatic setting, the chemical makeup of the water is essential to aquatic life Species dispersion is influenced by morphometric characteristics such as depth, velocity, and substrate; it is influenced by spatial differences in physical and chemical elements such as water temperature, electric conductivity, concentrations of nitrogen and phosphorous and pH (Daga et al., 2012).

Using vegan library in ‘R’(Oksanen et al., 2015), redundancy analysis (RDA), a direct multivariate ordination method (Ter Braak 1988a; Ter Braak& Prentice 1988) based on a linear response of species to environmental gradients (Gauch 1982; Ter Braak 1986;Palmer 1996), was applied to analyse the relationship between environmental variables and species diversity. Temperature is a major indicator of water quality since it regulates many biological processes in a river system. Most aquatic life found in rivers is usually cold-blooded; that is, they can only survive in water that is within a certain temperature range. Temperature also has an impact on the spawning growth and mortality rates of these species. Variations in water temperature that are not within that ideal thermal range might have a detrimental effect on the overall health of the aquatic ecosystem. It has been demonstrated that a wide variety of fish species suffer from increased mortality rates in water temperatures between 23 and 25 C.

3. Materials and methods

3.1 Study area

The present study area, Babai River, an important river in Nepal, falls under the category of a secondary river since its origin lies in the Mahabharat range. In the upper basin, the river's course is influenced by geological factors like the Main Boundary Thrust (MBT) and other faults, causing it to bend (Source; Google). It is forced to flow in a northwest direction due to the presence of the Siwalik hills before it reaches the Terai plain. The water of the Babai River is typically crystal clear except during the rainy season. The riverbed is characterized by rocky stones, pebbles, gravels and sand giving it a distinct appearance of study Area.

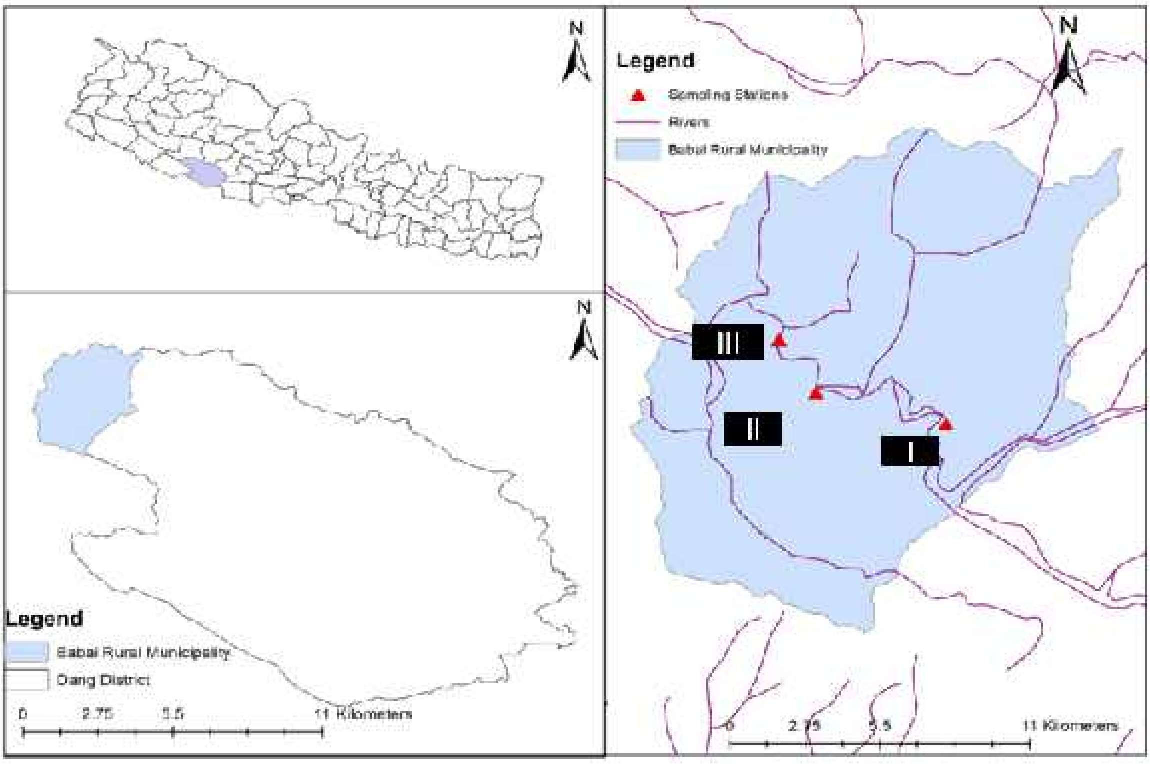

Fig.1: Map of the study area

3.2 Sampling stations

Altogether three sampling stations (Fig.1) were selected along the river sides. As the total length of the Babai River inside Babai Gaupalika covers around 25 kms distance, only three sampling sites were selected. The sites were selected on the basis of anthropogenically disturbed area, crowded area and undisturbed area. The three sampling stations are listed as below;

Site I

The sampling site I (28◦09.145'N, 082°06.841'E) was chosen at the Kalitara of Babai Gaupalika which is about 7km away from Hapure bazar. There was the presence of crystal-clear water along with the rocky stones, pebbles etc. Sampling site I was selected on the basis of undisturbed and peaceful environment without anthropogenic activity.

Site II

The sampling site II (28◦09.822'N, 082◦04.264'E) was selected at Jaluke which was 3 km west of the station I. This was selected on the basis of human intervention and crowded area. The river bed consists of rocky stones, pebbles etc.

Site III

The sampling site III (28◦10.969'N, 082◦03.556'E) Purandhara Chhahara was selected on the basis of anthropogenically disturbed area. It was about 6 km west from the station II. The river bed consists of cobble, pebble and sand.

3.3 Sampling time period

The field work was conducted for four times in the month of March (Spring), August (Summer), October (Autumn) and December (Winter) from March to December 2023.

3.4 Fish sampling, preservation techniques and identification:

In this study, fish were collected from various stations with the assistance of local fisherman who used locally available fishing equipment such as cast nets, mosquito nets, hooks and lines. The collection was carried out using cast nets with a mesh size of (1cm*1cm) during the morning hours from 8 to 11 am, across different seasons including spring, summer, autumn and winter. Sampling took place within a 2km upstream and downstream of each station, with each station receiving 20 throws of the cast net. Fish were primarily sampled near runs, marshy areas and river edges (Appendix I).

Fish specimens were photographed on-site using Pocco X3pro mobile camera. Identification of the fish specimens was conducted both in the field and at the CDZ laboratory, employing identification keys of Talwar and Jhingran (1991), Jayaram (1999) and Shrestha (2019). Unidentified fish samples were preserved in 10% formalin for further examination at the CDZ lab.

3.5 Diversity Status:

3.5.1. Species diversity Index

The diversity of species was calculated by using Shannon-Weiner diversity index (Shannon and Weiner, 1949).

Shannon Weiner diversity index is designated as H' which is calculated as,

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

Where, Pi=n/N

n= no.of all individuals of a species

N= Total no. of all individuals in the sample

ln =Logarithm of base e

3.5.2 Species richness index (d):

The species richness is calculated by using Margalef species richness (Margalef's 1968), which is designated by d and calculated mathematically as,

Margalef species richness (d) = S-1/logN

Where,

S= Total no. of species

N= Total no. of individuals in the sample

3.5.3 Evenness Index

To calculate whether species are distributed evenly across seasons and across landscapes elements, evenness index was determined by the following equation (Pielou, 1974).

E= H'/log S

Where,

H'= Shannon Weiner's diversity Index

S= Total no. of species in the sample

3.6 Analysis of physico-chemical parameters of water :

3.6.1 Physical parameters of water

The physical parameters that were measured in each sampling stations include;

a. Water temperature

Digital thermometer was used to measure the water temperature (C).

b. Transparency

The water transparency was assessed using a Secchi disc, a metallic device with a 20 cm diameter and black-and-white quadrants. It is equipped with a hook for a rope. The disc was immersed in water, and the depth at which it disappeared was noted.

c. Water velocity

The water velocity was determined using a straightforward method involving the timing of a plastic table tennis ball as it floated along the river. A stopwatch was used to measure the time it took for the ball to travel a specific point, and the velocity was then expressed in meters per second.

3.6.2. Chemical parameters of water

All the chemical parameters were measured on-site (i.e. at the field) in each sampling stations. The chemical parameters that were measured include:

a) Hydrogen ion concentration (pH)

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

b) Dissolved oxygen (DO)

The DO meter (D.O meter-DO 9100) was used to record the dissolved oxygen of water during the study period at every sampling station.

c) Free Carbon Dioxide (CO_2)

To measure the free carbondioxide in a water sample, 100 milliliters of the sample were taken, and a few drops of phenolphthalein indicator were added. The colorless solution obtained indicated the presence of CO_2. This solution was then titrated with a standard alkali titrate, specifically 0.05N Sodium hydroxide, until a slight pink endpoint was reached. The calculation for determining the free CO_2 in the water sample is given by the formula:

Free CO_2= (ml * N of NaOH* 1000*44)/V

Where,

V=Volume of the water sample in milliliters.

d) Alkalinity:

To measure the alkalinity in a water sample, 50 ml of water sample was taken in a conical flask and few drops of phenolphthalein was added. We didn't observe the color change in the solution , which indicated the absence of phenolphthalein alkalinity or carbonate & hydroxide. Again few drops of methyl orange indicator was added in the same solution. This time colour of the solution changed into yellow. Then the solution was titrated against 0.1 N HCl till the pink colour appeared. The total volume of HCl consumed indicated the alkalinity level in that water sample in each sampling stations.

Formula to calculate alkalinity:

Alkalinity as $CaCO_3$ (mg/ltr) = (X * N of HCl *1000 * 50)/ V

Where,

X= volume of HCl consumed during titration

V= volume of water sample taken

e) Hardness:

The burette was filled with a standard EDTA solution upto the zero level. A 50 ml sample of water was taken in a flask, and 1 ml of Ammonia buffer was added to the solution. Subsequently, 5-6 drops of Erichrome black-T indicator were introduced, resulting in the solution turning into a wine-red colour. The initial reading was then recorded. The solution was titrated against the EDTA solution until the wine-red color transformed into a blue hue, and the final reading was noted. This process was repeated until three concurrent values were obtained.

Formula:

Total hardness of water as $CaCO_3$ (mg/l)= (ml of EDTA used * 1000)/ V

Where,

V= volume of water sample used

f) Total dissolved solids (TDS):

The term "total dissolved solids" encompasses all types of solutes present in the water, including ions, minerals, gases, and other compounds. This measure is often expressed in terms of concentration, typically in units such as parts per million (ppm) or milligrams per liter (mg/l). Monitoring the TDS is essential in various fields, such as environmental science, water quality assessment, and analytical chemistry, as it provides insights into the composition of the water and its suitability for different purposes.

The TDS was measured using digital TDS & EC meter.

g) Electrical conductivity (EC):

Electrical conductivity in water refers to the ability of water to conduct an electric current. It is a measure of how well water can transmit electrical flow. It also provides insights into the composition and purity of water. The conductivity of water is influenced by the presence of dissolved ions, which are charged particles. These ions can come from various dissolved substances, such as salts, acids, or bases.

Conductivity is typically measured in siemens per meter (S/m) or microsiemens per centimeter (µS/cm). High conductivity in water may indicate the presence of dissolved ions, which can have both natural and anthropogenic sources. It was measured using digital TDS & EC meter.

3.7 Statistical analysis:

For the statistical analysis, R software was used where the calculations were performed to determine the Shannon- Weiner index for different seasons and sites. To analyze the association between species abundance, sites, season and environmental variables, redundancy analysis (RDA) was employed. This method, based on a linear response of species to environmental gradients was chosen over canonical correspondence analysis (CCA) after considering the results of Detrended Correspondence analysis (DCA). The axis length and eigen values obtained from DCA indicated that the linear model associated with RDA was more suitable for the data.

4. Results

4.1. Seasonal Ichthyofaunal Diversity and Distribution of Babai River,Dang

4.1.1 Systemic Position of the Fishes

The study identified a diverse array of 26 fish species, which were further classified into six orders, eight families and 15 genera (Table 1).

Table 1: Systematic position of the fishes

S.N.	**Scientific name of Fish species**	**Local name**	**Order**	**Family**	**Site**
1	*Chagunius chagunio* (Hamilton 1822))	Gardi	Cypriniformes	Cyprinidae	I, II, III
2	*Danio devario* (Hamilton-Buchanan, 1822)	Patali machha/ Tharuni machha	Cypriniformes	Cyprinidae	I, II, III
3	*Pethia ticto (*Hamilton-Buchanan,1872)	pateyla	Cypriniformes	Cyprinidae	I, II, III
4	*Barilus shacra* (Hamilton-Buchanan,1872)	Setala	Cypriniformes	Cyprinidae	I, II, III
5	*Danio rerio* (Hamilton)	Khida machha	Cypriniformes	Cyprinidae	I
6	*Garra annandalei* (Hora,1921)	Buduna	Cypriniformes	Cyprinidae	I, II, III
7	*Barilius barila* (Hamilton-Buchanan, 1822)	Faketa	Cypriniformes	Cyprinidae	I, II, III
8	*Puntius terio* (Hamilton-Buchanan, 1822)	Pateyla	Cypriniformes	Cyprinidae	I, II, III
9	*Garra gotyla* (Gray,1830)	Kalo buduna	Cypriniformes	Cyprinidae	I, II, III
10	*Tor tor* (Hamilton)	Sahar	Cypriniformes	Cyprinidae	I, II, III
11	*Garra lissorhynchus* (McClelland)	Buduna	Cypriniformes	Cyprinidae	I, II, III
12	*Puntius sophore* (Hamilton-Buchanan,1822)	Pothe	Cypriniformes	Cyprinidae	I

13	*Paracanthocobitis botia* (Hamilton-Buchanan,1822)	Gadela	Cypriniformes	Nemacheilidae	I, II, III
14	*Physoschistura prashadi* (Hora)	Gareyla	Cypriniformes	Nemacheilidae	I, II
15	*Schistura multifasciata* (Day)	Gareyla	Cypriniformes	Nemacheilidae	I, II, III
16	*Mastacembelus armatus* (Lacepede)	Bam machha	Synbranchiformes	Mastacembelidae	I, II, III
17	*Macrognathus pancalus* (Hamilton)	Bam machha	Synbranchiformes	Mastacembelidae	I, II, III
	Macrognathus lineatomaculatus (Britz)	Bam machha	Synbranchiformes	Mastacembelidae	I, II, III
19	*Channa punctata* (Bloch, 1793)	Sauri machha	Anabantiformes	Channidae	I, III
20	*Channa orientalis* (Bloch and Schneider, 1801))	Bhoti machha	Anabantiformes	Channidae	II, III
21	*Channa striata* (Bloch)	Bhoti machha	Anabantiformes	Channidae	I, II
22	*Wallago attu* (Schneider)	Buhari machha	Siluriformes	Siluridae	I
23	*Bagarius bagarius* (Hamilton)	Goach	Siluriformes	Sisoridae	II
24	*Mystus tengara* (Hamilton)	Junge machha	Siluriformes	Bagridae	I, II
25	*Xenontodon cancila* (Hamilton-Buchanan,1822)	Kauwa machha	Beloniformes	Belonidae	I, II, III
26	*Channa gaucha* (Hamilton,1822)	Sauri machha	Perciformes	Channidae	I, II

4.1.2 Diversity Status of Ichthyofaunal in Babai, River

4.1.2.1Spatial variation in fish assemblage

The diversity of species, as measured by the Shannon-Weiner diversity index (H'), was found to be highest at stations I and II, both recording a value of 1.87. Conversely, station III exhibited the lowest diversity index at 1.81. Similarly, when considering Margalef's species richness index (d), station I displayed the highest value at 2.3, followed by station II at 2, with station III showing the lowest value at 1.81. Interestingly, Pielou's evenness index showed a different trend, with station III having the highest evenness value of 0.95, followed by station II at 0.91, and station I recording the lowest evenness value at 0.85. This indicates that while stations I and II have higher species richness and diversity, station III has a more even distribution of species (Fig.2).

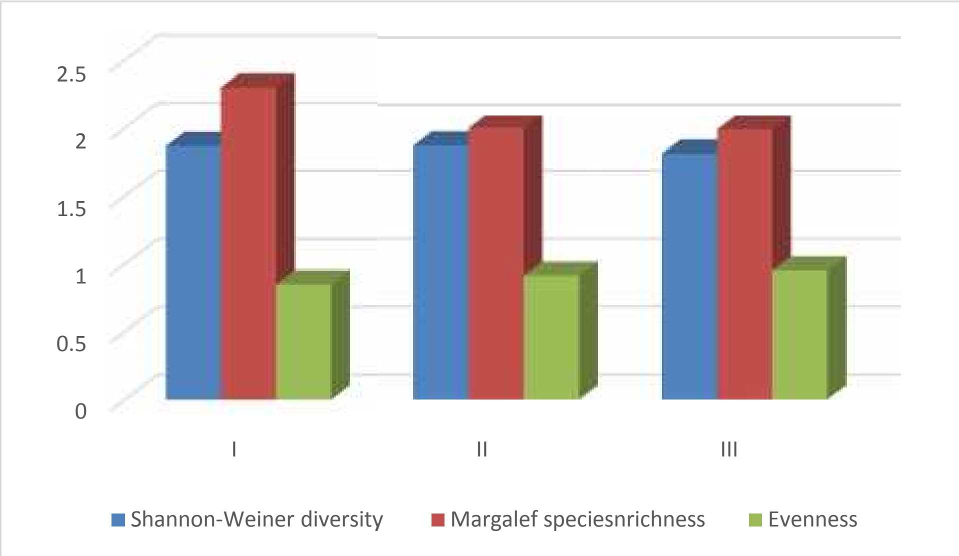

Figure 2: Spatial Variation in Fish Assemblage

4.1.2.2 Temporal variation in fish assemblage

Spring (2.5), Autumn (1.81), and Summer (2.86) had the highest Shannon-Weiner fish diversity index (H’), while Winter (1.49) had the lowest. Likewise, Spring (4.25) was the highest point for the species richness index (d), which was then followed by Summer (3.07), Autumn (1.88), and the Winter (1.1). The evenness index, on the other hand was lowest in Autumn (0.82) and the highest in Summer (0.94), followed by Spring (0.84) and Winter (0.83) , (Fig.3).

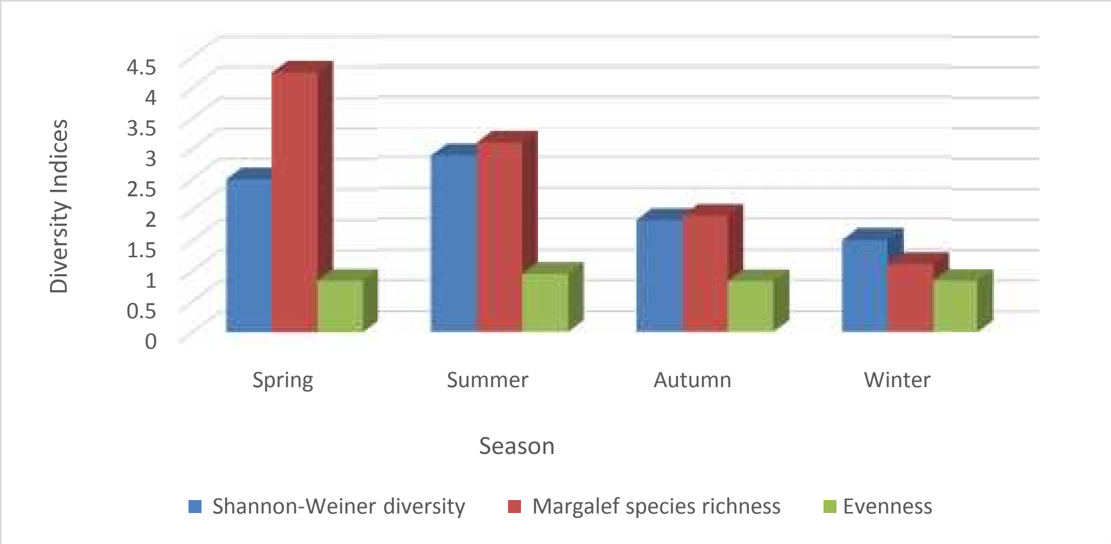

Figure 3: Temporal variation in fish assemblage

4.1.2.3 Distribution Pattern and Frequency Occurrence of Fishes in Babai River

In Babai River, Dang, the most abundant fish species observed was *Pethia ticto*, constituting 13.13% of the total fish population. Conversely, the species with the lowest occurrence frequency was *Danio rerio*, accounting for only 0.12% of the total fish population in the river.

Table 2: Distribution and Frequency Occurrence of Fishes in Babai River, Dang

S. n	**Name of species**	**Seasons**												**Total**	**Frequency (%)**
		Spring			**Summer**			**Autumn**			**Winter**				
		Stations													
		I	II	III	I	II	III	I	II	III	I	II	III		
1	*Mastacembelus armatus*	2	4	2	12	7	6	0	0	0	0	0	0	33	4.2
2	*Macrognathus lineatomaculatus*	2	2	0	16	8	2	0	0	3	0	0	0	33	4.2
3	*Chagunius chagunio*	2	6	7	26	15	0	14	7	2	0	0	0	79	10.07
4	*Channa punctata*	2	0	0	6	0	5	0	0	0	0	0	0	13	1.65
5	*Danio devario*	12	3	6	19	12	6	0	0	0	0	0	0	58	7.39
6	*Pethia ticto*	22	3	2	33	13	9	0	0	0	12	9	0	103	13.13
7	*Paracanthocobitis botia*	2	6	0	5	2	8	0	0	0	0	0	0	23	2.93

8	*Barilius shacra*	11	1	0	18	12	5	0	0	0	8	3	0	58	7.39
9	*Xenontodon cancila*	1	0	2	3	1	7	2	0	4	3	0	0	23	2.93
10	*Channa gaucha*	1	0	0	0	0	0	0	3	0	0	0	0	4	0.51
11	*Danio rerio*	1	0	0	0	0	0	0	0	0	0	0	0	1	0.12
12	*Garra annandalei*	1	0	0	9	5	11	0	0	0	0	12	4	42	5.35
13	*Physoschistura prasadi*	1	0	0	0	0	0	0	3	0	0	0	0	4	0.51
14	*Schistura multifasciata*	10	0	0	19	16	5	1	0	2	0	0	0	53	6.76
15	*Macrognathus pancalus*	1	0	0	8	3	5	0	0	0	0	0	0	17	2.16
16	*Barilius barila*	1	0	3	15	9	4	0	0	0	0	0	0	32	4.08
17	*Puntius terio*	1	0	2	5	14	0	10	3	0	13	21	3	72	9.18
18	*Channa orientalis*	0	3	1	0	2	6	0	0	0	0	0	0	12	1.53
19	*Garra gotyla*	0	0	7	9	5	16	0	0	0	0	0	0	37	4.71
20	*Tor tor*	0	0	4	2	5	20	0	0	0	0	0	0	31	3.95
21	*Garra lissorhynchus*	0	0	1	3	5	14	0	0	0	0	0	0	23	2.93
22	*Wallego attu*	0	0	0	6	0	0	0	0	0	0	0	0	6	0.76
23	*Bagarius bagarius*	0	0	0	0	3	0	0	0	0	0	0	0	3	0.38
24	*Puntius sophora*	0	0	0	4	0	0	0	0	0	0	0	0	4	0.51
25	*Channa striata*	0	0	0	0	0	0	13	2	0	0	0	0	15	1.91
26	*Mystus tyangra*	1	0	0	0	0	0	0	1	0	0	0	3	5	0.63
Total														784	100%

4.1.2.4 Order Wise Ichthyofaunal Distribution of Babai River,Dang

Among the six orders of fish species identified in Babai River, Cypriniformes exhibited the highest distribution, comprising 58% of the total fish population (Photo plates I & II). Following Cypriniformes, Siluriformes accounted for 12% of the fish population, while Syncbranchiformes and Anabentiformes each represented 11% of the total distribution. Beloniformes and Perciformes were less prevalent, constituting only 4% each of the fish population in the river (Fig.4).

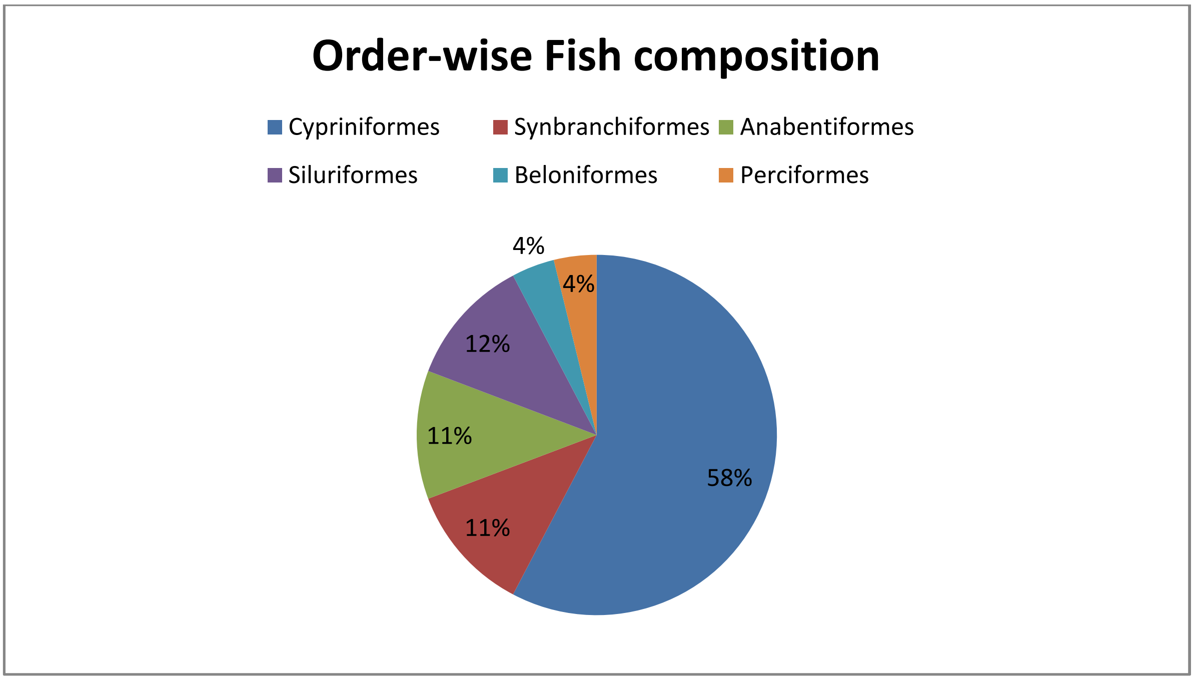

Figure 4: Order wise fish distribution

4.1.2.5 Family Wise Ichthyofaunal Distribution of Babai River,Dang

In the Babai River, the most prevalent family of fish was Cyprinidae, making up 46% of the total fish population. Conversely, the least abundant families were Siluridae, Bagaridae, Sisoridae, and Belonidae, collectively accounting for only 4% of the fish population in the river (Fig.5).

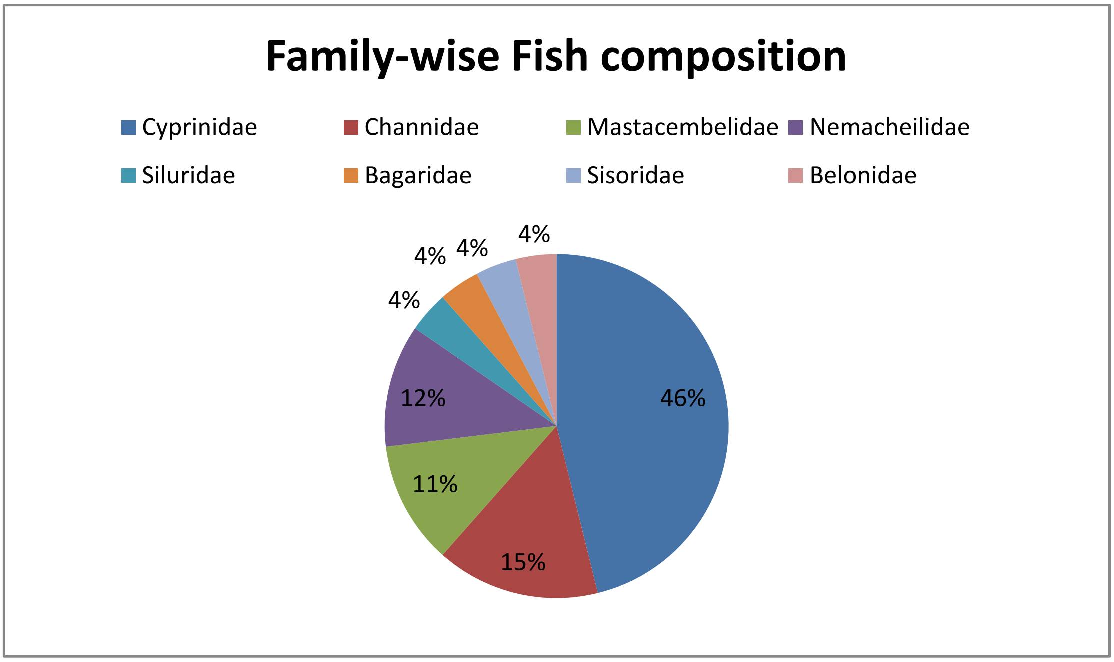

Figure.5: Family wise fish composition

4.2 Seasonal Variation in Water Quality Parameters of Babai River

4.2.1 Physical parameters of Water

4.2.2. Water Temperature

During summer, station III recorded the highest water temperature of 36.2°C, while the lowest temperature of 14°C was observed at station I during winter. Across all seasons, the average temperatures at stations I, II, and III were 25.67°C, 26.42°C, and 26.2°C, respectively. Seasonally, the average temperatures for spring, summer, autumn, and winter were 29.33°C, 35.72°C, 24.46°C, and 14.86°C, respectively. Overall, there wasn't significant fluctuation in the average temperatures among the stations (Fig.6).

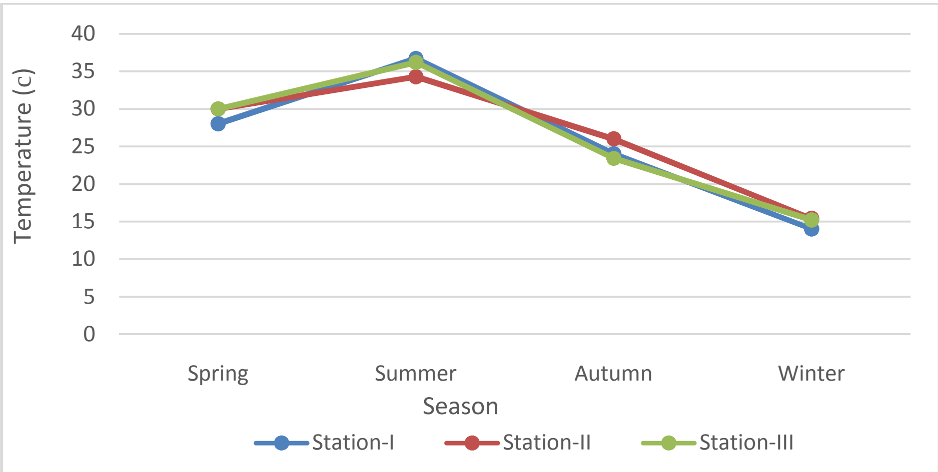

Figure 6: Variation in Water Temperature in Different Seasons

4.2.3. Water Velocity

During summer, the highest water velocity of 1.9 m/s was recorded at station III, while the lowest water flow of 0.3 m/s was observed at station I during spring. The average velocities across stations I, II, and III were 0.77 m/s, 0.55 m/s, and 0.815 m/s, respectively. Across the seasons, the average velocities were 0.32 m/s, 1.6 m/s, 0.51 m/s, and 0.4 m/s during spring, summer, autumn, and winter, respectively (Fig.7).

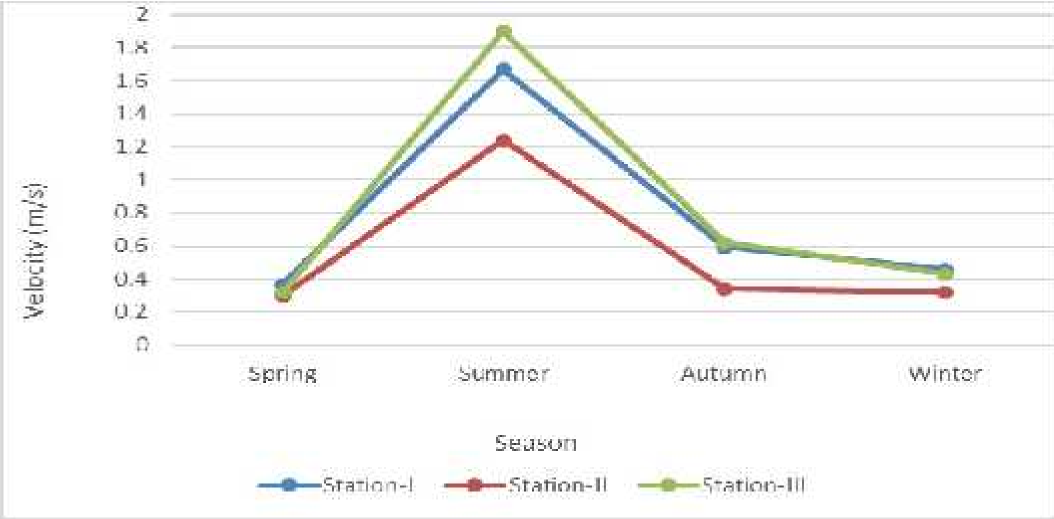

Figure 7: Variation in water velocity in Different Season

4.2.4. Transparency (cm)

During spring, transparency reached its peak at station III, measuring 152 cm, while the lowest transparency level of 11 cm was observed at station II during summer. The average transparency values across all stations, I, II, and III, were 60.48 cm, 86.65 cm, and 77 cm, respectively. Regarding seasonal averages, transparency measured 98.33 cm, 13 cm, 83.24 cm, and 104.26 cm during spring, summer, autumn, and winter, respectively (Fig.8).

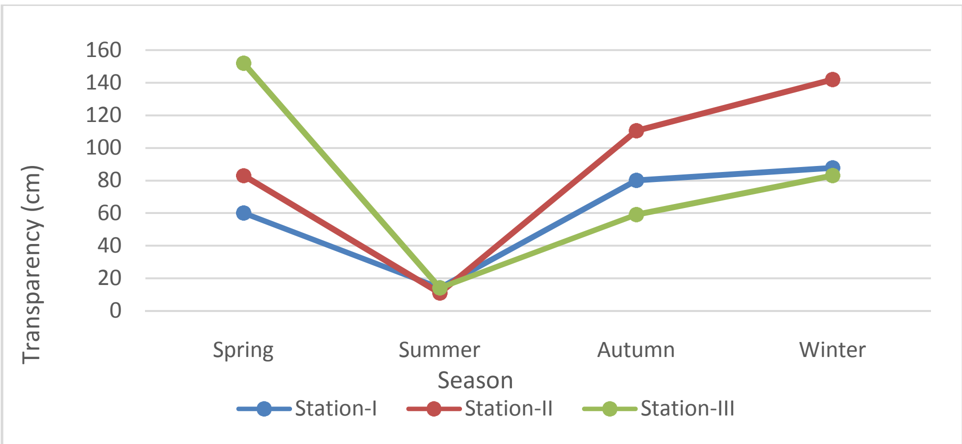

Figure 8: Variation in Transparency in Different Season

4.2.2 Chemical Parameters of Water

4.2.2.1 Hydrogen Ion Concentration (pH)

Throughout all stations and seasons, the pH of the Babai River remained slightly alkaline. The lowest pH value of 7.5 was observed at station I during summer, while the highest pH of 8.32 was recorded at stations I and II during both autumn and spring. The average pH across all four seasons at stations I, II, and III were 7.84, 8.08, and 8.07, respectively. Regarding the seasonal variations, the average pH values during spring, summer, autumn, and winter were 8.1, 7.8, 8.3, and 7.7, respectively (Fig.9).

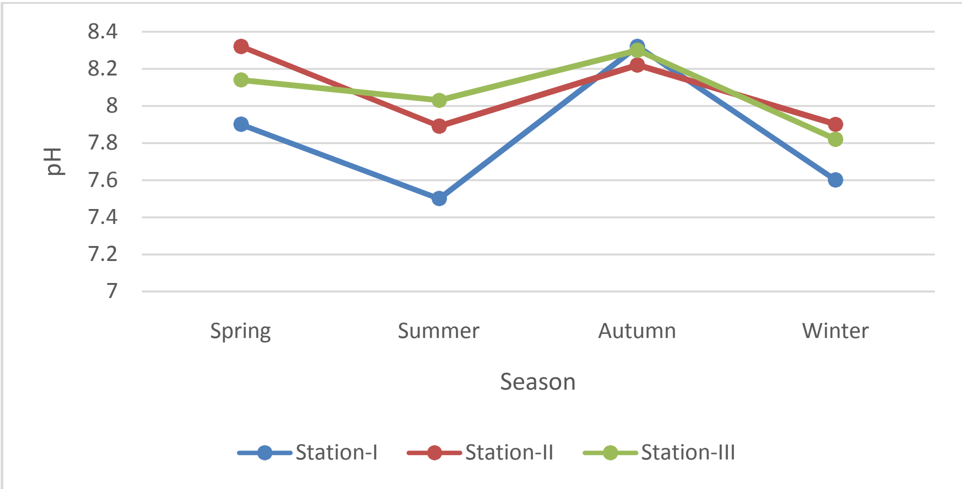

Figure 9: Variation in pH in Different Season

4.2.2.2 Dissolved Oxygen (DO)

During the summer season, the highest recorded dissolved oxygen (DO) level was 7.2 mg/L at station III, while the lowest was 5.3 mg/L at station I. Across all four seasons, the average DO levels were 6.31 mg/L at station I, 6.23 mg/L at station II, and 6.62 mg/L at station III. Specifically, the average DO levels throughout spring, summer, autumn, and winter were 6.04 mg/L, 6.07 mg/L, 6.6 mg/L, and 6.87 mg/L respectively (Fig.10).

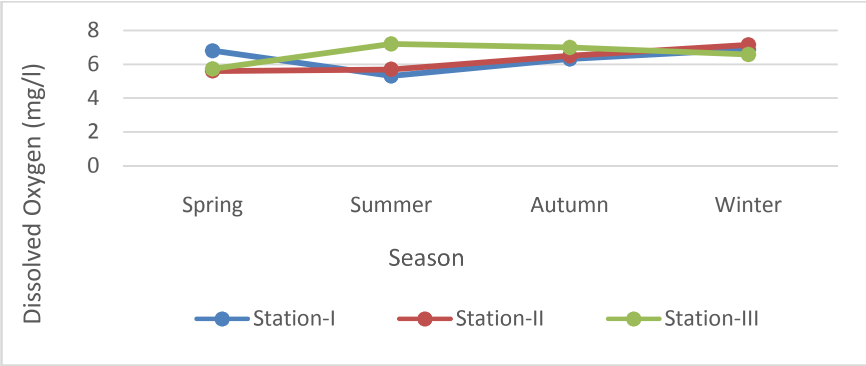

Figure 10: Variation in Dissolved Oxygen in Different Season

4.2.2.3 Free Carbon Dioxide (CO_2)

In spring, station III recorded the highest free CO_2concentration at 13.6 mg/l, while during winter, the lowest CO_2 value of 6.6 mg/l was observed at the same station. Across all four seasons, stations I, II, and III displayed average CO_2 concentrations of 7.82 mg/l, 8.61 mg/l, and 9.54 mg/l, respectively. The average CO_2 concentrations across all four seasons were 9.7 mg/l, 8.6 mg/l, 9.09 mg/l, and 7.23 mg/l (Fig.11).

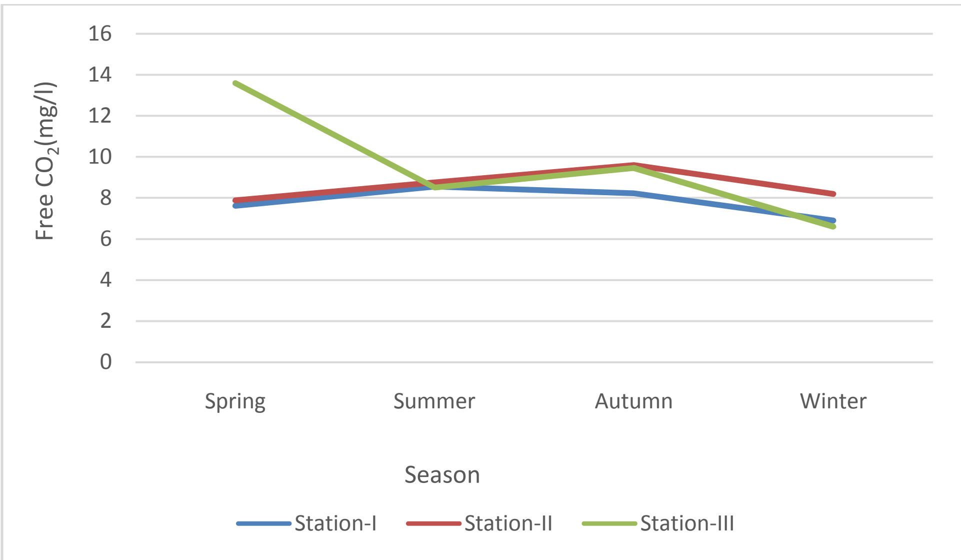

Figure 11: Variation in CO_2 in different Seasons

4.2.2.4 Total Alkalinity (mg/l)

During spring, station III exhibited the highest alkalinity level at 87.6 mg/l, while the lowest alkalinity value during winter was recorded at 64.3 mg/l, also at station III. Across all four seasons, the average alkalinity levels were 74.82 mg/l for station I, 76.31 mg/l for station II, and 77.39 mg/l for station III. The overall average alkalinity values for the four seasons were 85.2 mg/l, 75.08 mg/l, 76.65 mg/l, and 67.76 mg/l, respectively (Fig.12).

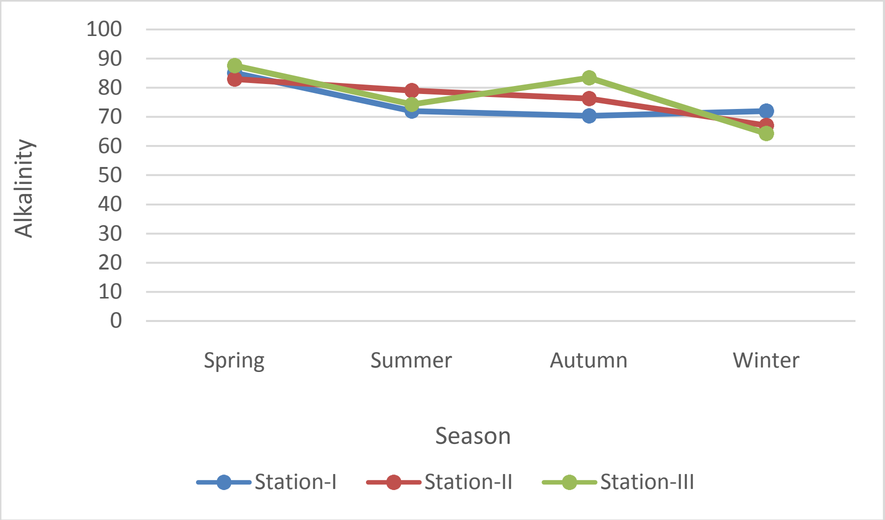

Figure 12: Variation in Alkalinity in Different Seasons

4.2.2.5 Total dissolved solids (TDS)

During the summer season, station I recorded the highest Total Dissolved Solids (TDS) level, measuring 245 ppm, while station II exhibited the lowest TDS concentration of 183 ppm during autumn. Across all four seasons, the mean TDS concentrations were 219.5 ppm for station I, 213.25 ppm for station II, and 216.75 ppm for station III. The overall average TDS concentrations for the four seasons stood at 215.33 ppm, 231.67 ppm, 197.33 ppm, and 221.67 ppm, respectively (Fig.13).

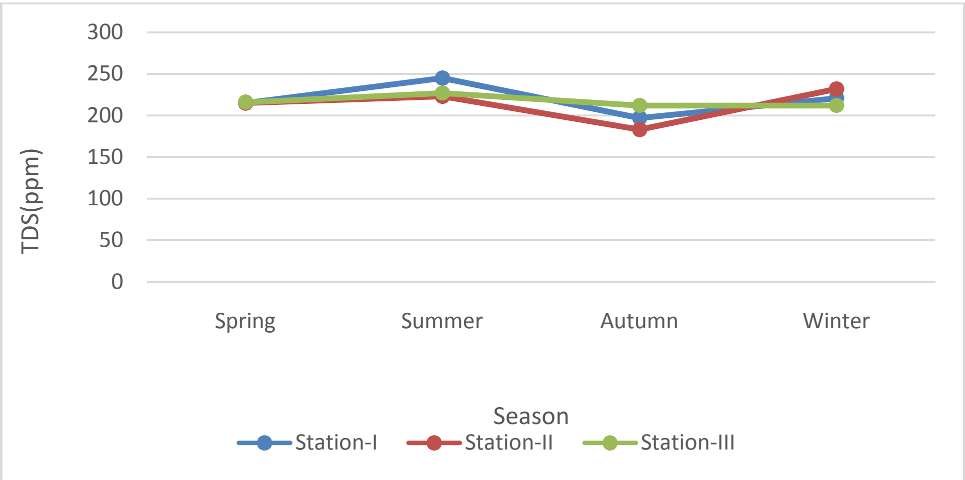

Figure 13: Variation in TDS in Different Season

4.2.2.6 Electrical Conductivity

During summer, the highest EC (Electrical Conductivity) value, reaching 517µS/cm, was recorded at station III, while the lowest EC value, measuring 392 µS/cm, was observed at station II during spring. Across all four seasons, the average EC values at stations I, II, and III were 455.25 µS/cm, 443 µS/cm, and 449.25 µS/cm, respectively. The overall average EC values for all four seasons were 425.33 µS/cm, 512.67 µS/cm, 409.67 µS/cm, and 449 µS/cm (Fig.14).

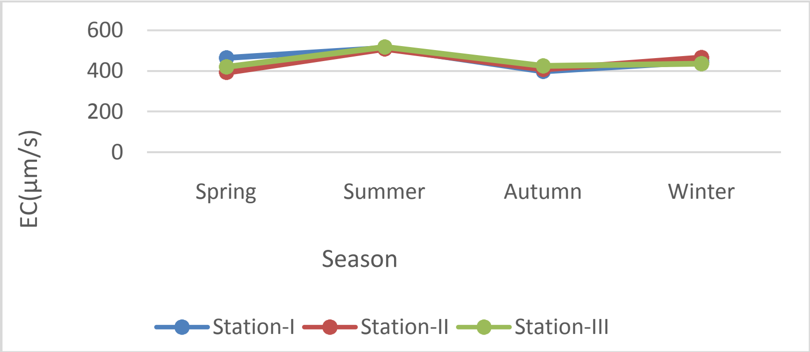

Figure 14: Variation in EC in different Season

4.2.2.7 Hardness (mg/L)

During autumn, the highest hardness value, reaching 59.4mg/L, was recorded at station III, while the lowest hardness value, measuring 47mg/L was observed at station II. Across all four seasons, the average hardness values at stations I, II, and III were 55.4mg/L, 53.06mg/L, and 55.92mg/L, respectively. The average hardness values for all four seasons were 57.76mg/L, 53.79mg/L, 55.14mg/L, and 52.5mg/L, respectively (Fig.15).

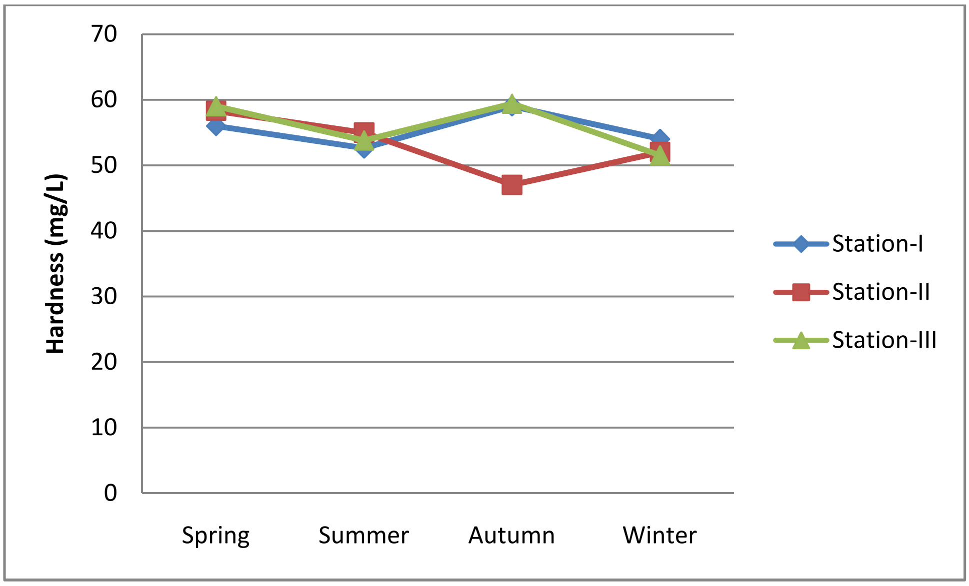

Figure 15: Variation in Hardness in different season

4.3 Ordination

Detrended Correspondence Analysis (DCA) showed 1.65 Standard Deviation Unit (SD unit) for the first DCA axis and 1.01 for the second. Redundancy Correspondence analysis (RDA) was justified in its use based on the overall variance explained by the data matrix (Table 3).

Table 3: DCA Summery

	DCA1	DCA2	DCA3	DCA4
Eigen values	0.186	0.088	0.071	0.067
Decorana Values	0.225	0.104	0.034	0.005
Axis lengths	1.65	1.01	0.95	1.36

4.3.1 Relationship between Fish Species, Seasonal and Environmental Variables

The Redundancy Analysis (RDA) revealed distinct correlations between various fish species and environmental variables. Notably, dissolved oxygen, free carbon dioxide, pH, velocity, electrical conductivity, and temperature exhibited significant correlations, showing predominantly strong negative relationships with total dissolved solids (TDS), hardness, alkalinity, and transparency.

In the RDA plot, certain fish species, such as *Channa striata* (S25), *Garra annandelei* (S12), *Puntius sophore* (S24), *Chagunius chagunio* (S3), *Schistura multifasciata* (S14), *Mystus* *tyangra* (S26), and *Puntius ticto* (S6), demonstrated noteworthy associations with pH, temperature, and velocity. Specifically, *Garra annandelei* (S12), *Schistura multifasciata* (S14), and *Channa orientalis* (S18) exhibited significant relationships with water velocity and pH. Moreover, species like *Barilus shacra* (S8), *Chagunius chagunio* (S3), *Mystus tyangra* (S26), and *Mastacembalus armatus* (S1) were found to have strong correlations with pH and dissolved oxygen. *Tor tor* (S20) and *Garra gotyla* (S19) were associated with velocity, while *Garra lissorhynchus* (S21) and *Wallago attu* (S22) showed strong correlations with alkalinity. Additionally, *Mastacembelus armatus* (S1) and *Xenontodon cancila* (S9) exhibited significant relationships with velocity, electrical conductivity, temperature, and TDS (Fig.16).

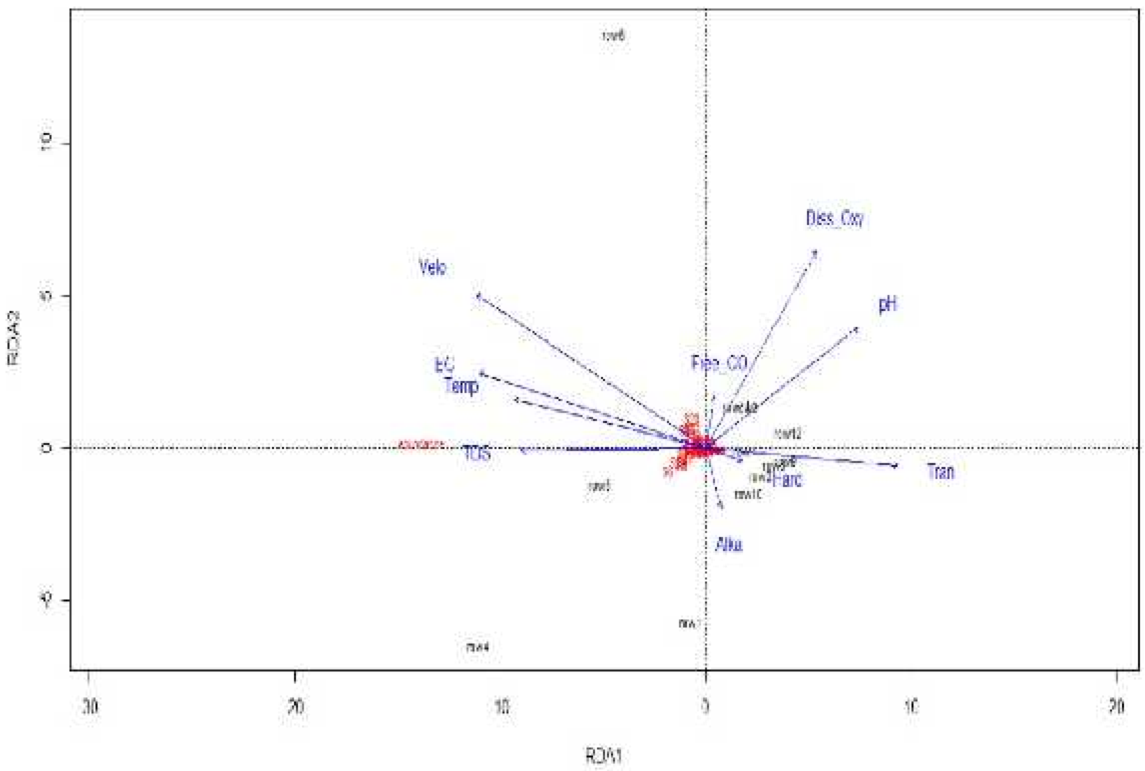

Figure 16: RDA analysis of Species Abundance with Environmental Variable

Table 4: IUCN (2020) Red list Cagtegories

IUCN (2020) Red List Categories				
S. N.	**Data Deficient**	**Least Concern**	**Near Threatened**	**Vulnerable**
1	*Paracanthocobitis botia*	*Danio devario*	*Bagarius bagarius*	*Chagunius chagunio*
2	*Physoschistura prashadi*	*Pethia ticto*	*Wallago attu*	*Danio rerio*
3	*Macrognathus lineatomaculatus*	*Garra annandalei*		
4	*Schistura multifasciata*	*Barilus barila*		
5	*Channa orientalis*	*Puntius terio*		
6	*Mystus tyangra*	*Garra gotyla*		
7	*Channa gaucha*	*Garra lissorynchus*		
8	*Tor tor*	*Puntius sophore*		
9		*Xenontodon cancila*		
10		*Barilius shacra*		
11		*Mastacembelus armatus*		
12		*Macrognathus pancalus*		
13		*Channa punctata*		
14		*Channa striata*		

5. Discussion

5.1 Spatial variation in fish assemblage

The research conducted on the Babai River in Dang, Western Nepal, revealed a rich diversity of fish species, with a total of 26 species identified belonging to six orders, eight families, and 15 genera. Among the 26 species, *Pethia ticto* was the dominant (13.13%) followed by *Chagunius chagunio* (10.07%) and the least *Danio rerio* was least comprised species (0.12%). G.C. et. al. 2019 identified 24 species from the Babai River among which *Puntius sophore* was the dominant species comprising 17.40% followed by *Barilius bendelensis* 15.18%. Singh (2001) identified 40 species from the Babai River Bardiya, among which *Barilius barila, Channa punctata, Puntius sophore, Xenentodon cancila* and *Mastacembalus armatus* are common in all above studies.

252 fish species, comprising 15 orders, 35 families and 104 genera were identified in Nepal by Shrestha (2019). With 135 species, the most dominant order is Cypriniformes. The majority of the river's fish species are members of the Cypriniformes oder having 2,422 species making it the biggest order of freshwater fishes (Nelson, 1948). The current study also showed that with 15 species of all fish species, Cypriniformes is the dominant order (58%) followed by Siluriformes (3 species), which accounts for 12% of all fish species. The findings of this study are in line with those of Jha and Bhujel (2015), who indicated that 29% of the fish species in the Narayani River system are Siluriformes and 49% of all fish species are Cypriniformes. Additionally, according to Singh (2001), Cypriniformes is a dominant order that makes up 44.73% of all total catch from Babai River, Bardiya. The findings of Limbu et al. (2016), Limbu et al. (2019a), Limbu and Gupta (2019b), and Limbu et al. (2018), who reported the order Cypriniformes as a dominant order from Ratuwa and Bakraha River, are also consistent with the results of this study.

Only station I had *Danio rerio, Puntius sophore,* and *Wallago attu.* It could be because of the quiet and calm surroundings. These species were not found in stations II and III because of the pollution and crowded conditions in those station. Only at station II was *Bagarius bagarius* discovered; this could be because of the water's deep depth. The species like *Schistura prasadi, Channa striata, Mystus tyangra* and *Channa gaucha* were found in close proximity to ditches and river borders at stations I and II. The most prevalent species in the study were *Puntius ticto, Chagunius chagunio, Puntius terio, Danio devario,* and *Xenontodon cancila*, which together accounted for 13.13%, 10.07%, 9.18%, 7.39% and 2.93%

respectively of the total catches from the three sample locations. The study identified *Puntius ticto*, *Chagunius chagunio*, *Puntius terio*, *Danio devario*, and *Xenontodon cancila* as the predominant species across all three sampling stations, constituting 13.13%, 10.07%, 9.18%, 7.39%, and 2.93% of the total catches, respectively. Notably, *Pethia ticto, Puntius terio,* and *Chagunius chagunio* were consistently found in all stations, indicating a favorable habitat for these species, typically characterized by shallow waters and aquatic vegetation. *Mastacembelus armatus, Macrognathus pancalus, Macrognathus lineatomatus*, and *Xenontodon cancila* were predominantly associated with areas containing pebbles and cobbles across all stations. These findings align with previous research by G.C. and Limbu, supporting the notion that the Babai riverine ecosystem provides suitable conditions for *Puntius* species. Additionally, *Garra* species were observed in moderately flowing waters across all stations, representing 4.33% of the total catch. These hill stream fishes exhibit specialized adaptations such as modified barbells, lips, and adhesive discs, indicating similar habitat preferences.

5.2 Temporal Variation in Fish Assemblage

Puntius terio and *Xenontodon cancila* were the sole fish species observed throughout all four seasons, with *Puntius terio* being the most abundant and dominant species in the Babai River during the recent field survey. This finding corroborates the results reported by G.C. and Limbu in 2019 regarding the prevalence of *Puntius terio* in the Babai River. *Macrognathus lineatomaculatus, Schistura multifasciata,* and *Chagunius chagunio* were present in three seasons: spring, summer, and autumn. Among them, *Chagunius chagunio* exhibited the highest catch numbers during summer, while *Macrognathus lineatomaculatus* and *Schistura multifasciata* had the lowest catches in winter. Additionally, *Pethia ticto, Barilus shacra*, and *Garra gotyla* were found in three seasons: spring, summer, and winter, with *Puntius ticto* being most abundant during summer (13.13% of total catch). *Danio rerio* (0.12%) was the sole species found in spring, whereas *Bagarius bagarius* (0.38%) and *Puntius sophore* were exclusive to summer. Furthermore, *Channa striata* was solely observed in autumn. The study indicates that *Tor tor* was a rare species, constituting only 3.95% of the total catch and being recorded in spring and summer.

A biodiversity index aims to encapsulate the diversity of a sample or community using a singular metric (Magurran, 1988). Species diversity comprises two fundamental elements: species richness, denoting the number of species, and the distribution of individuals among these species. Nonetheless, the comprehensive treatment and measurement of this concept are intricate (Williamson, 1973). The highest Shannon-Weiner diversity index was recorded at sites I and II and summer, while the lowest was observed at site III and winter.

Seasonal variations in species diversity were evident in the studied area, with the highest Shannon Weiner diversity index recorded during summer (2.86), because summer is the breeding season for the fishes and also availability of water and shelter and the lowest during winter (1.49) due to the low amount of water levels. But, G.C. (2019) recorded highest seasonal Shannon Weiner diversity index value was found in winter (2.62) and lowest value in Spring (2.28) from Babai River, which is opposite to our present study. Similarly, station-wise analysis revealed that stations I & II exhibited the highest diversity index (1.87) because of peaceful area and less human disturbed area while station III had the lowest (1.81) because of anthropogenic activities (station III is a tourist area). Margalef's richness was maximum in spring (4.25) and minimum in winter (1.1), with station I showing the highest richness (2.3) and station III the lowest (1.81). Evenness index peaked in summer (0.94) and decreased in autumn (0.82), while station III displayed the highest evenness (0.95) and station I the lowest (0.85). Despite these fluctuations, no significant differences were noted in diversity index (H'), evenness (E), and Margalef richness (d) among seasons or stations. Thus, it can be inferred that seasonal disparities in species diversity are a regular occurrence in the region under study.

5.3 Variation in Fish Assemblage Structure with Water Quality

The abundance of fish is influenced by various environmental and physicochemical factors, including water temperature, free carbon dioxide levels, dissolved oxygen concentrations, and pH levels. These factors exhibit variability based on altitude and seasonal changes. While some researchers propose that fish diversity correlates directly with seasonal variations, Ostrand and Wilde (2002) suggest that spatial differences in environmental conditions among sites have a greater impact on fish abundance, particularly for dominant species. This implies that long-term alterations in environmental conditions across different locations exert a more significant influence on fish community structure than seasonal fluctuations.

The dissolved oxygen (DO) concentration in water is a crucial factor for supporting diverse aquatic life, with levels above 5 mg/L considered optimal (APHA, 1978). In the Babai River, DO ranged from 13.60 mg/L at station I during winter to 6.47 mg/L at station II in summer. Higher DO levels during winter at station I may be attributed to increased water transparency, enhancing light penetration and favoring photosynthesis by algae and aquatic vegetation.

Water temperature exhibited seasonal variation, with higher temperatures in spring and summer and lower temperatures in winter, consistent with previous studies (Mishra & Gupta, 2015). pH levels throughout the study area were generally suitable for fish growth, slightly alkaline at all stations and seasons, with a lower value (pH 7.5) observed in summer compared to spring (pH 8.14), potentially influenced by acid rain and rock weathering. Maximum and minimum water temperatures were recorded in summer and winter, respectively, aligning with findings from the Tinau River (Sharma & Shrestha, 2001). Water velocity was highest in summer, likely due to increased water levels, with velocity primarily determined by river characteristics. In the plain area of the Babai River, velocity variations within stations were minimal.

In order to foster optimal development in fish populations, it is essential that the concentration of free carbon dioxide in water remains below 5 mg/L (Santosh & Singh, 2007).In the present study, free carbon dioxide (CO2) concentrations slightly exceeded the preferable range for excellent fish development, with the highest observed at station III (13.6 mg/L) in spring and the lowest at station II (4.2 mg/L). Water hardness fell within the preferred range for fish health, with the highest value (55.92 mg/L) observed at station III and the lowest (53.06 mg/L) at station II. Bhatnagar et al. (2004) reported that water hardness exceeding 300 mg/L can be fatal to fish, while levels below 20 mg/L may cause stress due to nutrient deficiency, particularly in winter. In freshwater ecosystems, the optimal range of Total Dissolved Solids (TDS) for most fish species usually lies between 100 to 500 parts per million (ppm). This range facilitates the presence of crucial ions and minerals vital for maintaining fish health and sustains a diverse community of species adapted to freshwater conditions. In the present study, TDS measurements ranged from 183 ppm at station II during autumn to 342 ppm at station II during winter in the Babai River, Dang. This indicates that the TDS levels in the river support the diversity of fish species present in the ecosystem.

6. Conclusions and recommendations

6.1. Conclusions

The survey documented a total of 26 fish species across six orders, eight families, and fifteen genera, with Cypriniformes emerging as dominant order, notably representing 58% of the collected specimens. *Pethia ticto* stood out as the most abundant species, comprising 13.13%

of the total catch, while *Danio rerio* was the rarest, accounting for only 0.12%. The Redundancy Analysis (RDA) ordination plot highlighted spring and summer as optimal seasons for the existing fish population. The latest research uncovered new fish species, such as *Bagarius bagarius, Wallego attu, Tor tor, Channa gaucha, Macrognathus lineatomaculatus,* and *Macrognathus pancalus,* which had not been observed in prior studies conducted by G.C. et al. 2019. The present study did not find fish species such as *Erethistes pussilus, Heteropnestus fossilis*, and *Labeo fimbriatus,* which were documented in the research conducted by G.C. et al. 2019.

6.2. Recommendations

- Regular monitoring of fish species diversity in Babai River, Dang, Western Nepal should be conducted by the local authorities and ichthyologists.
- Care should be given by the local authorities as well as the visitors at the tourist destination (Purandhara waterfall) located in Babai River, Dang (Station III at present study area) regarding the sustainable ecotourism fostering on environmental cleanliness around the river side, proper management of solid wastes (plastics, bottle cans, use of insecticides and pesticides in the water source etc.).

7. References

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Photo plate-I

Order : Cypriniformes

Photo 1: *Chagunius chagunio*

Photo 2: *Danio devario*

Photo 3: *Pethia ticto*

Photo 4: *Barilius shacra*

Photo 5: *Danio rerio*

Photo 6: *Garra gotyla*

Photo 7: *Garra annandalei*

Photo 8: *Barilius barila*

Photo 9: *Puntius terio*

Photo Plate II

Photo 10: *Puntius sophore* Photo 11: *Paracanthocobitis botia*

Photo 12: *Physoschistura prashadi* Photo 13: *Schistura multifasciata*

Photo 14: *Tor tor* Photo 15: *Garra lissorhynchus*

Photo plate-III

Order: Synbranchiformes

Photo 16: *Mastacembelus armatus*

Photo 17: *Macrognathus lineatomaculatus*

Photo 18*: Macrognathus pancalus*

Photo plate-IV

Order: Anabentiformes

Photo 19: *Channa punctata*

Photo: 20 *Channa orientalis*

Photo 21: *Channa striata*

Photo plate-V

Order: Siluriformes

Photo 22: *Mystus tyangra*

Photo 23*: Wallago attu*

Photo 24*: Bagarius bagarius*

Photo plate-VI

Order: Beloniformes

Photo 25: *Xenentodon cancila*

Order: Perciformes

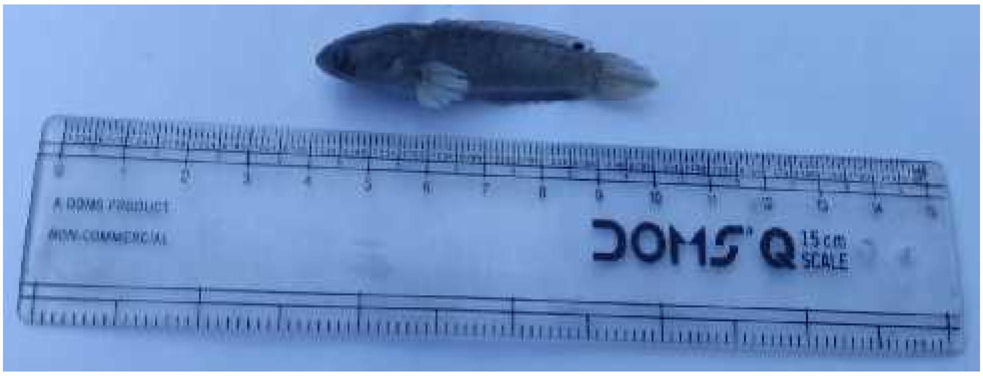

Photo 26: *Channa gaucha*

Appendices

Appendix I : Photos during the field

Photo 27: Station III

Photo 28: Collecting fishes from Cast net in station I

Photo 29: Taking data of water parameters on the site

Photo 30: Interacting with the fishermen about the depth of River

Photo 31: Chemical titration

Photo 32: Fisherman throwing cast net

Photo 33: Measuring water velocity

Photo 34: Identifying the collected sample in the site

Photo 35: Chemical titration on Site-II

Photo 36: With local fishermen

Appendix II: Physico-chemical parameters in different three stations and four season of West, Babai,Dang

Water parameters	**Seasons**											
	Spring			**Summer**			**Autumn**			**Winter**		
	S1	S2	S3	SU1	SU2	SU3	A1	A2	A3	W1	W2	W3
Water temperature(◦C)	28	30	30	36.7	34.28	36.2	24	26	23.4	14	15.4	15.2
Water velocity(m/s)	0.37	0.3	0.3125	1.67	1.24	1.9	0.59	0.34	0.62	0.46	0.32	0.43
pH	7.9	8.32	8.14	7.5	7.89	8.03	8.38	8.22	8.3	7.6	7.9	7.82
Dissolved Oxygen(mg/L)	6.80	5.60	5.73	5.30	5.70	7.20	6.30	6.50	7.00	6.87	7.15	6.58
Free CO2)(mg/L)	7.62	7.89	13.6	8.56	8.76	8.5	8.23	9.6	9.46	6.9	8.2	6.6
Alkalinity(mg/L)	85	83	87.6	72	79	74.26	70.31	76.25	83.4	72	67	64.3
TDS(ppm)	215	215	216	245	223	227	197	183	212	221	232	212
EC(µs/cm)	464	392	420	513	508	517	398	407	424	446	465	436
Transparency(cm)	60	83	152	14	11	14	80.12	110.6	59	87.8	142	83
Hardness(mg/L)	56	58.3	59	52.6	54.97	53.8	59.03	47	59.4	54	52	51.5