Original Research Article

Water Quality Assessment of The Three Lakes of Barandabhar Forest Corridor, Central Nepal

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Abstract

Addressing the global challenge of securing water for both human needs and ecosystem health is crucial. This study aims to characterize the physiochemical parameters of three lakes in the Bharandabhar forest corridor, Chitwan, Central Nepal: Tiger Lake, Kalimati Lake, and Rhino Lake. During the pre-monsoon season, four different sites (Eastern, Western, Northern, and Southern) of each lake were examined. To ensure precision, five replicated water samples were collected from each site, and standard protocols were applied to analyze various physiochemical parameters, such as pH, temperature, dissolved oxygen, free carbon dioxide, total hardness, chloride, total alkalinity, conductivity, nitrate, inorganic phosphorus, and total solid matter. Also, the Water Quality Index (WQI) was calculated.

Results show that physiochemical parameter values mostly align with permissible limits according to regional and international guidelines. However, the mean phosphorous concentration and pH values of Tiger and Kalimati lakes exceed these limits. Rhino Lake displayed a mildly alkaline pH, while Kalimati and Tiger lakes exhibited slightly acidic characteristics. An interesting observation is the significant negative correlation between temperature and dissolved oxygen, indicating that as temperature rises, dissolved oxygen levels decrease. Additionally, WQI suggests that all three lakes maintain good water quality.

However, a concerning finding is that all three lakes exhibited hyper-eutrophic conditions based on their phosphorous concentration. The lakes face significant threats due to high levels of organic pollutants and a rapid eutrophication process. Authorities must take significant actions to safeguard the lakes and ensure their future well-being.

This research highlights the urgent need for environmental protection and conservation efforts to preserve the water quality and ecological balance of the Bharandabhar forest corridor lakes for the well-being of both human communities and the ecosystem.

Keywords: *Physicochemical, Water Quality Index (WQI), Wetlands, Hydrology, Bharandabhar.*

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Introduction

Wetlands are often referred to as *the kidneys of the landscape* (Mitsch & Gosselink, 2015) and characterized as *biological super markets"* (Odum & Barrett, 1971), and therefore, wetlands are known as among the most productive ecosystems globally (Barbier et al., 1997). Wetlands play a significant role in the primary functions of water supply and environmental control. They aid in groundwater recharge, manage floods and erosion by absorbing and storing excess water, enhance water quality through the filtration of sediments and contaminants, support local and migrating animals, and provide a vital source of food for both humans and animals (Achal & Thakur, 2023). In Nepal, approximately 5% of the total land area is occupied by wetlands, with the majority located in the low-lying Tarai region (68.2%), followed by the High Mountains (31.6%) and mid-hill areas (1%) (GN/MFSC, 2009). These wetlands are home to 27% of nationally threatened bird species (Inskipp et al., 2013), 85% of endemic vertebrates (IUCN, 2004), 24% of protected plant species and a minimum of 230 native fish species (Rajbanshi, 2012). As crucial components of the biosphere, wetlands face ongoing threats such as eutrophication, sedimentation, the invasion of alien species, pollution, and agricultural runoff (Shrestha et al., 2020).

Monitoring water quality is essential for understanding wetland health and implementing necessary conservation measures. The physical and chemical characteristics of water significantly impact the quality of an aquatic ecosystem (Kunwar & Devkota, 2012). The hydrology of a wetland is influenced by multiple factors, including rainfall, soil permeability, location in the landscape, surrounding land use, and the type of vegetation (Gopal, 2003). The well-being of wetlands depends on the quality of their water, including factors like temperature, nutrients, alkalinity, hardness, dissolved CO_2, and dissolved oxygen, which are crucial for the life in the water and the overall functioning of the ecosystem (Trivedy & Goel, 1984).

Unwanted changes in the physical, chemical, and biological aspects of water pose a substantial threat to organisms, as water contamination profoundly impacts human and animal health and performance (Wright, 2007).

To figure out if water is good, we can check the physical, chemical, and microbial characteristics of water, along with the Water Quality Index (WQI), which assists in assessing the overall quality of water at a particular location and time, promoting more effective management practices (Adesakin et al., 2020). The Barandabhar

Forest Corridor (BFC), rich in biodiversity, provides essential ecological services. For instance, the lakes within the corridor serves as sources for drinking water, irrigation of agricultural lands, flood regulation, and groundwater recharge for the adjoining Chitwan area. While most studies have focused on the lakes beside the BFC, there is a lack of systematic water quality characterization, especially regarding drinking water and aquaculture. This research aims to collect data on the physicochemical characteristics of these vital wetlands, essential for assessing the Water Quality Index (WQI) of the lakes.

Materials and Methods

Location and Geo-Morphology

The Barandabhar Forest Corridor (BFC) is a vertical forest strip linking the Terai Arc Landscape (TAL) in low-lying plains and the Chitwan Annapurna Landscape (CHAL) in the mid-hills and high mountains, situated between 27°34' to 27º40'N latitude and 84º21' to 84º28'E longitude (Thapa & Tuladhar, 2021). The corridor covers an area of 109.13 sq. km and serves as the habitat for more than 32 mammal species, 329 bird species, 37 fish species, and 45 herpetofauna species (NTNC-BCC and CNP, 2020). The corridor is a host to numerous wetlands recognized for their international importance, including Ramsar sites such as Beeshazar and Associated Lakes. The primary wetlands within the Barandabhar Forest Corridor (BFC) comprise three rivers (Rapti, Budirapti, and Khageri) and various lakes, including Beeshazari Lake (a Ramsar site), Ratomate Lake, Batulpokhari, Rhino Lake, Tiger Lake, Tikauli Lake, Gundre-Mandre Lake, and Kalimati Lake (Adhikari et al., 2018). The three wetlands of BFC Rhino Lake, Tiger Lake, Kalimati Lake as depicted in Figure 1 served as important water reserves for the wildlife in the area and it has gained great environmental significance, so they were selected for study as presented in Table 1.

The climate in the study lakes area is characterized as humid and subtropical, following a monsoon rainfall pattern. The region experiences distinct seasons, including a rainy monsoon period from June to September, a cool dry winter from October to February, and a hot dry summer from March to May. The highest maximum average temperature reaches 36.57°C, while the minimum average temperature is 8.29°C. Over the period from 1992 to 2022, the average annual rainfall is recorded at 167.00 mm as depicted in Figure 2.

Figure 1

Map of sampling sites in Barandabhar Forest Corridor (BFC) for water parameter analysis

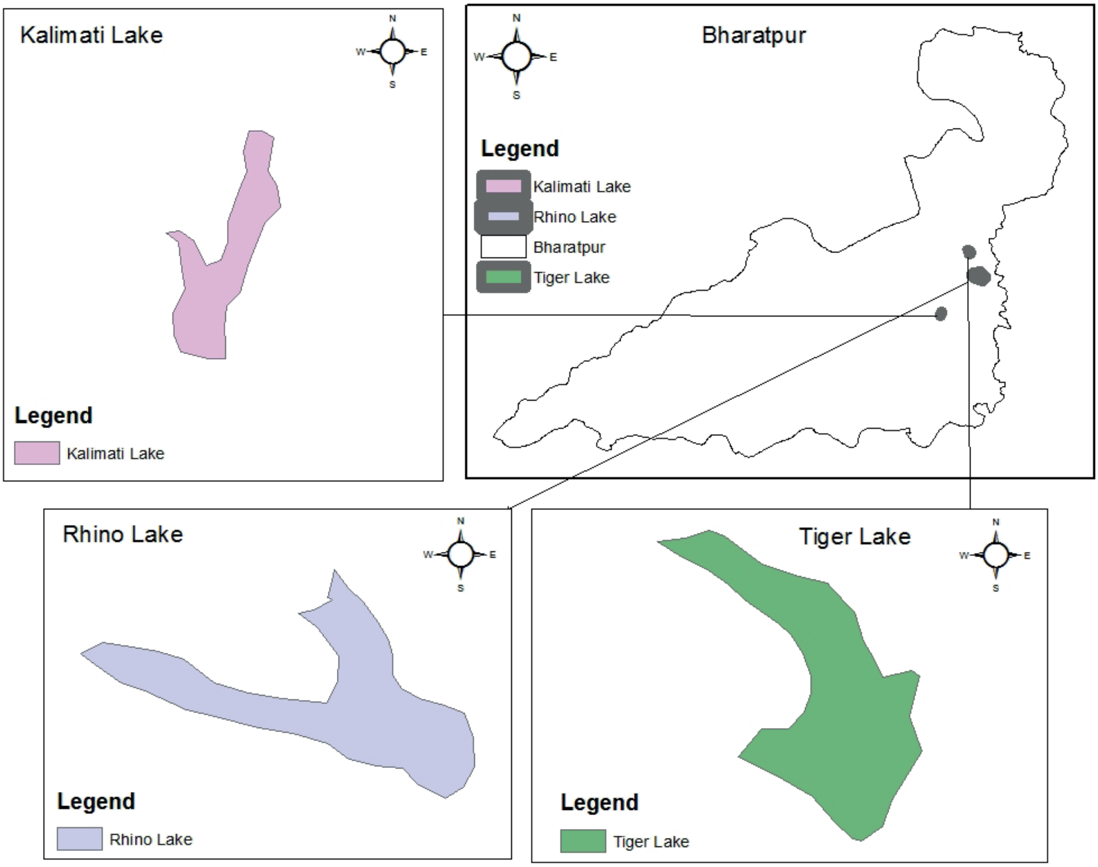


Table 1

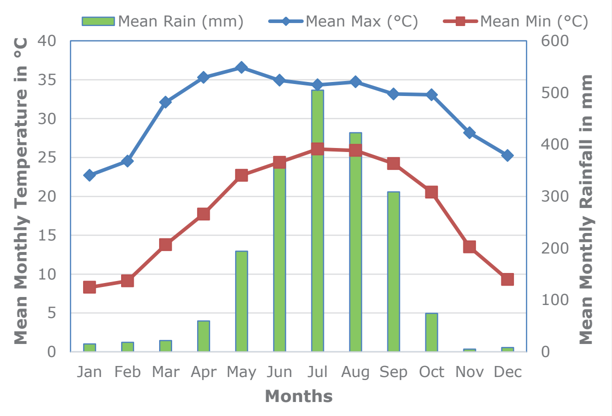
Description of sampling sites in Barandabhar Forest Corridor (BFC) for water parameter analysis

S. N	Site	GPS Coordintes	Bio-physical description of site
1.	Rhino Lake	27°37’5” N and 84°26’12” E; 286m	Oxbow lake; *Shorea robusta* dominant forest; Managed by Rambel Community Forest; Source monsoon rainfall
2.	Tiger Lake	27°40’54” N and 84°27’54” E; 209m	Oxbow lake; Shorea robusta dominant forest; Managed by Nawajagriti Community Forest; Source monsoon rainfall
3.	Kalimati Lake	27°41’41” N and 84°27’54” E; 211m	Oxbow lake; Shorea robusta dominant forest; Managed by Nawajagriti Community Forest; Source monsoon rainfall

The lake shows typical tropical vegetation and is surrounded by *Shorea robusta* forest along with the other species *Terminalia alata*, *Terminalia tomentosa, Cheistocalyx operculate, Bombax ceiba*, *Trewia nudiflora, Mallotus philippensis, Listsea monopelata,* and *Sapium insignene* etc. Prominent associated vegetation includes *Lemna perpusilla*, *Saccharum spontaneum, Phargmites karka*, *Ipomea carnea*, *Clerodendrum infortunatum*, *Pontederia crassipes*, *Alternanthera sessilis*, *Ageratum conyzoides, Trapa quadrispinosa*, *Ludwigia adscendens*, *Azolla imbricate*, *Alternanthera philoxeroides*, *Pistia stratiotes*, *Leersia hexandra*, *Chromolaena odorata*, *Ceratophyllum demersum*, *Hydrilla verticillata* and *Najas minor*.

Figure 2

Seasonal temperature and precipitation pattern of study area



Note: Thirty years (1992 to 2022) data taken from Agricultural and Forestry University, Rampur station of Hydrology and Meteorology were averaged for each month.

Water Sampling and Physiochemical Analysis

Water samples were collected using the grab sampling method (Ji et al., 2022). In May 2023, sampling was conducted during the pre-Monsoon season. Samples were taken at a depth of 0.5 m, with 20 sampling bottles collected from each lake (5 samples from each corner). The bottles used in the sampling process were initially cleaned by rinsing them with water from the particular lake. Afterward, the bottles were sealed, lowered to a depth of 0.5 m, opened until filled, and then sealed again before being taken outside for additional analysis. After collection, the samples were placed in an icebox and transported to the laboratory at Saptagandaki Multiple Campus for additional analysis. They were then stored in a refrigerator until testing. Water temperature, pH, and Dissolved Oxygen were on time measured in the field during sample collection, while various physiochemical parameters such as Conductivity, Hardness, Chloride, Total Solid Matter, Nitrate, Inorganic Phosphate, Free CO_2, and Total Alkalinity were recorded in the laboratory. Water quality parameters were sampled, preserved, and analyzed in accordance with established standard methods for examination (Table 2).

Table 2

Methods and Instruments used for determination of physiochemical parameters in lakes' water in BFC

Parameters	Methods/ Instruments	References
Temperature	Mercury Thermometer	(Zobel et al., 1987)
p^H	p^H -Meter (Model-p^H 009)	(Zobel et al., 1987)
DO	Digital Dissolved Oxygen Meter (Ecosense DO 200A)	
Free CO_2	Phenolphthalein-Titration	(Zobel et al., 1987)
Total Hardness	EDTA method	(Trivedy & Goel, 1984)
Total Alkalinity	Acid-Base Titration	(Trivedy & Goel, 1984)
Total Solid Matter	Complete Evaporation Method	(Zobel et al., 1987)
Conductivity	Conductivity meter (Model 191)	(Gupta, 2007)
Nitrate	Phenol Disulphonic acid method (Spectronic 21, Milton Roy Company)	(Trivedy & Goel, 1984)
Inorganic Phosphate	Ammonium Molybdate Solution Method (Spectronic 21, Milton Roy Company)	(Gupta, 2007)
Chloride	Mohr's Method	(Gupta, 2007)

Water Quality Index

The Water Quality Index (WQI) is an effective instrument for converting a large amount of hydro chemical data into a single numerical value, providing a concise summary of overall water quality and facilitating its assessment for various uses (Tripathee et al., 2016; Pant et al., 2021; Pantha et al., 2022). The WQI was calculated using the weighed arithmetic index method. (Brown et al., 1972).

$$\mathrm{WQI} = \frac{\sum_{n=1}^{n}(Qi \times Wi)}{\sum_{n=1}^{n} Wi}$$

Where, Qi=quality rating scale, Wi=unit weight. For quality, rating scale Qi of each parameter was computed during the formulas (Thapa et al., 2020) below:

$$\mathrm{Qi} = \frac{[Vi - Vo]}{[Si - Vo]} \times 100$$

Except for p^H and dissolved oxygen, all ideal values (Vi) for drinking water are considered to be zero (Tripathy & Sahu, 2005). In the case of natural or pure water, the ideal pH is 7.0, whereas 8.5 is considered tolerable for polluted water.

$$\mathrm{Q_{pH}} = \frac{[Vi - 7]}{[Si - 7]} \times 100$$

$$\mathrm{Q_{DO}} = \frac{[Vi - 14.6]}{[Si - 14.6]} \times 100$$

Where Vi = estimated the concentration of examined water, Vo = ideal value of parameters in pure water, Vo = 0 (except pH and DO), Si = Standard value of parameters (WHO guidelines for drinking water), (Table 3). The Unit weight (Wi) to various water quality parameters is inversely proportional to the recommended standards for the corresponding parameters, as calculated by following formula (Thapa et al., 2020):

$$\mathrm{Wi} = \frac{K}{Si}$$

Where K=proportionality constant calculated by

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

Various agencies including WHO (2016) have prescribed the standard guideline values for water quality parameters which are displayed in table 3 as follows;

Table 3

Standard Guideline values of Physico-chemical Water Parameters

Parameters	NWQGAC	NDWQAS	NWQGLW	WHO (2016)
Nitrate	300 mg/L	50 mg/L	<100 mg/L	50 mg/L
Inorganic Phosphorous	<1 mg/L	-	-	1.0 mg/L
pH	6.5-9.0	6.5-8.5	6.5-8.5	6.5-8.5
Free Co_2	<75 mg/L	-	-	-
Chloride	600 mg/L	250 mg/l	250 mg/L	250 mg/L
Dissolved Oxygen	5-8 mg/L	6.5-8 mg/L	6.5-8 mg/L	6.5-8 mg/L
Total Hardness	20-100 mg/L	500 mg/L	500 mg/L	500 mg/L
Conductivity	-	1500 µs/cm	1500 µs/cm	750µs/cm
Total Alkalinity	20-100 mg/L	-	-	300 mg/L
TSM	2000 mg/L	1000 mg/L	100 mg/L	1500 mg/L
Temperature	16-32ºC	-	-	-

Sources: (CBS, 2019; WHO, 2017)

Table 4

Weighted Arithmetic WQI by classification status

WQI	Rating class
0–25	Excellent
26–50	Good
51–75	Poor
76–100	Very poor
>100	Unsuitable

Sources: Pantha et al., (2022); Shrestha & Basnet, (2018)

The data collected from the experiments were analyzed through descriptive statistics to find the average and standard deviation for all physiochemical parameters. To assess and compare the significance of differences in these parameters among three lakes, Analysis of Variance (ANOVA) and Tukey multiple comparison test were employed. Pearson's correlation analysis was used to examine the relationships between water temperature, p^H conductivity, dissolved oxygen, hardness, chloride, total solid matter, nitrate, inorganic phosphate, free CO_2, and total alkalinity. All statistical analyses were conducted using Statistical Package for Social Sciences (IBM SPSS statistics version 25).

Results and Discussion

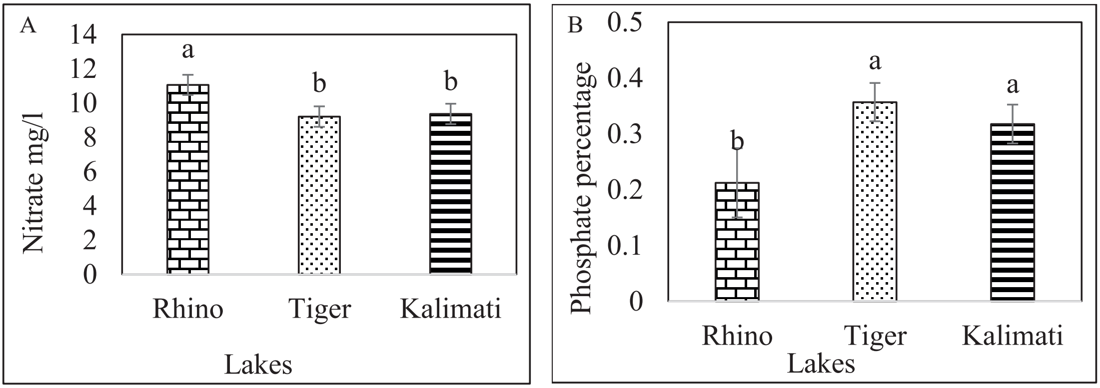
Water physicochemical parameters

The variations in the physicochemical parameters of the observed lakes can be attributed to distinct values recorded across different parameters throughout the study duration. The measured physico-chemical values were cross-referenced with guidelines from the World Health Organization (WHO, 2017), Nepal's Drinking Water Quality Standards (NDWQS), Nepal Water Quality Guidelines for Aquaculture (NWQGAC), and Nepal Water Quality Guidelines for Livestock Watering (NWQGLW) (CBS, 2019) guidelines. The average nitrate level of three lakes is 9.88±0.22 mg/L. There's a significant difference ($p<0.05$) in nitrate levels among the lakes (Table 5). Rhino Lake has the highest nitrate level (11.12 ± 0.44 mg/L), while Tiger Lake has the lowest (9.21 ± 0.32 mg/L) (Figure 3A). Nitrogen and phosphorus are crucial nutrients for freshwater, but an excess can lead to eutrophication, negatively impacting lake water quality. Rhino Lake has a higher nitrate level, possibly due to increased microbial activity from decomposition. This could also result from runoff carrying pollutants like agricultural fertilizers, domestic and wild animal wastes, as noted by (Haile & Mohammed, 2019). (Bhusal & Devkota, 2020) observed a similar trend in nitrate levels in Lakes of Chitwan National Park. In Kalimati Lake, lower nitrate levels may be attributed to reduced microbial activity and higher temperatures compared to other lakes. Nitrate values in all samples adhere to WHO and NDWQS guidelines. For phosphate (PO_4) levels, Tiger Lake has the highest (0.36 ± 0.03 mg/L), and Rhino Lake has the lowest (0.21 ± 0.06 mg/L) values (Figure 3B).

The average phosphate level is 0.29 ± 0.18 mg/L, and there's a significant difference among the lakes (Table 5). Inorganic phosphorus in freshwater is primarily present in inorganic forms. Tiger Lake exhibits a high concentration, possibly due to runoff carrying phosphorus from the forest, natural disasters like flooding, or higher pollution levels (Bhattarai et al., 2008). Rhino Lake shows a lower concentration, possibly due to efficient utilization by macrophytes and algae. Similar findings were reported in Ghodaghodi Lake in post-monsoon season (Devkota & Joshi, 2022).

Figure 3

Physiochemical parameters under Nitrate and Phosphate of Rhino Lake, Tiger Lake, Kalimati Lake of BFC



Note: **A:** Nitrate, **B:** Phosphate (PO_4). Different letters above the bars indicate significant differences ($P \leq 0.05$) between lakes according to Tukey multiple comparison test.

The lakes are categorized as hyper-eutrophic based on phosphorous values, following Forsberg's (1980) suggestion.

Table 5

Physico-chemical characteristics of three lake water of BFC

S.N	Parameters	***Mean ± SD***	F	Sig.
1.	Nitrate (mg/L)	9.88±0.22	7.789	0.001
2.	PO_4 (mg/L)	0.295±0.18	5.951	0.003
3.	DO (mg/L)	6.03±0.11	55.387	0.000
4.	Free CO_2	45.78±3.87	20.745	0.000
5.	Total hardness (mg/L)	52.54±1.62	2.205	0.113
6.	Conductivity (µs/cm)	87.10±3.09	6.122	0.000
7.	Chloride (mg/L)	38.38±1.80	297.890	0.000
8.	Total Solid Matter(mg/L)	1815.56±199.55	4.970	0.008
9.	Total alkalinity (mg/L)	118.46±2.51	13.578	0.000
10.	p^H	6.66±0.19	15.260	0.000
11.	Temperature (ºC)	32.60±0.25	25.495	0.000

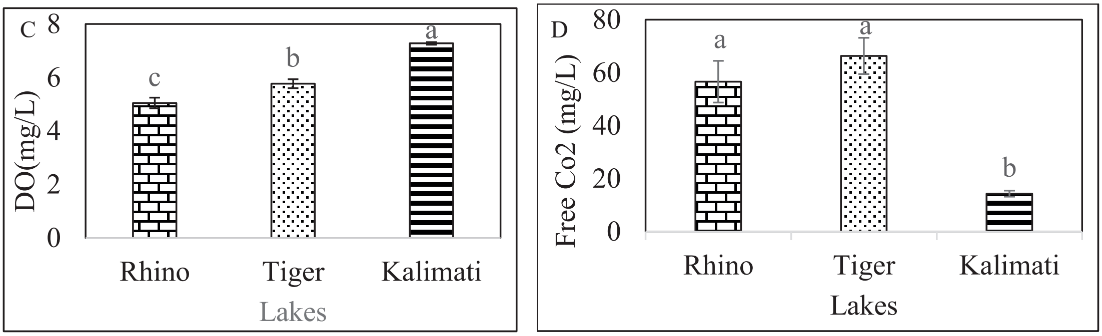
Note: F- value and significance value (p) were determined by Analysis of variance (ANOVA).

(DO=Dissolved Oxygen, PO_4=Phosphate, Free CO_2=Free Carbon dioxide, p^H=Potential of hydrogen).

Dissolved Oxygen (DO) levels vary significantly among the lakes, with a mean DO value of 6.03 ± 0.11 mg/L (Table 5). DO is a crucial water quality parameter, indicating the presence of organic pollution in aquatic environments and playing a vital role in the respiration of fish and other aquatic organisms (Thapa et al., 2019). Typically, an increase in temperature is associated with a decrease in DO, impacting the growth and development of organisms, particularly in the monsoon season (Dey et al., 2021). The current study revealed that the average DO value in Rhino Lake is lower (5.05 ± 0.2 mg/L), despite its lower temperature. On the other hand, Kalimati Lake exhibited a higher average DO value (7.3 ± 0.05 mg/L) (Figure 4C) alongside a higher temperature, possibly due to the accumulation of organic waste following a seasonal pattern (Pant et al., 2021). Despite differences in DO levels among the lakes, all studies confirm that the DO values fall in the acceptable limits set by the WHO (WHO, 2017), National Water Quality Guidelines for Aquatic Ecosystems Conservation (NWQGAC), and NDWQS (CBS, 2019).

Figure 4

Physiochemical parameter of DO and Free CO_2 of Rhino Lake, Tiger Lake, Kalimati Lake of BFC



Note: **C:** Dissolved Oxygen (DO), **D:** Free Carbon dioxide (CO_2). Different letters above the bars indicate significant differences (P≤0.05) between lakes according to Tukey multiple comparison test.

Free carbon dioxide concentration depends on factors like temperature, depth, rate of respiration and photosynthesis of microbes and macrophytes, organic matter decomposition(Boyd & Boyd, 2020). Free carbon dioxide levels show a significant difference (Table 5) among the lakes. Tiger has the highest (66.35 ± 6.9 mg/L), while

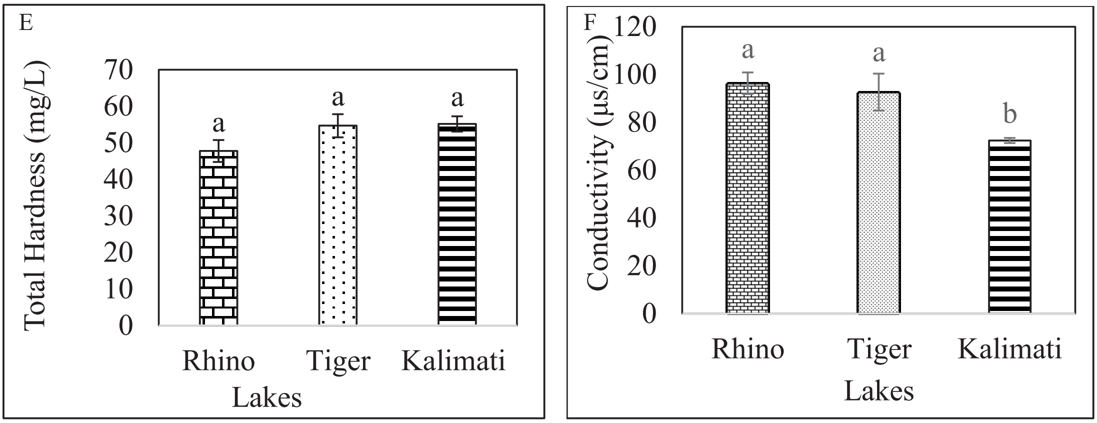
Kalimati has the lowest (14.35 ± 1.13 mg/L) values (Figure 4D). The average free carbon dioxide level is 45.78 ± 3.87 mg/L. Tiger Lake exhibits an increase in free carbon dioxide, possibly due to favorable temperatures, while Kalimati Lake has a lower value, potentially from slow organic matter decomposition. These findings align with post-monsoon season results (Bhusal & Devkota, 2020). In this study, the rise in free carbon dioxide levels can be linked to the accelerated decomposition of macrophytes and the favorable temperature conditions (Pant & Adhikari, 2015), Kalimati Lake, however, exhibited a lower free CO_2 value, suggesting reduced CO_2 production, possibly due to the slower decomposition of organic matter.

Total hardness values range from 47.7 to 55.1 mg/L, with Kalimati having the highest and Tiger Lake having the lowest values (Figure 5E). There's no significant difference ($p<0.05$) in the mean total hardness (52.54 ± 1.62 mg/L) among the lakes (Table 5). Water's total hardness, impacting soap lathering and increasing the boiling point, is primarily due to cations such as calcium, magnesium, bicarbonate, carbonate, nitrate, and silicate (Trivedy & Goel, 1984). Water hardness results from the combined concentrations of alkaline earth metal ions such as calcium and magnesium (Pant et al., 2019). Water hardness can be categorized as soft (<60 mg/L), medium (60–119 mg/L), hard (120–180 mg/L), and very hard (>180 mg/L) based on hardness levels (Durfor & Becker, 1964). In this study, Tiger Lake has the highest total hardness value of 162 mg/L, while Rhino Lake has the lowest with 10 mg/L. Similar observations were noted in Beeshazari Lake (Pant et al., 2021). Total hardness in the study sites follows to the guidelines of NWQGAC, WHO, and NDWQS (300 mg/L), with all lakes classified as having soft water (Durfor & Becker, 1964).

The electrical conductivity (EC) of water indicates its capacity to conduct electricity, determined by the quantity and mobility of ions present, their overall concentration, and the temperature of the solution (Pant et al., 2019).

Figure 5

Physiochemical parameter of hardness and conductivity of Rhino Lake, Tiger Lake, Kalimati Lake of BFC



Note: **E:** Total hardness, **F:** Conductivity. Different letters above the bars indicate significant differences (P≤0.05) between lakes according to Tukey multiple comparison test.

Conductivity varies significantly among the lakes (Table 5), Rhino has the highest conductivity (96.32 ± 4.52 µs/cm) while Kalimati has the lowest (72.4 ± 1.04 µs/cm) ((Figure 5F). The average is 87.10 ± 3.09 µs/cm. Rhino's higher conductivity, potentially from more ions or dissolved substances, affects its suitability for irrigation (El-Amier et al., 2021). Kalimati's lower conductivity suggests softer water and more ion absorption by organisms (Canli & Canli, 2015). The electrical conductivity in the study sites falls within the recommended guidelines of NWQGAC and WHO.

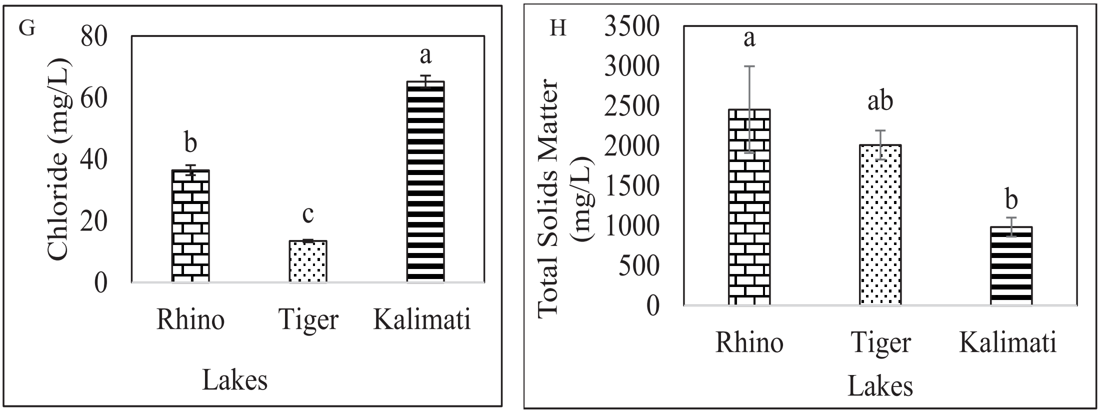
Chloride in water can come from minerals like mica and apatite, as well as from liquid inclusions in igneous rocks, including some human-made sources (Das & Malik, 1988). Chloride levels show a significant difference (Table 5) among the lakes, Kalimati has the highest chloride level (65.20 ± 1.9 mg/L), while Tiger has the lowest (13.51 ± 0.4 mg/L) (Figure 6G). The average chloride level is 38.38 ± 1.80 mg/L. In lakes high chloride levels are mainly attributed to fecal deposition and household sewage, making it an important indicator of pollution (Pant et al., 2019). The chloride values were within the prescribed guidelines of NWQGAC, WHO, and NDWQS.

Total solid matter levels vary significantly (Table 5), with Tiger having the highest (2010 ± 180.1 mg/L) and Kalimati the lowest (983.33 ± 119.2 mg/L) values

(Figure 6H). The average total solid matter level is 1815.56 ± 199.55 mg/L. High TDS was probably coming from wastewater, released from residential and wastes of industrial units, discharged into the lakes (Rehman et al., 2023). The elevated total solid matter (TSM) value in Tiger Lake, situated near a residential area, may be attributed to the introduction of domestic wastewater, garbage, sewage, etc. (Bhusal & Devkota, 2020). A lower value of TDS was found in Kalimati, with less disturbance.

Figure 6

Physiochemical parameters under Chloride and Total Solids Matter of Rhino Lake, Tiger Lake, Kalimati Lake of BFC

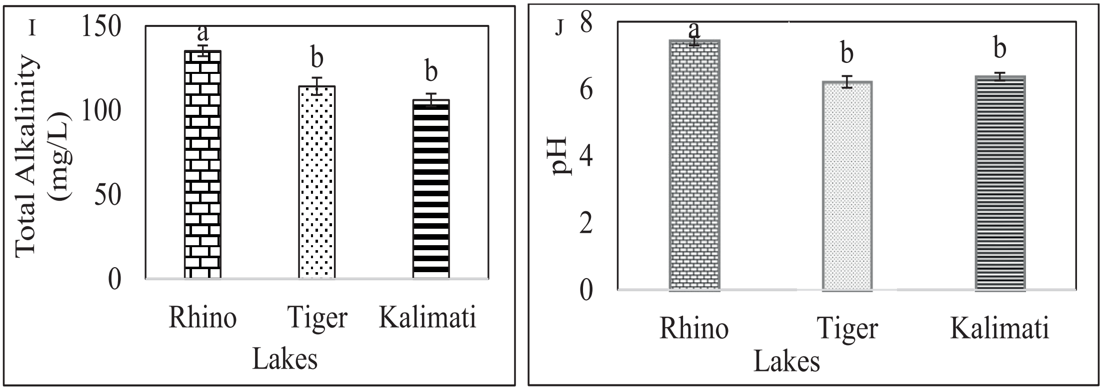


Note: **G:** Chloride, **H:** Total Solid Matter. Different letters above the bars indicate significant differences ($P \leq 0.05$) between lakes according to Tukey multiple comparison test.

The total alkalinity in water is determined by the presence of specific chemicals like bicarbonates, carbonates, and hydroxides (Patil et al., 2012). This parameter is important because it indicates the water's buffering capacity, which helps maintain a stable pH (Patil et al., 2012). In three studied lakes, total alkalinity ranged from 106.1 to 135.13 mg/L, with Rhino Lake having the highest values and Kalimati Lake the lowest (Figure 7I). The average total alkalinity across all lakes was 118.46 ± 2.51 mg/L (Table 5). While all samples contained bicarbonates, carbonate was only present in some samples from Rhino and Kalimati Lakes. This may be due to the absence of free CO_2 and pH values exceeding 8.3 (Tiwari et al., 2023). The average total alkalinity was higher in Rhino Lake (128.7 mg/L) compared to Kalimati Lake (111.2 mg/L), with Tiger Lake falling in between (119.3 mg/L). Importantly, all study sites maintained total alkalinity levels within the prescribed guidelines of NWQGAC, NDWQS, and WHO. These guidelines recommend that alkalinity in drinking water should not exceed 200 mg/L, as higher levels can lead to an unpleasant taste (Pantha et al., 2022).

Figure 7

Physiochemical parameters under Alkalinity and pH of Rhino Lake, Tiger Lake, Kalimati Lake of BFC

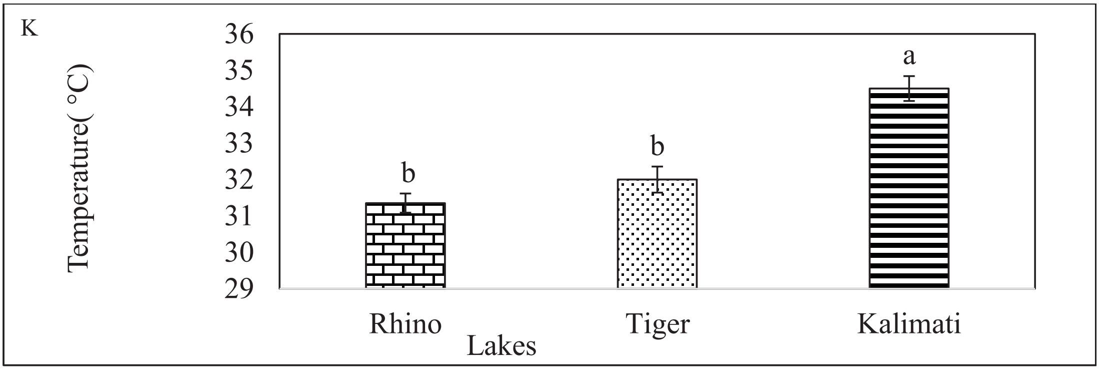


Note: **I:** Total alkalinity, **J:** p^H. Different letters above the bars indicate significant differences ($P \leq 0.05$) between lakes according to Tukey multiple comparison test.

pH, a measure of water's acidity or alkalinity, plays a critical role in aquatic life. Even slight changes can significantly impact its acid-base balance (Rehman Qaisar et al., 2018). In this study, pH levels ranged from 6.21 to 7.4, with Rhino Lake exhibiting the highest (7.4) and Tiger Lake the lowest (6.21) values (Figure 7J). The average pH across all lakes was 6.66 ± 0.19, revealing a significant relationship (Table 5) between them. Interestingly, Rhino Lake maintained a consistent near-neutral to mildly alkaline pH, while Tiger and Kalimati Lakes displayed fluctuations between acidic and mildly alkaline states. Despite this variation, all lakes remained within the permissible limits established by NWQGAC, WHO, and NDWQS. The observed higher pH in Rhino Lake during the pre-monsoon season might be attributed to increased temperatures and other geochemical processes (Pant et al., 2021). Notably, this average pH range (6.5-8.5) aligns with WHO guidelines (WHO, 2017), signifying favorable conditions for optimal aquatic life survival.

Figure 8

Physiochemical parameters under temperature of Rhino Lake, Tiger Lake, Kalimati Lake of BFC



Note: **K:** Temperature. Different letters above the bars indicate significant differences (P≤0.05) between lakes according to Tukey multiple comparison test.

Water temperature, a crucial factor in aquatic ecosystems, significantly impacts water chemistry, biological reactions, and organism health (Cairncross et al., 2010). Temperatures varied across the studied lakes, with Kalimati exhibiting the highest (34.5 ± 0.34°C) due to increased chemical interactions and reactivity, suggesting decreased water quality (Pokhrel et al., 2021). On the other hand, Rhino recorded the lowest temperature (31.35 ± 0.3°C) (Figure 8K). While the measured range (32–37°C) falls within the optimal range for many aquatic organisms (Pandey & Devkota, 2016), it exceeds the WHO's recommended 15°C criterion. The elevated temperatures potentially lead to decreased water quality through heightened interactions and reactivity of various components (Parihar et al., 2012). Additionally, warmer water promotes increased growth of plants and algae, influencing their interactions with aquatic animals and accelerating the decomposition of organic matter in the lake (Asthana, 2001).

Table 6

Spearman Correlation coefficient values between physiochemical parameters in lakes' water in BFC

Parameters	Nitrates	PO_4	DO	Free CO_2	Tot_Hrd	Cond.	Chloride	TSM	TA	pH	Temp.
Nitrates	1										
PO_4	0.095	1									
DO	**-.202****	**.225****	1								
Free CO_2	0.049	0.116	-0.113	1							
Tot_Hrd	0.023	**.157***	**.183***	**.419****	1						
Cond.	0.109	-0.033	0.025	**.352****	**.269****	1					
Chloride	-0.029	-0.095	**.356****	**-.453****	-0.039	**-.191***	1				
TSM	0.065	-0.026	**-.281****	-0.038	-0.047	-0.051	-0.014	1			
TA	0.019	0.039	-0.104	**.202****	0.026	**.202****	-0.082	0.068	1		
pH	**-.338****	0.25	**.316***	0.04	-0.032	0.082	-0.069	-0.182	-0.012	1	
Temp.	-0.035	**-.283***	**-.546****	**-.492****	**-.439****	-0.166	**.407****	**.399****	0.121	-0.073	1

Note: **Correlation is significant at the level. *Correlation is significant at the 0.05 level. (DO=Dissolved Oxygen, PO_4=Phosphate, Tot_Hrd=Total Hardness, Free CO_2=Free Carbondioxide, TA=Total Alkalinity, TSM=Total Solid Matter, Cond.=Conductivity, Temp.=Temperature). Here positive value indicates highly positively correlated to other variable while negative value indicates highly negatively correlated to other variable.

A Spearman correlation coefficient analysis was performed to assess the correlation between different hydrochemical parameters in three lakes of the Barandabhar Forest Corridor (Table 6). Temperature and Chloride show a strong positive correlation (0.407), indicating that as temperature increases, chloride concentration also increases. This could be due to factors like evaporation or increased dissolution of minerals containing chloride at higher temperatures. Strong positive correlation exists between temperature and total solid matter (TSM) (0.399). This suggests that higher temperatures lead to higher concentrations of dissolved and suspended solids in the water. A significant positive correlation (0.183) between temperature and hardness indicates that temperature influences the concentration of dissolved ions contributing to water hardness. pH and Dissolved Oxygen show a moderate positive correlation (0.316). This suggests that higher pH levels are associated with higher DO concentrations, possibly due to increased photosynthetic activity. Free CO_2 and Total Alkalinity exhibit a moderate positive correlation (0.202). This suggests that higher concentrations of free CO_2 are associated with higher TA, indicating a possible buffer system in the water.

A strong negative correlation between temperature and DO (-0.546) indicates that as temperature increases, DO levels decrease. This is likely due to decreased oxygen solubility in warmer water and increased oxygen consumption by aquatic organisms. A strong negative correlation (-0.453) suggests that higher CO_2 concentrations lead to lower pH levels, as CO_2 dissolves in water to form carbonic acid, decreasing the pH. A moderate negative correlation between DO and TSM (-0.281) indicates that higher concentrations of suspended matter can decrease DO levels by reducing light penetration and hindering oxygen diffusion.

A moderate positive correlation of PO_4 and DO (0.225) suggests a potential link between phosphorus availability and oxygen levels. A moderate positive correlation (0.269) indicates that higher conductivity is associated with increased water hardness, as dissolved ions contribute to both parameters. A moderate negative correlation (-0.338) suggests that higher pH levels may negatively affect nitrate availability, possibly influencing plant growth. This correlation analysis provides valuable insights into the relationships between various physicochemical characteristics in the lake water. The observed correlations can be used to inform further studies and better understand the dynamics of these aquatic ecosystems.

Water quality index (WQI)

Water quality index, a unique and valuable indicator, summarizes the overall water quality in a single term, thereby aiding in the selection of appropriate treatment methods to address relevant issues (Tyagi et al., 2013). The WQI is determined based on how well surface waters meet the requirements for various purposes, such as human and animal consumption (Yaseen et al., 2015). The WQI uses five classifications to describe water quality: excellent (0-25), good (26-50), poor (51-75), very poor (76-100), and not suitable for drinking (> 100) (Pantha et al., 2022). In this research, the Drinking Water Quality Index was calculated according to WHO guidelines, revealing a score of 33.86 for Rhino, 45.91 for Tiger and 39.65 Kalimati Lake. This places the water quality in the good category. Similar findings were reported in Beeshazar and associated lakes in Central Nepal (Pant et al., 2021). According to the Water Quality Index, it can be declared that the water quality in Rhino, Tiger and Kalimati lakes waters of Barandabhar Forest Corridor is considered suitable for drinking.

Table 7

Water quality index (WQI) in lakes' water in Barandabhar Forest Corridor (BFC).

Lakes	WQI	Rating class
Rhino Lake	33.868	Good
Tiger Lake	45.915	Good
Kalimati Lake	39.697	Good

Conclusion and Implication

This study contributes to an improved understanding of hydrochemical relationships and provides guidance for assessing surface water quality in wetlands. Water quality of Kalimati and Tiger lakes is slightly acidic, while Rhino Lake is mildly alkaline. Higher phosphorous levels in all three lakes raise concerns about water pollution and hyper-eutrophication, with invasive species posing an additional threat, indicating an initial stage of anthropogenic stress that requires urgent attention from aquatic ecologists. The study recommends comprehensive environmental assessments and treatment before using the water. Despite these concerns, the water quality index for the studied lakes indicates good quality, supporting the safety of the water for drinking purposes. These findings align with WHO, NDWQS, NWQGAC, and NWQGLW guidelines, providing a baseline for future assessments. Regular monitoring of physio-chemical parameters is essential, and ongoing checks on drinking water quality are crucial to prevent waterborne diseases for both humans and animals.

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Authors' contribution

KA conceptualized the idea and conducted statistical analyses; KA and BS prepared and review the manuscript; KA, BS, and AD collected samples and performed physicochemical analyses.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

Achal, B., & Thakur, A. (2023). Study of Distribution and Importance of Wetland in India-A Review. *Advances in Water Science*, *34*(2), 86–96.

Adesakin, T. A., Oyewale, A. T., Bayero, U., Mohammed, A. N., Aduwo, I. A., Ahmed, P. Z., Abubakar, N. D., & Barje, I. B. (2020). Assessment of bacteriological quality and physico-chemical parameters of domestic water sources in Samaru community, Zaria, Northwest Nigeria. *Heliyon*, *6*(8).

Adhikari, J. N., Bhattarai, B. P., & Thapa, T. B. (2018). Diversity and conservation threats of water birds in and around Barandabhar corridor forest, Chitwan, Nepal. *Journal of Natural History Museum*, *30*(November), 164–179. https://doi.org/10.3126/jnhm.v30i0.27553

Asthana, D. K. (2001). *Environment: Problems and solutions*. S. Chand Publishing.

Barbier, E. B., Acreman, M., & Knowler, D. (1997). *Economic valuation of wetlands: a guide for policy makers and planners*.

Bhattarai, K. R., Shrestha, B. B., & Lekhak, H. D. (2008). Water quality of sundarijal reservior and its feeding streams in Kathmandu. *Scientific World*, *6*(6), 99–106.

Bhusal, A., & Devkota, A. (2020). Physico-chemical characteristics of Lakes of Chitwan National Park, Central Nepal. *Biological Forum-An International Journal*, *12*(1), 33–39.

Boyd, C. E., & Boyd, C. E. (2020). Microorganisms and water quality. *Water Quality: An Introduction*, 233–267.

Brown, R. M., McClelland, N. I., Deininger, R. A., & O'Connor, M. F. (1972). A water quality index—crashing the psychological barrier. *Indicators of Environmental Quality: Proceedings of a Symposium Held during the AAAS Meeting in Philadelphia, Pennsylvania, December 26–31, 1971*, 173–182.

Cairncross, S., Bartram, J., Cumming, O., & Brocklehurst, C. (2010). Hygiene, sanitation, and water: what needs to be done? *PLoS Medicine*, *7*(11), e1000365.

Canli, E. G., & Canli, M. (2015). Low water conductivity increases the effects of copper on the serum parameters in fish (Oreochromis niloticus). *Environmental Toxicology and Pharmacology*, *39*(2), 606–613.

CBS. (2019). *Environmetntal Statistics of Nepal 2019*. Thapathali, Kathmandu, Nepal: National PlanningCommission,Government of Nepal. https://unstats.un.org/unsd/environment/Compendia/Nepal_Environment Statistics of Nepal_2019.pdf

Das, P. K., & Malik, S. D. (1988). Groundwater of Khatra region of Bankura district, West Bengal: Some chemical aspects in reference to its utilization. *Jour. Indian Water Res. Soc*, *8*(3), 31–41.

Devkota, A., & Joshi, B. K. S. (2022). Assessment of the water quality of Ghodaghodi lake using selected physicochemical parameters. *International Journal of Ecology and Environmental Sciences*, *48*(4), 495–504.

Dey, S., Botta, S., Kallam, R., Angadala, R., & Andugala, J. (2021). Seasonal variation in water quality parameters of Gudlavalleru Engineering College pond. *Current Research in Green and Sustainable Chemistry*, *4*, 100058.

Durfor, C. N., & Becker, E. (1964). *Public water supplies of the 100 largest cities in the United States, 1962* (Issue 1812). US Government Printing Office.

El-Amier, Y. A., Kotb, W. K., Bonanomi, G., Fakhry, H., Marraiki, N. A., & Abd-ElGawad, A. M. (2021). Hydrochemical assessment of the irrigation water quality of the El-Salam canal, Egypt. *Water*, *13*(17), 2428.

Forsberg, C. (1980). Eutrophication parameters and trophic state indices in 30 Swedish-receiving lakes. *Arch. Hydrobiologia*, *89*, 189–207.

GN/MFSC. (2009). *Nepal fourth national report to the convention on biological diversity.* Government of Nepal Ministry of Forests and Soil Conservation (Issue March). www.mofsc.gov.np

Gopal, B. (2003). Perspectives on wetland science, application and policy. *Hydrobiologia*, *490*, 1–10.

Gupta, P. K. (2007). *Methods in environmental analysis: water, soil and air*. Agrobios Jodhpur, India.

Haile, M. Z., & Mohammed, E. T. (2019). Analysis of physico-chemical characteristics of water collected from different sampling sites of Lake Hawassa, Ethiopia. *Orld Environment*, *9*(2), 38–45.

Inskipp, C., Baral, H. S., Inskipp, T., & Stattersfield, A. (2013). The state of Nepal birds 2010. *Journal of Threatened Taxa*, *5*(1), 3473–3503.

IUCN. (2004). *A Review of the Status and Threats to Wetlands in Nepal*. IUCN Nepal.

Ji, Y., Zheng, F., Du, J., Huang, Y., Bi, W., Duan, H., Savic, D., & Kapelan, Z. (2022). An Effective and Efficient Method for Identification of Contamination Sources in Water Distribution Systems Based on Manual Grab-Sampling. *Water Resources Research*, *58*(11), e2022WR032784.

Kunwar, D., & Devkota, A. (2012). Seasonal variation on physiochemical parameters and macrophytes production of Rupa Lake, Kaski, Nepal. *Journal of Natural History Museum*, *26*, 80–87.

Mitsch, W. J., & Gosselink, J. G. (2015). *Wetlands*. John wiley & sons.

NTNC-BCC and CNP. (2020). *A Checklist of Fauna and Flora in and Around Chitwan National Park* (Issue September). https://ntnc.org.np/publication/checklist-fauna-and-flora-and-around-chitwan-national-park

Odum, E. P., & Barrett, G. W. (1971). *Fundamentals of ecology* (Vol. 3). Saunders Philadelphia.

Pandey, B., & Devkota, A. (2016). Physico-Chemical Parameters In Tinau River Water In Rupandehi District, Nepal. *Octa Journal of Environmental Research*, *4*(2), 100–109.

Pant, R. R., & Adhikari, N. L. (2015). Water quality assessment of Phewa Lake, Pokhara Nepal. *Cogn Transdiscipl Res J*, *1*, 130–140.

Pant, R. R., Chalaune, T. B., Dangol, A., Dhital, Y. P., Sharma, M. L., Pal, K. B., Shah, S. T. H., Shrestha, A. K., & Thapa, L. B. (2021). Hydrochemical assessment of the Beeshazar and associated lakes in Central Nepal. In *SN Applied Sciences* (Vol. 3). Springer.

Pant, R. R., Pal, K. B., Adhikari, N. L., Adhikari, S., & Mishra, A. D. (2019). Water quality assessment of Begnas and Rupa lakes, lesser himalaya Pokhara, Nepal. *Journal of the Institute of Engineering*, *15*(2), 113–122.

Pantha, S., Timilsina, S., Pantha, S., Manjan, S. K., & Maharjan, M. (2022). Water quality index of springs in mid-hill of Nepal. *Environmental Challenges*, *9*, 100658.

Parihar, S. S., Ajit, K., Ajay, K., Gupta, R. N., Manoj, P., Archana, S., & Pandey, A. C. (2012). Physico-chemical and microbiological analysis of underground water in and around Gwalior city, MP, India. *Research Journal of Recent Sciences ISSN*, *2277*, 2502.

Patil, P. N., Sawant, D. V, & Deshmukh, R. N. (2012). Physico-chemical parameters for testing of water-a review. *International Journal of Environmental Sciences*, *3*(3), 1194.

Pokhrel, S., Ghimire, N. P., & Rai, S. K. (2021). Seasonal variation of algal diversity with reference to water quality in Jagadishpur Reservoir, Nepal. *Limnological Review*, *21*(4), 189–199.

Rajbanshi, K. G. (2012). Biodiversity and distribution of freshwater fishes of Central/ Nepal Himalayan Region. *Nepal Fisheries Society (NEFIS)*, *136*.

Rehman, H. U., Rahman, M. U., & Ahmed, S. (2023). Depthwise evaluation of total dissolved solids and arsenic from a drilled borehole near River Ravi, Lahore, Pakistan. *Journal of Water and Climate Change*, jwc2023170.

Rehman Qaisar, F. U., Zhang, F., Pant, R. R., Wang, G., Khan, S., & Zeng, C. (2018). Spatial variation, source identification, and quality assessment of surface water geochemical composition in the Indus River Basin, Pakistan. *Environmental Science and Pollution Research*, *25*, 12749–12763.

Shrestha, A. K., & Basnet, N. (2018). The correlation and regression analysis of physicochemical parameters of river water for the evaluation of percentage contribution to electrical conductivity. *Journal of Chemistry*, *2018*.

Shrestha, B., Shrestha, S., Shrestha, A., & Khadka, U. R. (2020). Ramsar sites in Nepal: Conservation, present scenario, biodiversity value and threats. *Journal of Wetlands Ecology*, *15*.

Thapa, K., Tuladhar, S. (Eds. . (2021). Connecting Corridors. *Connecting Corridors.WWF Nepal, Kathmandu, Nepal.*, 1–30. https://doi.org/10.12987/yale/9780300212273.003.0001

Thapa, B., Pant, R. R., Thakuri, S., & Pond, G. (2020). Assessment of spring water quality in Jhimruk River watershed, lesser Himalaya, Nepal. *Environmental Earth Sciences*, *79*(22), 504.

Thapa, K., Shrestha, S., Sharma, K., Shrestha, N., Bhandari, R., Bashyal, A., & Shrestha, S. (2019). Assessment of Physico-Chemical Parameters of Meltwater of Ponkar Glacier, Manang, Nepal. *Hydrology: Current Research*, *10*, 313.

Tiwari, S., Timalsina, B., Sitaula, S., Awasthi, M. P., Mahat, A., & Pant, R. R. (2023). Evaluating the Major Sources of Surface Water Quality in Pokhara Metropolitan City, Gandaki Province, Nepal. *Himalayan Biodiversity*, 29–38.

Tripathee, L., Kang, S., Sharma, C. M., Rupakheti, D., Paudyal, R., Huang, J., & Sillanpää, M. (2016). Preliminary health risk assessment of potentially toxic metals in surface water of the Himalayan Rivers, Nepal. *Bulletin of Environmental Contamination and Toxicology*, *97*, 855–862.

Tripathy, J. K., & Sahu, K. C. (2005). Seasonal hydrochemistry of groundwater in the Barrier Spit system of the Chilika Lagoon, India. *Journal of Environmental Hydrology*, *13*.

Trivedy, R. K., & Goel, P. K. (1984). *Chemical and biological methods for water pollution studies*. Environmental publications.

Tyagi, S., Sharma, B., Singh, P., & Dobhal, R. (2013). Water quality assessment in terms of water quality index. *American Journal of Water Resources*, *1*(3), 34–38.

WHO. (2017). *Guidelines for drinking-water quality: first addendum to the fourth edition*.

Wright, C. L. (2007). Management of water quality for beef cattle. *Veterinary Clinics of North America: Food Animal Practice*, *23*(1), 91–103.

Yaseen, S., Pandit, A. K., & Shah, J. A. (2015). Water quality index of fresh water streams feeding Wular Lake, in Kashmir Himalaya, India. *International Journal of Water Resources and Environmental Engineering*, *7*(4), 50–57.

Zobel, D. B., Jha, P. K., Behan, M. J., & Yadav, U. K. R. (1987). A practical manual for ecology. *Ratna Book Distributors, Kathmandu, Nepal*, *149*.