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Research Article

WATER QUALITY, EUTROPHICATION, AND ECOSYSTEM SERVICES OF TWO URBAN WETLANDS OF LALITPUR DISTRICT, CENTRAL NEPAL

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ABSTRACT
Eutrophication is a major cause of wetlands degradation worldwide. In Nepal, urban wetlands play a crucial role in delivering ecosystem services essential for maintaining biodiversity and supporting local livelihoods. Therefore, conservation, sustainable management, and wise use of wetlands are imperative. This study evaluates water quality, eutrophication status, and the ecosystem services of two urban wetlands- Nagdaha and Ankhidaha situated within the Kathmandu Valley, Nepal. Standard methodologies were followed to assess water quality parameters, while key informant interviews were conducted to evaluate ecosystem services. Temporal changes in Land use land cover (LULC) for the years 2000, 2010, and 2020 were analyzed using Landsat-7 satellite imagery. The water quality index values of Nagdaha (50.15) and Ankhidaha (52.47) indicate poor water quality. Statistical analyses revealed a strong correlation between nitrate and dissolved oxygen levels in both wetlands- Nagdaha ($t = 35.68$, $p<0.001$) and Ankhidaha ($t= 9.42$, $p<0.001$). Dissolved oxygen levels in Ankhidaha for the years 2018, 2019, and 2021 were found to pose a substantial threat to aquatic life. The findings indicate that eutrophication is compromising wetlands quality, subsequently diminishing the provision of ecosystem services. LULC analysis highlights rapid urbanization, leading to a decline in vegetated areas and a consequent deterioration in water quality. Nine ecosystem services were identified as relevant to both local and broader communities, with recreation and ecotourism, biodiversity maintenance, and educational opportunities emerging as the most prioritized. These insights provide valuable guidance for urban wetlands management and ecological restoration efforts.

Keywords: Eutrophication, land use land cover, water quality, urbanization, wetlands

INTRODUCTION
Nepal is home to over 5000 standing water bodies, which serve as critical water resources while providing essential ecosystem services (ES) to their surrounding environments (Bhuju *et al.*, 2012; Thapa *et al.*, 2020). However, the ecological integrity of these wetlands has been increasingly compromised due to anthropogenic influence. Once pristine, many of these wetlands now face severe degradation as a result of various environmental stressors. Prominent among these are sewage contamination, improper waste disposal, agricultural runoff laden with chemical fertilizers, and land encroachment all of which have significantly deteriorated the wetlands (Rewati, 2012). Wetlands function as recipients of nutrients and sediment from their surrounding landscapes due to natural erosion, surface runoff, and anthropogenic activities (Scheren *et al.*, 2000). Consequently, these ecosystems accumulate nutrients over time, ultimately leading to eutrophication (Vollenweider; 1968; Andersen *et al.*, 2006; Tett *et al.*, 2007).

Nagdaha and Ankhidaha are not merely water bodies; they constitute essential components of the Kathmandu Valley's ecological, cultural, and historical landscape. Nagdaha serves as a crucial resource for irrigation, offers a tranquil space for recreation, and functions as a sacred site for religious practices, including rituals dedicated to serpent deities (nagas) believed to reside in the wetlands and bring prosperity and rainfall (Shankar, 2010). Similarly, Ankhidaha, historically renowned for its petroleum spring, holds cultural and mythological significance, as it was once believed to be the dwelling place of serpent deities (Shankar, 2010). These wetlands provide water for irrigation, support domestic activities such as washing clothes and bathing, serve as sanctuaries for migratory birds, and preserve local folklore that fosters a profound human-nature connection (Shankar, 2010).

The study wetlands, Nagdaha and Ankhidaha, were originally surrounded by dense forested landscapes. However, urban expansion in the Kathmandu Valley (Ishtiaque *et al.,* 2017) has led to significant land use transformations. Between 1989 and 2009, extensive urbanization resulted in the conversion of surrounding forested areas into residential settlements.

This urban encroachment has likely exacerbated the vulnerability of these wetlands to pollution, as increased sedimentation, sewage inflow, and nutrient runoff from adjacent built-up and agricultural lands have directly impacted water quality. Moreover, the construction of concrete walls along the wetland periphery has disrupted natural hydrological processes, restricted aquatic habitat availability, and altered the ecological balance. Additionally, frequent usage of these wetlands by local communities for washing clothes and bathing has further contributed to their degradation (Shankar, 2010). The conservation of these wetlands is not solely an environmental concern but also a cultural imperative, as they embody traditions, stories, and cultural heritage that must be preserved for future generations. Therefore, the assessment of water quality and eutrophication levels, as well as the evaluation of ecosystem services provided by these wetlands, is essential for devising effective and sustainable management strategies. This study aims to investigate the trophic status of these wetlands, identify the drivers of eutrophication, and assess the ecosystem services they offer by employing a multidisciplinary approach incorporating water quality analysis, key informant interviews, and temporal land use and land cover change assessment.

MATERIALS AND METHODS

Study Area

Nagdaha and Aakhidaha, situated in ward 24 of Lalitpur Metropolitan City within the Lalitpur district of the Kathmandu Valley, were selected for a study. Nagdaha spans an area of 0.92 km² and exhibits a distinctive zig-zag shape (Fig. 1). The name 'Nagdaha' is derived from a snake, often referred to as the 'serpent wetland'. A statue of Nag is positioned on the north-western side of the lake, signifying its cultural and religious importance. Nagdaha serves as a habitat for diverse aquatic and avian species. Several native fish species, including barbs and snakeheads, are abundant in the wetland. Additionally, it provides a vital refuge for numerous bird species, making it a popular site for birdwatching (Shrestha *et al.*, 2023).

Ankhidaha, located approximately 250 meters east of Nagdaha, is regarded as the 'eye' of Nagdaha. It has an area of 0.21 km² (Fig. 1). Although Ankhidaha supports a comparatively lower diversity of fish and bird species, it holds substantial social and cultural significance (Shankar, 2010).

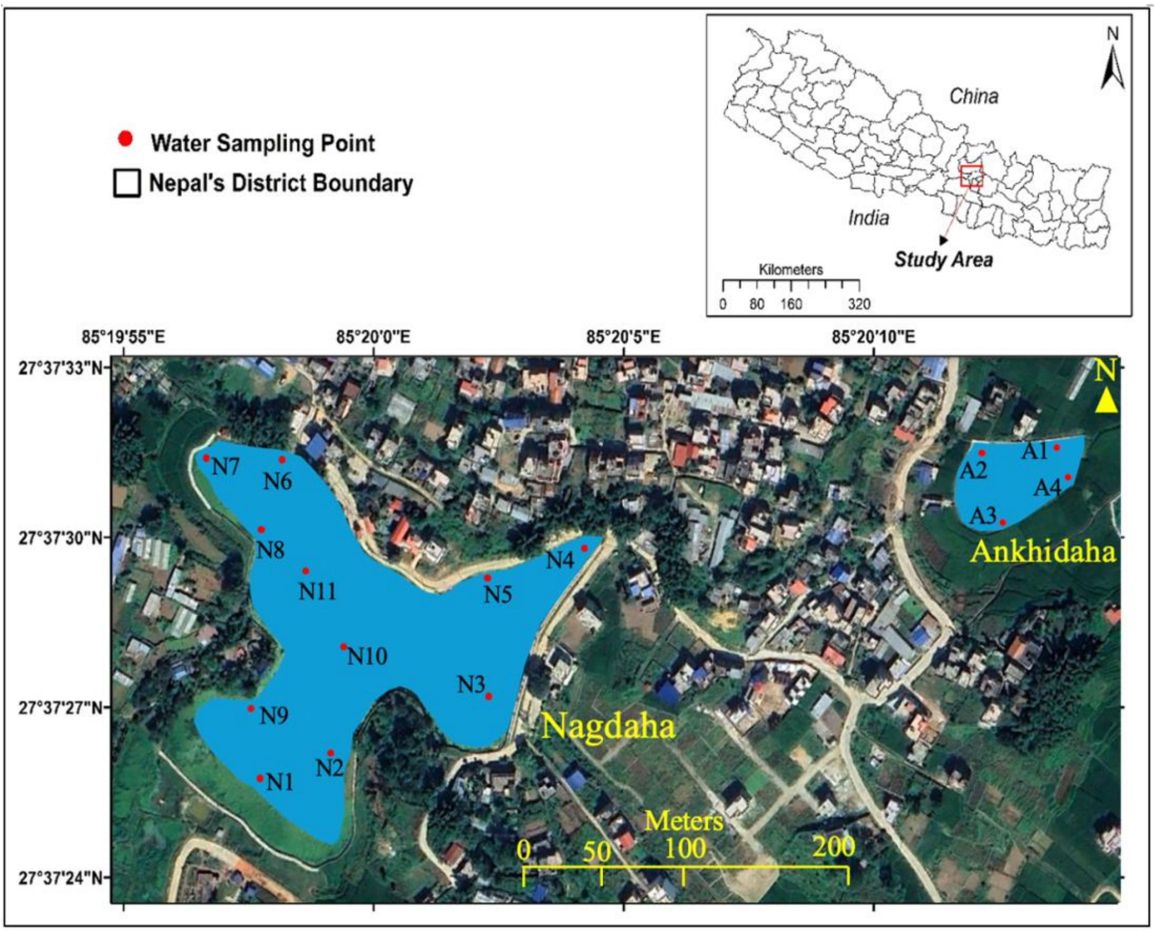

Figure 1. Nagdaha and Ankhidaha wetlands in Lalitpur district. The red dots represent the sample points in each wetland. (Source: Survey Department of Nepal; Google Earth)

Methods

Water Quality

The water samples were systematically collected from 15 locations between 2013 and 2021 using a purposive sampling approach. Key sites targeted included inlets, central areas, outlets, locations affected by human disturbances, and areas adjacent to agricultural fields. Eleven samples were collected from Nagdaha, while four samples were collected from Ankhidaha during the pre-monsoon season. Each sample was collected at a depth of 20 cm below the surface and stored in a 1 L HDPE bottle. All samples were maintained at 4°C in an icebox. In-situ measurements were conducted for dissolved oxygen (DO), electrical conductivity (EC), pH, total dissolved solids (TDS), chloride, and total hardness, while additional parameters were analyzed in the laboratory following the standard procedures (APHA-AWWA-WEF, 2017).

Ecosystem Services (ES)

Key informant interviews (KII) were conducted using purposive sampling to evaluate ecosystem services (ES). Participants included local residents and stakeholders aged between 35 and 50 years, all of whom had lived in the area for more than 15 years. A total of eighteen local residents including hotel owners and teachers were interviewed, with nine individuals from each wetland (five male and four female), all of whom regularly utilize the wetlands for daily activities such as washing clothes and bathing. The responses obtained from these informants provide a representative understanding of the ecosystem services offered by the wetlands.

Land Use Land Cover (LULC) Change

Land use land cover (LULC) maps for the years 2000, 2010, and 2020 were generated through supervised classification using ArcMap 10.3.1. The analysis was based on satellite imagery obtained from Landsat-7 (USGS, 2022). To enhance classification accuracy, composite images were created by integrating bands 1, 2, and 3 from the downloaded satellite images. The LULC maps were subsquently developed using the Training Sample Manager tool, with more than 30 training samples collected for each land cover class to ensure precise classification. The LULC maps from 2000, 2010, and 2020 were compared to analyze changes in vegetation cover, built-up areas, agricultural land, and water bodies.

Data Analysis

Water Quality Index

The water quality index (WQI) has been recognized as a robust tool for evaluating overall water quality (Abbai and Abbasi, 2012). In this study, the WQI was determined using the Arithmetic Weight Water Quality Index (AWWQI) method, which facilitates the assessment of wetland water conditions based on physicochemical parameters (Tyagi *et al.*, 2013). For the assessment of wetlands water quality for drinking purposes, WHO guideline (WHO, 2017) was consulted. The calculation of WQI follows the methodology governed by the following formula (Brown *et al.*, 1972).

$$WQI = \frac{\sum Q_i * W_i}{\sum W_i}$$

$$Q_i = \frac{V_i - V_O}{S_i - V_O} * 100$$

Where,

Q_i = Quality rating scale for each parameter

W_i = Unit weight for each water quality parameter

V_i = Estimated concentration of i^{th} parameter in the analyzed water

S_i = Recommended standard value of i^{th} parameter (In this study, WHO (2017) guidelines were consulted)

V_o = Ideal value of this parameter in pure water, so, its value is always zero except pH (7) and dissolved oxygen (14.6 mg/L)

The unit weight (W_i) for each water quality parameter is determined by:

$$W_i = \frac{K}{S_i}$$

Where,

K = Proportionality constant which can be calculated by:

$$K = \frac{1}{\sum\left(\frac{1}{S_i}\right)}$$

The water quality of the wetlands were compared against the drinking-water standards set by the WHO (2017) and NDWQS (CBS, 2019) to evaluate the suitability of wetland water for human consumption and aquatic life. Additionally, the water quality was evaluated in accordance with the Indian (CPCB, 1983) and Chinese (SEPA, 1997) water quality guidelines for aquatic life.

Eutrophication Assessment

Following the calculation of nitrate-nitrogen (NN) and phosphate concentrations, the obtained values were compared against the threshold values for eutrophic lakes (see Sawyer, 1947), which define eutrophic conditions as phosphate concentrations exceeding 0.01 mg/L and NN concentrations exceeding 0.3 mg/L. To further investigate the potential influence levels on oxygen dynamics within the wetlands, a scatter plot was generated to illustrate the relationship between nitrate, phosphate, and dissolved oxygen. This analysis provides valuable insights into the potential risks of eutrophication in the study area.

RESULTS

Water Quality

The Arithmetic Weighted Water Quality Index (AWWQI) was calculated to be 50.15 for Nagdaha and 52.47 for Ankhidaha, classifying both wetlands into poor water quality class.. Sites in close proximity to human disturbances and agricultural activities exhibited comparatively higher levels of pollution, as indicated in their elevated AWWQI values.

Although most physicochemical parameters remained within the permissible limits, dissolved oxygen levels in Ankhidaha fell outside the acceptable range established by Indian guidelines for aquatic life (Table 1). Similarly, phosphate concentrations in both wetlands exceeded the thresholds defined by Chinese guidelines for aquatic life (Table 1). These findings suggest that the water quality in these wetlands is moderately polluted, posing potential risks to both aquatic life and human consumption.

Table 1. Mean values of physicochemical parameters of Nagdaha (N) and Ankhidaha (A) urban wetlands across different years.

Parameters	2013		2018		2019		2021		Guideline			
	N	A	N	A	N	A	N	A	Drinking water		Aquatic life	
Temperature (°C)	24.00	24.00	26.60	24.50	25.00	24.00	24.97	24.63				
pH	7.09	7.10	7.20	7.23	7.20	7.31	7.71	7.73	6.50-8.50	6.50-8.50	8.5	8.5
EC (µS/cm)	135	160	291	310	268	288	310	292	-	1500	1000	-
DO (mg/L)	8.64	6.14	4.85	2.62	4.56	3.02	4.47	2.10	-	-	4	-
TDS (mg/L)	67	80	145	155	134	144	155	146	1000	1000	-	-
TH (mg/L)	33	41	72	77	67	72	76	72	500	500	-	-
Turbidity (NTU)	-	-	-	-	-	-	6	6	5	5	-	-
Cl^- (mg/L)	18.33	13.12	20.11	12.30	18.14	10.12	19.17	12.92	250	250	-	250
Nitrate (mg/L)	0.13	0.17	0.13	0.19	0.23	0.31	0.25	0.45	50	50	-	20
Phosphate (mg/L)	0.47	0.48	0.56	0.67	0.52	0.61	0.51	0.54	-	-	-	0.05
Ammonia (mg/L)	0.41	0.31	0.38	0.37	0.44	0.27	0.45	0.70	1.5	1.5	1.2	-
Iron (mg/L)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.3	0.3	0.5	-

The mean phosphate concentration in Nagdaha and Ankhidaha were recorded at 0.52 mg/L and 0.58 mg/L, respectively. Similarly, the mean NN concentrations were 0.19 mg/L in Nagdaha and 0.28 mg/L in Ankhidaha. Both wetlands exceed the guideline values of NN, and phosphate given by Sawyer (1947) for eutrophication. Dissolved oxygen (DO) levels exhibited notable variation, with Nagdaha having a mean DO concentration of 5.63 mg/L, while Ankhidaha recorded a considerably lower mean of 3.47 mg/L.

In Nagdaha, phosphate, NN, and DO concentrations varied within the ranges of 0.47-0.56 mg/L, 0.13-0.25 mg/L, and 8.64-4.47 mg/L, respectively. Correspondingly, in Ankhidaha, phosphate concentrations ranged from 0.48 to 0.67 mg/L, NN from 0.17 to 0.45 mg/L, and DO from 6.14 to 2.10 mg/L. The phosphate and nitrate levels were comparatively higher in Ankhidaha (Fig. 2). Furthermore, an inverse relationship was observed between DO levels and the concentrations of total nitrogen (TN) and phosphate in both wetlands (Fig. 3).

Statistical analysis revealed a significant negative correlation between phosphate and DO in Nagdaha ($t = 39.067$, $p < 0.001$) and Ankhidaha ($t = 60.4$, $p < 0.001$). Likewise, a strong negative correlation was identified between DO and TN in Nagdaha ($t = 35.68$, $p < 0.001$) and Ankhidaha ($t = 9.42$, $p < 0.001$). A comparative analysis of water quality parameters from 2013 demonstrates a substantial decline in its quality. In 2013, DO concentration in Nagdaha was recorded at 8.64 mg/L, while nitrate and phosphate concentrations were 0.13 and 0.47 mg/L, respectively (Table 1). However, by 2021, DO concentrations in both wetlands had decreased by approximately 50%, and nitrate and phosphate concentrations increased by approximately 10%. These findings indicate a progressive decline in water quality, emphasizing the potential influence of anthropogenic activities in exacerbating eutrophication within these wetland ecosystems.

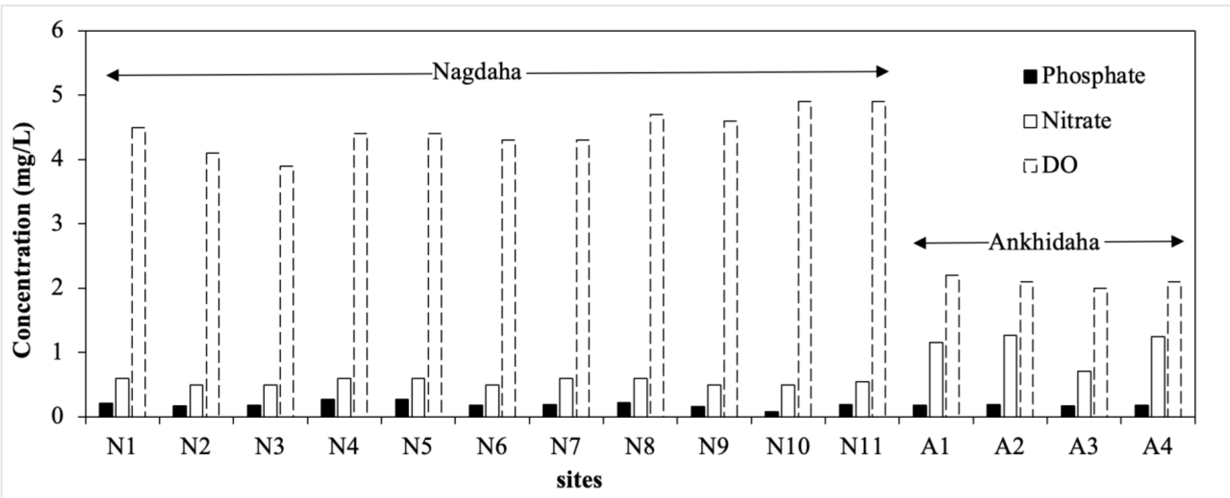

Figure 2. The water quality parameters: dissolved oxygen, nitrate, and phosphate in Nagdaha and Ankhidaha.

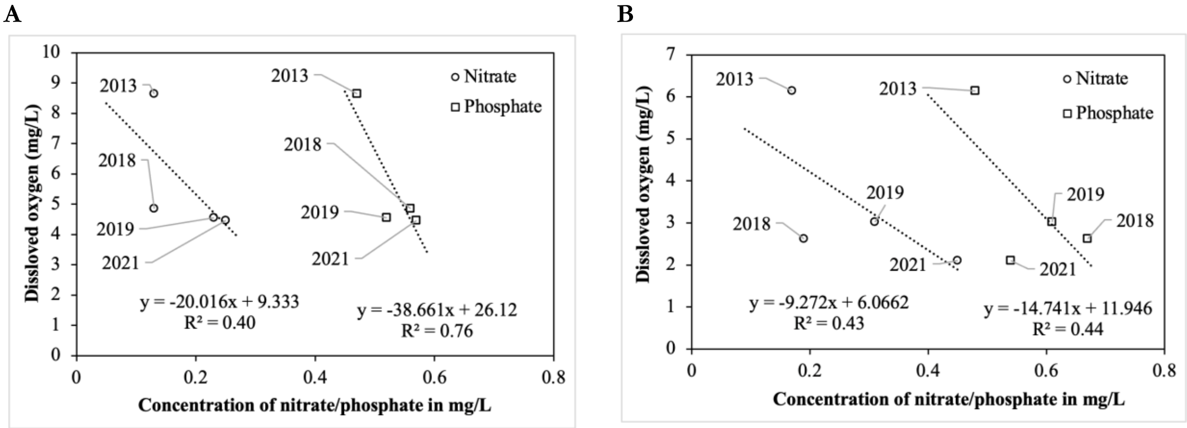

Figure 3. Temporal relationship between dissolved oxygen and nitrate and phosphate concentrations in Nagdaha (A) and Ankhidaha (B) wetlands.

Land Use Land Cover Change

The land use land cover (LULC) analysis for the years 2000, 2010, and 2020 (Fig. 4) reveals significant transformations, particularly in the expansion of built-up areas and the reduction of agricultural land. The findings indicate a marked increase in land encroachment, leading to a substantial decline in wetlands (0.91% in 2000 to 0.79% in 2020) and vegetative cover (15.65% in 2000 to 9.56% in 2020). Over time, the expansion of urban infrastructure (4.22 % in 2000 to 23.73% in 2020) has intensified, resulting in pronounced alterations in land use patterns.

Ecosystem Services

The Nagdaha and Ankhidaha wetlands provide a diverse range of ecosystem services (ESs) (Table 2). Among these, provisioning and cultural services were the most widely recognized and understood by local communities, primarily due to the wetlands' historical and cultural significance and their direct role in subsistence livelihoods. While local residents were also aware of regulating services (e.g., carbon sequestration) and habitat services (e.g., biodiversity maintenance and habitat protection), their direct interaction with these services was relatively limited.

The significance of cultural services has evolved over time (Table 2). Aesthetic values have remained consistently moderate, while educational opportunities have gained greater importance, shifting from low to high after 2020. Recreation and ecotourism continue to provide substantial benefits at both local and wider scales. In contrast, provisional services like freshwater supply have declined in importance, dropping from high to moderate at the local level and from moderate to low on a wider scale. Irrigation for crop production has consistently remained a minor service throughout the period. Similarly, biodiversity maintenance, which was once a high-priority service, has diminished to moderate importance.

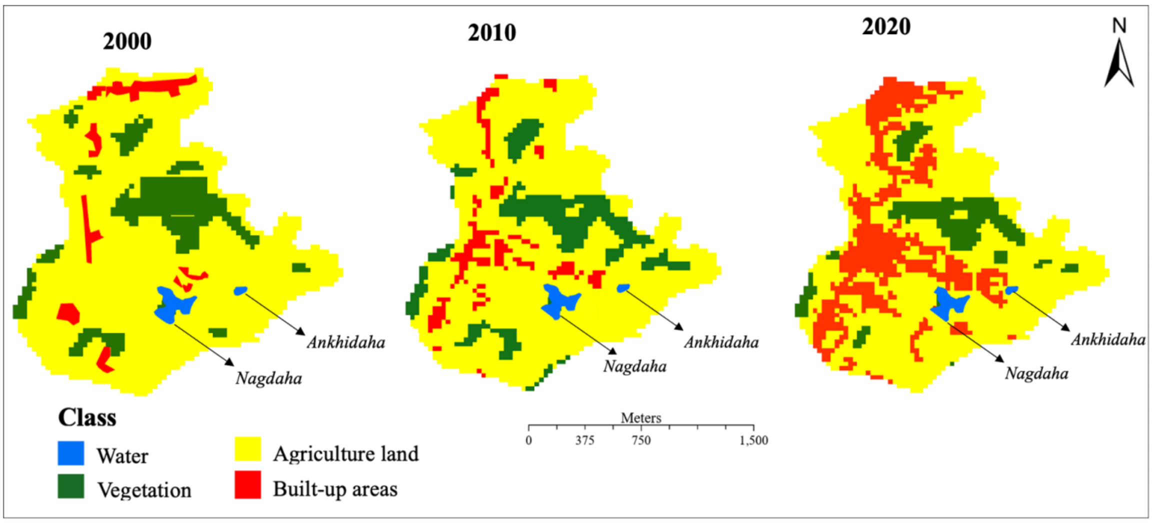

Figure 4. Land Use Land Cover Change in Lalitpur Metropolitan City Ward No. 24, for the years 2000, 2010, and 2020. (Source: Landsat-7 image courtesy of the USGS, 2022)

Regulating services, such as groundwater recharge, carbon storage, and sediment retention, have remained relatively low across different time periods. However, ecosystem services such as carbon sequestration, biodiversity conservation, sediment retention, and recreational benefits remain widely valued. Overall, there has been a noticeable shift in priority toward cultural services, particularly education and recreational opportunities, in recent years.

Table 2. People's perception of wetland's capacity to provide various ecosystem services, based on resource utilization

SN	Ecosystem Services	Local benefits		Wider benefits	
		Before 2010	After 2020	Before 2010	After 2020
1.	**Cultural**				
	Aesthetic values	**	**	**	**
	Educational opportunities	*	***	*	***
	Recreation and ecotourism	***	***	***	***
2.	**Provisional**				
	Freshwater	***	**	**	*
	Crop production	*	*	*	*
3.	**Supporting services**				
	Biodiversity maintenance	***	**	***	**
4.	**Regulating**				
	Groundwater recharge	*	*	*	*
	Carbon stock	*	*	*	*
	Sediment retention	*	*	*	*

*Low, **Moderate, ***High

DISCUSSION

Water quality

The water quality of both wetlands is classified as moderately polluted. However, specific sites adjacent to agricultural land, hotels and restaurants, households, and areas experiencing high human disturbances exhibit elevated nitrate and phosphate concentrations. These findings suggest that land-use patterns and anthropogenic activities significantly influence water quality.

A comparative analysis of water quality across different years (2013, 2018, 2019, and 2021) reveals a concerning trend. DO levels in Ankhidaha and phosphate concentrations in both Nagdaha and Ankhidaha consistently fail to meet the criteria set for aquatic life. The observed decline in DO and relatively high nitrate and phosphate concentrations at specific sites can likely be attributed to the influx of chemical and organic pollutants originating from agricultural runoff, wastewater discharge from hotels and restaurants, domestic effluents, and other human disturbances such as cloth washing and bathing and temple activities (e.g., Hai *et al.,* 2009; Bishwakarma *et al.*, 2019; Pant *et al.*, 2019).

Moreover, rapid urbanization is likely exacerbating pollutant infiltration into these wetlands. Unregulated urban expansion and increased land encroachment is leading to greater pollutant loading from untreated sewage, solid waste, and surface runoff, further deteriorating wetland health (Rhodes *et al.*, 2001; Bishwakarma *et al.*, 2019). These findings highlight the urgent need for integrated land-use planning, pollution mitigation strategies, and wetland conservation measures to safeguard the ecological integrity of these freshwater ecosystems.

Eutrophication

The analysis reveals a significant decline in DO levels alongside increasing nitrate and phosphate concentrations from 2013 to 2021, indicating a strong impact on DO depletion (Fig. 3) and eutrophication (Sawyer, 1947) in both wetlands. This trend poses serious risks to aquatic life and ecosystem services (Le & Zha, 2010; Hallouin *et al.*, 2018).

Rapid urbanization and land-use changes have intensified pollution sources, with both wetlands surrounded by agricultural and built-up areas. Nitrate contamination likely originates from agricultural runoff and human and animal waste (e.g., Magar & Khatri, 2017). Ankhidaha, being smaller and entirely surrounded by agricultural land, exhibits higher nitrogen levels and lower dilution capacity compared to Nagdaha, consistent with the findings of Dojlido and Best (1993). Similarly, phosphate concentrations suggest agricultural runoff and phosphorus-laden waste as major contributors, consistent with the findings of Magar and Khatri (2017).

Based on depleted oxygen and the guideline values for NN and phosphate given by Sawyer (1947), eutrophication is evident in both wetlands, though more severe in Ankhidaha. The proliferation of algae, water hyacinths, and lilies suggests excess nitrogen availability, with microbial decomposition further depleting oxygen (Sawyer, 1947; Berner, 1985; Srivastava et al., 2009; Ansari *et al.*, 2010). DO levels confirm water pollution in both systems, with Ankhidaha experiencing more severe degradation. These findings underscore the urgent need for targeted conservation and pollution control measures.

Ecosystem Services

The study confirms strong connections between social values, local practices, and resource use in ES assessment (e.g., Paudyal *et al.*, 2018). Place and demographic characteristics significantly shape social and cultural values. For example, Hindu communities deeply value the cultural significance of Nagdaha and Ankhidaha, while other religious groups do not align with these rituals (Iniesta-Arandia *et al.*, 2014). Local perceptions of ES depend on personal experiences, residence, and occupational interactions with wetlands (Paudyal *et al.*, 2018). Women prioritize provisioning and cultural services, particularly for household water use, bathing and religious ceremonies (e.g., Martin-Lopez *et al.*, 2012; Desta, 2021). In contrast, professionals, such as teachers and business owners, emphasize habitat and cultural services for environmental and economic benefits (Pietrzyk-Kaszyńska *et al.*, 2022).

Comparing ES contributions before 2010 and after 2020, recreation and ecotourism, and biodiversity maintenance have gained increasing importance for the local and national economy. Wetlands support rich biodiversity, regulate sediments, and sequestering carbon stocks enhancing their ecological and economic value. Their protection is vital for sustaining these functions.

In this study, recreation and ecotourism, biodiversity maintenance, and educational opportunities emerged as the most highly ranked ecosystem services. The prioritization of ES depends on perceived benefits, supply capacity, and market demand (Hicks, 2015; Paudyal *et al.*, 2018; de Castro Pardo, 2020). While cultural services were ranked highest, followed by supporting and regulating services (Iftekhar and Takama, 2007; Hartter, 2010), findings contrast with other studies (Castro *et al.*, 2011; Martin-Lopez *et al.*, 2012; Paudyal *et al.*, 2018).

CONCLUSIONS

Nagdaha and Ankhidaha are ecologically and culturally significant wetlands currently facing eutrophication due to rising nitrate and phosphate concentrations and declining dissolved oxygen levels. Key drivers include sewage contamination, improper waste disposal, agricultural runoff, and land encroachment. These wetlands provide essential ecosystem services, with provisioning services prioritized locally before 2010, while cultural and habitat services have consistently remained high priorities across wider scales both before 2010 and after 2020. The evolving importance of these services has resulted in trade-offs and synergies among stakeholders, presenting opportunities for integrated management strategies that maximize benefits for both local and wider communities.

The degradation of water quality threatens ecosystem services, necessitating urgent conservation measures. Implementing wastewater treatment systems, designating specific areas for human activities, and enforcing stricter land-use policies could mitigate pollution and encroachment. Additionally, minimizing fertilizer application in agricultural areas adjacent to wetlands would help sustain their ecological integrity. Prioritizing ecosystem services in management strategies can support natural resource conservation, community livelihoods, and environmental sustainability.

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AUTHOR CONTRIBUTIONS

DNS, RDTS, and KM: conceptualized the study; KM, SKC and MD. AA: carried out sampling and sample analysis; DNS, RDTS and KM: data analysis, preparation of original draft, review and editing. All authors read and approved the manuscript.

CONFLICT OF INTEREST

The author declares no conflict of interest.

DATA AVAILABILITY STATEMENT

All relevant data are within the manuscript. Supporting information is fully available at a reasonable request from the corresponding author.

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