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Review

Ramsar wetlands in Nepal: Status, uses, challenges, and conservation strategies – a review

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Abstract

The wetlands of Nepal extend from the lowlands of Tarai to the high Himalayas, supporting biodiversity and livelihoods by providing valuable goods and services. This research is based on the published literature at both national and international levels, discussing the geographical distribution, status, major benefits, threats and management strategies for the wetlands of Nepal. Nepal hosts only two categories of wetlands, as a Ramsar Site i.e., natural freshwater and manmade wetlands. Ramsar sites of Nepal comprises of ten wetlands i.e., nine natural freshwater and one manmade. Total estimated area of the wetlands is about 8192.77 km^2, while Ramsar sites cover a surface area of 605.61 km^2. Despite their ecological significance, these wetlands are facing immense pressure from factors like global climate change, population growth, haphazard development, urbanization, land use changes and the shrinkage of watershed areas. Although various policies and the presence of a legal framework, there is no effective institution for the management of wetlands in Nepal. To ensure sustainable management of the wetlands, it is imperative to establish a dedicated and effective institution at federal, provincial and local levels, enhance coordination among the stakeholders and implement comprehensive conservation strategies.

Keywords: Biodiversity; Ecological threats, Institutional gaps; Livelihood, Ramsar sites; Sustainable management

1 | Introduction

Wetlands provide many significant ecological, economic and Wetlands provide many significant ecological, economic and aesthetic services to humans and environment (Mitsch & Gossilink 2000; Zhou et al. 2020). They are generally described as rivers, streams, reservoirs and forests, as well as waterlogged lands. Wetlands also include flooded rice fields and reservoirs. Wetlands, as per the Nepal Biodiversity Strategy (2002), are distinct areas characterized by the presence of water, as well as swampy and marshy soils. Although wetlands provide valuable functions and essential ecosystem services, they are often overlooked in the policymaking process for sustainable conservation and management. However, these ecosystems are being degraded or threatened despite various national and international initiatives for their conservation and management (Turner et al. 2000; Paudel et al. 2022; Tammeorg et al. 2024).

Land use changes in the catchment areas of wetlands can reduce water inflow and increase the polluted runoff from agricultural and urbanized areas (Khatri & Tyagi 2015; Bishwakarma et al. 2019). Furthermore, these water bodies also act as sinks for municipal and industrial waste and face further threats from encroachment and excessive water diversion (Pant et al. 2022; Xu et al. 2019). Although several initiatives are underway, wetlands continue to degrade due to the lack of a strong and coordinated policy and legal framework for their effective conservation and management (Kundu et al. 2024).

The diverse landscape supports a wide range of wetlands from subtropical Tarai to high-altitude glacial lakes in Nepal, providing critical habitats for endemic and ecologically important species, many of which are endangered (IUCN Nepal 2004). These wetlands not only support biodiversity but also sustain the livelihoods of more than 21 ethnic communities and a broader segment of the general population who depend on wetland resources for food, fiber, fodder, fuel, habitat, water and income (Khatri 2013; IUCN Nepal 2004). Wetlands are known as *"Simsar Areas"* in Nepal, means the areas with a constant and reliable source of water. On December 17, 1987, Nepal designated the Koshi Tappu Wildlife Reserve as its first Ramsar site, officially joining the Ramsar Convention and affirming its commitment to the conservation and sustainable use of wetlands. Currently, ten wetlands of international importance are spread across Nepal, from the lowlands to the high Himalayas. However, many of these vital ecosystems are deteriorating due to rapid urban expansion, population growth, haphazard development and increasing economic pressures (KC et al. 2013). Despite their

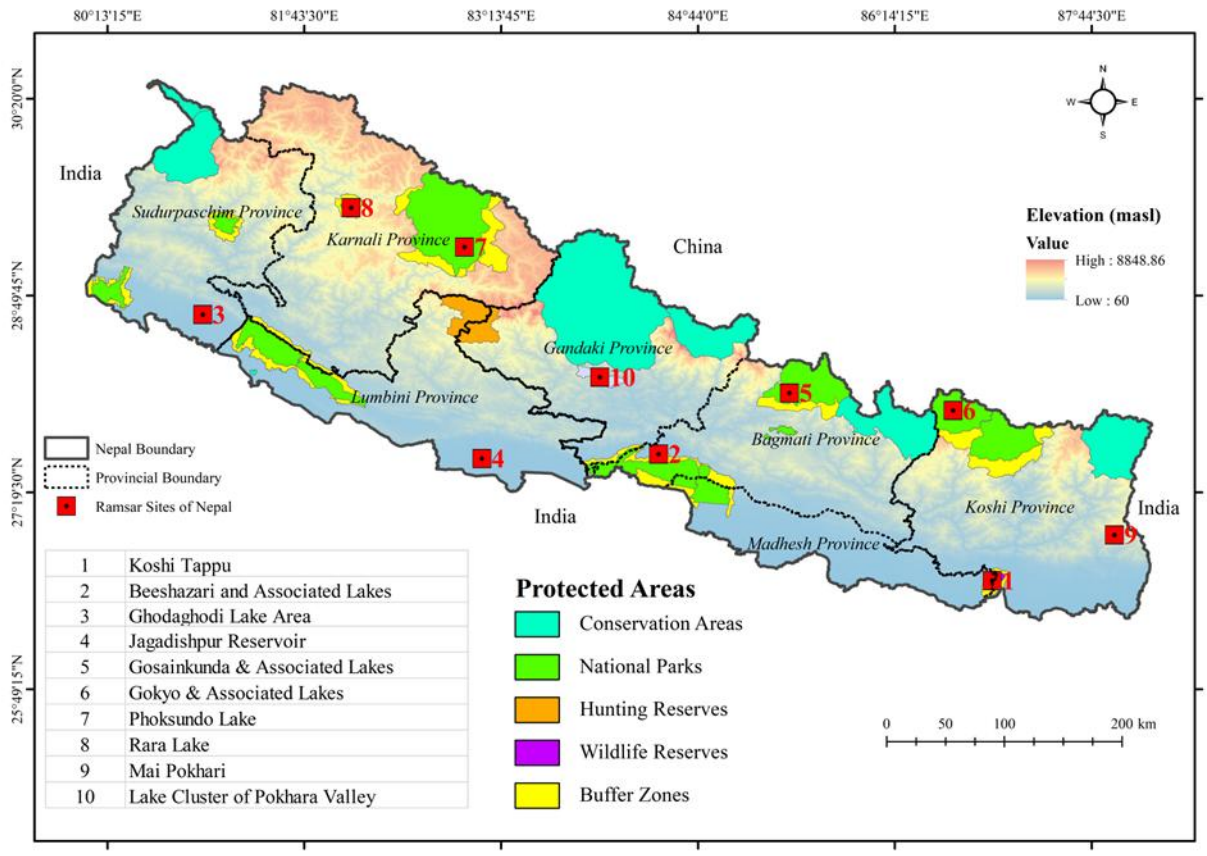

Figure 1. Geographical locations of the Ramsar-listed wetlands of Nepal

numerous ecological and socio-economic benefits, many wetlands are still perceived as 'wastelands' with surrounding communities often using them as dumping grounds for household and industrial waste (Newcome et al. 2005). Direct as well as indirect supplies of waste are the major cause of worsening status of the wetlands. However, this impression must change as these water bodies are one of the most dynamic ecosystems on the planet (Ramsar Convention 1971).

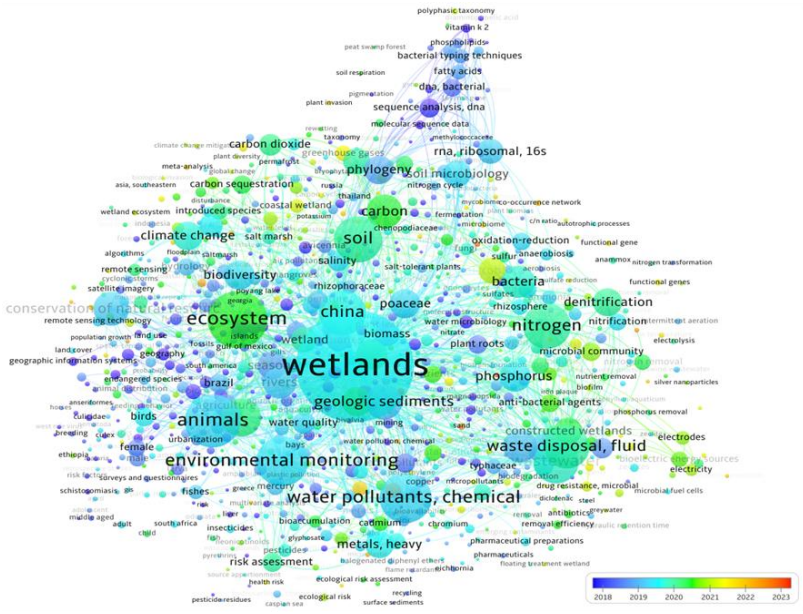

Figure 2. Network map for the most central keywords of articles published over the years related to wetlands research

Wetlands are often neglected in policymaking primarily due to policymakers' limited awareness of their ecological, social and economic importance. Moreover, competing land use interests such as urban development, industrialization and agriculture frequently take priority over wetland conservation. Additionally, wetland conservation in Nepal receives limited prioritization in resource allocation. While numerous studies have examined the ecological significance and conservation challenges of wetland ecosystems, few have investigated the critical links between wetland degradation, policy effectiveness and stakeholder engagement. To address this gap, this study aims to review the current status, uses, threats and institutional strategies related to Ramsar-listed wetlands in Nepal.

2 | Materials and methods

This review-based study focuses specifically on the ten Ramsar-listed wetlands of Nepal. It is grounded in a comprehensive desk review and analysis of diverse sources, including peer-reviewed journal articles, academic books, government publications, and reports from nationally and internationally recognized organizations and personal communications. Most of the documents reviewed in this study were primarily sourced from reputable academic databases and platforms, including Google Scholar, Web of Science, PubMed, Scopus, JSTOR, SciProfiles and ScienceDirect. Key information sources included the National Ramsar Strategy and Action Plan, Nepal (2018-2024), the National Wetland Policy, (2012), and the Ramsar

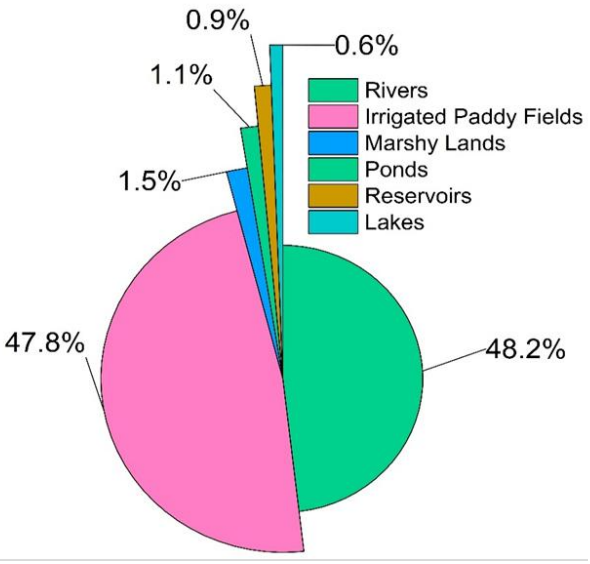

Figure 3. Extent of wetlands in Nepal (Source: DoFD, 2012)

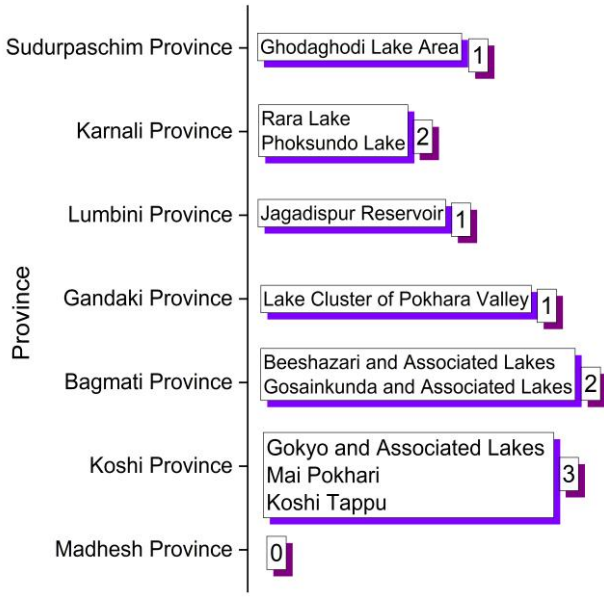

Figure 4. Categorization of Ramsar Sites of Nepal by Province

Convention of 1971, with additional data obtained from the Ramsar Sites Information Service (Figure 1).

Furthermore, the necessary Ramsar related insights were collected from different organizations, including the Department of National Parks and Wildlife Conservation (DNPWC), International Union for Conservation of Nature (IUCN), National Trust for Nature Conservation (NTNC) etc. The review also analyzed government policies, legislation, reports, historical records and articles related to wetlands. Systematic searches were conducted in selected databases using a mix of keywords and phrases, including management, status, importance, distribution, threats, significance of wetlands etc. Figure 1 illustrates the geographical distribution of Ramsar sites in Nepal, categorized by their designation status and Figure 2 displays a network map highlighting the most central and frequently co-occurring keywords in wetlands research articles published across different years.

3 | Results

3.1 | Overview of wetlands extent in Nepal

Water bodies, including irrigated paddy fields have coverage of approximately five percent and a water storage capacity of about 225 billion m^3 (Water Resource Strategy Nepal 2002). According to the Directorate of Fisheries Development, Kathmandu, Nepal (DoFD 2012), the total estimated area of wetlands in Nepal is about 8192.77 km^2. Rivers occupy the largest area, i.e., 3950 km^2 (47.99%) and ponds occupy the least, i.e., 72.77 km^2 (0.88%). Other water bodies like lakes cover 50.00 km^2 (0.60%), reservoirs cover 15.00 km^2 (0.18%), marshy lands cover 125 km^2 (1.51%), and irrigated paddy fields cover an area of 3980 km^2 (48.15%) (Figure 3).

Surface and underground water sources, or rainfall, both permanently or temporarily, natural or manmade, fresh or salty, including marshy or swampy lands, are the wetlands, and among these, Nepal hosts only two categories of wetlands as a Ramsar Site, i.e., natural freshwater and manmade wetlands. The Ramsar Sites of Nepal comprises of ten wetlands - nine natural freshwater wetlands and one manmade wetland. Koshi Tappu; Beeshazar and associated lakes; Ghodaghodi Lake area; Gokyo and associated lakes; Gosainkunda and associated lakes; Phoksundo Lake; Rara Lake; Mai Pokhari (the smallest) and Lake Cluster of Pokhara Valley (the

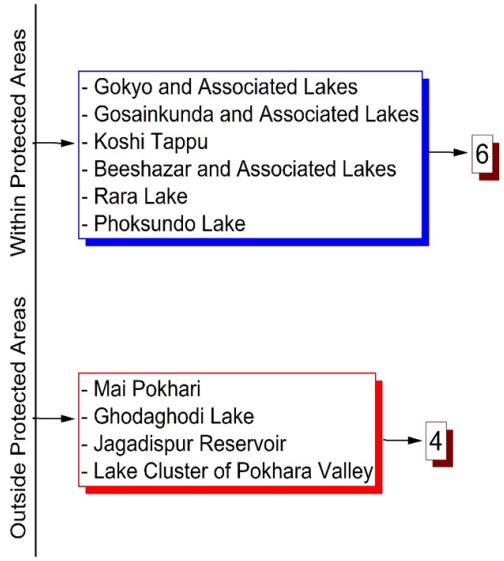

Figure 5. Categorization of Ramsar Sites outside and inside the Protected Areas of Nepal

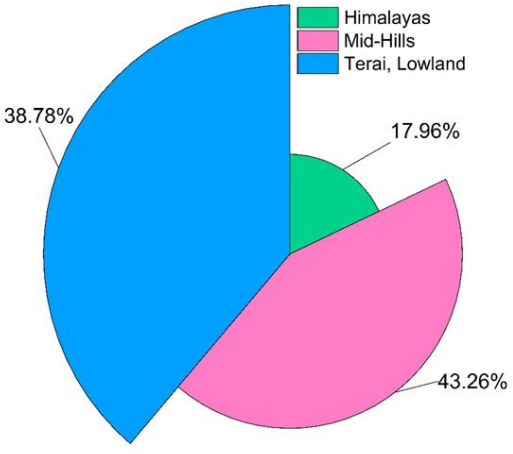

Figure 6. Ecological extent of Ramsar sites of Nepal

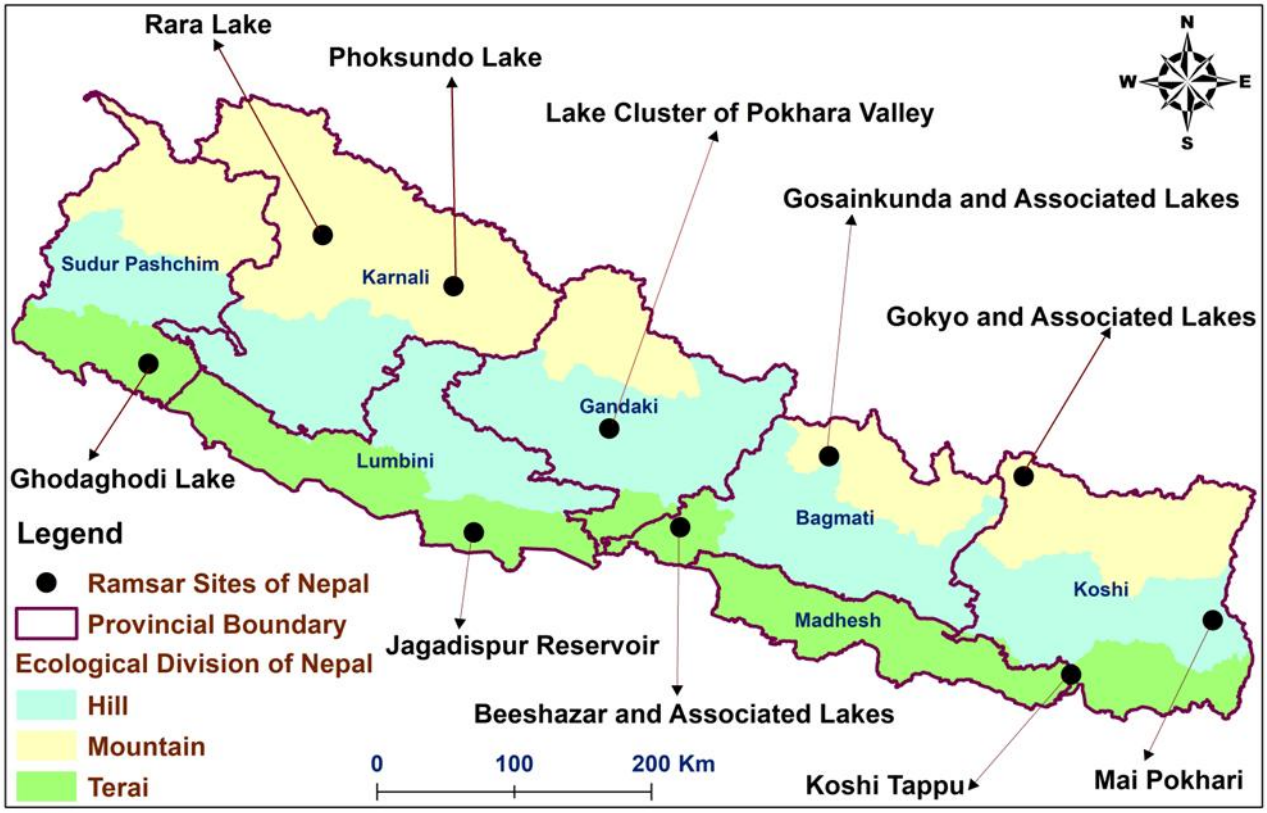

Figure 7. Ecological distribution of Ramsar sites of Nepal

largest) are the natural freshwater wetlands whereas Jagadishpur Reservoir is the only manmade wetland listed as a Ramsar Site of Nepal. Among the ten Ramsar Sites of Nepal, six sites are located within the protected areas, *viz.* Gokyo and Associated Lakes, Gosainkunda and Associated Lakes, Koshi Tappu, Beeshazar and Associated Lakes, Rara Lake and Phoksundo Lake, whereas Mai Pokhari, Ghodaghodi Lake, Jagadishpur Reservoir and Lake Cluster of Pokhara Valley lie outside the protected areas of Nepal (Figure 5).

Except for Madhesh Province, all six provinces of Nepal consist of Ramsar Sites. Koshi Province has three Ramsar Sites, i.e. Gokyo and Associated Lakes, Mai Pokhari and Koshi Tappu. The Bagmati Province and the Karnali Province have two Ramsar sites each. Gandaki Province, Lumbini Province and Sudur Pashchim Province each consist of one Ramsar Site listed wetland (Figure 4).

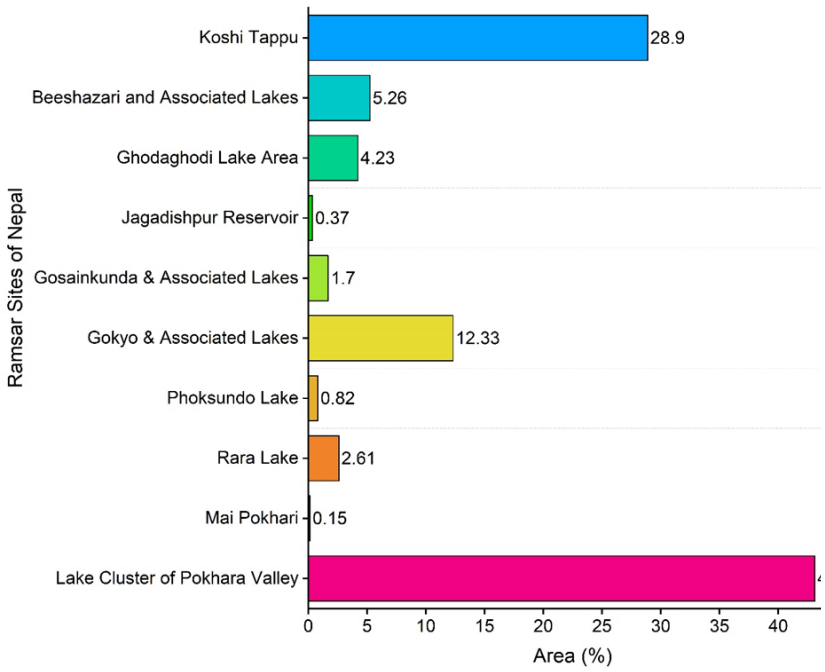

Figure 8. Area extent of Ramsar sites in Nepal

3.2 | Ecological extent of Ramsar sites of Nepal

Among Ramsar sites of Nepal, four lie in the lowland of Tarai, the other four wetlands are located in the Himalayas, and the remaining two are located in the Mid Hills of Nepal (Figure 6 and Figure 7). Ramsar sites of Nepal cover an area of 605.61 km^2, and out of this, 234.88 km^2 (38.78%) lies in the lowland of Tarai, 108.77 km^2 (17.96%) in the Himalayas and the remaining 261.96 km^2 (43.26%) in the hilly region of Nepal (Ministry of Forest and Environment 2018).

3.3 | Overview of Ramsar sites of Nepal

Department of Agricultural Development (1992) estimated that wetlands cover roughly five percent of Nepal's land area. Only ten of these numerous wetlands have been listed in the list of Ramsar Sites of Nepal. Table 1 and Figure 8 illustrates the distribution extent of Ramsar Sites in Nepal, along with the designation date and key flora and fauna found in those respective wetlands.

4 | Discussion

4.1 | Multiple uses of wetlands

Wetlands are used for multiple purposes like irrigation, drinking water, biodiversity hotspots, fisheries, recreational uses and domestic uses, depending on the regional location of wetlands (Masi et al. 2018). Carbon sequestration, flood control, toxin retention, groundwater recharge and biodiversity management are the major services provided by the wetlands (Prasanya et al. 2024; Ye et al. 2022). Mai Pokhari holds significant religious and cultural value for Buddhist, Hindu, and Mundhum traditions. The water resources of Koshi Tappu wetlands are mostly used for rafting and sightseeing and carry religious significance (*Chhath Festival*). People use water resources for irrigation and drinking purposes, and they also host significant flora and fauna (Karki 2008). Gokyo and its associated lakes and the Gosainkunda Lake area carry high significant cultural values, as these water resources are less stressed due to their presence in the high Himalayas.

According to the annual World Travel and Tourism Council, travel and tourism sector has contributed 7.9% to GDP, was able to generate US$ 1.75 billion in revenue, and supported more than 1.05 million jobs in Nepal (Prasain 2019). These are important numbers, as wetlands are weighed as a key part of the tourism experience. Economic profit generated from the Begnas Watershed was worth US$ 3.91 million per year, which equates to US$ 650.67 per household and US$ 799.79 per ha. 85% of this total valuation was due to the recreational service provided by the lake (Thapa et al. 2020). Jagadishpur reservoir of Kapilbastu District, which is also known as '*Paradise of Birds*', has an estimated annual total economic valuation of US$ 689,200, irrigates at least 4.06 km^2 of land and provides shelter to numerous mammals and reptiles (Chaudahary & Devkota 2018; Baral et al. 2016). Jagadishpur Reservoir and Ghodaghodi Lake have been designated as bird sanctuaries by the Government of Nepal, as they serve as important habitats for both local and migratory bird species.

4.1.1 | Livelihoods and wetlands

Wetlands play a critical role in sustaining human livelihoods by providing essential human resources like fishing, rice farming, transportation, tourism and water supply, all of which are reliant on wetlands (Nwankwoala 2012; Pant et al. 2024). Wetlands are viewed as natural capital for the rural poor; in addition, they play a vital role in sustaining people livelihoods (McCartney et al. 2015). Wetlands provide multiple unique ecological features to mankind, like drinking water, irrigation, fisheries, non-timber forest products like food, medicinal plants, fuel, bamboo, etc. (Environmental Protection Agency 2017).

Thousands of people depend upon Phewa Lake, Koshi Tappu, and other major wetlands for sustaining their livelihood (Nwankwoala 2012; Pant et al. 2022). The livelihoods of the indigenous communities like 'Pode', 'Jalari' living near Phewa Lake and associated lakes are closely tied to the effective management of the wetland areas. The increase in livelihoods of the fishing group (Pode

Table 1. Overview of Ramsar Sites of Nepal

Ramsar sites	Ecological region	Site number	Area (km^2)	Province	Location (district)	Designation (date)	Key flora and fauna
Koshi Tappu	Terai	380	175	Koshi	Sunsari, Saptari & Udayapur	1987/12/17	Supports birds like Bengal falcon, white tailed eagle etc. and supports fauna like *Bubalus arnee*, gharial, Gangetic dolphin etc.
Beeshazari and Associated Lakes	Terai	1,313	32	Bagmati	Chitwan	2003/08/13	Endangered wildlife species like *Rhinoceros unicornis, Panthera tigris,* etc.
Ghodaghodi Lake Area	Terai	1,314	25.63	Sudur Paschim	Kailali	2003/08/13	Wildlife corridor between lowland and Siwalik, Supports critically endangered species of turtle, vulnerable *Lutrogale perspicillata,* etc.
Jagadishpur Reservoir	Terai	1,315	2.25	Lumbini	Kapilbastu	2003/08/13	Serves as a buffer zone for the movement of birds like sarus (*Grus antigone antigone*), Presence of endangered species of flora like serpentine (*Rauvolfia serpentine*), lotus (*Nelumbo nucifera*)
Gosainkunda & Associated Lakes	Himalayas	1,693	10.30	Bagmati	Rasuwa	2007/09/23	Supports Himalayan black bear, snow leopard, serow, etc. and more than 250 species of birds
Gokyo & Associated Lakes	Himalayas	1,692	77.70	Koshi	Solukhumbu	2007/09/23	Supports Himalyan tahr (*Hemitragus jemlahicus*), woond snipe (*Gallinago nemoricola*), etc. and endemic species like *Kobresia fissiglumis*,
Phoksundo Lake	Himalayas	1,694	4.94	Karnali	Dolpa	2007/09/23	Supports animals like snow leopard (*Panthera uncial*), musk deer (*Moschus chrysogaster*) etc.
Rara Lake	Himalayas	1,695	15.83	Karnali	Mugu	2007/09/23	Habitat for endemic species of plants and amphibians such as *Rara paha*
Mai Pokhari (Smallest)	Mid hills	1,850	0.9	Koshi	Illam	2008/10/20	Provides habitat for significant epiphytic orchids, home to endangered fauna like white–rumped vulture, Eurasian otter etc. and supports endemic species like Hariyo cheparo (*Japalura variegata*)
Lake Cluster of Pokhara Valley (Largest)	Mid hills	2,257	261.06	Gandaki	Kaski	2016/02/02	Hosts site for globally threatened species of migratory birds like Baer's pochard, Indian vulture etc.

or Jalari) can be traced to the combination of participatory fisheries management (Gurung et al. 2005). Local people extracted water resources from Ghodaghodi Lake worth NRs 4379 (US$ 63) per year, indicating wetlands' significant contribution to the household economy (Lamsal et al. 2015). Similarly, as per a study conducted in Ghodaghodi Lake, its water is good for irrigation purposes with very low salinity hazards (Paudel et al. 2024). Additionally, the ecotourism-based wetland management ensures the wise use of their services and secures sustainable livelihoods (Aryal et al. 2019).

4.1.2 | Carbon sequestration

Wetlands act as a "carbon sink or source" depending on their biogeochemical processes and hydrology. Despite contributing to 38% to 56% of the total global emission of methane, they store a high amount of carbon through high rates of organic matter inputs and decreased rates of decomposition (Zhang et al. 2017). Vegetation present in wetlands store carbon temporarily, as it is subject to turnover and decay (Barbier 2013). Wetlands retain 20 - 30% of the estimated 1,500 Pg of global soil carbon, even though they account for just 5-8% of the Earth's land surface (Nahlik & Fennessy 2016). According to IPCC (2000), the carbon sequestration capacity of wetlands is estimated at around 0.4 tons C/ha/year over 50 years. In case of Chitwan district, the freshwater stored annually sequesters carbon at the rate of 1.3 tons C/ha/year, whereas the forests sequester carbon at the rate of 1.38 tons C/ha/year (Baral et al. 2016). In Nepal, WWF Nepal has contributed to the restoration of wetlands capable of replenishing two billion liters of water each year.

4.1.3 | Pollution reduction

Riparian wetlands remove phosphorous and nitrate load from Riparian wetlands remove phosphorous and nitrate loads from runoff water and sub-surface water (Khanijo 2002). An artificially created wetland can act as the sink for pollution loads (Almuktar et al. 2018). Furthermore, wetlands designed to retain nutrients do not certainly enhance biological diversity and vice versa (Hansson et al. 2005). Under normal circumstances, wetlands retain nutrient loads from the surface and sub-surface runoff and stop nutrients from running into water bodies. Plants like *Typha, Phragmites, Eichhornia, Azolla*, *Lemna* etc. can remove heavy metals from wastewater and other nutrient loads are removed by the process of nitrification, sedimentation and adsorption (Rai 2008). Well-designed constructed wetlands can efficiently sustain wetland hydraulics and are seen as a viable alternative to wastewater treatment plants (Kadlec & Wallace 2008). In a developing country like Nepal, the construction of artificial wetlands is eminently appropriate. The government, planners and policymakers of Nepal should be well aware of the importance of constructed wetlands (Gurung 2012).

4.1.4 | Flood and soil erosion control

Flood control is one of the major specific services performed by wetlands. Absorption of floodwater, slowing its flow, retaining suspended solids and minimizing nutrient load can reduce the impact of floods. Natural wetlands are considered to have the best flood control mechanism and can perform better than man made flood control mechanisms like dikes, levees, dams and embankments (Boyd & Banzhaf 2007). As per the study conducted in Rat River Watershed (Canada), 10% increase in the area of wetland can lead to a reduction of 11.1% to 18.6% in total flood volume (Juliano & Simonovic 1999). The drastic reduction in wetland area is a major factor contributing to flood-induced catastrophes (Bassi et al. 2002). In the case of Koshi River near Kusaha village in Sunsari District, a breach on the left embankment on 18th August 2008 inundated 60 km^2 of agricultural land and damaged more than US$ 3.7 million in agricultural products (Yogacharya & Gautam 2008).

Wetlands also play a vital role in soil erosion control. Wetlands along the shores of water bodies can minimize the erosion caused by waves during floods and storms. They prevent excessive erosion of shoreline, riverbank, or stream bank by dissipating wave and current energy or binding and stabilizing the soil. Two mechanisms of wetlands, i.e. vegetation present, act as a barrier by absorbing the impact of crashing waves or water running down a hill and vegetation uses its roots to bind and lock down the soil (Pimentel & Kounang 1998). Dense root systems of wetlands absorb the surface water energy and bind the soil and deposited sediments.

4.1.5 | Biodiversity hotspots

Wetlands play crucial role in sustaining biodiversity, with some species depending on them throughout their life cycle, while others rely on them only during specific stages (Quesnelle et al. 2013). The Department of National Parks and Wildlife Conservation (2019) reported that Koshi Tappu wetland hosts 527 species of birds, of which 12 are globally threatened and 101 are nationally threatened. The surrounding area of Beeshazar Lake is dominated by the *Shorea robusta*, additionally, it also hosts 17 fish species and 273 avian species. Ghodaghodi and its associated lakes host 450 plant species, 29 fish species and 16% (140 species) of migrating avifauna in Nepal (WWF Nepal and DNPWC 2006). Jagadishpur Reservoir and its peripheral region are famous for 42 avian species and 25 fish species. Approximately 100 species of flowering plants are recorded in the Gosainkunda catchment area, while 80 species of flowering plants are found in Gokyo and associated lakes (WWF Nepal & DNPWC 2006). The Phoksundo area has about 155 species of flowering plants documented (WWF Nepal & DNPWC 2006). Rara Lake is home to Rara paa frog (*Nanorana rarica*), an endemic species of snow trout and *Schizothorax macropthalus*, *S. nepalensis,* and *S. raraensis*, which is also known as Asala macha. A study conducted by Bhattarai (2018) indicated that Mai Pokhari hosts 238 species of plants. The Lake Cluster of Pokhara Valley hosts 60 aquatic plants species, 203 terrestrial plant species and 168 species of birds (Tamrakar 2008).

4.2 | Threats and challenges to wetland ecosystems

Freshwater wetlands are among the most heavily utilized and manipulated ecosystems and are critically important for long term survival and well-being (Ramus et al. 2017). According to MEA (2005), more than 50% of wetlands of Australasia, North America and Europe were converted into barren land. Agriculture, dam construction and other human-induced activities are the major factors for the loss of more than 5000 km^2 of wetland annually in Asia alone (Zedler & Kercher 2005). Furthermore, 21% of avian species, 37% of mammalian species and 20% of freshwater fish species that depend upon wetlands directly or indirectly have been lost due to global destruction of wetlands and are extinct or globally threatened (MEA 2005). Major drivers for degradation are lack of clear policies and management, encroachment, random urban expansion, redirection of water, haphazard commercial fishery, siltation, erosion and increasing need for resources (MEA 2005). While the National Wetland Policy published in 2012 of Nepal aims to conserve and promote sustainable use of wetlands, its implementation is less effective due to overlapping mandates among government agencies and a lack of clear guidelines and enforcement mechanisms.

4.2.1 | Climate change and land use/cover change

Global climate change is projected to significantly impact wetland habitats, leading to destruction and alteration (MEA 2005). It makes the conservation and protection of wetlands even more challenging. Increasing temperature and declining rainfall present potential threats to existing water resources (Agrawala et al. 2003). Regarding water resources of Nepal, rapidly melting glaciers (retreating over 30 m/year), a substantial upswing of temperature (>0.06°C), erratic precipitation and intensification in the occurrence of extreme events like floods and droughts are major threats to wetlands (Karki et al. 2009). Climate change has several effects on the water quality of wetlands, like unseasonal thermal stratification

and depletion of oxygen levels (Shrestha & Aryal 2011). Glaciers of Nepal are retreating rapidly; the study estimated that glaciers of Nepal may disappear within three to four decades (Chaulagain 2009). Pressure on the wetlands for drinking water purposes is already skyrocketing; in addition, decreased precipitation will exacerbate the problems (Dai et al. 2018).

Land use/cover change is the major driver for wetlands degradation. Degradation and disintegration of wetlands as a result of unsystematic agricultural growth impact the wetlands and their biodiversity. The deterioration of wetlands, increased variability in water levels and disturbance in floodplains are the major impacts on wetlands due to land use changes (Liu et al. 2004). Expansion of agricultural land is estimated to decrease Nepal's overall wetland by 5.41%, primarily through drainage, land encroachment, water extraction and pollution (MoFE 2018). Comparative land use maps of 1990 and 2010 revealed a decrease in agricultural land at the annual rate of 0.2% in Rasuwa, 2.4% in Gorkha, and 0.8% in Chitwan (Shrestha et al. 2019), which directly or indirectly impact the surface area of wetlands.

4.2.2 | Population growth and urbanization

Population growth is a major driver of wetland degradation. Population growth is to be blamed for the instability in all land use classes, with forested and non-forested wetlands being the most affected (Arfanuzzaman & Dahiya 2019). Massive encroachment on wetlands for settlement purposes has significantly reduced the area. The annual population growth trend of Nepal decreased from 2.10% in 1971 to 0.92% in 2021; however, the trend of urban population increased from 4% in 1971 to 66.2% in 2021 (Regmi 2015). This significant increase in urban population growth trend is likely to influence the peripheral region of wetlands as most people migrate or settle near the peripheral region of the wetlands and eventually lead to encroachment, decreasing the lake surface area. The study has indicated that wetland shrinkage occurs in regions with large population. Population growth exerts significant pressure on the hydrological cycles at the global and regional scales.

Pressures on wetlands are likely to be caused by the draining of wetlands for urban expansion and increased withdrawal of water from wetlands (Novoa et al. 2020). In the context of Nepal, barrage, diversion, and reservoir sites, the rapid growth of population, unmanaged facilities and redirection for water supply and inefficient wastewater management are crucial elements for the deterioration of water bodies. Most of the water bodies present near urban areas are significantly becoming eutrophic (Arthur & Cole 2014). However, due to the intense flow of nutrients, the nutrient-storing capacity has far exceeded its natural capacity. Anthropologically affected ecosystems show severe variations in nutrient cycling and changes in biodiversity (Almuktar et al. 2018).

4.2.3 | Environmental contaminants

Natural wetlands are at risk from regional drainage and input from the agricultural land. Deterioration of wetlands from tremendous contamination can disturb the biodiversity and recreational opportunities. Agricultural runoff and wastewater discharges are the major cause for degradation of wetlands of Asia, leading to eutrophication (An et al. 2007). In Nepal, most of the wetlands are polluted through untreated urban sewage and agricultural runoff. Similarly, from 1991/92 to 2015/16, chemical fertilizer usage increased at the rate of 882.43 metric ton (MT) per year, and in the fiscal year 2015/16, under the subsidy program, 259,061 MT of chemical-based fertilizers were distributed across Nepal and average consumption of fertilizer was about 83.8 kg per ha (Pandey et al. 2017). Likewise, urea is the most used fertilizer, followed by DAP and Muriate of Potash.

Algal blooms from excess nutrient load from the surrounding agricultural fields make water unsuitable for drinking purposes and any industrial use (Chislock & Doster 2013). Untreated wastewater from industries also contributes significantly to the degradation of wetlands water quality. Wastewater treatment efforts in Nepal have significantly expanded since the 1970s; however, rapid urban growth has outpaced infrastructure development, resulting in an insufficient number of properly functioning wastewater management facilities (Jha & Bajracharya 2012).

4.2.4 | Eutrophication and sedimentation

The wetlands of Nepal are worsening primarily as a result of sedimentation and eutrophication. Encroachments, deforestation along the wetlands edges, heavy fishing, human pressure and increased input of pollutants are the major anthropogenic influences predominantly accountable for the decline of water quality. High use of nutrient rich fertilizers along the surrounding agricultural field to increase crop yield; however, the planting season and monsoon season overlap, leading to the flow of nutrient rich water into the lake, causing eutrophication. The extensive spread of macrophytes not only affect the water organisms but also affect the waterfowl which require open water for feeding (Bakker et al. 2016). Overgrazing along the shoreline of wetlands contributes to the erosion of soil and high input of nitrogenous nutrients which results in elevated eutrophication. This eventually leads to the loss of suitable habitats for freshwater birds and many additional aquatic organisms (IUCN Nepal 2004). For example, Phewa Lake is one of the most eutrophic lakes in Nepal, mostly due to the seepage of nutrient rich wastes from anthropogenic sources.

Most of the wetlands of Nepal have shrunk due to sediment influx. For example, dead Common Water Hyacinth (*Pontederia crassipes*) settles at the bottom of water, resulting in an increase in sedimentation and it alters the wetland soil profile, impacting native species (Degaga 2018). Extensive sedimentation leads to the suffocation of native species and allows alien species to thrive. Native macro-invertebrates are highly affected due to the changes in native soil profile due to sedimentation (Jones et al. 2012). Lake shrinkage, mostly due to sedimentation, has been a major problem for lakes present near the settlement areas as well as the forest areas. The primary example of sedimentation problem is Phewa Lake. It is estimated that Phewa Lake will lose 80% of its surface area in the next 110-347 years (Watson et al. 2019), which will create a threatening situation for wetland-dependent humans and organisms.

4.2.5 | Invasive species

Invasion causes monoculture in wetlands, altering the food web, lowering the biodiversity and altering the quality and quantity of food availability (Zedler & Kercher 2005). Wetland invasions are closely linked to sedimentation, which creates altered habitat conditions that favor invasive species and is further intensified by their spread (Zedler & Kercher 2004). Thus, the invasion of alien species along the wetlands has a significant impact on the ecosystem services and natural beauty of the wetlands.

Invasive Alien Species (IAS) are the second most significant threat to biodiversity, the first one being habitat loss and degradation (MEA 2005). The most problematic invasive species in Koshi Tappu Wetland (KTW) are water hyacinth (*Pontederia crassipes*) and bush morning glory (*Ipomoea carnea*) and their increased coverage has led to a decrease in dissolved oxygen and an increase in total alkalinity and free CO_2 (Pandey et al. 2020). Five invasive alien species are recorded in the Lake Cluster of Pokhara, namely *Pontederia crassipes*, *Ipomoea carnea* subsp. *fistulosa*, *Leersia hexandra*, *Pistia stratiotes* and *Alternanthera philoxeroides*. These species have harshly reduced the fish production, loss of biodiversity, obstructed recreational activity and boating and relentlessly impacted ecosystem services (Pathak et al. 2021).

4.3 | Institutional strategies for wetland management in Nepal

4.3.1 | Legal framework

Although there is no explicit legal framework for wetlands management in Nepal, several other legal instruments have an indirect effect. These are: Aquatic Animal Protection Act 1961, National Parks and Wildlife Conservation Act 1973, Soil and Watershed Conservation Act 1982, Water Resources Act 1992, Electricity Act 1992, Forest Act 1993, Environmental Protection Act (EPA) 2019, Environmental Protection Rule (EPR), 2020 and Local Government Operation Act, 2017 (Poudel 2009; Nepal et al. 2025). These EPA 2019 and EPR 2020 consider the conservation of wetlands for sustainable development. Recognizing the need for a coordinated approach for wetlands conservation, the National Wetland Co-ordination Committee (NWCC) under MoFE was established in 2010 to protect the wetlands and ensure their sustainable use. NWCC provides an approach for encompassing issues related to wetlands into national policies and planning and plays a catalytic role between stakeholders and the Government of Nepal.

4.3.2 | Policy support

On 17 December 1987, Nepal signed the Ramsar Convention and showed its commitment to wetland conservation by adding Koshi Tappu Wetland (KTW) to the "Ramsar list". Ever since then, the Nepal Government has taken multiple steps for safeguarding wetlands sustainable management. The major policies formulated for the conservation of wetlands in Nepal are: Nepal's Strategy for National Conservation of 1988, Comprehensive Forestry Sector Plan introduced by government in 1989, Nepal's Environmental Policy and Action Plan formulated in 1993 (NEPAP), Policy for managing the Forestry Sector Policy, established in 2000, Nepal's strategic approach to Biodiversity Strategy, developed in 2002, Nepal's Policy to promote Hydropower Development Policy, introduced in 2002, National Policy for wetland management, introduced in 2003 and revised in 2012, strategy for managing Water Resource, formulated in 2002, National Policy for enhancing agriculture productivity of 2004, National Water Plan of 2005, National policy for sustainable tourism in 2009, National Industrial development Policy of 2011, Nepal's Climate Change Policy of 2011 and National Climate Change Policy 2019, focusing on mitigation and adaptation, Policy for improving irrigational system of Nepal, formulated in 2013, Nepal's strategic approach for energy development in 2013, Strategy for modernizing and developing Nepal's agriculture, introduced in 2014, policy for developing Nepal's Land Use, formulated in 2015, National Forest Policy for promoting sustainable forest management, formulated in 2015, Forestry Sector Strategy implemented in 2016, strategy for sustainable urban development, introduced in 2017, policy for minerals resources development of 2017, Nepal's action plan and strategy for sustainable development of biodiversity conservation, covering 2014 to 2020, Ramsar Strategy and Action Plan for Nepal's wetlands protection, covering from 2018 to 2024, National Environment Policy introduced in 2019 are some of the major policies formulated for the conservation of wetlands of Nepal.

Among many policies formulated, the National Wetland Policy of 2003, NEPAP of 1993, and Action Plan of 2014 to 2020 for National Biodiversity Conservation include major initiatives for the long-term conservation of wetlands. Sustainable use of wetlands are highlighted in the National Conservation Strategy (1988). The use of words like "marshes" and "wetlands" in the Nepal Environmental Policy and Action Plan (1993) (NEPAP) shows the initiation of wetlands protection by the Government of Nepal. Further elaborated, NEPAP-II (1998) provided a good quality foundation for wetlands conservation and identified 54 projects related to forestry and wetlands conservation directly or indirectly (Poudel 2009b). NEPAP-II states that wetlands and many other essential natural resources are being neglected, drained and transformed into farmlands. Primarily wetland ecosystems were mentioned in the Nepal Biodiversity Strategy (2002), the first governing document of Nepal to address conservation strategies to manage wetlands ecosystem; furthermore, it emphasizes the safeguard of wetland habitats that host more than 20,000 waterfowl. It aims at updating and improving the existing wetlands directory and database and works on resolving land use conflicts. The primary goal of 2003's National Wetland Policy was to include local communities in maximizing the beneficial utilization and sustainable management of the biodiversity of wetlands. It also emphasizes local people's wetlands awareness, expertise and practice and gradually implements international treaties for wetlands conservation.

The Strategic Action Plan, covering 2014 to 2020 for National Biodiversity, states that the wetlands of Nepal are environmentally significant as they host diverse flora and fauna. Ramsar Strategy and Action Plan for Nepal's Wetlands Protection, covering 2018 to 2024, published by the Ministry of Forest and Environment, wetlands sustainable management practices. It also recommends synergizing the efficient as well as strategic use of wetlands. The Environment and Biodiversity Division of Ministry of Forests and Environment works with Department of National Parks and Wildlife Conservation (inside protected areas) and the Governments of seven Provinces, 753 Local Government bodies collaborate with wetland communities to manage wetlands.

4.3.3 | Enhancing Nepal's wetlands conservation: Lessons from international best practices

Nepal has implemented many conservation practices for sustainable use of wetland resources, giving major focus on community-based wetland management. Protected areas, buffer zones, and watershed management programs have also contributed to conservation efforts. However, Nepal's wetland conservation efforts lack several challenges and gaps. Nepal lacks clear zoning regulations that designate areas for urban development, buffer protection and core conservation. Looking at international practices, Nepal can learn from the zoning approach used in Suncheon Bay, South Korea (Ramsar Site: 1594), in which initiation from NGOs and Suncheon National University, Suncheon City Government of South Korea established four conservation zones: urban, transition, buffer and core zone. Development activities were only allowed within the urban zone, while wetland restoration programs were implemented within the core zone. This collaborative approach helped in balanced restoration along with local economic development. Similarly, long-term adaptive management techniques, weak institutional coordination and international financial resources have hindered the effective wetland management in Nepal. From Australia's Lake Monger (Galup) management model, Nepal can learn the importance of strategic zoning, long-term conservation planning and stakeholder collaboration to balance urban growth with ecological sustainability. Further, UK approach of managing Ramsar sites with a major focus on habitat restoration and biodiversity monitoring can also be the major idea that can be followed to protect Ramsar Sites in Nepal. For example: Somerset Levels and Moors (Ramsar Site: 914) is the prime example of habitat restoration.

5 | Conclusions

Wetlands are considered the biological hotspots, kidneys of the ecosystem and reservoir of genetic diversity and are considered the most productive ecosystems in the world. As Nepal is a landlocked country, Nepal has only freshwater inland wetlands, i.e., both natural and artificial. Among the Ramsar-listed wetlands of Nepal, four are located in Tarai, another four are in the Himalayas and the remaining two are in the Mid Hills of Nepal. Each wetland hosts several endangered and threatened species. Ilam's Maipokhari, Gosainkunda and associated lakes of Rasuwa, Kailali's Ghodaghodi Lake,and Kaski's Phewa Lake Clusters have cultural significance and

are home to significant biodiversity. The management and conservation of wetlands in Nepal have received less attention, thus being ruined by anthropogenic stress like climate change, urbanization, land use change, and so on. All the wetlands should be used wisely and require strategic planning at basin, catchment, local, regional, national and international levels for conciseness. Even though there is availability of several policies and legal frameworks, only a few selected wetlands have received significant attention. The participation of stakeholders as well as the government's plans and strategies are required for the sustainable development of Ramsar-listed and other wetlands. While government participation is crucial for policy development, local communities also play an essential role in wetlands conservation efforts, such as by engaging in community-based monitoring, sustainable resource management, eco-tourism initiatives and so on. Hence, community-based conservation initiatives must be prioritized along with policy enhancement and effective regulation of existing policies and improving inter-governmental/agency coordination. Real-time monitoring of wetlands using remote sensing and GIS technologies can also effectively help in developing adaptive strategies along with the early detection of changes. Therefore, the insertion of wetlands management objectives in regional plans, local planning schemes and local laws is required to increase the appreciation of wetlands and the importance of protecting their values.

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Authors' contributions

R.T. collected the data, performed the analysis, and prepared the draft manuscript. S.M. and S.K. also collected data and contributed to drafting the manuscript. R.T. and M.P.A. did data analysis, graphical representation, GIS mapping, and finalizing the draft. K.B. contributed to editing and visualization, while U.D. assisted with data interpretation. L.B.T. and V.B.S. provided critical reviews and edits. R.R.P. conceptualized the study, critically reviewed and finalized the manuscript, and supervised the project.

Conflicts of interest

The authors declare no conflict of interest.

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