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Research Article

FISH DIVERSITY OF GHODAGHODI LAKE AREA: AN IMPORTANT RAMSAR WETLAND SITE, KAILALI, FAR-WESTERN, NEPAL

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ABSTRACT

Fish diversity of Ghodaghodi Lake Area (Ghodaghodi and Nakhrod Lake) from April 2019 to August 2021, covering three seasons; Pre-monsoon (April 2019), Post-monsoon (February 2020), and Monsoon (July 2021) by using conventional and locally accessible fishing gears such as gill nets, cast nets and hook lines in 17 sampling points. A total of 2810 individuals with 39 species, 27 genera, 19 families, and 8 orders were documented. The most common fish species were *Pethia ticto, Xenentodon cancila, Notopterus notopterus, Nandus nandus,* and *Pethia conchonius*. The order Cypriniformes accounts for the majority of both Ghodaghodi (42%) and Nakhrod Lake (33%) respectively. The diversity indices were found to be higher in the pre-monsoon season in both Ghodaghodi Lake (2.58) and Nakhrod Lake (1.85), whereas lower in post-monsoon (2.36) in Ghodaghodi Lake and monsoon (1.35) in Nakhrod Lake. Similarly, species richness was highest in the monsoon season (9.33) in Ghodaghodi Lake and pre-monsoon season (3.29) in Nakhrod Lake while it was lowest in the post-monsoon season (4.19), (2.25) in Ghodaghodi and Nakhrod Lake respectively. Likewise, the evenness value for Ghodaghodi and Nakhrod Lake was found to be higher in the pre-monsoon season (0.95), (0.92) and lower in the monsoon season (0.79), (0.68) in Ghodaghodi and Nakhrod Lake, respectively.

Keywords: Community structure, diversity indices, fish composition, Ghodaghodi Lake, Nakhrod Lake

INTRODUCTION

Nepal, a landlocked country, has freshwater resources that span around 5% (743,756 ha) of the total area of the country, accounting for about 2.27% of the world's freshwater resources in the form of rivers and streams, lakes, reservoirs, ponds, swamps/wetlands, and paddy fields rich in freshwater diversity (Petr & Swar, 2002). Of 42 wetlands categorized by Ramsar (IUCN, 2004), Nepal holds 19 types of natural and 10 types of man-made inland wetlands (Siwakoti, 2007). Hydrologically, Nepal's wetlands are considered the Himalayan wetlands irrespective of size and geography because each drop of water wetlands receive has a link with the water dynamics of the Himalayas (Pokharel & Nakamura, 2012). The Mai Pokhari is the smallest, and the Lake Cluster of Pokhara Valley is the largest Ramsar site in Nepal. In total, Nepal's Ramsar sites contribute 0.025 percent (surface area) to the global target of the Ramsar sites. As of 2017, 60,561 hectares of wetlands are listed under the Ramsar convention (Ramsar, 2017). Wetlands harbor many threatened and endangered flora and fauna and provide excellent ecological habitats for internationally important winter migratory birds, aquatic fauna, and other wildlife. They harbor at least 230 indigenous fish species with 104 genera having higher economic, environmental, and academic values; whereas 6 endemic species (Rajbanshi, 2013). Further, they hold 102 species of phytoplankton; 109 species of zooplankton; 192 species of mollusks, and 117 species of amphibians (IUCN, 2004; ICIMOD & MoEST, 2007; Budha, 2012). Twenty-seven percent of nationally threatened bird species (BCN, 2011); 85 percent of endemic vertebrates (IUCN, 2004), and about 24% of government-protected plants are known recorded from wetlands.

Wetlands are often recognized as contributing to human well-being as they provide water purification, climate regulation, flood regulation, recreational opportunities, fish, water supply, fiber, and other ecological benefits (MEA, 2005). Overexploitation, water pollution, including the global phenomena of eutrophication, sedimentation and flow modification, water abstraction, degradation of habitat, and alien species invasion (Pokharel, 2010; Russel, 1993), have all contributed to a decline in freshwater biodiversity far greater than that of the most affected terrestrial.

Fish are one of the most important and diverse groups of vertebrates in the globe, with an estimated 35,400 species (Froese & Pauly, 2023). The diversity of fish species has a

specific elevational distribution, with less variety as elevation increases (Bhatt *et al.*, 2012; Swar, 2002). The Terai region has the most diversity (41%), followed by the Siwaliks (39%), the middle mountains (4%), and the high mountains (4%) (MoFSC, 2014). Despite its abundant water resources, Nepal's knowledge of fish variety is limited and unorganized, with survey efforts scattered and inconsistent, and many species still to be found or described (Leveque *et al.*, 2008). Many researchers have concentrated on inventorying only a few stretches of rivers and tributaries, as well as various lentic systems around the nation, such as lakes, ponds, pools, and irrigation canals. There is even less research on fish from Ghols in Nepal (Jha & Shrestha, 2000).

Despite its rich natural resources and diversity, Ghodaghodi Lake Area (GLA) is plagued by a slew of environmental issues such as siltation, invasive species, reduced inflow into the lake, and eutrophication (Kafle *et al.*, 2007). Above that, the high degree of human disturbance from growing human populations (Bhandari, 2009), has exacerbated these issues. Ghodaghodi Lake has not yet been largely explored by the scientific world. A little information regarding its biodiversity (Kafle, 2005), particularly on fish species and its diversity, was explored from Ghodaghodi and the associated lake (Joshi & K.C., 2017). The lack of comprehensive studies and knowledge about the country's ichthyofauna is a key roadblock to exploring fish diversity and developing conservation plans. Hence, there is an urgency to explore the fish diversity in the GLA area to avoid the possibility of the disappearance of fish species, even before they are discovered.

Materials and methods

The present study was carried out at Ghodaghodi Lake (138 ha) and Nakhrod Lake (70 ha)- two of the 24 lakes that comprise the GLA at an elevation of 205 m between 28°41'03" N, 80°56'43"E (CGLTDB, 2019). In 2003, the lake was designated a Ramsar Site of international importance (IUCN, 1998; Kafle, 2005; Lamsal *et al.*, 2014). It is the biggest natural lake system in the Terai area, with finger-like extensions covering 2563 hectares of land with 14 associated lakes and ponds. The lake system is connected to large forests along the Siwalik (Churia) hills to the north and lies between two Protected Areas- Bardia National Park and Suklaphanta National Park- serving as a vital biological corridor for wildlife movement (Lamsal *et al.*, 2014). GLA is notable for its rich biodiversity and harbors many threatened and endangered flora and fauna with; 470 plant species, 30 mammal species, 29 fish species, 32 butterfly species, and 299 resident and migratory bird species (representing 33% of the national avifauna) and 9 herpetofauna species (Kafle, 2006).

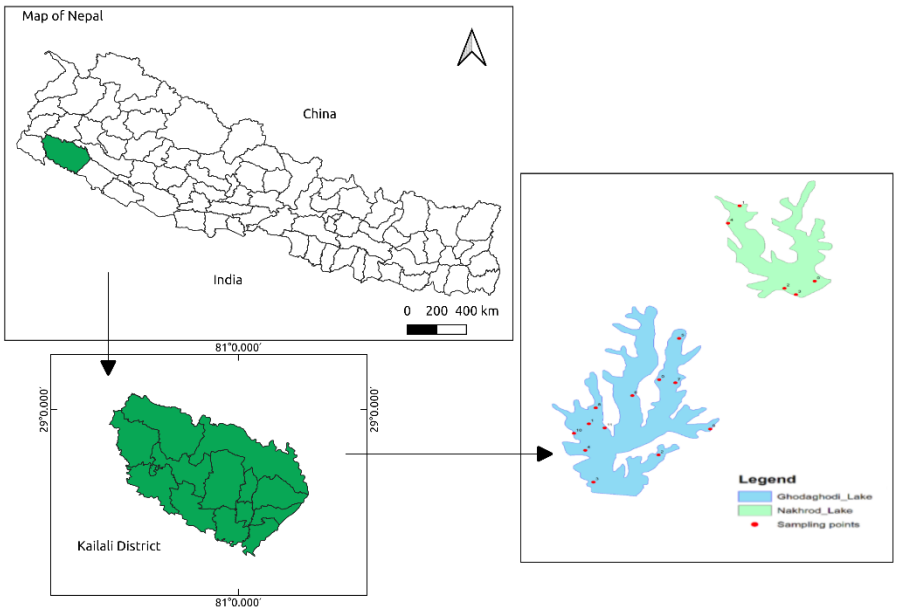

Figure 1. Sampling points at the of Ghodaghodi and Nakhrod Lake.

Fish samples were collected by local fishermen from each sampling point of Ghodaghodi and Nakhrod Lake in the Ghodaghodi Lake Area (GLA) from April 2019 to August 2021. Sampling from selected sites was taken for three seasons i.e. pre-monsoon (April 2019), post-monsoon (February 2020), and monsoon (July 2021). Altogether, 17

sampling points, i.e., Ghodaghodi (12) and Nakhrod Lakes (5) were established for the survey (Fig. 1).

Fish sampling was employed by conventional and locally accessible fishing gears such as gill nets (mesh size 0.5 to 2.5 cm) and cast nets (mesh size 5mm to 8mm), hook lines, and fish traps (Dhadiya). To increase the likelihood of capturing more fish species, sampling points were maintained within each survey time. Cast nets, hook lines, and fish traps were set up in the afternoon, whilst gill nets were set up overnight, later in the evening, and recovered in the early morning for 15 days in each survey time. Habitat and morphological features were taken in situ. The collected fish were rinsed in clean water and photographed to make it easier to identify fishes based on their body color and pattern. Fishes were categorized initially broadly with the help of local people, local fishermen, and identification followed by Shrestha (1981; 1994), Shrestha (2019), Jayaram (2013), and Jhingran and Talwar (1991).

Statistical analysis

All the data acquired from the field were accumulated, screened, and systematically arranged in Excel, and Excel was used to calculate the indices.

Species Diversity Index (H'**)**:

The species diversity was calculated by using the Shannon-Weiner diversity index Shannon and Weaver (1949). The following formula is used to calculate Shannon Diversity Index (H'):

$$S\,(\mathrm{H}') = -\sum_{i=1}^{S} p_i \ln p_i$$

Where,

$p_i = \frac{n_i}{N}$

n_i = Number of individual species

N = Total number of all individual species

Species Richness Index (d):

Species richness is the number of different species present in an ecological community. The species richness was calculated by using Margalef Species richness, Margalef's (1958). Margalef richness index is designated as d, which is calculated as;

$$Margalef\ species\ richness\ (d) = \frac{(S-1)}{\ln N}$$

Where,

S= Total number of species recorded

N= Total number of individuals of all species

Evenness index

To calculate whether species are distributed evenly across seasons and landscape elements, the evenness index was determined by the following equation (Pieleu, 1966).

E= H'/ log S

Where,

H' = Shannon-Wiener's diversity index.

S = Total number of species in the sample.

Relative Abundance of Species

It is widely used by ecologists to find the abundance of certain species in a study area. Relative abundance was calculated by using the following formula Magurran (1988).

$$RA\ (\%) = \frac{n}{N} X100$$

Where,

n= Total number of individuals of specific species

N= Total number of individuals of all species

RESULTS

Composition of fish fauna and status

The GLA provides a good habitat for a variety of freshwater fish species. Fish sampling at various points in Ghodaghodi Lake and Nakhrod Lake reported 39 different fish species belonging to 8 orders, 19 families, and 27 genera, totaling 2810 individuals (2589 of Ghodaghodi Lake and 221 of Nakhrod Lake). In comparison to the monsoon season (31 species), the pre-monsoon and post-monsoon seasons only had 14 and 12 fish species respectively.

The highest catch of 31 species was recorded in the monsoon season at Ghodaghodi Lake, while the lowest catch of 12 species was recorded in the post-monsoon season. Similarly, in Nakhrod Lake, the highest catch of 7 fish species was recorded in the pre-monsoon and monsoon season while only 5 species were recorded in the post-monsoon season. The most common fish species were *Pethia ticto, Xenentodon cancila, Notopterus notopterus, Nandus nandus,* and *Pethia conchonius* which were found in both Ghodaghodi Lake and Nakhrod Lake.

Ghodaghodi Lake recorded 38 fish species (14 species in the pre-monsoon, 12 species in the post-monsoon, and 31 species in the monsoon) belonging to 27 genera, 19 families, and 8 orders (Table 1). Out of the total species, 36 species are classified as Least Concern (LC) whereas *Wallago attu* is classified as Vulnerable (VU) (Ng *et al.*, 2019), and *Labeo pangusia* as Near Threatened (NT) (Dahanukar, 2010).

Table 1. Fish species recorded from Ghodaghodi Lake.

S.N.	Order	Family	Scientific Name	Local name
1	Cypriniformes	Cyprinidae	*Pethia ticto*	Sidhre
			Pethia conchonius	Sidhre,
			Puntius sophore	Lalpetiya sedhri
			Amblyphryngodon mola	Mada
			Chagunius chagunio	Patharchetti
			Labeo gonius	Kursa
			Labeo rohita	Rohu
			Labeo pangusia	Kalanch
			Labeo angra	Thed
			Labeo boga	Boga
			Aspidoparia sps	Tilori
		Danionidae	*Rasbora daniconius*	Dira
			Opsarius bendelisis	Jhojhi
			Esomus danrica	Darai
		Cobitidae	*Lepidocephalichthys guntea*	Goira
			Lepidocephalichthys goalparensis	Gherra
2	Anabantiformes	Channidae	*Channa gachua*	Bichhali Charangi
			Channa maurilius	Chrocha
			Channa stewartii	Chitaina
			Channa striata	Sauri
			Channa punctata	Kabra Charanga
		Osphronemidae	*Trichogaster fasciata*	Khesti
		Anabantidae	*Anabas testudineus*	Bhansariya
		Nandidae	*Nandus nandus*	Dhorri
		Badidae	*Badis badis*	Pasari
3	Siluriformes	Heteropneustidae	*Heteropneustes fossilis*	Singi
		Amblycipitidae	*Amblyceps mangois*	Pichiya
		Sisoridae	*Glyptothorax trilineatus*	Latuwa therwa
		Siluridae	*Wallago attu*	Parhni
		Bagridae	*Mystus tengara*	Tengra
		Clariidae	*Clarias batrachus*	Mungri
4	Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Bam
			Macrognathus aral	Bamli
			Macrognathus pancalus	Kath gainchi
5	Perciformes	Ambassidae	*Parambassis baculis*	Chandrabijuwa, Chanari
6	Cyprinodontiformes	Aplocheilidae	*Aplocheilus panchax*	Uperteri
7	Beloniformes	Belonidae	*Xenentodon cancila*	Kauwa
8	Osteoglossiformes	Notopteridae	*Notopterus notopterus*	Patara

Similarly, 12 fish species belonging to 11 genera, 9 families, and 6 orders have been recorded from the Nakhrod Lake (7 from pre-monsoon, 5 from post-monsoon, and 7 from monsoon) seasons (Table 2). 11 of the 12 fish species were classified as Least Concern (LC), IUCN red list 2019 while *Anabas cobojius* was classified as Data Deficient (DD) (Chaudhry & Pal, 2010).

Table 2. Classification of fish species recorded from Nakhrod Lake.

S.N.	Order	Family	Scientific Name	Local name
1	Cypriniformes	Cyprinidae	*Pethia ticto*	Sidhre
			Pethia conchonius	Sidhre
			Labeo boga	Boga
		Cobitidae	*Lepidocephalichthys guntea*	Goira
2	Anabantiformes	Osphronemidae	*Trichogaster fasciata*	Khesti
		Anabantidae	*Anabas cobojius*	Samhar
		Nandidae	*Nandus nandus*	Dhorri
3	Siluriformes	Heteropneustidae	*Heteropneustes fossilis*	Singi
4	Synbranchiformes	Mastacembelidae	*Macrognathus aral*	Bamli
			Macrognathus pancalus	Kath gainchi
5	Beloniformes	Belonidae	*Xenentodon cancila*	Kauwa
6	Osteoglossiformes	Notopteridae	*Notopterus notopterus*	Patara

Fish community structure

The majority of the fish species collected from the Ghodaghodi and Nakhrod Lake fall under the order Cypriniformes. Among the fish species recorded in Ghodaghodi Lake, 42% comprising to order Cypriniformes (16 species), 24% to Anabantiformes (9 species), 16% to Siluriformes (6 species), 8% to Synbranchiformes (3 species) and remaining orders Perciformes (1 species), Beloniformes (1 species), Cyprinodontiformes (1 species) and Osteoglossiformes order (1 species) comprises 3% (Fig. 2). *Badis badis, Pethia ticto, Trichogaster fasciata, Nandus nandus,* and *Notopterus notopterus* were the most abundant fish species in the Ghodaghodi Lake while *Glyptothorax trilineatus, Mastacembelus armatus, Channa stewartii, Labeo rohita, Labeo gonius and Lepidocephalichthys guntea* were the least abundant.

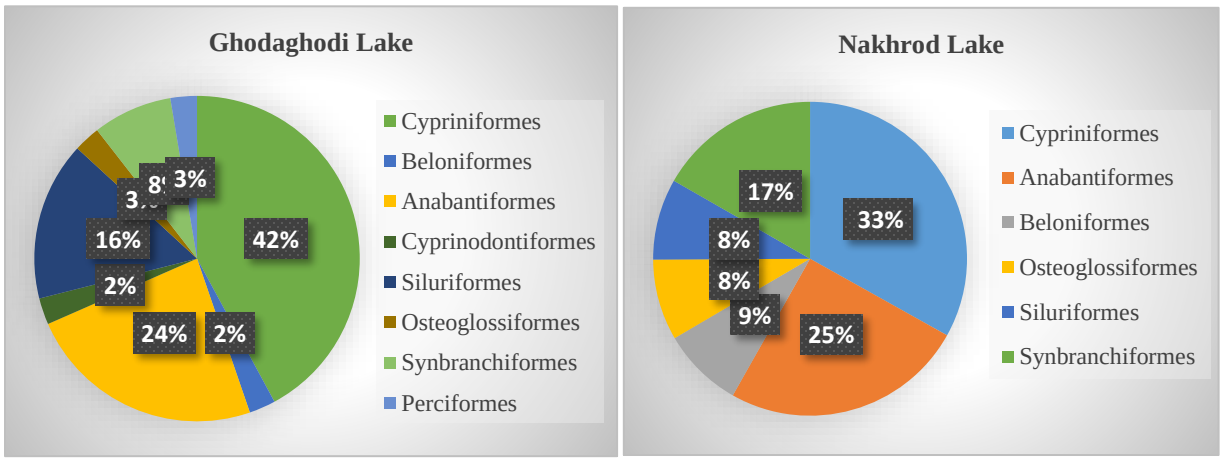

Figure 2. Order-wise distribution of fish species from Ghodaghodi Lake (Left) and Nakhrod Lake (Right).

Similarly, in the Nakhrod Lake, out of the captured fish species, 33% comprising to order Cypriniformes (4 species), 25% to Anabantiformes (3 species), 17% to Synbranchiformes (2 species), and the remaining orders Beloniformes (1 species), Siluriformes (1 species) and Osteoglossiformes (1 species) comprise 8% (Fig. 2). *Trichogaster fasciata, Nandus nandus,* and *Pethia conchonius* were the most abundant fish species while *Anabas cobojius, Lepidocephalichthys guntea,* and *Macrognatus aral* were the least abundant fish species.

Frequency and abundance

The monsoon season at Ghodaghodi Lake had the highest numbers with 31 species and 1643 individuals while the

post-monsoon season had the least with 12 species and 424 individuals. Regarding individual fish species, *Notopterus notopterus* was the most frequently recorded fish species in pre-monsoon (90.91%) followed by *Labeo pangusia,* and *Puntius sophore* (72.73%) while *Xenentodon cancila* (27.27%) was the least frequently recorded fish species followed by *Labeo angra* (45.45%). Meanwhile, in the post-monsoon season, *Notopterus notopterus* (81.82%) was the most frequently recorded fish species followed by *Clarias batrachus* (72.73%) and *Labeo boga* (36.36%) was the least frequently recorded fish species followed by *Pethia conchonius* (45.45%). Furthermore, *Nandus nandus* (90.91%) was the most frequent species followed by *Parambassis baculis* (81.82%); and *Badis badis, Wallago attu,* and *Glyptothorax trilineatus* (9.09%) were the least frequently recorded species followed by *Anabas testudineus, Channa gachua* (18.18%) during monsoon season in the Ghodaghodi Lake.

Similarly, in the Nakhrod Lake, the highest numbers of species and individuals were recorded during the pre-monsoon and monsoon seasons (7 species each) with 66 and 95 individuals respectively, while the lowest number was recorded during the post-monsoon season (5 species with 60 individuals). Regarding the individual fish species of Nakhrod Lake, Puntius *ticto* and *Labeo boga* (100%) were the most frequently recorded fish species, and *Notopterus notopterus,* and *Nandus nandus* (66.67%) were the least frequently recorded fish species in pre-monsoon season. Meanwhile, in post-monsoon season, *Pethia ticto* (100%) was the most frequently recorded fish species, and *Xenentodon cancila* (33.33%) was the least frequent. And in the monsoon season, *Trichogaster fasciatus,* and *Nandus nandus* were recorded mostly with 66.67% while *Puntius ticto, Lepidocephalichthys guntea,* and *Anabas cobojius* with 33.33% were the least frequently recorded fish species.

In regard to relative abundance, *Notopterus notopterus* has the highest value of relative abundance in pre-monsoon (13.98%) and post-monsoon season (18.87%) in Ghodaghodi Lake whereas in monsoon season *Badis badis* (21.42%) has the highest relative abundance value. These species were followed by *Puntius ticto* (10.54%) and *Labeo angra* (9.20%) in the pre-monsoon season, *Clarias batrachus* (11.79%) and *Pethia ticto* (10.85%) in post-monsoon and *Trichogaster fasciata* (14.30%) and *Pethia ticto* (13.39%) in monsoon season. Likewise, the lowest value of relative abundance recorded in Ghodaghodi Lake in the pre-monsoon season was *Esomus danrica* (3.64%), *Labeo boga* (1.42%) in post-monsoon and *Mastacembelus armatus*, and *Glyptothorax trilineatus* in monsoon season with 0.06%. These species were followed by *Labeo pangusia* (4.79%) in pre-monsoon, *Nandus nandus* (4.01%) in post-monsoon and *Wallago attu, Channa stewartii, Labeo rohita (0.12%)* in monsoon season.

In the Nakhrod Lake, *Nandus nandus* has the highest relative abundance value in the pre-monsoon (24.24%) and post-monsoon (26.67%) seasons whereas *Trichogaster fasciata* (53.68%) has the highest value in monsoon season. These species were followed by *Macrognathus pancalus* (19.70%) in pre-monsoon, *Notopterus notopterus* with 25% in post-monsoon and *Nandus nandus* and *Heteropneustes fossilis* (16.84%) in monsoon season. Likewise, the *Pethia ticto* has the lowest value of relative abundance in pre-monsoon (6.06%) and post-monsoon (6.67%) seasons and *Lepidocephalichthys guntea* in monsoon season with 2.11%. These species were followed by *Labeo boga* (7.58%) in pre-monsoon, *Pethia conchonius* (20%) in post-monsoon, and *Macrognathus aral* (3.16%) in monsoon season.

Diversity indices

Shannon-Wiener diversity index (H'), Margalef richness (d), and Evenness (E) values were calculated from Ghodaghodi and Nakhrod Lake in three distinct seasons pre-monsoon, post-monsoon, and monsoon (Table 3). According to the computation, pre-monsoon had the most species vary in terms of fish species, with the Shannon-Wiener index value of H' = 2.58, followed by monsoon with H' =2.53 and post-monsoon with H' = 2.36. Similarly, in Nakhrod Lake, pre-monsoon had the highest species vary in terms of fish species, with the Shannon–Wiener index value of H' = 1.85, followed by post-monsoon with H' = 1.53 and monsoon with H' =1.35.

In regard to Margalef richness (d), the value of pre-monsoon, post-monsoon, and monsoon of Ghodaghodi Lake was found to be 4.78, 4.19, and 9.33 respectively. The monsoon season has the highest species richness, followed by the pre-monsoon and post-monsoon seasons. Similarly, the Margalef richness (d) value for the pre-monsoon, post-monsoon, and monsoon seasons in Nakhrod Lake was found to be 3.29, 2.25, and 3.03, respectively, with the value being greater in the pre-monsoon season, followed by the monsoon and post-monsoon seasons.

Likewise, the Evenness index (E) of Ghodaghodi Lake was found to be 0.95, 0.90, and 0.79 for the pre-monsoon, post-monsoon, and monsoon respectively where the evenness value was found to be high in pre-monsoon season and low in monsoon season. Similarly, the Evenness index (E) value of Nakhrod Lake was found to be 0.92, 0.86, and 0.68 respectively in the pre-monsoon, post-monsoon, and monsoon seasons, with the pre-monsoon season being higher and the monsoon season being lower.

Table 3. Diversity Index of Ghodaghodi and Nakhrod Lake.

S.N	Diversity Index	Ghodaghodi Lake			Nakhrod Lake		
		Pre-monsoon	Post-monsoon	Monsoon	Pre-monsoon	Post-monsoon	Monsoon
1	Shannon Weiner Index (H)	2.58	2.36	2.53	1.85	1.53	1.35
2	Margalef Richness (d)	4.78	4.19	9.33	3.29	2.25	3.03
3	Evenness Index (E)	0.95	0.90	0.79	0.92	0.86	0.68

DISCUSSION

The present study was carried out across three seasons from April 2019 to August 2021. During the research period, a total of 2810 individual fish were recorded from the Ghodaghodi and Nakhrod Lakes, representing 39 species belonging to 8 Orders, 19 Families, and 27 Genera. The accounted fish species from the study are greater than the report by IUCN in 1998 (27 species), DNPWC and WWF Nepal in 2003 (29 species), and Kafle et. al in 2007 (25 species) from Ghodaghodi Lake Complex. Lamsal *et al.* (2014) recorded 19 fish species (*Colisa fasciatus, Clarias batrachus, Channa striatus, Channa punctatus, Lepidocephalus guntea, Channa gachua, Puntius gelius, Puntius conchonius, Puntius chola, Puntius sophore, Rasbora daniconius, Heteropneustes* sp., *Labeo boga, Mastacembelus pancalus, Xenentodon cancila, Mastacembelus armatus, Mystus vittatus, Notopterus notopterus*) and Joshi and KC (2017) recorded 13 species (*Labeo gonius, Puntius sophore, Amblyphryngodon microlepis, Amblyphryngodon mola, Esomus danricus, Mystus tengara, Xenentodon cancila, Macrognathus pancalus, Pseudambassis baculis, Nandus nandus, Badis badis, Channa punctatus, Channa striatus*) from Ghodaghodi Lake Areas.

The diversity reported in this study will be important baseline data for any future assessments; nevertheless, the majority of past research has been focused on Ghodaghodi Lake, whereas the adjoining lake of Ghodaghodi Lake Area (GLA), has remained off the radar despite having high potential for fish diversity. The most abundant and commonly distributed fish species in Ghodaghodi Lake and Nakhrod Lake were *Pethia ticto, Xenentodon cancila, Notopterus notopterus, Nandus nandus, Pethia conchonius*. Among the recorded fish species, 37 species are found under the Least Concern (LC) category of the IUCN red list while 3 fish species *Wallago attu, Labeo pangusia* and *Anabas cobojius* were classified as Vulnerable (VU), Near Threatened (NT) and Data Deficient (DD) respectively. The categorization of these species aids in drawing the ichthyofauna conservation action plan for the GLA. In Ghodaghodi and Nakhrod Lake, the monsoon season had the highest number of species and individuals while the post-monsoon season had the lowest. The findings were consistent with earlier research by Acharjee and Barat (2014) and Prasad *et al.* (2020).

The Cypriniformes was the most dominant Order both in Ghodaghodi (42%) and Nakhrod Lake (33%). Edds (1986), Pokheral (1999), Shrestha (2001), Shrestha (2008), Shrestha (2013), Shrestha (2016), and Subba *et al.* (2017) also found the similar results from different water bodies of Nepal. Adding to this, a fish diversity survey by Johal and Rawaal (2005) in different sections of Ghaggar, Yamuna, and Ganga, Vishwakarma (2013) and Bose *et al.* (2013) at Jamner and Tawa River, tributary of Narmada River, Vijayalaxmi *et al.* (2010) in Mullameri River, trivial waterway of river Bheema in Gulbarga district of Karnataka, Rathore and Dutta (2015) in Ujh River, tributary of Ravi in Jammu have found the order Cypriniformes as the most dominant order as compared to other. In regard to the relative abundance, *Badis badis* (13.60%) in the Ghodaghodi Lake and *Trichogaster fasciatus* (23.1%) in the Nakhrod Lake have a high relative abundance value while *Glyptothorax trilineatus, Mastacembelus armatus* (0.04%) in Ghodaghodi Lake and *Lepidocephalichthys guntea* (0.9%) in Nakhrod Lake has a low value. A high value of relative abundance signifies the fish species are recorded commonly in the studied lake whereas low abundance is likely a consequence of natural mortality, particularly among recruits (Smith & Reay, 1991).

In the current study, the Shannon-Wiener diversity index values were not very high. The highest Shannon diversity index value of Ghodaghodi and Nakhrod Lakes was found in the pre-monsoon season (2.58) and (1.85), respectively, which may have resulted from less depth of water, minimal rainfall, and long night periods that allowed fishermen to set up gill-nets efficiently, whereas the lowest value of Ghodaghodi and Nakhrod Lake was found in the post-monsoon season (2.36) and monsoon season (1.35), respectively. Atmospheric air currents and environmental circumstances are the major reasons for variances in biodiversity indices (Keskin & Unsal, 1998). Furthermore, the structure and composition of wetland fish populations are influenced by habitat diversity (Golterman, 1975). The majority of fish in small, stable wetlands are likely habitat specialists that have acquired morphological and behavioral adaptations to exploit certain habitat types (Magnuson *et al.*, 1998).

The higher number and diversity of fish species in both Ghodaghodi (14 and 31species, respectively) and Nakhrod Lake (7 species each) occurred in pre-monsoon and monsoon seasons, respectively, which might be attributed to the existence of sufficient water, ample food resources, and fewer anthropogenic activities. On the contrary, in the post-monsoon season, low water flow and increased anthropogenic activities could be the reason for a lower number of fish species (12 and 5 fish species) as well as

their abundance and diversity in Ghodaghodi and Nakhrod Lake.

Regarding Margalef richness (d), the maximum value was recorded in Ghodaghodi and Nakhrod Lake during the monsoon season (9.33) and pre-monsoon season (3.29) whereas the minimum value in Ghodaghodi and Nakhrod Lake was recorded in post-monsoon season (4.19) and (2.25), respectively. The highest Margalef richness value indicates a more diverse community in terms of species and numbers while the lowest value indicates a less diverse fish community. The highest evenness index value of Ghodaghodi and Nakhrod Lake was recorded in the pre-monsoon season (0.95 and 0.92, respectively) while the lowest value was recorded in the monsoon season (0.78 and 0.68, respectively). A high value of evenness indicates that fish species were uniformly distributed, whereas a low value indicates not uniformly distributed in the study areas, which could be due to differences in water temperature (Gurung, 2012), depth, transparency, turbidity, conductivity, pH, and DO (Joshi & K.C., 2017).

The on-field observation and interaction with key stakeholders and local people highlighted the root cause for water supply shortage at the lake which is deforestation and watershed encroachment within the Betini forest, a major water source for GLA. Above that, the water from Ghodaghodi and Nakhrod Lake is extensively used for irrigation, a practice that gets much more severe during the dry season. Water extraction for irrigation purposes might have negative impacts on the aquatic ecosystem and migratory birds of GLA. DFO (2000) also reported a similar finding in lacer Mining - Yukon Territory where the input of sediment into water has been recognized as a potential threat to the well-being of aquatic organisms.

CONCLUSIONS

The GLA exhibits a good ichthyofaunal diversity. A total of 39 fish species belonging to 8 orders, 19 families and 27 genera were collected over three different seasons from Ghodaghodi and Nakhrod Lake. *Puntius ticto, Xenentodon cancila, Notopterus notopterus, Nandus nandus,* and *Pethia conchonius* were the abundant and frequently observed fish species at the study sites. These species were found commonly in all sampling points in each sampling period. Out of the reported 39 fish species, 36 were classified as Least Concern (LC) while 3 species *Wallago attu, Labeo pangusia,* and *Anabas cobojius* are classified as Vulnerable (VU), Near Threatened (NT), and Data Deficient (DD), respectively. Cypriniformes and Cyprinidae were the dominant order and family of Ghodaghodi and Nakhrod Lake. Similarly, the most common fish species are *Notopterus notopterus* and *Pethia ticto.* The pre-monsoon season had the highest species diversity whereas, the monsoon and pre-monsoon seasons have a high value of Margalef richness (d) indicating a more diverse fish community. The highest value of the Evenness index in the pre-monsoon season indicates the fish species are uniformly distributed in both lakes. This might help to develop plans and strategies to conserve these species and more importantly, understand the ichthyofauna genetic resources of the threatened species in the GLA. Although the threats of exotic fish species in GLA are relatively low, progressive commercial farming in the adjoining areas is a major concern for the future. Conservation challenges can be addressed through community-based conservation groups with comparable interests, experience, and ability to gather, assess, and communicate information to the concerned agencies in order to formulate and drive native fish conservation policy.

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AUTHOR CONTRIBUTIONS

Laba KC conceptualized the research, finalized the research methodologies, collected data and analyzed them and wrote the manuscript. Dayaram Chaudhary supported the research team and facilitated the fish sampling and data collection process and helped to identify the local names of captured fish species. Prakash Sigdel supported during the data management and analysis. Santoshi Shrestha discussed the data, reviewed the manuscript, and provided constructive suggestions. All the authors revised and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interests.

ETHICAL STATEMENT

The whole research process from conceptualization, data collection, analysis to report preparation has followed research ethics. The methodology followed during the data collection and the data analyzed are original and have been presented in the manuscript without any manipulation.

DATA AVAILABILITY STATEMENT

All the data relevant to the study are presented in the manuscript and can be provided upon request from the corresponding author.

REFERENCES

Acharjee, M.L., & Barat, S. (2014). Seasonal dynamics of ichthyodiversity in a hill stream of the Darjeeling

Himalaya, West Bengal, India. *Journal of Threatened Taxa*, *6*(14), 6635-6648.

MEA. (2005). *Ecosystems and human well-being: wetlands and water*. Millennium Ecosystem Assessment, World Resources Institute.

BCN. (2011). Annual report 2010/2011, Bird Conservation Nepal, Kathmandu.

Bhandari, B. (2009). Wise use of wetlands in Nepal. *Banko Janakari, 19*(3)*,* 10-17.

Bhatt, J.P., Manish, K., & Pandit, M.K. (2012). Elevational gradients in fish diversity in the Himalaya: water discharge is the key driver of distribution patterns. *PlOS ONE, 7*(9), e46237.

Bose, A.K., Jha, B.C., Suresh, V.R., Das, A.K., & Parasar, A. (2013). Fishes of the middle stretch of river Tawa , Madhya Pradesh, India. *Journal of Chemical, Biological and Physical Science, 3*(1), 706–716.

Budha, P.B. (2012). *Review of freshwater and terrestrial Molluscan studies in Nepal: Existing problems and future research priorities*. Presented at the Entomological Review Workshop organized by Nepal Agriculture Research Council, Khumaltar, 4-6 March 2012.

Chaudhry, S., & Pal, M. (2010). *Anabas cobojius*. The IUCN Red List of Threatened Species 2010: e.T166593A6243318. https://dx.doi.org/10.2305/IUCN.UK.2010-4.RLTS.T166593A6243318.en.

CGLTDB. (2019). *Comprehensive Master Plan of Ghodaghodi Lake Area.* Comprehensive Ghodaghodi Lake and Tourism, Ghodaghodi Municipality, Sukhad, Kailali, Nepal.

Dahanukar, N. (2010). *Labeo pangusia* (errata version published in 2020). The IUCN Red List of Threatened Species 2010: e.T166497A174786155.

DFO. (2000). *Effects of sediment on fish and their habitat*. DFO Pacific Region Habitat Status Report 2000/01.

DNPWC, & WWF Nepal. (2003). *Factsheet on Ghodaghodi Lake*.

Edds, D.R. (1986). Fishes of the Kali Gandaki/Narayani River, Nepal. *Journal of the Nepal Natural History Museum*, *10*, 13-22.

Froese, R., & Pauly, D. (2023). *FishBase*. World Wide Web electronic publication. Retrieved October 15, 2023 from www.fishbase.se.

Golterman, H.L. (1975). *Physiological limnology*. Elsevier Scientific Publishing, Amsterdam, Netherlands.

GoN/MoFSC. (2014). *Nepal biodiversity strategy and action plan 2014-2020*. Government of Nepal, Ministry of Forests and Soil Conservation, Kathmandu, Nepal.

Gurung, T.B. (2012). Native fish conservation in Nepal: Challenges and opportunities. *Nepalese Journal of Biosciences, 2*, 71-79.

IUCN. (2004). *A review of the status and threats to wetlands in Nepal*. International Union for Conservation of Nature Nepal, Kathmandu, Nepal.

IUCN. (1998). *The Ghodaghodi Tal Conservation Area*: A Community Centred Management Plan, International Union for Conservation of Nature Nepal, Kathmandu, Nepal.

ICIMOD, & MoEST. (2007). *Nepal biodiversity resource book: Protected areas, Ramsar sites and World Heritage Sites*. International Centre for Integrated Mountain Development (ICIMOD) and Ministry of Environment, Science and Technology (MoEST), Kathmandu in cooperation with UNEP Regional Office for Asia and the Pacific, Bangkok, Thailand.

Jayaram, K.C. (2013). *The freshwater fishes of the Indian region*. Narendra Publishing House. Delhi.

Jha, D.K., & Shrestha, M.K. (2000). *Fish biodiversity of the wetland at IAAS, Rampur, Chitwan*. Phase-I and Phase-II. *IAAS* Research Reports*,* (1995-2000).

Jhingran, A.G., & Talwar, P.K. (1991). *Inland fishes of India and adjacent countries, Vol 1 & 2*. Oxford & IBH publishing Co. Pvt. Ltd, New Delhi.

Johal, M.S., & Rawal, Y.K. (2005). Key to the management of the Western Himalayan hill streams in relation to fish species richness and diversity. *Hydrobiologia, 532*(1), 225–232. https://doi.org/10.1007/s10750-004-9523-3.

Joshi, D., & K.C., B. (2017). Fish diversity of Ghodaghodi Lake in Kailali, far-west Nepal. *Journal of Institute of Science and Technology, 22*(1), 120–126. https://doi.org/10.3126/jist.v22i1.17762.

Kafle, G. (2005). *Avifaunal survey and vegetation analysis at Ghodaghodi Lake of Nepal*. A Report Submitted to Oriental Bird Club (OBC), United Kingdom.

Kafle, G. (2006). *Status and conservation of Ghodaghodi lake, Kailali, Nepal*, Wetland Friends of Nepal.

Kafle, G., Balla, M.K., Baral, H.S., & Thapa, I. (2007). Ghodaghodi Lake area: resources, opportunities and conservation. *Danphe, 16*(3), 1-6.

Keskin, C., & Unsal, N. (1998). The fish fauna of Gökçeada Island, NE Aegean Sea, Tlirkey. *Italian Journal of Zoology, 65*, 299–302.

Lamsal, P., Pant, K.P., Kumar, L., & Atreya, K. (2014). Diversity, uses, and threats in the Ghodaghodi Lake complex, a Ramsar site in western lowland Nepal. *International Scholarly Research Notices,* 680102. https://doi.org/10.1155/2014/680102.

Lévêque, C., Oberdorff, T., Paugy, D., Stiassny M.L.J., & Tedesco, P.A. (2008). Global diversity of fish (Pisces) in freshwater. *Hydrobilogia, 595*(1), 545–567.

Magnuson, J.J., Tonn, W.M., Banerjee, A., Toivonen, J., Sanchez, O., & Rask, M. (1998). Isolation vs. extinction in the assembly of fishes in small northern lakes. *Ecology, 79*(8), 2941–2956.

Magurran, A.E. (1988). *Ecological diversity and its measurement*. Princeton University Press, Princeton.

Margalef, R. (1958). Temporal succession and spatial heterogeneity in phytoplankton. *In*: Buzzati-Traverso (Ed,), *Perspectives in marine biology*, University of California Press, Berkeley, pp. 323-347.

MoFSC. (2014). National Biodiversity Strategy and Action Plan, 2014. Ministry of Forest and Soil Conservation, Government of Nepal, Kathmandu, Nepal.

Ng, H.H., de Alwis Goonatilake, S., Fernado, M., & Kotagama, O. (2019). *Wallago attu* (errata version published in 2020). The IUCN Red List of Threatened Species.

Petr, T., & Swar, D.B. (Eds.). (2002). *Cold water fisheries in the trans-Himalayan countries* (No. 431). Food & Agriculture Organisation.

Pielou, E.C. (1966). The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology, 13*, 131-144.

Pokharel, S., & Nakamura, M. (2010). *Integrated lake basin management for the sustainable conservation of Himalayan lakes of Nepal*. In: ILBM for the Sustainability of Himalayan Lakes. Proceedings of National Seminar, National Lake Conservation Development Committee/Ministry of Tourism and Civil Aviation/Government of Nepal. Kathmandu.

Pokharel, K.K. (2010). Fish diversity of Seti Gandaki River and Vijaypur Stream and need for their conservation. *A Journal of Zoology and Environment, 1(*1), 40-53.

Pokharel, K.K. (1999). *Fish bio-diversity of lakes in Pokhara Valley and need of their conservation*. In Proceeding of IIIrd National Conference on Science and Technology.

Prasad, A., Shrestha, A., Limbu, J.H., & Swar, D. (2020). Spatial and temporal variation of fish assemblage structure in Seti Gandaki River, Tanahu, Nepal. *Journal of Resource Science and Technology, 10*(2), 93-104. https://doi.org/ 10.33736/bjrst.2048.2020.

Rajbhandari, K.G. (2013). *Biodiversity and distribution of freshwater fishes of central Nepal Himalayan region*. Kathmandu, Nepal, Nepal Fisheries Society.

Ramsar Convention. (2017a). *Nepal: Ramsar*. Retrieved January 20, 2018 from https://www.ramsar.org/wetland/Nepal.

Rathore, V., & Dutta, S.P.S. (2015). Fish fauna of River Ujh, an important tributary of the River Ravi, District Kathua, Jammu. *Environmental Conservation Journal, 16*(1), 81–86.

Russel, S. (1993). Using wetlands widely. In *Conservation with people Worldwide Fund for Nature*. Gland Switzerland.

Siwakoti, M. (2007). Mikania weed: a challenge for conservationists. *Our Nature, 5*(1), 70–74.

Shannon, C.E., & Wiener, W. (1949). *The mathematical theory of communication*. Urbana, University of Illinois Press.

Shrestha, T.K. (2019). *Ichthyology of Nepal: A study of fishes of the Himalayan waters*. Vedams Books International, India.

Shrestha, J. (1981). *Fishes of Nepal*. Curriculum Development Centre, Tribhuvan University.

Shrestha, J. (1994). Fish species in different water bodies of Nepal and their need for conservation. *Ecoprint, 1*, 7-19.

Shrestha, J. (2001). Taxonomic revision of fishes of Nepal. *Environment and Agriculture: Biodiversity, Agriculture and Pollution in South Asia, p171-180, Ecological Society (ECOS), Kathmandu, Nepal*.

Shrestha, J. (2013). *Biodiversity of fish appeared in (biological diversity and conservation)*. Nepal Academy of Science and Technology (NAST), Kathmandu, Nepal.

Shrestha, J.N. (2016). Fish diversity of Triyuga River, Udayapur district, Nepal. *Our Nature*, *14*(1), 124-134.

Shrestha, T.K. (2008). *Ichthyology of Nepal. A study of fishes of the Himalayan water*. Himalayan Ecosphere. Kathmandu, Nepal.

Smith, C., & Reay, P. (1991). Cannibalism in teleost fish. *Reviews in Fish Biology and Fisheries*, *1*(1), 41-64.

Subba, B.R., Pokharel, N., & Pandey, M.R. (2017). Ichthyofaunal diversity of Morang district, Nepal. *Our Nature, 15*(1-2), 55-67.

Swar, D.B. (2002). The status of cold-water fish and fisheries in Nepal and prospects of their utilization for poverty reduction. In Petr, T., & Swar, D.B. (Eds.), *Cold water fisheries in the trans-Himalayan countries*. Fisheries Technical Papers No. 431, FAO.

Vijaylaxmi, C., Rajshekhar, M., & Vijaykumar, K. (2010). Freshwater fishes distribution and diversity status of Mullameri River, a minor tributary of Bheema River of Gulbarga District, Karnataka. *International Journal of Systems Biology, 2*(2), 1-9.

Vyas, V., & Vishwakarma, K.S. (2013). Study on ichthyofaunal diversity of Jammer River : A tributary of Narmada River. *International Journal of Theoretical & Aquatic Sciences, 5*(2), 84-89.