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Review Article

Freshwater biodiversity in western Nepal: A review

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Abstract

Western Nepal is known for its rich freshwater resources that support diverse flora and fauna. Freshwater ecosystems of western Nepal provide multitudes of ecosystem goods, services (irrigation, hydroelectricity, drinking water) to humans, and provide breeding and feeding grounds for many wetland-dependent flora and fauna. But these wetlands are under tremendous pressure mainly due to anthropogenic activities. In this review, we provide a brief overview of the freshwater biodiversity, distributions of wetlands and their status in western Nepal. From this review, we found that western Nepal is rich in freshwater resources and supports diverse flora and fauna. The biologically significant Karnali River is the home of globally endangered species, South Asian river dolphin. We also discuss the conservation history of wetlands, identify the gaps, and further suggest priority hotspots for the formulation of future conservation strategies for these ecosystems.

Keywords: Biodiversity; Conservation; Lakes; Threats; Western Nepal

1 | Introduction

Freshwater wetlands are amongst the most productive ecosystems providing multitudes of ecosystem goods and services to human beings (Dudgeon et al. 2006). For example, wetlands regulate the water cycle and have a unique role in maintaining the food webs (Mitsch et al. 2015). With this realization the Convention on Biological Diversity 1992 has given a high priority to wetlands conservation as the services they provide directly contribute to the livelihoods of the people (Bell 1972).

Globally, over 126,000 described species of fish, amphibians, reptiles, birds, mammals, molluscs, insects, and plants inhabit freshwater systems, and they are concentrated in less than 1% of the world's surface area (Baillie et al. 2008). Despite their immense significance, freshwater ecosystems are among the most vulnerable ecosystems on the planet (Geist 2011). These systems face serious threats due to increased human population, economic growth and global environmental changes (Vörösmarty et al. 2010). Major anthropogenic stressors in freshwater ecosystem include the construction of dams, pollution, invasive species, and overharvesting (Junk et al. 2013). These threats on freshwater ecosystems not only diminish the quality and quantity of services including food security and nutrition, which are essential to human populations (Lamsal et al. 2015) but also affect their biodiversity (Allen et al. 2010). Declines in biodiversity are far greater in freshwater than terrestrial ecosystems and marine realms (Vörösmarty et al. 2010).

Nepal, with its rich water resources distributed over the landscape, has contributed to create ecologically valued wetlands. The country's freshwater habitats cover about 745,000 hectares (5% of the total area) that comprises rivers, lakes, ponds, wetlands, reservoirs, and irrigated rice fields (Sharma 2008). The total drainage area by rivers of Nepal is estimated to be about 194,471 km^2; 76% of the area lies within Nepal (WECS 2003; DoFD 2011; ICIMOD 2014) (Table 1). About 74% of the area in the country is drained by the four major rivers, viz., Koshi, Gandaki, Karnali, and Mahakali (Fig. 1). Among them, Karnali River provides the largest drainage area (28.46%) in comparison to other rivers in Nepal.

Freshwater ecosystems provide a wide range of habitats and harbor a large proportion of plants and animals (Dudgeon et al. 2006; Collen et al. 2014). Both wetlands and terrestrial habitat of western highlands support 56 species of mammals, 288 species of birds, 11 species of herpetofauna, and three species of fish; likewise, western mid-hills support 55 mammals, 388 birds, 80 herpetofauna and 17 fish, similarly western Terai and Siwalik support 64 mammals, 469 birds, 48 herpetofauna and 77 fish

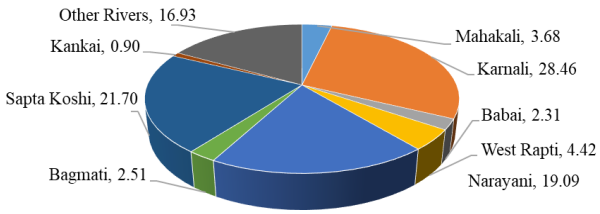

Figure 1. Drainage area (%) covered by the river in Nepal (Source: DoFD 2011).

(Bhuju et al. 2007; Kunwar et al. 2016). However, due to a lack of proper assessment of the distribution of freshwater diversity, formulation of conservation and management strategies are constrained in western Nepal. Conservation plans and programs have given due attention mainly to terrestrial biodiversity. There are seven Protected Areas - Five National Parks (Banke, Bardia, Suklaphanta, Rara and Shey Phoksundo) and two Conservation Areas (Api-Nampa and Krishnasar Conservation Area) in western Nepal. The Department of National Parks and Wildlife Conservation (DNPWC), Ministry of Forest and Environment, Government of Nepal prepares the action and management plans for the management of National Parks and Conservation Areas (DNPWC 2020a). The majority of these action plans and management plans focus on terrestrial ecosystems, large mammals, and birds, while freshwater biotic communities hardly draw the attention of the planners. To effectively implement conservation programs for freshwater biodiversity, it is important to understand the value and distribution of diversity across water bodies, including the identification of species and their distribution inside and outside of the protected areas (Rodrigues et al. 2004). The freshwater of Karnali and Mahakali river systems have been utilized for economic purposes such as irrigation, hydroelectricity, and river-based ecotourism, which at the same time are critical habitats for freshwater biodiversity. The Karnali and Mahakali river basins are the most biologically diverse ecosystems for freshwater fish, amphibians, reptiles, birds, and mammals with high endemism (Dubois 1973; Dubois & Matsui 1983; Terashima 1984). This rich biodiversity could be explained by its large altitudinal gradients (100 m – above 7132 m) linked to the creation of a variety of climatic conditions (Dobremez 1976; Grytnes 2003). Also, there are unique habitats throughout the region, such as productive flooded grassland and forests, oxbow lakes, clear and white-water streams, which promote higher biological diversity and endemism. In the Himalayan region, a large proportion of the landscape has been transformed over a long period of time by human activities such as cultivation, grazing, and extraction of natural resources (Ives 2004; Byers 2005). These human-induced activities threaten its long-term viability, the integrity of its biodiversity, and the ecosystem services that human populations have been deriving.

Studies elsewhere have shown that certain freshwater species could be used as proxy/indicators of habitat quality (Abell et al. 2011; Bogardi et al. 2020); however, the research on this aspect in Nepal is scanty. Although increasing efforts to estimate the richness of freshwater vertebrate species at a global scale has been witnessed (Collen et al. 2014), the comprehensive information on overall aquatic biodiversity crucial for the management and conservation interventions at smaller geographical scales (i.e., watershed, streams, rivulets) is limited in Nepal and especially in the Karnali and Mahakali river basins is largely missing (Fig. 2). These river basins offer a striking example of the ecological and socio-economic complexities that challenge conservation of lotic ecosystems in western Nepal. However, a paucity of systematically documented information about freshwater species and their distribution could hinder the development and implementation of conservation and management plans for Western Nepal. This review discusses i) the distribution and physical characteristics of freshwater ecosystems (lakes and rivers) of western Nepal, ii) ecosystem services and biodiversity of wetlands of western Nepal, iii) threats to freshwater ecosystems and conservation history of wetlands exploration.

2 | Extent and distribution of freshwater ecosystem in Western Nepal

In Nepal, rivers occupy the largest proportion based on the total area covered (53%) followed by the irrigated paddy fields (Fig. 3). Available literature suggests that there are more than 6000 rivers, 3252 glaciers, 2323 glacial lakes, 5358 tectonic and ox-

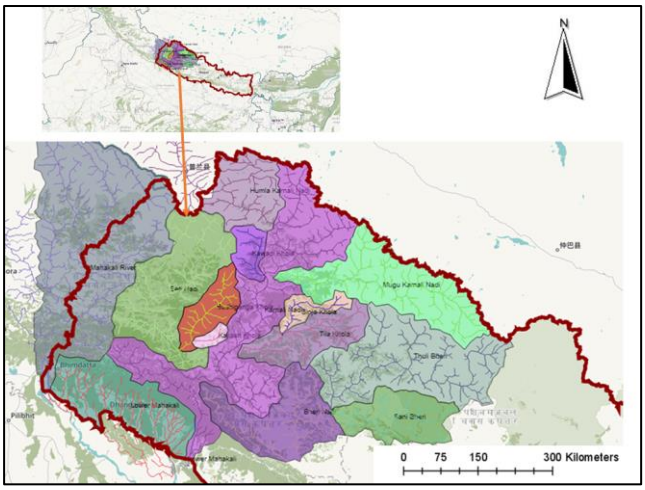

Figure 2. Map of Karnali and Mahakali river basins (Source: ICIMOD 2014)

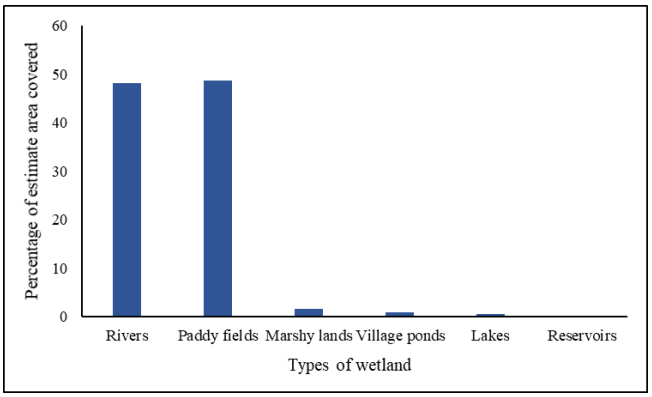

Figure 3. Estimated area covered by wetlands in Nepal (Source: DoFD 2011)

Table 1. Estimated runoff from the rivers of Nepal (ICIMOD 2014)

S. N.	River	Length (km)	Drainage area (km^2)		Estimated Runoff (m^3/sec)	
			Total	Nepal	From all Basins	From Nepal
1	Mahakali	223	15,260	5,410	698	247
2	Karnali	507	44,000	41,890	1441	1371
3	Babai	190	3,400	3400	103	103
4	West Rapti	257	6,500	6,500	224	224
5	Narayani	332	34,960	28090	1753	1409
6	Bagmati	163	3,700	3,700	178	178
7	Sapta Koshi	513	60,400	31940	1658	878
8	Kankai	108	1330	1330	68	68
9	Other rivers		24921	24921	1001	1001
Total			**194,471**	**147,181**	**7125**	**5479**

bow lakes in Nepal (NLCDC 2019). Among them, 1271 lakes (23.72%) were recorded from the Sudurpaschim and Karnali provinces of western Nepal (Bhuju et al. 2010). The map-based inventory showed that 75 districts out of 77 districts contain lakes. Sixteen districts have over 100 lakes in each (NLCDC 2020).

More than 6,000 rivers, streams, rivulets, brooks, and channels (*nalas)* of Nepal have a linear length of approximately 45,000 km. Among them, 66% of the total rivers have been originated from Nepal while others have been originated from the Tibetan Plateau. The total drainage area occupied by rivers and watersheds is 191,000 km^2, 70% of which lies in Nepal. Nepal has 24 rivers which have more than 500 km in length. Likewise, more than 100 rivers are approximately 160 km long, and more than 1000 rivers are 11 km long on average (Table 1)

Nepal's permanent lakes are broadly categorized into the glacial, tectonic and ox-bow lakes (IUCN Nepal 2004; Lacoul & Freedman 2005). Glacial lakes formed from the glacial activities are located in the high mountain regions. Tectonic lakes were formed due to tectonic activities of the earth and are largely distributed across mid-hills, whereas ox-bow lakes are found mostly in the lowland areas of the southern plain in the Terai region (Lacoul & Freedman 2005). These ox-bow lakes are mainly formed due to the impoundment of rivers (IUCN Nepal 2004). Overall, the surface area and the number of glacial lakes is the lowest (total 241) in the Gandaki river basin compared to the Koshi, and Karnali river basins (Khadka et al. 2018).

2.1 | Lakes of western Nepal

The Karnali river basin has 645 glacial lakes that cover around 33.50 $km^{2,}$ and the Mahakali river basin has 18 glacial lakes that cover around 0.33 km^2 surface area (Khadka et al. 2018) (Table 2). Highlands of Sudhurpaschim and Karnali province have 917 lakes (74.49%) followed by mid-hills 115 (9.34%) and Terai and Siwalik 199 (16.16%). Humla district has the highest number of lakes (n=381) while Kalikot (n=1) and Baitadi (n=1) have the least number of lakes (Bhuju et al. 2010) (Table 2).

Table 2. Number of lakes recorded as ecological zones and districts from Sudurpaschim and Karnali Province of Western Nepal (NLCDC 2020).

Area	Ecological zones	District	Total lakes	Famous lakes	Remarks
Sudurpaschim Province	Highland	Bajhang	25	Surma Sarovar	Holy lake
				Tima Daha	
	Highland	Bajura	57	Chhede Daha	
				Buddhinanda	
				Kailash Taal	Holy lake
				Rakshyas	
				Masta Daha	
	Highland	Darchula	19	Brahama Daha	Holy lake
				Pasa Daha	
	Midhill	Achham	13	Khaptad	Holy lake
				Ramaroshan	Holy lake
				Kalidaha	
				Batulee	
				Barha Banda	Holy lake
	Midhill	Dadeldhura	3	Ali Taal (Dadeldhura)	Holy lake
				Bodapanthi Taal	
				Nayal Tal	
	Midhill	Baitadi	1	Baite Tal	
	Midhill	Doti	19	Khaptad Lake	Holy lake
				Ali Taal (Doti)	Holy lake
				Chatiwan Lake	
	Terai-Siwalik	Kailali	114	Jokhar Lake	
				Ghodaghodi Lake	Ramsar Site
				Muchheli River (Godawariseti)	
	Terai-Siwalik	Kanchenpur	85	Jhilmila Taal	Holy lake
				Bedkot Taal	Holy lake
				Mudka Taal	
				Rani Taal	
				Sundeu Taal	
				Kamalpokhari	
Karnali Province	Highland	Dolpa	210	Phoksundo Lake	Ramsar site
				Pritha Daha	
				Jagadulla	
				Matae Taal	
				Chhamkuni Taal	
	Highland	Humla	381	Selima Chho	
	Highland	Jumla	99	Jumla Lake	
				Giridaha	
				Thakurjyu Daha	
				Sanka Daha	
				Pani Pokhari	
				Bistajyu Daha	
	Highland	Mugu	125	Rara Lake	Largest lake, Ramsar site
				Dudh Taal	
	Midhill	Dailekh	7	Kunya Lake	
				Khal Taal	
				Bada Pokhari	
				Tal Pokhari	
	Midhill	Salyan	5	Kubinde Daha	Holy lake
				Kachhuwa Daha	
	Midhill	Surkhet	22	Bulbule Lake	
	Midhill	Western Rukum	70	Syarpu Taal	Holy lake
				Kamal Taal	
				Chhipri Daha	
				Thuli Daha	
	Midhill	Jajarkot	16	Kali Raha	
	Highland	Kalikot	1	Pan Daha	

Many lakes in western Nepal (Sudurpaschim and Karnali provinces), such as Ramaroshan lake complex, Gididaha, Jhilmila, Bedkot, Sati-Karnali etc. have cultural and biological significant values (Chalaune et al. 2020). The largest (Rara Lake) and the beautiful Shey-

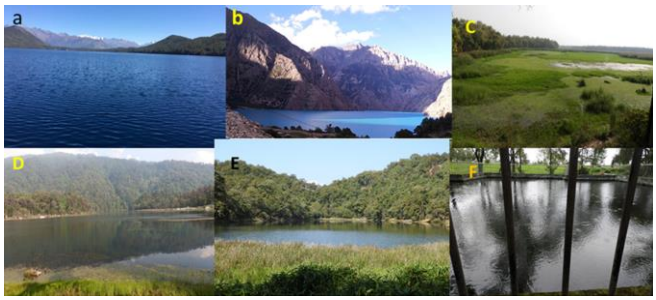

Figure 4. Some famous lakes of Western Nepal: a- Rara Lake (the largest lake of Nepal and Ramsar site, Photo credit: K. P. Kandel), b- Phoksundo Lake (the Ramsar site, Photo credit: K. C. Ghimire), c- Rani Lake (largest lake of Sukla Phanta National Park, Photo credit: J. N. Adhikari), d- Ramaroshan Lake complex (Jingale Lake, Photo credit: J. N. Adhikari), e- Jhilmila Lake (The holy lake of Kanchanpur, Photo credit: J. N. Adhikari), f- Bulbule Lake (Famous lake of Surkhet, Photo credit: J. N. Adhikari).

Phoksundo Lake of Nepal also lie in the western region which are also listed as Ramsar sites (MoFE 2018; NLCDC 2020) (Fig. 4).

2.2 | Rivers of western Nepal

The western region of Nepal is drained by two major river basins Karnali (550 km) and Mahakali (223 km) (ICIMOD 2014, Table 3). The Karnali River is also called Saptakarnali or Geruwa in Nepal and Ghaghara in India, formed by seven major tributaries and other associated rivers; Bheri and Seti are the major tributaries. The Karnali drains western Nepal, andthe upper Bheri river drains Dolpo valley. Likewise, Mahakali or Kali River is the union of major rivers named Surma, Chamelia, and Lipu river and runs along the Nepal-India border on the west and joins Karnali in India, where this river is called Ghaghara (ICIMOD 2014) (Fig. 2).

3 | Ecosystem services

Carbon and nutrient cycling in streams and lakes are largely controlled by aquatic invertebrate consumers that largely feed on organic matter, graze on periphyton, or consume dead organic matter (Atkinson et al. 2017). Therefore, the ecosystem's functioning is highly dependent on human dimensions and other environmental characteristics. This review discusses the major goods and services provided by freshwater resources.

3.1 | Water services

Wetlands provide an incessant flow of ecosystem services and directly support millions of people to sustain their lives (Dudgeon et al. 2006; Sharma et al. 2015; Olalde et al. 2019). In Nepal, a total of 22 wetlands dependent communities such as Bantar (Sardar), Barhamans, Bote, Danuwar, Darae, Gongi, Jhagat, Kewat, Khanwas (Rhanjhi), Khuna, Kumal, Kusahar (Kusaha), Manjhi, Dusadh, Mallaha, Mukhiya (Bihin), Musahar, Pode, Sahani, Satar, Sunaha, and Tharu depend on lakes and wetlands for their survival (NLCDC 2020). Ecosystem goods (provisioning services) provided by the aquatic ecosystem/wetlands are mainly: water for drinking, irrigation, generation of hydroelectricity, fisheries, non-timber forest products, and recreation. Other services include flood control, groundwater recharge, carbon sequestration, nutrient removal, and biodiversity maintenance (Naiman & Turner 2000).

Hydroelectricity

In Nepal, the perennial nature of rivers estimated up to 170 billion m^3 annual runoff flows from steep gradients and rugged topography. The estimated feasible hydropower potential is estimated 45610 Mega Watt (MW), which is equivalent to 50% of the total theoretical potential (83290 MW) (Bhatt 2017; DoED 2020).

The production of hydroelectricity is low in western Nepal. The government of Nepal purposed the Pancheshowar Multipurpose Project in the Mahakali River. Pancheshowar Multipurpose Project has been identified as a huge storage scheme to be developed to maximize peak power benefit in the order of 6,720 MW (Pancheshowar High Dam- 6480 MW and Rupali Gad Re-Regulating Dam- 240 MW) with an annual average energy production of 12,333-Gigawatt hour (GWh) (DoED 2020). The government of Nepal has proposed to construct more than 46 hydropower plants of more than 1 MW from Western Nepal that can produce 6923.98 MW electricity (DoED 2020) (Table 4).

Irrigation

Irrigation is an important ecosystem service of the wetland. Nepal has a total of 2,642,000 ha cultivated land (18% of its land area), of which only two-thirds (1,766,000 ha) of land is potentially irrigable (Poudel & Sharma 2012). The report of WECS (2011) showed that 42% of the total cultivated area has irrigation of some sort (only in the rainy season), whereas 17% of the cultivated area has year-round irrigation.

The famous Rani Jamara Kulariya Irrigation Scheme from Karnali River, located in Kailali District in the Far Western Terai Region of Nepal, provided more efficient, reliable, and flexible water services to farmers and households. About 25,000 farming households comprising close to 160,000 people are benefited from this project. This irrigation scheme irrigates more than 14,300 ha of farmland (The World Bank 2019). Another national pride irrigation project is the Sikta irrigation project which will irrigate about 43,000 ha of land of Banke district. The construction of the 45 km western canal of the project has been

Table 3. Number and surface area (km^2) of glacial lakes in Karnali and Mahakali river basins of western Nepal in 2017 (Khadka et al. 2018).

SN	River basin	Sub basin	Numbers	Total surface area (km^2)
1	Karnali	Humla Karnali	237	12.63
		Mugu Karnali	174	5.65
		Kawari	21	0.95
		Karnali sub part	4	0.3
		Tila	57	3.76
		Bheri	129	9.09
		West Seti	23	1.12
	Total		645	33.5
2	Mahakali		18	0.33

Table 4. Proposed Hydropower project in Western Nepal (NPC 2020)

S.N.	Project	Capacity (MW)	River	Latitude N		Longitude E		District
1	Middle Budhiganga HEP	5	Budhi Ganga	29° 18' 36"	29° 20' 29"	81° 17' 30"	81° 19' 15"	Achham, Bajura
2	Betan Karnali HEP	439	Karnali	28° 50' 57"	28° 56' 04"	81° 11' 43"	81° 24' 42"	Achham, Kailali, Bijaura, Surkhet
3	Mugu Karnali Storage HEP	1902	Karnali	29° 23' 43"	29° 41' 22"	81° 39' 14"	81° 57' 13"	Bajura, Humla, Mugu
4	Lower Kalanga Gad HEP	8	Kalanga Gad	29° 28' 50"	29° 30' 40"	80° 52' 30"	80° 54' 26"	Bajhang
5	Seti Nadi-3 HEP	65	Seti Khola	29° 30' 00"	29° 36' 00"	81° 07' 51"	81° 15' 00"	Bajhang
6	Upper Sunigad HEP	8.42	Suni Gad	29° 40' 05"	29° 41' 35"	81° 12' 15"	81° 14' 00"	Bajhang
7	Bajhang Upper Seti HEP	140	Seti	29° 44' 50"	29° 50' 30"	81° 15' 00"	81° 18' 45"	Bajhang
8	Chainpur Seti HEP	210	Seti Khola	29° 36' 20"	29° 44' 40"	81° 16' 00"	81° 20' 15"	Bajhang
9	Humla Karnali 1 HEP	235	Humla Karnali	29° 41' 30"	29° 47' 00"	81° 56' 30"	82° 02' 00"	Humla
10	Humla Karnali 2 HEP	335	Humla Karnali	29° 46' 00"	29° 52' 47"	81° 51' 00"	81° 56' 29"	Humla
11	Upper Chuwa Khola HEP	103	Chuwa, Lurupya	29° 55' 50"	29° 59' 00"	81o 56' 05"	81° 58' 50"	Humla
12	Chuwa Khola HEP	70	Chuwa	29° 56' 30"	29° 57' 45"	81° 51' 30"	81° 56' 05"	Humla
13	Gidi Khola HEP	9	Gidi	29° 11' 12"	29° 13' 55"	82° 09' 11"	82° 10' 55"	Jumla
14	Upper Gidi Khola HEP	3.3	Gidi	29° 09' 30"	29° 10' 59"	82° 08' 30"	82° 10' 20"	Jumla
15	Mugu Khola HEP	57	Mugu	29° 35' 27"	29° 38' 45"	82° 25' 55"	82° 31' 15"	Mugu
16	Namlan Khola HEP	260	Namlan	29° 33' 35"	29° 35' 27"	82° 26' 10"	82° 37' 00"	Mugu
17	Upper Mugu Karnali HEP	306	Mugu Karnali	29° 33' 00"	29° 35' 50"	82° 13' 45"	82° 24' 00"	Mugu
18	Mugu Karnali HEP	159.62	Mugu Karnali	29° 34' 37"	29° 37' 39"	81° 51' 22"	82° 06' 46"	Mugu
19	Upper Bheri PROR HEP	281	Thuli Bheri	28° 58' 00"	29° 02' 32"	82° 35' 00"	82° 52' 52"	Dolpa
20	Tarap Khola HEP	50	Tarap	28° 53' 45"	28° 57' 00"	83° 01' 55"	83° 04' 25"	Dolpa
21	Jagdulla HEP	106	Bheri	29° 03' 16"	29° 07' 53"	82o 33' 43"	82° 38' 00"	Dolpa, Jajarkot
22	Jagdulla A HEP	82.3	Bheri	28° 59' 00"	29° 03' 16"	82° 33' 00"	82° 36' 00"	Dolpa, Jajarkot
23	Api Naugad HEP	4.84	Naugad	29° 48' 40"	29° 49' 35"	80° 40' 00"	80° 41' 03"	Darchula
24	Naugad HEP	9.5	Naugad	29° 46' 11"	29° 48' 30"	80° 39' 00"	80° 40' 00"	Darchula
25	Lower Nwagad Small HPP	2	Nwa Gad	29° 44' 44"	29° 45' 04"	80° 47' 43"	80° 48' 31"	Darchula
26	Aayu Chhatigad HEP	13.942	Chatti Gad	29° 48' 50"	29° 49' 35"	80° 52' 37"	80o 53' 10"	Darchula
27	Middle Chameliya HEP	35	Chameliya Khola	29° 42' 55"	29° 45' 00"	80° 42' 38"	80° 46' 45"	Darchula, Baitadi
28	Lower Chameliya HEP	20	Chameliya	29° 40' 00"	29° 41' 40"	80° 34' 41"	80° 37' 59"	Darchula, Baitadi
29	Super Lohare Khola -A HEP	1.3	Lohare Khola	28° 57' 11"	28° 57' 49"	81° 47' 09"	81° 48' 09"	Dailekh
30	Super Lohare Khola HEP	1.53	Lohare	28° 55' 01"	28° 55' 45"	81° 48' 32"	81° 49' 06"	Dailekh
31	Upper Rukum Gad HEP	4.7	Rukum Gad (Lukum, Thaban, Kuchiba	28° 34' 19"	28° 35' 24"	82° 37' 50"	82° 38' 49"	Rukum
32	Sani Bheri HEP	44.7	Sani Bheri	28° 38' 50"	28° 40' 43"	82° 39' 23"	82° 42' 30"	Rukum
33	Sisne Khola HEP	4.78	Sisne Khola	28° 41' 02"	28° 42' 08"	82° 41' 23"	82° 42' 30"	Rukum
34	Syarpu HEP	3.3	Dharne	28° 40' 10"	28° 41' 25"	82° 28' 24"	82° 29' 25"	Rukum
35	Sani Bheri-2 HEP	23.31	Sani Bheri	28° 37' 30"	28° 38' 52"	82° 37' 02"	82° 38' 50"	Rukum
36	Sani Bheri 3 HEP	49.59	Sani Bheri	28° 37' 15"	28° 40' 15"	82° 29' 48"	82° 35' 15"	Rukum
37	Lower Rukumgad HEP	5.25	Rukum gad	28$_o$ 36' 58"	28° 37' 52"	82° 37' 30"	82° 38' 25"	Rukum
38	Nalsyau Gad Storage HEP	417	Nalsyau	28° 47' 21"	28° 58' 00"	82° 14' 00"	82° 20' 00"	Jajarkot
39	Bheri-2 HEP	256	Bheri	28° 46' 45"	28° 52' 00"	82° 18' 41"	82° 26' 40"	Jajarkot
40	Taksu Khola HEP	7.1	Taksu	28° 52' 23"	28° 53' 50"	82° 26' 15"	82° 27' 20"	Jajarkot
41	Bheri-1 HEP	270	Bheri	28° 52' 00"	28° 57' 32"	82° 26' 40"	82° 31' 28"	Jajarkot, Rukum
42	Bheri 4 HEP	300	Bheri	28° 33' 30"	28° 43' 15"	81° 59' 30"	82° 15' 00"	Jajarkot, Rukum, Salyan, Surkhet
43	Madi Storage HEP	156	Madi	28° 13' 30"	28° 20' 55"	82° 33' 40"	82° 39' 15"	Rolpa
44	Phukot Karnali HEP	426	Karnali	29° 09' 32"	29° 19' 03"	81° 35' 28"	81° 45' 00"	Kalikot
45	Upper Ruru Banchu Khola HEP	24.5	Rurubanchu Khola	29° 05' 00"	29° 06' 30"	81° 48' 13"	81° 51' 35"	Kalikot
46	Thuligad Khola Small HEP	9	Thuli Gad	28° 55' 50"	28° 58' 47"	80° 47' 41"	80° 51' 22"	Doti, Kailali
	Total	**6923.982**						

completed, while 53 km eastern canal construction is underway (Investopaper 2020). Besides these, several farmers widely used small irrigation canals (called *Kulo*) from nearby small rivers and streams and managed themselves (Poudel & Sharma 2012).

3.2 | Biodiversity

The freshwater biodiversity of Nepal is quite diverse and supports a high diversity of wild flora and fauna and other hydrofauna (Lamsal et al. 2014). It is also a habitat of several globally threatened species of mammals, birds, reptiles, amphibians, fish, and other macro-invertebrates. This rich diversity is possibly explained by the wide elevation distribution of various aquatic ecosystems such as rivers, streams, high altitude lakes, and ponds from hot and humid to cold alpine climates.

Birds

Among 886 bird species in Nepal (DNPWC & BCN 2018), 200 species (22 percent) are known to be dependent on wetlands (Inskipp et al. 2017). The BirdLife International (2019) listed 38 species which are globally threatened species that are wetland-dependent, including pink-headed duck (*Rhodonessa caryophyllacea*), greater adjutant (*Leptoptilos dubius*), lesser adjutant (*Leptoptilos javanicus*), sarus crane (*Grus antigone*), black-necked crane (*Grus nigricollis*), lesser florican (*Sypheotides indicus*), Baikal teal (*Anos formosa*), swamp francolin (*Francolinus gularis*), Baer's pochard (*Aythya baeri*), spot-billed pelican (*Pelecanus philippensis*), Indian skimmer (*Rynchops albicollis*), and Pallas's fish-eagle (*Haliaeetus leucoryphus*).

Western Nepal also supports the high richness of avifauna (Baral & Inskipp 2009). Shukla Phanta National Park provides habitat for more than 450 bird species; among them, 23 species are globally threatened, and 74 species are nationally threatened (Poudyal & Chaudhary 2019). The park also has several streams and lakes. Rani Lake is the largest lake in the Park and supports many globally threatened bird species such as black stork (*Ciconia nigra*), black bittern (*Dupetor flavicollis*), yellow bittern (*Ixobrychus sinensis*), and striated grassbird (*Megalurus palustris*). Eight species of wetland birds were recorded from Ramaroshan Lake, including globally vulnerable Asian Woolly-neck and five migratory birds (Poudel & Adhikari 2020). Similarly, 241 species of birds, including 49 wetland bird species, were recorded from Rara National Park. Rara Lake supports the feeding and breeding grounds for migratory and residential wetland-dependent birds (DNPWC 2019). The Pokshundo Lake supports more than 46 species of wetland birds (DNPWC 2020c). Acharya and Ghimirey (2015) recorded 114 species of birds in the area between Limi Valley, including notable wetland birds-common tern (*Sterna hirundo*) and ibisbill (*Ibidorhyncha struthersii*). The biodiversity study of four lakes (Sati Karnali, Jhilmila, Rani, and Ramaroshan) reported 41 wetland birds from Sati Karnali, 15 species from Jhilmila, 48 species from Rani Lake, and 15 species from Ramaroshan Lake (Khatiwada et al. 2019a) (Table 5). Similarly, Karnali and Mahakali rivers also provide a suitable habitat for various water birds (Manel et al. 2000).

Table 5. Checklist of globally threatened wetland birds recorded by various authors from Western Nepal (Here, EN-Endangered, VU-Vulnerable, NT-Near Threatened)

SN	Common Name	Scientific Name	IUCN Status
1	Pink-headed duck	*Rhodonessa caryophyllacea* (Latham, 1790)	CR
2	Baer's pochard	*Aythya baeri* (Radde, 1863)	CR
3	Pallas's fish-eagle	*Haliaeetus leucoryphus* (Pallas, 1771)	EN
4	Lesser florican	*Sypheotides indicus* (Miller, 1782)	EN
5	Indian skimmer	*Rynchops albicollis* (Swainson, 1838)	EN
6	Lesser adjutant	*Leptoptilos javanicus* (Horsfield, 1821)	VU
7	Common pochard	*Aythya ferina* (Linnaeus, 1758)	VU
8	Asian woollyneck	*Ciconia episcopus* (Boddaert, 1783)	NT
9	Sarus crane	*Antigone antigone* (Linnaeus, 1758)	VU
10	Lesser fish-eagle	*Icthyophaga humilis* (Müller & Schlegel, 1841)	NT
11	River lapwing	*Vanellus duvaucelii* (Lesson, 1826)	NT
12	Painted stork	*Mycteria leucocephala* (Pennant, 1769)	NT
13	Oriental darter	*Anhinga melanogaster* Pennant, 1769	NT
14	Spot-billed pelican	*Pelecanus philippensis* Gmelin, 1789	NT
15	Northern lapwing	*Vanellus vanellus* (Linnaeus, 1758)	NT
16	Black-necked crane	*Grus nigricollis* Przevalski, 1876	NT

Mammals

A total of 212 species of mammals have been recorded from Nepal (Amin et al. 2018). Among them, only 27 mammalian faunae are under the protection of the NPWC Act 1973 (DNPWC 2020b). The western low-land of Nepal supports the key globally threatened mammals, and most of them are wetland-dependent. These include tiger (*Panthera tigris*), pygmy hog (*Sus salvanius*); hispid hare (*Caprolagus hispidus*), South Asian river dolphin (*Platanista gangetica*), greater one-horned rhinoceros (*Rhinoceros unicornis*), elephant *(Elephas maximus*) and barasingha (*Cervus duvaucelii*) (Henshaw 1994; Pradhan et al. 2008; Jnawali et al. 2011; Aryal et al. 2012; Flagstad et al. 2012).

Karnali River is a major habitat for globally endangered South Asian river dolphin in Nepal. Shrestha (1989) reported 12 individuals of dolphin from Patharboji, Lalmati, and the area upstream of Golaghat up to Kachali of Karnali River. Later, Smith (1994) recorded only seven individuals of dolphin, whereas Timilsina et al. (2003) reported only four individuals from Karnali River. Based on the data, there is decreasing trend of population of the Dolphin in the Karnali River ($y = -1.2238x + 16.288$, $R^2 = 0.4383$) (Fig. 5). Dolphins prefer slow water current with adequate amounts of deep pool habitats in Karnali River (Paudel et al. 2015a). Paudel et al. (2015a) estimated 12 dolphins in the two southern sections of the Karnali River. Shah et al. (2020a) reported 43 dolphins from Mohana River and its tributaries but not recorded from Karnali River.

River geometry and infrastructure development (constructed dam at the India/Nepal border of Karnali River) caused the greatest threats to dolphins due to changes in river flow characteristics (Paudel et al. 2015b). Anthropogenic activities in the river such as the presence of fishing boats, stone quarries, and motorboats

used for local transportation, construction of irrigation canals, extraction of construction materials such as sands, gravels, stones from the river are the other major threats to Dolphins (Malla 2009; Khanal et al. 2016). Furthermore, changing the natural course of river systems (e.g., Geruwa to western flow in Karnali) fluctuate the water depth of the river. The deep pools are critical habitats that greatly affect the occurrence and distribution of dolphins (WWF 2006; Khanal et al. 2016).

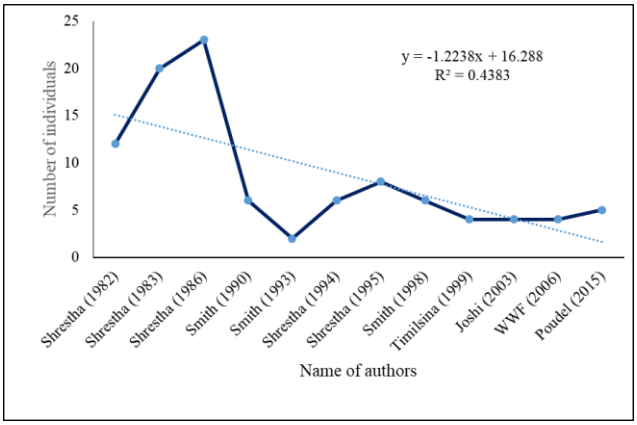

Figure 5. Population trend of the dolphin. (Source: WWF 2006 and Paudel et al. 2015b).

Fish

Nepal is very rich in native fish diversity. There are more than 186 indigenous and 11 introduced fish taxa belonging to 93 Genera from 31 Families and 11 Orders (Shrestha 1990, Shrestha 1999; Ng & Edds 2005; Edds 2007; Edds & Ng 2007; Shrestha & Edds 2012). Literature show that about 121 species of fishes are found in the Karnali River and its tributaries. Similarly, Rara Lake provides a habitat for three endemic fishes named *Schizothorax macrophthalmus*, *S. nepalensis*, and *S. raraensis* (Terashima 1984; Acharya & Paudel 2020). Lamsal et al. (2014) reported 19 fish species from Ghodaghodi Lake, Kailali district, whereas DoF (2017) reported more than 29 species from the same area. These different statistics of fish diversity could be due to the difference in data collection techniques/sampling time used in these studies. Most of these studies were carried out through the questionnaire survey and anecdotal information; therefore, a rigorous field-based study is needed to explore the current change in diversity pattern. Khatri et al. (2019) recorded 16 species of fishes from the Bheri and its tributaries followed by 22 species from Babai and its tributaries, including three species, viz., *Neolissochilus hexagonolepis, Schizothorax richardsonii* and *Tor putitora* as globally threatened fish. Khatiwada et al. (2019a) reported 29 species of fishes from Sati Karnali Lake, three species from Jhilmila Lake, six species from Rani Lake, and three species, namely 'Bucche Asala' (*Schizothorax nepalensis*), 'Tikhe Asala' (*Schizothorax richardsonii*), and garra (*Garra gotyla*) from Ramaroshan Lake. Still, information regarding the current conservation status of wetlands fishes of low-land, western Nepal is greatly lacking.

Herpetofauna

Nepal supports a rich unrecognized amphibian and reptilian diversity (Schleich & Kästle 2002). It harbors more than 54 species (Khatiwada et al. 2020, Khatiwada et al. 2021) of amphibians and 134 taxa/species of reptiles (Shah & Tiwari 2004), but information about them is generally derived from relatively old studies (Smith & Battersby 1953; Nanhoe & Ouboter 1987; Mitchell & Zug 1995; Zug & Mitchell 1995). These records are primarily based on the species already discovered from neighboring countries like India and Tibet in China. However, these numbers are not based on detailed field studies of population densities within Nepal but from presence-only surveys or anecdotal information. This confirmed that Nepalese herpetofauna are poorly understood and many of them are incorrectly classified (Khatiwada 2017; Khatiwada et al. 2017). In western Nepal, in the late 1970s, French herpetologist A. Dubois made a significant contribution to the biology of Nepalese amphibians. He and other collaborators collected more than 15,000 amphibian specimens from Nepal (Dubois 1999) and described more than 10 new species (Dubois 1973, 1974, 1974 1975a, 1975b, 1977; Dubois & Matsui 1983; Dubois 1984, 1987). In the meantime, Nanhoe and Ouboter (1987) surveyed the amphibians and reptiles of the Annapurna-Dhaulagiri region of western Nepal and compiled an updated checklist based on both field observation and museum specimens and they reported 42 species of herpetofauna. Similarly, Khatiwada et al. (2019a) reported seven species of amphibian and eight species of reptiles from Sati Karnali Lake area; likewise, 10 species of amphibian and 16 species of reptiles from the Rani Lake area, five species of reptiles and seven species of amphibian from Ramaroshan area, six species of amphibian and seven species of reptiles from Jhilmila Lake area. Recently, Khatiwada et al. (2020) described a new species of *Amolops* frogs, which has wide distributional ranges in the mid-hill of Darchula, the Mahakali River basin of western Nepal. Skittering frog (*Euphlyctis cyanophlyctis*), Indian bull frog *(Hoplobatrachus tigerinus),* marbled toad *(Duttaphrynus stomaticus),* Syhadra frog *(Minervarya syhadrensis)* from lowland, black-spined toad (*Duttaphrynus melanosticus),* common Indian tree frog (*Polypedates maculatus*) from Midhill and Himalayan toad (*Duttaphrynus himalayanus),* Liebig's paa frog (*Nanorana legibii),* small paa frog (*Nanorana minica)* from highland were reported from of Karnali and Mahakali river basins (Khatiwada et al. 2019).

Aquatic invertebrates

Macroinvertebrates are major fauna in the freshwater ecosystem and have been widely used as a proxy/indicator of wetland conditions based on species richness, composition, or functional diversity (Ormerod et al. 1994; Marzin et al. 2012). Unfortunately, current knowledge of benthic macroinvertebrates in the freshwater ecosystem in Nepal is still very fragmentary (Brewin & Ormrod 1994; Suren 1994; Manel et al. 2000). In western Nepal Himalaya, only a few studies have assessed richness, diversity, and relationship with environmental variables using

benthic macroinvertebrate communities as the model organisms (Shah 2020; Matangulu et al. 2017; Suren 1994; Manel et al. 2000). Suren (1994) examined the relationship of elevation and the land-use changes on the richness and composition of macroinvertebrates in the Karnali River. Manel et al. (2000) reported the curvilinear relationship of macroinvertebrates with elevation. Major invertebrate fauna in the Karnali River was Orders Ephemeroptera, Plecoptera, Trichoptera, and Diptera. Budha (2010) made an inventory of Barhaiya Lake, Bardiya and reported eight species of freshwater snails and mussels- *Pila globosa*, *Bellamya bengalensis*, *Indoplanorbis exustus*, *Melanoides tuberculatus*, *Lymnaea acuminata*, *Gyraulus* sp., *Segmentina* sp. and *Lamellidens marginalis.* A study of the macroinvertebrates in West Seti river basin recorded 34 Families of the macroinvertebrates belonging to 7 Orders (Matangulu et al. 2017). Similarly, Shah et al. (2020b) reported 128 taxa of macroinvertebrates belonging to 84 families and 22 orders from the Karnali River Basin.

Wetland associated vegetation

Nepal's wetland harbors a wide range of vegetation. A recent publication listed over 711 species of plants including ferns as wetland plants (Ghimire et al. 2020); however, their list may contain some of the forest flora. Terai wetlands are rich in plant diversity. Sah et al. (2002) carried out a floristic inventory of Ghodaghodi Lake and reported a total of 401 plant species belonging to 264 Genera and 84 Families, among them 269 were dicots, and 132 were monocots. Lamsal et al. (2014) found 45 species of aquatic plants; among them, nine were submerged, six free-floating, 21 floating leaf, and nine emergent species from the same area. Mahakali River and associated wetlands also support high plant diversity. The study by Kunwar et al. (2015) from the far western region found 140 plant species, with 78 species having ethnomedicinal importance. Similarly, the study of Khatiwada et al. (2019a) reported 37 species of aquatic macrophytes from Sati Karnali Lake followed by 15 species from Jhilmila Lake, 28 species from Rani Lake, and 30 species from Ramaroshan Lake complex.

4 | Threats to freshwater ecosystems

About 5.41% of the total coverage of wetlands of Nepal was decreased due to the expansion of croplands in Nepal (Li et al. 2017; MoFE 2018). The major drivers of degradation of wetlands are population growth, more demand for wetland resources, removal of construction materials from the wetlands, invasions of alien species, siltation, and unclear national policies and management issues (MoFE 2018; NLCDC 2020). Besides these, fishing, grazing, siltation, pollution, extraction of construction materials nearby lakes, and rivers and conversion of wetlands for farming practices are the major threats to the aquatic ecosystems of Nepal.

The introduction of invasive species (commercial fishes), the use of fertilizers and pesticides further deteriorate the water health of wetlands (Budha 2010). Wetlands are shrinking, particularly in the lowland areas, because of siltation and eutrophication. In Terai, the majority of ox-bow lakes have been facing the problems of siltation and plant succession; for example, Ghodaghodi Lake Complex, Rani Lake and Jhilmila Lake are dominated by emergent and amphibious vegetation (Baral & Inskipp 2009; Budha 2010; Lamsal et al. 2014). Over-exploitation of aquatic biodiversity also imposes a serious threat to aquatic biodiversity. Amphibians and reptiles have long been used by humans as food and medicine (Gonwouo & Rödel 2008; Khatiwada & Haugaasen 2015). Studies have shown that frogs are an important source of livelihood for many people (Khatiwada & Haugaasen 2015) and remain an integral part of local medicinal heritage (Mohneke et al. 2011). Particular species are collected on a large scale, and over-collecting may lead to local extinctions or severe population declines. *Quasipaa* frogs in China have become rare, some being even on the verge of extinction, due to over-exploitation (Chan et al. 2014). As many amphibian species predictably aggregate for reproduction or hibernation, this makes them particularly vulnerable to intensive collecting efforts. Recent studies have indicated that commercial or subsistence harvesting has contributed to a decline in many reptile species (Webb et al. 2002). It has been revealed that *Paa* and *Amolops* are the most exploited frog species by the local people for food and medicinal purposes in mountainous parts of Nepal (Khatiwada & Haugaasen 2015; Khatiwada et al. 2019b; Khatiwada et al. 2020). This heavy exploitation may also lead to local or global declines and even extinctions through the unsustainable collection (Warkentin et al. 2009). Monitoring of these species and collection activities is, therefore, a conservation priority in the study area and elsewhere in Nepal.

5 | Conservation history of wetlands' exploration in Nepal

Nepal has a long conservation history of wetland, particularly related to the protection of nature and its natural resources. The first Wildlife Act was introduced in 1957 for the conservation of the Rhinoceros population in Chitwan. Later, in 1964, a rhino sanctuary was declared in Chitwan district (now Chitwan National Park), and a special guard force called the *Gaida Gasti* (Rhino Patrol) was created in the same year (Heinen & Kattel 1992). Since then, several conservation efforts have been undertaken for the future conservation of forests and overall biodiversity. The Government of Nepal launched the National Parks and Wildlife Conservation Act in 1973 (in short, it is called NPWC Act 1973), with national commitments for the conservation of protected areas and important wildlife species (HMG 1973). Nepal showed its conservation commitment with the Ramsar convention by signing on April 17, 1988. As a response to Ramsar signatory members, Nepal declared the Koshi Tappu Wildlife Reserve (KTWR) as the first Ramsar site of Nepal in 1988 (IUCN Nepal 2004; NLCDC 2019). To date, ten wetland sites of Nepal have been listed in the Ramsar sites (NLCDC 2019).

IUCN (1998) made the first wetland inventory and provided the conservation status of wetlands of low land Terai, Nepal. Then several surveys and inventories of the wetlands of Nepal have been undertaken (IUCN 1998; WECS 2003; IUCN Nepal 2004; NLCDC 2019), and these studies highlighted the major problems facing the wetlands and status of wetlands of Nepal. National Wetland Policy 2003 highlighted the need for an inventory of wetland resources. This policy aimed to conserve and manage wetlands resources wisely and in a sustainable way with local people's participation (GoVN 2003; NLCDC 2019). Hence, National Lake Conservation Development Committee (NLCDC) focuses on the conservation of lakes and preparing the lake database of Nepal. Recently, the Department of Forests and Soil Conservation, Government of Nepal has published a report on the Wetland of Western Nepal and has made an inventory of lakes of western and far-western Nepal (DoF 2017). They recognized a total of 92 lakes/wetlands from 13 districts. Among them, the Kailali district occupied the largest number of lakes (n = 48), followed by Kanchanpur (n = 28) and Achham (n = 7) (DoF 2017). Many rules and regulations were made to manage wetland resources, but its implementation is very weak. Many Acts and Rules are contradictory to each other. The policy of the DNPWC act, the Forest Act, is in contradiction with National Wetland Policy. Hence, these gaps should be minimized.

6 | Conclusion

Freshwater ecosystems of western Nepal (Karnali and Mahakali river basins) support habitats for several threatened and endangered flora and fauna and are distributed from low to higher elevation in various climatic zones. Wetlands of western Nepal are rich in biological diversity and provide a wide range of goods and ecosystem services, including irrigation, domestic supply, fisheries, and recreation to humankind. Fishing, grazing, and conversion of wetlands for farming practices are the major threats to the aquatic ecosystem of western Nepal. There are several acts and regulations related to wetland conservation and management; this sector has received inadequate attention in the national policy. Available studies on freshwater/wetland research and conservation initiatives in western Nepal assessed richness, diversity of wetland fauna and relationship with limnological factors. However, the effect of current land-use, climate change and socio-economic factors leading to limnological changes have not been explored adequately. Further, policy gaps in freshwater management have received limited attention in conservation. Therefore, further research on the effect of current land use, socioeconomic, and policy factors influencing wetland biodiversity and sustainability is suggested.

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Authors' contributions

Khatiwada, J. R. and Adhikari, J. N. conceptualized the study, collected the literatures and prepared the manuscript. All authors finalized the manuscript with their inputs.

Conflicts of interest

Authors declare no conflict of interest.

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