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Fish Diversity and Water Quality Parameters of Dudhkoshi River, Nepal

Om Hari Shrestha[1,] *, Sudeep Thakuri [2], Dimitra Bobori[3], Daya Ram Bhusal[1]
[1]Central Department of Zoology, T.U., Kirtipur, Nepal
[2]Central Department of Environmental Science, T.U., Kirtipur, Nepal
[3]Aristitole University of Thessaloniki, Greece
***Corresponding Author: oshresth@gmail.com**

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ABSTRACT

The present study was carried out to explore fish species in the Dudhkoshi River of eastern Nepal. The study covered two seasons, including the post-monsoon of 2020 and the pre-monsoon of 2021. Ten permanent sampling sites were fixed to collect fish and measure water quality parameters. Fishes were collected using cast nets and gill nets with the help of local fishermen. Water quality parameters were measured using water-quality test kits and applying titration methods. A total of 21 fish species belonging to 3 orders, 6 families and 12 genera were recorded. Among them, the least concern (LC) was represented by 17 species, DD (2), VU (1), and NT (1). Higher fish diversity was associated with pre-monsoon than post-monsoon, and Cypriniformes was the most dominant order with 16 species, representing 76.19% of the total fishes collected. The dominant family, Cyprinidae, accounted for 11 species (52.38%) of the total, followed by Botiidae and Sisoridae, each with three species (14.28%), while Psilorhynchidae had two species (9.52%). Each of the Ailidae and Channidae accounted for a single species (4.76%). Dissolved oxygen (DO) was at optimum levels, ranging from 8.4 mg/l to 12.2 mg/l. Ranges of other parameters, including water temperature (12.0 -18.5^{0}C), conductivity (41.6- 82.66µs/ cm), total acidity (3.1- 4.0mg/ l), free CO_2, (3.0- 4.0mg/ l), hardness (30.3- 35.6mg/ l), alkalinity (16.2- 19.5mg/ l), salinity (19.3- 39.0ppm) and TDS (27- 56ppm) were determined. The redundancy analysis (RDA) was used to investigate the association between species and water quality parameters. The two axes of RDA explained 66% variation such that RDA_1 was accounting for 51%, and RDA_2 was accounting for 15%. A strong association was observed between DO and species such as *Schizothorax. richardsonii* and *S. progastus.* Similarly, *Labeo dyocheilus*, *Barilius bendelisis*, *Psilorhynchus pseudecheneis* and *Botia lohachata* showed high kinship towards conductivity, temperature and salinity.

INTRODUCTION

The South Asian country, Nepal, is located between Palaearctic and Oriental Zoogeographical realms and is blessed with rich ichthyofauna **(Shrestha *et al.*, 2009; Shrestha & Edds, 2012; Chaudhury, 2014)** due to its location, drastic elevation gradients (from 80– 8848masl), topography and diverse climates generating different aquatic habitats **(Shrestha & Edds, 2012)**. Carps are the dominant group in the country with 128 species, representing 51.20% of the total species, followed by catfishes (76

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species, 30.15%) and Anabantiforms (14 species, 5.55%) **(Shrestha, 2019)**. Nepal's freshwater fishes account for 1.38% on the global scale. In addition, Nepal is rich in water resources. Rivers (48.2%), marginal swamps (1.5%), ponds (0.9%) and lakes (0.6%) **(MoFSC, 2014)** are the country's major water resources, which support 252 freshwater fishes **(Shrestha, 2019)**.

Nepal has three major river basins: the Koshi, the Gandaki, and the Karnali in the eastern, central and western regions of the country, respectively. The Koshi basin (KB) is the largest basin of eastern Nepal, with a 60,400km^2 total catchment area, of which 31,940 km^2 lies in Nepal **(WECS, 2011)**. The KB has seven major tributaries; namely, Indrawati, Sunkoshi, Likhu, Tamakoshi, Dudhkoshi, Tamor and Arun. Fish diversity studies have been conducted on KB in the recent past **(Shrestha *et al.*, 2009; Limbu & Subba, 2011; Doody *et al.*, 2016; Mishra & Baniya, 2016; Tumbahangfe *et al.*, 2021)**. However, many unexplored rivers need to be surveyed for fish species in KB, and one of them is the Dudhkoshi River, a major tributary of the KB. The Dudhkoshi River is originated from Imja peak (6,189m) of the Himalayan range, the vicinity of the world's highest summit, Mount Everest. The river is located in the Dudhkoshi sub-basin (3,712km^2), whose altitude ranges from 6,189 (north) to 465m asl (south; at the Rabuwa bazar) **(Nepal, 2016)**. It is a snow-fed perennial river flowing south through the borders of the Okhaldhunga and Khotang districts. Its upstream sites are dominated by boulders, while the downstream sites have mainly cobble and pebble. The major tributaries of the Dudhkoshi River are Inkhu, Honu and Rawa. Ultimately, the Dudhkoshi River merges with the Sunkoshi River, another tributary of KB at Sukmatar.

Globally, the freshwater ecosystem is more severely endangered **(Dudgeon *et al.*, 2006)** than the terrestrial ecosystem. Furthermore, freshwater biodiversity has been severely affected by, the construction of dams **(Degerman *et al*., 2001)**, climate change **(Findlay *et al*., 2001)**, deforestation, habitat alteration and the degradation of wetlands **(Alin *et al*., 2002)**, and Nepal is not an exception. Fishes are one of the largest groups of vertebrates with 18,132 valid freshwater species **(Fricke *et al*., 2021)**; they are suffering from adverse environmental and anthropogenic impacts **(Xenopoulus & Lodge, 2006)**. Therefore, fish diversity study becomes essential for proper documentation about species account. To our knowledge, this is the first fish diversity research carried out addressing the Dudhkoshi River, with an aim of filling the gap of knowledge in that regard. It also aimed to find out the relationship between species richness and water quality parameters in the pre- and post-monsoon. The results of this study would contribute to the updating of fish diversity status in the KB in particular and the country in general.

MATERIALS AND METHODS

Fish collection, preservation and identification

Based on habitat heterogeneity and accessibility, ten permanent sampling sites were fixed for fish sampling and measurement of water quality parameters. Sampling sites selected were: Jubhing (S1), Dibli (S2), Barkhughat (S3), Panchan (S4), Tuintar (S5), Rabuwa bazar (S6), Rawa confluence (S7), Ghopatar (S8), Karki bensi (S9) and Jayramtar (S10). The altitudinal variation of those sampling sites ranged from 318 to 1486masl. Fish samples were collected from September 2020 to May 2021, covering two seasons (post-monsoon 2020 and pre-monsoon 2021) assuming that more fish could be captured in low water levels in those seasons. Three sub-samples collected at each site generated a total of 30 samples in each season. A cast net (mesh size: 2- 4cm) and a gill net (3- 5cm) were used for fish sampling with the help of local fishermen from available microhabitats, viz., riffles, runs and pools. Each site was sampled for 30- 45 minutes, using cast nets from downstream to upstream in the daytime and covering about 150- 200m of river length **(Edds, 1993; Adams *et al.*, 2004; Liu *et al.*, 2021)**. However, gill nets were set across the bank of the river in the evening, left overnight, and removed the next morning. Some fish specimens were preserved in 10% formalin in bottles as voucher specimens, while others were released back to the river. Fishes were identified to the species level following **Day (1978)**, **Shrestha (1981)**, **Talwar and Jhingran (1991)**, **Jayaram (2010)** and **Shrestha (2019)** in addition to other relevant literature.

Water quality measurements

Prior to fish sampling, ten physicochemical parameters were measured at each site. Water temperature (^{0}C), pH, conductivity (µS/cm), TDS (ppm) and salinity (ppm) were recorded by a multi-parameter combo pen (M0199720). Dissolved oxygen (mg l^{-1}) was measured by using a DO test kit (WT028A, HiMedia). Alkalinity (mg l^{-1}) was measured with the help of an alkalinity test kit (Mquant, 1.11109, Merck). The total hardness (mg l^{-1}) was measured by using test stripes (Hardness-Test, Aquadur; Nitrat-Test, 1.10020, Aquadur). Free carbon dioxide (mg l^{-1}) and total acidity (mg l^{-1}) were calculated by titrating the water sample against NaOH and Na_2CO_3 solutions, respectively. Methyl orange and/or phenophthalein indicators were used in titration methods.

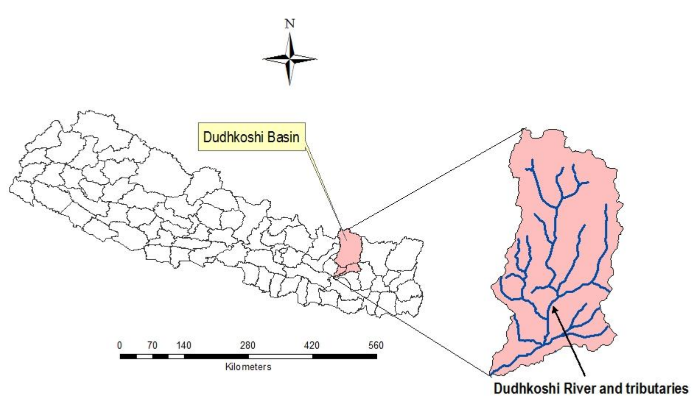

Fig. 1. Study area showing Dudhkoshi River and its tributaries

Fish diversity analysis

Species diversity of the Dudhkoshi River was evaluated from four diversity indices, such as Shannon-Wiener's diversity, Margalef's richness, Pielou's evenness and Simpson's diversity.

Shannon-Wiener's diversity

It was calculated using the following formula:

$$H' = -\sum_{i=1}^{S} P_i * \ln P_i \qquad \textbf{(Shannon, 1949)}$$

Where, H'= diversity index; pi= relative abundance (ratio of the number of i^{th} individuals and the total number of individuals), and S= the total number of species.

Margalef's richness index

It was performed based on the following formula:

d = S-1/lnN **(Margalef, 1968)**

Where, d= Margalef's richness index; S= the number of species, and N= the total number of individuals of all species.

Pielou's evenness index

It was applied based on the following formula:

E =H/lnS **(Pielou, 1966)**

Where, E= Pielou's evenness index; H'= Shannon-Wiener's diversity index, and S= the total number of species.

Simpson's index of diversity (1-D)

It was implemented based on the succeeding following formula:

1-D = 1- ∑n (n-1)/N (N-1) **(Simpson, 1949)**

Where, 1-D= Simpson's index of diversity; n= the number of individuals of a particular species, and N= total number of individuals of all species.

Statistical analysis

Before choosing the appropriate ordination technique, the axis length and Eigenvalue were examined through the *decorana* function in the *Vegan* package in R software **(R core team, ver. 4.1.3)**. Following the output of the *decorana* function, redundancy analysis (RDA), which is a constrained ordination technique, was used to analyze the relationship between water quality parameters and fish assemblage structure. One-way analysis of variance (ANOVA) was used to determine the differences between water quality parameters by season, using palentological statistics **(PAST, version 4.03**; **Hammer *et al*., 2001)**. If significant, a post hoc Tukey HSD test was used to find out which means were significantly different at α=0.05. Water quality parameters that did not meet the assumptions of normality were natural log transformed following the Shapiro-Wilk test at a significance level of P<0.05.

RESULTS

Species diversity and abundance

A total of 642 individuals representing 21 species (14 in the post-monsoon and 19 in the pre-monsoon) were collected during the study. They belong to 3 orders, 6 families and 12 genera. Cypriniformes was the most dominant order with 16 species, accounting for 76.19% of the total species collected, followed by Siluriformes (4 species; 19%). But, a single species (*Channa barca*) of Anabantiformes was collected during the study. The dominant family, Cyprinidae, accounted for 11 species (52.38%) of the total species collected, followed by Botiidae and Sisoridae, each with three species (14.28%), while Psilorhynchidae had two species (9.52%). Each of the Ailidae and Channidae accounted for a single species (4.76%). Of the total species collected, 17 were listed as least concern (LC), two species as data deficient (DD), one species as vulnerable (VU) and one species as near threatened (NT) **(**Fig. 4, **IUCN, 2021)**.

Table 1 Checklist of fish species recorded from the Dudhkoshi River with their IUCN status

Order	**Family**	**Species**	**Common name** [NA: not available]	**Species codes**	**IUCN Red List Status**
Cypriniformes	Cyprinidae	*Schizothorax richardsonii* (Gray, 1832)	Snowtrout	S. ric	VU
Cypriniformes	Cyprinidae	*Schizothorax progastus* (McClelland, 1839)	Dinnawah snowtrout	S. pro	LC
Cypriniformes	Cyprinidae	*Labeo dyocheilus* (McClelland, 1839)	NA	L. dyo	LC
Cypriniformes	Cyprinidae	*Neolissochilus hexagonolepis* (McClelland, 1839)	Copper mahseer	N. hex	NT
Cypriniformes	Cyprinidae	*Barilius bendelisis* (Hamilton, 1807)	NA	B. ben	LC
Cypriniformes	Cyprinidae	*Barilius barila* (Hamilton, 1822)	NA	B. bar	LC
Cypriniformes	Cyprinidae	*Barilius shacra* (Hamilton, 1822)	NA	B. sha	LC
Cypriniformes	Cyprinidae	*Puntius sophore* (Hamilton, 1822)	Pool barb	P. sop	LC
Cypriniformes	Cyprinidae	*Garra annandalei* Hora, 1921	NA	G. ann	LC
Cypriniformes	Cyprinidae	*Garra gotyla* (Gray, 1830)	Sucker head	G. got	LC
Cypriniformes	Cyprinidae	*Garra lamta* (Hamilton, 1822)	NA	G. lam	LC
Cypriniformes	Botiidae	*Botia geto* (Hamilton, 1822)	Bengal loach	Bo. get	LC
Cypriniformes	Botiidae	*Botia lohachata* Chaudhuri, 1912	Reticulate loach	Bo. loh	LC
Cypriniformes	Botiidae	*Botia histrionica* Blyth, 1860	Loach	Bo. his	LC
Cypriniformes	Psilorhynchidae	*Psilorhynchus pseudecheneis* Menon and Datta, 1964	Nepalese minnow	Ps. pse	LC
Cypriniformes	Psilorhynchidae	*P. homaloptera* Hora and Mukerji, 1935	Torrent stone carp	Ps. hom	LC
Siluriformes	Sisoridae	*Pseudecheneis eddsi* Ng, 2006	NA	Pse. edd	DD
Siluriformes	Sisoridae	*Glyptothorax cavia* (Hamilton, 1822)	NA	G. cav	LC
Siluriformes	Sisoridae	*Glyptothorax pectinopterus* (McClelland, 1842)	River cat	G. pec	LC
Siluriformes	Ailiidae	*Eutropiichthys murius* (Hamilton, 1822)	NA	Eu. mur	LC
Anabantiformes	Channidae	*Channa barca* (Hamilton, 1822)	Barca snakehead	C. bar	DD

The catch composition (CC) of each fish collected in the Dudhkoshi River in the post- and the pre-monsoon is shown in Fig. (2). A total of 19 species were considered for the analysis; rare species like *Puntius sophore* and *Eutropiichthys murius* were not included in the analysis of catch composition since their CC was represented below one percent. *Schizothorax richardsonii* was the most common and abundant species, which was collected from 9 of 10 sites and accounted for 19.17% of the total number of specimens collected. The next abundant species was *S. progastus*, which accounted for 12.42% of the total number of specimens, followed by *Labeo dyocheilus* (10.58%), *Barilius barila* (7.36%) and *B. bendelisis* (6.29%). *Botia geto* (1.23%), *Channa barca* (1.23%) and *Garra lamta* (1.23%) were the least abundant species recorded in the Dudhkoshi River.

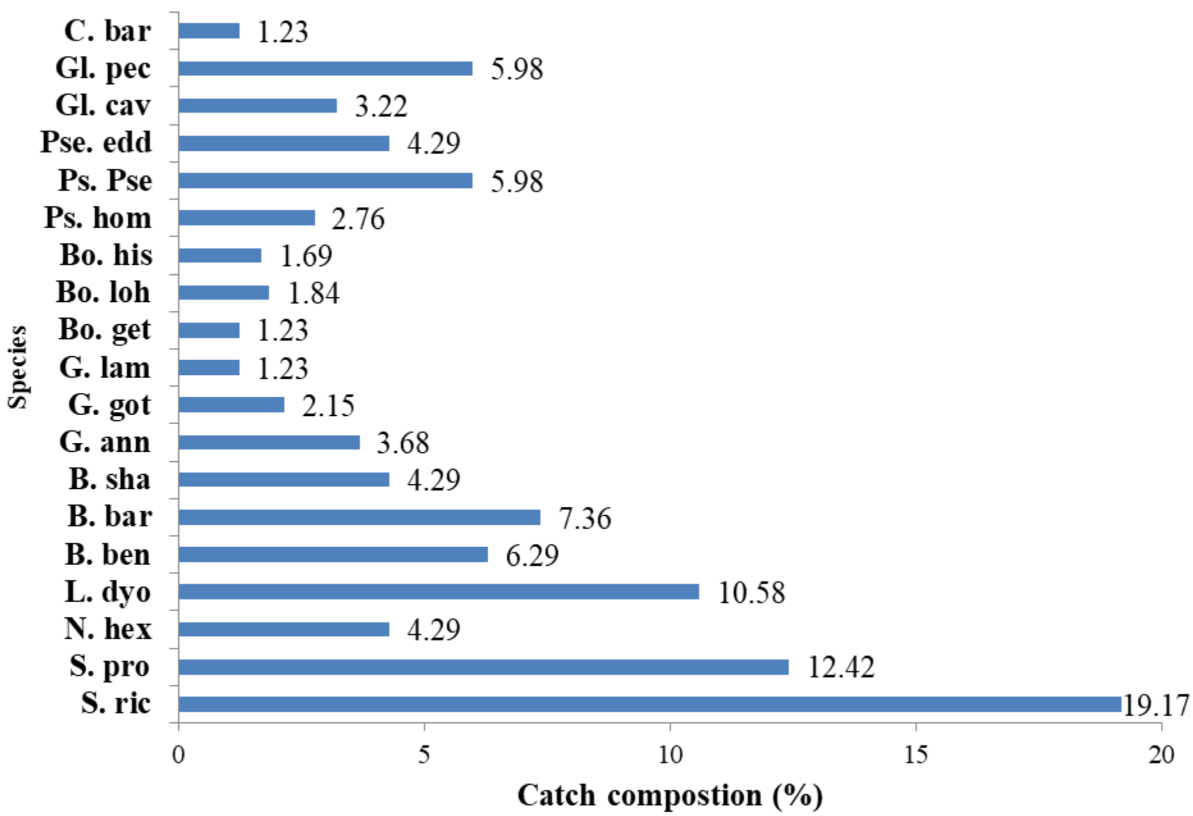

Fig. 2. Total catch composition of fish species collected in the Dudhkoshi River during two seasons

Diversity status

The highest value of Shannon-Wiener's diversity (H') (2.491) was recorded at S8, while the lowest (0.636) was at S1 in pre-monsoon. In post-monsoon, H' was high (2.136) at S7 and low (0.69) at S2. The highest Simpson's diversity (1-D) (0.920) was recorded at S8, and the lowest (0.444) was recorded at S2 in pre-monsoon. In post-monsoon, 1-D was high (0.866) at S7 and low (0.497) at S2. In pre-monsoon, the value of Margalef's index (d) was high (2.934) at S6 and low (0.346) at S2. In post-monsoon, the value of d was high (2.393) at S7 and low (0.379) at S3. Pielou's evenness (E) was high (0.935) at S1 and low (0.869) at S7 in pre- monsoon. In post-monsoon, the value of E was high (0.938) at S5 and low (0.889) at S10.

Water quality parameters

DO ranged from 8.30mg/ l at S9 in post-monsoon to 12.2mg/ l at S1 in pre-monsoon, with a maximum mean of 12.16mg/ l at S1 and a minimum mean of 8.36mg/ l at S9. DO showed a significant difference among sites (F=347.94, P<0.05) and between seasons (F=35.11, P<0.05). The highest pH (7.9) and the lowest pH (7.0) were recorded at S4 and S3, respectively, in post-monsoon, with a maximum mean of 7.7 at S8 and a minimum mean of 7.3 at S4. The pH showed significant difference among sites (F=4.5, P<0.05) but not between seasons (P=0.32). The temperature ranged from 11.9^{0}C at S1 in post-monsoon to 18.6^{0}C at S10 in pre-monsoon, recording a maximum mean of 18.05^{0}C at S8 and a minimum mean of 12.8^{0}C at S1. The temperature showed a significant difference among sites (F=993.60, P<0.001) and between seasons (F=1488.4, P<0.001). On the other hand, the conductivity was high (84 µs/cm) at S9 and low (41.6 µs/cm) at S2 in post-monsoon, showing a maximum mean of 83µs/ cm at S9 and a minimum mean of 41.7µs/ cm at S2. Conductivity showed a significant difference among sites (F=584.7, P<0.05) and between seasons (F=2884.54, P<0.05). For alkalinity measurement, it ranged from 16.1mg/ l at S1 in post-monsoon to 19.5mg/ l at S10 in pre-monsoon, with a maximum mean of 19.5mg/ l at S10 and a minimum mean of 16.16mg/ l at S1. Alkalinity showed a significant difference among sites (F=9.68, P<0.05) and between seasons (F=1083, P<0.05). The total hardness ranged from 29.8mg/ l at S3 in post-monsoon to 30.7mg/ l at both S9 and S10 in pre-monsoon, recording a maximum mean of 35.6mg/l at S9 and S10 and a minimum mean of 30.3mg/ l at S3. In addition, the total hardness showed a significant difference among sites (F=26.28, P<0.05) and between seasons (F=1220.72, P<0.05). For CO_2, ranges from 3.0mg/ l at S10 in pre-monsoon to 4.1mg/ l at S1 in post-monsoon were recorded, with a maximum mean of 4.0mg/ l at S1 and a minimum mean of 3.06mg/ l at S10. With respect to CO_2, a significant difference was detected among sites (F=10.63, P<0.05) and between seasons (F=56.54, P<0.05). Concerning the TDS values, ranges from 26 to 57ppm were respectively recorded at S2 in post-monsoon and S9 in pre-monsoon, with a maximum mean of 56ppm at S9 and a minimum mean of 26.6ppm at S2. The TDS showed a significant difference among sites (F=238.94, P<0.05) and seasons (F=2957.7, P<0.05). The salinity ranged from 19.3ppm at S2 in post-monsoon to 40ppm at S10 in pre-monsoon, with a maximum mean of 39.3ppm at S10 and a minimum mean of 19.33ppm at S2. The salinity showed a significant difference among sites (F=206.30, P<0.05) and between seasons (F=2409.75, P<0.05). Acidity ranged from 2.8mg/ l at S6 in post-monsoon to 4.0mg/ l at both sites of S2 and S4 in post-monsoon, with a maximum mean of 4.0mg/ l at S2 and a minimum mean of 3.13mg/ l at S2. Acidity showed a significant difference among sites (F=5.38, P<0.05); however, no significant difference was detected between seasons (P=0.18).

Relationship between species richness and water quality parameters

The two axes of redundancy analysis (RDA) (Fig. 5) explained a total of 66% variation such that RDA_1 is accounting for 51% and RDA_2 is accounting for 15% variation. A strong positive association was observed between DO and *S. richardsonii* and *S. progastus*, whereas a negative association was recorded with *G. lamta*, *Botia lohachata*, *B. bendelisis* and *L. dyocheilus*. A high positive association was found between CO_2 and species such as *G. lamta* and *Neolissochilus hexagonolepis*. Species including *L. dyocheilus*, *B. bendelisis*, *Psilorhynchus pseudecheneis* and *B. lohachata* displayed high positive kinship towards conductivity, temperature and salinity; whereas, a negative correlation was observed with *S. richardsonii* and *S. progastus*. Similarly, a high correlation was noticed between the total hardness, *Botia histrionica* and *Pseudecheneis eddsi*. Species including *Psilorhynchus homaloptera*, *Glyptothorax cavia*, *Garra annandalei*, and *Barilius shacra* were highly positively correlated with alkalinity. Furthermore, *B. barila* showed a strong positive affinity towards pH.

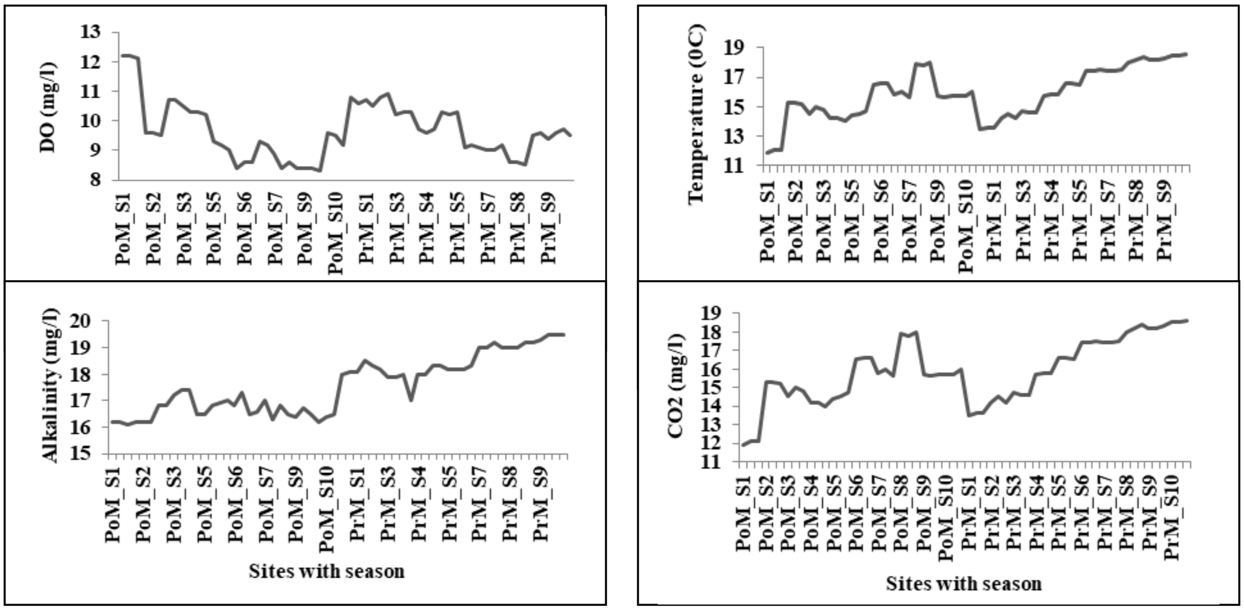

Fig. 3. Water quality parameter at different sites in different seasons

DISCUSSION

Species diversity and abundance

Being the first fish diversity research conducted on the Dudhkoshi River, as per our knowledge, no comparison was possible for species richness. The Koshi basin of eastern Nepal harbors 176 species **(Rajbanshi, 2012)** out of 252 freshwater fishes of Nepal **(Shrestha, 2019)**. The fishes collected in this study accounted for 11.93% of the fishes of KB. *S. richardsonii* was the most common species which was recorded from 9 out of 10 sampling sites. This might be due to favorable conditions viz. cold water with the high volume of water in the Dudhkoshi River. Species like *P. sophore*, *C. barca* and *E. murius* were rare species. *B. bendelisis*, *B. barila*, and *B. shacra* were recorded mainly from lower reaches, and may be favored by the moderate water temperature. *P. pseudechenei*s and *P. homaloptera* were occasionally recorded species in this study. Gear choice (e.g. cast net, gill net) in fish sampling might have caused their occasional capture because they are generally attached to the lower surface of rocks.

Our study is in line with **Shrestha *et al.* (2009)**, **Shahnawaz *et al.* (2010)**, **Mishra and Baniya (2016)** and **Shrestha (2016)** who reported Cypriniformes as the dominant order. Generally, Cypriniformes is the dominant order in rivers **(Shahnawaz *et al.*, 2010;**

Rajbanshi, 2012). Like Dudhkoshi, Tamor is another tributary of KB which is also a snow-fed perennial river. **Shrestha *et al*. (2009)** described 30 fish species from the Tamor River. Species recorded in the present study including *B. bendelisis*, *B. shacra*, *P. pseudecheneis*, *S. progastus*, *S. richardsonii*, *N. hexagonolepis*, *G. annandalei*, *G. gotyla*, *Botia almorhae*, *B. histrionica* and *B. lohachata* were also reported from Tamor River in the study of **Shrestha *et al*. (2009)**. However, the endemic species, *Myerglanis blythii* reported in the Tamor River was absent in the current study. Among the seven exotic species (*Aristichthys nobilis*, *Clarias gariepinus*, *Cyprinus carpio*, *Ctenopharyngodon idella*, *Hypophthalmichthys molitrix*, *Oreochromis niloticus*, and *Pangasius* sp.) reported in KB in the study of **Doody *et al*. (2016)**, none of them was detected in our collection.

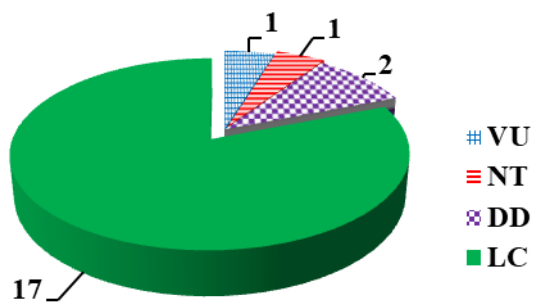

Fig. 4. IUCN status of the fishes collected in the Dudhkoshi River

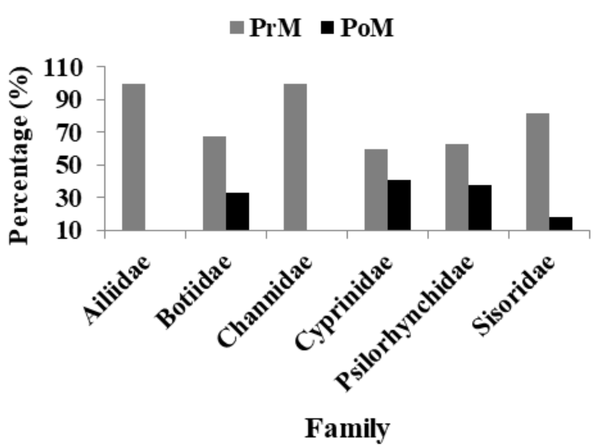

Fig. 5. Family-wise fish composition (%) in two seasons

Diversity status

The value of Shannon-Wiener's diversity (H') ranged from 0.637 to 2.568 during the study period, indicating low to medium species diversity. They are comparatively higher in pre-monsoon than post-monsoon. The variation of diversity indices is attributed to several factors such as the number of fish caught, spatial dissimilarity with different physicochemical parameters, the availability of nutrients **(Huh & Kitting, 1985)** and season **(Hossain *et al*., 2012)**. The higher value of H' found in the pre-monsoon may be related to low water levels supporting higher fish catch. The higher the catch, the higher the H' value will be, so gear selectivity also plays a vital role in this regard **(Hossain *et al.*, 2012)**. Our results are similar to those of **Ogamba *et al.* (2017)** and **Tumbahangfe *et al.* (2021)**. The higher value of 1-D is associated with higher fish diversity. We found higher fish diversity in the pre-monsoon. Margalef's index (d) is concerned with species richness. It is dependent on sampling effort such that, the greater the sampling effort, the higher the Margalef's index. The value of d in **Ogamba *et al.* (2017)** is comparatively higher than ours, and this may be associated with differences in sample size. The value of E ranges from 0 to 1, and its value closer to 1 indicates an evenly distribution. Sampling sites of S2 and S3 showed evenly distribution trends in the Dudhkoshi River.

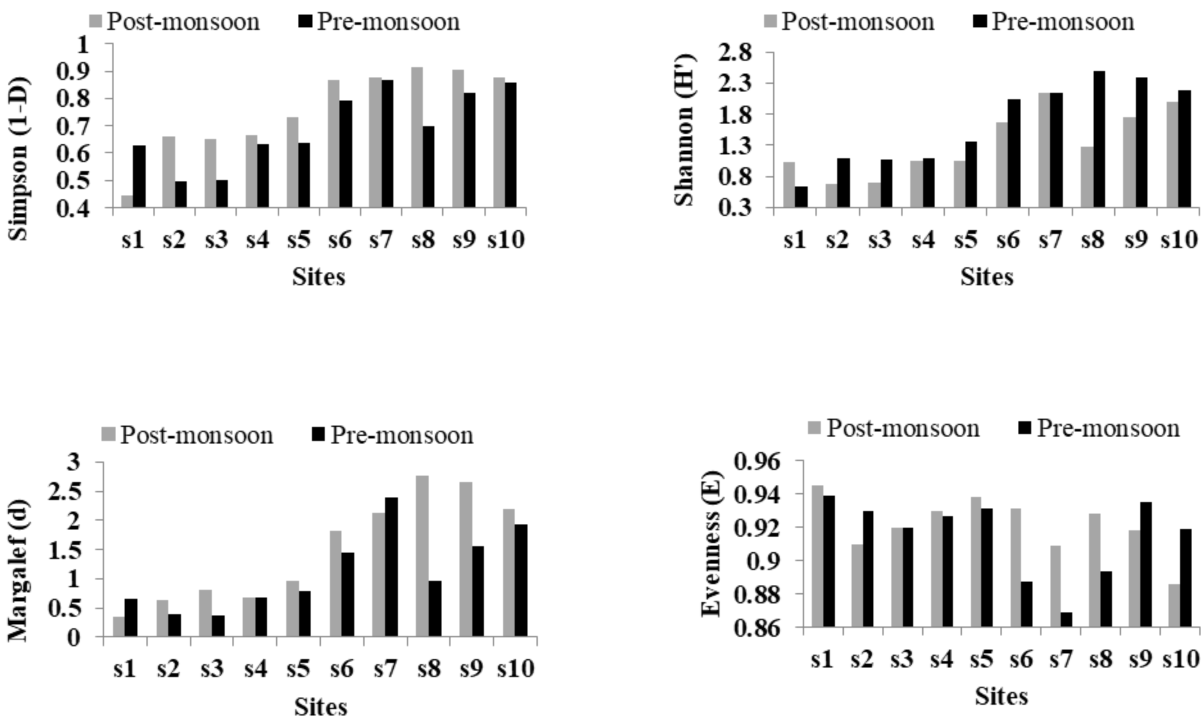

Fig. 6 Simpson, Shannon, Margalef and Evenness indices of the Dudhkoshi River in two seasons

Water quality parameters

The DO requirements for different fish species vary. For example, Salmonids need more (8-10 mg/l) DO than Cyprinids (6-8 mg/l), and DO below 5mg/l is detrimental to fish **(Svobodová *et al.*, 1993)**. In general, DO greater than 6mg/ l is in the favor of the growth of fish **(Ravindra *et al.*, 2003)**. High DO levels measured in this study indicated the good quality of water in the Dudhkoshi River. The highest DO was recorded at S1 (upper reach; 1486 masl) and the lowest was at S9 (lower reach, 333 masl); values are associated with water temperature and elevational gradients. Our results coincide with those of **Shrestha *et al.* (2009)**, **Bhatt *et al.* (2012)**, and **Tumbahangfe *et al.* (2021)**. Dissolved oxygen of snow-fed rivers is comparatively higher and is suitable for cold-water fish **(Shrestha *et al.*, 2009)**. The pH in the Dudhkoshi River was alkaline throughout the study period, with values varying from 7.3 (at S2) to 7.67 (at S4). This may be attributed to unpolluted and productive water **(Ravindra *et al*., 2003)**. Similar results have been postulated in the works of **Shrestha *et al*. (2009)** and **Bhatt *et al*. (2012)**. Our results, however, differ from those of **Tumbahangfe *et al*. (2021)** who reported acidic water. The pH of water ranging from 6.5 to 8.5 is optimum for fish **(Timmons *et al*., 2002)** and becomes detrimental (e.g. to carps) if it was greater than 10.8 and lower than 5.0 **(Svobodova *et al*., 1993)**. **Ravindra *et al*. (2003)** found higher pH in the pre-monsoon, but we found higher pH in the post-monsoon. Remarkably, water temperature plays an important role in fish diversity. The variation of water temperature in the post- and pre-monsoon is attributed to seasonal fluctuations. Variation in water temperature is also related to geographical location and altitudinal gradients of sampling sites. **Shrestha *et al*. (2009)** and **Tumbahangfe *et al*. (2021)** assessed the maximum water temperature with a value of 19^0C. The difference in water temperature by 4^0C among sites was mentioned in the study of **Tumbahangfe *et al*. (2021)**. In this context, **Bhatt *et al*. (2012)** elucidated a significant association between fish diversity (pattern) and water temperature. Because warm water and cold water species can tolerate $(22\text{-}32)^0$C and $(10\text{-}18)^0$C, respectively, **(Yildiz *et al*., 2017)**, the Dudhkoshi River was found to be suitable, especially for the latter species. In the current study, the highest conductivity (84 µs/cm) was recorded at S9 in the pre-monsoon and the lowest (41.6 µs/cm) at S2 in the post-monsoon. In this respect, our study is in accordance with neither **Shrestha *et al*. (2009)** nor **Khatri *et al*. (2020)**, though both studies were conducted on the Koshi River system. The former reported higher conductivity (250µs/cm), while the latter reported lower conductivity (56.7 µs/cm) than ours. Alkalinity in this study ranged from 16.1 (mg/l) in the post-monsoon to 19.5 (mg/l) at S10 in the pre-monsoon. In contrast to our findings, **Shahnawaz *et al*. (2010)** reported higher alkalinity (90mg/ l) and conductivity (300 µs/cm), indicating a sort of water pollution. According to **Ogamba *et al*. (2017)**, hardness below 24mg/ l is considered soft water, and value ranging from 20 to 300 (mg/l) are suitable for fishes. Therefore, the total hardness of the water of the Dudhkoshi River lies within the desirable range for fish. Salinity measures the concentration of dissolved salts (e.g. NaCl, $CaCO_3$) in water. Comparatively, its recorded value was higher in the lower reaches of the Dudhkoshi River. The total acidity of Dudhkoshi River was not significantly different among sites as well as between seasons, varying from 2.8 (mg/l) at S6 to 4 (mg/l) at both S2 and S4 in post-monsoon. On the other hand, free CO_2 recorded its highest value of 4.0 (mg/l) at S1 in post-monsoon and its minimum value of 3.0 (mg/l) at S10 in pre-monsoon. It is worthy to mention that, the sources of free CO_2 in natural waters include the decomposition of organic matters and the respiration of aquatic organisms. Eminently, its value is higher in polluted waters. With respect to the total dissolved solids (TDS) in the natural freshwater systems, their values vary from 20 to 1000mg/ l **(Boyd, 2019)**. The value of TDS in this study ranged from 27 (ppm) at S2 in post-monsoon to 56 (ppm) at S9 in pre-monsoon. Comparatively, higher TDS was recorded in pre-monsoon than post-monsoon. The redundancy analysis showed mixed effects of water quality parameters on shaping the fish assemblages in the Dudhkoshi River. For example, dissolved oxygen and water temperature play an important role in the conservation of snow trouts (e.g. *S. richardsonii, S. progastus*) that generally prefer habitats with high DO and low water temperature.

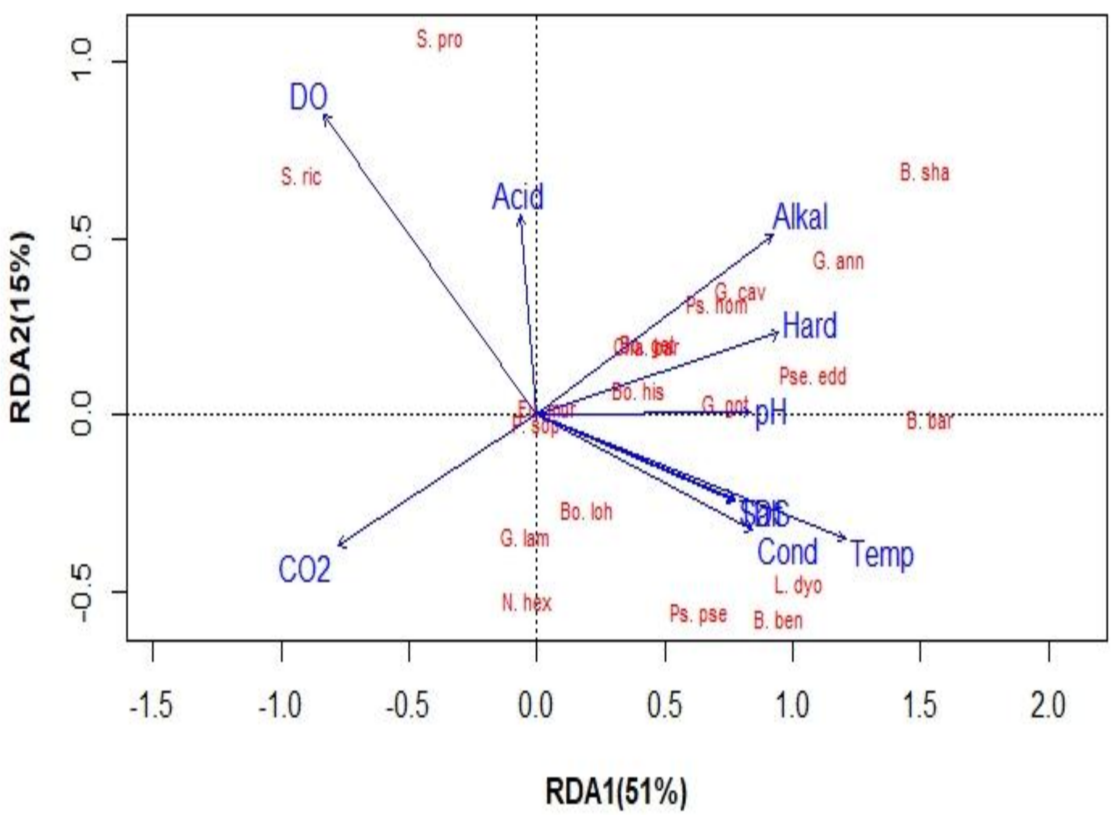

Fig. 7. RDA ordination plot showing relationship between fish species and physico-chemical parameters in Dudhkoshi River

CONCLUSION

Fish species richness of Dudhkoshi River, a snow-fed tributary of KB, was higher in pre-monsoon (19 species) than post-monsoon (14 species) during the study period. Based on the Shannon-Wiener diversity index (H'), low to medium fish diversity status was observed in two seasons. Comparatively, higher values of H' were found in pre-monsoon than in post-monsoon. Water quality parameters were found at optimum levels for fish. Seasonal variability in diversity indices and water quality parameters are attributed to resource availability as well as habitat conditions. It should be noted that the present research covered data from only two seasons. To make a generalized conclusion, future diversity study covering data from more seasons is highly recommended. The results of this study may provide baseline information that will be useful for conservationists and aquatic ecologists for the conservation and management of fish in the Dudhkoshi River.

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