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Review article

Climate Change Vulnerability and Conservation Strategies for Nepal's Ramsar Sites: Safeguarding Freshwater Biodiversity and Ecosystem Services

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ABSTRACT
Wetland ecosystems globally, particularly in countries like Nepal, face significant threats from climate change, jeopardizing their ecological integrity and the services they provide. This review paper consolidates existing knowledge on the susceptibility of the wetlands of Nepal to climate change and explores strategies for sustainable conservation and management. Through an extensive review of scientific studies, government reports, and conservation initiatives, the paper elucidates the diverse effects of changing climate on Nepal's wetlands, encompassing variations in hydrological regimes, habitat degradation, and loss. It underscores the need for comprehensive vulnerability assessments, long-term monitoring, and economic evaluations to inform effective policy decisions and conservation efforts. Furthermore, the paper emphasizes the importance of embracing holistic approaches, prioritizing ecosystem health, community involvement, and integrating indigenous knowledge. This review contributes to the scientific understanding of vulnerability driven by climate change in wetland ecosystems. It provides practical insights for policymakers, conservation practitioners, and researchers working towards the sustainable management of Nepal's wetlands.

Key words: Environmental conservation, Wetlands, Vulnerability

INTRODUCTION

Climate change is anticipated to significantly impact growth and well-being, especially among developing nations, due to their increased vulnerability and limited ability to withstand climatic risks (Pachauri et al. 2014). The forthcoming threat to species' persistence and ecosystems' health due to climate change worldwide has been widely acknowledged (Schroter et al. 2005, Malhi et al. 2020). Scientists globally are investigating the ecological and hydrological repercussions of climate change. Some predictions indicate that climate change will substantially affect these systems by altering their hydrological regimes, with the impacts varying significantly across different regions (Erwin 2009). Wetlands have been particularly prone to alterations in the volume and quality of water they obtain (Mortsch 1998). The anticipated rise in the global average temperature by 1.4 to 5.8^{o}C over the coming century is already exerting its influence on the Himalayas, which can be verified by the glaciers and glacial lakes falling in these regions as they are experiencing swift alterations overtime (Bajracharya et al. 2007).

Wetlands, which include wet areas such as marshes, swamps, fen, sloughs, bogs, glades, veli, jheel, and simsar, imply water management and provide various ecological services, including replenishing groundwater, carbon storage, and preventing flooding. They can be artificial or natural, permanent or temporary, with stagnant or moving water ranging from freshwater to brackish or salty. According to the Ramsar Convention Secretariat, the definition also includes marine regions with a depth of no greater than six meters (Anonymous 2016). These critical biosphere areas are of religious, sociocultural, economic, ecological, and aesthetic importance to humans and the broader environmental community, as stated in the report of the Ministry of Forestry and Environment, Government of Nepal (Anonymous 2018a). The Ramsar Convention, also known as the Convention on Wetlands of International Importance, was established to encourage the preservation, sustainable utilization, and acknowledgment of wetlands noteworthy for their ecological, botanical, zoological, limnological, or hydrological value. It was signed in Ramsar, Iran,

on February 2, 1971. Seventeen years after the initiation of this convention, Nepal joined as a signatory (Kafle and Savillo 2009). Nepal's wetlands provide indirect benefits, such as regulating climate and conserving biodiversity and direct economic value. Wetlands contribute 47% of the global ecosystem value, a higher value per hectare than other ecosystems (Costanza et al. 1997, Smardon 2009, Hu et al. 2017).

The wetlands in Nepal are directly interlinked with the water dynamics of the Himalayas and are considered biological hotspots and indispensable storehouses of genetic diversity. Roughly around 230 native fish species, 27% of nationally threatened bird species, 85% of its indigenous vertebrates, and 24% of preserved plant species are facilitated by these ecosystems, a substantial portion of the country's biodiversity (Shrestha et al. 2020). The Himalayan mountains, known as the "water towers of the world," are crucial to the hydrological cycles that sustain densely inhabited regions (Messerli et al. 2009). Some of the important rivers, such as the Indus, Ganges, Brahmaputra, Yangtze, and Yellow, have a tremendous effect on the survival of around 1.4 billion people, and these rivers originate from the Himalayan mountains, which inhabit approximately 170 million residents. These wetlands pose substantial threats due to anthropological activities and ecological changes such as overgrazing, pollution, and climate change. To safeguard the ecological and hydrological functioning of these regions, suitable approaches to management are needed (Murray 2009, Immerzeel et al. 2010).

Climate change has a noticeable impact in developing nations like Nepal, causing habitat degradation and putting various species at risk (Lamsal et al. 2017). Though the possible challenges are known, the country needs more resources to cope effectively. In the case of freshwater wetland ecosystems in the country, this is quite relevant as the effects of climate change are profound (Erwin 2009). Scientific research in Nepal, particularly regarding climate change and its impacts on freshwater wetlands, must be more extensive and scattered. This review aims to consolidate knowledge on climate change vulnerability and its specific implications on Nepal's freshwater wetland ecosystems.

RAMSAR SITES OF NEPAL

Nepal has been committed to safeguarding wetlands, which are deeply intertwined with cultural, tourism, and forest management initiatives in the country, for a long time, and this has strengthened since it joined the Ramsar Convention. The Government of Nepal (GoN) formally joined the Ramsar Convention on April 17, 1988, and chose Koshi Tappu as Nepal's first Ramsar Site in 2003, confirming its dedication to preserving these vital ecosystems. This action solidified Nepal's position as the 46th Contracting Party to the Convention (Anonymous 2018a). Wetlands in Nepal have only recently been studied systematically, leaving much to be discovered about their exact distribution, extent, and the biodiversity they support. Wetlands occupy 5.6% of Nepal's overall land area, including ten freshwater wetlands (Table 1, Fig. 1) recognized as Ramsar sites of global importance (Lamsal et al. 2017).

ECOSYSTEM SERVICES OF WETLANDS

Wetlands are essential ecosystems supporting ecosystems and communities, contributing to ecological, cultural, and economic well-being. In Nepal, nearly 10% of the rural population, including various ethnic groups, depend on wetland resources for survival (Anonymous 2004, 2018a). These highly productive ecosystems provide essential goods and services for daily life, including cultural sustenance and regulatory functions, as delineated by the Millennium Ecosystem Assessment (MEA) (Tables 2, 3) (Anonymous 2005).

Local populations derive certain ecosystem services from wetlands in four primary categories:

Regulatory services: The majority of the natural phenomena are regulated by the Wetlands, including water filtration, pollination, climate regulation, control of invasive species, disease, and pest control, and natural hazard management, which contribute to environmental equilibrium and social well-being (Zedler and Kercher 2005).

Cultural services: Wetlands offer spiritual and cultural values, different educational prospects, and options for recreation, aesthetic pleasure, and green tourism. Historically, they are considered the commencement points for numerous civilizations

Table 1. Ramsar sites of Nepal (Source: Anonymous 2024)

S.No.	Ramsar site	Designation date	Province	Area (ha)	Location
1	Koshi Tappu	17/12/1987	Koshi	17,500	26°39'N 86°58'E
2	Beeshazar and Associated Lakes	13/08/2003	Bagmati	3,200	27°37'N 84°25'E
3	Ghodaghodi Lake Area	13/08/2003	Sudurpashchim	2,563	28°40'N 80°57'E
4	Jagadishpur Reservoir	13/08/2003	Lumbini	225	27°34'N 83°04'E
5	Gokyo and associated lakes	23/09/2007	Koshi	7,770	27°57'N 86°40'E
6	Rara Lake	23/09/2007	Karnali	1,583	29°30'N 82°04'E
7	Gosaikunda and Associated Lakes	23/09/2007	Bagmati	1,030	28°04'N 85°25'E
8	Phoksundo Lake	23/09/2007	Karnali	494	29°12'N 82°57'E
9	Mai Pokhari	20/10/2008	Koshi	90	27°00'N 87°55'E
10	Lake Cluster of Pokhara Valley	02/02/2016	Gandaki	26,106	28°12'N 83°59'E

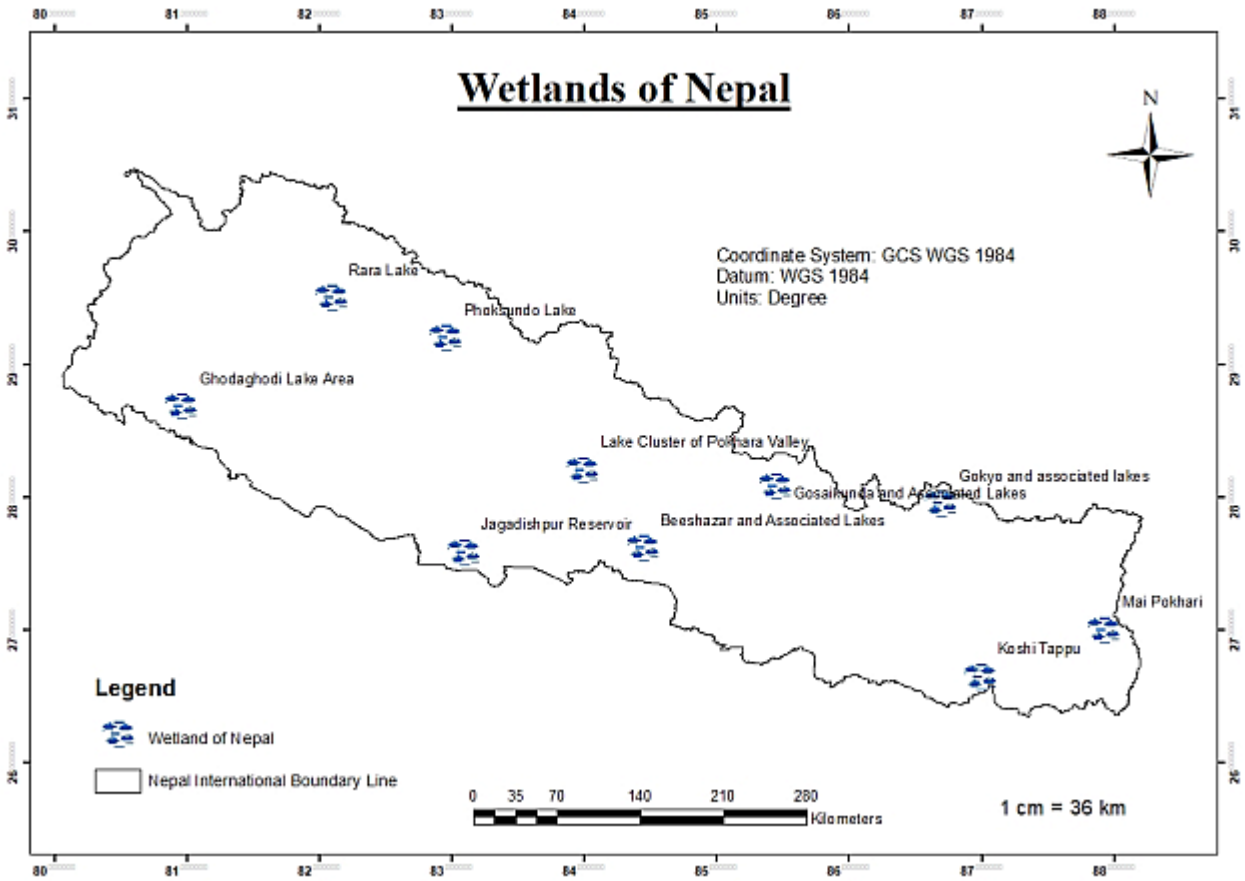

Figure 1. Distribution of Ramsar sites in Nepal (Source: Anonymous 2024)

and continue to serve a vital role in religious ceremonies (Chaudhary et al. 2019).

Provisioning services: Wetlands supply food, fuel, clean water, and genetic resources along with vital food sources like fish, frogs, and insects (Smith et al. 2019).

Supporting services: Wetlands support aquatic habitats by production, nutrient cycling, soil development, and retention (Zedler and Kercher 2005).

Table 2. Ecosystem services of wetlands (Source: Voora and Venema 2008)

Relevance	Services	Description-function
Water Quantity Quality - Lake Eutrophication	Water Regulation	Regulation of water flows, which transport contaminants and **and** cleanse water - **Regulating**
	Water Supply	Filtering, retaining, and preserving fresh water - **Provisioning**
	Erosion Control	Maintains arable land and prevents water silting by lowering soil losses by wind and sediment retention and runoff - **Regulating**
	Waste Treatment	Removal, breakdown, or abatement of pollutants - **Regulating**
Climate Change	Atmospheric Regulation	Regulation of atmospheric compositions by various processes such as carbon sequestration - **Regulating**
	Climate Regulation	Influence of land covers on climate (temperature, precipitation, etc.) - **Regulating**
Biodiversity	Biological Control	Control of populations, pests, and diseases through trophies - dynamic processes - **Regulating**
	Habitat	Suitable living space for species to evolve and breed - **Supporting**
Social Well-being	Recreation	Opportunities for recreation, relaxation, and refreshment - **Cultural**
	Cultural	Spiritual, religious, historical, and symbolic values - **Cultural**
Environmental Integrity	Soil Formation	Rock weathering and organic matter accumulation lead to the formation of productive - **Supporting**
	Nutrient Cycling	Storage processing and acquisition of nutrients within the biosphere - **Supporting**
	Pollination	Movement of Plant genes for reproduction - **Supporting**

Table 3. Types of wetland services with references to Nepal (Source: Anonymous 2018a)

Type of services	Examples in Nepal
Regulating	Beeshazar and associated lakes: Regulating flow in the Khageri River in controlling flood
Cultural	Gosainkunda and associated lakes: culturally rich according to Hindu mythology,Lake Cluster of Pokhara Valley: Rich in tourism and recreational value
Provisioning	Jagadishpur reservoir: The reservoir provides irrigation services to a large command area measuring 6070 ha
Supporting	Koshi Tappu and Beeshazar and associated Lakes: Support wetland habitat for birds and aquatic wildlife

CLIMATE CHANGE IMPACTS ON WETLANDS

Climate change is an unequivocal reality caused by anthropogenic activity disrupting the natural balance in the entire atmosphere, leading to significant changes to the climate along with climate variability across comparable periods (Sands 1992). Climate change poses a substantial threat to global eco-networks, and species survival is evident because of climate change, demanding adaptive strategies to mitigate impacts, enhance resilience, and ensure long-term ecological integrity amid environmental shifts (Hulme 2005). There is anticipation that climate change and CO_2 emissions will significantly influence ecosystem functions and environmental changes (Shukla et al. 2019). Climate change, together with invasive species, intensifies ecosystem degradation and biodiversity loss as it enhances the capacity of invasive species to disturb across diverse

bio-geographic and environmental circumstances (Burgiel and Muir 2010, Mainka and Howard 2010). *Cylindrospermopsis raciborskii*, a freshwater cyanobacterium from the tropics, has adapted to temperate zones in response to climate change-induced early increase in spring water temperature. Moreover, its competitive advantage in eutrophic systems has assisted in its spread (Howarth and Viner 2022).

Climate change poses a substantial risk to freshwater wetlands globally, disrupting hydrology and compromising functionality through elevated temperatures, droughts, floods, CO_2 rises, and brine intrusion (Poff et al. 2002). These alterations impact essential processes and ecosystem services, such as carbon retention, ecological diversity, wildlife habitat, and water integrity (Figs. 2, 3). Moreover, when combined with other pressures like alien invasive species and shifting land use, these adverse effects amplify the challenges of restoring and preserving wetlands, aloft the possibility of the disappearance of native species (Moomaw et al. 2018).

Across Asia, climate change, together with severe weather, has substantially influenced numerous wetland sites, amounting to 71 locations, alongside lake wetlands emerging as especially vulnerable, with 24% experiencing significant effects (Xu et al. 2019). With just below 1% of Earth's surface, freshwater ecosystems are crucial for sustaining a high degree of species variety per unit area, supporting roughly 6% of the planet's species (Anonymous 2005, Dudgeon et al. 2006). When integrated with stressors imposed by human beings, climate change stands out as one of the primary drivers contributing to the loss of biodiversity in wetlands across the globe (Anonymous 2005).

Since 1700, there has been an 87% decline in global wetlands, underscoring their alarming loss. Acknowledging their vital significance, both the Convention on Wetlands and the United Nations Decade on Ecosystem Restoration (2021-2030) emphasize the urgent need for their restoration to ensure a sustainable future, offering a pivotal chance for the worldwide endeavour to avert, halt, and reverse the degradation of the wetlands (Anonymous 2021c).

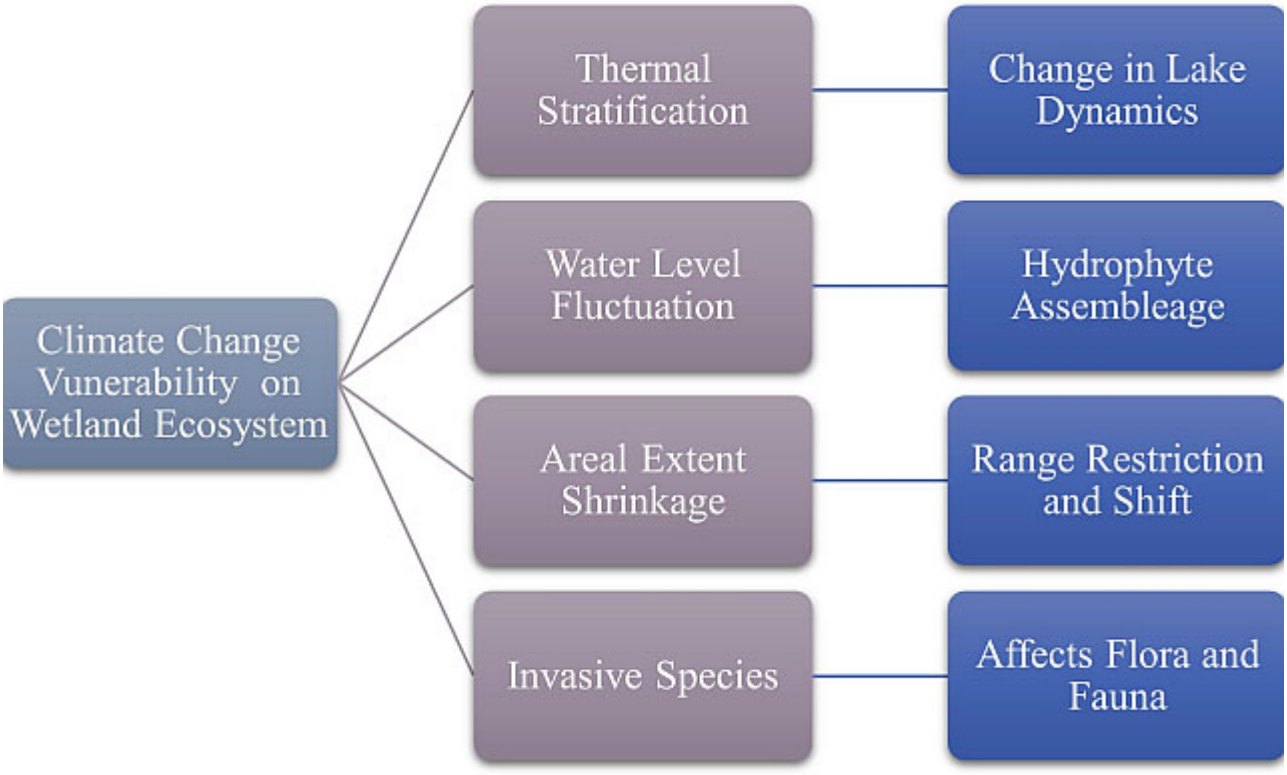

Figure 2. Vulnerability of climate change on the ecosystem of inland wetlands (Source: Lamsal et al. 2017)

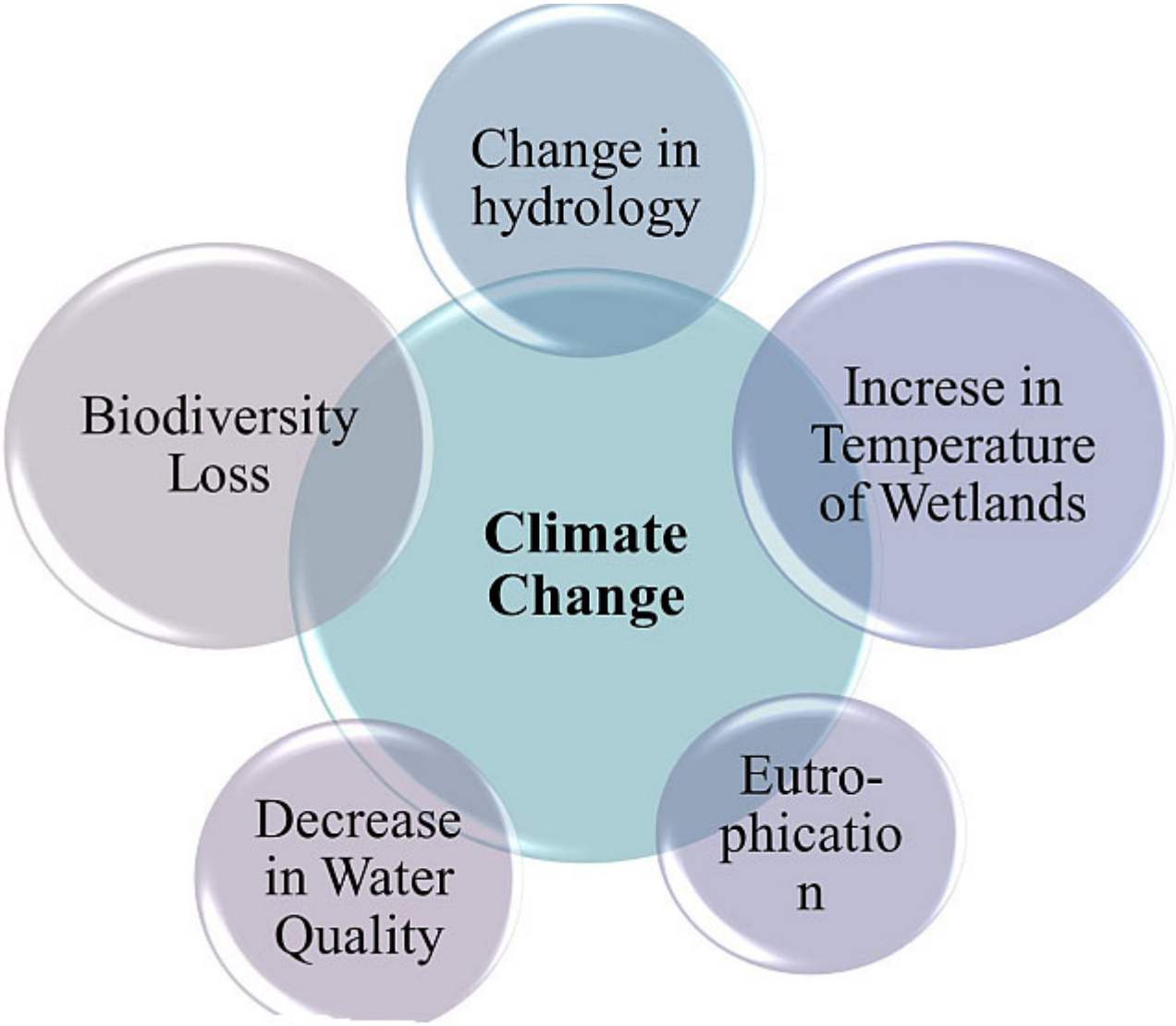

Figure 3. Effect of climate change on wetlands

VULNERABILITY OF RAMSAR SITES IN NEPAL

Ramsar sites in Nepal are at risk from changing climate change and human pressures, varying on spatial and temporal scales and influenced by local conditions and adaptive capacity. Gitay et al. (2011) highlight the significance of vulnerability analysis in directing wetland conservation, including factors like context, scale, uncertainties, and biophysical vulnerability, which are intimately linked with risk assessment amidst the face of climate change impacts.

Land use pressure: The resilience of many freshwater wetlands towards climate-induced hydrological changes has been reduced due to the increased land use pressure among them. Human alterations along river corridors increase these challenges, and rising demands for river resources are expected to exacerbate these issues. River re-engineering hinders the free flow of water despite its benefits for oxygenation and plant health (Moomaw et al. 2018).

Flash floods and drought: Climate change-induced events like flash floods in Darchula in 2013 and severe droughts in Himalayan districts Bajura, Humla, and Mugu in 2016, along with alterations in plant and animal behaviour, aquatic habitat shifts, and disease outbreaks, significantly impacted communities and development in Nepal (Anonymous

2018a, Bhattarai and Conway 2021). Altitudes between 2900 and 3500 meters above sea level are especially vulnerable, threatening freshwater ecosystems (Shah et al. 2015, Dubey et al. 2023).

Rapid ice melting: The increasing rate of ice melting causes glacial lakes to retreat, turning wetlands into swamps and causing small ones to vanish. In Sagarmatha National Park, glacier retreats and reduced snow cover affect water sources in dry seasons (Anonymous 2018a). Over recent years, Nepal has faced the repercussions of twenty-one glacier lake outburst flood incidents, with more than 200 potentially perilous glacial lakes pinpointed across the Himalayan region (Bajracharya et al. 2007).

Fluctuations in water availability: Beyond Ramsar sites, Nepal hosts numerous additional freshwater wetlands supporting various endangered species. Bhuju et al. (2010) documented 5358 wetlands distributed across lowland, mid-hill, and high-altitude Himalayan regions. Fluctuations in water availability in Nepal's rivers and streams, predicted by Chaulagain (2011), are expected to impact both Ramsar and other wetlands due to either their reliance on glacier melt or riverine floodwaters. These fluctuations could lead to changes in wetland ecosystems and a reduction in wetland areas, posing a threat to numerous endangered fauna (Ouyang et al. 2014, Lou et al. 2015).

As indicated by Rijal et al. (2021), Nepal's wetlands face challenges that include limited understanding, insufficient coordination among government agencies, and confusion in wetland management due to fragmented laws, neglect of ongoing mismanagement and degradation, and invasion of alien species. Climate change poses long-term consequences without adequate adaptation systems. Dulal et al. (2010) revealed that local communities reliant on the Koshi Tappu floodplain have limited adaptive capacity, leaving them vulnerable to climatic hazards like floods and droughts. Gurung and Bhandari (2009) noted insufficient adaptation measures in the Chitwan district due to a lack of climate expertise and financial resources, which obstruct effective long-term strategies against climate change repercussions.

CONSERVATION STRATEGIES

The Ramsar Convention emphasizes the conservation of wetlands through its core missions and strategically adopted three pillars (Anonymous 2014). These pillars are obligatory for all signatory contracting parties, usually governmental departments. The first pillar involves incorporating wetland conservation into national land-use plans, ensuring execution, establishing nature reserves, and advancing wetland-related research and management. The second pillar requires designating at least one Ramsar site nationally, ensuring its preservation, and reporting any alterations in its ecological makeup. The third pillar mandates consultation among signatories, particularly concerning transboundary wetlands, common water systems, and common species.

Nepal has a noteworthy conservation history regarding wetlands, rooted in protecting nature and its resources, which can be witnessed with the introduction of the first Wildlife Act in 1957 to preserve the Rhinoceros population in Chitwan (Prajapati et al. 2020). The Government of Nepal further solidified its commitment to conservation with the National Parks and Wildlife Conservation Act of 1973 (Anonymous 1973). As the Ramsar Convention's signatory, Nepal's dedication to wetland conservation was foreseen, along with the Koshi Tappu Wildlife Reserve declaration as the country's first Ramsar site (Khatiwada et al. 2021). In 2016, nine lakes in Kaski district were declared Ramsar sites named 'Lake Cluster of Pokhara Valley' on World Wetlands Day. With this, Nepal has 10 Ramsar sites, which can be taken as a significant step towards conserving wetlands. This accomplishment was part of Nepal's National Biodiversity Strategy and Action Plan for 2014-2020, which aimed to list a minimum of five wetlands in the Ramsar Site (Anonymous 2018b).

The Government of Nepal (GoN) is giving precedence to the valuation of climate-induced loss and damage (L&D) as part of its Nationally Determined Contributions (NDC) revision. Nepal's Climate Change Policy 2019 (Anonymous 2019) focuses on studying L&D linked to climate change effects and executing strategies to mitigate climate

change-related susceptibilities (Anonymous 2021a). Additionally, developing a National Adaptation Plan (NAP) is underway to decrease the country's susceptibility to climate change and promote incorporating climate adaptation into policies, programs, and activities across various fields and administrative levels (Table 4). The NAP process considers Nepal's climatic and geographical attributes and the opportunities and challenges linked with climate adaptation and development (Anonymous 2021b).

Amidst periods of flux and uncertainty, especially with the influence of climate change and evolving economic and political landscapes, it is wise to recognize the complex power dynamics in wetland resource utilization, access, and decision-making at a broader level. It is more practical to consider adaptive management approaches rather than assuming one-size-fits-all solutions beneficial to all parties involved, as underscored by Cleaver and Whaley (2018). Thagunna et al. (2023) highlighted the need for innovative financing mechanisms to support wetland conservation and local livelihoods. Funding from various sources, including REDD++, the World Bank, NGOs, and governments, is essential for these efforts. Strengthening upstream linkages and clarifying roles and responsibilities across government tiers are crucial conservation priorities.

A global pilot program for climate change mitigation is underway, emphasizing the need to prioritize vulnerable local communities, particularly those dependent on wetlands (Lamsal et al. 2017). Integrated interventions and technological support can accelerate effective adaptation efforts in wetlands ecosystems. Utilizing frameworks such as those proposed by Acreman et al. (2009) allows decision-makers to systematically assess climate-related risks to wetlands, even in data-deficient countries like Nepal. Prioritizing local knowledge is crucial for tailoring context-specific strategies and ensuring successful long-term adaptation. The World Bank and other agencies have introduced screening tools like ADAPT and CRiSTAL to help project planners assess and mitigate climate-related risks during the design phase. These tools emphasize risk management (Gitay et al. 2011).

RESEARCH GAP AND FUTURE DIRECTION

The vulnerability of wetlands varies depending on their location, and different habitats exhibit distinct vulnerabilities. This makes it challenging to identify and implement responses. Scenario setting can help by envisioning possible futures and involving

Table 4. Strategies for Sustainable Wetland Management and Conservation (Source: Anonymous 2018b)

Strategies	Key actions to be done
Resource Conservation	· Identify and demarcate regions prone to flooding and build elevated structures to shield wildlife from floods. · Encourage a holistic and resilient tactic for watershed protection, encompassing river basins, subbasins, watersheds, sub-watersheds, and micro-watersheds.
Capacity Building	· Strengthen the abilities of indigenous communities to facilitate their meaningful engagement in planning, executing, and overseeing processes. · Setting up an information center and advocating for the involvement of native communities in wetland management will foster comprehensive and collaborative public initiatives.
Research	· Conduct a comprehensive inventory of wetlands, assess their importance, and formulate a management strategy with precise conservation objectives, such as preserving species, culture, habitats, and more.
Policy Initiatives	· Develop an inclusive watershed management strategy incorporating participatory and integrated strategies for watershed management. · Create an operational mechanism, including a two-way communication and reporting system, for climate change adaptation involving the national, provincial, and local governments, as well as local communities.

stakeholders in identifying response options. To support adaptive capacity in local communities and effectively implement responses, it is often necessary to address mismatches between ecosystem boundaries and management jurisdictions (Gitay et al. 2011).

There are research gaps in wetland management that need to be addressed. Long-term monitoring of crucial wetland biophysical parameters and their catchments is needed to establish benchmarks or baselines. It is also essential to assimilate data gathering for risk calculation, management, and monitoring and address any shortfalls in these areas. However, downscaling climate and other models and developing circumstances that outline future changes in system drivers, status, and conditions is challenging due to limited present knowledge (Ghimire 2023).

Payment for Ecosystem Services (PES) is gaining recognition in Nepal, but the absence of a clear understanding and policy framework hampers its equitable implementation. Although economic evaluations have been conducted for specific Ramsar sites like Phewa Lake of Pokhara, Koshi Tappu, and Jagadishpur Reservoir, a comprehensive assessment of all wetlands in Nepal needs to be conducted. Therefore, future research endeavours should prioritize conducting economic evaluations of wetlands across Nepal to gain a more nuanced understanding of their value and guide informed policy decisions (Anonymous 2018a).

To enhance wetland resilience against climate change, addressing pollution and habitat destruction and preserving natural river flow patterns is necessary. Restoring riverine wetlands for flood accommodation is increasingly recognized over traditional methods like levees. Embracing holistic approaches to prioritizing ecosystem health is also essential (Sandholz 2016).

Integrating local indigenous knowledge and monitoring systems bolsters resource management. Initiatives like participatory watershed conservation and engaging communities from upstream to downstream be crucial. Recognizing Indigenous rights ensures their meaningful contribution (Anonymous 2018b).

CONCLUSION

Nepal's wetlands are internationally recognized for their ecological value despite escalating pressures from anthropological activities and climate change. While strict policies can reinforce conservation efforts, justifiable solutions such as renewable energy initiatives and community engagement are essential. Moreover, promoting eco-tourism and continuing research endeavours offer additional channels for funding. Regardless of praiseworthy efforts, including Ramsar site designation and policy execution, gaps and challenges continue, imposing a concentrated focus on continuing sustainability.

Assimilating indigenous knowledge into adaptation strategies would enhance resilience to climate change. Existing research and literature demonstrate Nepal's wetland's sensitivity to climate change-induced alterations in hydrological regimes, habitat degradation, and loss. Insufficient studies and fragmented knowledge aggravate the obstacles faced by these ecosystems. The prioritization of detailed and descriptive vulnerability assessments, long-term monitoring, and economic evaluations are needed to address these gaps and effectively develop policy decisions.

Furthermore, conservation initiatives must progress to include holistic approaches that emphasize ecosystem health, public involvement, and the integration of indigenous knowledge. Initiatives like participatory watershed conservation and unbiased benefit-sharing mechanisms can boost the resilience of wetland ecosystems. In conclusion, Nepal's wetlands must be conserved with collaborative efforts across local, national, and international levels, backed by strong policies and continuous investment in research and management. Nepal can mitigate the impacts of climate change and preserve these invaluable ecosystems for future generations by addressing research gaps and implementing adaptive management strategies.

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