HYDROGEOLOGY OF RENUKA WETLAND, HIMACHAL PRADESH

AN ASSESSMENT FOR INTEGRATED MANAGEMENT

हिमाचल प्रदेश सरकार

IKI INTERNATIONAL CLIMATE INITIATIVE

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of:

Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection

of the Federal Republic of Germany

As a federally owned enterprise, GIZ supports the German Government in achieving its objectives in the field of international cooperation for sustainable development.

Published by
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn

Address
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Indo-German Biodiversity Programme (IGBP),
GIZ-India, A-2/18, Safdarjung Enclave, New Delhi - 110029, India

E-Mail: biodiv.india@giz.de
Web: www.giz.de & www.indo-germanbiodiversity.com

Programme/project description
Wetlands Management for Biodiversity and Climate Protection
Indo-German Biodiversity Programme

Implementing Partners
Ministry of Environment, Forest and Climate Change
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Wetlands International South Asia, New **Delhi**

Responsible
Ravindra Singh, Director, Indo-German Biodiversity Programme, GIZ
Geetha Nayak, Project Manager, Wetlands Management for Biodiversity and Climate Protection, GIZ

Prepared by
Advanced Center for Water Resources Development And Management (ACWADAM)
Indian Institute of Technology, Roorkee
People's Science Institute (PSI)

Suggested Citation
ACWADAM, IIT Roorkee, PSI (2023). Hydrogeology of Renuka Wetland, Himachal Pradesh- An Assessment for Integrated Management. Prepared for GIZ.

Authors
Neha Bhave, Siddharth Patil, Himanshu Kulkarni, Himanshu Joshi, Sumit Sen, Moushumi Hazra, Priyanka Singh, Anil Gautam, Iqbal Ahmad, S K Bartarya and Rajesh Kumar

Technical Contributions
Kunal Bharat, Avantika Bhaskar, Shambhavi Krishna and Minakshi Gehlot (GIZ)
Ritesh Kumar, Harsh Ganapathi (Wetlands International South Asia)
Also acknowledging contributions from Debojyoti Mukherjee, Ridhi Saluja, Chaitanya Raj and Sakshi Saini.

Photo credits/sources
GIZ/Kunal Bharat (cover page photo) and as specified against images.

Page Layout and design
Tryphena Kirubakaran
E-Mail: tryphenaa@gmail.com

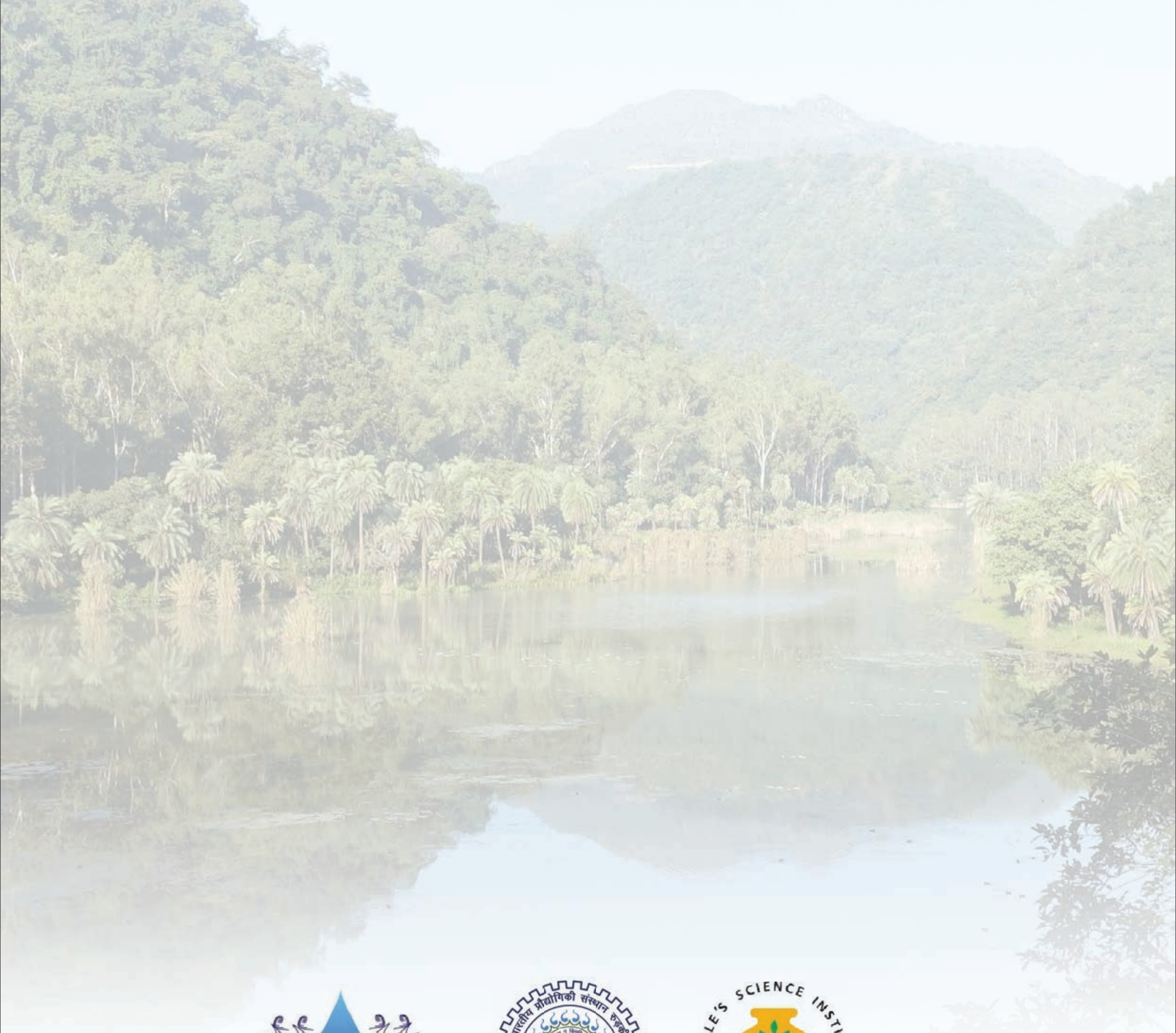
This project is part of the International Climate Initiative (IKI).

On behalf of
German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV).

New Delhi, 2023

HYDROGEOLOGY OF RENUKA WETLAND, HIMACHAL PRADESH

AN ASSESSMENT FOR INTEGRATED MANAGEMENT



ACWADAM

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

PEOPLE'S SCIENCE INSTITUTE

PSI

Table of Contents

List of Tables

List of Figures

List of Images

1 INTRODUCTION

ABOUT THE WETLAND

The Renuka wetland was declared a Ramsar site on 8 November 2005. The wetland is home to at least 443 animal species including 19 species of fish. These species are representative of lacustrine ecosystems, for example, Puntius, Labeo, Rasbora and Channa. Prominent plant species of the catchment area include dry deciduous species such as *Shorea robusta, Terminalia tomentosa* and *Dalbergia sissoo* and hydrophytes such as Phragmites, Typha, Carex, Sparganium, Utricularia and Hydrilla species. There are 103 species of birds, of which 66 are resident, for example, *Psilopogon haemacephalus* (Crimson-breasted Barbet), *Acridotheres tristis* (Common Myna), *Pycnonotus leucogenys* (Himalayan Bulbul), *Centropus sinensis* (Pheasant), *Egretta intermedia* and *E. garzetta* (egret), *Ardeola grayii* (Pond Heron), *Mallard* and *Vanellus indicus* (Red-wattled Lapwing). *Cervus unicolor* (Sambar), *Muntiacus muntjack* (Barking Deer) and *Nemorhaedus goral* (Goral) are the ungulates that are abundant in the area. The site is managed by the Himachal Pradesh Forest Department[1]. The State Government of Himachal Pradesh had declared the area around the wetland (402 ha) a wildlife sanctuary on 22 July 1964.

There are two water bodies in the Renuka wetland: Renuka Lake and Parshuram Tal.

Several studies have been conducted in Renuka Wetland and it has been found that the lake is hypereutrophic due to nutrient enrichment. The presence of “nutrient-limited large-sized algae” as well as phosphorus is considered to be the main factor for the high productivity and trophic state index of Renuka Wetland[2].

Parshuram Tal receives water from Renuka Lake through a small gravelled channel. Parshuram Tal is 173 m long and approximately 160 m wide.

***Table 1** Details of Renuka Lake*

District	Sirmaur
Type of lake	Rural
Latitude	30° 36′ 36″ N
Longitude	77° 27′ 30″ E
Altitude (m)	645
Depth range (m)	0.50–13.0
Length (m)	1706.7
Width (m)	132.5–246.8
Wetland area (ha)	20
Shoreline length (m)	3214
Surface area (m2)	1,76,945
Catchment area (ha)	254

The wetland receives water from nullahs draining the catchment and by numerous subterranean springs. 0.5% of the land in the catchment is built-up, 9.5% is under agriculture and 90% is sub-tropical deciduous reserved forest with broad-leaved trees, Sal trees, bamboo, etc.[2] Thus the lake has a forested catchment. The lake rests in a long valley, and the surrounding slopes are covered with various kinds of vegetation and thick woods.

Although the lake is eutrophic due to the nutrient load of the water, its floral and faunal diversity is rich, as seen during our field visits, conducted during February and November 2020.

The overall objective of this assignment was to carry out a hydrogeological assessment of the Renuka wetland and recommend management measures for maintaining the hydrological and ecological functions of the wetland. The study aimed to identify the sources of water (springs, the catchment), their quantitative and qualitative characteristics, their recharge zones and the hydrogeological layout of the entire wetland.

The study also assessed the sediment yield, its drivers and future implications. The nutrient status of the wetland and inflow of nutrients from anthropogenic and natural activities were assessed along with their impacts on the ecology of the wetland. Management strategies are to be

[1] Ramsar (8 November 2005). Retrieved from Ramsar Sites Information Service: https://rsis.ramsar.org/ris/1571?language=en#:~:text=Renuka%20Wetland.,out%20to%20the%20Gi ri%20river.
[2] Kumar P., Mahajan A. K. and Meena N. K (2019). Evaluation of trophic status and its limiting factors in the Renuka Lake of Lesser Himalaya, India. Environ Monit Assess, 191(105): 1–11.

suggested on the basis of these assessments and the threats identified, taking into cognizance the measures that have been implemented over the years and their effectiveness.

2 HYDROGEOLOGICAL ASSESSMENT

The functioning of ecosystems, such as rivers, wetlands, forests and coastal areas, is directly or indirectly dependent on climate variability, surface water and groundwater flows and modifications in the vegetative cover. Over the last two to three decades, erratic precipitation patterns, regulation of surface water flows, increased groundwater abstraction and the deteriorating quality of both the surface water and groundwater have been affecting the functioning of ecosystems and thereby jeopardising the services these systems provide.

The health of ecosystems is critically dependent on the availability and state of groundwater resources although this is not perceived in most contexts. Climate change and an unprecedented dependence on aquifers, however, have threatened groundwater resources in India. There have been few successful demonstrations of good groundwater management and governance across the country in response to this crisis. The knowledge of the myriad dimensions of aquifers is limited. However, the functioning of groundwater systems and their relationship with other ecosystems are either often neglected or remain unknown. Therefore, the ecosystems dependent on and linked to groundwater resources have been grossly compromised.

Groundwater-dependent ecosystems, particularly in the Himalayas, have become extremely fragile. In this mountainous region, groundwater manifests itself in the form of springs or seeps from saturated aquifers. Over the years, there has been an increasing concern that springs are drying up, becoming seasonal or that their discharge is reducing. A number of studies based on people's perceptions have attributed the drying of springs to causes such as an increase in the ambient temperature[3], late onset of rains, erratic rainfall patterns[4], changes in land use -mostly in the form of conversion of forest to agricultural land[5], and forest degradation[1,6], including changes in forest type[7,8.] Springs are not just the lifeline of not just the millions that inhabit this region but also play an important role in providing water for and sustaining ecosystem services, such as base flows in rivers, while supporting the vegetation and wildlife[9,10].

Apart from climate change, the other major threat to the ecological character of ecosystems and their biodiversity is a decline in the discharges of springs. One such fragile ecosystem is the Renuka Wetland, located in Sirmaur District, of Himachal Pradesh. It is a natural wetland spread over an extent of 20 ha, with freshwater springs and inland subterranean karst formations, fed by a small stream flowing from the Lower Himalaya to the Giri River[11]. Accelerated siltation, a reduction in water holding capacity, prolific weed growth, neglect and over-exploitation of forest resources and water pollution, mainly due to waste generation from tourism, are some of the main threats to the Renuka wetland[12]. Although all the other factors are well understood, aquifers and their management

[3] Pandey, R., Kumar, P., Archie, K. M., Gupta, A. K., Joshi, P. K., Valente, D. & Petrosillo, I. (2018). Climate change adaptation in the western-Himalayas: Household level perspectives on impacts and barriers. Ecological Indicators, 84(August 2017): 27–37.
[4] Macchi, M., Gurung, A. M., Hoermann, B. & Choudhury, D. (2014). Community perceptions and responses to climate variability and change in the Himalayas. Climate and Development, 7(5): 78.
[5] Joshi, A. K., Joshi, P. K., Chauhan, T. & Bairwa, B. (2014). Integrated approach for understanding spatio-temporal changes in forest resource distribution in the central Himalaya. Journal of Forestry Research, 25(2): 281–290.
[6] Rautela, P. (2015). Traditional practices of the people of Uttarakhand Himalayan in India and relevance of these in disaster risk reduction in present times. International Journal of Disaster Risk Reduction, 13: 281–290.
[7] Naudiyal, N. & Schmerbeck, J. (2015). The changing Himalayan landscape: Pine-oak forest dynamics and the supply of ecosystem services. Journal of Forestry Research, 28(3): 431–443.
[8] Ghimire, C. P., Bruijnzeel, L. A., Lubczynski, M. W. & Bonell, M. (2012). Rainfall interception by natural and planted forests in the Middle Mountains of Central Nepal. Journal of Hydrology, 475: 270–280.
[9] Ghimire, C. P., Lubczynski, M. W., Bruijnzeel, L. A. & Chavarro-Rincón, D. (2014) Transpiration and canopy conductance of two contrasting forest types in the Lesser Himalaya of Central Nepal. Agricultural and Forest Meteorology, 197: 76–90.
[10] Cantonati, M., Gerecke, R. & Bertuzzi, E. (2006) Springs of the Alps: Sensitive ecosystems to environmental change: From biodiversity assessments to long-term studies. Hydrobiologia, 562(1): 59–96.
[11] https://rsis.ramsar.org/ris/1571
[12] R. K. Mazari (1992) Comments on the comprehensive management action plan on conservation and management of Renuka wetland.

are usually left out of the discourse on sustainability of wetland ecosystems. This is a consequence of the invisible nature of aquifer systems, the difficulty in collecting accurate data, high dependence on the resource for various needs and the complexity in quantifying and characterising groundwater. The gradual degradation of the Renuka Wetland is a classic example exhibiting the intertwined connections between climate, surface water and aquifers, on one side, while the biota that depend on these systems, on the other.

With this background, a study was conducted that was aimed at providing scientific inputs on the hydrogeology, water quality and sediment and nutrient fluxes for management of Renuka wetland. With support from Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), three organisations, namely, ACWADAM, PSI and IITR, collaboratively studied different aspects of the Renuka wetland.

Geological and hydrogeological characterisation and assessment of the regions around the wetland were carried out by ACWADAM. This section of the report provides a summary of the outcomes of the hydrogeological investigations and identifies the recharge zone of each spring that is critical for rejuvenating the Renuka wetland.

REGIONAL GEOLOGY[13]

Sirmaur District, lying within the Lesser Himalayas and the foothills of the Siwalik Range, has a variety of rocks, ranging in age from the Proterozoic to the Quaternary. The complex geology and structure in the state are clearly captured by the Geological Map of Sirmaur (GSI, 2002). On the basis of the lithological complexity, the district is clearly divided into two parts, separated by the thrust zones of the Main Boundary Fault (MBF), Chail Thrust (CT) and Krol Thrust (KT). To the north of these thrusts, older sedimentary rocks are exposed, which were deposited from the Meso-Proterozoic era to the Cambrian period. Sandstone, shale, limestone, slate, phyllite and quartzite are some of the major rock types found in this region. To the south, younger (recent) rock deposits belonging to the Tertiary and Quaternary periods predominate. These include sand, silt and clay deposits with sandstone, shales and quartzites exposed between the MBF and KT.

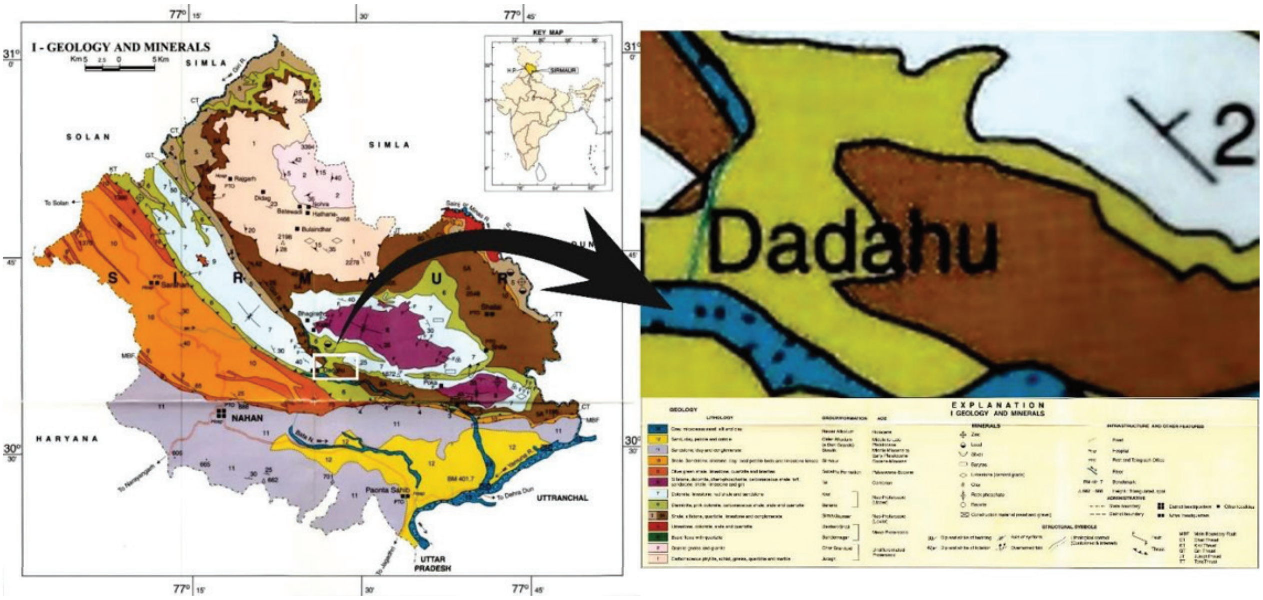


Figure 1 District resource map of Sirmaur with location of study area (Renuka wetland) depicts the geological and structural diversity of the region (Source: Geological Survey of India, 2002)

[13] Derived mainly from the district resource map of Sirmaur published by Geological Survey of India, 2002.

The degree of rock deformation is quite variable. Rocks in the southern parts show minimal deformation while those found in the northern regions show variable inclination, folding in the form of anticlines and synclines and brittle deformation, which are evident from the presence of numerous faults and thrusts that traverse the rock assemblage. The dominant trend of these rocks is north west - south east and east - west, with dips varying between 10° and 40°. The rock structures strongly influence the river flow, which is evident from the almost linear flows of rivers Jalal and Giri.

Figure 1 shows the location of the study area and illustrates the complex geological character of the district. The rocks particularly surrounding the Renuka wetland belong to the Krol, Baliana and Jaunsar groups of the Neo-Proterozoic age. They are composed of an areno-argillaceous sequence of shale, siltstone, quartzite, limestone, conglomerates, diamictite, dolomite and sandstone. These details formed a baseline study that provided basic but useful insights about the variety of rocks likely to be encountered in the region. On the basis of this situational analysis, a local-scale geological and hydrogeological mapping of the region around Renuka Wetland was conducted to understand the local geology, rock structure and aquifer systems, which play a vital role in the formation and discharge of the local springs.

LOCAL GEOLOGY

The area around Renuka wetland and Dadahu town is geologically and structurally complex. A variety of rocks are exposed in the region that have undergone several episodes of deformation such as fracturing and folding. The wetland is located to the north of the Giri River, a tributary of the Yamuna River, and is bordered by east–west running ridges of the Lesser Himalayas.

The local geology of the area was mapped by identifying rock exposures and structural features exposed along road cuts. Lithological exposures (fresh, unaltered/less- weathered outcrops) were difficult to find along the southern ridge compared with the northern ridge because of the thick vegetation which was difficult to penetrate. The dominant lithology around Renuka Wetland consisted of limestones having dolomitic characteristics and siltstone alternately. The outcrops of limestone were easily observable in the field as thickly bedded, white-to-cream-coloured layers that were slightly hard in nature and resistant to weathering. In places where the rock was weathered, it was identified by its characteristic elephant-skin texture . On the other hand, the outcrops of siltstone were less prominent as they were highly weathered. In locations where these were exposed along road cuttings, the rock was thinly bedded, varied in colour from grey to maroon and displayed intense jointing, which made it susceptible to weathering. While limestone and siltstone were commonly interbedded along the hill slopes, the assemblage of rocks along the southern ridge was slightly different. Here, carbonaceous shale and quartzite were encountered along with dolomitic limestone.

Image 1 *Inclined hard limestone outcrops (left) are seen alternating with friable and jointed grey-coloured siltstone (right) along road cuts to the north of the Renuka wetland*

[14] Elephant-skin weathering is found almost exclusively on fine-grained carbonate rocks forms due to dissolution of $CaCO_3$ along joints and fractures, leaving behind an enlarged crack or opening (closely resembling the texture of elephant-skin hide) (Reference: https://epod.usra.edu/blog/2013/05/elephant-skin-weathering.html).

Image 2 *An elephant-skin texture observed on the weathered surfaces of limestone typically*

The orientation of rocks is similar to the regional trend of the Himalayan geology, which is along the NW–SE direction, but with a slight deviation towards E–W and ENE–WSW. The rocks are moderately inclined, with the dip angle varying between 30° and 64° and the directions of inclination being opposite on either side of the wetland. Along the northern ridge of the wetland, the rocks are inclined towards the north and north-east, while the rocks exposed along the southern ridge dip towards the south-west and south.

The extrapolation of the bedding planes and dips suggests the presence of an anticlinal fold[15] in the region with its axis trending along E–W, coinciding with the trend of the wetland. The crest of the anticline is not visible as most of the rocks have been weathered and eroded away.

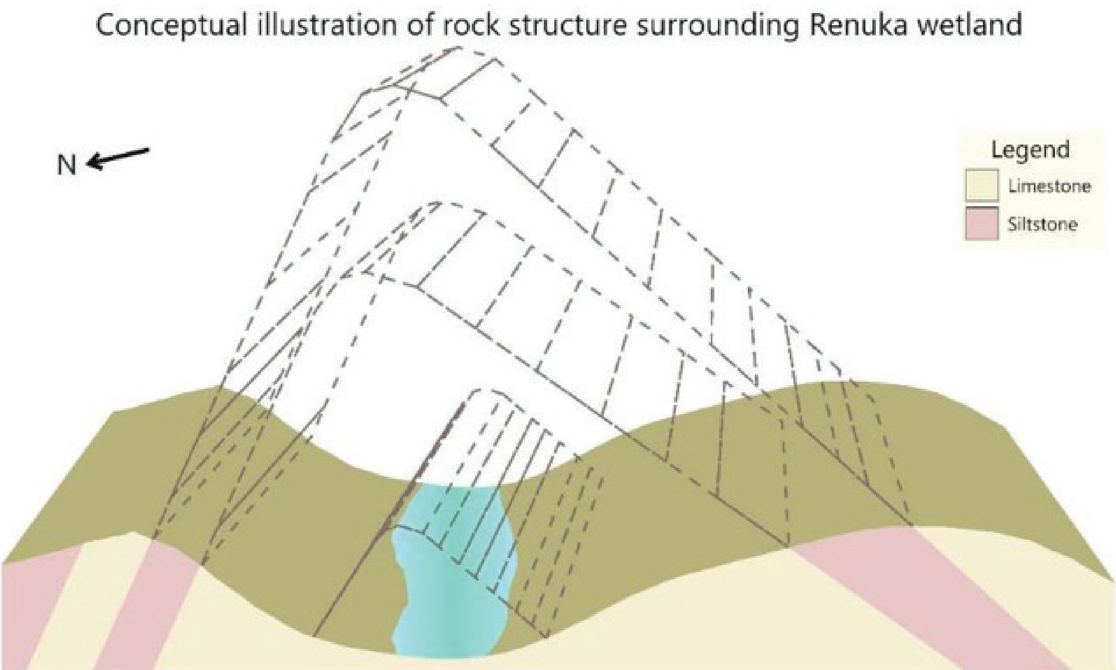


Figure 2 *A conceptual illustration of the Renuka wetland based on field measurements of rocks suggests the presence of an anticlinal fold, with the axis of this fold oriented along the trend of the wetland*

[15] An anticlinal fold is an upright fold wherein rocks on either side of the fold crest dip away or in opposite directions. This geological structure occurs in a region that has undergone ductile deformation due to compressional stresses.

The region has undergone both ductile and brittle deformation owing to the regional Himalayan orogenic movement. The ductile deformation is evident from the anticlinal fold, while the brittle deformation is expressed in the form of fracturing, shearing and faulting. The rock sequence of limestone and siltstone is traversed by several fractures, with NE–SW being the most dominant trend. The other, less prominent trends are along the NW–SE and N–S direction. These fracture sets in the lithological units control the rivers strongly, with the stream water flowing along the linear trend of fractures and easy to identify on Google Earth. Apart from the fracture sets, a series of normal faults[16] is exposed in rocks at the top of the southern ridge. The fault plane is inclined, striking NE–SW and dipping steeply (80°) towards the SE. The rocks have undergone at least two episodes of faulting, which have produced displacements of 40 cm and 90 cm. As is typical in a fault zone, the rocks are sheared with intense silicification and brecciation. Similarly, the fracture trends mapped in the surrounding area are also parallel to this trend.

Image 3 *Different fracture sets (yellow dashed lines) in limestone rock indicate that the region has experienced intense deformation*

[16] A normal fault is a geological structure in which the hanging wall has moved down relative to the foot wall of the fault plane. It usually occurs in a tensional regime where lithospheric plates are pulled apart.

Image 4 *A series of normal faults exposed at the top of the southern ridge in quartzitic and carbonaceous shale. The rock units are displaced by 40 cm along the left-hand side fault and by 90 cm along the right-hand side fault plane*

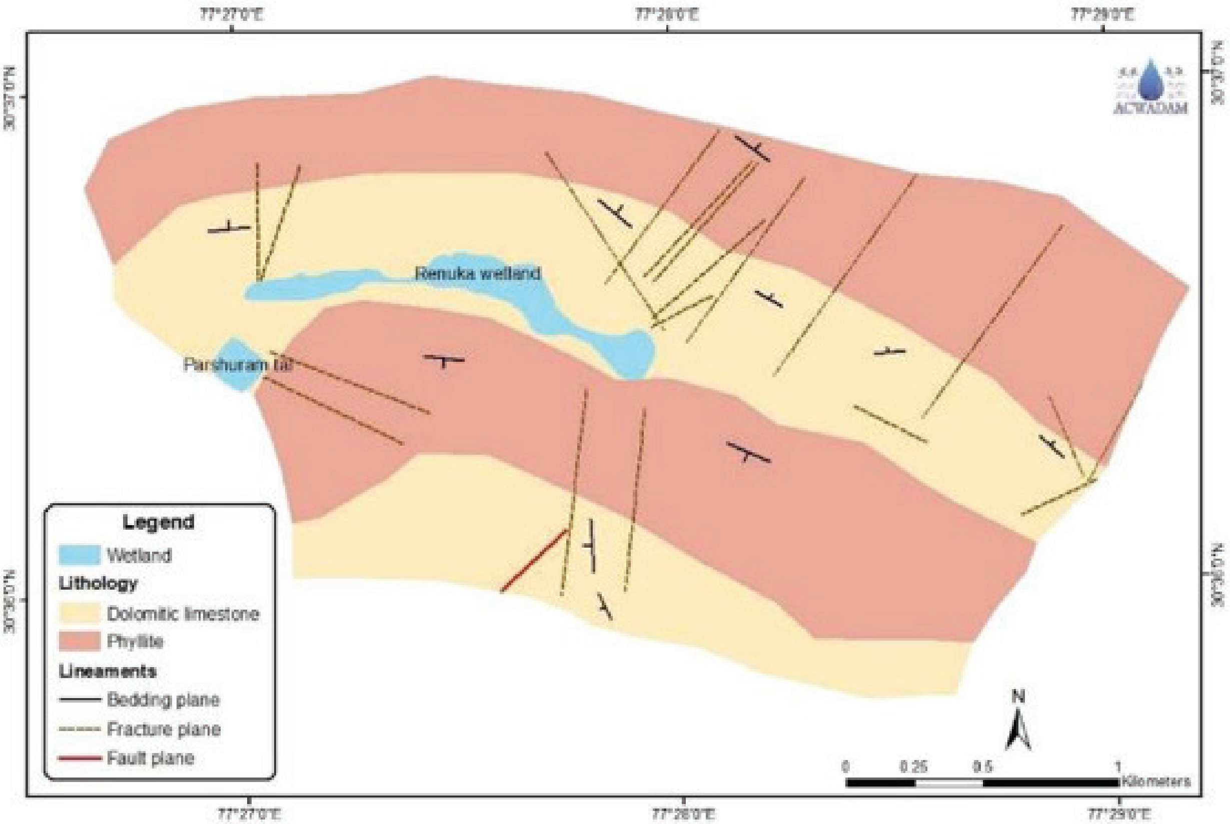


Figure 3 *A planar illustration depicting the surface geology and most dominant fracture trends in the wetland region*

THE SPRINGS, THEIR CHARACTERISTICS AND RECHARGE ZONES

Springs are points on the surface of the earth where groundwater emerges or oozes out naturally. This happens whenever and wherever the water table intersects the slope or topography. These groundwater sources are fed by aquifers, which are rocks that are sufficiently porous and permeable to store water and allow it to move through open spaces. The extent, geometry and characteristics of aquifers in the Himalayas are controlled not only by the type of lithological unit but also by intense deformations that cause aquifer discontinuity. In such a context, understanding localised aquifers is important because it is the local geology, structure and topography that play a vital role in the formation of such (mountain) aquifers, and also in the behaviour of the springs produced by them[17].

The geological texture and structure together govern the properties of aquifers. Sometimes, however, the flow of groundwater is controlled by complex geological structures rather than the geometry of the rock and land surface. Limestone and siltstone, which dominate the lithology of the Renuka wetland and the hillocks around it possess both primary and secondary porosity, but it is the presence of fractures and joints that primarily determines the stock and flow of groundwater.

The amount of water discharged by a spring varies with time and depends on the recharge of the aquifer, the storage of groundwater and the transmission properties of the aquifer[14]. Recharge areas are those zones of an aquifer where water that percolates into the aquifer is transmitted to other parts of the same aquifer and discharges the same in the form of springs.

The simplest method of identifying recharge zones is through hydrogeological mapping, developing a conceptual layout of the springshed and topoligising springs on the basis of the geology[18]. Once the location and boundary of a recharge zone have been delineated, the next step is to determine the best-suited recharge structure, given the topographic slope, land use, land cover, land ownership rights, rainfall intensity, etc.

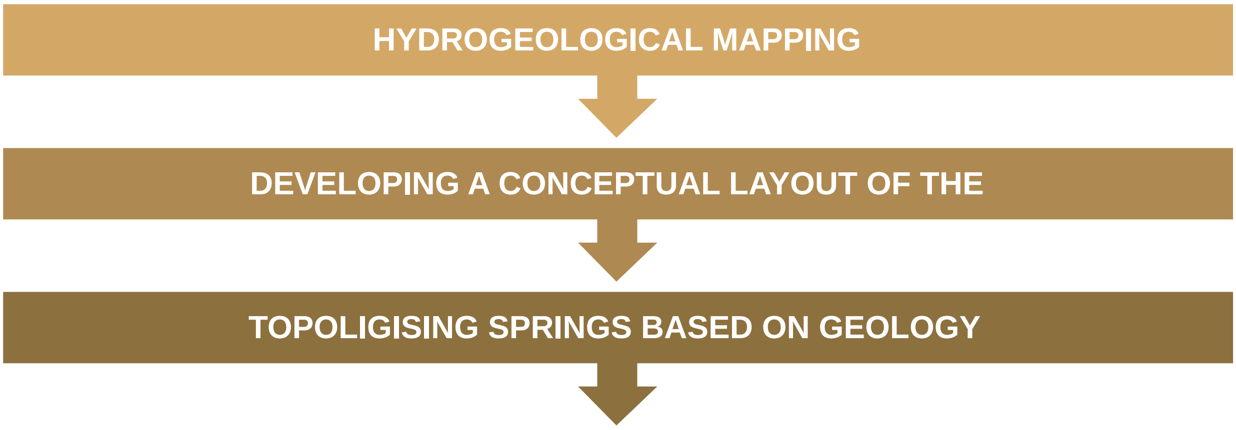


Figure 4 *Flowchart depicting the three steps followed for springshed studies under the project*

Five springs could be mapped in the hills around the Renuka wetland. Three of them emerge from the northern slopes of the wetland, one from the southern slopes and one between the Renuka Wetland and Parshuram Tal. The springs that emerge from the hill slopes contribute to the wetland's groundwater in the form of base flows. The spring, which emerges between the wetland and lake, is called the Ram Baori. Sufficient geological data could not be gathered about this spring to determine its typology and thus identify its recharge zone. Only the water quality of the water in the baori was measured. Thus, information regarding Ram Baori has not been included in this report.

[17] Mahamuni, K. & Kulkarni, H. (2012) Groundwater resources and spring hydrogeology in south Sikkim, with special reference to climate change. In Arrawatia, M. L. and Tambe, S. (Eds.), Climate Change in Sikkim: Patterns, Impacts and Initiatives (pp. 261–274). Information and Public Relations Department, Government of Sikkim

[18] Shrestha, R. B., Desai, J., Mukherji, A., Dhakal, M., Kulkarni, H., Mahamuni, K., Bhuchar, S. & Bajracharya, S. (2018). Protocol for reviving springs in the Hindu Kush Himalayas: A practitioner's manual. ICIMOD Manual 2018/4. Kathmandu: ICIMOD.

Table 2 Location, discharge and chemical parameters measured in March 2020

Spring	Location (lpm)	Discharge (µS)	EC (ppm)	TDS (ppm)	Salinity	pH	Temperature (°C)
S1	30° 36′ 39.93″ N 77° 28' 02.73″ E	23.54	274	193	131	8.06	22.2
S2	30° 36′ 23.66″ N 77° 28' 37.76″ E	28	382	272	183	8.60	16.5
S3	30° 36′ 29.81″ N 77° 27' 21.06″ E	19.03	687	488	332	7.76	19.1
S4	30° 36′ 32.54″ N 77° 26′ 59.17″ E		660	470	320	8	19.5
S5	30° 36' 38.2" N 77° 28' 23.5" E	40	NA	NA	NA	NA	NA

The discharge and water quality of the other springs were measured. The two springs S1 and S3 together contribute nearly 42.57 litres of water every minute on average as measured during March 2020. Springs S1, S3 and S5 cumulatively discharge about 90 lpm of groundwater as base flows which feed Renuka wetland downstream. Similarly, preliminary studies were conducted to understand some of the basic chemical characteristics of the spring water. A handheld in situ pocket tracer was used. The results obtained from the in situ testing clearly indicate that the four springs were fed groundwater by different geological units. The TDS, EC and salinity values of springs S3 and S4 were twice those of S1 and S2, implying a higher dissolution of minerals in the groundwater of the former springs due to a longer period of rock- water interaction. The pH of the groundwater was alkaline in all the springs. The values of S1 and S2 were higher. The pH value of water from S2 was higher than that of S1.

The recharge zones of three springs were demarcated on the basis of their typology. As most of them are fracture springs, which receive groundwater from shallow aquifers, the recharge zones are in the regions where the fractures are exposed. Thus, there are multiple areas that recharge a particular spring.

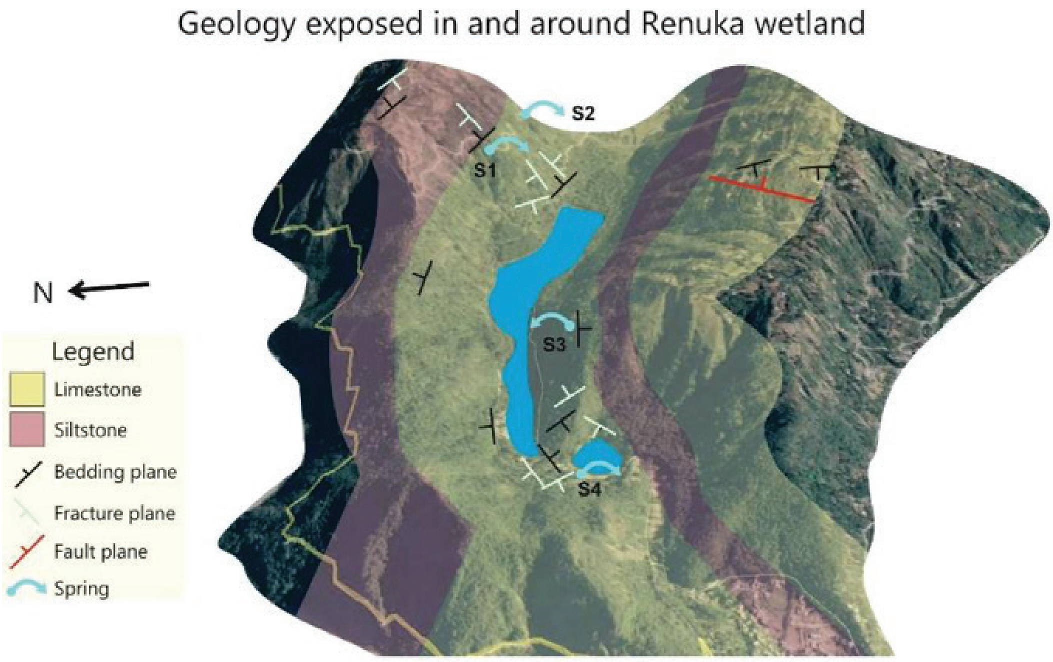


Figure 5 Overlay of geology and locations of four identified springs on Google Earth imagery

The following section provides a detailed description and graphical illustrations of the hydrogeological setting of each spring. along with its recharge zones, which were demarcated primarily on the basis of the spring typology. Springs emerging from the northern ridge. The highest spring (S1) emerges roughly 905 m above mean sea level from the northern slope along a road cutting. It emerges along the escarpment slope where a highly weathered and sheet-jointed dark grey coloured siltstone with dips towards the northeast is exposed. Some loose weathered material washed down and deposited from the rocks above is observed slightly above the point of emergence of the spring. The spring emerges from three spouts, with a water collection box constructed below it.

Two main sets of fractures cut across the rocks. Fracture F1 dips towards the northwest by 75°, while F2 dips towards the NNE by 40°. S1 can be classified as a fracture spring on the basis of the rocks and rock structure[19]. The cumulative discharge measured at the three spouts was 23.54 lpm.

The ridge just above the spring where the inclined NE–SW trending fracture is exposed was identified as the recharge zone on the basis of the spring type and the orientation of the fractures (Figure 7). The approximate area of the recharge zone is 0.98 ha.

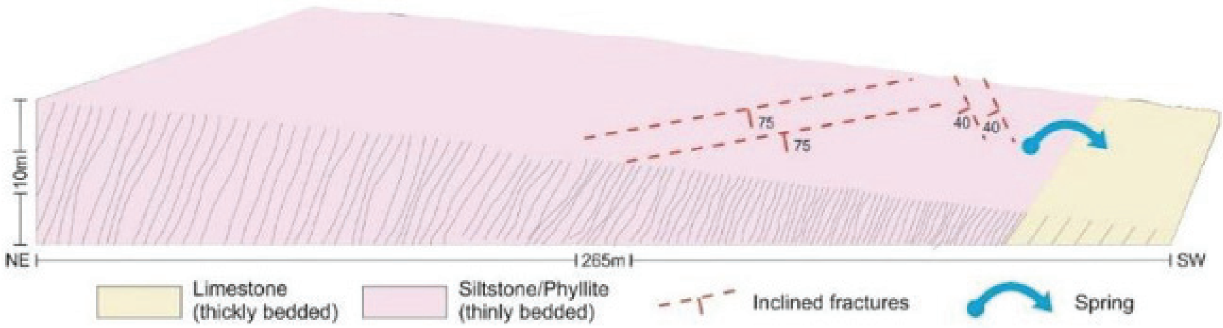


Figure 6 *A cross-section of the subsurface geology exposed around spring S1. It is a fracture spring fed by two sets of inclined fractures in siltstone and limestone rocks.*

Location:
30° 36′ 39.93″ N;
77° 28′ 02.73″ E
Elevation: 905 m
Discharge:
23.54 lpm

EC: 274 µS
TDS: 193 ppm
Salinity: 131 ppm
pH: 8.06
Temperature:
22.2°C

Spring typology:
Fracture

Image 5 *Spring S1 emerging from three spouts along a road cutting. Fractured and weathered siltstone with loose weathered material is exposed around the spring.*

Figure 7 *The recharge zone of spring S1 is the area where inclined NE–SW fractures are exposed.*

The spring (S2) emerges in a baori at 755 m above msl on the northern side of the wetland. The water from this baori is used for drinking and domestic purposes by the neighbouring households. The spring has a constant discharge throughout the year[20] and emerges from fractured limestone. There are three fracture sets that cut across the rock. One is along the NE–SW and dips by 86° towards the NW. The other strikes E–W and is steeply inclined, by 79°, to the south, and the third is a vertical fracture running almost N–S. Like S1, this spring too emerges along the escarpment slope, with rocks dipping towards the northeast. On the basis of the surrounding geology and field evidence, S2 is classified as a fracture spring. It has a discharge of 28 lpm. However, S2 lies at the edge of the Renuka Wetland and may not contribute to its baseflow.

On the basis of the geology, spring typology and orientation of fractures, an area of roughly 12.9 ha to the north of spring S2 was demarcated as the recharge zone. However, the main areas are where NNE–SSW and NE–SW vertical to sub-vertical fractures are exposed (Figure 9).

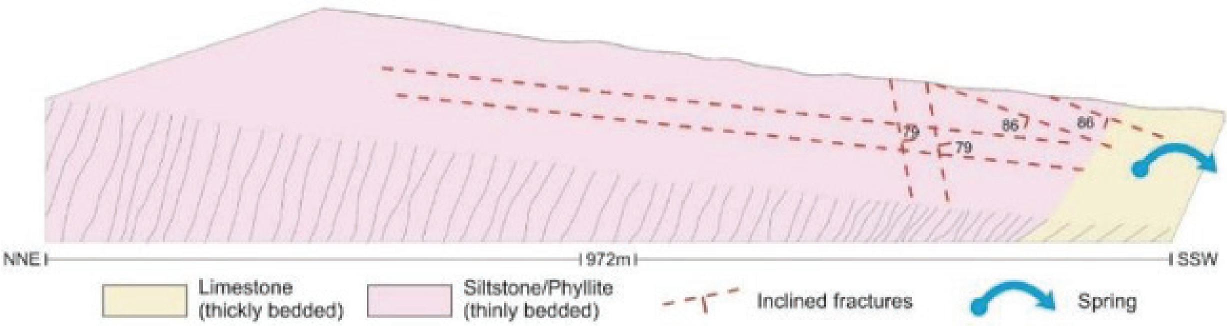


Figure 8 *A cross-section of the subsurface geology exposed around spring S2. It is a fracture spring fed by three sets of fractures in siltstone and limestone rocks.*

20 As communicated by a village member during discussion.

Location:
30° 36′ 23.66″ N
77° 28′ 37.76″ E
Elevation: 755 m
Discharge:
28 lpm

EC: 382 µS
TDS: 193 ppm
Salinity: 272 ppm
pH: 8.60
Temperature:
16.5°C

Spring typology:
Fracture

Image 6 *Spring S2 emerging from a spout in a baori located near Parshuram Temple*

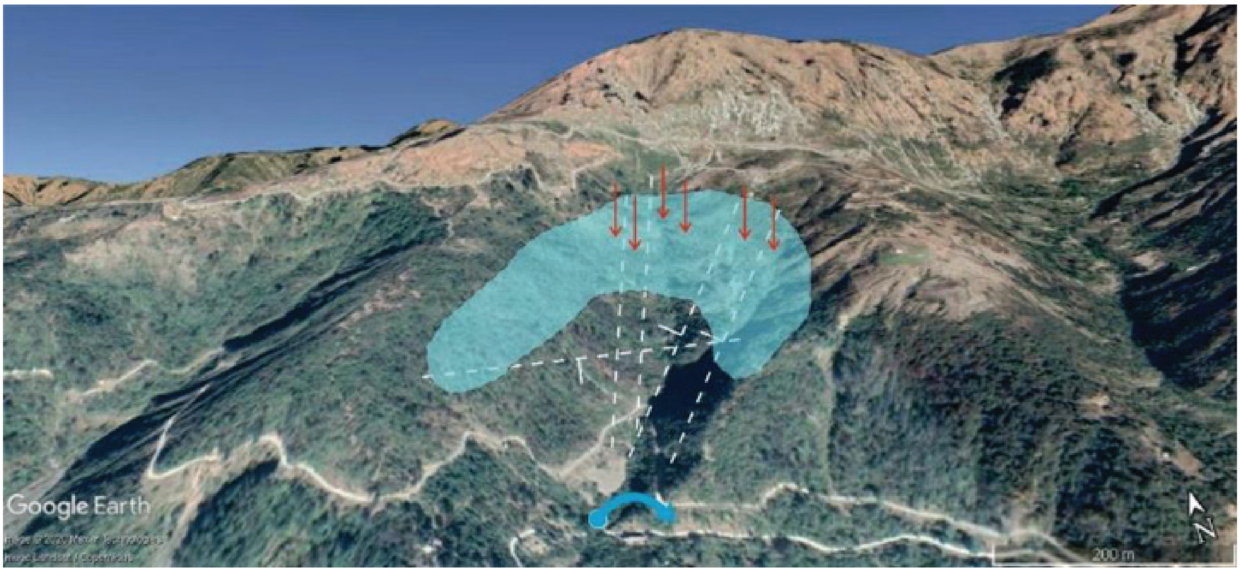


Figure 9 *Recharge zone of spring S2 is the area where sub-vertical to vertical inclined fractures are exposed.*

Spring (S5) emerges on the northern slope of the wetland. Water quality data for S5 is not available, however, its discharge was measured at almost 40 litres of water every minute during the month of October 2021. It has a recharge area of 8 ha.

- ***SPRINGS EMERGING FROM THE SOUTHERN RIDGE***

The spring (S3) is located along the southern ridge and seeps out of the surface at 787 m. The ridge is thickly vegetated, with few outcrops of fractured limestone exposed all along the route to the spring. The limestone beds dip towards the south and south-east with vertical NW–SE-trending fractures. The spring discharges groundwater at a rate of 19.03 lpm. The typology of these springs could be a combination of fracture and depression.

The recharge zone of S3 has been demarcated as the area to the southeast of the spring where NW–SE vertical and inclined fractures are exposed (Figure 11).

Spring (S4), Ram baori, emerges between Renuka Wetland and Parshuram Tal. It has a recharge area of 1.0 ha. Water discharge measurements are not available, but water quality data has been assessed.

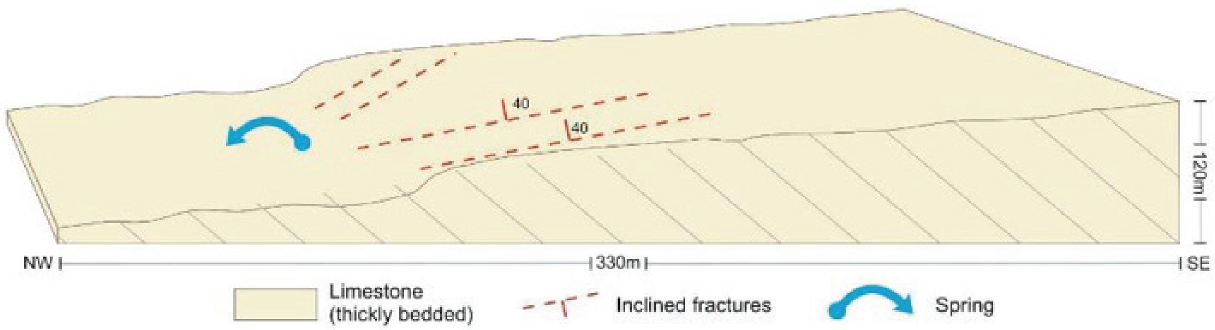


Figure 10 *Cross-section of spring S3 showing fractured limestone rocks*

Location:
30° 36′ 29.81″ N
77° 27′ 21.06″ E
Elevation: 787 m
Discharge:
19.03 lpm

EC: 687 µS
TDS: 488 ppm
Salinity: 332 ppm
pH: 7.76
Temperature:
19.1°C

Spring typology:
Fracture fed by depression

Image 7 *Spring S3 emerging as a seep on the southern ridge. At one place the spring water is channelised and collected in a storage tank that supplies water downstream.*

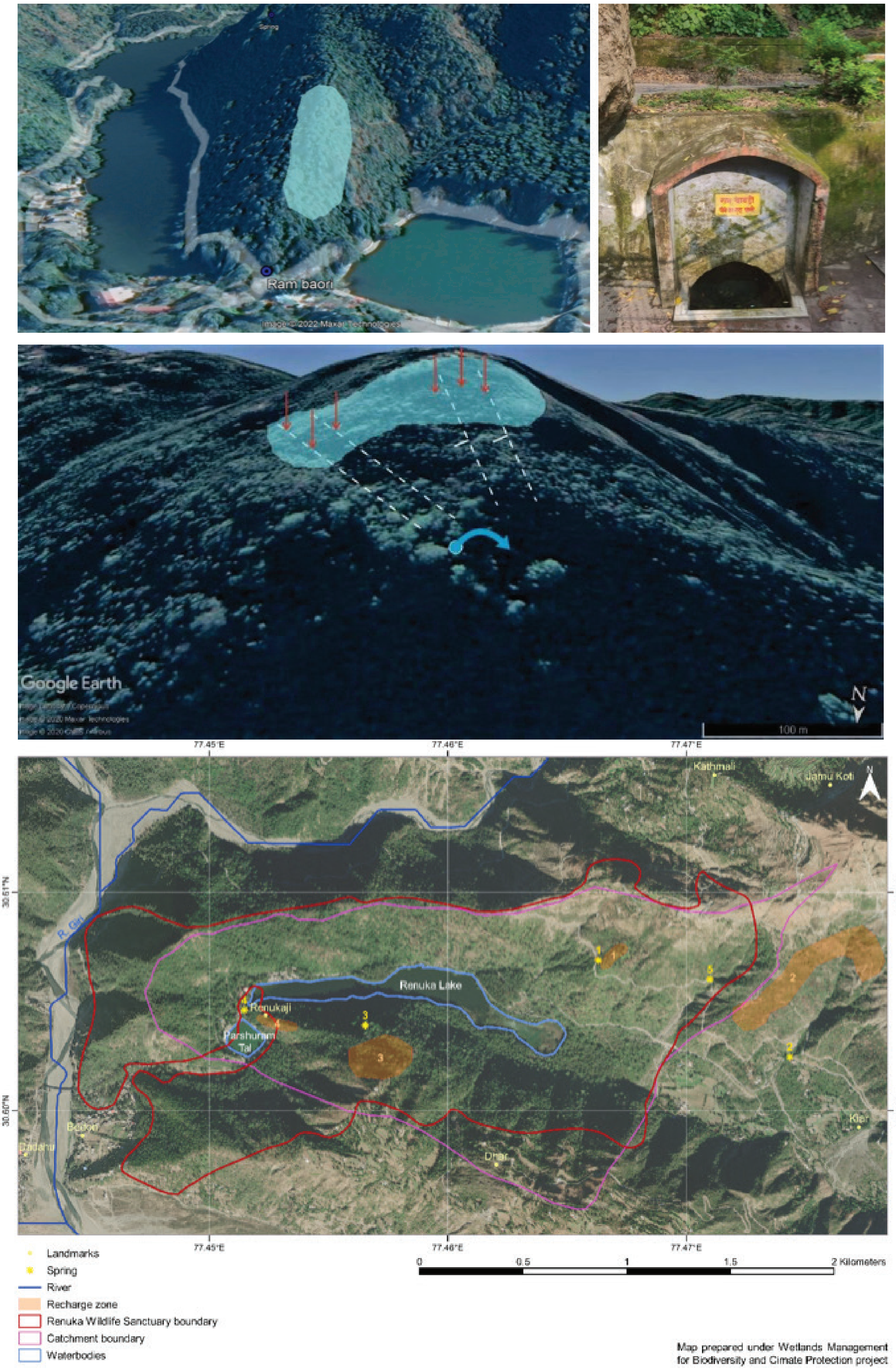


Figure 11 *Recharge zone of spring S4, photograph of Ram baori (top left & right); recharge zone of spring S3 (middle); location of 5 springs and recharge zones (bottom)*

3 ASSESSMENT OF SOIL EROSION AND SEDIMENT YIELD

SOIL EROSION

Soil erosion and sediment transport have been recognised as a significant global environmental issue that causes degradation of land and sedimentation of reservoirs and waterways, resulting in ecological diseqilibrium and depletion of flora and fauna.. The eroded sediment gets transported from higher-elevation regions to relatively lower elevations and ultimately to the sea. Sedimentation of lakes, rivers and reservoirs have been affecting the water storage capacities of hydraulic structures. Hence, either additional costs must be incurred in making the dead storage free of sediments, or the designed service time of the structure shall be shortened. However, an appropriate study and good watershed management practices are the scientifically proposed solutions for the problems related to soil erosion and sedimentation. The water storage capacity of the Renuka Wetland is being affected due to soil erosion from different parts of the watershed. The present study focuses on the assessment of the soil erosion in the Renuka Wetland watershed to take preventive measures to counteract the negative impacts of soil erosion.

The employed methodology was based on secondary data as well as data of the Renuka Wetland watershed collected in-situ. The secondary information was collected from the relevant sources to establish the pattern of sediment deposition in the past years. Remote sensing image analysis was performed to predict the soil erosion based on factors such as topography, land cover and drainage. The soil erosion model was used to estimate the sediment erosion rates under different environmental conditions to account for the eroded material being deposited in the lake.

Secondary data (such as land use/land cover maps, soil maps and digital elevation models) were collected from state government offices or downloaded from open-source websites. Soil samples from different representative locations of the watershed were collected to study the overall characteristics and, specifically, the soil–water interaction. Information related to agricultural practices, management and policies were also obtained from government agricultural offices and non-governmental organizations working in the area. Hydro-meteorological and other climate data were obtained from the meteorological department, IMD sites and state meteorological sites. The universal soil loss equation was used to assess the soil erosion:

$$A=R.K.L.S.C.P$$

where, R is the rainfall erosivity (MJ mm/ha/h), K is the soil erodibility, LS is the slope length-gradient, factor C is the crop management factor and P is related to the conservation practices.

DEVELOPMENT OF SEDIMENT YIELD MODEL INPUTS

The model inputs for the estimation of the soil erosion and sediment yield were established as follows:

- ***RAINFALL EROSIVITY FACTOR (R-FACTOR)***

The rainfall erosivity factor represents the eroding power or capacity of the rainfall. It measures the kinetic energy and intensity of the precipitation to describe its erosive effect on the soil. Various researchers have given equations for estimating the erosivity of rainfall depending upon the conditions of applicability. The rainfall erosivity of the Renuka Lake watershed was estimated as suggested by Kumar et al. (2014)[21] specifically for the state of Himanchal Pradesh as:

$$R=79+0.363RN$$

where, RN is the average annual rainfall in millimetres and R is the rainfall erosivity factor (MJ mm/ha/h).

[21] Kumar, A., Devi, M., & Deshmukh, B. (2014). Integrated remote sensing and geographic information system-based RUSLE modelling for estimation of soil loss in western Himalaya, India. Water Resources Management, 28(10): 3307–3317.

Mahapatra et al. (2018)[22] also recommended the use of this equation for estimating the erosivity factor in Himalayan regions. Since there was no rain gauge in the watershed, the rainfall value measured at the nearby station (Dadahu/Renuka) was used (indiawris.com). The precipitation was assumed to be uniformly distributed throughout the whole watershed. The mean annual rainfall measured over the last 30 years (1989–2019) at the rain gauge station was 1696.8 mm. Using the equation mentioned in the foregoing, the rainfall erosivity factor was estimated to be 694.938 MJ mm/ha/h, and a typical rainfall erosivity map of the watershed is shown in Figure 12.

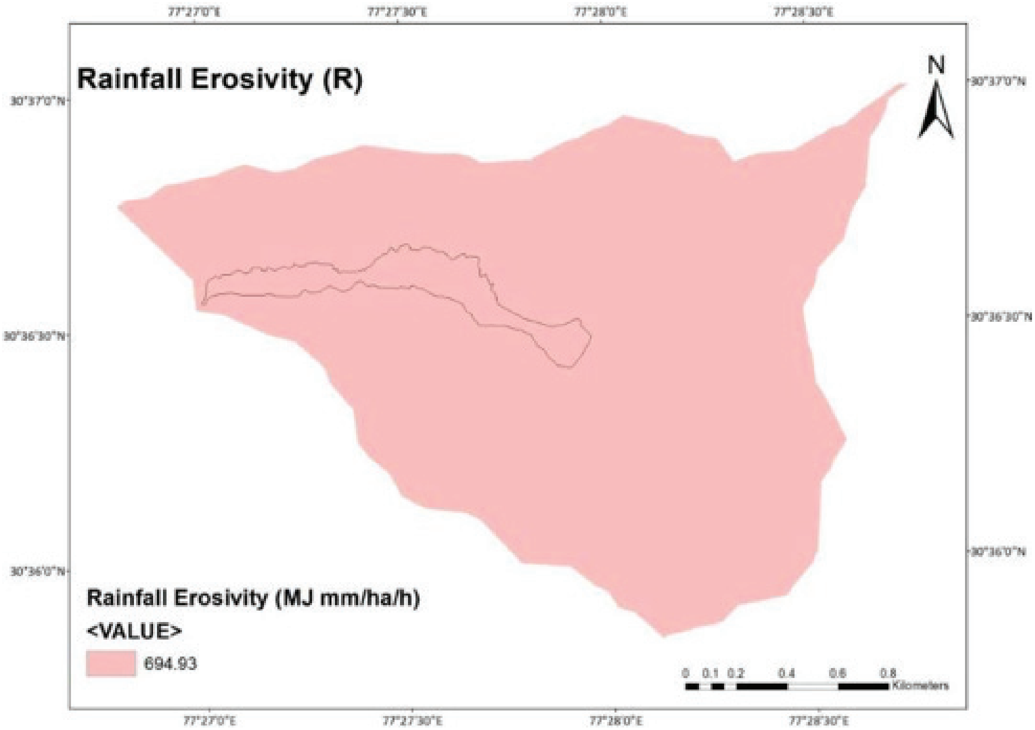


Figure 12 *Rainfall erosivity of the Renuka Lake watershed*

- ***SOIL ERODIBILITY FACTOR (K-FACTOR)***

The soil erodibility factor represents the susceptibility of soil particles to detachment and transport by rainfall and runoff. Discrete samples of the topsoil (0–20 cm) were collected from different representative locations of the watershed to estimate the soil erodibility. The particle size distribution and organic matter content of the samples were analysed. Williams' equation (1995) was used to estimate the erodibility of the watershed. The estimated values of the K-factor range from 0 to 0.36, with relatively lower values for the built-up areas. A typical K-factor map is shown in Figure 13. The percentages of sand, silt and clay determined in the laboratory are listed in Table 3.

Table 3 *Characteristics of soil from different locations of the watershed*

Class	Sand % topsoil	Silt % topsoil	Clay % topsoil	OC % topsoil	fc sand	fcl-si	forg	fhi sand	Kusle
Agriculture	2.36	96.47	1.17	6.10	0.49	0.99	0.75	1	0.36
Coniferous	2.50	95.54	1.56	7.55	0.49	0.99	0.75	1	0.36
Eucalyptus	2.58	95.27	2.15	5.36	0.49	0.99	0.75	1	0.36
Deciduous	2.32	96.51	1.17	11.19	0.49	0.99	0.75	1	0.36
Barren	1.60	89.76	8.64	4.04	0.48	0.97	0.75	1	0.35
Water	-	-	-	-	-	-	-	-	0
Built-up area	-	-	-	-	-	-	-	-	0

[22] Mahapatra, S. K., Reddy, G. O., Nagdev, R., Yadav, R. P., Singh, S. K., and Sharda, V.N. (2018). Assessment of soil erosion in the fragile Himalayan ecosystem of Uttarakhand, India using USLE and GIS for sustainable productivity. Current Science, 115(1): 108.

WILLIAMS' (1995) EQUATION[23]:

K_USLE = f_csand.f_(cl - si).f_orgc.f_hisand

f_csand = (0.2 + 0.3. exp [−0.256.m_s.(1-m_silt/100)])

f_(cl - si) = (m_silt/(m_c + m_silt))^0.3

f_orgc = (1 - (0.25.orgC /(orgC + exp[3.72 - 2.95 orgC]))

f_hisand = (1-0.71(1-m_s/100)/((1-m_s/100) + exp[-5.51 + 22.9 (1-m_s/100)]))

ms is the sand fraction content [%],

msilt is the silt fraction content [%]

mc is the clay fraction content [%] and

orgC is the organic carbon (SOC) content [%].

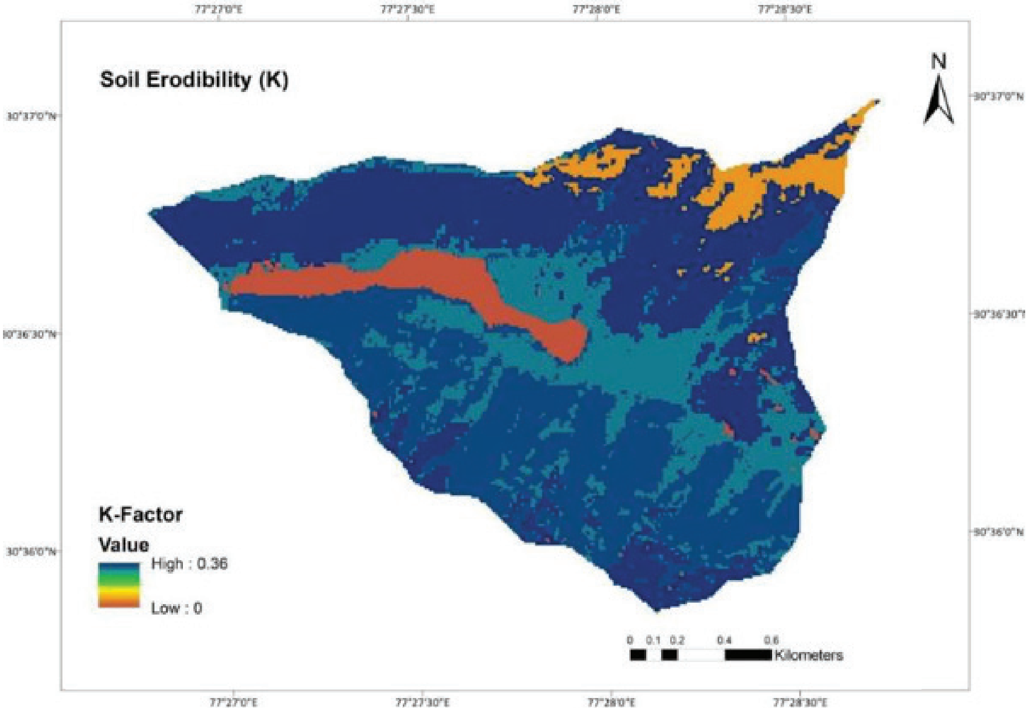


Figure 13 *Soil erodibility of the Renuka Lake watershed*

- ***SLOPE LENGTH-GRADIENT FACTOR (LS-FACTOR)***

The LS-factor also plays a significant role in the erosion of soil. The value of the LS-factor was calculated using the equation of Stone and Hilborn (2012)[24] and a 12.5m × 12.5 m digital elevation model (DEM; 01/01/2010, source: ALOS PALSAR).

LS = [0.065 + 0.0456 (slope) + 0.006541 (slope)2] (slope length ÷ constant) NN

where, the slope is expressed as a percentage, the slope length is the length of the slope in metres, the constant is 22.1 m, and NN is the exponent, which depends on the slope.

Table 4 *Exponent NN for different slopes*

Slope (S) (%)	<1	1 ≤S<3	3 ≤S<5	≥5
NN	0.2	0.3	0.4	0.5

[23] Williams, J. R. (1995). The EPIC model. In V. P. Sing (ed.), Computer Models of Watershed Hydrology. (pp. 909–1000). Water Resources Publication, Littleton, Colorado
[24] Stone, R. P. & Hilborn, D. (2012). Universal soil loss equation (USLE) factsheet. Ministry of Agriculture, Food and Rural Affairs, Ontario.LS = [0.065 + 0.0456 (slope) + 0.006541 (slope)2] (slope length ÷ constant)NN

Since the slope is greater than 5% in most of the areas, we have adopted the value 0.5 for the exponent NN. The LS-factor map derived using the 12.5 m DEM is shown in Figure 14. The mean value is 1.81.

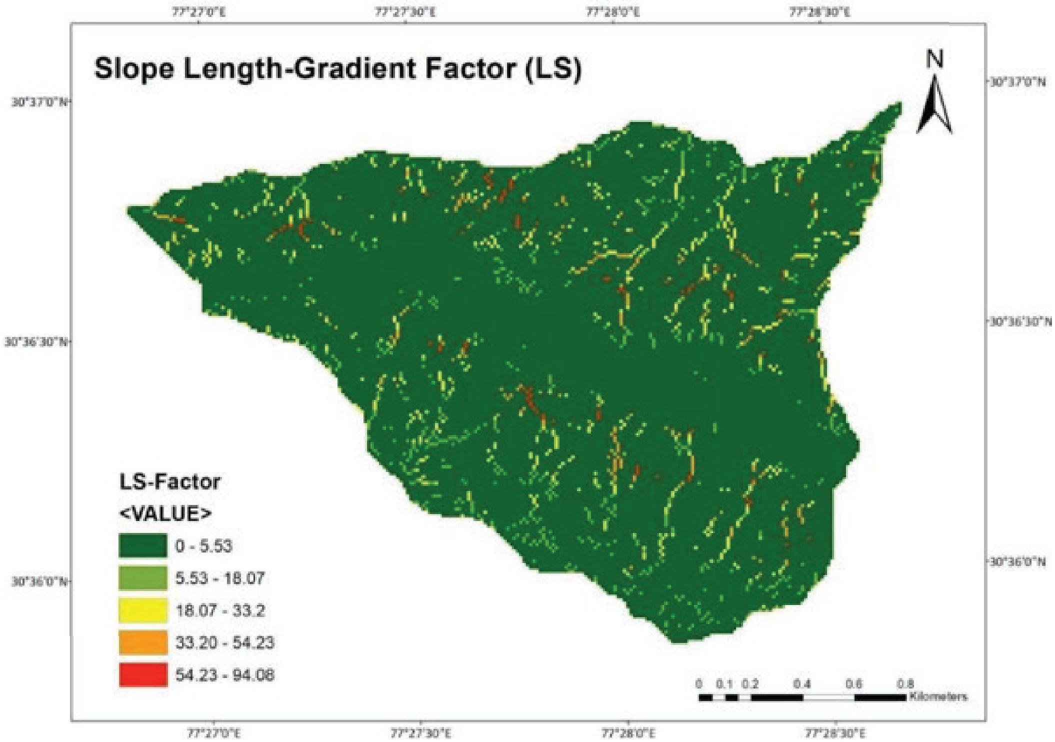


Figure 14 *LS-Factor of Renuka Lake Watershed*

- ***CROP MANAGEMENT FACTOR (C-FACTOR)***

The crop management factor depends on the land use land cover (LULC) of the watershed. It is used to determine the relative effectiveness of the soil and crop management systems in terms of preventing soil erosion. The C-factor is a ratio comparing the soil loss from the land under a specific crop and management system with the corresponding loss from continuously fallow and tilled land. The C-factor values used (on the basis of experience and values in the literature) for the seven identified land use classes of the Renuka Wetland are listed in Table 5. The LULC classification of the watershed was done using Sentinel imagery at a fine resolution of 10 m × 10 m. The relative percentages of different classes are listed in Table 5. Sentinel 2-MSI data and ground-truthing data (along NH 5 and 3.5, Himachal Pradesh) from the CEDAR data repository were used. The bands used were B2, B3, B4, B5, B6, B7, B8, B11, EVI, NDVI, NDWI and DEM. The imagery was downloaded on 09/02/2019.

Table 5 *C-factor values for different land use classes*

S. No.	Class	C-factor	Area (km2)	Percentage (%) of total area of watershed
1	Agriculture	0.5	0.05	1.57
2	Barren	1	0.16	4.55
3	Built-up	0.1	0.01	0.39
4	Coniferous	0.03	1.14	31.72
5	Deciduous	0.01	1.26	35.01
6	Eucalyptus	0.02	0.77	21.49
7	Water (lake)	0	0.19	5.29

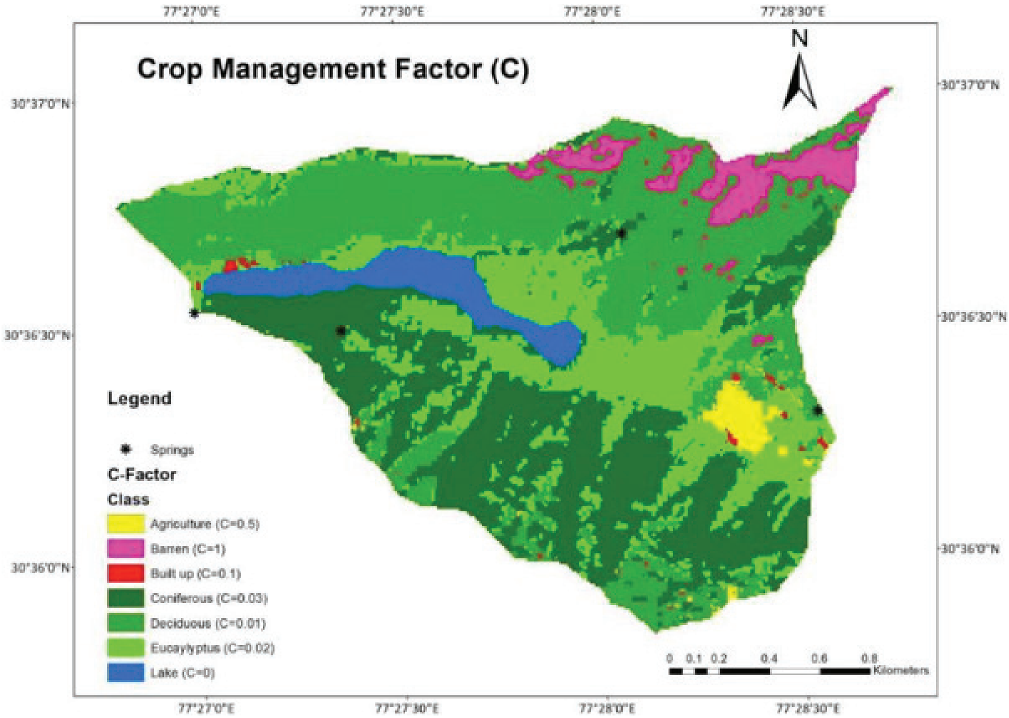


Figure 15 C-factor of Renuka Lake watershed

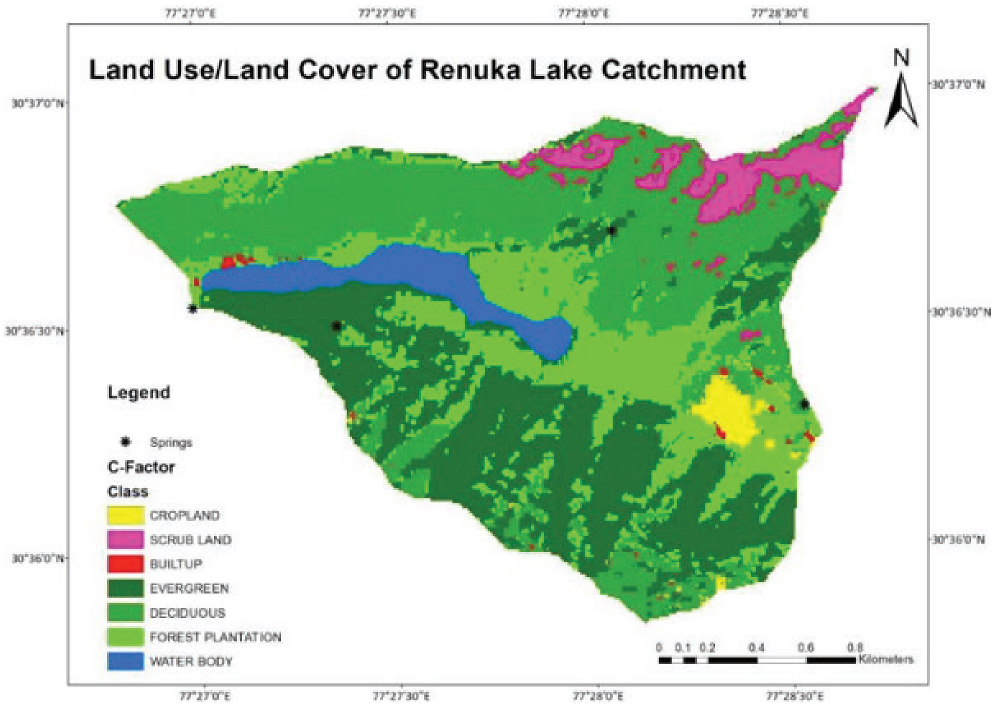


Figure 16 LULC of Renuka Lake watershed; spring locations

- ***CONSERVATION PRACTICES FACTOR (P-FACTOR)***

The conservation/support practices factor reflects the effects of practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion. The P-factor represents the ratio of soil loss under a support practice to that of straight row farming up and down the slope. The most used supporting cropland practices are cross-slope cultivation, contour farming and strip cropping. A soil conservation programme has already been implemented in the past under the Wetland Conservation Program 2018, Himanchal Pradesh. The Himachal Pradesh State Wetland Authority (HPSWA), constituted in 2017 under the aegis of the H.P. Council for Science, Technology & Environment (HIMCOSTE), is acting as the nodal agency for coordinating the Wetland Conservation Programme in the state with active participation of all the stakeholders' departments. The Wetland Conservation and Management action plans involve components such as Habitat Improvement, Soil and Water Conservation, De-weeding & Desilting, Income Generating Activities, Training/Workshops/Awareness Camps, Research Studies Covering Site-Specific Conservation Works, and Awareness Activities. Most of the flow in the watershed is known from experience to be cross-slope and thus a P-factor value of 0.6 was adopted.

IDENTIFICATION OF THE EROSION-PRONE AREAS

The areas of the watershed that suffer considerably large erosion rates and volumes were identified for effective implementation of the soil conservation programmes and strategies. The barren land of the watershed experiences the most erosion, followed by the agricultural area. The area with dense forest cover and steep slopes also suffers considerably high levels of erosion. The soil erosion map (Figure 17), generated using a GIS-based USLE model, illustrates this pattern. Figure 17 shows that the worst soil erosion (shown in white) occurs with a combination of steep slopes and barren land followed by the area shown in violet and brown.. Even though most of the watershed has erosion values less than 10 tonnes/ha/year, the mean erosion rate of the watershed is considerably higher (18 t/ha/yr) than the acceptable erosion rate. This is because there is higher erosion occurring in some parts of the watershed.

ESTIMATION OF SEDIMENT YIELD

The USLE-based model was set up in ArcGIS by incorporating the R-factor, K-factor, LS-factor, C-factor and conservation practices factor. All the factors were overlaid using the map algebra to predict the erosion rates. A major part of the catchment has erosion rates below 1 tonne/ha/year, and the steep slopes with barren land have considerable erosion rates and volumes. However, the mean erosion rate of the catchment was found to be 18.25 tonnes/hectare/year, which is considerably more than the normal erosion rate of 5–10 tonnes/ha/year (George K et. al., 2021[25]). A typical erosion map of the catchment is shown in Figure 17

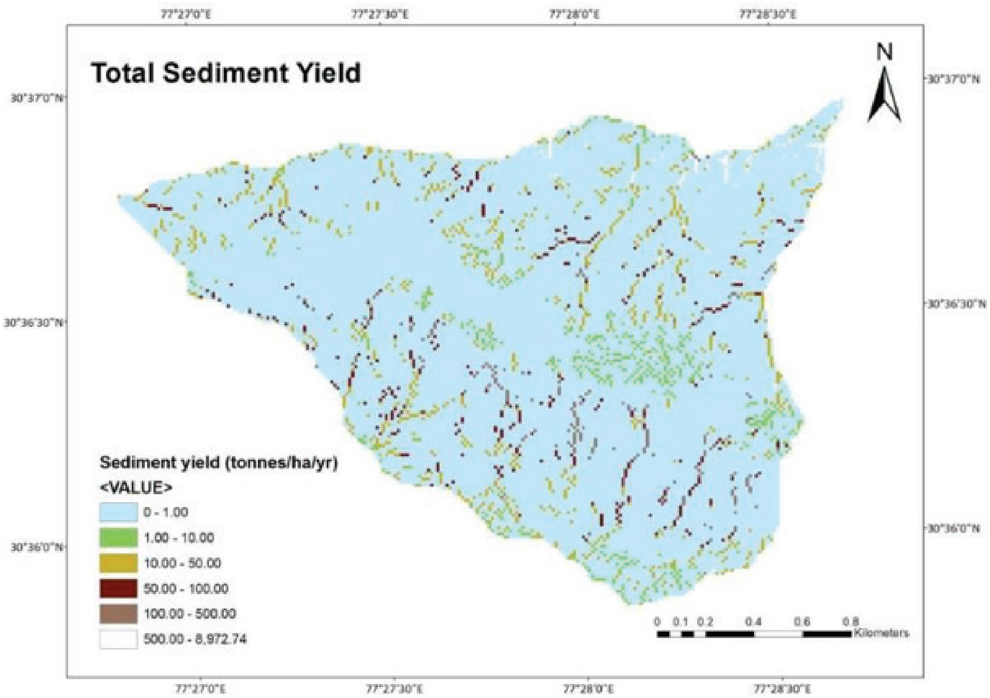


Figure 17 *Erosion map of the Renuka Lake watershed*

IDENTIFICATION OF DRIVERS OF SOIL EROSION

Although the rainfall intensity was one of the main drivers of the soil erosion, rainfall intensity was assumed to be uniformly distributed in the catchment. With this uniform rainfall distribution assumption, the other factors (soil erosivity, slope, crop cover and conservation practices) were used to determine soil erosion.

The soil erosivity of the catchment, as determined using Williams' (1995)[23] equation, shows that the soils in the deciduous, coniferous and eucalyptus areas were more erodible compared with the other parts. The soils in the dense forests contain organic matter and are susceptible to erosion but are protected by the impact of raindrops by the forest cover. Thus, the steep slope and slope-length of the landscape seems to be the major drivers of soil erosion, as confirmed by the LS-factor and the sediment yield map. The barren land also drives a major part of the total erosion, followed by the agricultural area, with intermediate erosion rates and volumes as shown by the analysis. The raindrops impact on the barren land directly throughout the year, while the agricultural land faces the raindrop impacts for a shorter duration, during the no-crop season. Moreover, the tillage and other practices in the agricultural land make it more susceptible to erosion. The barren land on steep slopes becomes even worse, as even a small impact of raindrops can result in significant erosion. Thus, the worst soil erosion was found to be that of barren land on steep slopes (Figure 18).

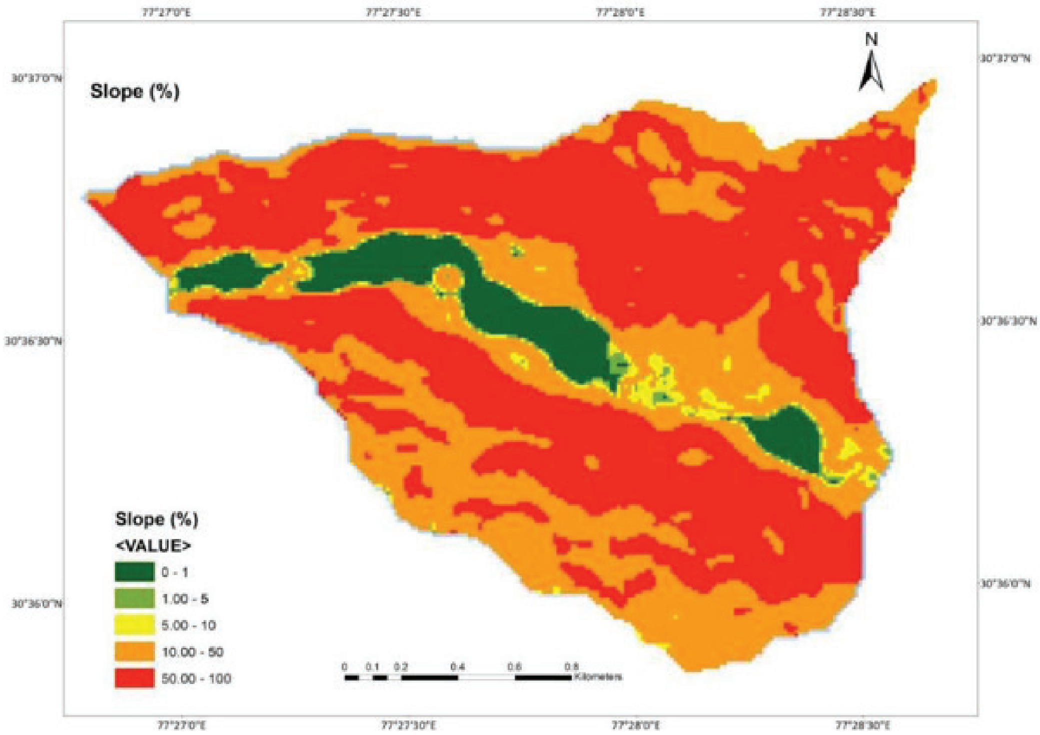


Figure 18 Variation of slope within the Renuka Lake watershed

4 ASSESSMENT OF NUTRIENT STATUS, NUTRIENT FLUX AND WATER QUALITY

An extensive study was carried out to determine the contamination level in the water of Renuka Wetland and Parashuram Tal alongwith the sources of contamination.

The water quality of Renuka Wetland is gradually deteriorating due to various anthropogenic activities such as bathing, feeding of fishes, immersion of flowers and other items used in worship and deforestation. Moreover natural phenomena such as soil erosion from nearby hills are responsible for siltation which has shrunk the lake by about a fourth. Thus, nutrients are concentrated in the lake resulting in eutrophication. Discharge of various pollutants from point and non-point sources and various anthropogenic activities are reducing the storage capacity of the lake[26].

In a study by Omkar Singh and C.K Jain, the water quality of lakes of the Western Himalayas (i.e., Mansar, Surinsar, Tsokar, Tsomoriri and Renuka) were discussed and it was found that the values of the physico-chemical water quality parameters were within the desirable limits for Mansar and Surinsar (Jammu Division), except for low DO values in the hypolimnion. On the other hand, the corresponding values of Tsomoriri and Tsokar (Ladakh region) were beyond the limits. The pH, total dissolved solid levels, total hardness and chloride, calcium, and magnesium concentrations were beyond the limits. Renuka Wetland has higher concentrations of magnesium, iron, manganese and lead, higher total coliform bacteria faecal coliform bacteria counts and low DO values in the hypolimnion. The eutrophication status, assessed on the basis of the phosphate concentration, showed eutrophic conditions in Mansar, Surinsar and Tsomoriri and hyper-eutrophic conditions in Tsokar and Renuka Wetland[27].

Pawan Kumar et al (2019) found that the WQI values of the water of Renuka Wetland during the period from the monsoon to the pre-monsoon season (176.45–184.91) were unsuitable for drinking. The higher WQI values are mainly due to a high concentration of F^-, which is produced by fluorapatite, cryolite, mica etc. and anthropogenic activities. Ca^{2+} and Mg^{2+} were the dominant cations, whereas SO^{2-} and HCO^{-} were the dominant anions during all seasons.

Alkaline earth metals (Ca^{2+} and Mg^{2+}) were found to be in higher concentrations compared with alkali metals (Na^+ and K^+), and the concentration of weak acids (HCO^-) was greater than that of strong acids (SO^{2-}) in all seasons. The carbonate weathering of the surrounding rocks was the source of major ions present in the lake during the period from the pre-monsoon to the post-monsoon[28].

The eutrophication level of Renuka Lake was relatively high. However, another study indicated a decreasing trend from hypertrophic to eutrophic. Appropriate conservation and restoration measures are necessary to reduce the existing eutrophication level of Renuka Wetland[29]. Along with conservation measures, community awareness is necessary to save this vulnerable lake and wetland.

To study the nutrients dynamics and the trophic status of Renuka Lake, water and sediment samples were collected from the surface and bottom, respectively, during the winter pre-monsoon (February 2020) and summer post-monsoon (September 2020). A total of 17 water samples from the lake surface and 15 sediment samples from the bottom of the lake during the former period and a total of 26 water samples from the lake surface and nine sediment samples from the bottom of the lake were collected during the latter period (Figure 19).

[26] Das, B. (2016). Renuka Lake ecosystem and wetland protection, Lesser Himalaya, Published literature - Water Ecosystems, State Centre on Climate Change, Himachal Pradesh. Available at: http://www.hpccc.gov.in/PDF/Water%20Ecosystem/Renuka%20Lake%20Ecosystem%20and%20Wetland%20Protection,%20Lesser%20Himalaya,.pdf.
[27] Singh, O. & Jain, C. K. (2013). Assessment of water quality and eutrophication of lakes. J. Environ. Nanotechnol, 2(13): 46–52.
[28] Kumar, P., Meena, N. K. & Mahajan, A. K. (2019). Major ion chemistry, catchment weathering and water quality of Renuka Lake, north-west Himalaya, India. Environmental Earth Sciences, 78(319): 1–16.
[29] Singh, O. & Sharma, M. K. (2012). Water quality and eutrophication status of the Renuka Lake, District Sirmaur (H.P.). Journal of Indian Water Resources Society, 32(3–4): 1–7.

The samples were taken to the Environmental Hydrology Laboratory of IIT Roorkee. Some of the quality parameters (such as pH, electrical conductivity, dissolved oxygen, temperature, oxidation reduction potential (using electrical probes) and transparency (Sechhi disk depth) were measured at the site itself. The other chemical water quality parameters (alkalinity, free ammonia, total Kjeldahl nitrogen, total nitrogen (TN), total phosphorus (TP), orthophosphate, chlorophyll a, calcium and magnesium) were measured in the laboratory. All the monitoring, storage and analytical processes followed the standard protocols and standard methods as internationally prescribed (APHA, AWWA, WEF, 1998)[30]. Physical parameters such as transparency along with depth, temperature, pH, TDS, dissolved oxygen, alkalinity, total coliform and faecal coliform bacteria counts were analysed at the sampling site. The alkalinity was analysed using the acid titration method, the total hardness, and calcium were determined using the EDTA titration method, and the chloride was determined using the argentometric titration method. The sulphate was assessed using the turbiditimetric method, and the PDA method was used for nitrate. The stannous chloride method was used to determine the phosphate, and the membrane filter method was used for the biological parameters (total coliform and faecal coliform bacteria counts).

The vertical (depth-wise) variation of temperature and DO was also monitored to study the thermal and chemical stratification of the lake during the winter pre-monsoon. Three locations were selected for this (R13, 13 m; R16, 9 m; R25, 8 m). The distribution of different thermal layers was identified, and their physico- chemical properties were studied. Unfortunately, a similar monitoring attempt during the summer post-monsoon had to be conducted on a much smaller scale.

The trophic state is defined as the total weight of the biomass in a water body at a specific location and time (Devi Prasad et al. 2012)[31]. The level/status of eutrophication has been assessed on the trophic state index described by Carlson (1977)32. The equations for calculating the TSI values are as follows: where SD is in metres, Chl and TP are in milligrams per cubic metre, and TN is in milligrams per litre:

Secchi disk : $TSI\text{-}SD = 60 - 14.41 \times \ln(SD)$ (i)

Chlorophyll a : $TSI\text{-}Chl = 9.81 \times \ln(Chl) + 30.6$ (ii)

Total phosphorus: $TSI\text{-}TP = 14.42 \times \ln(TP) + 4.15$ (iii)

Total nitrogen : $TSI\text{-}TN = 54.45 + 14.43 \times \ln(TN)$ (iv)

The following equation was used to compute the Carlson Trophic State Index (CTSI).

$CTSI = \{(TSI\text{-}SD) + (TSI\text{-}Chl) + (TSI\text{-}TP) + (TSI\text{-}TN)\}/4$ (v)

[30] APHA, AWWA, WEF. (1998). Standard Methods for the Examination of Water and Wastewater. 20th ed., Washington DC, USA.
[31] Devi Prasad, A. G. & Siddaraju (2012) Carlson's Trophic State Index for the assessment of trophic status of two lakes in Mandya district. Advances in Applied Science Research, 3(5): 2992–2996.
[32] Carlson, R. E. (1997). A trophic state index for lakes. Limnology and Oceanography, 22(2): 361–369.

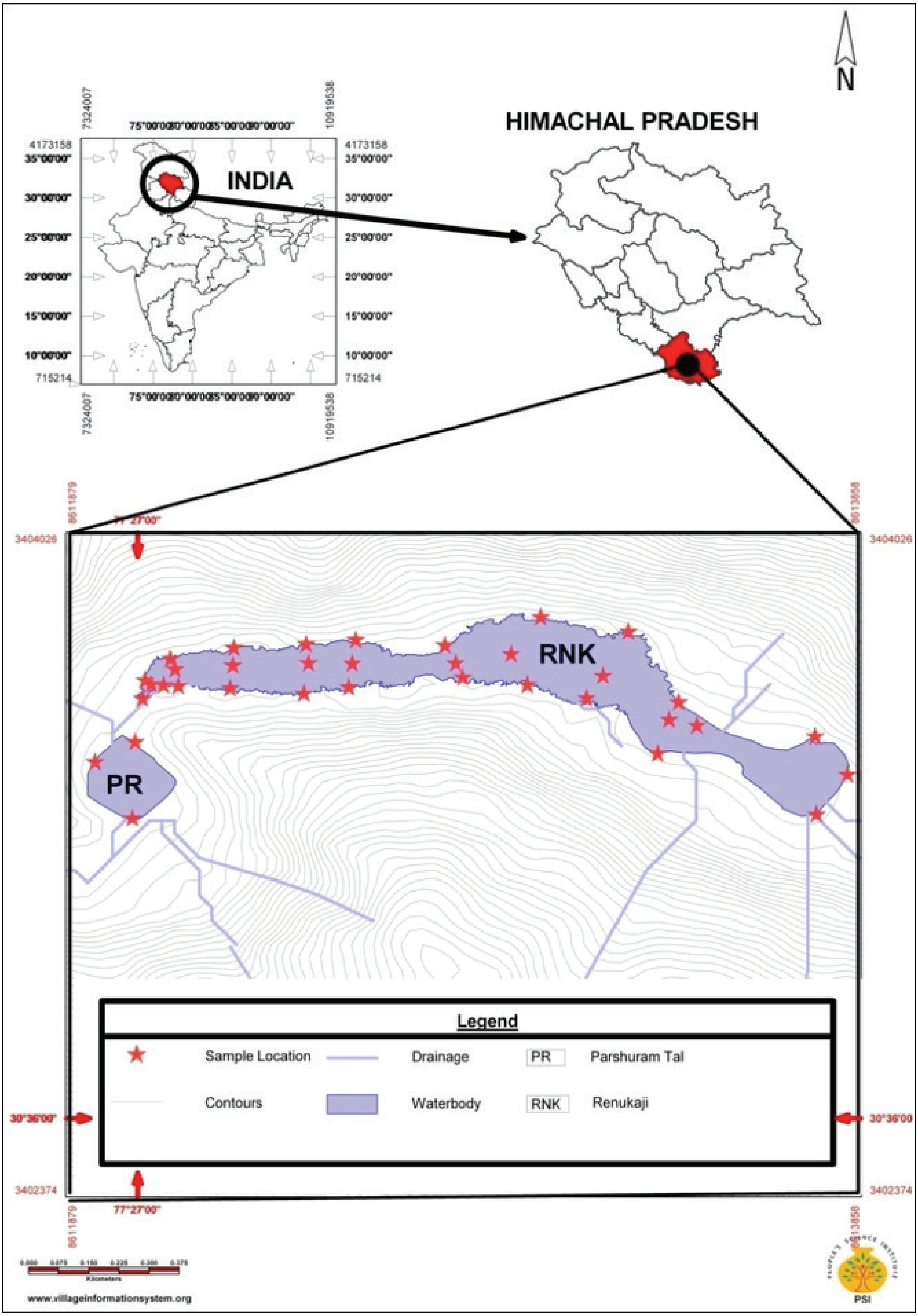


Figure 19 Sampling stations at Renuka Lake and Parashuram Tal (PSI)

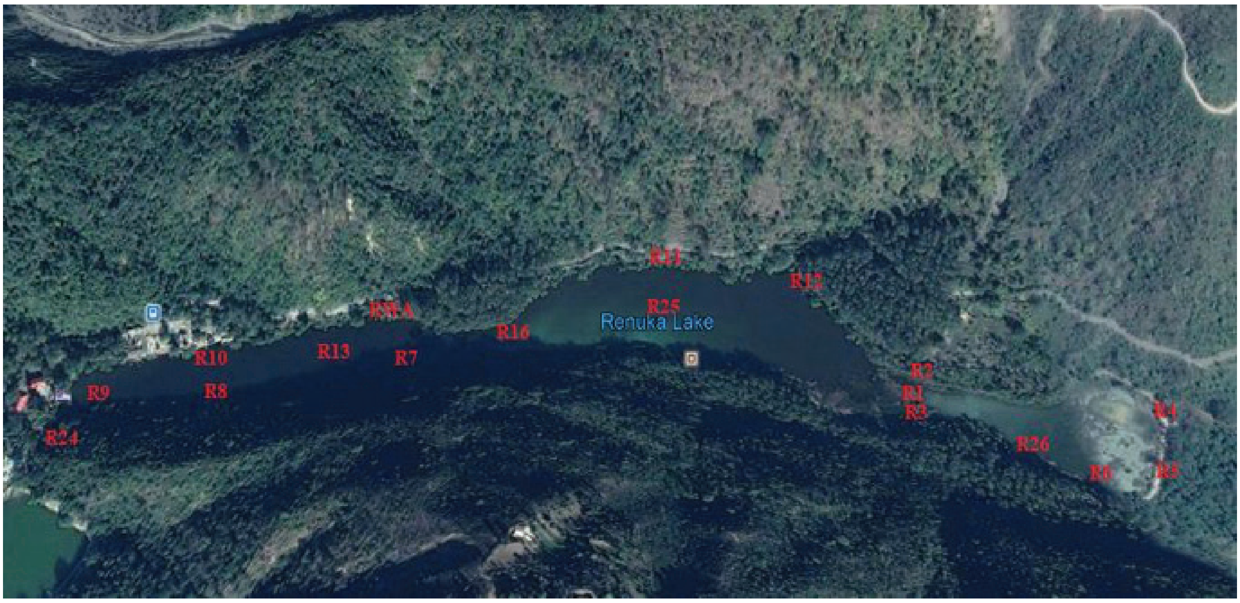


Figure 20 Sampling stations of the winter pre-monsoon sampling (IITR)

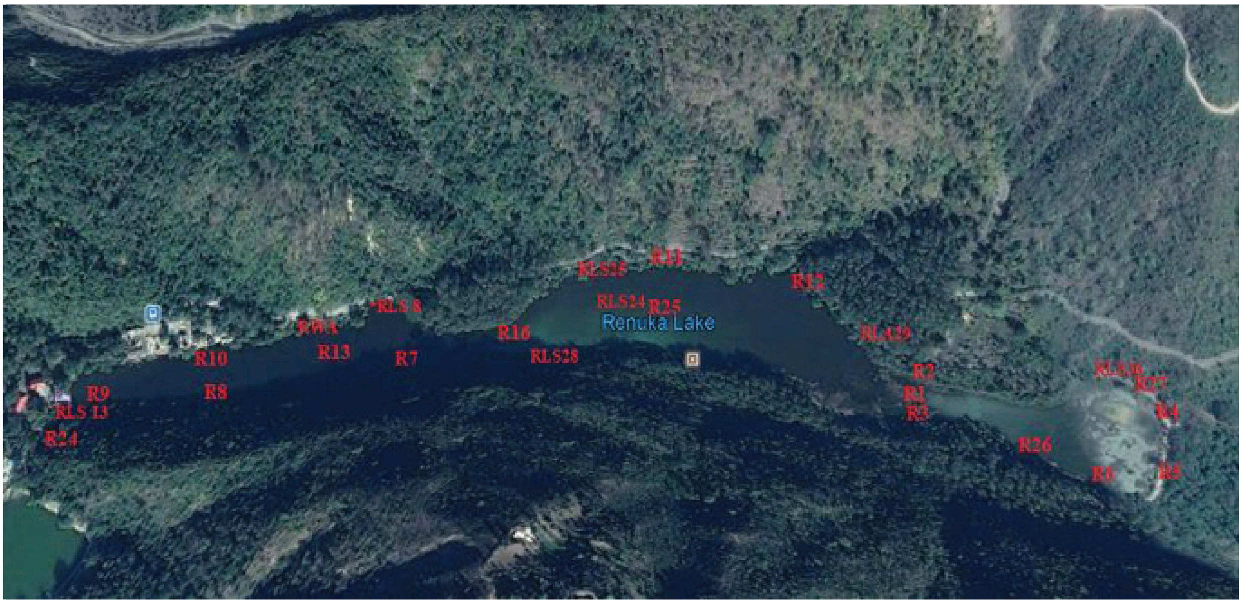


Figure 21 Sampling stations of the summer post-monsoon sampling (IITR)

Table 6 *Locations and details of sampling stations*

Sampling Station (Renuka Lake)	Elevation (MSL) (m)	Latitude	Longitude
RLS-13	670	30°36′33.81″N	77°27′0.40″E
RLS-10	665	30°36′34.89″N	77°27′2.13″E
RLS-11	666	30°36′34.94″N	77°27′1.12″E
RLS-12	666	30°36′35.30″N	77°27′0.72″E
RLS-1	666	30°36′36.99″N	77°27′2.67″E
RLS-2	663	30°36′36.17″N	77°27′3.05″E
RLS-3	672	30°36′34.82″N	77°27′3.31″E
RLS-4	673	30°36′34.64″N	77°27′7.47″E
RLS-5	660	30°36′36.48″N	77°27′7.69″E
RLS-6	661	30°36′37.88″N	77°27′7.77″E
RLS-7	670	30°36′38.20″N	77°27′13.60″E
RLS-8	667	30°36′36.66″N	77°27′13.79″E
RLS-9	685	30°36′34.21″N	77°27′13.41″E
RLS-16	680	30°36′34.72″N	77°27′17.02″E
RLS-17	669	30°36′36.63″N	77°27′17.30″E
RLS-18	671	30°36′38.25″N	77°27′17.68″E
RLS-19	662	30°36′37.87″N	77°27′24.97″E
RLS-20	664	30°36′36.27″N	77°27′25.33″E
RLS-21	670	30°36′35.51″N	77°27′26.21″E
RLS-23	674	30°36′35.02″N	77°27′31.26″E
RLS-24	660	30°36′37.39″N	77°27′30.10″E
RLS-25	669	30°36′40.13″N	77°27′32.52″E
RLS-26	670	30°36′33.84″N	77°27′36.18″E
RLS-27	666	30°36′35.64″N	77°27′37.50″E
RLS-28	676	30°36′39.18″N	77°27′39.54″E
RLS-29	661	30°36′33.30″N	77°27′43.26″E
RLS-30	659	30°36′32.10″N	77°27′42.84″E
RLS-31	660	30°36′30.90″N	77°27′42.18″E
RLS-32	659	30°36′31.62″N	77°27′45.06″E
RLS-35	669	30°36′24.54″N	77°27′54.72″E
RLS-36	669	30°36′30.54″N	77°27′54.54″E
RLS-34 Ram Bavdi	665	30°36′31.50″N	77°26′59.10″E
RLS-14 B/C Parashuram Tal	669	30°36′31.73″N	77°26′58.83″E
RLS-33 Parashuram Tal	668	30°36′30.30″N	77°26′59.82″E
RLS-15 Parashuram Tal	669	30°36′24.18″N	77°26′59.67″E
RLS-22 (spring)		Doodh Dhara	

STRATIFICATION-INDUCED IMPACTS

Many physical factors influence the nutrient dynamics and trophic status of lakes. Thermal stratification is one of the most important amongst them. A density difference primarily due to a temperature variation leads to a reduction in turbulent mixing and an accumulation of algae at the surface layer. A lake is classified as stratified if there is a temperature difference of 0.2°C/m or more with depth near the surface of the water body (Pernica and Wells, 2012)[33]. As the radiation energy increases, the depth of penetration also increases. If the temperature at the surface falls below the temperature of the underlying layer, the entire water body can overturn (Boehrer et al., 2008)[34]. Hence, in lake studies, it is most important to first evaluate the status of stratification.

The temperature and dissolved oxygen values at three different locations during the winter pre-monsoon revealed that the lake was stratified during the study (Figure 22). The temperature differences were 0.4, 1.4 and 1.5°C/m at R13, R16 and R25, respectively, with the depth of the epilimnion (the depth at which the temperature gradient is more than 0.2°C) being 2m at R13 and 1 m at R16 and R25. Physical and chemical forces are both responsible for the process of stratification. The variation of temperature with depth is shown in Table 7 and Figure 22.

It was observed that the depth of the hypolimnion increased with the depth of the lake. It was found to be the maximum at sample location R13, where the lake water depth was greatest (i.e., 12 m). The hypolimnion at all three locations was found to be anoxic, with a minimum DO of 0.04 mg/l at sample location R16 (9 m below the water surface), with strong reducing conditions. It may be concluded from Table 7 that in the shallower portions of the lake, the water body remained oxidative till a greater depth due to the external forces (like wind, temperature etc.), as at sample locations R16 and R25, the reduction in DO up to the mid depth was lower than at sample location R13. As the water body was thermally stratified, the nutrient concentrations varied between the epilimnion and hypolimnion. In the epilimnion of sample locations R13 and R25, free ammonia and nitrate were absent, but TKN was present at concentrations of 1680 and 1120 mg/m^3, respectively. In contrast, at R16, free ammonia was absent, but the nitrate and TKN values were 177 and 2240 mg/m^3, respectively. In contrast to the epilimnion, the hypolimnion at sample locations R13 and R25 had free ammonia and TKN at concentrations of 1560 and 2800 mg/m^3, and 2520 and 3640 mg/m^3, respectively, whereas at R16, free ammonia and nitrate were absent but TKN was present (840 mg/m^3).

The variations in free ammonia, nitrate and TKN with depth can be related to the DO levels of water, as the concentration of free ammonia and TKN have a negative correlation (r= -0.6, -0.4 and r= -0.4, -0.5) and nitrate has a positive correlation (r = 0.5 and r = 0.5) in water, with both temperature and DO, repectively. The autotrophic bacteria that help in degradation are temperature sensitive. They are more active at higher temperatures and DO levels[36]. The total phosphorus concentrations in the epilimnion and hypolimnion at sample locations R13, R16 and R25 were (915, 673), (746, 1999) and (820, 160) mg/m^3, respectively, and the orthophosphate concentrations in the epilimnion and hypolimnion at R13, R16 and R25 were (508, 538), (509, 543) and (482, 515) mg/m^3, respectively.

[33] Pernica, P. & Wells, M. (2012). Frequency of episodic stratification in the near surface of Lake Opeongo and other small lakes. Water Quality Research Journal of Canada, 47(3–4): 227–237.
[34] Boehrer, B., Fukuyama, R. & Chikita, K. (2008). Stratification of very deep, thermally stratified lakes. Geophysical Research Letters, 35: 1–5.

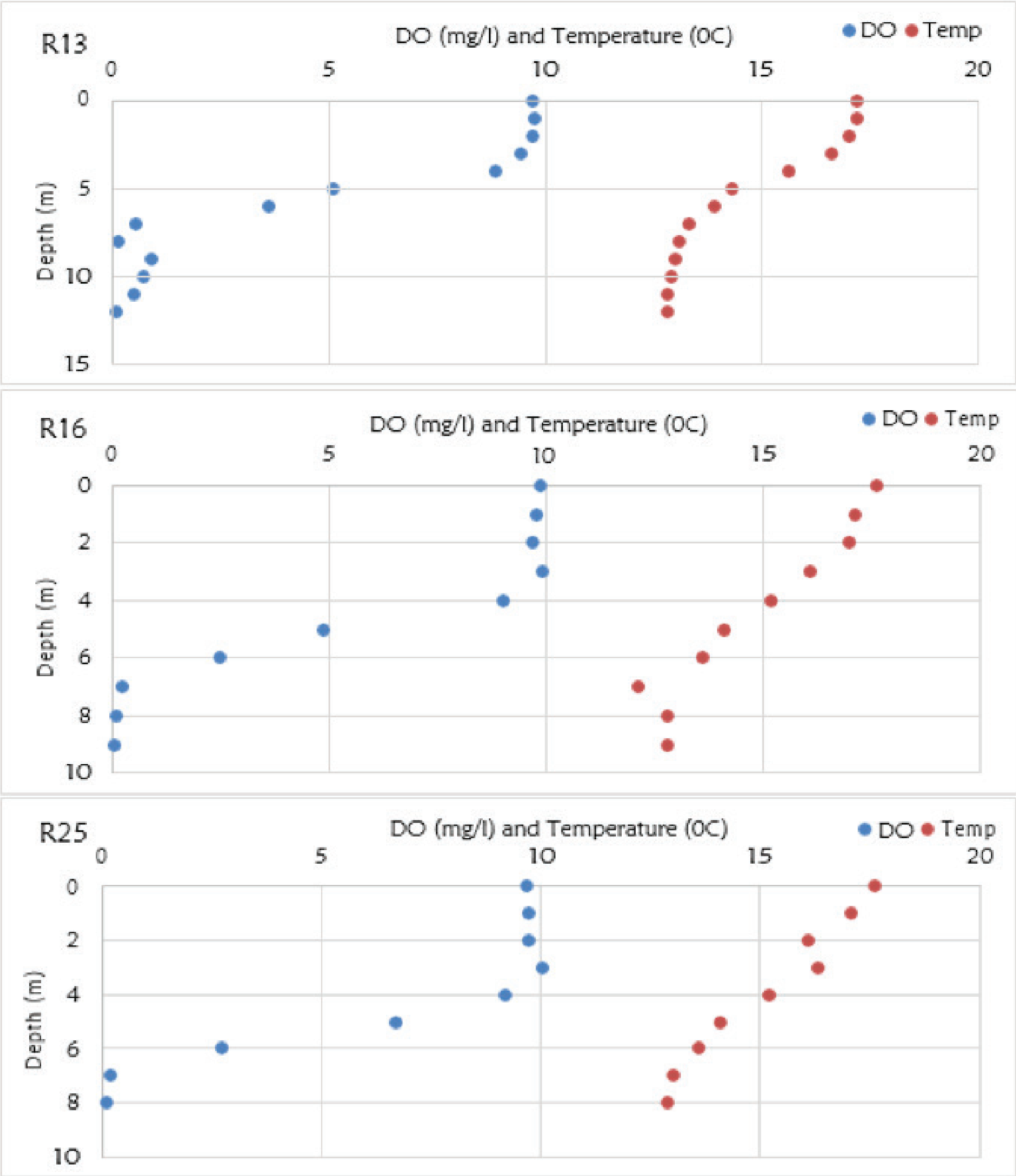


Figure 22 *Variation of dissolved oxygen and temperature with depth at three locations (R13, R16 and R25) during the winter pre-monsoon*

Precipitation of phosphate generally takes place at higher DO and pH values, and as the epilimnion has a basic nature and higher DO levels, the available phosphate (as orthophosphate) was lower compared with the available phosphate in the hypolimnion. Due to the prevailing reducing condition in the hypolimnion, the high values of orthophosphate indicated a high level of desorption of phosphate from sediments.

Table 7 Chemical characteristics of lake water at different depths at three different locations (R13, R16 and R25) during the winter pre-monsoon

Sample Location	DO (mg/l)	T (°C) (mg/m³)	SD (m)	NH3-N (mg/m³)	Nitrate (mg/m³)	TKN (mg/m³)	Total phosphate (mg/m³)	Ortho phosphate (mg/m³)
R13(E) (at 0.5 m)	9.7	17.2	4.72	0	0	1680	915	508
R13(T) (at 6 m)	3.6	13.9	-	1120	0	2800	551	527
R13(H) (at 12 m)	0.1	12.8	-	1560	0	2800	673	538
R16(E) (at 0.5 m)	9.9	17.6	5.1	0	177	2240	746	509
R16(T) (at 4 m)	9.0	15.2	-	0	35	840	1083	526
R16(H) (at 9 m)	0.04	12.8	-	0	0	840	1999	543
R25(E) (at 0.5 m)	9.7	17.6	5.37	0	0	1120	820	482
R25(T) (at 4 m)	9.2	15.2	-	1120	38	2240	1998	513
R25(H) (at 8 m)	0.1	12.9	-	2520	0	3640	160	515

During the summer post-monsoon, the thermal gradient got increased by 1.7°C/m, signifying a stronger thermal stratification during that season, with a slight increase in the depth of the epilimnion. During the winter pre-monsoon and summer post-monsoon, the surface water was apparently heated by radiation. Due to the contact with the atmosphere, mixing was usually driven by the wind, and so overturning was not found in the lake.

Table 8 Chemical characteristics of lake water at different depths at three locations (R13, R16 and R25) during the summer post-monsoon

Sample Location	ORP (mV)	DO (mg/l)	SD (m)	NH3-N (mg/m³)	Nitrate (mg/m³)	Total phosphate (mg/m³)	Ortho phosphate (mg/m³)
R13(E) (at 0.5 m)	-64	8.47	1.53	840	16.40	332	10
R13(T) (at 3 m)	-160	6.89	-	1120	12.45	228	167
R13(H) (at 5 m)	-286	0.44	-	840	16.05	321	143
R16(E) (at 0.5m)	-133	9.07	1.51	560	0.00	302	50
R16(T) (at 3 m)	-300	3.91	-	840	19.15	257	66
R16(H) (at 5 m)	-526	0.62	-	2520	19.00	418	249
R25(E) (at 0.5 m)	-42	8.89	1.44	1400	0.00	470	205
R25(T) (at 3 m)	-37	1.17	-	2520	0.00	158	102
R25(H) (at 5 m)	-118	0.03	-	1120	0.00	293	118

The variation in the water quality of the lake water with depth at different locations during the summer post-monsoon has been shown in Table 8. During the summer post-monsoon, the start of anoxic conditions were observed around 5m from the water surface at all the three locations. Hence samples were collected below this depth (characterised as the upper hypolimnion region), considering the poorer water quality beyond this depth. The condition was found to be highly reducing in the upper hypolimnion of the lake, much as in the hypolimnion layer of the winter pre-monsoon condition. The Secchi disk depth got significantly reduced during the summer post-monsoon as the number of large macrophytes increased in the lake during that season.

As the water body was observed to be stratified during both sampling periods, it could be safely concluded that Renuka Wetland is a permanently stratified water body, with the degree of stratification getting progressively higher during the summer post-monsoon compared with the winter pre-monsoon. The quality of water in the epilimnion, was however found to be better (with a low nutrient load) during the summer post- monsoon, while in the hypolimnion, the water quality remained almost constant during both the study periods.

SURFACE WATER QUALITY ASSESSMENT

The water quality (based on physico-chemical characterisation of collected water samples) showed that the water lay in a slightly alkaline range, with average pH values of 8.6±2.4 and 9.2±0.8 during the winter pre-monsoon and summer post-monsoon, respectively (Table 9). An increase in the mean surface temperature from 17±1.7°C in the winter pre-monsoon to 30°C in the summer post-monsoon was observed. The average DO concentration of the surface water during the winter pre-monsoon and summer post-monsoon was 8.4±3.0 mg/l and 8.5±1.6 mg/l, respectively. Low temperatures, high spread areas and wind currents are effective in maintaining the DO level of surface water (George, 1981)[35]. Despite the availability of oxygen, the average oxidation-reduction potential (ORP) of the lake surface water was found to be 6±328 mV (i.e., less oxidative) and -45±91 mV (i.e., reducing) during the winter pre-monsoon and summer post-monsoon, respectively. A positive correlation of ORP with DO during the winter pre-monsoon and a negative correlation during the summer post-monsoon were observed (Table 12).

The nitrogen concentration (as free ammonia and organic nitrogen) was used to explore the extent of organic pollution in the lake. During the winter pre-monsoon, free ammonia was absent, and the average concentration of the total Kjeldahl nitrogen in the surface water was 2.5±2.7 mg/l. This may be related to the nitrogenous organic pollution in the lake. In the summer post-monsoon, the average concentration of free ammonia in the surface water was 1.2±0.7 mg/l, which indicated recent organic pollution in the lake. The shift of ORP could also be related to the nitrogenous organic pollution during the summer post-monsoon. The average concentration of total phosphate was observed to be significantly high (considering its value, greater than 100 mg/m3, to have a high potential for creating a hypereutrophic condition in a lake) as 1870±1557 and 282±200 mg/m3 during the winter pre-monsoon and summer post-monsoon, respectively. Further, the average concentration of the available phosphate (orthophosphate phosphorus) was 524±47 mg/m3 (under reducing conditions, ORP 6±328 mV) and 108±120 mg/m3 (under reducing conditions, ORP -45±91 mV) in the winter pre-monsoon and summer post-monsoon, respectively.

The average chlorophyll-a concentration got reduced from 9510±12513 mg/m3 in the winter pre-monsoon to 241±231 mg/m3 during the summer post-monsoon. This reduced the average turbidity of the surface water from 8±11 to 3±1 NTU, respectively.

The increase in the surface temperature and water level of Renuka Wetland significantly affected the quality of the surface water during the summer post-monsoon. A 25% increase in the volume of water was observed from the analysis of the water level/depth data during the two seasons, which also indicates a possibility of dilution flows

[35] George, D. G. (1981). Wind-induced water movements in the South Basin of Windermere. Freshwater Biology, 11: 37–60.

being present (while also increasing the possibility of non-point contribution). Apparently the temperature-induced stratification increased the depth of the epilimnion (the photosynthetically active zone) and the thermal radiation escalated the microbial activity (thereby increasing the nutrient uptake). The observed increase in large macrophtes during the summer post-monsoon also had some role in improving the water quality.

Table 9 *Variation of physico-chemical parameters of the surface water of Renuka Wetland during the winter pre-monsoon and summer post-monsoon*

Parameters	Winter pre-monsoon (mean±SD; N=17)	Summer post-monsoon (mean±SD; N=26)
pH	8.6 ±2.4	9.2±0.8
Temperature (°C)	17.2±1.7	30.0
Electrical conductivity (µS/cm)	470±75	512±99
Oxidation reduction potential (mV)	6±328	-45±91
Dissolved oxygen (mg/l)	8.4±3.0	8.5±1.6
Turbidity (NTU)	8±11	3±1
Alkalinity (mg/l)	204±31	119±64
NH3-N (mg/l)	-	1.2±0.7
Nitrate (mg/l)	0.03±0.06	0.01±0.01
TKN (mg/l)	2.5±2.7	-
Total phosphate (mg/m3)	1870±1557	282±200
Orthophosphate (mg/m3)	524±47	108±120
Chl-a (mg/m3)	9510±12,513	241 ±231

SEDIMENT PHOSPHATE DYNAMICS DURING THE PRE-MONSOON AND POST-MONSOON

Unlike other elements, phosphate does not escape from the system but changes from one form to another, depending upon the prevailing physico-chemical conditions (Singh et al., 2019)[36]. Sediments in the lake systems have a dual role: they are the source as well as the sink of phosphate. Benthic sediments have generally much higher phosphate than that present in water, and the major physicochemical factors responsible for mobilization and fixation of phosphorus in lake sediments are temperature, pH and redox potential (Bostrom et al. 1988)[37]. Despite the reducing conditions during the summer post-monsoon season, the phosphate concentration in sediments was observed to increase as shown in Table 10. The concentration of phosphate in the sediments increased with decreasing concentration of phosphate in the water column from the winter pre-monsoon to the summer post-monsoon, quite like the relation between sediment-bound phosphate and phosphate in the water column reported by Singh et al. (2019)[36]. Thus, the precipitation followed by deposition of phosphate could apparently be related to the change in temperature and not the ORP of Renuka Wetland.

[36] Singh, P., Haritash, A. K. & Bagrania, J. (2019). Seasonal behaviour of thermal stratification and trophic status of palustrine water body. Applied Water Science 9:139.
[37] Boström, B., Andersen, J. M. & Fleischer, S. (1988). Exchange of phosphorus across the sediment–water interface. Hydrobiologia, 170: 229–244.

Table 10 Sediment characteristics in Renuka Wetland during winter pre-monsoon and summer post-monsoon.

Sample ID	WINTER PRE-MONSOON			SUMMER POST-MONSOON		
	Organic matter (%)	Organic carbon (%)	Phosphate (mg/m^3)	Organic matter (%)	Organic carbon (%)	Phosphate (mg/m^3)
R1	11.2	0.2	35,277	25.9	0.2	3,50,975
R9	23.5	0.2	1,17,812	19	0.2	7,13,421
R10	20.1	0.3	1,22,604	19.8	0.3	5,03,055
R13	15.3	0.3	2,57,100	18.8	0.2	8,71,517
R25	13.2	0.2	2,73,670	10	0.2	18,51,106

IMPACTS OF CATCHMENT CONTRIBUTION ON RENUKA WETLAND

Renuka Wetland has a catchment area of 3.58 km^2, which includes agricultural, barren, built-up and forest lands (Table 5). Apart from the forested area, downstream Renuka Wetland has a temple, hotel and ashram where a major point source of wastewater (it is known as the ashram point input) has also been noticed. The characteristics of the water and the sediment quality at the point input are shown in Table 11.

Table 11 Water quality parameters and sediment characteristics at ashram outlet and of springs/others

WATER QUALITY PARAMETERS										
	Sample ID	pH	ORP (mV)	DO (mg/l)	COD (mg/l)	TP (mg/m3)	Chl a (mg/m3)	OM (%)	OC (%)	TP (mg/m^3)
(a) Ashram outlet										
Winter pre-monsoon	R10	8.6	251	9	48	965	0	20	0.1	68
Summer post-monsoon	R10	9.6	-27	9.1	98	216	424	20	0.3	503
(b) Springs/others										
Winter pre-monsoon	R26	9	215	9	0	4983	0	-	-	-
Summer post-monsoon	R26	8.5	73	7.5	80	153	0	6	0.1	320
	R28	8.3	103	7.8	28	134	0	-	-	-

During the winter pre-monsoon, at the sampling location near the ashram (R10), the discharge meeting the lake has an alkaline pH, a positive redox potential, a high chemical organic demand, high total phosphate and chlorophyll concentrations, along with high organic content and low total phosphate concentrations in the sediments. However, during the summer post-monsoon, a negative redox potential and a high chemical oxygen demand prevails.

As mentioned in Chapter III (Assessment of Soil Erosion and Sediment Yield), the erodibility study revealed that the catchment soil has a high affinity towards sediment erosion. The water collected from the Dudhsagar spring (found flowing during both the monitoring periods) had no organic impurity but a high total phosphate concentration during the winter pre-monsoon and summer post-monsoon. There was an additional input (R 28) joining Renuka Wetland only during the summer post-monsoon (which apparently brought in the runoff from the catchment), indicating a high degree of erosion of nutrients from the catchment. To summarise, the ashram outlet (R 10) was observed to be contributing towards both the organic and nutrient loads. The other sources, viz., springs/others (R26 and R28), mainly contributed to the nutrient load flowing into Renuka Wetland. These observations primarily rule out any possibility of the non-point runoff from the Renuka Wetland catchment being a major contributor of an organic load, apparently due to a lack of dense habitations.

ASSOCIATION BETWEEN WATER QUALITY PARAMETERS

The Pearson's correlation coefficient, indicating inter-parameter associations, was estimated for different water quality parameters measured during the winter pre-monsoon and summer post-monsoon. The classification of positive and negative correlations was attempted on the same lines as done by Kumar et al. (2019)[38]. The correlation coefficients of various parameters during different seasons at Renuka Wetland are tabulated in Table 12.

During the winter pre-monsoon season, strong positive correlations of DO with pH and temperature; pH with temperature and ORP; nitrate with total phosphate; and chlorophyll with turbidity were observed, whereas during the summer post-monsoon no strong positive correlations were observed.

Table 12 *Correlation between several water quality parameters of Renuka Lake during (a) winter pre-monsoon and (b) summer post-monsoon*

a)	pH	Temp	ORP	DO	Turbidity	NO3-	TKN	TP	OP	Chl a
pH	1.0									
Temp	0.6	1.0								
ORP	0.6	0.3	1.0							
DO	0.8	0.8	0.4	1.0						
Turbidity	-0.1	-0.4	0.3	-0.5	1.0					
Nitrate	0.3	-0.2	-0.2	-0.1	0.0	1.0				
TKN	0.1	0.2	0.0	0.1	-0.1	-0.1	1.0			
TP	0.2	-0.2	0.3	-0.2	0.4	0.6	0.0	1.0		
OP	0.1	0.2	0.0	0.2	0.2	-0.3	0.1	0.2	1.0	
Chl a	-0.2	-0.4	0.1	-0.2	0.5	-0.3	-0.1	-0.2	0.1	1.0
b)	**pH**	**ORP**	**DO**	**Turbidity**	**SD**	**NH3-N**	**Nitrate**	**TP**	**OP**	**Chl a**
pH	1.0									
ORP	-0.5	1.0								
DO	0.2	-0.1	1.0							
Turbidity	-0.2	0.3	-0.1	1.0						
SD	0.2	-0.1	-0.1	-0.1	1.0					
NH3-N	0.0	0.0	0.1	-0.3	-0.4	1.0				
Nitrate	0.1	-0.1	-0.1	-0.3	-0.2	0.1	1.0			
TP	-0.3	0.1	0.1	-0.1	0.0	0.3	0.1	1.0		
OP	-0.1	0.2	0.2	0.0	-0.2	-0.2	0.1	0.1	1.0	
Chl a	-0.4	0.1	-0.3	-0.1	-0.4	0.2	0.2	0.0	-0.1	1.0

[38] Kumar, P., Meena, N. K. & Mahajan, A. K. (2019). Major ion chemistry, catchment weathering and water quality of Renuka Lake, north-west Himalaya, India. Environmental Earth Science, 78(319): 1–16.

TROPHIC STATUS DURING WINTER PRE-MONSOON AND SUMMER POST-MONSOON

Trophic State Index values for total phosphate (TSI-TP), chlorophyll (TSI-Chl), total nitrogen (TSI_TN) and Secchi depth (TSI-SD) were calculated for the surface water of Renuka Wetland. Further, an aggregated average, referred to as Carlson's Trophic State Index (CTSI), was calculated. It was observed that TSI-TP had the maximum value, followed by TSI-Chl, TSI-SD and TSI-TN during the winter pre-monsoon. TSI-Chl was minimum during the summer post-monsoon as shown in Table 13. The combined average CTSI was observed to be more than 70, apparently due to heavy algal blooms throughout the summer, often under a hypereutrophic state[31] during both study periods. The trend of average TSI of different parameters during the winter pre-monsoon and summer post-monsoon was TSI-TP>TSI-Chl>TSI-SD>TSI-TN. This may be attributed to zooplankton grazing and/or a limitation of nitrogen (Carlson 1977)[32]. On the basis of the physico-chemical characteristics, the lake water was observed to be rich in phosphate (more than 100 mg/m^3) and deficient in nitrogen (lower than 4000 mg/m^3). Although the Trophic State Index (TSI) due to phosphate was high, its CTSI values were lower than TSI-TP, indicating that eutrophication in the ecosystem is regulated by limited nitrogen and zooplankton grazing. The TN/TP ratio being less than 10 further strengthened our hypothesis of a nitrogen-limited eutrophic lake.

Table 13 *Trophic status index of Renuka Wetland water during the winter pre-monsoon and summer post-monsoon*

	TSI_SD	TSI_TP	TSI_Chla	TSI_TN	CTSI	Attribute
Pre-monsoon (mean±SD)	65±21	107±11	70±65	64±9	77±20	Heavy algal blooms possible throughout the summer, often hyper-eutrophic
Post-monsoon (mean±SD)	70±20	85±7	75±29	58±8	72±11	

The surface water quality was categorised on the basis of the trophic status index, and the different classes and their attributes are shown in Table 14. Sample locations R1, R3, R7, R12, RWA and R25 show a positive shift toward lower CTSI values; R2, R4, R5, and R6 show no shift in their CTSI values, but R8, R9, R10, R11, R13, R16, and R24 show a positive shift towards higher CTSI values. It could therefore be concluded that the water quality of the hypereutrophic zones showed seasonal variation in their CTSI values, but in the clearer water zones, a significant shift towards higher CTSI values were observed with changing seasons.

Table 14 *Spatial and temporal variations of CTSI*

CTSI	Winter pre-monsoon	Summer post-monsoon	Attribute (Devi Prasad et al. 2012)31
<50	-	RWA, RLS8, RLS18, RLS24, RLS25, RLS29	Water moderately clear, but increasing probability of anoxia during summer
50–60	R8, R9, R10, R11, R13, R16, R24	R25, RLS13, RLS28,	Lower boundary of classical eutrophy: Decreased transparency, warm-water fisheries only
60–70	RWA	R12, R13, R16, RLS36	Dominance of blue-green algae, algal scum probable, extensive macrophyte problems
70–80	R25	R1, R3, R7, R8, R9, R10, R11, R24, R27	Heavy algal blooms possible throughout the summer, often hyper-eutrophic
>80	R1, R2, R3, R4, R5, R6, R7, R12	R2, R4, R5, R6	Algal scum, summer fish kills, few macrophytes

The main source of nitrogen in surface water are human and animal excreta and agricultural activities. When nitrite and nitrate occur in large amounts in drinking water, they cause the Blue Baby Syndrome[39]. The nitrate level was 7.37±3.02, 0.04±0.09 and 0.07±0.04 mg/l in the winter pre-monsoon, the summer post-monsoon and the winter post-monsoon of 2020, respectively (Figure 23). In the winter pre-monsoon of 2020, the nitrate level was high due to mixing of sewage through seepage and decomposition of macrophytes and algae.

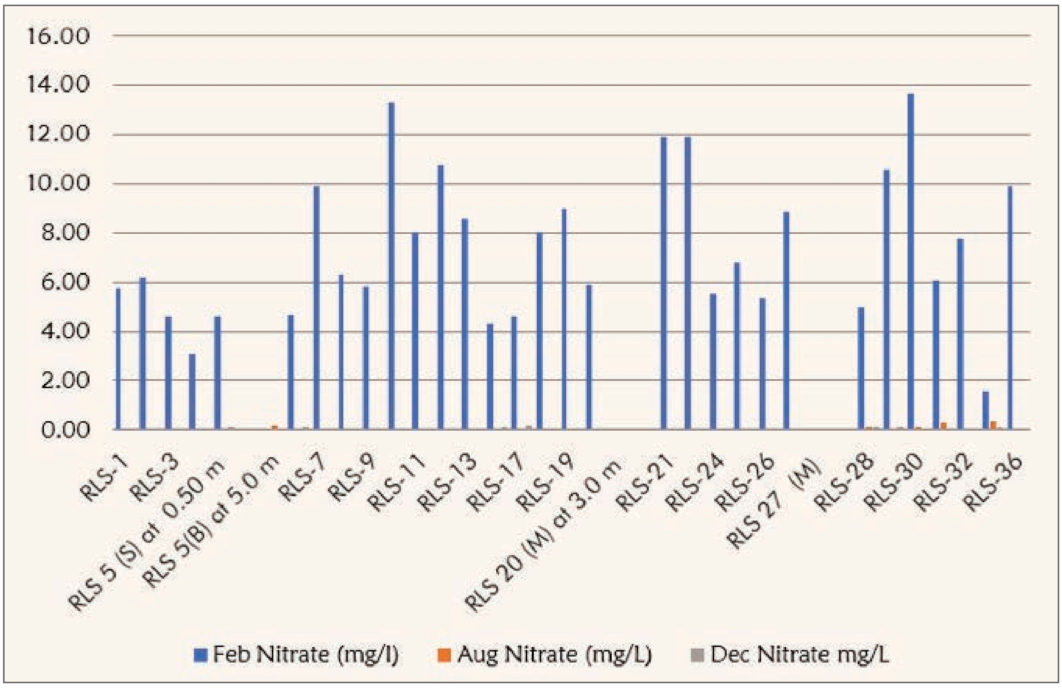


Figure 23 *Nitrate level in Renuka Wetland in different seasons*

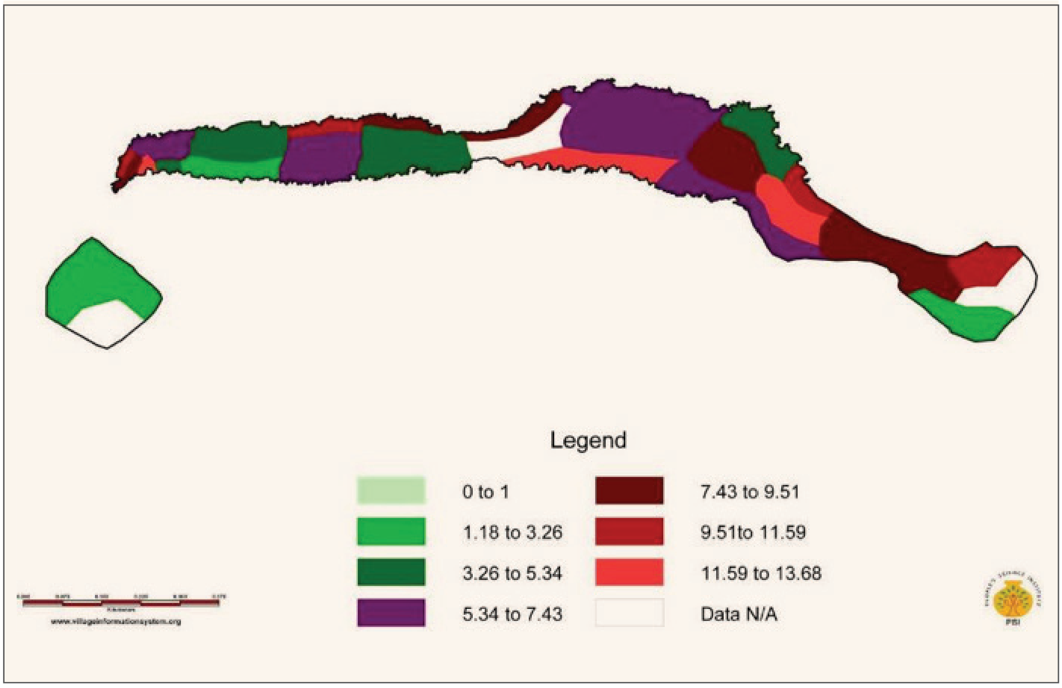


Figure 24 *Nitrate level in Renuka Wetland in the winter pre-monsoon of 2020*

[39] Basha, A. A., Durrani, M. I. & Paracha, P. I. (2010). Chemical characteristics of drinking water of Peshawar. Pakistan Journal of Nutrition, 9(10): 1017–1027.

The coliform group includes all the aerobic and facultative anaerobic Gram-negative, non-spore-forming rod-shaped bacteria. Coliform bacteria indicate the presence of disease-causing organisms in water. The average total coliform count was 300±191, 300±235 and 200±62 CFU/100 ml in the winter pre-monsoon, summer post-monsoon and winter post-monsoon of 2020, respectively (Figure 25). The TC was found to be much higher than the designated A category-prescribed limit of CPCB[40] (<50 CFU/100 ml).

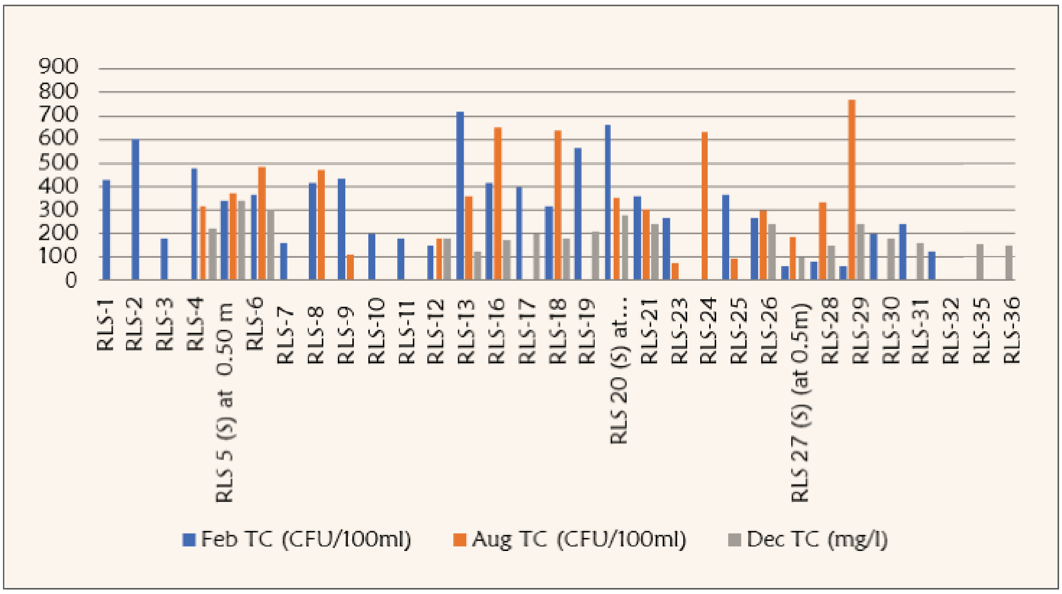


Figure 25 *TC in Renuka Lake in different seasons*

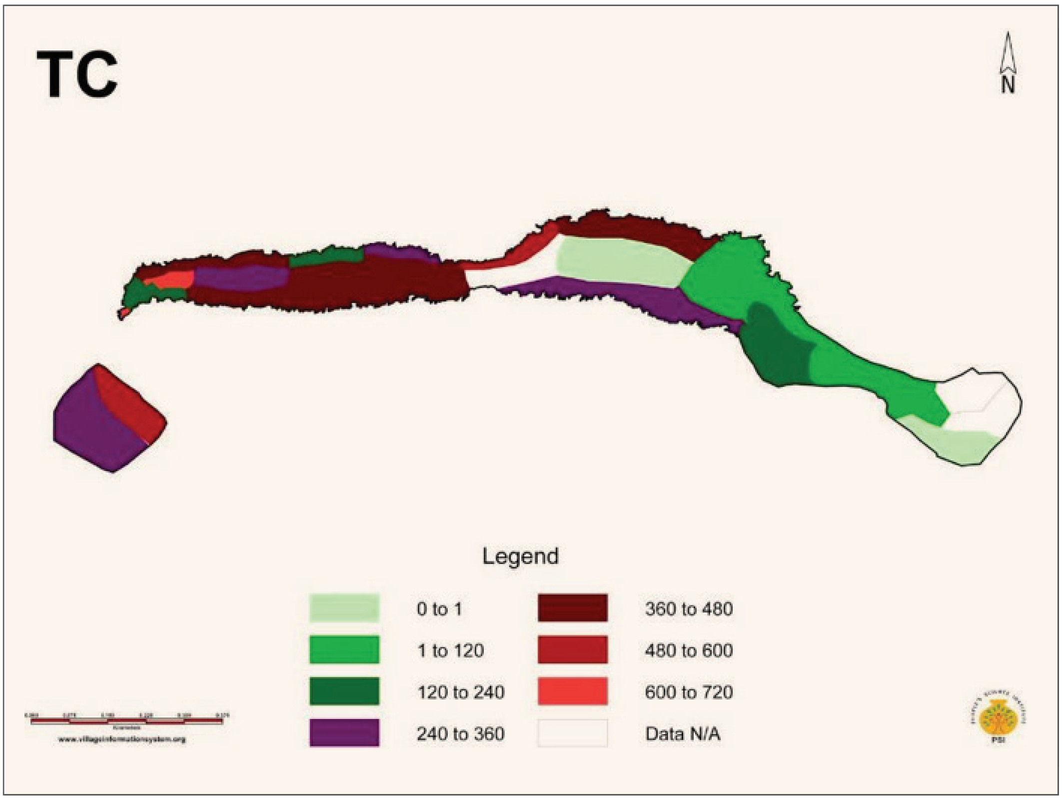


Figure 26 *Total coliform count in Renuka Lake in the winter pre-monsoon of 2020*

[40] CPCB. (1979). Standard for Surface Water Quality Criteria for Different Uses.

Faecal coliform bacteria exist in the intestines of warm-blooded animals and humans. The presence of faecal coliform bacteria or E. coli indicates contamination of water with faecal waste that may contain other harmful or disease-causing organisms, including bacteria, viruses or parasites such as Giardia, the cause of beaver fever. The average faecal coliform was 172±154, 153±174 and 73±65 CFU/100 ml in the winter pre-monsoon, summer post-monsoon and winter post-monsoon of 2020, respectively (Figure 28).

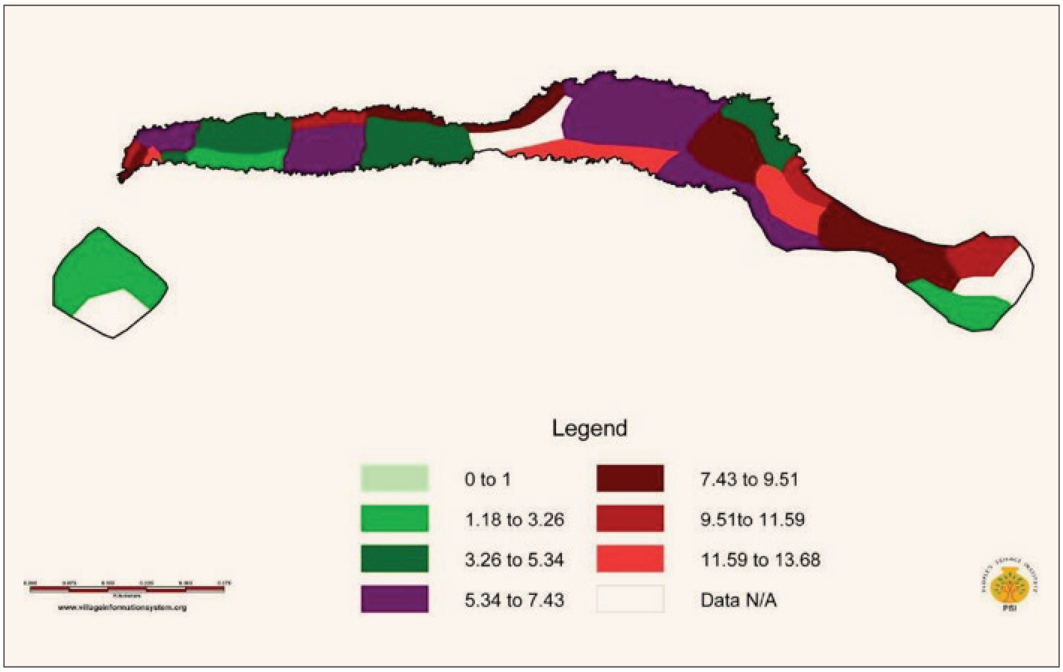


***Figure 27** Faecal coliform bacteria in Renuka Lake in the winter pre-monsoon of 2020*

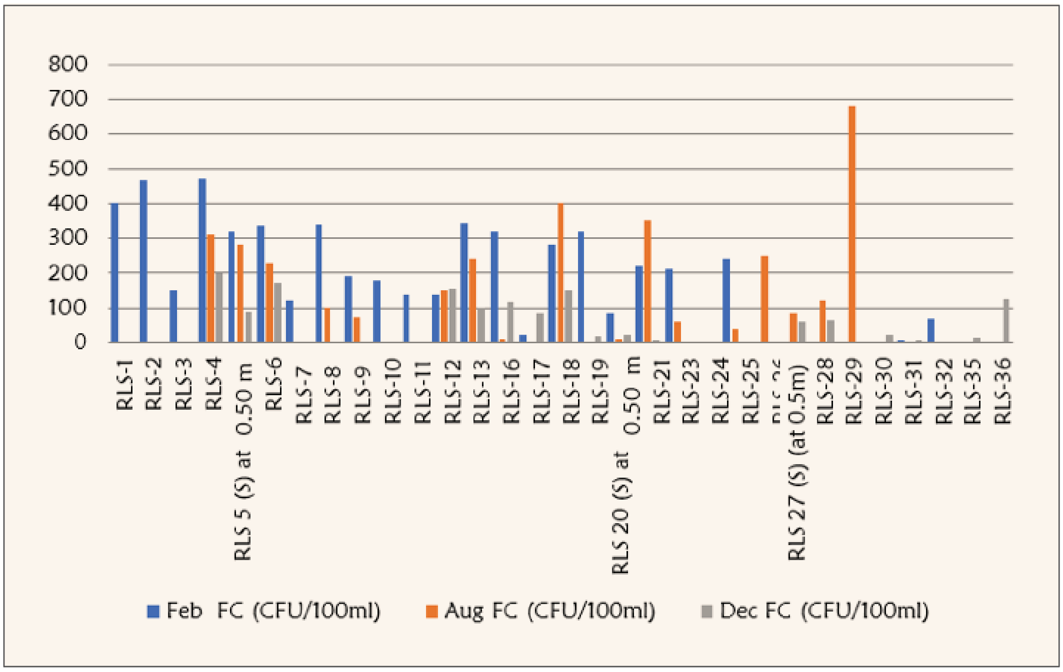


***Figure 28** FC in Renuka Lake in different seasons*

It was assessed that most of the physico-chemical parameters were within the prescribed limits. The nitrate level was higher in the winter pre-monsoon of 2020, which may be due to decomposition of vegetables and plants and agricultural activities around Renuka Lake. However, it was within the permissible limits. The presence of TC and FC in samples of Renuka Wetland indicate that sewage or human or animal excreta is entering the water body.

THE IMPACT OF RENUKA FAIR

Due to the Covid-19 pandemic, the Renuka fair was not organised in 2020 at the level at which it used to be held every year. Visitors were not allowed to enter the Renuka wetland complex, and bathing activity was prohibited. Therefore, it will not be representative to compare the two seasons' data in reference to the Renuka fair. However, the water quality data of the summer post-monsoon and winter post-monsoon of 2020 are shown in Figure 29 and Figure 30, which do not show any significant changes for the above-mentioned reason, except the DO and BOD. The BOD increased and DO decreased in the winter post-monsoon compared with the summer post-monsoon except the samples of RLS-35 and RLS-36. Those two samples were from the eastern flank of the lake and show the difference due to eutrophication (growth of weeds and macrophytes).

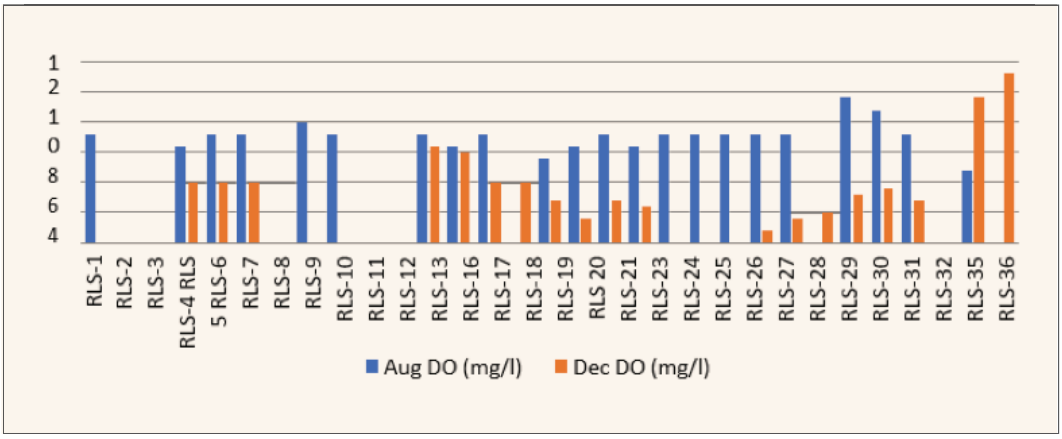


Figure 29 *Dissolved oxygen (mg/l) in the summer post-monsoon (pre-fair) and winter post-monsoon (after fair) of 2020*

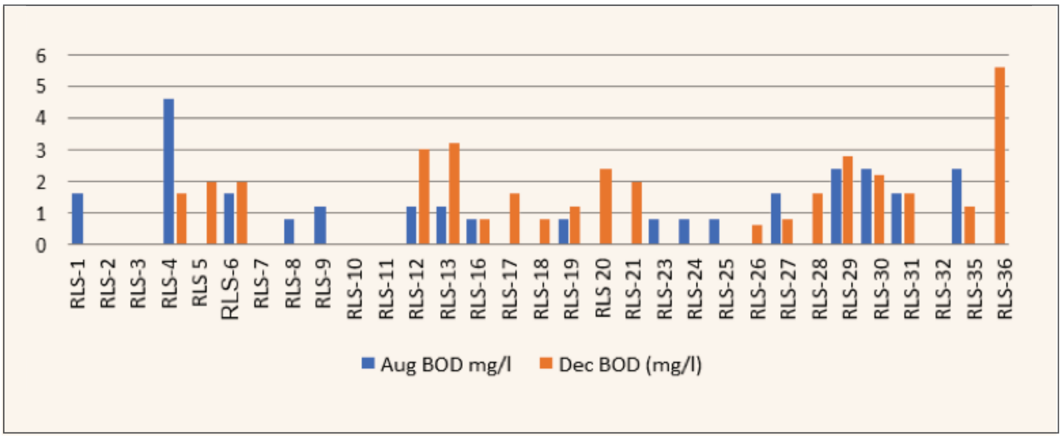


Figure 30 *BOD (mg/l) in the summer post-monsoon (pre-fair) and winter post-monsoon (after the fair) of 2020*

CONCERNS REGARDING DUMPING OF ANIMAL WASTES (EXCRETA) FROM ZOO

In the winter pre-monsoon of 2020, the total coliform colony counts were the highest at the outlet point of Renuka Wetland (RLS-13), while in the summer post-monsoon 2020, they were highest in the north-eastern part (RLS-29) of the wetland. In the winter post-monsoon of 2020, they were highest near the bathing ghat (RLS-5).

In the winter pre-monsoon and winter post-monsoon, the faecal coliform colony counts were highest opposite the bathing ghat (RLS-4), i.e., in the southern part of the wetland. In the summer post-monsoon, they were highest at the north-eastern part (RLS-29) of the wetland area. Overall, the TC and FC bacterial colony counts were higher in the summer post-monsoon compared with the winter pre-monsoon and winter post-monsoon. This may be due to mixing of surface runoff containing organic impurities in the lake during the monsoon. Therefore, it may be inferred that the sources of total coliform and faecal coliform bacteria may be the zoo, situated on the south-eastern extremity of the lake and bathing ghat (where the ashrams are also established). However, the wind pattern and surface runoff also play an important role in redistribution of coliform colonies and ions. Apart from this a further study is also required to differentiate the faecal coliform bacteria and faecal streptococci bacteria. Faecal streptococci bacteria indicate the penetration/presence of animal excreta in any water body, and so this will help us find out the actual source of the coliform bacteria, whether it is coming from human waste or animal excreta from the zoo.

BENTHIC MACRO-INVERTEBRATES

The term benthic means “bottom-living”, and the prefix macro indicates that these organisms are retained by a mesh size of ~20–25 mm and are visible to the naked eye. Benthic macro-invertebrates are common inhabitants of ponds, lakes and rivers. Benthic macro-invertebrates have a sedentary and long life span. They are sensitive to organic loading, thermal impacts, substrate alteration and toxic pollution[41].

Some macro-invertebrates, such as mayflies, stoneflies and caddis fly larvae, are sensitive or intolerant of toxins and of changes in stream conditions. These include changes in temperature and decreased concentrations of dissolved oxygen in water caused by pollution. Some organisms can move to more favourable habitats while others die or become unable to reproduce[45].

Macro invertebrates that can survive in polluted conditions, such as rat-tailed maggots and midge larvae, are known to be tolerant organisms. An organism is considered tolerant if it can survive in polluted conditions. Other facultative or semi-tolerant organisms (such as dragonfly and damselfly larvae) prefer a good stream quality but can survive in semi-polluted conditions[45]. These special characteristics of macro-invertebrates can give us reliable information about stream and lake water quality[42, 43]. Their long life cycles allow studies to be conducted by aquatic ecologists to determine any decline in environmental quality. The presence of pollution-tolerant species or a lower diversity indicates a polluted water body[44].

Hence, a bio-monitoring study was conducted in November 2020 to find the current situation of the water of Renuka Wetland. In this study, seven approachable sampling stations were selected and studied. The observations are discussed in the following.

ODONATA

The Odonata families identified were Gomphidae at B3 and B6, Aeshnidae at B3, B4, B6 and B7, Cordulegasteridae at B2 and B5, Lestidae at B4, Agriidae at B2, B4, B6 and B7, Corduliidae at B4, and Coenagriidae at B2 and B3. This group was not observed at B1 and B5. The occurrence of this order indicates that there is slight to moderate pollution in Renuka Wetland.

[41] Sharma, M. P., Sharma, S., Goel, V., Sharma, P. & Kumar, A. (2006). Water quality assessment of Behta River. Life Science Journal, 3(4): 68–74.
[42] Semwal, N. & Akolkar, P. (2006). Water quality assessment of sacred Himalayan rivers of Uttaranchal. Current Science, 91(4): 486–496.
[43] http://www.dnr.state.md.us/streams/pubs/ea99_2rev2003.pdf, 2003
[44] https://www.epa.gov/national-aquatic-resource-surveys/indicators-benthic-macroinvertebrates
[45] Macroinvertebrate Mayhem. (2010). Minnesota: USFWS Sport Fish Restoration

HEMIPTERA

Pleidaea and Belastomatidae species were present at B6 and B7, respectively.

HIRUDINEA

Glossiphoniidae species were observed at B1 and B3, but Erpobdellidae species were found only at B1.

CRUSTACEA

The only species of this order observed were Atydae species. These were observed only at B3.

COLEOPTERA

Species of Hydrophilidae were observed at B1, B5 and B7, and a Haliplidae species was observed at B3.

DIPTERA

Chironomidae species were identified at B1, B2, B5 and B7. Tipulidae species were found only at B5.

OLIGOCHAETA

Earthworms were found at B1 and B7.

MOLLUSCA

Species of the families Bithyniddae and Planorbidae were identified at all stations except B2. Unionidae species were identified at B2, B3, B5 and B6, Lymnaeidae species at B3 and B4, and Thiaridae species at B1, B3 and B5. Hydrobiidae and Viviparidae species were found only at B1 and B2, respectively.

Diversity Score (Sequential Comparison Index): The Sequential Comparison Index (SCI) is a measure of the distribution of individuals among groups of organisms. It was calculated using the following formula.

Resulting SCI = (Total no. of runs) / (Total no. of individuals)

Biomonitoring Working Party Site Score (BMWP Score): All possible families are classified on a score-scale of 1–10 according to their preference for saprobic water quality[46]. It was calculated using the following formula.

BMWP = (Grand total multiplied score) / (Grand total number of families encountered)

Diversity Index: From this procedure the biodiversity is assessed with the help of the Shannon-Weiner Index.

$$H' = -\sum [p_i \log_2 p_i]$$

where, H′=Diversity Index, Pi=ni/N, ni=number of individuals in each group, and N= total number of individuals in the sample

Table 15 *Categorisation of Diversity Index by Shannon-Weiner Index*

SHANNON-WEINER INDEX	DIVERSITY INDEX
>3.5	10
3.0–3.5	8
2.5–3.0	6
2.0–2.5	4
<2.0	2

[46] http://cpcbenvis.nic.in/newsletter/bio-mapping-march1999/march1999.htm. (n.d.).

Table 16 Saprobic score (BMWP), Sequential Comparison Index (SCI)

Location	Latitude	Longitude	BMWP	SCI	Class	BWQC
B1	30°36′33.9″N	77°26′59.8″E	4.20	0.74	C	Moderate pollution
B2	30°36′33.3″N	77°27′37.0″E	5.60	0.52	C	Moderate pollution
B3	30°36′34.5″N	77°27′06.4″E	5.20	0.70	C	Moderate pollution
B4	30°36′24.6″N	77°27′53.7″E	6.67	0.68	B	Slight pollution
B5	30°36′37.6″N	77°27′03.5″E	5.17	0.89	C	Moderate pollution
B6	30°36′35.1″N	77°27′43.0″E	6.50	0.57	B	Slight pollution
B7	30°36′30.1″N	77°27′53.3″E	4.75	0.63	C	Moderate pollution

Table 17 Diversity index values

Sampling Stations	Biodiversity (H')	Evenness (J)
B1	1.85	0.80
B2	1.30	0.81
B3	2.11	0.91
B4	1.79	0.82
B5	1.66	0.93
B6	1.49	0.72
B7	1.80	0.86
Avg H'	1.71	0.84

Table 18 Guidelines for classifying water quality (CPCB)[47]

S. No	Taxonomic Groups	Range of Saprobic Score	Range of Diversity Score	Water Quality Characteristic	Water Quality Class and Indicator Colour
1	Ephemeroptera, Plecoptera, Trichoptera, Hemiptera, Diptera	7 and more	0.2–1	Clean	A
2	Ephemeroptera, Plecoptera, Trichoptera, Hemiptera, Planaria, Odonata, Diptera	6–7	0.5–1	Slight pollution	B
3	Ephemeroptera, Plecoptera, Trichoptera, Hemiptera, Odonata, Crustacea, Mollusca, Polychaeta, Coleoptera, Diptera, Hirudinea, Oligochaeta	3–6	0.3–0.9	Moderate pollution	C
4	Mollusca, Hemiptera, Coleoptera, Diptera, Oligochaeta	2–5	0.4 and less	Heavy pollution	D
5	Diptera, Oligochaeta, no animals	0–2	0–0.2	Severe pollution	E

[47] de Zwart, D. & Trivedi, R. C. (1995). Manual on Integrated Water Quality Evaluation. Central Pollution Control Board.

The benthic macro-invertebrate study was carried out by identifying the species and calculating the SCI, BMWP score and Diversity Index. The absence of the most sensitive species (of the orders Ephemeroptera, Plecoptera and Trichoptera) and the occurrence of various tolerant species of the phylum Mollusca and order Diptera indicate the extent of pollution in Renuka Wetland. It is alarming that sewage or faecal coliform bacteria are reaching the water body through either seepage or the runoff from the area around the lake. The Sequential Comparison Index (SCI) value ranges from 0.52 to 0.89 and the BMWP score ranges from 4.20 to 6.67 (Table 17, Figure 31 and Figure 32). The observed SCI and BMWP scores were compared with the classification of Table 2.2, and it was observed that Renuka Wetland has slight to moderate pollution and falls in categories B and C (Table 17). The diversity index was calculated using the Shannon-Weiner biodiversity index (Table 15), which revealed that the average diversity of Renuka Lake was less than 2, indicating poor diversity.

Image 8 *Macro-invertebrates at B1*

Image 9 *Macro-invertebrates at B2*

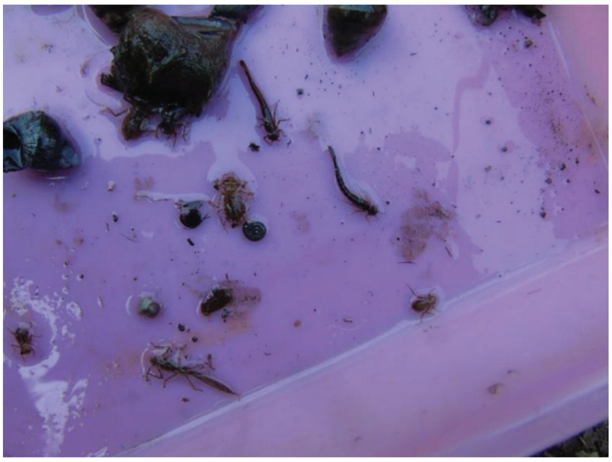


Image 10 *Macro-invertebrates at B4*

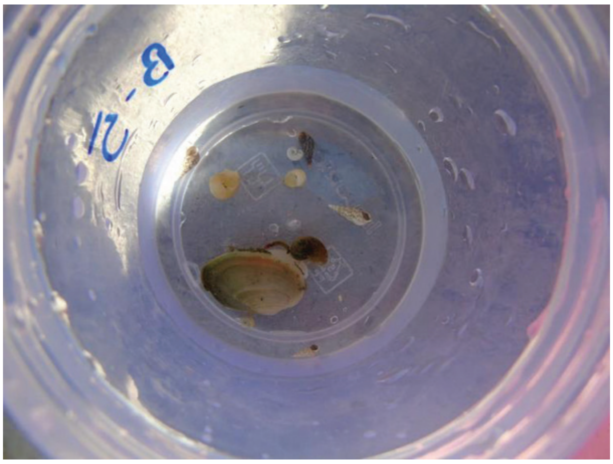
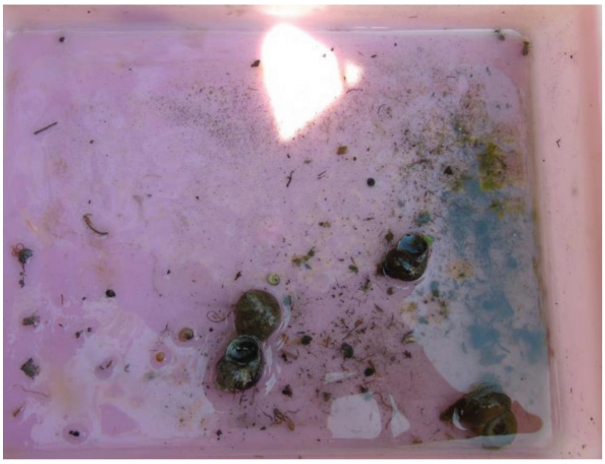


Image 11 *Macro-invertebrates at B5*

Image 12 Macro-invertebrates at B6



Imageh 13 Macro-invertebrates at B7

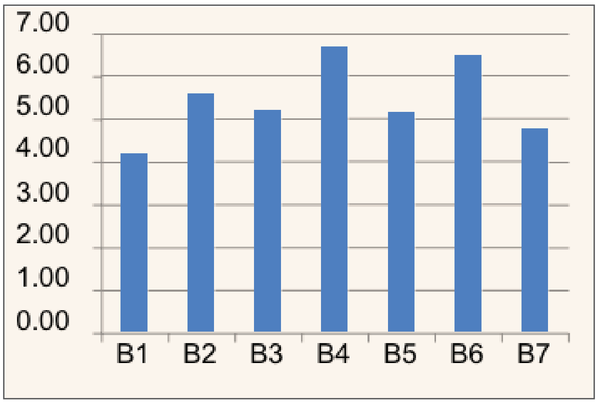


Figure 31 *Average Saprobic score (BMWP) of Renuka Lake*

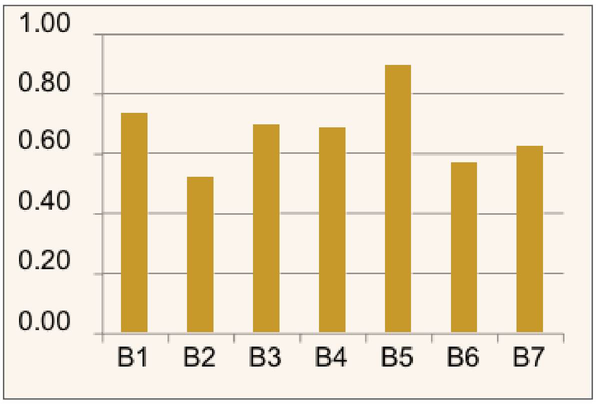


Figure 32 *SCI of Renuka Lake*

MACROPHYTES IN RENUKA WETLAND

Wetlands are transition areas between land and water compartments that are essentially characterized by shallow water overlying waterlogged soil as well as interspersed emergent, submerged or floating macrophytes (Kumar, 2018)[48]. Natural wetlands serve as kidneys of the earth and play a significant role in improving the water quality and removing pollutants of concern (Brix, 1994)[49]. The major mechanisms involved in pollutant removal are generally sedimentation, absorption by the aquatic macrophytes and adsorption on the root surface.

Aquatic macrophytes are also known as hydrophytes. They are the key components of the wetlands and play a significant role in wetland ecosystems. Being the primary producers, they provide food to invertebrates, fishes, birds and other aquatic organisms and organic carbon to the bacterial community. They also provide attachment sites alongwith shelter for amphibians and reptiles and breeding grounds for fishes. The leaves and roots provide substrate for periphyton. The macrophytes transport approximately 90% of the oxygen available in the rhizosphere which stimulates both aerobic decomposition of organic matter and promotes the growth of nitrifying bacteria. Macrophytes also reduce the velocity of water currents in wetlands, aiding in preventing erosion. It has been often found that macrophytes have a major impact on the biogeochemical processes in the water and soil compartments of a wetland and hence they are regarded as important. Moreover, through their abundance and diversity they contribute to humans directly or indirectly, by providing resources such as water or food or maintaining the environment (Liu et al., 2020).[50].

[48] Kumar, R. (2018). Economic valuation of wetlands: Overview. The Wetland Book: I: Structure and Function, Management, and Methods. https://doi.org/10.1007/978-90-481-9659-3_296
[49] Brix, H. (1994). Functions of Macrophytes in Constructed Wetlands. Water Sci Technol (1994) 29 (4): 71–78.
[50] Liu, J., Dong, B., Cui, Y., Zhou, W. and Liu, F. (2020). An exploration of plant characteristics for plant species selection in wetlands. Ecol. Eng., 143: 105674.

Aquatic macrophytes include aquatic spermatophytes, pteridophytes and bryophytes. They are generally classified as (i) emergent macrophytes (e.g., Typha latifolia, Phragmites australis), (ii) floating leaved macrophytes (e.g., Nuphar luteum), (iii) free floating macrophytes (e.g., Eichhornia crassipes) and (iv) submerged macrophytes (e.g., Myriophyllum spicatum). Their efficiency in accumulating nutrients and water pollutants vary with the plant species and its abundance.

Macrophytes consist of taxonomically different groups. They affect the food web dynamics, affecting the flora and fauna of the wetland in any particular season (Srivastava et al., 2008)[51]. The nutrient availability affects a wetland ecosystem and alters the presence or absence of plant species. Monocultures and multispecies ecosystems have different nutrient cycling and food web dynamics. The roles of macrophytes and sediment microorganisms in wetland ecosystems are closely connected. Wetlands, in association with all biotic and abiotic factors, sustain a diverse group of organisms and functions (Rejmánková, 2011)[52].

The present study comprises of identifying the significant macrophytes in Renuka Wetland. Field visits were conducted during the Winter pre-monsoon and in November 2020) for the dominant species. The abundant macrophytes of the eutrophicated region (Figure 33 and Figure 34) were observed and noted. Specimens were collected in zip pouches after washing with the wetland water itself. For some macrophytes that possessed stout root structures, a plant cutter was used to separate the specimen from the anchorage zone. Photographs were taken on-site and assigned particular ID to avoid confusion with others. For some macrophytes such as Phragmites, separate zip pouches were used for shoot and root structures. Some macrophytes such as Potamogeton, Azolla, Lemna, Colocasia and Nelumbo are commonly found in Indian wetlands.

- ***SIGNIFICANCE OF WETLAND MACROPHYTES***

Plants in wetlands have multiple roles. Plants serve as the primary producers in the food chain of a wetland ecosystem. Plants are crucial in the biogeochemical cycling of nutrients through the wetland system and can even affect the physical form of the wetland according to the biogeochemical processes. They play a pivotal role in the formation of habitats for both micro and macro-organisms, ranging from bacteria through higher vertebrates. Plants provide many ecosystem services, not just to the immediate wetland area but also to the larger area of the watershed. They even provide services that can be impactful at the global level, depending on the scale of the wetland (Deka and Sarma, 2014)[53].

Plants, especially woody species, sequester carbon in their tissues. This carbon is largely in the form of lignin and cellulose, both of which are slow to degrade, thus increasing the carbon retention time in woody plants. Carbon sequestered by plants accumulates in decayed plant matter (peat). Wetland conditions are favourable for the accumulation and slow degradation of organic carbon because of the prevalence of anaerobic conditions resulting either due to standing water or saturated soil conditions. Plants function as a carbon scavenger by fixing atmospheric carbon dioxide for producing biomass. As portions of the plant die, they are cycled down through the water column, where they break down slowly due to anaerobic conditions. Just as plants are able to sequester carbon, it is also possible for them to scavenge other elements and serve as sinks. Some plant nutrients, such as nitrogen and phosphorus, that are limiting in many non-anthropogenically modified ecosystems, are generally abundant to the point of being pollutants in urban runoff.

Plants are widely and traditionally valued for their aesthetic appeal (Misra et al., 2012)[54]. Factors such as shape, form, and colour greatly affect the perception and preference of plant species. Commonly, plants with unusual forms, bright colours or prominent flowers are viewed as having high aesthetic appeal. Plants can thus also contribute to the overall experience of the observer..

[51] Srivastava, Jatin & Gupta, Amit & Chandra, Harish. (2008). Managing Water Quality with Aquatic Macrophytes. Reviews in Environmental Science and Bio/Technology. 255–266. 10.1007/s11157-008-9135-x.
[52] Rejmánková, E. (2011). The role of macrophytes in wetland ecosystems. 34: 333–345.
[53] Deka, U. & Sarma, S. K. (2014). Present status of aquatic macrophytes of the wetlands of Nalbari District of Assam, India. Asian Journal of Plant Science and Research, 2014, 4(3):67-75.
[54] Misra, M. K., Panda, A. & Sahu, D., (2012). Survey of useful wetland plants of South Odisha, India. Indian Journal of Traditional Knowledge (IJTK) 11: 658–666

• CLASSIFICATION AND CHARACTERISTICS OF AQUATIC MACROPHYTES IN RENUKA WETLAND

A difference in plant community structure was observed during the winter pre-monsoon and November visits. Potamogeton was dominant in the eutrophic region during November, replacing Azolla that initially formed a red mat-like structure in the eutrophicated zone during the winter pre-monsoon. The area with Potamogeton allowed the association of Sparganium species on the fringes of the wetland, wheras the silted/sedimented zone was dominated by Alternanthera species, and the area that was waterlogged had Azolla. Azolla was the dominant species during the winter pre-monsoon in the eutrophicated region. On the first visit, Nelumbo (Common Lotus) was not present at all, whereas Najas species were observed during both the field visits. Bryophytes and pteridophytes were noted in the vicinity of the wetland, representing the lower groups of aquatic macrophyte. Populations of Phragmites were present in the peripheral region as well as in the transition area between the eutrophicated and non-eutrophicated zones. They have roots that are runners holding another turf of the species. Boating was difficult as the Najas species formed a network of mesh that marked the beginning of the eutrophicated area. Therefore, it was important to note the latitudes/longitudes as reference points all along the eutrophicated region. The points were noted by moving along the infestations caused by the macrophytes. Figure 33 and Figure 34 show the macrophyte-infested area in the Renuka Wetland. The extent of the eutrophicated zone was approximately 3.46 ha on the first visit, compared with 5.39ha (4.15 ha under Potamogeton and Alternanthera species and 1.24 ha under Najas, Nelumbo, Hydrilla and Phragmites species) during the second visit.

Eutrophic Area Determination for Renuka Lake
1st Visit: 26/02/2020

1st Patch: Red, Area: 34609.702 m^2 (3.46 Ha)   Total Area: 175788.421 m^2 (17.57 Ha)

Figure 33 *Eutrophicated zone in the Renuka wetland (mainly dominated by Azolla and Najas spp.)*

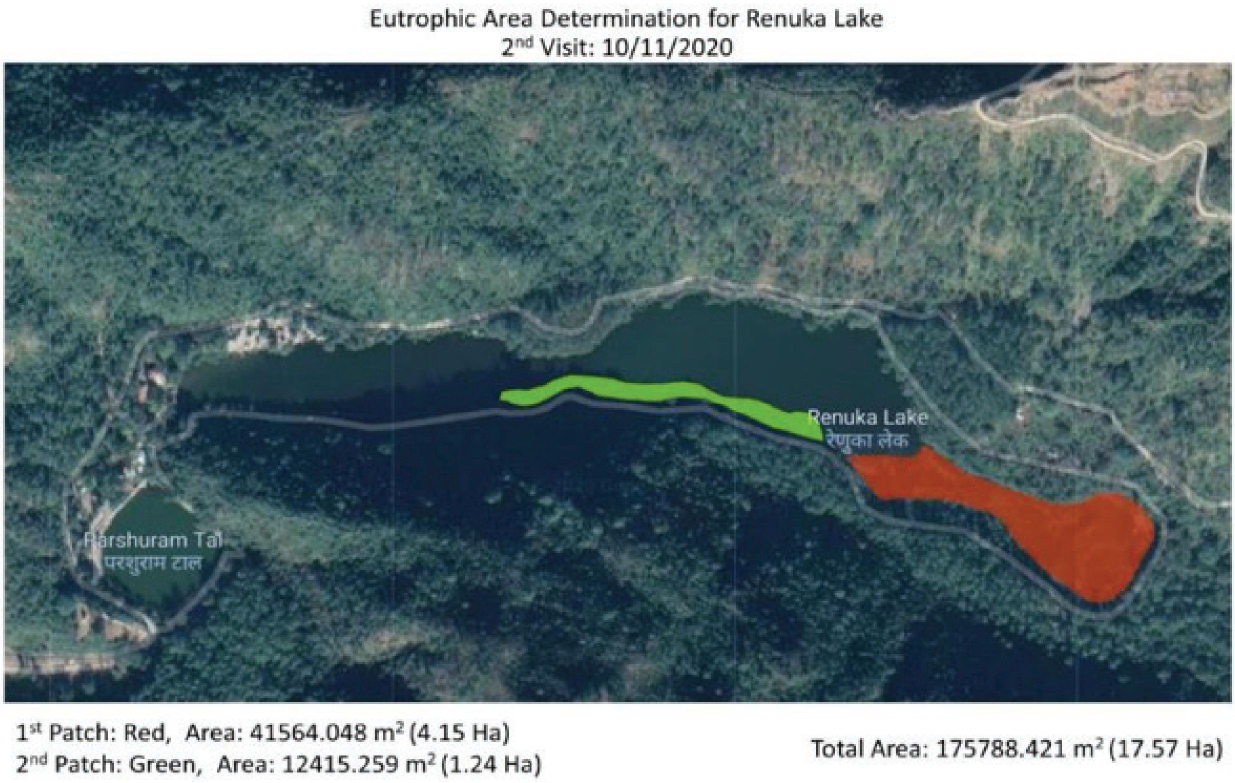


Figure 34 *Eutrophicated zone in the Renuka wetland (mainly dominated by Potamogeton, Alternanthera, Azolla and Najas (red patch) and Phragmites, Hydrilla and Nelumbo (green patch))*

DETAILS OF IDENTIFIED SPECIES

1. Potamogeton species

Classification

Kingdom:	Plantae – Plants
Subkingdom:	Tracheobionta – Vascular plants
Superdivision:	Spermatophyta – Seed plants
Division:	Magnoliophyta – Flowering plants
Class:	Liliopsida – Monocotyledons
Subclass:	Alismatidae
Order:	Najadales
Family:	Potamogetonaceae – Pondweed
Genus:	*Potamogeton*
Species:	*natans, epihydrus*

Description

During the field visit (November) to Renuka Wetland, the eutrophicated region was infested with *Potamogeton natans*, replacing *Azolla pinnata,* which had been recorded during the first visit, on February 2020. Two species of *Potamogeton* were identified, namely *P.natans* (Floating-leaf Pondweed) and *P.epihydrus* (Ribbon-leaf Pondweed). Both the species belong to the family Potamogetonaceae and were identified by the type of leaf. They are generally dominant in eutrophicated wetlands and demonstrate a high potential for heavy metal accumulation. They are even use in constructed wetlands for remediating wastewater containing cobalt, cadmium and manganese (Rashid et al., 2016)[55].

[55] Rashid, I., Ara, R. & Andrabi, S. M. A. (2016). Heavy metal accumulation in the leaves of Potamogeton natans and Ceratophyllum demersum in a Himalayan Ramsar site: Management implications. Wetl. Ecol. Manag. 24: 469–475. https://doi.org/10.1007/s11273-015-9472-9

They are characterised by good adaptability, relatively high growth rates and resistance to abiotic stress. The aquatic macrophyte is a perennial rhizomatous herb producing narrow, compressed, unspotted stems, up to 1 m long, that are unbranched or sparingly branched, generally with two types of leaf: (i) floating leaves, similar to the floating leaves of other *Potamogeton* species, which are petiolate and opaque, and up to 8 cm long and 3 cm wide; and (ii) submersed leaves, which are sessile and 5–25 cm long, 0.1–1 cm wide, translucent, linear in shape and ribbon-like, and red-brown to light green in colour, with a blunt to acute tip. The inflorescence is a small spike of flowers that arises from the water on a peduncle 1.5–5 cm (rarely, up to 16 cm). The floating leaves are firm, green, elliptic, 1 to 3+ inches long, up to 0.75 inches (2 cm) wide, toothless, rounded to bluntly pointed at the tip, tapering at the base to a stalk up to 1.5 times as long as the blade but often shorter than the blade. Submersed leaves are alternate on opposite sides of the stem (2-ranked), bright green to reddish, linear, and ribbon-like, 2 to 8 inches long, 2 to 10 mm (to 3/8 inch) wide, bluntly to sharply pointed at the tip, and stalkless. The mid-vein is flanked by several narrow rows of large, empty cells (known as the lacunar band), giving leaves a three-striped appearance, the central stripe more translucent than the edges and about 1/3 the leaf width. *P.gramineus, P.nodosus, P.perfoliatus* and *P.bicupulatus* are examples of hybrid species of *Potamogeton.*

Reproduction of pondweeds occurs both vegetatively and by seed and fruits, which may be produced in large quantities from mid-summer onwards, are ingested by waterfowl. Vegetative propagation occurs by a variety of mechanisms including growth from turions (vegetative buds) and via the growth and fragmentation of rhizomes and shoots. Plants of this genus are found in lakes, ponds and ditches, especially on a highly organic substratum, usually in water less than 1 m deep. It is a perennial aquatic species that grows fast up to 1 m. It flowers from May to September. The flowers are hermaphrodite and are pollinated by wind. The genus tolerates a wide range of soil textures and pH and even grows luxuriantly in highly acid or alkaline soils. Although they occur in a range of environments, most species prefer standing or slow-flowing waters with some calcium and fairly low nutrient levels. In general, the fine-leaved species are more tolerant of human impacts such as eutrophication. They are important as food and habitats for animals including insect larvae, water snails, ducks and other waterfowl and aquatic mammals such as beavers. In relation to the ecosystem, *Potamogeton* is often a common habitat for insects. For example, *C.annularius* and other insects from the genus *Chironomus* have been found to inhabit and mate around certain species of *Potamogeton.* The closeness to a fresh water source as well as cover from predators allows *C. annularius* to thrive.

Dense cylindrical spike held above the surface of the water, 0.5 to 2 inches (to 5 cm) long at the tip of the stem and arising from the axils of floating leaves. Spikes have 5 to 12 whorls of flowers, each flower with a 4-parted style surrounded by 4 stamens, each stamen with a green to orange- brown, ladle-shaped, sepal-like appendage. Turions are not produced. Glands at the leaf nodes are mostly absent. *P.cayugensis, P.claytonii, P.nuttallii, P. pennsylvanicus, P.pumilus,* and *P.purshii* are some species of Potamogeton. Ribbon-leaf Pondweed is usually abundant in the shallow, quiet waters of freshwater lakes and pond margins, most often in mucky substrates, less often in deeper or flowing water. It is distinguished by elliptic floating leaves up to 3 inches long, tapering at the base (not rounded), rounded to bluntly pointed at the tip, on stalks not much longer than the blades (often shorter); submersed leaves strongly 2-ranked, stalkless, flexible and ribbon-like, 2 to 8 inches long, up to 10 mm (3/8 inch) wide, appearing three-striped with a broad lacunar band along each side of the mid-rib, the central stripe totalling about 1/3 the leaf width. The floating leaves are sometimes absent, especially in deeper water.

2. Azolla pinnata

Classification

Kingdom:	Plantae - Plants
Subkingdom:	Tracheobionta - Vascular plants
Division:	Pteridophyta - Ferns
Class:	Filicopsida
Order:	Hydropteridales
Family:	Azollaceae - Azolla family
Genus:	*Azolla*
Species:	*pinnata*

Description

This species is aquatic and native to India. It is found floating on the surface of water bodies that are generally quiet. It does not show any movement. It has a fast growth rate and doubles its biomass in 1.9 days. It is a small fern with triangular fronds that measure up to 2.5 cm, and has rounded or angular overlapping leaves, each 1 or 2 mm long. They are usually green, bluish green or dark red in colour, with a velvety appearance, with tiny hairs. The hairs make the top surface of the leaf water-repellent, keeping the plant afloat even when it is pushed down. The leaves contain Anabaena azollae, a cyanobacterium that is a symbiont with the ability of fixing nitrogen from the atmosphere. It gives the fern the ability to grow in habitats that are low in nitrogen. This fern is an invasive weed that reproduces vegetatively, when branches break off the main axis, or sexually, when sporocarps on the leaves release spores. It becomes especially abundant in water with high nutrient levels, such as ponds and wetlands, where it can completely cover the water's surface. It can block sunlight from reaching submersed plants and can also reduce oxygen levels in the water by blocking the interface between the water surface and the atmosphere. Azolla can survive on moist soil in and around rivers, ditches and ponds. It can also survive during dry periods. The plant has the ability to absorb a certain amount of heavy metal pollutants, such as lead, from polluted water. It is considered to be the smallest fern and to have the capacity to alter the aquatic environment. Azolla pinnata dies in the summer heat, and the decaying plants release nitrogen to the soil. The species can quickly spread to cover open areas of water. It forms dense surface mats that impede water flow, navigation and clog irrigation pumps. The mats also reduce oxygen levels and the light available to other aquatic organisms. Vegetative reproduction is by dispersal of basal branches that themselves form pinnate branches and break off the main stem. Azolla has high tolerance to pollutants (nutrients) and hyper-accumulates heavy metals such as zinc, chromium, cadmium, mercury and arsenic. It has been used for ages as a biofertilizer for wetland paddy and is used to control mosquito larvae in rice fields. The plant grows as a thick mat on the surface of the water, making it more difficult for the larvae to reach the surface to breathe, thereby effectively choking the larvae.

3. Nelumbo nucifera

Classification

Kingdom:	Plantae - Plants
Subkingdom:	Tracheobionta - Vascular plants
Superdivision:	Spermatophyta - Seed plants
Division:	Magnoliophyta - Flowering plants
Class:	Magnoliopsida - Dicotyledons
Subclass:	Magnoliidae
Order:	Nelumbonales
Family:	Nelumbonaceae - Lotus-lily family
Genus:	*Nelumbo*
Species:	*nucifera*

Description

Generally known as Lotus, Bean of India, Egyptian Bean or simply Water Lily, this species belongs to the family Nelumbonaceae. *N.nucifera* has potential for use in wastewater treatment for removal of heavy metals (copper, cadmium, arsenic), nutrients (generally phosphates) and other pollutants. It grows in variable water conditions and even in eutrophic water. The leaves float, thereby reducing the sunlight that penetrates the water. This suppresses algal growth. The plant is a perennial aquatic herb, flowering during July–September. The fruits ripen during November and December. The roots are adventitious, and the leaves are solitary, stipulate, simple suborbicular, dark green above, paler beneath, with lamina ca. 20–80 cm across and petioles 2 m long. Flowers solitary on long, peduncles, ca. 8–25 cm across, rose-pink or white, expanding and emerging above water; sepals ca. 1.5–2.5 × 0.5–0.6 cm, linear-elliptic, concave, obtuse, with midrib distinct near apex and produced into a 3–5 cm long tail, greenish purple outside, purplish inside; corolla shorter than sepals, green outside, purplish inside, lobes broadly or narrowly oblong; inner stamens ca. 2–2.5 mm long, fertile, incurved. Fruit berry, ca. 1–1.5 cm across. Seeds are globose, approximately 1 mm across, brown, spinulose; spines radiating, tufted at micropylar region. The leaves are water repellent and exhibit ultra-hydrophobicity, meaning high water contact angle between droplet of water and leaf surface, and very low roll-off angle. It has a waxy coating on its surface, which makes it water loving. This helps the water droplets roll off from the surface even at the slightest disturbance and allows stomata on the upper surface of the leaf, not blocked by water droplets, to function efficiently. It has medicinal properties, being antifungal, antipyretic, sudorific, diuretic and cardiotonic. Various parts such as the rhizomes have been used for curing cough, smallpox, pectoralgia, leucoderma, pharyngopathy and spermatorrhoea. The stem is used as a diuretic and to treat nervous exhaustion, strangury, leprosy, skin diseases and vomiting. The young leaves are mixed with sugar for rectal prolapse therapy. Both the flowers and leaves have been used in Ayurveda for treating bleeding disorders. In traditional folk medicines, the seeds are used as antidotes for poisons and to treat skin diseases. Powdered seeds, mixed in honey, are useful in treating cough. Lotus seeds have been used as an antimicrobial due to their antimicrobial properties. The flowers can cure fever, diarrhoea, cholera and hepatopathy and can be administered as diuretics to children (Steve and Obando, 2012).They are also used as vegetable resources – dried, canned and used to make pickles or lotus root tea.

4. Hydrilla verticillata

Classification

Kingdom:	Plantae - Plants
Subkingdom:	Tracheobionta - Vascular plants
Superdivision:	Spermatophyta - Seed plants
Division:	Magnoliophyta - Flowering plants
Class:	Liliopsida - Monocotyledons
Subclass:	Alismatidae
Order:	Hydrocharitales
Family:	Hydrocharitaceae - Tape-grass family
Genus:	*Hydrilla*
Species:	*verticillata*

Description

Hydrilla is a submerged, fast-growing aquatic weed which has no aerial leaves. It is usually gregarious and grows in a great variety of aquatic habitats but is rarely found in swiftly flowing water and avoids shady habitats. It has the potential to alter water chemistry and cause shifts in zooplankton communities. It forms dense masses, which replace native species. The dense masses formed affect the predatory behaviour of fishes, altering the food chain, comprising small insectivores. It can spread through fragmentation, and the tubers survive in sediments for more than 4 years. Hence, eradicating it completely is a major challenge. It normally grows in shallow water (up to ca. 50 cm deep), where it is photosynthetically most efficient. It grows and spreads very quickly, and the fragmented detached stem readily develops into new plants and gets attached to the substrate by fine, unbranched adventitious roots. Hydrilla can grow in fresh water (springs, lakes, marshes, ditches, rivers, tidal zones). It can grow in only a few inches of water; it finds its comfort area even in oligotrophic (low nutrient) to eutrophic (high nutrient) conditions and in saline seawater. The roots are long and simple, adventitious, arising at nodes and stems either creeping or stoloniferous or erect, slender, up to 2 m or more long, freely branched near the base, usually sparingly branched above. The leaves are in opposite pairs (opposite leaves usually found on stolons or at the base of the stem or branch, usually ovate or widely ovate, rarely more than 4 mm long) or in whorls of three to eight (maximum 12), sessile, linear to lanceolate, green, with or without reddish-brown spots and stripes. Some species are dioecious and others monoecious, reproducing by fragmentation and from tubers, turions ('buds' in some of the leaf axils) and seeds (Umetsu et al., 2012)[56]. The fruit is cylindrical, about 7mm long and 1.5 mm long, and contains two elliptic seeds. *Hydrilla* has the capacity to accumulate a high percentage of arsenic (approximately more than 70% arsenic removal by 100 g fresh biomass of plants in 45 days) and does not show any signs of toxicity. Moreover it can be used as feed for cattle when mixed with their food.

Hydrilla verticillata might be confused with at least two other submersed, long-stemmed plants that have small, narrow leaves *(Elodea canadensis* and *Egeria densa)*. It is distinguished from other species by the presence of mid-veins on the lower surface of the leaf, with sharp spicules and teeth widely present on the leaf margin and leaf axils with minute scales.

[56] Umetsu, C.A., Beatriz, H., Evangelista, A., Thomaz, S.M., 2012. Colonization, regeneration potential and growth rates of fragments of the exotic aquatic macrophyte Hydrilla verticillata 16, 197–202. https://doi.org/10.3354/ab00450

5 Phragmites australis

Classification

Kingdom:	Plantae - Plants
Subkingdom:	Tracheobionta - Vascular plants
Superdivision:	Spermatophyta - Seed plants
Division:	Magnoliophyta - Flowering plants
Class:	Liliopsida - Monocotyledons
Subclass:	Commelinidae
Order:	Cyperales
Family:	Poaceae - Grass family
Genus:	*Phragmites*
Species:	*australis*

Description

P.australis has been used to treat wastewater in constructed wetlands to eliminate/reduce the nitrogen level, chemical oxygen demand, biological oxygen demand and levels of suspended solids, coliforms and bacteria. They also prevent soil erosion, apart from removing water pollutants and remediating soil. It is known to be a common reeds and occurs widely in wet areas, including tidal and non-tidal wetlands, brackish and freshwater marshes, river edges, lake and pond shores, ditches and roadsides. It is a non-native invasive plant that dominates the land by out-competing the surrounding native vegetation (Quirion et al., 2018)[57]. The spread of invasive species is often the result of human activity, but invasive species can also be spread by wildlife. This species flourishes well in warm climates and can tolerate sunlight and saline conditions. It is a dominant plant species that has the potential to replace other plant species in its vicinity to form dense habitats suitable for its growth. It is a perennial grass, with dark leaves that are elongate, and typically 1 to 2 inches wide. The stem is attached to the leaf sheath tightly and does not get affected by low temperatures. The seed is dispersed by water and wind. Vegetative reproduction is through rhizomes or fragments. The leaves are used for making baskets, mats and ropes and can be a source of income of tribal communities. They are also used for thatch and traditional crafts. Young leaves are used a fodder for cattle. The plant alters wetland hydrology, increases the potential for fire and degrades the habitat for wetland fauna because of it's dense growth.

6. Alternanthera philoxeroides

Classification

Kingdom:	Plantae - Plants
Subkingdom:	Tracheobionta - Vascular plants
Superdivision:	Spermatophyta - Seed plants
Division:	Magnoliophyta - Flowering plants
Class:	Magnoliopsida - Dicotyledons
Subclass:	Caryophyllidae
Order:	Caryophyllales
Family:	Amaranthaceae - Amaranth family
Genus:	*Alternanthera*
Species:	*philoxeroides*

[57] Quirion, B., Simek, Z. & Da, A. (2018). Management of invasive Phragmites australis in the Adirondacks: A cautionary tale about prospects of eradication. Biological Invasions 20, 59–73. https://doi.org/10.1007/s10530-017-1513-2

Description

The species is quite widespread, and it is found growing in aquatic habitats, generally rivers, swamps, lakes, ditches, canals, wetlands, etc. It is rooted to the ground but also emerges above the water surface. It can also be found floating free in dense mats on the water surface or in soil on land. It is considered as a weed. It is perennial, creeping, semi-upright and semi aquatic, producing roots at its stem joints. The leaves are stalkless and elongated in shape, with small flowers, generally white in colour. The leaves get a papery appearance as the fruit matures (Masoodi and Khan, 2012)[58]. The whitish flowers are borne in dense globular clusters (1–2 cm across) at the top of stalks (i.e., peduncles) 2–9 cm long. These flower clusters are usually produced in the forks (i.e., axils) of the upper leaves. Each flower has five small white petals (i.e., perianth segments or tepals) and five yellow stamens. The petals (5–7 mm long) tend to develop a papery appearance and may turn straw- coloured as they mature. Flowering occurs from late spring through early autumn. The stems are runners and therefore spread out over the surface of water bodies, over the ground or in the transition region of a wetland. The younger stems are light greenish in colour and have swollen joints. The small fruiting 'capsules' (i.e., utricles) are brownish in colour, bladder-like in appearance and contain a single seed. The macrophyte generally reproduces vegetatively by stem fragmentation and through seed dispersal. Because this weed is adapted to both water and the terrestrial environment, it is very difficult to eradicate it (Chen et al., 2013)[59]. It does not allow penetration of sunlight and thus affects submerged native plant species in wetlands. It has the potential to displace native species, forming dense mats. The terrestrial form has a massive network of roots underground that promotes sedimentation and flooding, altering the water quality in the wetland. It bears propagules that remain viable for more than a year and promotes a monoculture environment.

7. Sparganium erectum

Classification

Kingdom:	Plantae – Plants
Subkingdom:	Tracheobionta - Vascular plants
Superdivision:	Spermatophyta - Seed plants
Division:	Magnoliophyta - Flowering plants
Class:	Liliopsida - Monocotyledons
Subclass:	Commelinidae Order: Typhales
Family:	Sparganiaceae - Bur-reed family
Genus:	*Sparganium*
Species:	*erectum*

Description

Sparganium erectum is a perennial plant that can grow up to 1.00 m tall. It is generally found on the muddy shores of water bodies and wetlands, on the periphery to 30 cm-deep water. *S.erectum* is most often found at the margins of lakes, rivers, streams, canals and drainage ditches in permanent water, ponds, ditches and ungrazed marshlands. It grows best in water between 10 and 20 cm deep in silty mud. It is restricted to the shallow margins and cannot withstand prolonged immersion. It can flourish well in sandy, loamy and clay soils that are acidic, alkaline or neutral in nature. It can strive both in wet soil and in water-logged areas. In summer it produces branched stems with greenish-white male and female flowers in separate clusters, followed by prickly green, then brown, fruits up to 1 cm across. It is a noxious weed that has flat leaves either floating or held above the water, depending on the life stage and water depth. The roots are resistant to uprooting and can concentrate nutrients. The plants typically spread via

[58] Masoodi, A. & Khan, F. A. (2012). Invasion of alligator weed (Alternanthera philoxeroides) in Wular Lake. Aquatic Invasions, 7: 143–146. https://doi.org/10.3391/ai.2012.7.1.016
[59] Chen, Y., Zhou, Y., Yin, T., Liu, C. & Luo, F. (2013). The invasive wetland plant Alternanthera philoxeroides shows a higher tolerance to waterlogging than its native congener Alternanthera sessilis. PLoS ONE 8(11): e81456. https://doi.org/10.1371/journal.pone.0081456

vegetative growth or through dispersal of detached rhizomes. Seedling survival and spread is not high and may be important only in undisturbed habitats. The species decreases the perceived aesthetics of wetlands, and it is generally monospecific where it survives. The stem and roots are edible but are generally not consumed.

8. Colocasia esculenta

Classification

Kingdom:	Plantae – Plants
Subkingdom:	Tracheobionta - Vascular plants
Superdivision:	Spermatophyta - Seed plants
Division:	Magnoliophyta - Flowering plants
Class:	Liliopsida - Monocotyledons
Subclass:	Arecidae
Order:	Arales
Family:	Araceae - Arum family
Genus:	*Colocasia*
Species:	*esculenta*

Description

Colocasia esculenta is a fast-growing emergent aquatic or semi-aquatic herbaceous plant that originates from a large corm (storage stem) and can grow to 4 feet (1.5 m) in height. It possesses several adaptations that assist its survival as a weed.

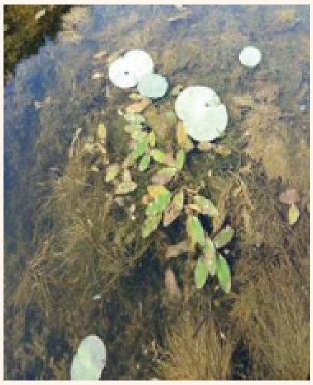
C. esculenta can be found growing mainly in moist forests and wet areas in riparian habitats, river banks and wetlands and along streams, marshes and canals. It is perennial, globous with a massive, fleshy corm at the base and with thick edible lateral runners. The root system is adventitious, with fibres. The corm is massive, cylindrical or spherical, up to 30 cm × 15 cm, usually brown, with lateral buds located above leaf scar that gives rise to new cornels, suckers or stolons. The leaves are arranged in a loose rosette; blades pointing downward, 23-55 × 12-38 cm, cordate or lanceolate, sub-coriaceous, green above, glaucous below, the apex obtuse, acute, or shortly acuminate, the base peltate-cordate, the margins more or less wavy, with a submarginal collecting vein; petioles erect, to 85 cm long, inserted 3–7 cm from base of blade. The inflorescences are axillary, ascending, solitary; peduncles nearly as long as the petiole, cylindrical; spathe fleshy to about 35 cm long. The fruit is a many-seeded berry, densely packed and forming a fruiting head. The seeds are ovoid to ellipsoid, less than 2 mm long, with copious endosperm. In traditional medicine it is used to treat arterial hypertension, liver problems, ulcers, snake bites and rheumatism. The tubers and corms are edible when boiled, fried or roasted, and they are easily digestible. The leaves can be used for cattle. They grow in hot and humid regions and provide starch as their source of energy. Commonly known as Taro, these tubers provide a number of desirable nutritional and health benefits. They have anticancer activity and provide phenolic acid and phytochemicals (Boampong et al., 2018)[60]. Seed germination is uncommon, with very low viability, and therefore the tubers and corms assist the spread of the population.

[60] Boampong, R., Aboagye, L. M., Nyadanu, D. & Esilfie, M. (2018). Agro-morphological characterization of some taro (Colocasia esculenta (L.) Schott.) germplasms in Ghana. Journal of Plant Breeding and Crop Science, 10(8), 191-202. https://doi.org/10.5897/JPBCS2018.0734

9. Najas minor

Classification

Kingdom:	Plantae - Plants
Subkingdom:	Tracheobionta - Vascular plants
Superdivision:	Spermatophyta - Seed plants
Division:	Magnoliophyta - Flowering plants
Class:	Liliopsida - Monocotyledons
Subclass:	Alismatidae
Order:	Najadales
Family:	Najadaceae - Water-nymph family
Genus:	*Najas*
Species:	*minor*



Description

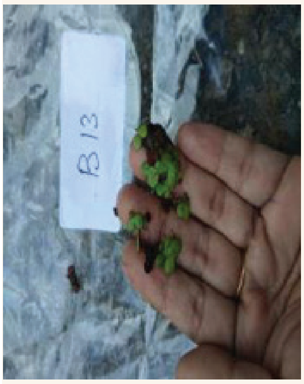
Najas minor is an annual, submersed, rooted, floating and monoecious plant that prefers to grow in stagnant or slow-moving waters, such as wetlands, ponds, lakes, reservoirs and canals and can grow in depths of up to 4 m. It is more tolerant of turbidity and eutrophic conditions than some of the native species of Najas and has replaced them in many instances. *N.minor* is water-pollinated, and its population can fluctuate dramatically over a period of a few years. It is often correlated with years of low rainfall and increased amounts of available light. Although this annual can reproduce by fragmentation, the primary means of reproduction appears to be by single-seeded fruits. *N.minor* grows in dense clusters and has highly branched stems that fragment easily and grow. The stems may reach up to 2.5 m in length and are profusely branched near their apex (Range, 2018)[61]. The small flowers are located in clusters along the leaf axils. The leaves are opposite or sub-opposite, about 1 mm wide and 0.5–3.5 cm long, becoming stiff and recurved with age. The leaves have seven to 15 small but conspicuous teeth along each side of the leaf. The leaves have serrations (rough at the margins) that are visible to the naked eye. The fruits are 1.5–3.0 mm long and slightly curved with rectangular areolar arranged in distinct longitudinal rows and produced singly, and they are very abundant. The presence of this macrophyte is a problem because its dense growth covers wide areas, inhibiting the growth of native species of aquatic macrophyte. The thick, clustering growths of Brittle Naiad *(N.minor)* can make fishing access or the operation of a boat difficult in a pond or lake. The reproductive season of *N.minor* starts in July, when flowers appear. Seed production peaks in September and continues into October. During the late summer or early fall, the stems become brittle, and the profusely branched apical portions of the stem break into small fragments. The seeds remain attached to the leaf axils, and the fragments are dispersed by wind and water currents. Seed germination occurs from early spring to late summer. *N.minor* prefers calm waters such as ponds, lakes, and reservoirs but may grow in streams and rivers as well. It prefers alkaline environments and is known to grow in pH levels of 6.0–9.3, with an optimum range of about 6.6–7.2. It occurs at depths up to 5 m, with an ideal range of about 0.5–2 m at temperatures down to 8°C. It may be found in brackish waters with a salinity of up to 0.3 ppt. *N.minor* is tolerant of turbidity and eutrophic conditions, which may allow it to out-compete and replace native species. It reproduces sexually and asexually. Sexual production of an abundant seed supply and seed banks of up to tens of millions of seeds/ha appear to be its primary means of reproduction. It may also reproduce vegetatively, producing clonal populations that may fragment and propagate. It has major ecological impacts such as creating dense-packed macrophytes. It tangles up fishes and other animals and blocks sunlight from entering the bottom of a wetland, impacting the plant biodiversity. When the plant decays, a large amount of oxygen is utilized from the water body, thereby suffocating other aquatic organisms. The plant causes problems for boats' movements in water bodies and for fishing because of its mesh-like structure.

[61] Range, N. (2018). Brittle Water Nymph (Najas minor) Ecological Risk Screening Summary 1 Native Range and Status in the United States 2018, 1–13.

10. Lemna gibba

Classification

Kingdom: Plantae - Plants
Subkingdom: Tracheobionta - Vascular plants
Superdivision: Spermatophyta - Seed plants
Division: Magnoliophyta - Flowering plants
Class: Liliopsida - Monocotyledons
Subclass: Arecidae
Order: Arales
Family: Lemnaceae - Duckweed family
Genus: *Lemna*
Species: *gibba*



Description

This macrophyte is also known as Gibbous Duckweed, Swollen Duckweed or Fat Duckweed. It has a simple plant body, known as a thallus, which floats on the surface of the water and measures about 3–5 mm in diameter. A single root hangs down into the water. The plant is generally abundant in still or slow-flowing water bodies, on mud and on damp rocks. It reproduces mainly through vegetative propagation and seldom produces flowers. It is a rich source of protein, with a protein content of about 30-40% of the dry matter, and can be utilized as a food resource for animal feed. It has remedial properties and is therefore used for phytocleaning of sites contaminated with nutrients such as nitrogen and phosphorus, organic chemicals, and heavy metals. Possessing a high growth and high photosynthetic rate, it is found abundantly in wetlands. Other species of Lemnaceae such as Spirodela and Wolfia have been used for toxicity assessments. Hence Lemna species are also used as test organisms for water quality assessments as well as for ecotoxicological studies regarding the adverse effects of, e.g., herbicides, pharmaceuticals and heavy metals on aquatic plants. This macrophyte of the family Lemnaceae are 100% edible, nutritious and non-toxic. It has a strong capacity for growing and doubling in 1–3 days, and hence it is used for cleaning polluted water. One of the significant features it possesses on the lower side of its thallus is a swollen frond with air chambers that allow it to float. The property of possessing such swellings is known as gibbosity.

11. Nephrolepis exaltata

Classification

Kingdom: Plantae - Plants
Subkingdom: Tracheobionta - Vascular plants
Division: Pteridophyta - Ferns
Class: Filicopsida
Order: Polypodiales
Family: Dryopteridaceae - Wood Fern family
Genus: *Nephrolepis*
Species: *exaltata*

Description

This pteridophyte is generally found growing in partial to deep shade and needs moist but well-drained soil until established but later it can survive periodic bouts of dry weather. Propagation is easily done by division of the clumps. The Sword Fern may at times be bothered by scales, mites, mealy bugs, snails or slugs. It has broad fronds with alternate leaflets (pinnae) on either side of the midrib. The pale- to medium-green fronds can grow up to 4 feet long and 6 inches wide. There are two rows of round sori (clusters of spore-bearing organs; ferns are seedless vascular plants that produce spores instead of seeds) near the margins on the underside of the pinnae.

Each leaflet is generally deltoid in shape, with slightly serrate, undulating edges. The plants will also send out long, thin runners (stolons) that will root to form a new plant when they touch the ground. *N.exaltata* is a perennial plant and can survive in dry and wet seasons and is capable of accumulating heavy biomass that can accommodate interactions with herbivores. This is a significant candidate plant for use as a bio-indicator organism in eco-toxicological applications to assess the effects of heavy metals in polluted or disturbed environments. Bio-indicators are used in determining the biological effects of a single pollutant, the synergetic and antagonistic effects of multiple pollutants on an organism alongwith early recognition of pollutant damage to plants as well as toxic dangers to humans.

Significant properties of the identified macrophytes, including their life cycles, roles in pollution control and their native/invasive attributes are presented in Table 19.

***Table 19** Macrophytes and their significant properties*

Name of the macrophyte	Native/invasive nature	Life cycle	Significant role in pollution control
Potamogeton species	Native to North America	June to September	Fish prefer to spawn among this macrophyte species. It can accumulate heavy metals such as zinc, copper, lead, cobalt and manganese, but it is generally not used because of its fast decay rate.
Azolla pinnata	Native to India, Africa, China, Japan, Korea, the Philippines and parts of Australia	Summer and spring	Can accumulate lead, zinc, chromium, cadmium, mercury, arsenic. It is also efficient for reduction of nitrogenous waste and phosphorus from poultry wastewater. Remediates dye wastewater containing rhodamine, malachite green, methyl violet, etc. It plays an important role in reversing the greenhouse effect. Used as biofertilizer, animal feed, biofilter and bio-weedicide. Controls mosquito larvae in rice fields.
Nelumbo nucifera	Native to central and northern India, through northern Indochina and East Asia	April to September	Due to rhizo-filtration, it is efficient in removing arsenic, copper, cadmium, lead and zinc from water, with no morphological changes or any toxicity symptoms. It provides habitats for bacterial growth and fish spawning. It helps in denitrification, i.e., it removes fixed nitrogen (nitrate) from the ecosystem and returns it to the atmosphere in a biologically inert form (N2). It is used as a bio-indicator to determine the impact and progression of human activities on ecosystem vitality.

Name of the macrophyte	Native/invasive nature	Life cycle	Significant role in pollution control
Hydrilla verticillata	Native, originates from south India	Generally from summer till the beginning of winter	It is a super-weed and grows very fast, about 6 inches in a day. Hyper-accumulator of cadmium, lead, mercury and chromium. Harmful to fish populations though it may provide breeding grounds for some fish species.
Phragmites australis	Native to Australia, this invasive replaces native species and forms dense habitats for its growth.	Perennial	Accumulates zinc, copper, lead, chromium and other heavy metals. Used in constructed wetlands for remediating heavy metals and nutrients and lowering water quality parameter values. It has a wide range of local uses.: nests for migratory bird, can be used for making thatch, ropes, etc.
Alternanthera philoxeroides	Invasive in India, the United States of America, Sri Lanka, Indonesia, Myanmar, Singapore, Australia, New Zealand, China and Italy	Perennial	Drives down the population of native species, has adverse effects on the flora and fauna of a wetland. It is resistant to control measures, and it is capable of invading the terrestrial and aquatic environments of a wetland. Accumulates cadmium, lead and zinc.
Sparganium erectum	Considered native to Europe and Asia, Morocco and Australia	Perennial	Used for phytoremediation of contaminated bottom sediments because it accumulates manganese and iron in the roots and limits their movement from the roots and rhizomes to the leaves these are once absorbed. Persisting necrotic leaves and stems in winter can accumulate fine sediments. It influences both the physical environment of habitats and retains seeds. It can be exploited to create mesohabitats for other aquatic plants/animals (physical and biological habitat diversification) in rivers.
Colocasia esculenta	Native to southeastern Asia and India	Perennial	Accumulates arsenic, lead, mercury, cadmium and nickel from wastewater and aquaculture water. Tubers are edible.Generally, grows in the transition zone between the wetland and land.
Najas minor	Native to Europe and Asia	Annual, especially after summer	Generally abundant in silted, polluted or eutrophicated wetlands. Waterfowl such as ducks feed on it. Other species of Najas (such as N.indica) have been used for phytoremedial purposes.

Name of the macrophyte	Native/invasive nature	Life cycle	Significant role in pollution control
Lemna gibba	Native to Africa, Asia, Europe and North America	Perennial	Species of Lemna remediate copper, zinc and lead due to their rapid growth. Generally used for arsenic and uranium removal. Used by local people for eating. Also used for animal feed. Acts as a bio-filter of nitrogen and phosphate in fish ponds.
Nephrolepis exaltata	Native to Florida, the West Indies, Mexico, Central America, South America, Polynesia and Africa	Perennial	Ornamental plant, used for remediation of arsenic, copper and cadmium. It can also be used as an insecticide. It acts as a bio- indicator of nickel in the environment since it shows toxicity at ≥ 1 ppm. Roots provides niche for bacterial community.

FLORA AND FAUNA OF RENUKA WETLAND

As a part of our current project, relevant information was collected through online sources available from the Zoological survey of India (ZSI 2000)[62] and published reports on the Renuka wetland, in the form of secondary data. ZSI had identified approximately 443 species of 26 faunistic groups from unicellular Protozoa to multicellular mammals during a survey conducted in the period 1992–1993. ZSI prepared an inventory that is available to the local people. They have reported 24 species of mammal, 103 species of bird, 14 species of reptiles, nine species of amphibian, 19 species of fish, 225 species of insect and 49 species of other invertebrate. Since there is a gap of about 27 years after the last survey was conducted for identification of plants and animals, there is an urgent need to understand the changes/shifts/replacements/extinctions of the identified species. Therefore, the present report (which is basically a compilation of published report) comprises scientific names of the macrophytes and tree species in Renuka Wetland and its catchment area, which consists of a forest. It also presents the faunal species in tabular form according to the major groups of animal.

- ***SIGNIFICANCE OF WETLAND FLORA AND FAUNA***

Wetlands are the cradle of biodiversity and a significant component of the environment. They are among the most productive ecosystems, having the largest floral and faunal species. These ecosystems provide several key functions or ecological services, which both directly and indirectly affect the biodiversity. Macrophytes play an important role in the structure of freshwater wetlands and have been targeted for their restoration and conservation. Moreover, macrophytes act as an indicator of environmental conditions prevailing within the wetland and long-term ecological changes as they react to the alterations in the physical and chemical environment of the ecosystem, often originating from anthropogenic activities. Growth of invasive species, natural and anthropogenic eutrophication, seasonal fluctuations in the water level and lack of efficient inlets and outlets are identified as major threats faced by a wetland ecosystem. Different macrophyte life forms rely on different nutrient sources, perform different functional roles and vary in their responses to environmental gradients.

[62] Fauna of Renuka Wetland, Wetland Ecosystem Series 2. Zoological Survey of India (2000).

Therefore, the macrophyte species richness and proportion of various life forms closely reflect the trophic state of a lake, with meso-trophic and eutrophic lakes supporting significantly more species compared with oligotrophic lakes. Generally the faunal species of a wetland are beavers, minks, alligators, snakes, turtles and other members of the reptilian group. Invertebrates such as mosquitoes, crayfish and shrimps are dominant. Herons and waterfowl are also dominant. The stability of any food chain in a wetland depends on the presence of all the living species in that wetland. Hence, the flora and fauna have an important relationship that is crucial for the survival of all the species and the ecology of the wetland.

- ***FLORAL IN AND AROUND THE RENUKA WETLAND***

The hydrophytes include *Phragmites, Typha, Carex* and *Hydrilla,* which are dominant in the water environment. The entire catchment area is a reserve forest and has been declared a wildlife sanctuary. The forest around the lake is of the sub-tropical dry deciduous type. Grasslands, marshy areas, rocky areas and open water are some of the major habitats of the wetland. The vegetation can be classified as hydrophytes, shrubs, climbers and woody plants. The main vegetation comprises bamboos, palms, Harar *(Terminalia chebula)* and Kacchnar *(Bauhinia variegata).* Plantations of an exotic species *(Eucalyptus)* have been created in the area. Due to an abundance of food, shelter and water, a good number of wild animals such as Sambhar *(Cervus unicolor),* Barking Deer *(Muntiacus muntjack)* and birds such as the Barbet *(Megalaima zeylanica),* Kingfisher *(Alcedo atthis),* Minivet *(Pericrocotus flammeus),* Lapwing *(Vanellus indicus),* Egret *(Egretta garzetta)* and Coot *(Fulica atra)* have made this catchment ecologically very important and have also made this area their habitat. Both the northern and southern aspects of the catchment valley are clothed with vegetation of a sub-tropical nature. Phoenix spp., Ficus religiosa and Shisham *(Dalbergia sissoo)* are the dominant trees present near the base of the valley i.e., around the lake. While Anogeissus, Beul and Kachnar are dominant near the ridge. The slopes have good shrubby growth *(Lantana, Murraya, Berberis etc.).* Reports compiled by MOEF highlight the fact that overwood *Terminalia tomentosa, Shorea robusta, Moringa pterygosperma, Ougeinia dalbergioides, Cassia fistula, Bauhinia variegata, Ficus palmata, Ficus religiosa, Bambusa arundinacea, Phoenix spp., Salix tetrasperma* and *Dalbergia sissoo* are found (dry deciduous type vegetation).

- ***FAUNA IN AND AROUND RENUKA WETLAND***

The fauna in Renuka Wetland comprises about 443 species identified by the Zoological Survey of India in 2000. No studies reported the dominant animal species subsequently. Therefore, a study needs to be conducted to identify the changes in the faunal species. The reported animal species have been tabulated in Table 20 for reference.

Table 20 *Faunal diversity in Renuka Wetland*

Faunal group	Examples of fauna in the Renuka wetland
Protozoa	*Coleps inermis, Colpoda cucullus, Monochilum ovale, Urocentrum turbo, Strobilidium gyrans*
Porifera	*Ephydatia meyeni*
Cnidaria	*Lillllocllida sp.,*
Bryozoa	*Lophophore;*
Mollusca	*Bellamya bengalensis, Bellamya bengalensls f. mandiensis, Thilua tuberculata, Lymnaea (P.) acuminata f. rufescens, Lymnaea (Radix) auricularia, Gyraulus labiatus, Sphaerium indicum*
Oligochaeta	*Limnodrilus hoffmeisteri Claparede, Dichogaster bolau, Lemnogaster chitagollgellsis, Octochaetona Beatrix, Amynthas corticis, Metaphire birmanica, Metaphire houlleti, Metaphire posthuma, Perionyx bainii, Perionyx excavatus, Perionyx simliaensis, Allolobophora parva*

Faunal group	Examples of fauna in the Renuka wetland
Hirudinea	*Alboglossiphonia weberi, Batracobdelloides reticulata, Hemiclepsis marginata,Salifa indica*
Araneae	*Oxyopes shweta, Pardosa birmanica, Nephila maculata, Leucauge decorata, Geodrassus sirmourensis*
Crustacea	*Cerlodapahnill cornuta, Simocephalus vetulus, Moinodaphnia macleayi, Macrothrix spinosa, Chydorus sphaericus, Pleuroxus similis, Dunhevedia crassa, Alona pulchella, Stenocypris Sars, Stellocypris hislopi, Mesocyclops leuckarti, Potamon koollooense*
Ephemeroptera	*Ephemera consors Eaton, Ephemera remensa, Caenis picea, Cloeon kimminsi, Cloeon marginale, Procloeon bimaculatum*
Od'onata	*Copera annulata, Copera marginipes, Copera vittata, Calicnemia eximia, Ceriagrion cerinorubellum, Ceriagrion coromandelianum, Ceriagrion fallax, Pseudagrion decorum, Pseudagrion rubriceps, Coenagrion dyeri, Ischnura delicata, Ischnura forcipata, Ischnura senegalensis, Agriocnemis pygmaea, Megalestes major, Rhinocypha quadrimaculala quadrimaculata, Libellago lineata lineata, Bayadera indica, Neurobasis chinensis chinensis, Ictinogomphus rapax, Nepogomphus modestus, Anax guttatus, Orthetrum brunneum brunneum, Orthetrum chrysostigma luzonicum, Orthetrum glaucum, Orthetrum pruinosum neglectum, Orthetrum sabina sabina, Orthetrum triangulare triangulare, Brachythemis contaminata, Crocothemis servilia servilia, Diplacodes nebulosa, Neurothemis fulvia, Neurothemis tullia tullia, Trithemis aurora aurora, Trithemis festiva, Trithemis pallidinervis, Acisoma panarpoides panarpoides*
Mantodea	*Ephesliasula intermedia, Creobroler laevicollis, Humbertiella indica, Nanomantis laclea, Mantis indica, Mantis nobilis, Statialla nemoralis*
Dermaptera	*Euborellia annulipes, Nala nepalensis, Labidura riparia, Forcipula trispinosa, Forcipula quadrispinosa, Proreus abdominalis*
Orthoptera	*Gryllus bimaculatus, Teleogryllus occipitalis, Plebeiogryllus guttiventris, Modicogryllus blennus, Modicogryllus facialis, Turanogryllus rufoniger, Gryllodes sigillatus, Velarifictorus dehradunensis, Loxoblemmus equestris, Loxoblemmus delectus, Loxoblemmus taicoun, Loxoblemmus macrocephalus, Pteronemobius csiki, Pteronemobius fascipes, Pteronemobius taprobanensis, Pteronemobius pantelchopardorum, Anaxipha longipennis, Trigonidium cicindeloides, Elimaea securigera, Letana despecta, Himertula kinnaeri, Conocephalus maculatus, Mecopoda elongata, Onomarchus sp., Acrida exaltata, Ceraclis striata, OedaleuS abruptus, Sphingonotus longipennis, Spathosternum prasiniferum, Eucoptacra saturata, Paraconophyma scabra, Diabolocatantops innotabilis, Xenocatantops h. humills, Xenocatantops karnyi, Eyprepocnemis rosea, Choroedocus illustris, Atractomorpha crenulata crenulata, Chrotogonus (Chrotogonus) Ir. Trachypterus, Aularches miliaris, Eucriotettix grandis, Euparatettix tenuis, Hedotetta attenatus, Redotettix gracilis, Ergatettix dorsiferus, Ergatettlx guenther, Teredorus frontalis, Tridactylus thoracicus, Xya sp.*
Aquatic Hemiptera	*Corixa (Tropocorixa) choprai, Laccotrephes griseus, Diplonychus molestus, Heleocoris vicinus, Hydrometra green, Ptilomera (Ptilomera) laticaudata, Chimarrhometra orientalis, Neogerris parvula, Limnogonus (Limnogonus) nitidus, Limnogonus (Limnogonus) fossarum*

Faunal group	Examples of fauna in the Renuka wetland
Aquatic Coleoptera	*Orectochilus murinus, Orectochilus neglectus, Laccophilus flexuosus, Laccophylus parvolus, Laccophylus sharpi, Hydrovatus sp., Hydrovatus Sharp, Hydaticus fabricii, Sandracottus dejeani, Sandracottus festivus, Georyssus sp., Coelosloma sp., Hydrochus sp., Laccobius sp., Helochares crenatus, Sternolophus rufipes, Berosus indicus, Amphiops pedestralis, Stenelmis sp., Byrrhus sp.*
Lepidoptera	*Papilio protenor protenor, Papilio polyctor polyctor, Papilio polytes romulus, Papilio demoleus demoleus, Graphium sarpedon luctatius, Delias belladonna horsfieldii, Pieris canidia indica, Catopsilia crocale crocale, Catopsilia pyranthe, Eurema, Eurema laeta laeta, Eurema hecabe fimbriata, Danaus chrysippus chrysippus, Tirumala limniace leopardus, Tirumala hamata septentrionis, Parantica aglea melanoides, Euploea core core, Mycalesis mineus mineus, Lethe rohria dytra, Ypthima nareda nareda, Polyura athamas, Neptis hylas astola, Neptis yerburyi yerburyi, Cyrestis thyodamas ganescha, Hypolimnas bolina, Kallima inachus huegeli, Precis hierta, Precis lemonias penicaria, Precis iphita siccata, Phalanta phalantha, Ariadne merione tapestrina, Libythea myrrha sanguinalis, Notocrypta curvifascia, Suastus gremius, Potanthus pallida, Parnara guttatus, Pelopidas mathius, Polytremis sp., Meganoton anilis, Psilogramma menephron, Polyptychus trilineatus, Nephele didyma, Hippotion celerio, Theretra alecto, Theretra nessus, Theretra oldenlandie, Argina argus, Creatonotos transiens, Zadadra distorta, Strysopha torticoides, Cyana gelida, Cyana puella, Hypsa ficus, Asota caricae, Anua tirhaca, Fodina pallula, Ischyja manlia, Spirama retona, Chrysodeixis eriosoma, Psimada quadripennis, Micronissa costata, Boarmia boarmiaria, Maxates sp., Botyodes asialis, Nausinoe pueritia, Terastia egialealis, Maruca testulalis*
Hymenoptera	*Apis (Megapis) donilla, Apis indica, Bombus tunicatus, Megachila bicolor, Polistes olivaceus, Stilbum cyanarum amethystinum, Compontitus comp*
Diptera	*Conosia irrorata, Plecia dispersa, Oplodontha rubrithorax, Adoxomyia heminopla, Tabanus (Tabanus) striatus, Episyrphus balteatus, Phytomia (Dolichomerus) crassa, Sepedon plumbella, Musca (Musca) domestica, Orthellia timorensis, Gymnodia tonitrui, Stomoxys calcitrans, Chrysomya megacephala,Parasarcophaga (Parasarcophaga) albiceps*
Pisces	*Mastacembelus armatus, Channa marulius, Channa orientalis, Channa punctatus, Nemacheilus botia, Nemacheilus montanus, Nemacheilus rupecola, Tor putitora, Tor tor, Puntius chola, Puntius conchonius, Puntius ticto, Labeo dero, Labeo rohita, Esomus danricus, Brachydanio rerio, Rasbora daniconius, Barilius bendelisis, Barilius vagra*
Amphibia	*Rana cyanophlyctis, Rana limnocharis, Raila tigrina, Raila (Tomopterlla) breviceps, Rana (Paa) minica, Bufo melanostictus, Bufo stomaticus, Bufo andersonii, Microhyla ornata*
Reptilia	*Kachuga kachuga, Hemidactylus brooki, Hemidactylus flaviviridis, Agama tuberculata, Caloles versicolor, Varanus bengalensis, Varanus flavescens, Mabuya carinata, Riopa punctata, Typhlops porrectus, Vipera russelii, Echis carinatus, Agkistrodon himalayanus, Ptyas mucosus*
Aves	*Ardeola grayii, Egretta intermedia, Egretta garzetta, Elanus coeruleus, Milvus migrans, Accipiter badius, Gyps bengalensis, Neophron percnopterus, Falco tinnunculus, Francolinus pondicerianus, Perdicula asiatica, Amaurornis, Amaurornis phoenicurus,*

Faunal group	Examples of fauna in the Renuka wetland
	Vanellus indicus, Tringa nebularia, Tringa ochropus, Tringa hypoleucos, Columba livia, Streptopelia decaocto, Streptopelia chinensis, Streptopelia senegalensis, Psittacula cyanocephala, Psittacula himalayana, Clamator jacobinus, Cuculus varius, Eudynamys scolopacea, Taccocua leschenaultii, Centropus sinensis, Athene brama, Apus affinis, Ceryle rudis, Alcedo atthis, Halcyon smyrnensis, Merops orientalis, Coracias bengalensis, Upupa epops, Tockus birostris, Megalaima zeylanica, Megalaima asiatica, Megalaima haemacephala, Picus chlorolophus, Picoides mahrattensis, Picoides canicapillus, Galerida cristata, Hirundo rustica, Hirundo daurica, Delichon urbica, Lanius schach, Oriolus oriolus, Dicrurus adsimilis, Sturnus pagodarum, Acridotheres tristis, Acridotheres ginginianus, Acridotheres fuscus, Cissa erythrorhyncha, Dendrocitta vagabunda, Dendrocitta formosae, Corvus splendens, Corus macrorhynchos, Tephrodornis pondicerianus, Coracina melaschistos, Pericrocotus flommeus, Aegithina tiphia, Pycnonotus leucogenys, Pycnonotus cafer, Pomatorhinus erythrogenys, Chrysomma sinense, Turdoides striatus, Garrulax lineatus, Muscicapa sibirica, Culicicapa ceylonensis, Rhipidura aureola, Rhipidura albicollis, Terpsiphone paradisi, Prinia hodgsonii, Prinia socialis, Orlholomus sutorius, Phylloscopus collybita, Phylloscopus neglectus, Phylloscopus proregulus, Seicercus xanlhoschistos, Copsychus saularis, Saxicola torquata, Saxicola caprata, Saxicola ferrea, Saxicoloides fulicata, Myiophonus caeruleus, Parus major, Certhia himalayana, An/hus novaeseelandiae, Motacilla citreola, Motacilla caspica, Motacilla alba, Motacilla maderaspatensis, Dicaeum erythrorhynchos, Nectarina asiatica, Aelhopyga siparaja, Zoslerops palpebrosa, Passer domesticus, Ploceus phillippinus, Lonchura punctulata, Carpodacus erythrinus, Melophus lathami
Mammalia	*Suncus murinus, Rousettus leschenaultii, Pteropus giganteus, Pipistrellus coromandra, Macaca mulatta, Presbytis entellus, Canis lupus, Canis aureus, Vulpes vulpes, Selenarctos thibetanus, Viverricula indica, Paradoxurus hermaphroditus, Herpestes auropunctatus, Felis chaus, Panthera pardus, Muntiacus muntjak, Axis axis, Cervus unicolor, Nemorhaedus goral, Lepus nigricollis, Hystrix indica, Rattus rattus, Mus musculus*

5 MANAGEMENT STRATEGIES

PROPOSED MANAGEMENT STRATEGIES FOR REDUCING SOIL EROSION

Since a major part of the watershed is covered with dense forests, the erosion rates are well below the normal erosion rates. The credit goes to the soil conservation programmes and strategies that were implemented in the past. However, some parts of the watershed suffer from higher soil erosion rates, making the overall erosion rates exeeded the acceptable erosion rates, i.e., 10 tonnes/ha/yr. For reducing the soil erosion rates below the normal rates, the following management strategies may be adopted:

- The worst soil erosion combination occurring on steep slopes with barren land, and nearly 4.55% of the watershed area comes under the barren land category. The erosion of this area can be reduced by afforestation or plantation activities accompanied social engineering with spreading awareness among people about the environment and negative impacts of soil erosion.

- Moreover, some of the areas with dense forest also cover suffer considerably high erosion rates, and so afforestation might not work for reducing the soil erosion. Approximately 35% of the watershed area on the northern bank of the lake is covered with dense deciduous forests, and this area consists of some patches with high erosion rates. This might be because of the steep slope and uninterrupted slope length. In this case, we must reduce the slope length to reduce the LS factor to minimize the erosion. This can be accomplished by constructing contour bunds, bench
- The patches of agriculture constitute less than 0.1% of the total watershed area and are exposed to high erosion rates. These rates can be reduced by adopting better agricultural practices (tillage and construction of bunds around the agricultural fields).
- On both the northern and southern banks of the lake, steep slopes of the watershed were found to be the main drivers of the soil erosion. Nearly 67% of the watershed area comes under the steep slope category (35% deciduous and 32% coniferous). In these regions, the erosion can be prevented by providing breaks in the slopes in the form of bunds, terraces, check walls and toe walls so that the slope lengths are reduced below 22.1 m.

- ***SPRING RECHARGE MEASURES***

In the Renuka wetland sanctuary, there are mainly three overland springs that contribute to the base flow of Renuka Wetland. These are shown in Figure 5. The most important of these is the Doodh Dhara spring which has a recharge area of 9.81 ha. Ram Baori has a recharge area of 1.0 ha, and the other spring has a recharge area of 0.98 ha. In the recharge area of Doodh Dhara, there exists a small pond (Figure 35) that feeds the aquifer. The surface area of this pond is about 265 m^2, and its average depth is about 0.3 m. This pond has silted up in the last few decades. According to the villagers, this pond was used for bathing around 25 years ago. The rest of the recharge area is covered with forests.

Figure 35 *Status of pond in the recharge area*

- ***PROPOSED ACTIVITIES IN THE RECHARGE AREA***

Desilting of pond: The pond located in the recharge area of the Doodh Dhara spring has silted up in the last few decades and needs to be de-silted to increase the capacity of the pond and the discharge of the spring. De-siltation of the pond to a depth of about 2 m (additional depth of approx. 1.5 m or about 400 m^3) will increase the capacity to about 500 m^3, approximately five times the present capacity. This will increase the discharge of the spring and the base flow of Renuka Wetland. The soil dug out may be used to strengthen the bund of the pond.

Staggered contour trenches: In the recharge area, the slope of the ground varies from 30% to 50%. Hence staggered contour trenches (SCT) can be made in this area. The trench size would be 2.5 m in length, 0.6 m in width and 0.6 m in depth. Each trench would have a capacity of about 0.9 m^3. The trenches are constructed on a contour at 2 m intervals. The horizontal spacing of the contours should be about 8 m. This means about 250 trenches can be dug in a 1 ha area. Thus about 2400 trenches can be dug, with a total capacity of about 2000 m^3. These trenches will obstruct the surface flow, retain the water in the trenches and allow it to percolate down to recharge the springs and increase the base flow of the lake. The soil dug out of these trenches can be used to make bunds on the three sides of the trenches downstream.

About 250 trenches can be dug in the recharge area of the Ram Baori spring also. The recharge area of the third spring is steeper than 50%, and therefore it is suggested that plantation activities be opted for in this area.

Grass plantation: To avoid siltation of the trenches, the bund of the trenches is planted with grasses and shrubs. At least eight saplings should be planted on the bund of each trench. Which means about 20,000 grass saplings would to be planted. This would also improve the eco-system.

- ***SOIL CONSERVATION MEASURES***

The total area of the Renuka Wetland Sanctuary, as provided by the forest department, is 405 ha (Figure 36). It has been observed that there is a lot of siltation in Renuka Wetland, which not only reduces the lake capacity but also affects the aquatic species. The silt that enters the lake is from the catchment area of Renuka Lake, which is different from the sanctuary (Figure 37).

Figure 36 *Renuka wetland area*

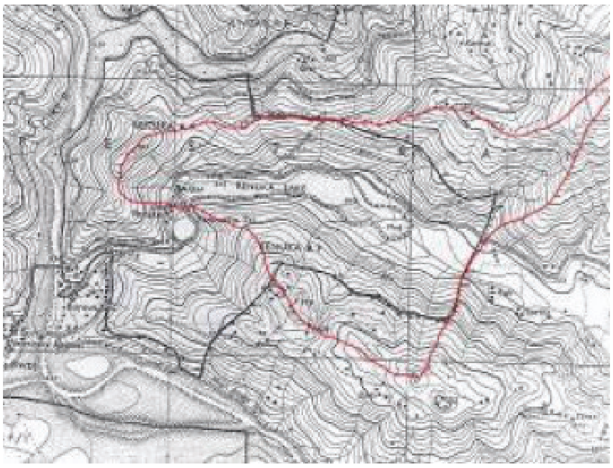


Figure 37 *Renuka catchment area*

The catchment area of Renuka Wetland is about 337 ha, of which 264 ha is in the sanctuary and the rest (about 73 ha) is either with the forest department, Sirmaur or with the villagers (Figure 38).

Figure 38 *Renuka Lake wetland, catchment and common area*

The most crucial patch of soil erosion is in the north-eastern part of the catchment (about 33 ha, as seen in Figure 39). This is only about 10% of the total catchment area, and it contributes about 90% of the total erosion.

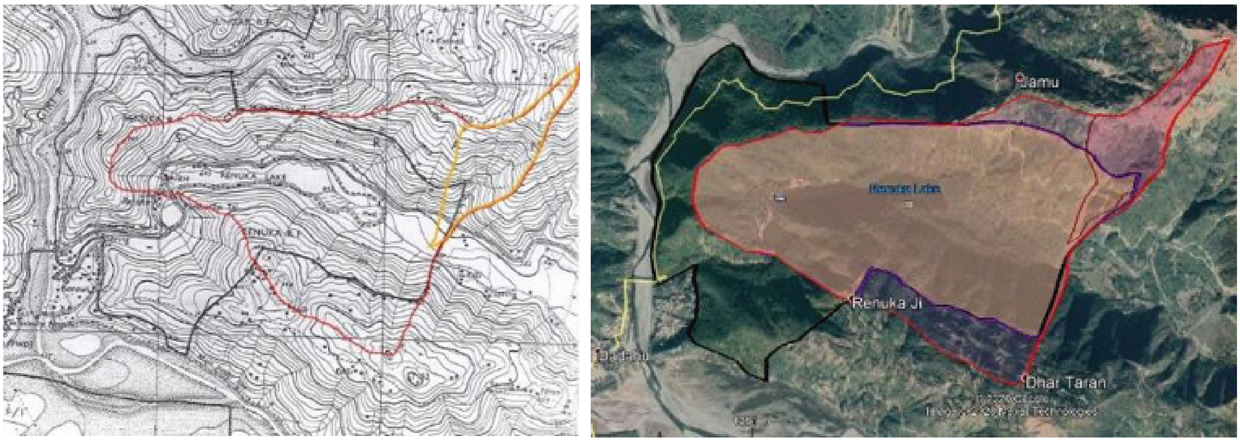


Figure 39 *Most erosive area of the catchment*

The problem with this patch is that about 75% of this area, especially the ridge area, is not in the sanctuary. It is either private land or under the division of the forest department, Sirmaur. The portion that is not in the sanctuary area has very steep slopes (from 60% to about 100%). The lower portion, which is within the sanctuary area, has a slope ranging from 30% to 50%. The soil type varies from loamy to clayey loam in this area.

In the last few years, efforts have been made in Renuka Sanctuary to control erosion. Gabion check dams have been constructed, which get filled up with debris every year (Figure 40).

Figure 40 *Efforts by the sanctuary authority*

- ***PROPOSED MEASURES***

To control soil erosion from the Renuka catchment area, soil and water conservation activities should be carried out. The activities depend on the soil type, slope, vegetation and land use of the area. In the case of the Renuka catchment, as mentioned in the foregoing, the area can be divided into two categories – the normal-erosivity area and the high-erosivity area. The normal-erosivity area has an extent of about 300 ha, and extent of the high-erosivity area is about 33 ha. extent of about 300 ha, and extent of the high-erosivity area is about 33 ha.

Normal-Erosivity Area

- ***STAGGERED CONTOUR TRENCHES***

About 25% of the catchment area (approximately 80 ha) has a slope less than or equal to 50%, where staggered contour trenches can be constructed (Figure 41). These areas are in patches, mostly located on or near the ridge lines, as can be seen in the figure. Staggered contour trenches are the simplest technique of conserving water and there by conserving soil in-situ.

These are techniques that make water walk rather than run, and provide the time required to percolate down. A top view of such activity can be seen in Figure 42. During the process, the surface runoff reduces and so does the erosion. In an extent of 80 ha, approximately 24,000 trenches can be dug, with a total capacity of about 15,000 m^3.

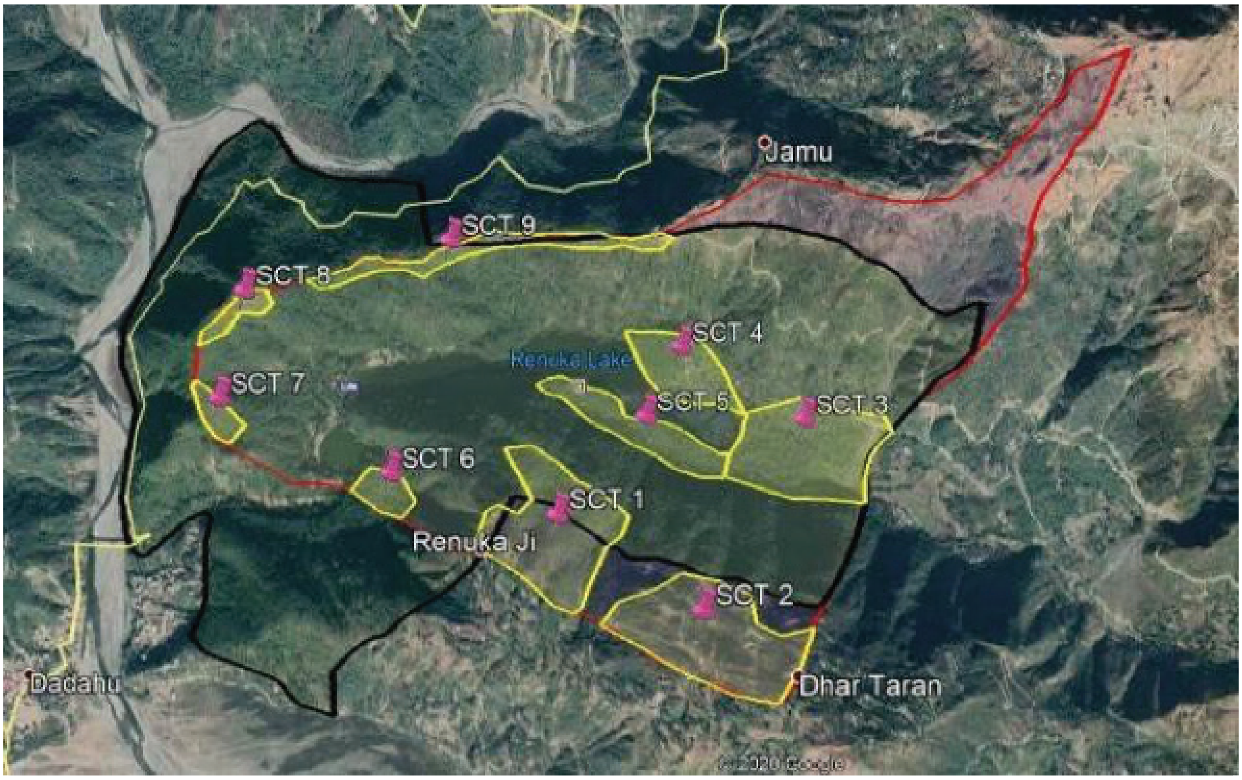


Figure 41 *Patches where staggered contour trenches can be made.*

Figure 42 *A top view of SCT work in Almora*

Figure 43 *A view of toe trench work in Nainital District*

- ***PROPOSED MEASURES***

To control soil erosion from the Renuka catchment area, soil and water conservation activities should be carried out. The activities depend on the soil type, slope, vegetation and land use of the area. In the case of Renuka catchment, as mentioned in the foregoing, the area can be divided into two categories – the normal-erosivity area and the high-erosivity area. The normal-erosivity area has an extent of about 300 ha, and extent of the high-erosivity area is about 33 ha.

- ***GRASS PLANTATION***

To avoid siltation of the trenches, the bund of the trenches is planted with grasses and shrubs. At least eight saplings should be planted on the bund of each trench. This means about 2,00,000 grass saplings need to be planted. This would also improve the ecosystem and further reduce soil erosion.

- ***TOE TRENCHES***

Toe trenches are trenches made along the retaining wall of a terraced field. These are primarily made on terraced agricultural fields in which agriculture is currently being practiced. 3–4 m long trenches are dug along the toe of the terrace. The width and depth of the trench are not more than 0.3 m so that no area is lost for agriculture. Toe trenches need to be made in the part of the catchment area that is being used by the villagers for agriculture. The villagers need to be motivated to de-silt the trenches regularly and spread the soil that has been dug out on their fields. This is the topsoil and will therefore improve the productivity of the field. This is a regular practice in Nainital District and parts of Tehri Garhwal District, in Uttarakhand (Figure 43).

The cost involved for all these activities is approximately Rs.50,000 per ha. Since most of the area has good forest cover, plantation activities have not been proposed. These activities can be carried out on a yearly basis, not necessarily at one time. The most important part is regular de-silting of the trenches to keep them active.

High-erosivity Area

The 33 ha patch on the north-eastern side of the Renuka Wetland experiences very high erosion. Of this, 25 ha has very steep slopes and an active landslide primarily because of the road cutting. Here primarily soil stabilization works need to be implemented.

- ***MECHANICAL METHOD***

The mechanical methods of soil stabilisation include cement grouting with GI meshes, a GI mesh-plantation method, the use of geojute, etc. These methods can be adopted at and near the ridge. In all these methods the GI mesh or geojute mesh is laid on the landslide surface and is properly anchored at different locations as shown in Figure 44. This does not allow soil particles to slide, and if grass seeds are spread over it, they will grow and hold the soil. In the worst situation, cement grouting can be done to stabilise the slope.

Figure 44 *GI mesh anchored on the ground.*

- ***KATTA CRATE***

Further down the slope, the Katta crate system can be adopted. In this method, empty cement bags are carried on to the slope, filled with debris, tied and placed on the contour one over the other in a zig-zag manner. This is to be done continuously for 2–4 years ,until the slope is stabilized.

- ***BIOENGINEERING***

Bioengineering can be done further down the slope. This method is used to control surface erosion by breaking long slopes into shorter ones. In this method, wattles, preferably of native species, are used, especially during the dormant stage and planted in trenches on contours. Bundles of wattles are placed on shallow trenches and covered with soil. In favourable weather, the wattles sprout and slowly stabilize the slope.

- ***RETAINING WALL***

At suitable places like roads and terraces, where the problem of landslide is severe, random rubble stone masonry walls can be constructed. Care should be taken that weeping holes are provided to reduce the soil pressure. Some efforts in this regard have already been made.

- ***GABION CHECK DAMS***

Further downstream, where the slope decreases to about 40% or less, gabion check dams should be constructed across the flow. A proper spillway needs to be planned before construction begins. Although a few gabions have been constructed, they were neither designed properly nor executed in the best manner.

Since this patch of 33 ha experiences high levels of erosion, the cost of the control measures will be quite high. The cost of control structures in this patch will be in the range of about Rs.1,25,000 per ha.

PROPOSED MANAGEMENT STRATEGIES FOR NUTRIENT DYNAMICS AND TROPHIC STATUS

The management strategies can be divided into three categories: (1) physical, (2) chemical and (3) biological. The physical strategies include dilution and flushing, deep aeration and sediment dredging. Renuka Wetland has a high spread area, and hence dilution and sediment dredging will be costly and can affect the lake ecosystem. The present study revealed that Renuka Wetland is a permanently stratified lake system. To improve the quality of the bottom water of the Renuka Wetland, artificial vertical mixing can be adopted without compromising the livestock safety, especially in the deeper regions. Earlier it was observed that the mechanical mixers used for reducing the scum forming micro cysts are effective for a shallower lake system only as they are not effective in breaking the thermal stratification, whereas compressed air mixers are effective (Visser et al., 2016). It is reported that the air diffusion-based mixing system has been in place at Nainital Lake for quite some time. Appropriate references and information may be collected for taking a decision to replicate a similar system. Also, in the shallower macrophyte-infested patches, dredging may be attempted in a careful manner along with raking, duly ensuring that the degraded sediments at the bottom are completely removed and are not allowed to be transported further to the deeper sections.

Chemical strategies include absorption, desorption, altering nutrient ratios and application of potent algicides and herbicides. But in a complex ecosystem, these strategies have been proven to be impractical. Nutrient reduction can be difficult (and expensive) to control, especially in the case of internal loading of nutrients from sediments. However, considering the nitrogen limiting nature as well as the high catchment input of phosphates, appropriate catchment control measures may be needed to arrest erosion from the catchment as well as diverting and treating the point input load to the lake. Treatment of the ashram point load, using an eco-friendly system (like constructed wetlands) or having a combination (hybrid) of conventional and eco-friendly systems alongwith subsequent application of the treated effluent on vegetation beds nearby is needed to prevent the organic input from getting into the lake. Monitoring/evaluation of the waste treatment systems of the guest houses on the bank and treating/disposing of these wastes on the same lines as the foregoing is also needed. The central issue, thus, is that all the waste inputs to the lake need to be stopped and diverted/treated/disposed of appropriately.

The use of algicides, such as copper sulphate, is also effective in reducing harmful algal blooms (HABs) temporarily. However, algicides are expensive to apply, do not generally control the primary cause of the problem (i.e., abundant resources for primary producers) and pose risks to humans, livestock and wildlife, in addition to harming a variety of non-target aquatic organisms. Adequate safety provisions and erection of a temporary barrier (for compartmentalisation) of the shallower and macrophyte-ridden area may be considered seriously, if this option is taken up.

Biological strategies include aquatic bioremediation and microbial remediation. Many past studies have shown strong correlations between the size structure of zooplankton communities and phytoplankton abundance. Their data support the notion that predatory top-down forces can have important implications for aquatic communities and ecosystems. The artificial alteration of the food web to restore ecosystem health (i.e., bio-manipulation) is an alternative for improving water quality in nutrient-rich lakes. The basic premise is that secondary consumers are removed either through the addition of tertiary consumers or harvesting as the generalist grazers (e.g., Daphnia) that control the phytoplankton also control the risk of algal blooms.

MANAGEMENT STRATEGIES FOR MACROPHYTES

Controlling nuisance vegetation in the Renuka wetland is necessary to ensure that further eutrophication and its adverse impacts on the water environment are checked. Aquatic weeds in wetlands are different from terrestrial weeds in the way that they grow excessively. This is becoming a prime concern in the Renuka wetland. Though sedimentation and silting has also aggravated the eutrophicated area, especially in the peripheral region of the wetland, a few macrophyte species have dominated the region, leading to a highly eutrophicated region. Hence methods involving physical, chemical or biological controls are required for controlling noxious species (invasive aquatic plants) altering the water quality and the diversity of living organisms in the wetland. Physical or mechanical methods simply remove macrophytes by manually uprooting them from their niche. Fragments of stems, roots, tubers, etc. are removed manually, with application of herbicides to avoid re-growth in the long term. Eradication of infestations of plant species is initially required at the first stage, followed by dredging of the region.

Chemical methods involve a judicious use of herbicides, algicides and other chemicals that have a direct impact on the specific aquatic macrophyte of concern, with care being taken that these chemicals do not alter the water quality. However, the treatment at the site should be supported by continuous monitoring plans to avoid further infestations. Controlling large patches of unwanted species requires long-term planning and treatment with both mechanical and chemical methods. Details of eradication of various macrophyte species are as follows:

- Repeated mechanical harvesting can reduce the stem densities of Potamogeton species, but the escaped stem fragments may develop into new plant structures (Newman, 2013)[64]. Therefore, boat propellers and fishing gear maybe used for the above purpose. Polyvinyl chloride (PVC) sheets and small-mesh screens used as bottom barriers are effective against Potamogeton. Endothall, fluridone and flumioxazin application control the growth but expert advice is required to use these. Weed cutters, T cutters, hand-held aquatic seaweed cutting and removal tools for lake/ponds can be used initially to control weeds in the wetland. Grass Carp, when introduced, reduces the growth of weeds and is one of the biocontro agents used in wetlands. De-silting and dredging are urgently needed for reviving the Renuka wetland and putting a check on weeds and noxious macrophytes.

- Macrophyte species such as Azolla (small infestations) can be removed using mesh nets. Large infestations may be controlled using surface skimmers or surface suction. The use of diquat, carfentrazone and flumioxazin is also effective against Azolla species.

[64] Newman, J. (2013). Chemical Control of Aquatic Plants: Why Use Herbicides?

- Nelumbo has medicinal uses and can be utilized by villagers living near the wetland. It cannot grow without sunlight, and therefore shading the area, along with manual removal, may decrease its population.
- Generally, herbicide application along with mechanical treatment is used to control Phragmites. One of the best control methods is application of herbicide, alongwith removal of dead and decayed plants should be by pulling, cutting and burning. For achieving long-term eradication, herbicides can be used in an area-specific manner, considering the sensitive zones of the wetland. Treatment can be done from mid to late June till October. Isopropylamine salt of glyphosate is commonly used for Phragmites control, known as Rodeo. It is mixed with water and a surfactant that allows it to be absorbed by the Phragmites. Herbicides are not efficient in reducing populations of Phragmites and kill other macrophytes in the vicinity. Glyphosates biodegrade rapidly in the environment and produce carbon dioxide, nitrogen, phosphate and water (Rohal et al., 2019)[65]. Since glyphosate does not volatilise, it will not vaporize from a treated site and move to a non-target area. The damaged Phragmites should be removed from the wetland as soon as possible to avoid re-entry of nutrients and macrophyte parts into the water environment. Cutting has been used successfully to control Phragmites, and repeated cutting of aerial parts, especially at the end of July, reduces the plant growth and vigour. Increasing the salinity and flooding the rhizomes also control the macrophyte.
- It is best to control an Alternanthera species as soon as it tries to establish itself in the vicinity of the wetland to avoid further dominance in that area. Hence, repeated harvesting along with the removal of fragments may reduce the population for a short duration of time. Though A. philoxeroides is resistant to most of the herbicides, some, such as bentazone, bifenox, dicamba, fenoprop, pendimethalin, propanil and triclopyr, can be used to control the species but not completely eradicate it. The herbicides metsulfuron methyl, glyphosate, dichlobenil and a mixture of glyphosate and metsulfuron methyl have been used to control Alternanthera species (Agribioscience et al., 2017)[66]. The flea beetle Agasicles hygrophila is used widely as a biocontrol agent. It resists plant growth and damages the leaves, hindering the photosynthetic activity of the plant.
- Physical/mechanical treatment of S. erectum involves cutting during the summer growing season. This has been shown to decrease the biomass of the stands significantly. However, cutting allows rapid regrowth of rhizomes, making it unlikely that mowing will be effective in eradicating established S. erectum populations. Regular cutiing during June and August will also eliminate the species. Moreover, glyphosate applied at a concentration of 5 litres per hectare during the growing season will reduce S. erectum growth. Repeated applications will be necessary after 2 or 3 years if the stand has regrown. Cattle and other livestock uproot and feed on the macrophyte, thereby controlling its growth. Shading the macrophyte with other large trees controls its growth. It is also controlled by lowering water levels to dry out stands for a period between 6 weeks and 3 months. It can be controlled by increasing the water depth beyond 50 cm or by increasing the flow significantly. If the stand is small, then manual removal by hand is recommended (pulling out each plant). If the stand is larger, cutting repeatedly for 3–4 years during July, followed by application of a herbicide can control the population.
- Physical/mechanical methods are effective for removing dense colonies of Colocasia but the removal of corms and tubers require a lot of effort. Therefore, mechanical cutting of the plant from the base of the stem and application of N-phosphonomethyl-glycine (glyphosate) and repeating the treatment at 6-week intervals is generally recommended. Application of glyphosate is not recommended for wetland areas with high dosage.
- Najas species can be temporarily removed manually, but fragmenting allows it to re-occur in a short duration of time. Therefore, barriers may be attached to the sediment bottom and maintained at intervals to avoid its growth. Hence, aquatic plant harvesters maybe used at intervals to control the species. Application of endothall, diquat dibromide, dipotassium, fluridone containing amine salts can control a large population of Najas species.
- Lemna species are put to human use because of their high protein rich content. They are not noxious. Therefore, harvesting them for beneficial uses with the involvement of local tribes/populations will help them earn a living.

[65] Rohal, C. B., Cranney, C. & Hazelton, E. L. G. (2019). Invasive Phragmites australis management outcomes and native plant recovery are context dependent. Ecology and Evolution, 9: 13835– 13849. https://doi.org/10.1002/ece3.5820
[66] Clements, D, Dugdale, TM, Butler, KL, Florentine, SK & Sillitoe, J (2017). Herbicide efficacy for aquatic Alternanthera philoxeroides management in an early stage of invasion: integrating above-ground biomass, below-ground biomass and viable stem fragmentation. Weed Research 57, 257– 266.

The following table sums up in brief the specific and common strategies used for removal of macrophytes:

Table 21 *Specific and common strategies for removal of macrophytes*

<table>
<tr><th>Name of the macrophyte</th><th>Specific management strategy</th><th>Management strategy that can be employed for Renuka wetland macrophytes</th></tr>
<tr><td>Potamogeton species</td><td>Repeated mechanical harvesting, weed/T cutters, boat propellers, fishing gears can be used initially for control. Application of endothall, fluridone, flumioxazin. Grass Carp (fish) can be used for biocontrol.</td><td rowspan="9">1. De-silting and dredging of bottom sediments are urgently needed for the Renuka wetland as dead and decayed plants/animals have settled at the bottom over the past years and silt is acting as a sink for nutrients.

2. Physical or mechanical removal is recommended at the initial stage. Meshes, nets, weed rollers and aquatic weed harvesters may be used for the purpose at intervals to avoid regrowth.

3. Use of Grass Carp as biocontrol.

4. Use of chemical control methods like glyphosate (with recommended dose as suggested by the manufacturer), followed by the above -mentioned methods, if needed.

5. Put a check on weeds and noxious macrophytes, as suggested in the list of specific management strategies for individual macrophyte species, ensuring optimum use of herbicides.</td></tr>
<tr><td>Azolla pinnata</td><td>Mesh nets and surface skimmers. Application of diquat, carfentrazone and flumioxazin</td></tr>
<tr><td>Nelumbo nucifera</td><td>Manual removal</td></tr>
<tr><td>Hydrilla verticillata</td><td>Application of fndothall, or chelated copper. Grass Carps can be used as biocontrol.</td></tr>
<tr><td>Phragmites australis</td><td>Repeated cutting not allowing biomass to return to water. Application of isopropylamine salt of glyphosate</td></tr>
<tr><td>Alternanthera philoxeroides</td><td>Repeated harvesting, application of metsulfuron methyl, glyphosate, dichlobenil and a mixture of glyphosate and metsulfuron methyl. Use of flea beetle Agasicles hygrophila as biocontrol.</td></tr>
<tr><td>Sparganium erectum</td><td>Regular cutting during the summer growing season. Can be controlled by increasing water depth to greater than 50 cm or by increasing flow significantly. Application of glyphosate as a chemical control method.</td></tr>
<tr><td>Colocasia esculenta</td><td>Mechanical cutting of the plant from the base of the stem and application of N-phosphonomethyl-glycine</td></tr>
<tr><td>Najas minor</td><td>Temporarily can be removed manually. It grows quickly from fragments. Aquatic plant harvesters can be used at intervals. Application of endothall, diquat dibromide, dipotassium, fluoridone</td></tr>
</table>

MANAGEMENT STRATEGIES FOR ANIMAL WASTES FROM THE ZOO

- Construction of catchwaters all along the roadside to check and collect surface runoff from the zoo side and bathing ghat. It is important to make appropriate arrangements for their safe disposal outside the catchment. This will check liquid waste from the zoo and other areas entering the water body.
- Creation of buffer zone with plantation inside the zoo boundary.
- Measures such as safety tank or mini wastewater treatment plant inside the zoo boundary needs to be taken to check the zoo waste (solid and liquid) from entering the water body.

6 MONITORING PLAN

MONITORING SPRINGS AND RAINFALL IN THE RENUKA WETLAND

Data on the periodic spring discharge and quality and the rainfall can help us understand spring behaviour and aquifer characteristics. Therefore, the data collector should understand the process of monitoring the discharge, quality and rainfall in the field and should timely collect and store data in the prescribed format and their transfer them to the concerned office. Rainfall should be recorded daily throughout the year, while spring discharge data should be recorded at least bimonthly or monthly, according to the availability of human and financial resources for a particular location.

- ***SETTING UP RAIN GAUGES FOR MEASUREMENT OF RAINFALL***

Rainfall data are important for establishing relationships between the recharge and spring discharge and the characteristics of an aquifer that feeds springs. Automatic and manual rain gauges are available to measure rainfall. Rainfall monitoring can be conducted at three levels. Automated (self-recording) rain gauges can be installed at select locations, depending on the financial resources of the programme.

If the resources do not permit automated rain gauges, then a minimum of one standard calibrated manual rain gauge should be installed in each springshed. Ideally, the rainfall should be monitored at the recharge site and at the spring site. However, in an event where only one rain gauge can be installed, it should be installed at a location between the recharge area and the spring.

- ***MEASUREMENT OF SPRING DISCHARGE***

Discharge (Q) is the volume of water flowing from a spring per unit time. It is measured in litres per minute (lpm) or litres per second (lps). The method of measuring spring discharge will depend on the amount of spring discharge, the type of spring as well as the infrastructure that surrounds a spring. Discharge is an important parameter to understand the characteristics of an aquifer. The long term discharge data of a spring indicate the nature of a spring (perennial or seasonal) and the storage and transmission capacity of an aquifer. Spring discharge can also be measured daily, weekly, fortnightly, monthly or seasonally. Depending on the resources available, springs should be monitored at least seasonally, and the frequency should increase during the monsoon. Various methods can be used for measuring spring discharge, such as the water-level drop method (for springs discharging into enclosed tanks), container method for low to medium discharge springs (measuring the time taken to fill a container of a known volume) and V-notch and rectangular weirs for high discharge springs.

DEVELOPING A WATER BALANCE FOR THE WETLAND

Monitoring the rainfall, evaporation, spring discharges, water level of the lake and outflow from the lake will enable the development of a water balance. Given that the lake seems to receive spring discharges below the water level, it is difficult to directly measure the groundwater contribution to the lake. Daily measurement of rainfall will enable quantification of surface inflows into the lake using a runoff coefficient. An evaporimeter will enable quantification of evaporation losses while the discharge from Renuka Lake (using the V-notch that already exists between the Renuka Wetland and Parshuram Tal) will enable quantification of the outflow from the lake. A formula for developing Renuka Wetland's water balance is given here:

Water balance equation

± Change in storage over time = evaporation + surface water inflow + groundwater inflow - outflow

Table 22 *Description and frequency of monitoring select parameters required for developing a water balance*

Water balance aspect	Parameter	Method for estimation/ calculation	Frequency of monitoring
Change in storage	Water level in the lake	Change in water level in the lake (using a staff gauge)	Daily monitoring of water level
	Bathymetry	Bathymetric survey	One time. Repeat surveys based on rate of sedimentation to assess changes in potential volume of lake.
Outflows	Evaporation	Directly using a pan evaporimeter	At least daily
	Surface outflows	V-notch	At least daily
Surface water inflows	Rainfall	Manual and/or automatic rain gauges. Manual gauges can be near the forest department office, while the automatic gauge can be in the catchment.	At least daily
	Watershed area		One time
	Runoff coefficient (for peak discharge)	Based on land use	One time. But can be assessed again if any significant changes in land use are observed.
Groundwater contribution	Spring discharge	Measurement based on the emergence of springs	Ideally weekly, but at least monthly, with a higher frequency in the monsoon
	Spring discharge/baseflow contribution that cannot be directly measured	Estimation using the formula given in the foregoing.	N.A.

WATER QUALITY MONITORING

DESIGN OF WATER SAMPLING AND MONITORING PROGRAMME

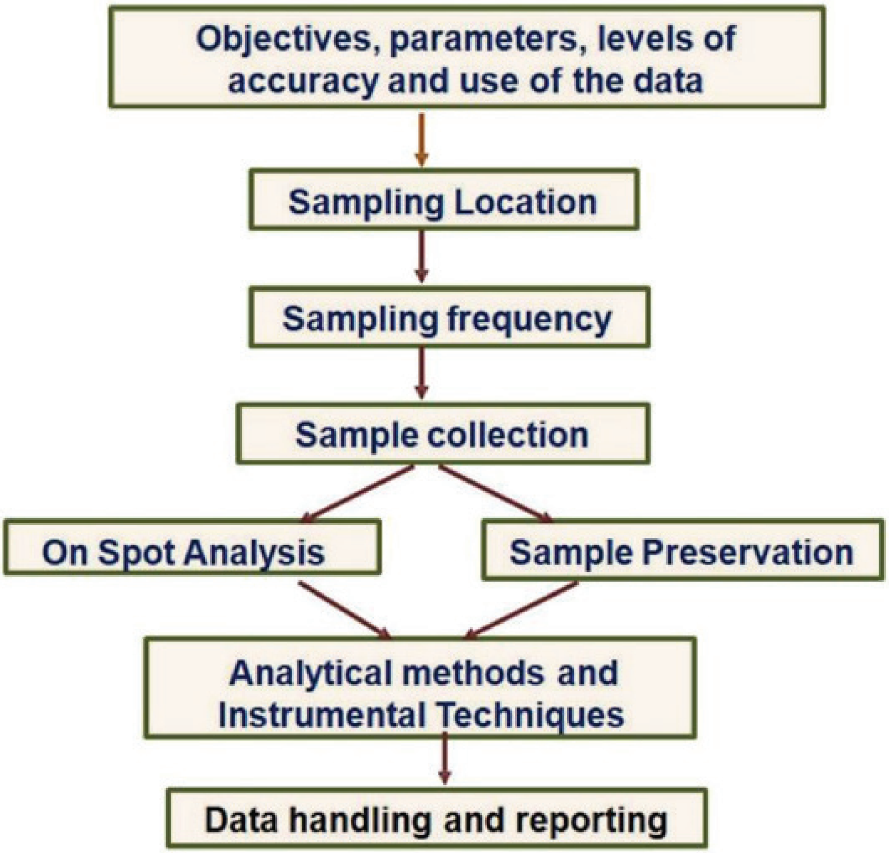


***Figure 45** Design of water sampling and monitoring programme*

• *SELECTION OF SAMPLING SITE FOR PHYSICO-CHEMICAL AND BACTERIOLOGICAL MONITORING*

The selection of sampling sites for water quality estimation in a lake depend on the size of the lake. Water sample should be collected from the point where water enters the lake (inlet point) and exits it (outlet points), and also from upstream and downstream of visible sources of pollution. Apart from this, samples should be collected at a distance to represent the quality of the entire water body. To monitor the vertical status of the lake, sampling should be performed at different depths at some of the sampling points. For example, if the depth of the lake is 12 m, then the first sample should be at a depth of 1.5 m below the surface, the second at 5.5–6.0 m, and the third sample should be taken at 11–11.5 m.

• *SAMPLE COLLECTION*

- Samples should always be collected against the water current.
- Sample should be collected as far as possible from mid-stream and mid depth.
- Samples near the bank should be avoided; they may be collected from a boat wherever feasible.

• *COLLECTION AND PRESERVATION OF WATER SAMPLES*

The samples should be collected and preserved following the processes described in Table 23.

Table 23 Procedure for water quality sampling, storage and frequency of sampling[67]

S. no.	Parameter	Sampling bottles/ containers	Sample size On-site testing	Preservation of samples	Maximum storage On-site testing	Frequency
1	Temperature			On-site testing		A
2	Transparency					A
3	pH	P/G	50 ml	Analysed immediately	0.25 hours	A
4	Dissolved oxygen	P/G	300 ml	Analysed immediately	0.25 hours	A
5	BOD	P/G	1000	Refrigerate	6 hours	
6	Specific conductance	P/G	500 ml	Refrigerate	28 hours	A
7	TDS	P/G	500 ml	Refrigerate	28 hours	A
8	Alkalinity	P/G	200 ml	Refrigerate	24 hours	A
9	Hardness	P/G	100 ml	HNO_3 or H_2SO_4 to adjust the pH<2.	6 months	B
10	Chloride	P/G	100 ml	Refrigerate	NA	B
11	Fluoride	P/G	100 ml	Non required	28 hours	B
12	Nitrate	P/G	100 ml	Analyse as soon as possible	48 hours	B
13	Phosphate	P/G	100 ml	Refrigerate	48 hours	B
14	Total Iron	P/G	200 ml	Filter immediately. Add HNO_3 to adjust the pH<2.	NA	B
15	Coliform	P/G	250 ml	Refrigerate	12 hours	A

- ***SELECTION OF SAMPLING SITE FOR BIOMONITORING***

In this technique, the water quality is determined on the basis of number of invertebrates found in the sediments of any water body such as a river, pond or lake. The main feature of these organisms is that they (larvae of insects, snails, oysters) live only in their fixed place. Some of these invertebrates are very sensitive to pollution and cannot survive in polluted water. But there are many that can survive in both types of water. There are some that are tolerant to pollution, and there are some invertebrates that prefer to live only in polluted water. On the basis of this property of these organisms, they are classified into different groups.

Unfortunately, these organisms are not randomly distributed in water bodies and different habitats (sand, soil, gravel or organic material). They tend to occur in clusters. Therefore, a minimum length of 100 m of the lake shore, at a depth of 0.5 m, should be assessed. The study should be conducted once per month from October to May.

[67] P, PVC; G, glass; A, monitoring weekly or fortnightly; B, seasonal

• ***STEPS FOR SEDIMENT DATA COLLECTION TO ESTIMATE SOIL EROSION FROM A WATERSHED***

Figure 46 *Sediment filtration unit at Watershed Management Laboratory, Department of Hydrology, Indian Institute of Technology Roorkee*

Figure 47 *Sediment trapped on filter paper (45 microns) after filtering of a water sample*

1. The sediment collection has to be done at a suitable site in the stream, which provides an ideal representation of the stream. The selected site should be a straight reach, preferably having a straight stretch of approximately four times the width and free from silting and scouring. The selected section should be in the middle of the stretch, preferably away from any disturbances, but should be easily accessible for sampling.
2. The sampler to be used should preferably be streamlined and should not disturb the flow. During sampling, the mouth of the sampler should face the direction of flow, and the velocity of flow at the mouth of the sampler should be equal to the flow velocity.
3. The sample should be collected from different depths from the same section to represent the average concentration of the sediments. A bottle silt sampler of the UPIRI type is most suitable for shallow depths and low velocities. However, the Turbidisonde L-80 sediment sampler is most accurate for larger depths. The USP- 63, USP-61, USP-50 and USP-46 samplers are also suitable. For depth integrating sampling in a vertical, the USDH-48 sampler is satisfactory at low velocities and depths. However, the USD-49 and Turbidisonde L-80 are preferred for higher depths and velocities because of their larger weight.
4. The collected water samples are then filtered through 45-micron filter paper using a filtration unit (powered by a suction pump) to quantify the sediment concentration.
5. Further, the sediments trapped on the filter paper are oven-dried for 24 hours at a temperature of 105–110°C. Subsequently, weight analysis is done to quantify the weight of the sediment in a known volume of water. It is generally expressed in g/l or kg/m3.

Registered Offices:

Bonn and Eschborn, Germany
Friedrich-Ebert-Allee 32 + 36
53113 Bonn, Germany

Dag-Hammarskjold-Weg 1-5
65760 Eschborn, Germany

Email: info@giz.de

A2/18, Safdarjung Enclave
New Delhi-110029, India
Tel: +91 11 4949 5353
Fax: +91 11 4949 5391

Email: biodiv.india@giz.de