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43/2 Varadarajulu Nagar, 5th Street West, Ganapathy, Coimbatore, Tamil Nadu 641006, India
Registered Office: 3A2 Varadarajulu Nagar, FCI Road, Ganapathy, Coimbatore, Tamil Nadu 641006, India
Ph: +91 9385339863 | www.threatenedtaxa.org
Email: sanjay@threatenedtaxa.org

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Cover: The critically endangered *Lilium polyphyllum* in watercolour and acrylics. © Aishwarya S Kumar.

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ARTICLE

Wetland biodiversity of Ramaroshan Lake complex: a need for conservation

Ram Devi Tachamo-Shah [1], Deep Narayan Shah [2], Subodh Sharma [3], Lila Sharma [4], Jagan Nath Adhikari [5] & Deepak Rijal [6]

[1] Department of Life Sciences, School of Science, Kathmandu University, Dhulikhel 45200, Nepal.
[1,3] Aquatic Ecology Centre, School of Science, Kathmandu University, Dhulikhel 45200, Nepal.
[2] Central Department of Environmental Science, Tribhuvan University, Kirtipur, Kathmandu 44618, Nepal.
[3] Department of Hydro and Renewable Energy, Indian Institute of Technology Roorkee (IITR), India.
[4] Forest Action Nepal, Lalitpur 44700, Nepal.
[5] Department of Zoology, Birendra Multiple Campus, Tribhuvan University, Bharatpur, Chitwan, Nepal.
[6] USAID Paani Program, Baluwatar, Kathmandu 44616, Nepal.
[1] ramdevi.shah@ku.edu.np, [2] dnshah@cdes.edu.np (corresponding author), [3] subodh.sharma@hre.iitr.ac.in,
[4] lilanathsharma@gmail.com, [5] jnnadhikari@gmail.com, [6] rijal.deepak@gmail.com

Abstract: The Ramaroshan Lake Complex, situated in the mid-hills of Sudurpaschim Province, is renowned for its scenic beauty, yet there is a notable dearth of information regarding its biodiversity and ecological status. This study represents the first systematic examination of seasonal variations in water quality parameters and biodiversity encompassing aquatic macroinvertebrates, fishes, birds, herpetofauna, mammals, and macrophytes, as well as the surrounding vegetation within the complex, spanning the winters and summers of 2018 and 2019. Among the twenty water quality parameters investigated, thirteen displayed significant seasonal differences across the lakes ($p < 0.05$), with Batula and Ramaroshan lakes exhibiting elevated nutrient levels. Lamadaya Lake stood out with a highly diverse macroinvertebrate community compared to other lakes, while overall, the study recorded 45 aquatic macroinvertebrate families, three fish species, 79 bird species, 12 herpetofauna species, 12 mammal species, and 26 macrophyte species within the complex. Additionally, the surrounding vegetation comprised 193 distinct plant species. Notably, the complex currently hosts 14 IUCN Red List species, including Near Threatened (5), Vulnerable (5), Critically Endangered (1), and Endangered (3) species, as well as five migratory wetland bird species, underscoring its significance for wildlife conservation. Given the diverse and cross-cutting nature of wetlands, the development of science-based policies and coordinated efforts among central, provincial, and local governments are essential for the preservation and sustainable management of these vital ecosystems.

Keywords: Avian diversity, Batula Lake, biodiversity, conservation, critical habitat, herpetofauna, Jingale Lake, Lamadaya Lake, macroinvertebrates, Ramsar Site, water quality.

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Author details: Ram Devi Tachamo Shah, Ph.D. is an assistant professor. She is interested in the assessment of freshwater ecosystems at spatial and temporal scales in particular macroinvertebrates, microbiota, and fish under changing environments. Deep Narayan Shah, Ph.D. is an assistant professor. His research and professional interests are freshwater ecology, wetland restorations, species distribution, and the development of bio-assessment tools. He has significantly contributed to wetland-related policy documents including management plans, strategy, and action plans. Subodh Sharma, Ph.D. is a professor. His interest lies in water quality assessment and freshwater ecology. Lilanath Sharma, Ph.D. is a vegetation ecologist and botanist. He is interested in biodiversity conservation, forest restoration, and invasive species management. Jagan Nath Adhikari, Ph.D. is an assistant professor of zoology and has a keen interest in the landscape ecology, conservation of birds, large mammals, and herpetofauna. Deepak Rijal, Ph.D. was affiliated with DAI Inc. and heads AGON Nepal. He is interested in biodiversity conservation.

Author contributions: RDTS: Conceptualization, designed the ecological field methods, led the field study, data curation, formal analysis, original draft, review and editing. DNS: Conceptualization, designed the ecological field methods, led the field study, formal analysis, original draft, review and editing. SS: Conceptualization, review and editing. LS: Conceptualization and review. JNA: Conceptualization, field study, data analysis, original draft, review and editing. DR: Conceptualization and review. All authors read and approved the manuscript.

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INTRODUCTION

Over 5% of Nepal's land surface area is covered by natural and man-made wetlands, of which nearly 97% are contributed by rivers and irrigated paddy fields, and only 3% of the wetlands belong to marshy lands and lakes, including reservoirs and ponds (DoFD 2012). These lakes are disproportionally distributed across the varying altitudes: 51% of the lakes are situated in the high mountains above 3,000 m, 42% are located in the Tarai below 500 m, and only 7% of lakes are located in the mid-hills between 500 m and 5,000 m (Bhuju et al. 2010). Wetland ecosystems provide critical habitats to a wide range of wildlife, support livelihoods, regulate ecosystem functions, and are a source of renewable energy (Zedler & Kercher 2005; Baral 2009; Shah et al. 2011; Lamsal et al. 2014; Regmi et al. 2021a; Shrestha et al. 2021). These wetlands support critical habitats for globally threatened species (BLI 2010). Many endemic species, including two mammals (ASM 2018), one bird (BLI 2020), 10 reptiles (Uetz et al. 2018), 11 amphibians (Web 2018), 15 fish (Eschmeyer 2015), and eight flowering species, are endemic to the wetlands of Nepal. Similarly, the majority of the wetlands have socio-economic and cultural values, and riparian communities are highly dependent on wetland products (Khatri et al. 2010; Lamsal et al. 2014).

Due to the high significance of wetlands for wildlife and society, they need to be preserved and maintained. The Convention on Wetlands of International Importance is an international treaty that was signed in the city of Ramsar, Iran, on 02 February 1971, for protecting and maintaining the wetlands of ecological, botanical, limnological, hydrological, and zoological significance across the globe and designate as Ramsar Sites. The Koshi Tappu wetland was the first Ramsar Site in Nepal, designated in 1979, due to its importance for migratory birds. Since then, the government of Nepal has successfully designated a total of 10 wetlands of international importance. Among the 10 Ramsar Sites, eight are situated either in the high mountains or lowland Tarai, while only two are located in the mid-hills though the region covers over 40% of the total land surface.

Most of the wetlands, particularly in lowland Tarai, are highly threatened due to the high dependency of people on wetland products to sustain their livelihood (Sah & Heinen 2001), while wetlands situated in the inaccessible areas of mid-hills and high-mountain areas are nearly free from human pressures, hence serving as biodiversity reservoirs for many native and/or endemic species.

Ramaroshan Lake complex, located in a unique geographic location in the mid-hills of Sudurpaschim Province of Nepal, may serve as a critical habitat for wide ranges of wildlife (DoF 2017). The lake complex is one of the major habitats of Nepal's national bird, the Himalayan Monal *Lophophorus impejanus*, and a new record of a breeding site of a wetland-dependent migratory species, the Mallard *Anas platyrhynchos* (Aditiya Pal pers. comm. June 2019). The inlets and outlets of the lake complex are also important habitats for a globally 'Near Threatened' species, *Epiophlebia laidlawi* (Nesemann et al. 2011; Shah et al. 2012; Deep Narayan Shah pers. comm. June 2019). Moreover, the lake complex is the source of the Kailash River, which sustains hundreds of thousands of downstream communities in the province. Many river systems of the province have been recently explored for their biodiversity across disturbance scales (Shah et al. 2020a), spatial scale along the longitudinal gradient (Shah et al. 2020b), stressor types (Sharma & Shah 2020), and microhabitats (Bhandari et al. 2018), but the lake complex has not yet been studied from the wider aspects of wetland biodiversity except for water quality and bathymetry (Chalaune et al. 2020). Therefore, a detailed scientific study of the wetland complex was felt necessary. The present study was carried out to assess and document the water quality and the extent and distribution of wetland floral and faunal diversity in the lake complex.

MATERIALS AND METHODS

Study area

The study was carried out in the four lakes of the Ramaroshan Lake complex, i.e., Ramaroshan, Batula, Jingale, and Lamadaya lakes (Figure 1; Image 1). The lake complex lies in Ramaroshan Rural Municipality in the Achham District of Sudurpaschim Province in Nepal. The rural municipality has 4,832 total households with a total population of 23,600, including 11,092 males and 12,508 females, respectively (CBS 2021). Ramaroshan is a proposed protected forest in Nepal that covers an area of 3051.29 ha for the conservation of its unique wetland ecosystem and biodiversity (DoF 2017). The ecosystems of the Ramaroshan protected forest consist of dense forest (96.95%), grassland (1.50%), lakes (1.09%), and rivers and streams (0.46%) (DFO 2019). The lake complex is the union of 12 lakes that cover an area of 30 ha (1.09%), but water remains throughout the year only in four lakes (Ramaroshan, Batula, Lamadaya, and Jingale).

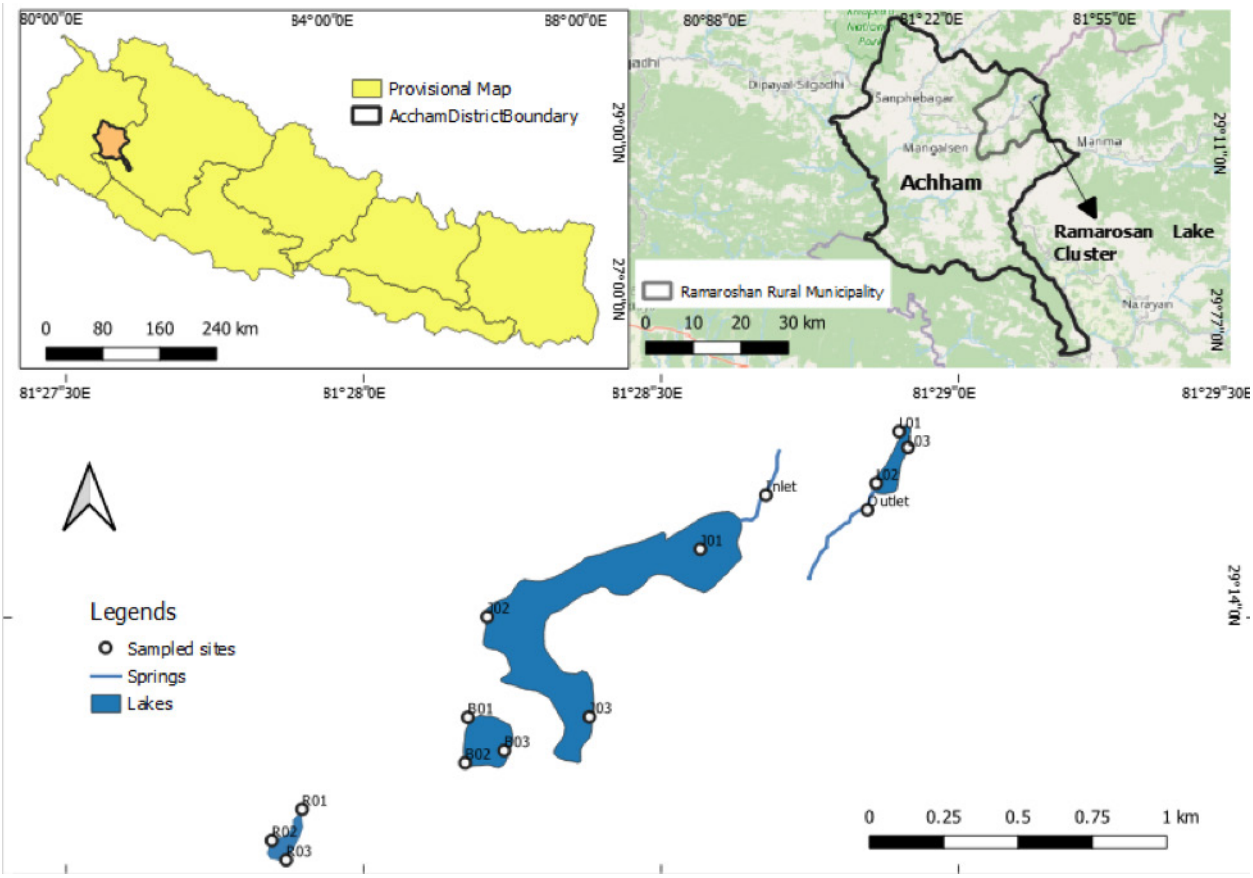

Figure 1. Location of study lakes in Ramaroshan Lake Complex in Sudurpaschim Province of Nepal. Only four major lakes from left to right: namely Ramaroshan (R01, R02, R03), Batula (B01, B02, B03); Jingale (J01, J02, J03); Lamadaya (L01, L02, L03) and the inlet of Jingale and outlet of Lamadaya are included in the study.

Sampling sites

The sampling sites were distributed in all the study lakes namely Ramaroshan, Batula, Jingale, and Lamadaya (Table 1). Jingale is the largest lake among the four lakes studied. In each lake, three littoral sections were selected for the sampling of aquatic macroinvertebrates and measurements of water quality parameters. The study was conducted during the winter (November–February) and summer (May-–June) seasons of 2018 and 2019.)

METHODS

Water quality parameters

Water quality parameters such as pH, water temperature, turbidity, dissolved oxygen (DO), electrical conductivity (EC), and total dissolved solids (TDS) were measured at three sites in each lake using a Hanna multi-parameter probe (Model: HI9829) and turbidity meter. Composite water samples were collected for the determination of total hardness, calcium hardness, magnesium hardness, total alkalinity, chloride, free carbon dioxide (CO_2), calcium cations (Ca^{2+}), magnesium cations (Mg^{2+}), sodium cations (Na^{+}), sulphate anions (SO_4^{2-}) and analysed following APHA guidelines (APHA 2017) at the Aquatic Ecology Centre (AEC), Kathmandu University (KU). Ammonia (NH_4^{+}), ortho-phosphate (PO_4^{2-}), and nitrate (NO_3^{-}) were analysed on-site using the portable HANNA photometers (Hannah Instruments HI96715C, HI96728C, and HI96717, respectively).

Aquatic macroinvertebrates

Aquatic macroinvertebrates were sampled from littoral sections of the lakes following Shah et al. (2015). The samples were collected from three littoral sections of each lake studied. In total, 15 macroinvertebrate samples, including one sample each from the inlet and outlet of the lake complex were collected during field visits. The samples were taken using a standard circular metallic framed hand net of mesh size 500 µm and preserved on site in 95% ethanol for further laboratory

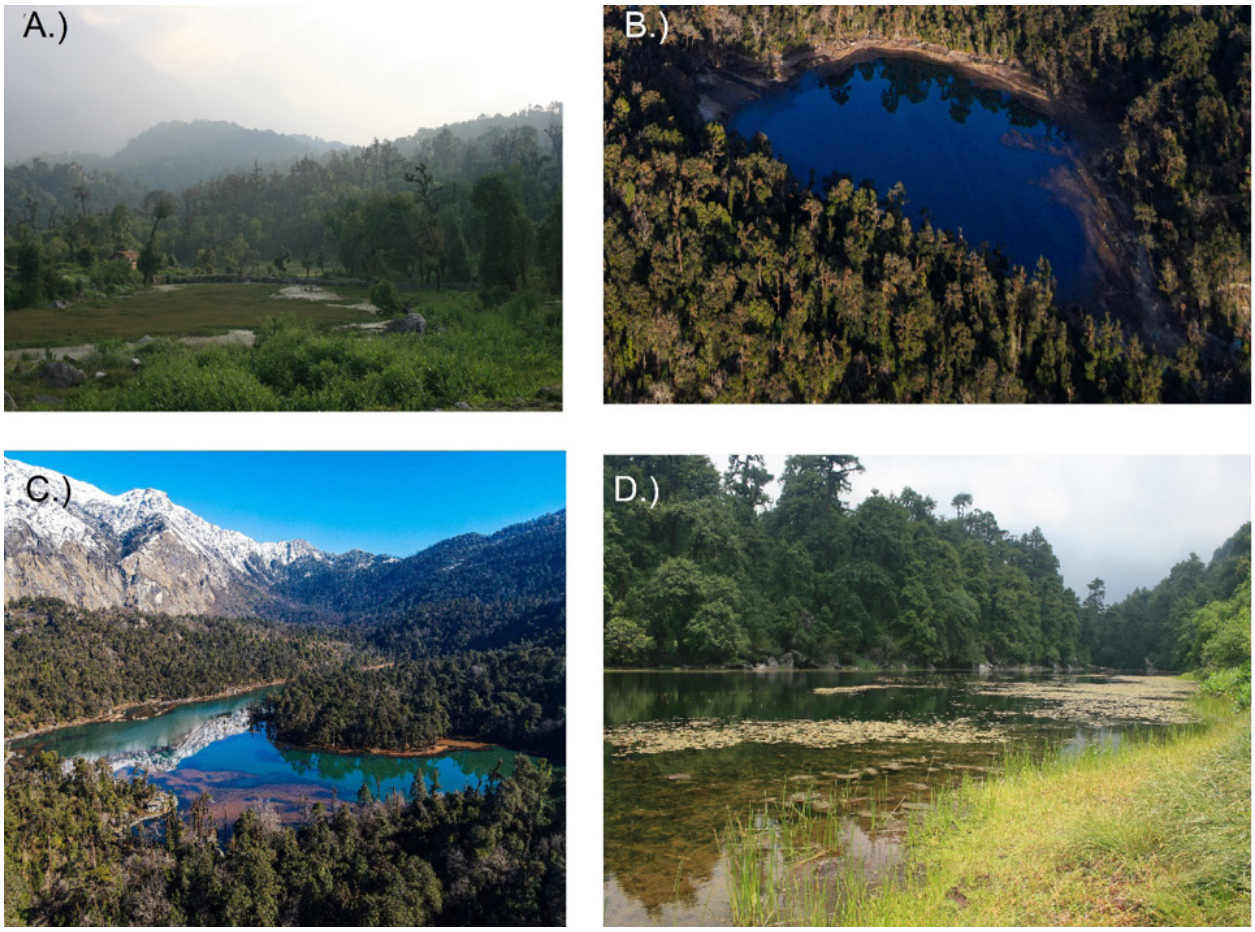

Image 1. Study lakes: A—Ramaroshan Lake. © Deep Narayan Shah | B—Batula Lake. © Ravi Ram | C—Jingale Lake. © Ravi Ram | D—Lamadayal Lake. © Ravi Ram.

Table 1. Geographical locations and morphometric features of the study lakes.

Lakes	Latitude	Longitude	Altitude (m)	Core area (ha)	Maximum Length & depth (m)
Ramaroshan	29.230936	81.461270	2,340	2.18	120 m and 2 m
Batula	29.230451	81.467531	2,405	3.20	130 m and 8 m
Jingale	29.233852	81.468570	2,430	21.50	300 m and 12 m
Lamadaya	29.238693	81.481549	2,545	1.12	100 m and 6 m

processing. The samples were processed at the Aquatic Ecology Centre (AEC) at Kathmandu University (KU). The macroinvertebrates were identified at the family level (Nesemann et al. 2007, 2011; Shah et al. 2015, 2020). The identified samples were preserved in 90% ethanol and stored at AEC, KU.

Fish

The passive entanglement gear technique was used for fish sampling. The fish samples were collected through gill nets placed at different parts of the lake.

Three lake sections — left bank, right bank, and center— were selected in each lake for fish sampling. At each site, two-gill nets were placed and removed every two hours. All captured individuals were taken to a nearby dry place, identified to species level (Shrestha 2019), measured, photographed, and then released back into their original habitats. Specimens that could not be identified in the field were fixed in 10% formalin for 24 hours and subsequently preserved in 70% ethanol. Voucher specimens were deposited at the National Fishery Research Centre, Godavari, Lalitpur, Nepal.

Bird survey

Bird surveys were conducted using the open-width point count method along transects near the lake's shoreline, following the protocol outlined by Bibby et al. (2000). Additionally, we employed the area search method during the field study, as described by Slater (1994), Dieni and Jones (2002), and Adhikari et al. (2022). The length of each transect was determined based on the specific characteristics of the habitat and landscape, following principles outlined by Hanowski et al. (1990). Within each transect, we established a minimum of five vantage points at 100-meter intervals, where we used binoculars (Nikon 20x50) to count bird species. At each point, we conducted five-minute counts of bird species. We documented all observed species, aided by both visual and auditory observations, including relevant habitat and environmental variables. To ensure data accuracy, each transect was surveyed by two observers. Subsequently, we combined the recorded bird species lists from various vantage points within each transect. Survey periods included mornings from 600 h to 1200 h and evenings from 1500 h to 1800 h. Bird species were identified using the field guidebook for birds of Nepal authored by Grimmett et al. (2016a, b).

Herpetofauna

Both amphibians and reptiles were surveyed using nocturnal and diurnal and transects respectively in a time-constrained visual encounter survey (Khatiwada 2012; Khatiwada et al. 2016; Khatiwada et al. 2019). Transects were searched by four people for two hours using torches, walking at a slow pace at night (700 h – 900 h) and during the day (1000 h– 1300 h). The number of species and individuals encountered in each transect was recorded along with all habitat and environmental variables. Apart from nocturnal and diurnal transects, opportunistic random surveys were also carried out to document the occurrence of herpetofauna species in the area. All individuals encountered were captured and stored in a 15 L plastic bucket with small holes in the lid. Some uncaptured individuals were also counted. All captured individuals were taken to a nearby dry place where the animals were measured and identified at the species level based on guide books: Schleich & Kästle (2002) and Shah & Tiwari (2004), and then released back into their original habitats. Male frogs were identified based on secondary sexual characteristics in the presence of black pigment on the throat (vocal sac) and nuptial pads, and females by the enlargement of the coelomic cavity in gravid individuals. Specimens that were difficult to identify based on morphological traits in the field were euthanized in a chlorobutanol solution, fixed in formalin for 24 hours, and subsequently preserved in 75% ethanol. The morphological parameters (e.g., body length, fin length, and eye diameter) were measured and compared with identification keys. The species nomenclature follows Frost (2019). Voucher specimens were stored at the Central Department of Zoology, Tribhuvan University, Kathmandu, Nepal.

Mammal survey

Five systematic transects (varying from 0.42 to 1.5 km) were laid in the riparian areas. The transect line was searched by 2-3 people, and all the animals sighted and indirect signs of mammals such as scats, pellets, droppings, dung, pugmarks, scrapings, carcasses, quills, and burrows were recorded. Apart from these, an opportunistic survey was also conducted around the lake to record mammals.

Macrophytes and vegetation survey

Macrophytes and vegetation were surveyed in and around the lake to enumerate the checklist of plant species. Surveying along line transects starting from shore to the lake interior is a flexible method to document macrophytes in small lakes (Titus 1993). We used two 25 m long-line transects from Lake Shore to the centre and noted the macrophytes at different distances. A floating tube was used to swim, and a rake was used to collect submerged macrophytes.

A vegetation survey in the surrounding forests (about 100 m from the lake shore) was carried out to prepare the checklist of plants occurring in the lake complex area. Transect walks along the trails and through the forest were performed to collect plant specimens.

Collected specimens were identified on-site, while unidentified specimens were preserved following standard herbarium methods (Bridson & Forman 1999). Herbarium specimens prepared for further identification were deposited at the National Herbarium and Plant Laboratory in Kathmandu. Plants were identified using relevant identification keys (Polunin & Stainton 1984; Grierson & Long 1983, 2001).

Data analysis

The Nepal Lake Biotic Index (NLBI) for lakes and the Biotic Index (Shah et al. 2020c) for running waters (inlet and outlet) were calculated by assigning tolerance scores to macroinvertebrates identified at the family level (Shah et al. 2011, 2020c). In these methods, the index value is the sum of the tolerance scores divided by the number of scored taxa for a site, which then

translates to the lake water quality class (LWQC) for indicating the degree of degradation).

Non-metric Multidimensional Scaling (NMDS): Non-metric multidimensional scaling (NMDS) was performed to cluster sites based on macroinvertebrate abundance data. Prior to analysis, macroinvertebrate abundance data were transformed to log (x+1). The Bray-Curtis distance measure was employed in NMDS, and the analysis was conducted using the R package (R Core Team 2019).

Shannon diversity index (H) The Shannon diversity index (H) was used to assess species diversity within a community (Shannon 1948):

Shannon Index (H) = $- \sum p_i \ln p_i$

Where p_i is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N),

ln is the natural log,

Σ is the sum of the calculations,

Community Diversity Measurement - Simpson Index (D): The Simpson index was determined to measure community diversity in relation to habitats (Simpson 1949).

$$\text{Simpson Index (D)} = 1 - \left(\frac{\sum n(n-1)}{N(N-1)}\right)$$

Where n is the number of individuals of one particular species,

N is the total number of individuals found.

Σ is the sum of the calculations.

D values range between 0 and 1.

Evenness and Equitability: Evenness (e) was used to determine the distribution of individuals of a taxon in a community. It is constrained between 0 and 1.0:

Evenness = H'/Hmax

Where H' is the Shannon diversity index

H_{max} is the maximum taxon recorded at a site.

Jacob's Equitability index: Jacob's Equitability (J) was used to measure the evenness with which individuals are divided among the taxa present.

Equitability (J) = H'/lnS

Where H' is Shannon's index of diversity,

S is the number of taxa

Fisher's Diversity Index: Fisher's index describes the mathematical relationship between the number of species and the number of individuals in those species (Fisher & Yates, 1943). The Fisher diversity index is defined implicitly by the formula below:

Fisher's diversity index $(S) = a \times ln\,(1 + \frac{n}{a})$

Where *n* is the number of individuals and *a* is Fisher's alpha).

RESULTS

Water quality parameters

Most of the water quality parameters except pH, free CO_2, Mg hardness, Ca hardness, potassium cations, and sulphate anions significantly varied between seasons across lakes (Table 2). For each lake, the water temperature was the single parameter that varied significantly in each study lake between seasons. Seasonal variation was recorded for electrical conductivity (86.86±4.93|75.23±5.53, p <0.001), ammonia (0.17±0.01|0.30±0.02, p <0.01), total alkalinity (64±4.93|55.66±4.91, p <0.01), chloride (14.33±1.45|16.67±1.45, p <0.01) and sodium cations (5.2±0.26|4.46±0.12, p <0.05) in Ramaroshan lake. Dissolved oxygen (7.36±0.42|5.35±0.05, p <0.05), nitrate (6.18±0.18|7.51±0.55, p <0.05), phosphate (1.19±0.09|1.64±0.12**, p <0.01) and total hardness (101±2.08|135.33±3.17, p<0.01) were different between seasons for Batula lake. Ammonia (0.28±0.03|0.34±0.03, p <0.05) and Mg hardness (18±2.64|18±1.52, P <0.001) were different between seasons for Jingale lake. TDS (49±7|36±3, p <0.01), turbidity (2.3±0.49|2.7±0.41, p <0.01), DO (2.3±0.49|2.7±0.41, p <0.01), Mg hardness (15±1.52|14±2, p <0.05) and sodium cations (5.33±0.14|4.3±0.20, p <0.01) were significantly different between seasons for Lamadaya lake.

Biodiversity survey

Aquatic macroinvertebrates

A total of 45 families belonging to 14 orders of macroinvertebrates were recorded in the study lakes including the inlet and outlet of the Ramaroshan Lake complex (Supplementary 1). Diptera was the most dominant and diverse order followed by Odonata and Mollusca in the lakes, while Trichoptera was the most dominant and diverse order followed by Diptera and Ephemeroptera in running waterbodies (inlet and outlet streams) of the lakes (Figure 2). Plecoptera was found only in Lamadaya Lake and running water bodies. Among lakes, Lamadaya was found to be highly diverse in terms of taxa composition, while Ramaroshan was the least diverse. Family richness ranged from 10 to 25 in the lakes, and 14 to 30 in running waterbodies. Family

Table 2. Mean and standard values of physico-chemical parameters for each study lake for the winter and summer seasons of year 2018 and 2019. Values indicated in bold digits are significant between seasons. The symbols (Asterisks) "*", "" and "***" represent significance levels at 0.05, 0.01, and <0.001.**

	Parameters/Lakes	Across lakes Winter| Summer	Lamadaya Winter| Summer	Jingale Winter| Summer	Batula Winter| Summer	Ramaroshan Winter| Summer
1	pH	8.36±0.42| 8.57±0.48	8.66±0.26| 8.77±0.35	8.68±0.14| 8.69±0.32	8.82±0.15| 8.46±0.21	8.03±0.27| 8.36±0.31
2	Temperature (°C)	**16.08±1.76| 23.98±2.11*****	**13.86±0.20| 22.27±0.56****	**15.23±0.26| 21.92±0.36****	**17.16±0.40| 25.35±0.43****	**18.06±0.26| 26.37±0.39*****
3	TDS	**47.08±9.23| 38.75±10.64***	**49±7| 36±3****	56.33±5.48| 43.66±12.12	36.66±0.88| 37.33±2.02	46.33±3.17| 38±5.50
4	Turbidity (NTU)	**2.97±1.06| 3.62±1.28****	**2.3±0.49| 2.7±0.41****	4.06±0.29| 5.36±0.46	2.93±0.42| 3.02±0.32	2.6±0.81| 3.4±0.62
5	DO	**7.49±0.67| 80.37±13.73*****	**8.13±0.17| 6.36±0.33****	7.73±0.12| 6.80±0.50	**7.36±0.42| 5.35±0.05***	6.73±0.29| 5.82±0.33
6	EC (µS/cm)	**88.49±14.86| 80.37±13.73***	88.03±4.23| 71.33±2.58	107.06±7.03| 98.41±5.95	72±1.89| 76.52±6.97	**86.86±4.93| 75.23±5.53****
7	Free CO2	3.43±1.32| 3.14±0.85	4.06±0.98| 3.8±0.20	3.56±0.81| 3.06±0.18	3.83±0.75| 3.66±0.47	2.26±0.24| 2.03±0.23
8	Nitrate (mg/L)	**2.87±2.83| 3.42±3.49****	0.12±0.02| 0.10±0.3	0.28±0.08| 0.21±0.06	**6.18±0.18| 7.51±0.55***	4.9±0.13| 5.86±0.23
9	Ortho-phosphate (mg/L)	**1.27±0.19| 1.48±0.21*****	1.41±0.12| 1.36±0.14	1.12±0.01| 1.41±0.08	**1.19±0.09| 1.64±0.12****	1.35±0.13| 1.53±0.14
10	Ammonia (mg/L)	**0.19±0.11| 0.27±0.14***	0.21±0.11| 0.36±0.11	**0.28±0.03| 0.34±0.03***	0.08±0.02| 0.09±0.02	**0.17±0.01| 0.30±0.02****
11	Total Alkalinity (mg/L)	**55.08±17.93| 48.05±16.09****	27.66±2.40| 24.33±4.33	59±2.3| 57±5.50	69.66±3.28| 55.22±5.07	**64±4.93| 55.66±4.91****
12	Mg Hardness	19.58±7.93| 20.08±8.36	**15±1.52| 14±2***	**18±2.64| 18±1.52*****	29.33±4.91| 31.22±3.84	16±4.04| 17±4.58
13	Ca Hardness	**57.83±13.75| 74.66±20.06****	42.33±1.20| 55.33±2.40	53.33±4.63| 73.33±2.90	71.66±6.93| 104±7	64±5.56| 66±4.35
14	Total Hardness (mg/L)	**77.41±16.83| 94.75±26.15*****	57.33±2.02| 69.33±3.52	71.33±2.02| 91.33±1.85	**101±2.08| 135.33±3.17****	80±2.30| 83±2.64
15	Chloride (mg/L)	**11.75±4.82| 13.5±5.16*****	5±0.57| 6.33±1.20	16.33±1.45| 18±3	11.33±1.20| 13±2	**14.33±1.45| 16.67±1.45****
16	Calcium cations (mg/L)	15.64±3.87| 15.79±3.51	9.98±0.89| 10.74±0.89	18.36±1.94| 17.47±0.77	17.53±0.55| 18.61±1.24	16.7±0.75| 16.33±1.20
17	Magnesium cations (mg/L)	3.13±0.88| 3.25±0.90	1.89±0.11| 1.96±0.23	3.33±0.34| 3.60±0.36	3.56±0.43| 3.66±0.14	3.76±0.17| 3.76±0.42
18	Potassium cations (mg/L)	1.80±0.60| 1.72±0.53	1.73±0.35| 1.5±0.30	1.63±0.08| 1.6±0.11	2.6±0.25| 2.43±0.20	1.26±0.08| 1.36±0.17
19	Sodium cations (mg/L)	**5.16±0.46| 4.36±0.42*****	**5.33±0.14| 4.3±0.20****	4.7±0.34| 3.93±0.18	5.43±0.14| 4.76±0.24	**5.2±0.26| 4.46±0.12***
20	Sulphate anions (mg/L)	0.80±0.67| 0.63±0.53	0.13±0.01| 0.12±0.02	1.6±0.40| 1.2±0.36	1.02±0.14| 0.90±0.11	0.46±0.12| 0.3±0.05

richness was low for the winter season compared to the summer season in the lakes and running water bodies (Figure 2)

The lakes were categorized into a 'fair' LWQC for both seasons while the water quality class for running water bodies was categorized into a 'good' status for winter and a 'fair' status for the summer season in the outlet (Figure 3).

Non-metric multidimensional scaling (NMDS) disentangled sites into three clusters- Cluster 1 representing sites of running water bodies, Cluster 2 for sites of Lamadaya, and Cluster 3 for sites of the remaining three lakes (Figure 4).

Fish

Altogether, three species of fish, namely *Schizothorax nepalensis*, *S. richardsonii,* and *Garra gotyla,* belonging to the Cyprinidae family, were recorded in the lakes of Ramaroshan Lake Complex. Among these reported species, *S. nepalensis* listed as Critically Endangered, which is endemic to northwest Nepal (Regmi et al., 2021b), and *S. richardsonii which is* common to major river systems (Koshi, Gandaki, and Karnali), is listed as a vulnerable category in the IUCN Red List.

Bird survey

In total, 1018 individuals (winter = 611 and summer = 423) of birds from 79 species belonging to 33 families and 15 orders were documented in the lake complex

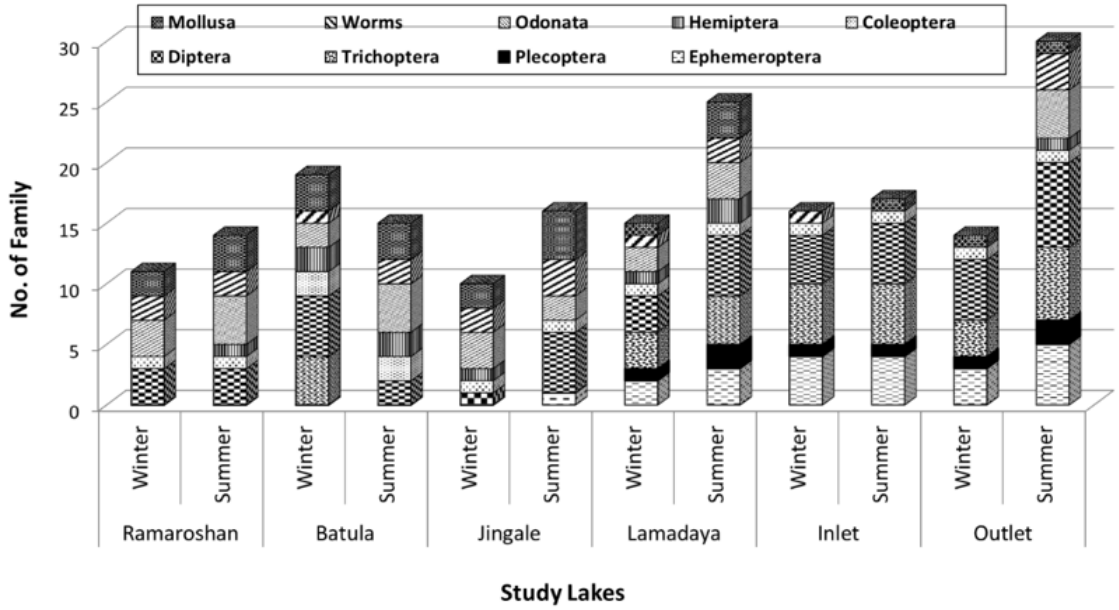

Figure 2. The family richness of aquatic macroinvertebrates was recorded in the winter and summer seasons of the year 2018 and 2019 in the study sites of the Ramaroshan Lake Complex. Inlets and outlets are running streams coming to the lake and leaving the lake.

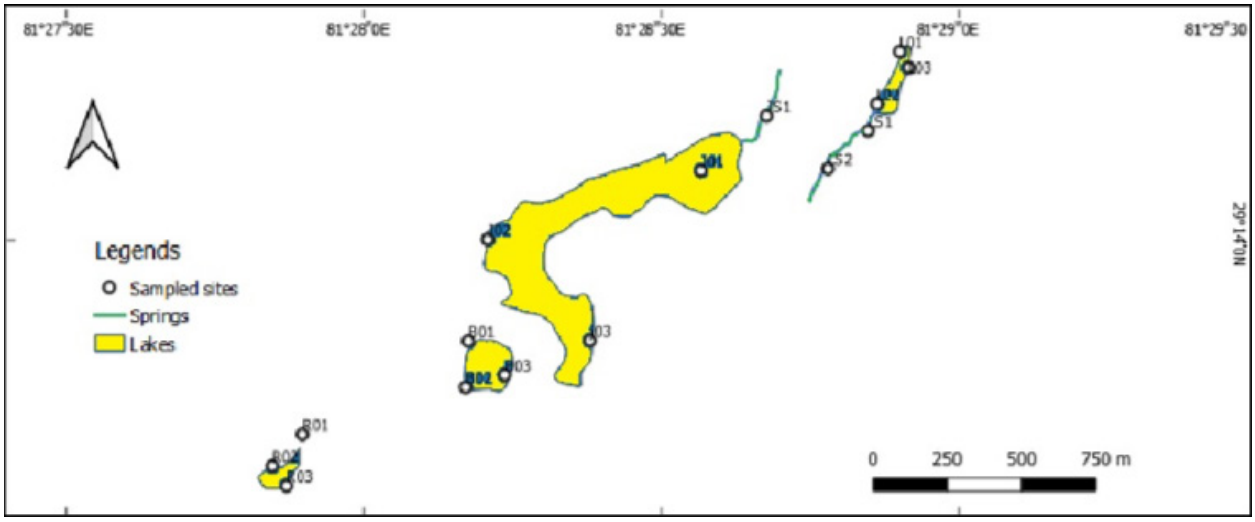

Figure 3. Lake water quality classes of four study lakes and water quality classes for running water bodies. Yellow color indicates fair water quality while green indicates good water quality.

(Supplementary 2). The abundance of birds was significantly higher in the winter season than in the summer season ($t = 2.81$, $p < 0.01$), but the species richness was higher in summer (n = 73) than in winter (n = 67). Of them, four species: *Neophron percnopterus* (Egyptian Vulture), *Ciconia episcopus* (Asian Wollyneck), *Catreus wallichii* (Cheer Pheasant), and *Vanellus vanellus* (Northern Lapwing) have been listed as Endangered, Vulnerable and Near Threatened, respectively in the IUCN Red List. The most abundant species were from the order Passeriformes for the summer (66.90%) and winter (64.84%) seasons (Figure 5).

A total of 15 species of wetland birds (winter – 14, and summer - 15) were recorded from the lakes of the Ramaroshan complex, followed by 37 forest birds (winter - 30, summer - 35), 16 open area and grassland-dependent birds (winter -14, summer -13), and 9 bush birds (winter - 9, summer - 10) (Figure 6). The study reported winter migratory birds such as the Eurasian Coot (*Fulica atra*), Little Grebe (*Tachybaptus ruficollis*), Mallard (*Anas platyrhynchos*), Eurasian Wigeon (*Anas Penelope*) and Common Teal (*Anas crecca*).

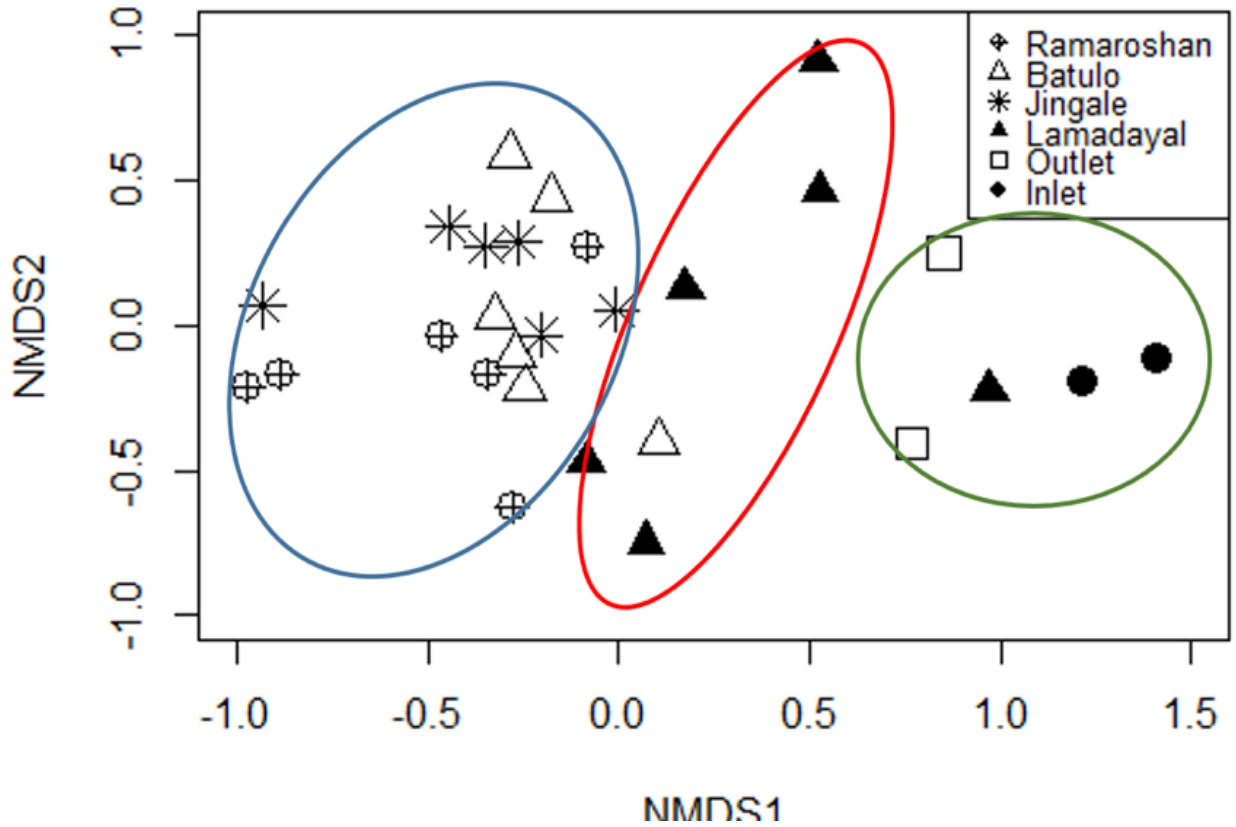

Figure 4. Non-metric multidimensional scaling based on aquatic macroinvertebrate abundance data. Each symbol type represents sites of a particular lake or inlet and outlet. Symbols: closed circle: Inlet sites; open square: outlet sites; closed triangle: Lamadaya sites; open triangle: Batula lake; Asterisk: Jingale lake; crossed circle: Ramaroshan lake. Stress value: 0.17.

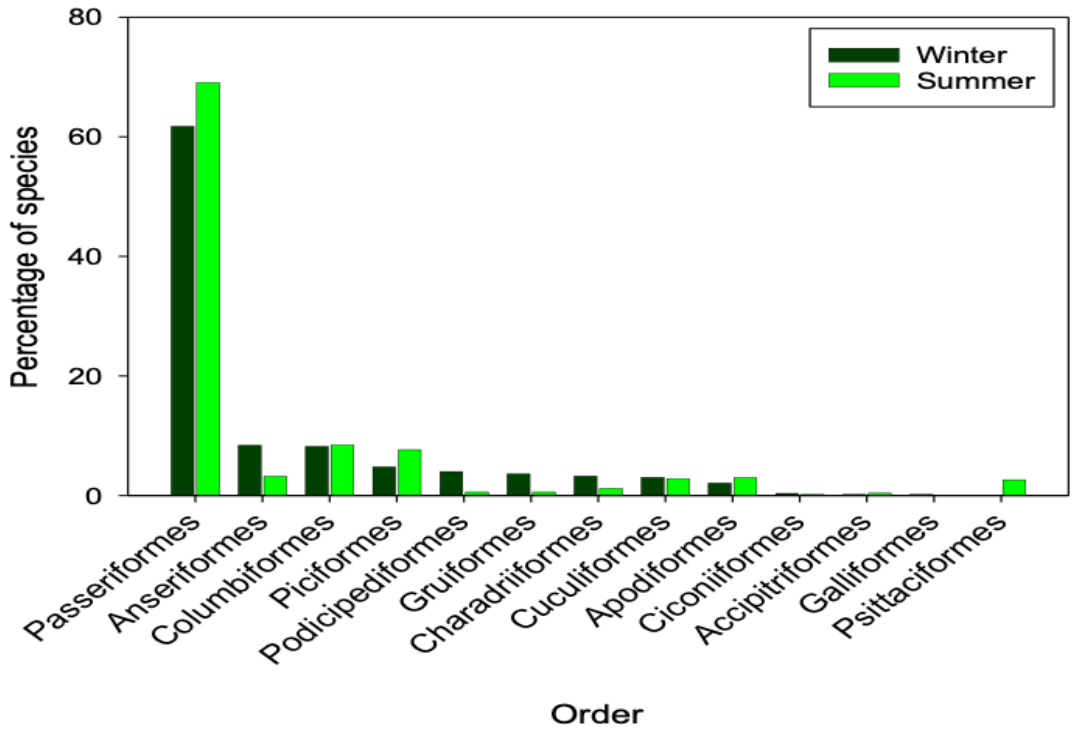

Figure 5. Number of bird species recorded with respect to order for winter and summer seasons in the Ramaroshan Lake Complex.

Table 3. Bird's diversity and dominance indices in Ramaroshan Lake Complex.

Metrics/Seasons	Winter			Summer		
	Average	Lower	Upper	Average	Lower	Upper
Shannon diversity index (H)	4.01	3.93	4.01	4.06	3.96	4.07
Species dominance index (D)	0.02	0.02	0.02	0.02	0.02	0.02
Simpson index of diversity (1-D)	0.98	0.98	0.98	0.98	0.98	0.98
Evenness (E)	0.82	0.76	0.82	0.80	0.72	0.80
Equitability (J)	0.95	0.93	0.95	0.95	0.92	0.95
Fisher diversity index (S)	19.19	19.19	19.19	25.44	25.44	25.44

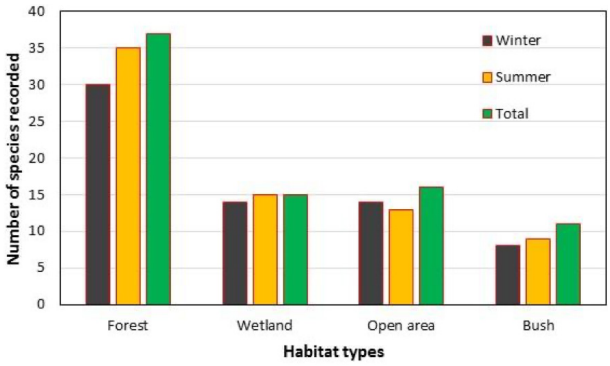

Figure 6. Number of bird species across habitat types recorded in and around Ramaroshan Lake Complex.

There was no significant variation in the Shannon diversity index, Species dominance index, and Simpson index of diversity for birds between winter and summer seasons (Table 3; p = 0.79). The species' evenness of birds (0.82) and Jacob's coefficient of equality (0.95) were lower in winter than in the summer season (evenness = 0. 80, Jacob's coefficient of equality = 0.95).

Herpetofauna

Within the lake complex, a comprehensive survey documented a total of 121 amphibians, representing 7 distinct species distributed across 5 families. Notably, *Nanorana legibii* dominated the population at 50.4%, followed by *Duttaphrynus himalayanus* at 32.2% and *Hoplobatrachus tigerinus* at 5.8% (Figure 7). Two endemic amphibian species, *Nanorana minica* and *Amolops marmoratus*, were also identified at the study sites (Table 4). It is worth highlighting that both Liebiegi's Paa Frog *Nanorana legibii* and Small Paa Frog *Nanorana minica* are categorized as globally Vulnerable on the IUCN Red List. Furthermore, the Indian Bull Frog *Hoplobatrachus tigerinus*, classified as globally Near Threatened by the IUCN in 2021, was also observed within the lake complex.

A total of five species of reptiles were recorded during the field survey. Among them, *Laudakia tuberculata* (48%) was the most abundant species in the study area, followed by *Calotes versicolor* (25%), and *Eutropis carinata* (21.4%), respectively (Table 4).

Mammals

This study documented a total of 12 mammal species. Notably, four of these species enjoy legal protection under the DNPWC Act of 1973, enforced by the government of Nepal. These protected species include the Leopard *Panthera pardus*, the Red Panda *Ailurus fulgens*, the Asiatic Black Bear *Ursus thibetanus*, and the Himalayan Goral *Naemorhedus goral*. The Red Panda is of particular concern as it holds the classification as being 'Endangered' according to the IUCN Red List. Similarly, the Himalayan Black Bear and Leopard are categorized as 'Vulnerable' under the IUCN Red List, while the Assam Macaque and Himalayan Goral fall within the 'Near Threatened' category (Table 5).

Macrophytes and Vegetation Survey

In total, the lakes of the Ramaroshan Lake complex harbored 25 species, encompassing 14 families of macrophytes (Table 6). Predominantly, *Scirpus compressus*, *Scirpus sinensis*, and *Polygonum hydropier* thrived as major emergent plants along the shores and in marshy areas. Among submerged vegetation, *Ceratophyllum demersum* and *Potamogeton nutans* prevailed. The complex featured *Nelumbo nucifera* as the sole-rooted floating macrophyte species. Additionally, the region supported two wetland-dependent plants, *Allium waalichina* and *Ophioglossum nudicaule*, esteemed for their medicinal attributes and utilized as vegetables by the local populace.

Expanding the scope, the Ramaroshan Lake complex area showcased an impressive biodiversity of 167 plant species, spanning 70 families (Supplementary 3).

Table 4. List of the herpetofauna recorded in the study transect. LC—Least Concern | NT—Near Threatened | VU—Vulnerable.

Types	Common name	Scientific name	Habitat type	IUCN Red List status
Amphibian	Marbled Cascade Frog	*Amolops marmoratus* (Blyth,1855)	River bank	LC
	Himalayan Toad	*Duttaphrynus himalayanus* (Gunther, 1864)	Lake edge	LC
	Indian Bull Frog	*Hoplobatrachus tigerinus* (Daudin, 1802)	Lake edge	NT
	Myanmar Pelobatid Toad	*Megophyrus parva* (Boulenger, 1893)	Grassland	LC
	Liebiegi's Paa Frog	*Nanorana legibii* (Gunther, 1860)	River bank	VU
	Small Paa Frog	*Nanorana minica* (Dubois, 1975)	Lake edge	VU
	Common Indian Tree Frog	*Polypedates maculatus* (Gray, 1830)	Lake edge	LC
Reptile	Common Garden Lizard	*Calotes versicolor versicolor* (Daudin, 1802)	River bank	LC
	Himalayan Rock Lizard	*Laudakia tuberculata* (Hardwicke & Gray, 1827)	Lake edge	LC
	Bengal Monitor	*Varanus bengalensis* (Daudin, 1802)	Lake edge	LC
	Common Indian Skink	*Eutropis carinata* (Schneider, 1801)	Lake edge	LC
	Mountain Keelback	*Amphiesma platyceps* (Blyth, 1854)	Lake edge	LC

Notably, Rosaceae stood out as the largest family with 17 species, followed closely by Asteraceae with 14 species and Poaceae with 13 species. *Taxus wallichiana*, a valuable medicinal plant, flourished abundantly within the complex area. It's worth mentioning that this species holds a spot on the IUCN Red List as endangered and is also listed in CITES Appendix III.

DISCUSSION

Ramaroshan Lake complex is known for its unique landscape and high biodiversity. The lake complex provides forest resources such as fodder for livestock and bamboo and firewood for household consumption in adjacent communities. The complex is an excellent area for livestock grazing. Local inhabitants obtain water for drinking purposes, domestic consumption, and irrigation. Like other wetlands in Nepal, the lake complex is also affected by land encroachment. In 30 years, the wetland area of the complex has shrunk by 16% due to land use and land cover changes (Paudel et al. 2022).

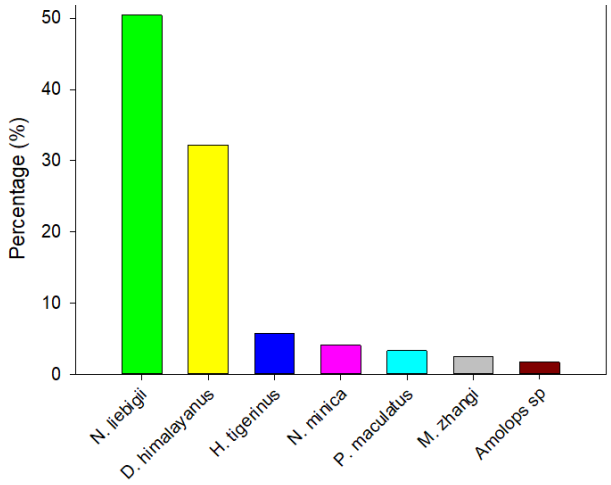

Figure 7. The relative percentage of amphibian species recorded in the Ramaroshan Lake Complex.

Water quality status

Ramaroshan Lake complex, being situated in the remote mid-hills of the country, has water quality parameter values for all four lakes within the permissible limit for the winter and summer seasons (see Table 2). Dissolved oxygen (DO) for all four lakes was greater than 5 mg/L, indicating good status for maintaining higher forms of aquatic life in water (Bozorg-Haddad et al. 2021). DO was highest in Lamadaya lake (6.35 mg/L) and lowest in Batula lake (5.26 mg/L). Similar DO values were also reported from the lake complex for the winter season in 2020 (Chalaune et al. 2020) and were comparable with the DO values recorded in other lakes of the region (Gurung et al. 2018). DO greater than 4 mg/L is suitable for bathing, aquaculture, and irrigation (Bozorg-Haddad et al. 2021).

Lamadaya Lake unlike other lakes, had many physical parameters that were significantly different. This might be due to its smaller size, being relatively shallow, and being surrounded by dense forest. Hydrological fluctuation between seasons might have played a major role in making it different (Regmi et al. 2021a). Similarly, Ramaroshan Lake and Batula Lake being situated in the lower region of the lake complex, the nutrient parameters such as nitrate and phosphate; hardness, and alkalinity were found to be high compared to Jingale and Lamadaya lakes.

Table 5. List of threatened mammals recorded from the Ramaroshan Lake Complex. LC—Least Concern | NT—Near Threatened | VU—Vulnerable | EN—Endangered.

	Order	Family	Common name	Scientific name	IUCN Red List status
1	Rodentia	Hystricidae	Indian Crested Porcupine	*Hystrix indica*	LC
2	Lagomorpha	Ochotonidae	Royle's Pika	*Ochotona roylei*	LC
3	Carnivora	Canidae	Golden Jackal	*Canis aureus*	LC
4	Rodentia	Hystricidae	Malayan Porcupine	*Hystrix brachyura*	LC
5	Primates	Cercopithecidae	Assam Macaque	*Macaca assamensis*	NT
6	Primates	Cercopithecidae	Rhesus Macaque	*Macaca mulatta*	LC
7	Cetartiodactyla	Cervidae	Northern Red Muntjac	*Muntiacus vaginalis*	LC
8	Cetartiodactyla	Bovidae	Himalayan Goral	*Naemorhedus goral*	NT
9	Carnivora	Felidae	Leopard	*Panthera pardus*	VU
10	Primates	Cercopithecidae	Nepal Grey Langur	*Semnopithecus schistaceus*	LC
11	Carnivora	Ursidae	Himalayan Black Bear	*Ursus thibetanus*	VU
12	Carnivora	Ailuridae	Red Panda	*Ailurus fulgens*	EN

Table 6. List of macrophytes species according to their types in the lakes of Ramaroshan Lake Complex for summer 2019.

	Family	Scientific name	Types
1	Brassicaceae	*Barbarea intermedia*	Amphibious
2	Caryophyllaceae	*Stellaria aquatica*	Emergent
3	Ceratophyllaceae	*Ceratophyllum demersum*	Submerged
4	Characeae	*Chara* sp.	Submerged
5	Cyperaceae	*Cyperus compressus*	Amphibious
6	Cyperaceae	*Scirpus sinensis*	Emergent
7	Hydrocharitaceae	*Hydrilla verticillata*	Submerged
8	Juncaceae	*Juncus articulates*	Amphibious
9	Juncaceae	*Juncus leucanthus*	Amphibious
10	Plantaginaceae	*Plantago aquatica*	Emergent
11	Poaceae	*Alopecurus geniculatus*	Amphibious
12	Poaceae	*Echinochloa crus-galli*	Amphibious
13	Poaceae	*Eleocharis congesta*	Amphibious
14	Poaceae	*Eragrostis* sp.	Amphibious
15	Polygonaceae	*Persicaria barbata*	Emergent
16	Polygonaceae	*Persicaria capitata*	Emergent
17	Polygonaceae	*Persicaria posumbu*	Emergent
18	Polygonaceae	*Polygonum hydropiper*	Emergent
19	Potamogetonaceae	*Potamogeton filiformis*	Submerged
20	Potamogetonaceae	*Potamogeton nutans*	Submerged
21	Potamogetonaceae	*Potamogeton crispus*	Submerged
22	Ranunculaceae	*Caltha scapose*	Emergent
23	Ranunculaceae	*Ranunculus trichophyllus*	Submerged
24	Typhaceae	*Typha angustifolia*	Emergent
25	Zygnemataceae	*Spirogyra* sp.	Submerged

Biodiversity

Ramaroshan Lake complex is situated in the temperate zone, low species richness can be expected in comparison to lowland Tarai because species richness declines with increasing elevation in the Himalayas (Shah et al. 2015; Basnet et al. 2016; Araneda et al. 2018).

Aquatic macroinvertebrates

Water quality is a crucial parameter that determines biotic community composition in lake environments. We observed significant changes in water quality parameters across the lakes (Table 2), and this could be a key factor for the differences in the composition of macroinvertebrates between Lamadaya and the other lakes (Figure 3, 4). Warm water-adapted macroinvertebrates of insect orders Odonata, Coleoptera, and Hemiptera, together with annelid worms and Mollusca were diverse and abundant in lakes during the summer season (Figure 3). These findings are similar to the findings for tropical lakes (Shah et al. 2011; Shrestha et al. 2021). Diverse macroinvertebrates were recorded in Lamadaya Lake which might be due to the occurrence of mosaic habitats mainly comprised of soft substrates like leaf litters, twigs, and macrophytes. Soft substrates not only provide suitable habitats for macroinvertebrate colonization but also prevent predation (sensu Shah et al. 2011).

Fishes

The lake complex highlights its importance as a critical habitat for critically endangered fish species: Snow Trout *Schizothorax nepalensis* and vulnerable fish species (*Schizothorax richardsonii*).

Birds

The Ramaroshan Lake Complex plays a pivotal role in providing a crucial habitat for bird diversity, as evident from Supplementary 2. A notable highlight is the documented presence of the globally endangered vulture species *Neophron percnopterus*, the Egyptian Vulture, underscoring the complex's significance. This mountainous ecosystem serves as a sanctuary for

globally threatened vulture species, with a majority (7 out of 9) choosing mountain cliffs and towering trees for nesting (DeCandido et al. 2012). Notably, this study reveals that 8.9% of the bird species documented in Nepal, amounting to 891 species according to DNPWC and BCN 2019, find a habitat in the Ramaroshan Lake complex. In Nepal, approximately 200 wetland bird species have been recorded (BCN 2018), with 15 of them (7.5%) also making their presence known in the Ramaroshan Lake complex. It's worth noting that the winter season sees a decline in the sighting of wetland birds, likely attributed to the sub-zero temperatures during this period (DFO 2019).

Herpetofauna

Ramaroshan Lake complex is rich in herpetofauna diversity. A total of 7 species of frogs and 5 species of reptiles were recorded during this study, which is 12.5% (out of 56) and 4.5% (out of 117 species) of the total species recorded from Nepal, respectively (Shah & Tiwari 2004a). High altitude supports a low number of herpetofauna as they are cold-blooded animals (Khatiwada et al. 2019).

Among the recorded amphibian species, Liebiegi's Paa Frog *Nanorana legibii* and Small Paa Frog *Nanorana minica* are listed under the globally vulnerable category, while the Indian Bullfrog *Hoplobatrachus tigerinus* is listed as a globally near threatened species. Studies have shown that frogs are an important source of livelihood for many people (Khatiwada & Haugaasen 2015) and remain an integral part of local medicinal heritage (Mohneke et al. 2011; Lynch et al. 2023). Amphibians and reptiles have long been used by humans as food and medicine (Gonwouo & Rödel 2008; Khatiwada & Haugaasen 2015). Local people in the Ramaroshan areas use Paha frogs (*Nanorana* and *Amolops* species) as food and medicines. Over-collection of the species may lead to local extinctions or severe population declines. As many amphibian species predictably aggregate for reproduction or hibernation, this makes them particularly vulnerable to intensive collecting efforts. Recent studies have indicated that commercial or subsistence harvesting has contributed to a decline in many reptile species (Webb et al. 2002). Khatiwada & Haugaasen (2015) revealed that *Paa* and *Amolops* are the most exploited frog species by the local people for food and medicinal purposes in mountainous parts of Nepal. This heavy exploitation may also lead to local or global declines and even extinctions through unsustainable collection (Warkentin et al. 2009).

Mammals

The mammals in the Ramaroshan lakes area were reported based on signs and direct sightings, and 12 species of mammals were reported during the field study. Among the reported species, one is endangered, two are vulnerable, and two are near threatened mammals, according to the IUCN Red List. Nepal supports 212 species of mammals (Amin et al. 2018), but this small area alone supports 12 species of mammals thus highlighting the importance of the Ramaroshan Lake complex for mammal conservation.

Macrophytes and Vegetation

This study significantly expanded upon the existing knowledge of the area's flora by documenting a total of 26 macrophyte species, thus surpassing the previously reported count of 10 wetland species (Paudel & Pandey 2016). Furthermore, compared to an earlier study (DoF 2017) that documented only 124 plant species within the lake complex (see Supplementary 3), our research uncovered additional plant species. It's worth noting that there is a limited body of research assessing macrophytes in the mid-hills (Basnet et al. 2016), Churia, and Tarai regions of Nepal (Regmi et al. 2021a). For instance, Basnet et al. (2016) identified fewer than 10 macrophytes in Rara Lake, located in the High Mountain region. In contrast, the wetlands of the Tarai-Plain, as highlighted by Regmi et al. (2021a) and Burlakoti & Karmacharya (2006), hosted over 50 macrophyte species. This observation suggests a pattern of increasing macrophyte species richness from the high mountain to the lowland Tarai regions. Despite its location in the mid-hill region, the Ramaroshan Lake Complex exhibited a modest richness of macrophytes. Additionally, the presence of terrestrial flora, including endangered species like *Taxus wallichiana*, contributes to the overall biodiversity of the lake ecosystem. It's important to note that our vegetation survey was exploratory, and further extensive sampling in both forests and lakes may reveal more plant species.

Threats to the Ramaroshan Lake Complex

The lake complex is a tourist destination for local people in the district. However, the area is not as well visited by domestic or international tourists as other lakes in Nepal, such as Gosaikunda, Rara Taal, Pokhara Lake Clusters, etc., due to poor road and air connectivity despite its beautiful landscape. Therefore, minimum tourist influences and minimum activities can be seen. However local people visit the areas frequently for fodder collection, and they use the lake complex for

grazing their livestock. Some of the local people are often sighted poaching birds such as the Kalij Pheasant *Lophura leucomelanos* for meat consumption (Aditiya Pal pers. comm. June 2019). Local people harvest Paha frogs (*Nanorana* and *Amolops* species) in large quantities for food and medicinal purposes, which may affect the population of the species in the near future. Plastic pollution is increasing in the littoral sections of the lakes

Conservation value of Ramaroshan Lake Complex

The Ramaroshan Lake Complex and its surrounding catchment area are home to a multitude of species with significant conservation value. These include various aquatic macroinvertebrates such as the Relict Himalayan Dragonfly *Epiophlebia laidlawi*, fish species like *Schizothorax nepalensis* and *Schizothorax richardsonii*, bird species including the Egyptian Vulture *Neophron percnopterus*, Asian Woolly-necked *Ciconia episcopus*, Cheer Pheasant *Catreus wallichii*, and Northern Lapwing *Vanellus vanellus*, frog species such as Liebiegi's Paa Frog *Nanorana legibii*, Small Paa Frog *Nanorana minica*, and Indian Bull Frog *Hoplobatrachus tigerinus*, as well as mammal species including Royle's Pika *Ochotona roylei*, Assam Macaque *Macaca assamensis*, Himalayan Goral *Naemorhedus goral*, Leopard *Panthera pardus*, Himalayan Black Bear *Ursus thibetanus*, and Red Panda *Ailurus fulgens*. The lake systems are encompassed by pasturelands, expansive grasslands, and dense forests that further support a diverse range of wetland-dependent and forest birds. Given its unique geographical location, suitable wetland habitat, native biodiversity, and essential ecosystem services, the Ramaroshan Lake Complex meets the criteria for designation as wetlands of international importance (Ramsar Site). It is imperative that the Ramsar focal agency for Nepal actively pursue this designation.

With the country's adoption of a federal structure, there exist opportunities to integrate wetland management considerations by formulating regulatory frameworks at the central, provincial, and local levels. To ensure the sustainable management of these wetlands, it is crucial to engage and incorporate local communities into this regulatory framework. This approach will facilitate timely monitoring, restoration efforts, and the judicious utilisation of wetland resources.

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Supplementary 1. List of aquatic macroinvertebrates recorded in the Ramaroshan Lake Complex. Symbol (√) represents the presence of the taxon in the waterbodies with respect to the season.

Order/Class	Lakes/ waterbodies	Ramaroshan		Batula		Jingale		Lamadaya		Inlet		Outlet	
	Family/season	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Ephemeroptera	Baetidae						√	√	√	√	√	√	√
Ephemeroptera	Caenidae							√				√	√
Ephemeroptera	Ephemerellidae								√	√	√		√
Ephemeroptera	Ephemeridae								√	√	√		√
Ephemeroptera	Heptageniidae									√	√	√	√
Plecoptera	Perlidae							√	√				√
Plecoptera	Perlodidae								√	√	√	√	√
Trichoptera	Brachycentridae									√	√		
Trichoptera	Hydropsychidae			√				√	√	√			√
Trichoptera	Leptoceridae			√				√	√	√	√	√	√
Trichoptera	Molannidae			√					√				
Trichoptera	Philopotamidae									√	√	√	√
Trichoptera	Polycentropodidae									√	√		√
Trichoptera	Psychomyiidae			√				√	√				√
Trichoptera	Rhyacophilidae										√	√	
Trichoptera	Uenoidae												√
Coleoptera	Dytiscidae	√	√	√	√	√	√		√				√
Coleoptera	Elmidae				√			√		√	√	√	
Coleoptera	Psephenidae			√									
Hemiptera	Mesoveliidae			√					√				
Hemiptera	Micronectidae				√				√				√
Hemiptera	Notonectidae		√	√	√	√		√					
Odonata	Aeshnidae		√	√	√								√
Odonata	Coenagrionidae	√	√		√	√	√		√				√
Odonata	Gomphidae	√	√		√	√		√	√				√
Odonata	Libellulidae	√	√	√	√	√	√	√	√				√
Diptera	Athericidae											√	
Diptera	Ceratopogonidae	√	√	√				√		√	√	√	√
Diptera	Chironomidae	√	√	√	√	√	√	√	√	√	√	√	√
Diptera	Culicidae	√	√	√	√		√	√	√				√
Diptera	Dixidae												√
Diptera	Dolicopodidae								√			√	
Diptera	Empididae						√				√		
Diptera	Psychodidae_									√	√		√
Diptera	Simulidae								√	√	√	√	√
Diptera	Tabanidae			√			√		√				
Diptera	Tipulidae			√			√						√
Acari	Hydracarina								√		√		
Haplotaxids	Megascolecidae	√	√	√	√	√	√	√	√				√
Haplotaxids	Naididae	√	√		√		√		√				√
Haplotaxids	Glossiphoniidae					√	√			√	√		√
Gastropoda	Lymnaeidae	√	√	√	√	√	√		√				√
Gastropoda	Planorbidae	√	√	√	√	√	√	√	√			√	
Gastropoda	Thiaridae						√						
Bivalvia	Sphaeriidae		√	√	√		√		√				√

Supplementary 2. Bird species with their number of individuals observed in the Ramaroshan Lake Complex area. Abundance (%) refers to the total percentage contribution of each species to the total sample for both seasons. EN = Endangered, VU = Vulnerable, NT= Near threatened and LC= Least concerned.

	Common Name	Species	Order	Family	Winter (%)	Summer (%)	Total	IUCN Red List status
1	Egyptian Vulture	*Neophron percnopterus* (Linnaeus 1758)	Accipitriformes	Accipitridae	0.16	0.47	0.29	EN
2	Common Teal	*Anas crecca* (Linnaeus 1758)	Anseriformes	Anatidae	2.62	1.18	2.03	LC
3	Mallard	*Anas platyrhynchos* Linnaeus 1758	Anseriformes	Anatidae	3.6	1.65	2.8	LC
4	Eurasian Wigeon	*Mareca penelope* (Linnaeus 1758)	Anseriformes	Anatidae	0.98	0.95	0.97	LC
5	Pacific Swift	*Apus pacificus* (Latham 1802)	Apodiformes	Apodidae	1.96	1.65	1.84	LC
6	Alpine Swift	*Tachymarptis melba* (Linnaeus 1758)	Apodiformes	Apodidae	0.65	0.95	0.77	LC
7	Northern Lapwing	*Vanellus vanellus* (Linnaeus 1758)	Charadriiformes	Charadriidae	0	0.16	0.1	NT
8	Common Sandpiper	*Actitis hypoleucos* (Linnaeus 1758)	Charadriiformes	Scolopacidae	1.96	0.95	1.55	LC
9	Asian Wolly necked	*Ciconia episcopus* (Boddaert 1783)	Ciconiiformes	Ciconiidae	0.33	0.24	0.29	VU
10	Common Pigeon	*Columba livia* (Gmelin 1789)	Columbiformes	Columbidae	2.29	0.47	1.55	LC
11	Spotted Dove	*Spilopelia chinensis* (Scopoli 1786)	Columbiformes	Columbidae	2.78	2.13	2.51	LC
12	Snow Pigeon	*Columba leuconota (*Vigors 1831)	Columbiformes	Columbidae	0.98	1.89	1.35	LC
13	Oriental Turtle Dove	*Streptopelia orientalis* (Latham 1790)	Columbiformes	Columbidae	3.11	3.31	3.19	LC
14	Common Cuckoo	*Cuculus canorus (*Linnaeus 1758)	Cuculiformes	Cuculidae	1.96	2.36	2.13	LC
15	Indian Cuckoo	*Cuculus micropterus* (Gould 1837)	Cuculiformes	Cuculidae	0.98	0.95	0.97	LC
16	Cheer Pheasant	*Catreus wallichii* (Hardwicke 1827)	Galliformes	Phasianidae	0.16	0	0.1	VU
17	Common Coot	*Fulica atra* (Linnaeus 1758)	Gruiformes	Rallidae	3.11	0.71	2.13	LC
18	Jungle Babbler	*Turdoides striata* (Dumont 1823)	Passeriformes	Leiotrichidae	0	0.24	0.1	LC
19	Long-tailed Minivet	*Pericrocotus ethologus* Bangs & Phillips 1914	Passeriformes	Campephagidae	1.15	2.13	1.55	LC
20	Large-billed Crow	*Corvus macrorhynchos* (Wagler 1827)	Passeriformes	Corvidae	2.13	3.55	2.71	LC
21	Grey Treepie	*Dendrocitta formosae* (Swinhoe 1863)	Passeriformes	Corvidae	2.29	1.89	2.13	LC
22	Yellow-billed Blue Magpie	*Urocissa flavirostris* (Blyth 1846)	Passeriformes	Corvidae	2.13	0.95	1.64	LC
23	Red-billed Blue Magpie	*Urocissa erythroryncha* (Boddaert 1783)	Passeriformes	Corvidae	3.11	1.65	2.51	LC
24	Ashy Drongo	*Dicrurus leucophaeus* (Vieillot 1817)	Passeriformes	Dicruridae	0.82	0	0.48	LC
25	Black Drongo	*Dicrurus macrocercus* (Vieillot 1817)	Passeriformes	Dicruridae	0.82	0	0.48	LC
26	Red-headed Bullfinch	*Pyrrhula erythrocephala (*Vigors 1832)	Passeriformes	Fringillidae	0.98	0.47	0.77	LC
27	Collared Grosbeak	*Mycerobas affinis (Blyth 1855)*	Passeriformes	Fringillidae	0.65	1.18	0.87	LC
28	Nepal House Martin	*Delichon nipalense* (Horsfield & Moore 1854)	Passeriformes	Hirundinidae	1.15	0.71	0.97	LC
29	Red-rumped Swallow	*Cecropis daurica (*Linnaeus 1771)	Passeriformes	Hirundinidae	1.96	1.65	1.84	LC
30	Long-tailed Shrike	*Lanius schach* (Linnaeus 1758)	Passeriformes	Laniidae	1.64	0.71	1.26	LC
31	Grey-backed Shrike	*Lanius tephronotus* (Vigors 1831)	Passeriformes	Laniidae	0.65	0.24	0.48	LC
32	White- throated Laughingthrush	*Garrulax albogularis* (Gould 1836)	Passeriformes	Leiothrichidae	0	2.36	0.97	LC
33	Streaked Laughingthrush	*Trochalopteron lineatum (Vigors 1831)*	Passeriformes	Leiothrichidae	1.96	1.65	1.84	LC

	Common Name	Species	Order	Family	Winter (%)	Summer (%)	Total	IUCN Red List status
34	Striated Laughingthrush	*Grammatoptila striata* (Vigors 1831)	Passeriformes	Leiothrichidae	2.78	2.13	2.51	LC
35	Rufous Sibia	*Heterophasia capistrata* (Vigors 1831)	Passeriformes	Leiothrichidae	2.29	4.02	3	LC
36	Grey Wagtail	*Motacilla cinerea* (Tunstall 1771)	Passeriformes	Motacillidae	0.65	0.71	0.68	LC
37	White Wagtail	*Motacilla alba (Linnaeus 1758)*	Passeriformes	Motacillidae	1.64	0.95	1.35	LC
38	Spotted Forktail	*Enicurus maculatus* (Vigors 1831)	Passeriformes	Muscicapidae	0	0.71	0.29	LC
39	Verditer Flycatcher	*Eumyias thalassinus* (Swainson 1838)	Passeriformes	Muscicapidae	0	0.47	0.19	LC
40	Plumbeous Water Redstart	*Phoenicurus fuliginosus* (Vigors 1831)	Passeriformes	Muscicapidae	0.16	0.95	0.48	LC
41	White-capped Redstart	*Phoenicurus leucocephalus* (Vigors 1831)	Passeriformes	Muscicapidae	0.16	0	0.1	LC
42	Blue Whistling Thrush	*Myophonus caeruleus* (Scopoli 1786)	Passeriformes	Muscicapidae	2.62	3.31	2.9	LC
43	Little Forktail	*Enicurus scouleri (*Vigors 1832)	Passeriformes	Muscicapidae	0.49	0.71	0.58	LC
44	Grey-headed Canary-flycatcher	*Culicicapa ceylonensis (Swainson 1820)*	Passeriformes	Muscicapidae	1.15	0.95	1.06	LC
45	Verditer Flycatcher	*Eumyias thalassinus Swainson, 1838*	Passeriformes	Muscicapidae	0.82	1.18	0.97	LC
46	Blue Whistling Thrush	*Myophonus caeruleus* (Scopoli 1786)	Passeriformes	Muscicapidae	1.8	1.89	1.84	LC
47	Blue-capped Redstart	*Phoenicurus coeruleocephala (Vigors 1831)*	Passeriformes	Muscicapidae	0.95	0	54	LC
48	Black Redstart	*Phoenicurus ochruros* (Gmelin 1774)	Passeriformes	Muscicapidae	1.15	0.47	0.87	LC
49	Pied Bushchat	*Saxicola caprata* (Linnaeus 1766)	Passeriformes	Muscicapidae	1.96	0.95	1.55	LC
50	Grey Bushchat	*Saxicola ferreus* (Gray 1846)	Passeriformes	Muscicapidae	1.15	2.36	1.64	LC
51	Green-tailed Sunbird	*Aethopyga nipalensis* (Hodgson 1837)	Passeriformes	Nectariniidae	0.49	0.95	0.68	LC
52	Indian Golden Oriole	*Oriolus kundoo* (Sykes 1832)	Passeriformes	Oriolidae	1.47	1.89	1.64	LC
53	Green-backed Tit	*Parus monticolus* Vigors 1831)	Passeriformes	Paridae	2.29	3.07	2.61	LC
54	Russet Sparrow	*Passer cinnamomeus* (Temminck 1836)	Passeriformes	Passeridae	2.29	2.13	2.22	LC
55	Grey-hooded Warbler	*Phylloscopus xanthoschistos* (Gray 1846)	Passeriformes	Phylloscopidae	0.49	0	0.29	LC
56	Oriental White-eye	*Zosterops palpebrosus (Temminck 1824)*	Passeriformes	Phylloscopidae	1.64	2.36	1.93	LC
57	Altai Accentor	*Prunella himalayana* (Blyth 1842)	Passeriformes	Prunellidae	0.33	1.18	0.68	LC
58	Brown Accentor	*Prunella fulvescens* (Severtsov 1873)	Passeriformes	Prunellidae	1.15	0.95	1.06	LC
59	Himalayan Bulbul	*Pycnonotus leucogenys* (Gray 1835)	Passeriformes	Pycnonotidae	0.82	0	0.48	LC
60	Red-vented Bulbul	*Pycnonotus cafer* (Linnaeus 1766)	Passeriformes	Pycnonotidae	2.95	4.02	3.38	LC
61	Black Bulbul	*Pycnonotus flaviventris* (Tickell 1833)	Passeriformes	Pycnonotidae	1.47	0.47	1.06	LC
62	Pycnonotidae	*Ixos mcclellandii* (Horsfield 1840)	Passeriformes	Pycnonotidae	4.26	4.02	4.16	LC
63	Velvet-fronted Nuthatch	*Sitta frontalis* (Swainson 1820)	Passeriformes	Sittidae	0	0.47	0.19	LC
64	Common Myna	*Acridotheres tristis* (Linnaeus 1766)	Passeriformes	Sturnidae	1.15	1.42	1.26	LC
65	Jungle Myna	*Acridotheres fuscus* (Wagler 1827)	Passeriformes	Sturnidae	0	0.71	0.29	LC
66	Grey-winged Blackbird	*Turdus boulboul* (Latham 1790)	Passeriformes	Turdidae	0	0.47	0.19	LC
67	White-collared Blackbird	*Turdus albocinctus* (Royle 1840)	Passeriformes	Turdidae	0.98	0.47	0.77	LC

	Common Name	Species	Order	Family	Winter (%)	Summer (%)	Total	IUCN Red List status
68	Mistle Thrush	*Turdus viscivorus* Linnaeus 1758	Passeriformes	Turdidae	0.75	0	0.56	LC
69	Blue Throated Barbet	*Psilopogon asiaticus* (Latham 1790)	Piciformes	Megalaimidae	0	0.47	0.19	LC
70	Fulvous-breasted Woodpecker	*Dendrocopos macei* (Vieillot 1818)	Piciformes	Picidae	0.65	1.89	1.16	LC
71	Great Barbet	*Psilopogon virens* (Boddaert 1783)	Piciformes	Megalaimidae	1.8	2.6	2.13	LC
72	Himalayan Woodpecker	*Dendrocopos himalayensis* (Jardine & Selby 1835)	Piciformes	Picidae	0	0.47	0.19	LC
73	Brown-fronted Woodpecker	*Leiopicus auriceps* (Vigors 1831)	Piciformes	Picidae	0.65	0.71	0.68	LC
74	Rufous-bellied Woodpecker	*Dendrocopos hyperythrus* (Vigors 1831)	Piciformes	Picidae	0.49	1.18	0.77	LC
75	Grey-headed Woodpecker	*Dendropicos spodocephalus* (Bonaparte 1850)	Piciformes	Picidae	0.82	1.18	0.97	LC
76	Scaly-bellied Woodpecker	*Picus squamatus (*Vigors 1831)	Piciformes	Picidae	0	0.47	0.19	LC
77	Little Grebe	*Tachybaptus ruficollis* (Pallas 1764)	Podicipediformes	Podicipedidae	2.62	0.71	1.84	LC
78	Rose-ringed Parakeet	*Psittacula krameri* (Scopoli 1769)	Psittaciformes	Psittacidae	0	2.13	0.87	LC
79	Plum-headed Parakeet	*Psittacula cyanocephala* (Linnaeus 1766)	Psittaciformes	Psittacidae	0	0.95	0.39	LC

Supplementary 3. Records of terrestrial plant species with respect to family in the surrounding forest of Ramaroshan Lake Complex.

	Species	Family
1	*Pteracanthus lachenensis* (C. B. Clarke) Bremek	Acanthaceae
2	*Strobilanthes species*	Acanthaceae
3	*Acer campbelli*	Aceraceae
4	*Cythula capitata* Moq.	Amaranthaceae
5	*Heracleum* sp.	Apiaceae
6	*Ilex dyprena* Wall.	Aquifoliaceae
7	*Arisaema propinqum* Schott	Araceae
8	*Hedera nepalensis* K. Koch	Araceae
9	*Asplenium ensiforme*	Aspleniaceae
10	*Ageratina adenophora*	Asteraceae
11	*Anaphalis busua* (Buch- Ham. ex D. Don.)	Asteraceae
12	*Anaphalis contorta* (D.Don) Hook.f.	Asteraceae
13	*Anaphalis triplinervis* (Sims) C. B. Clarke	Asteraceae
14	*Bidens tripartia* L.	Asteraceae
15	*Carpesium cernum* L.	Asteraceae
16	*Crassosephalum crepidoides*	Asteraceae
17	*Dicrocephala benthamii* C.B.Clarke	Asteraceae
18	*Erigeron karvinskianus*	Asteraceae
19	*Galinsoga parviflora* Cav.	Asteraceae
20	*Galinsuga ciliata* (Raf.) Blake	Asteraceae
21	*Myriactis nepalensis* Less	Asteraceae
22	*Senecio alatus* Wall.	Asteraceae
23	*Tanacetum dolichophyllum* Kitam.	Asteraceae
24	*Balanophora species*	Balanophoraceae

	Species	Family
25	*Impatiens racemosa* DC.	Balsaminaceae
26	*Impatiens serrata* Benth.	Balsaminaceae
27	*Berberis aristata* DC.	Berberidaceae
28	*Berberis asiatica* Roxb.ex DC.	Berberidaceae
29	*Mahonia nepaulensis* DC.	Berberidaceae
30	*Cynoglossum zelanicum* (Vahl) Thunb. Ex Lehm.	Boraginaceae
31	*Barbaria intermedia* Boreau	Brassicaceae
32	*Rorippa* Sp	Brassicaceae
33	*Sarcococca hookeriana* Baill.	Buxaceae
34	*Viburnum erubescens* Wall.	Caprifoliaceae
35	*Arenaria debilis* Hook. f. ex Edgew. & Hook. F.	Caryophyllaceae
36	*Arenaria depauperata* (Edgew.)	Caryophyllaceae
37	*Stellaria media*	Caryophyllaceae
38	*Stellaria monosperma* Buch -Ham ex D. Don	Caryophyllaceae
39	*Stellaria nepalensis*	Caryophyllaceae
40	*Euonymus tingens* Wall.	Celastraceae
41	*Carex baccans* Nees	Cyperaceae
42	*Carex* species	Cyperaceae
43	*Cyperus species*	Cyperaceae
44	*Eleocharis congesta* D. Don	Cyperaceae
45	*Kyllinga brevifolia* Rottb.	Cyperaceae
46	*Daphniphyllum himalense* (Benth.) Mull. Arg.	Daphniphyllaceae
47	Dryopteris zayuensis	Dryopteridaceae

	Species	Family
48	*Elaegnus parvifolia* Wall.	Elaegnaceae
49	*Equisetum arvense*	Equisetaceae
50	*Gaultheria nummularioides* D. Don	Ericaceae
51	*Lyonia villosa* (Hook. f.) Hand- Mazz.	Ericaceae
52	*Rhododendron arboretum* Sm.	Ericaceae
53	*Parochetus communis* Buch -Ham ex D. Don	Fabaceae
54	*Parochetus communis* Buch-Ham.	Fabaceae
55	*Piptanthus nepalensis* (Hook.) D. Don	Fabaceae
56	*Quercus semicarpifolia* Sm.	Fagaceae
57	*Corydalis hookeri* Prain	Fumaricaceae
58	*Swertia aungustifolia*	Gentianaceae
59	*Swertia chirayita* (Roxb. ex-Fleming) Karsten	Gentianaceae
60	*Geranium nepalense* Sweet	Geraniaceae
61	*Ribes griffithii* Hook. f. & Thomson	Grossulariaceae
62	*Aesculus indica* (Colebr.ex Cambess.) Hook.	Hippocastanaceae
63	*Hydrangea anomala* D. Don	Hydrangeaceae
64	*Hydrangea aspera Buch* -Ham ex D. Don	Hydrangeaceae
65	*Hypericum elodeoides* Choisy	Hydrangeaceae
66	*Iris kemaonensis* D.Don	Iridaceae
67	*Juncus articulatus* L.	Juncaceae
68	*Clinopodium umbrosum* (M. Bieb.) C. Koch	Lamiaceae
69	*Elsholtzia fruiticosa* (D. Don) Rehder	Lamiaceae
70	*Eltsholtzia strobilifera* Benth.	Lamiaceae
71	*Leucosceptrum canum* Sm.	Lamiaceae
72	*Origanum vulgare* L.	Lamiaceae
73	*Salvia lanata*	Lamiaceae
74	*Thymus linearis*	Lamiaceae
75	*Dodecadenia grandiflora* Nees	Lauraceae
76	*Lindera pulcherrima* (Nees) Benth.ex Hook.f.	Lauraceae
77	*Persea odoratissima* (Nees) Kosterm.	Lauraceae
78	*Utricularia australis* R.Br.	Lentibulariaceae
79	*Allium tuberosum* Rottl.ex Sprengel	Liliaceae
80	*Allium wallichii* Kunth.	Liliaceae
81	*Cardiocrinum giganteum* (Wall.) Makino	Liliaceae
82	*Fritillaria cirrhosa* D. Don	Liliaceae
83	*Frittelaria royeli*	Liliaceae
84	*Paris polyphylla* Smith.	Liliaceae
85	*Lobelia pyramidalis* Wall.	Lobeliaceae
86	*Lyonia ovalifolia* (Wall.) Drude	Lobeliaceae
87	*Unknown parasite*	Loranthaceae
88	*Stephania gracilenta* Miers	Menispermaceae
89	*Boerhavia diffusa* L.	Nyctaginaceae
90	*Jasminum humile* L.	Oleaceae

	Species	Family
91	*Oleandra wallichi*	Oleandraceae
92	*Epilobium palustre* L.	Onagraceae
93	*Ophioglossum nudicaule*	Ophioglossaceae
94	*Calanthe tricarinata* Lindl.	Orchidaceae
95	*Cephalanthera longifolia* (L.) Fritsch	Orchidaceae
96	*Malaxis muscifera* (Lindl.) Kuntze	Orchidaceae
97	*Platanthera species*	Orchidaceae
98	*Satyrium nepalense*	Orchidaceae
99	*Spiranthes sinensis*	Orchidaceae
100	*Oxalis corniculata* L.	Oxalidaceae
101	*Plantago erosa* Wall.	Plantaginaceae
102	*Arundinella hookeri* Munro	Poaceae
103	*Cynodon dactylon* (L.) Pers.	Poaceae
104	*Danthonia cumminsii* Hook .f.	Poaceae
105	*Digitaria cruciata* (Nees ex Steudel)	Poaceae
106	*Microstegium nodum* (Trin.) A. Camus	Poaceae
107	*Poa annua* L.	Poaceae
108	*Pogonantherum paniceum* (Lam.) Hackel	Poaceae
109	*Polypogon fugax* Nees ex Steudel	Poaceae
110	*Aconogonum molle* (D.Don) Hara	Polygonaceae
111	*Bistorta amplexicaulis* (D.Don) Greene	Polygonaceae
112	*Bistorta milletii* H. Lev.	Polygonaceae
113	*Fagopyrum tataricum* (L.) Gaertn.	Polygonaceae
114	*Persicaria capitata* Buch -Ham ex D. Don	Polygonaceae
115	*Persicaria posumbo* Buch -Ham ex D. Don	Polygonaceae
116	*Rumex nepaulensis* Spreng.	Polygonaceae
117	*Potamogeton crispus* L.	Potamogetonaceae
118	*Potamogeton lucens* L.	Potamogetonaceae
119	*Cheilanthes dalhousie* Hook.	Pteridaceae
120	*Lepisorus mehre* Fraser-Jenks	Pteridaceae
121	*Onychium species*	Pteridaceae
122	*Aconitum spicatum* (Bruhl) stapf	Ranunculaceae
123	*Thalictrum virgatum* Hook. f. Thoms.	Ranunculaceae
124	*Berchemia flavescens* (Wall.) Brongn.	Rhamnaceae
125	*Cotoneaster acuminatus* Lindl	Rosaceae
126	*Cotoneaster baciallaris* Wall.	Rosaceae
127	*Cotoneaster microphyllus* Wall.ex Lindl.	Rosaceae
128	*Fragaria nubicola* Lindl.	Rosaceae
129	*Gaultheria fragratissima*	Rosaceae
130	*Geum elatum* Wall. ex G. Don	Rosaceae
131	*Prinsepia utilis* Royle	Rosaceae
132	*Prunus cornuta* (Wall. ex-Royle) Steud.	Rosaceae
133	*Pyracantha crenulata* (D. Don) M. Roem.	Rosaceae
134	Ribes gracillis	Rosaceae
135	*Rosa brunonianum*	Rosaceae

	Species	Family
136	Rosa macrocarpa	Rosaceae
137	*Rosa microphylla* Lindl.	Rosaceae
138	Rosa serecia	Rosaceae
139	*Rubus ellipticus* Sm.	Rosaceae
140	*Rubus nepalensis* (Hook.f.) Kuntze	Rosaceae
141	*Rubus* Sp	Rosaceae
142	*Galium elegans* Wall.ex Roxb.	Rubiaceae
143	*Rubia manjith* Roxb. ex-Fleming	Rubiaceae
144	*Skimmia alatus* Wall.	Rutaceae
145	*Skimmia anquetilia*	Rutaceae
146	*Zanthoxylum nepalense* Babu	Rutaceae
147	*Salix babylonica* L.	Salicaceae
148	*Viburnum mullaha* Buch.-Ham. ex D. Don	Sambucaceae
149	*Schissandra species*	Schisandraceae
150	*Hemiphragma heterophyllum* Wall.	Scrophulariaceae
151	*Mazus surculosus* D.Don	Scrophulariaceae
152	*Schrophularia species*	Scrophulariaceae
153	*Smilax elegans* Wall. ex Kunth	Smilacaceae
154	*Solanum nigrum* L.	Solanaceae
155	*Symplocos paniculata* (Thunb.) Miq.	Symplocaceae
156	*Symplocos ramosissima* Wall. ex G. Don	Symplocaceae
157	*Taxus wallichiana* Zucc., Abh. Akad. Muench.	Taxaceae
158	*Daphne papyracea* Wall. ex Steud.	Thymelaeaceae
159	*Elatostema monandrum* (Buch.- Ham. ex D. Don.)	Urticaceae
160	*Elatostema obtusum* Wedd.	Urticaceae
161	*Elatostema sessile* J.R. and G.Forst.	Urticaceae
162	*Lecanthus peduncularis* (Royle) Wedd	Urticaceae
163	*Pilea symmerica* Wedd.	Urticaceae
164	*Pilea umbrosa* Blume	Urticaceae
165	*Valeriana hardwiki* Wall.	Valerianaceae
166	*Viola betonicifolia* Sm.	Violaceae
167	*Roscoea purpurea* Smith	Zingiberaceae

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ravi@threatenedtaxa.org

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