MINISTRY OF FORESTS AND ENVIRONMENT

WETLAND HEALTH REPORT CARD

A METHODOLOGICAL FRAMEWORK FOR ASSESSING THE STATUS OF WETLANDS IN NEPAL

Department of National Parks and Wildlife Conservation

Department of Forests and Soil Conservation

WETLAND HEALTH REPORT CARD: A METHODOLOGICAL FRAMEWORK FOR ASSESSING THE STATUS OF WETLANDS IN NEPAL

Published by

Government of Nepal
Ministry of Forest and Environment
Department of National Parks and Wildlife Conservation and
Department of Forests and Soil Conservation

In technical support with WWF Nepal

Technical Experts

Bishnu Shrestha, Under-Secretary, Department of National Parks and Wildlife Conservation
Rajesh Sada, Head of Freshwater Programs, WWF Nepal
Deep Narayan Shah, PhD, Wetland Expert, Tribhuvan University
Ram Devi Tachamo-Shah, PhD, Freshwater Ecologist, Kathmandu University
Shailendra Pokharel, Wetland Expert

Reviewers

Maheshwor Dhakal, PhD, Director General, Department of National Parks and Wildlife Conservation
Ram Chandra Kandel, PhD, Chief, REDD Implementation Centre
Bed Kumar Dhakal, Secretary, Ministry of Industry, Tourism, Forest and Environment, Sudurpashchim Province
Ajay Karki, Deputy Director General, Department of National Parks and Wildlife Conservation
Ganesh Paudel, Deputy Director General, Department of Forests and Soil Conservation
Nabaraj Pudasaini, Deputy Director General, Department of Forests and Soil Conservation
Ganesh Pant, PhD, Ecologist, Department of National Parks and Wildlife Conservation
Bishnu Bhandari, PhD, Wetland Expert
Richard Storey, PhD, Wetland Ecologist

Citation

DNPWC and DFSC (2023). Wetland Health Report Card: A Methodological Framework for Assessing the Status of Wetlands in Nepal. Department of National Parks and Wildlife Conservation and Department of Forests and Soil Conservation. Ministry of Forest and Environment, Kathmandu, Nepal.

Date: 2 February 2023

Front and Back Cover Page Photo
Beeshazari and Associated Lakes and Phoksundo Lake © DN Shah

Design, and Layout: Saurav Thapa Shrestha, Everything Creatives Pvt. Ltd.

WETLAND HEALTH REPORT CARD

A METHODOLOGICAL FRAMEWORK FOR ASSESSING THE STATUS OF WETLANDS IN NEPAL

Government of Nepal
Ministry of Forests and Environment
Department of National Parks and Wildlife Conservation and
Department of Forests and Soil Conservation

Government of Nepal
Ministry of Forest and Environment
Department of National Parks & Wildlife Conservation

Government of Nepal
Ministry of Forest & Environment
Dept. of National Parks & Wildlife Conservation
Babarmahal, Kathmandu
2037

Foreword

Wetland ecosystems are key landscapes for conservation as they provide several critical functions. They are the critical habitats for many species, and they provide numerous goods and services to the humankind. In addition to clean water supply, they act as basis of life for vegetation, wildlife, fisheries and agriculture and are also a source of energy production. They prevent and regulate floods, act as sediment and nutrient retention, also serve as a carbon sink. Besides, they are excellent sites for tourism from which country like Nepal can generate huge revenue. On top of these, they have significant cultural, religious and historical values in Nepal.

In Nepal, wetlands cover around 5% of the total land surface area. The country has over 5000 wetlands distributed across the country from lowland Tarai to highland Mountains and of which only 10 wetlands have been enlisted as Ramsar Site. Despite the invaluable importance of wetland, they have continuously been threatened by unsustainable human practices, domestic and industrial effluents, waste disposal, proliferation of invasive species, and water diversions for irrigation, hydropower development and domestic use which further impacted the services provided by the wetlands.

Hence, it is very important to understand the wetland condition for timely protection, restoration and management for which a systematic framework is imperative that can assess the ecological integrity of the wetlands. Department of National Parks and Wildlife Conservation (DNPWC) has a plan to prepare wetland health report card of Ramsar sites of Nepal as planned by Nepal's National Ramsar Strategy and Action Plan (NRSAP) (2018-2024). However, scientific methodological framework to assess the status of wetland health was not available.

In this regard, this "Wetland Health Report Card: Methodological Framework for Wetland Health Assessment" is very pertinent and timely and could be the biggest asset for understanding the wetland health status in the country. Timely preparation of health report cards for wetlands including Ramsar sites fulfills the objectives of the Wetland Policy 2012 and NRSAP (2018-2024).The wetland health report card will be extremely useful for a wide range of stakeholders including local people, conservationists, policy makers and decision makers.

I am confident that use of this methodological framework can showcase the changes in wetland health status over the years by helping decision makers and policy makers to prioritize the wetlands and allocate resources accordingly for effective wetland protection, restoration and management.

Finally, I would like to thank World Wildlife Fund Nepal for generous financial and technical support for preparing the document. I'd like to thank all the technical experts engaged in preparing this document and reviewers of the framework including Dr. Ram Chandra Kandel, Dr. Bishnu Bhandari, Mr. Bed Kumar Dhakal, Dr. Ganesh Pant,Mr. Bishnu Shrestha, Mr. Rajesh Sada, Dr. Deep Narayan Shah, Dr. Ram Devi Tachamo, Mr. Shailendra Pokharel and Dr. Richard Storey.

Maheshwor Dhakal, PhD
Director General

G.P.O. Box : 860, Kathmandu, Nepal. Tel. 4220919, 4220850, 4227926, Fax : 977-01-4227675

Government Of Nepal
Ministry of Forests And Environment
Department of Forests and Soil Conservation

Tel.: 977-1-4227574
977-1-4220303
977-1-4221231
977-1-4221744
977-1-4216379
977-1-4256227
Fax:977-1-4227374

Babar Mahal
Kathmandu, Nepal

Ref. No. 818

Government of Nepal
Ministry of Forests and Environment
Department of Forests and Soil Conservation
Babarmahal

Foreword

Healthy wetlands are vital ecosystems that offer numerous benefits, including high biological diversity, improved water quality, flood and sediment regulation, and wildlife habitats. They support rural livelihoods, fulfill cultural rituals, and aid in agriculture and local economies.

Wetlands are also significant sink of carbon, which makes them important in mitigating climate change. However, many wetlands are facing degradation due to wrong human practices, pollution and water diversions. To effectively manage and conserve wetlands a systematic framework is needed to assess their health. The wetland health report card provides this information, serving as an early warning tool for wetland health status that is easily understood by all stakeholders including policy makers. The report card can be used to compare the wetland health over time and prioritize protection, restoration and management efforts.

I appreciate the World Wildlife Fund (WWF) for their significant role in preparing this document and I thank all the technical experts and reviewers for their contribution.

Mr. Devesh Mani Tripathi
Director General

Beeshazari Taal
© Deep Narayan Shah

TABLE OF CONTENTS

LIST OF ANNEXES, TABLES AND FIGURES

ANNEXES

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

DNPWC	Department of NationalParks and Wildlife Conservation
DOF	Department of Forest
DPSIR	Driver, Pressure, Stressor, Impact, Response
GoN	Government of Nepal
IUCN	International Union for Conservation of Nature
IAS	Invasive Alien Species
LWQI	Lagoon Water Quality Index
MEA	Millennium Ecosystem Assessment
MoAD	Ministry of Agricultural Development
MoFSC	Ministry of Forests and Soil Conservation
MoFE	Ministry of Forests and Environment
MoPE	Ministry of Population and Environment
MT	Metric Ton
NBSAP	National Biodiversity Strategy and Action Plan
NLBI	Nepal Lake Biotic Index
NLCDC	National Lake Conservation Development Committee
NRSAP	National Ramsar Site Strategy and Action Plan
NWP	National Wetland Policy
US	United States
WESI	Wetland Ecosystem Status Index
WHS	Wetland Health Status
WMMI	Wetland Multi-Metric Index
WQI	Water Quality Index

GLOSSARY OF TERMS

Assessment
A detailed evaluation of how a wetland functions and its values as perceived by a society.

Dissolved oxygen
Amount of oxygen dissolved in water expressed in milligrams per liter (mg/L) or parts per million (ppm).

Eutrophication
Excessive enrichment of nutrients in the water that causes the excessive growth of aquatic plants and the activity of anaerobic microorganisms (which live with little to no oxygen). This growth causes the suffocation of aquatic organisms such as fish.

Healthy wetland
A healthy wetland can sustain its original ecological character and can perform all its vital functions regularly and provide quality ecosystem services to wildlife and people

Organic matter
Matter based on carbon compounds in nature that comes from a living organism such as plants and animals.

Parameter
An element or variable that can be used to measure or evaluate the condition or characteristics of a system

Sampling
Process by which a portion of material is selected in a sufficient volume to be transported and analyzed.

Wetland health
It is the condition or status of a wetland. It refers to the integrated state of physical, chemical and biological characteristics of the wetland. It is often seen as being analogous with human health.

Wetland health class
It is the classification of wetland conditions based on perturbations. Wetland health class is categorized into 4 classes, namely: High, Good, Fair and Poor.

Wetland health report card
A showcase to translate the complex information on physical, chemical and biological characteristics of a wetland into a simple format of different colors representing wetland health classes.

Water Quality Index
Water Quality Index (WQI) is widely regarded as the most accurate way of assessing water quality. A mathematical equation including a number of water quality parameters are used to grade water quality and determine its acceptability for a healthy ecosystem.

EXECUTIVE SUMMARY

Wetland ecosystems are key landscapes for conservation as they provide several critical functions. They are the critical habitats for many species, and they provide numerous goods and services to mankind. In addition to clean water supply, they act as the basis of life for vegetation, wildlife, fisheries and agriculture and are also a huge source of energy production. They prevent and regulate floods, retain sediment and nutrient, and also serve as a carbon sink. On top of these, they have significant cultural, religious and economic values in Nepal. Despite of these invaluable importance of wetlands, they are not prioritized in the conservation arena of Nepal, resulting in gradual destruction and degradation. The ecosystem integrity of wetlands has not been studied yet nor there is enough scientific evidence or documents prepared to show their status which otherwise would have been helpful in comparing the wetland condition every year or every two years to understand the status and trend. Assessing wetland health requires an accurate assessment of the current ecological state of the wetland ecosystem and hence need to consider all elements of a wetland ecosystem including water quality, aquatic flora and fauna, birds, hydrology, catchment disturbances and so on. In this regard, it is pertinent to develop a common and contextual methodological framework for Nepal so that all the upcoming wetland health assessments can follow the same methodology and can be made comparable to each other.

In this manual, a detailed methodological framework for assessing the health of wetlands including RAMSAR sites in Nepal is presented. Additionally, wetland health status is translated into a wetland health report card. The developed health report card comprises of three metrics: water quality (dissolved oxygen, pH, conductivity, total nitrogen, total phosphorus, chemical oxygen demand and biotic score), biodiversity (macroinvertebrates, fishes, birds and macrophytes and their respective Shannon Weiner diversity index), and ecosystem services (provisioning and cultural). Each metric gives four status classes: 1, 2, 3, and 4. This health report card does not address every indicator or environmental issue that our wetland faces, however, it does provide the public with broad fact-based knowledge about the condition of wetlands. Since the function and structure of wetland ecosystems vary across physiographic zones, i.e., High Mountain, Mid-hills and Lowland Tarai, the wetlands may not provide goods and services at the same quantity and degree. Therefore, different weightage scores are assigned to each metric with respect to physiographic zones. The sum of the final score gives a single numerical value and is called the “wetland multi-metric index (WMMI)”.

The newly developed WMMI will assess the health of wetland ecosystems across different physiographic zones: High Mountain, Mid-Hills and Lowland Tarai. The final WMMI value is tallied with transformation scale for the determination of final wetland health class. The wetland health has four classes: “Excellent”, “Good”, “Fair”, and “Poor”. Based on this, the health report card can be prepared, which will help decision makers and policy makers to prioritize the wetlands and allocate resources accordingly for their restoration. This card helps conservation partners and policy makers to prioritize the wetlands and allocate resources accordingly for their restoration and preservation. In the future, the assessment method can be revised based on the generation of huge dataset including other important biotic groups and analysing them to understand their influence.


© Deep Narayan Shah

PURPOSE OF THE MANUAL

Healthy wetlands are critical for biodiversity preservation, water quality enhancement, stream-flow maintenance, flood control, and carbon sequestration. They also provide key habitats to many threatened and endangered species. Despite their significance, wetlands are continuously being degraded due to unsustainable human activities, pollution, dumping of wastes, land use conversion, proliferation of invasive species and over-exploitation of the wetland resources. Approximately 35% of the wetlands were lost between 1970 and 2015 across the globe and the rate of loss is even accelerating annually since 2000. Nepal is not an exception, around 5.41% of the total wetland have been converted to cropland over the years. Lack of clear policies, management responsibilities, inadequate technical and institutional capacities have further aggravated the situation. Hence, assessment and monitoring of wetlands through a standardized protocol would help timely determination of their status and the restoration and maintenance could be done with limited resources and time. In this context, a wetland health report card is an effective showcase to translate the complex information on ecological quality, biodiversity and ecosystem services of wetlands into simple form that is easily understandable by local stakeholders and non-technicians including policy makers. Development of wetland health report card for wetlands in Nepal help to achieve the objectives and strategies envisioned in the National Wetland Policy (2012), National Biodiversity Strategy and Action Plan (2014-2020) and National Ramsar Strategy and Action Plan (2018-2024).

This manual provides a detailed assessment framework for evaluating the health of wetland ecosystems across the country. A systematic assessment approach provides a complete assessment method with a list of essential equipment and consumables required for the determination of wetland health and the production of wetland health report card.

Three metrics are calculated based on 16 key parameters from water quality parameters, biodiversity and ecosystem services for evaluation of wetland health. Each metric has four status classes: 1, 2, 3 and 4. Finally, the overall wetland health is calculated by determining the Wetland multi-metric Index (WMMI). The obtained value is translated to respective status class for developing a wetland health report card.


© Deep Narayan Shah

INTRODUCTION

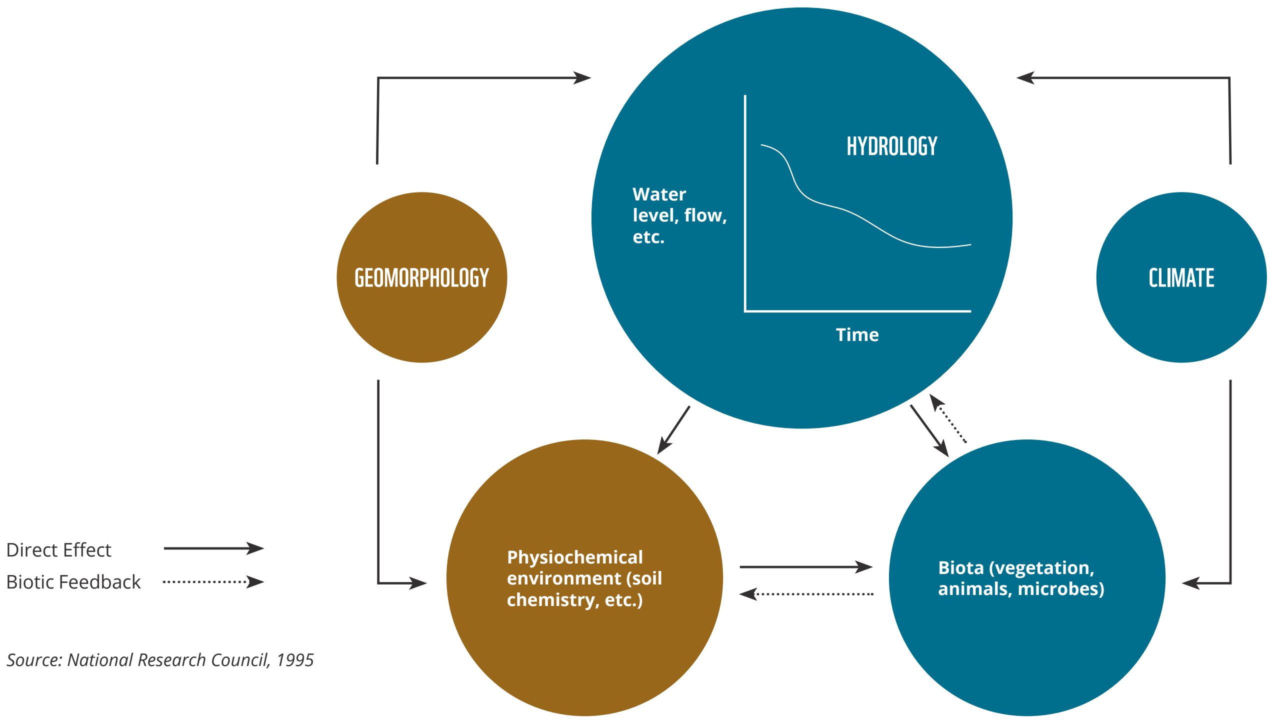
1.1 Wetland Ecosystem

National Wetlands Policy (NWP 2012) of Nepal defines wetlands as "perennial water bodies that originate from underground sources of water or rainfall. It means swampy areas with flowing or stagnant fresh or salt water that is natural or man-made, or permanent or temporary. Wetlands also mean marshy lands, riverine floodplains, lakes, ponds, water storage areas and agricultural lands"

Wetland ecosystems are key landscapes for conservation as they provide several critical functions. They are the transitional bridge between aquatic and terrestrial ecosystems. They have perennial sources of water which make the wetland ecosystems highly productive with high levels of nutrient availability and high yielding capacity. Therefore, wetland ecosystems harbor critical habitats for many species from primary to top level consumers. They also provide numerous goods and services to mankind such as clean water supply, wildlife, fisheries, water for agriculture, hydro-electricity, etc. They prevent and regulate floods, retain sediment and nutrients and serve as a carbon sink. Due to the functions that they perform in hydrological and chemical cycles, wetlands are also regarded as the kidney of landscapes. The wetlands' goods and services if utilized properly and manage sustainably, they help to increase economic growth of local people and the nation's economy (Rayamajhi, 2009). The estimated global value of wetland goods and ecosystem services is said to be 14 trillion US$ annually (Costanza et al., 1997).

Wetlands are the interface between aquatic ecosystems (rivers, lakes and estuaries) and terrestrial ecosystems (grassland and upland forests). Therefore, some wetlands share similar features as deep-water systems with anoxic substrate, vertebrates, invertebrates and algae whereas most wetlands have flora dominated vascular plants which are shared with the terrestrial ecosystems (National Research Council, 1995). The ecology of wetland looks at the relationship among organisms and their environment (Figure: 1).

Figure 1: Relationship between different components of wetland ecosystem



Source: National Research Council, 1995

Hydrology and flooding determine the characteristics of wetland. Hydrology is responsible for the biotic and abiotic components of wetlands. Abiotic components such as water quality, soil color/ texture depend on the movement and distribution of water which is followed by productivity, abundance and diversity of microbes, plants, vertebrates and invertebrates. Prolonged soil saturation by groundwater and the period of flooding determines if the wetland has swamp, aquatic or marsh vegetation (Keddy, 2010). The type of vegetation too gives significant feedback to hydrology via increase in flow resistance, evapotranspiration and in the physiochemical environment.

1.2 Wetland Conservation and Threats

Wetlands are magnificent wildlife nurseries. Nepal's wetlands are regarded as supermarkets of bio genes and biological hotspots as they are linked with the water dynamics of Himalaya (Pokharel & Nakamura, 2010). In Nepal, wetlands harbor 25% of nationally threatened bird species, 230 indigenous fish species, 24% of protected plant species, 85% of endemic vertebrates and 117 species of amphibians (Inskipp et al., 2017; Rajbanshi, 2013; IUCN, 2004; GON/MoFSC, 2014).

Since signing the Ramsar convention on December 17, 1987 with the designation of Koshi Tappu as a Ramsar site of international significance, Nepal has shown various initiations on conservation and protection of the wetland ecosystems. The Ministry of Forests and Environment (MoFE) is the focal ministry for all wetlands with the Department of National Parks and Wildlife Conservation as the Ramsar Administrative Authority in Nepal (DoF, 2017).

Conservation and management of wetlands is reflected in various conservation plans and policies of Nepal such as National Ramsar strategy and Action Plan (2018-2024), National Wetland Policy (2012), National Biodiversity Strategy (2002), National Biodiversity Strategy and Action Plan (2014-2020), Nature Conservation National Strategic Framework for Sustainable Development (2015), National Land Use Policy (2015), Forest Policy (2015), Forestry Sector Strategy (2016), Aquatic Animal Protection Act (1960), Soil and Watershed Conservation Act (1982).

Integrated Management Approach has been prioritized in different plans such as in Nepal's tenth five-year plan (2002-2007) that has focused on integrated watershed management. Similarly, an integrated water resource management approach had been introduced by the government in Water Resource Strategy (2002). Likewise, for integrated lake basin management through NLCDC/ GON.

Intergovernmental parties like IUCN, ICIMOD, WWF Nepal, National Trust for Nature Conservation (NTNC), ZSL Nepal, Bird Conservation Nepal (BCN) have worked with MoFE for restoration and conservation of wetland through establishment of different inventories and assessments.

In Nepal, wetlands are under threat because of habitat destruction mostly caused as a result of anthropogenic interferences. Based on the National Biodiversity Strategy and Action Plan (GON/MoFSC, 2014), wetlands in Nepal have shrunk by 5.41% because of croplands expansion. In the Tarai region industrial effluents have been deteriorating the land and water quality. IUCN's (1998) inventory of Tarai wetlands indicated that of the 163 wetlands surveyed, 61 percent were severely affected by agricultural run-off. In Koshi Tappu, many of the wetlands have converted to eutrophic status due to the accumulation of nutrients from natural and human activities (Regmi et al., 2021; Shrestha et al., 2021). Overexploitation of wetland's plant and animal has also been one of the major reasons for endangering wetland biodiversity. Exploitation in the form of illegal activities such as illegal fishing, poaching and clearance of forest have been recorded in different Ramsar sites of Nepal (Table 1) (Upadhaya et al., 2009; Neupane et al., 2010 ; IUCN, 2015).

Table 1 List of Ramsar sites and associated major threats

Ramsar Sites	Major Threats	References
KOSHI TAPPU	Over grazing, eutrophication due to agricultural runoff, sedimentation, overfishing, poisoning, invasion of alien species.	DNPWC (2018) Information related to wetlands of Nepal. Department of National Parks and Wildlife Conservation, Babarmahal, Kathmandu IUCN (2004). A Review of the Status and Threats to Wetlands in Nepal. International Union for Conservation of Nature, Kathmandu, Nepal, pp:78. Pandey, I., Shah, D.N. and Tachamo Shah, R.D. (2020). Impact of invasive alien plant species on aquatic biodiversity of Koshi Tappu Wetlands : Ramsar Site, Nepal. Banko Janakari 30 (2), 48–58.
BEESHAZARI AND ASSOCIATED LAKES	Invasion of alien species, agricultural runoffs	DNPWC (2018) Information related to wetlands of Nepal. Department of National Parks and Wildlife Conservation, Babarmahal, Kathmandu.
GHODAGHODI LAKE AREA	Invasion of alien species, deforestation, harvesting aquatic species, overfishing, poisoning, poaching, pollution due to pilgrims, eutrophication.	DNPWC (2018) Information related to wetlands of Nepal. Department of National Parks and Wildlife Conservation, Babarmahal, Kathmandu IUCN (2004). A Review of the Status and Threats to Wetlands in Nepal. International Union for Conservation of Nature, Kathmandu, Nepal, pp:78 Neupane, P. K., Khadka, M., Adhikari, R. and Bhuju, D. R. (2010). Lake Water Quality and Surrounding Vegetation in Dry Churiya Hills, Far-Western Nepal. Nepal Journal of Science and Technology, vol 11, pp: 181–188 Lamsal, P., Pant, K.P., Kumar, L. and Atreya, K. (2014). Diversity, Uses, and Threats in the Ghodaghodi Lake Complex, a Ramsar Site in Western Lowland Nepal", International Scholarly Research Notices, Article ID 680102.
JAGADISHPUR RESERVOIR	Eutrophication, invasion of alien species, poaching of small animals, extensive fishing, siltation.	IUCN (2015). Biodiversity and Livelihood Assessment in Jagadishpur Reservoir Ramsar Site. International Union for Conservation of Nature, Lalitpur, Kathmandu, Nepal DNPWC (2018) Information related to wetlands of Nepal. Department of National Parks and Wildlife Conservation, Babarmahal, Kathmandu. Shah, D.N., Pradhan, B. and Tachamo Shah, R.D. (2011). Diversity and Community Assemblage of Littoral Zone Benthic Macroinvertebrates in Jagadishpur Reservoir. Nepal Journal of Science and Technology 12, 211-219.
GOSAIKUNDA AND ASSOCIATED LAKES	Pollution from tourism	Kafle, G. and Savillo, I. T. (2009). Present status of Ramsar Sites in Nepal. International Journal of Biodiversity and Conservation 1(5), 146-150.
GOKYO AND ASSOCIATED LAKES	Glacial Lake Outburst flood (GLOF), overgrazing, deforestation, pollution	Upadhaya. S., Chalise, L. and Paudel, R. P. (2009). High Altitude Ramsar Sites of Nepal. The Initiation 3, 135-148.
MAI POKHARI	Invasion of Alien species	Kafle, G. and Savillo, I. T. (2009). Present status of Ramsar Sites in Nepal. International Journal of Biodiversity and Conservation , vol 1(5), pp: 146-150.

PHOKSUNDO LAKE	Pollution due to open defecation	Upadhaya, S., Chalise. L. and Paudel. R. P. (2009). High Altitude Ramsar Sites of Nepal. The Initiation, vol 3, pp: 135-148.
RARA LAKE	Encroachment, pollution	Upadhaya, S., Chalise. L. and Paudel. R. P. (2009). High Altitude Ramsar Sites of Nepal. The Initiation, vol 3, pp: 135-148.
LAKE CLUSTERS OF POKHARA VALLEY	Disposal of domestic sewage, eutrophication, sedimentation, invasion of exotic species, commercial Fishing	Gauli, S. B., Dhakal, M. and Khanal, R. (2016). Lake Clusters of Pokhara valley. Department of National Parks and Wildlife Conservation. International Union for Conservation of Nature. Kathmandu, Nepal Pant, R.R., Pal, K.B., Adhikari, N.L., Adhikari, S. and MishraWater, A.D. (2019). Water Quality Assessment of Begnas and Rupa Lakes, Lesser Himalaya Pokhara, Nepal. Journal of the Institute of Engineering 15 (2), pp: 113-122.

Invasive Alien Species (IAS) are posing a threat to wetland bio diversity in Nepal. The rapid proliferation of invasive species accelerates succession that in turn leads to extreme modification to wetland habitats, altering wetlands into marshy land and ultimately transformed into dry land. Majority of wetlands in hilly and Tarai region are dealing with the impact of IAS. They spread quickly and pose threats to biodiversity by impacting habitats of wetland dependent flora and fauna. Water hyacinth (*Pontederia crassipes*), has been present in the country for many years, which is widespread and is assumed to have altered aquatic ecosystems to some extent (IUCN, 2004). In Koshi Tappu Wildlife Reserve and Chitwan National Park, *Mikania spp*. has posed serious threats to native vegetation and has decreased the biomass production of Wild water Buffalo's (*Bubalus arnee*) and One-horned Rhino's (*Rhinoceros unicornis*) forage species, respectively (Khatri et al., 2010; Subedi, 2013).

Along with being a biodiversity hotspot, the wetland ecosystem also provides livelihood sustenance to the local people. More than 85% of agrarian communities in Nepal rely on the provisioning services; food, fodder, medicine, fishery, mine etc. provided by wetlands (MoFE, 2018). Especially, ethnic minority communities with poor economic background, for example Chepangs, ex-kamaiya, Mallah, Mushar, Tharu, Majhi, Bantar, Jhagar, etc have more dependence on these services for their livelihood (IUCN Nepal, 2004). People are also benefited by tourism as there is huge cultural and religious significance of water bodies.

Wetlands are spread across Nepal from highlands to lowlands therefore the degree of their reliance differs from locations (Lamsal et al., 2017) (Table 2).

Table 2 Dependency of Wetland Resources based on Location (Source: Lamsal et al., 2017)

	Wetland Uses					
Wetland Types	Aquatic Food	Drinking Water and Irrigation	Fuel, Wood, Timber, Medicinal Herbs	Tourism	Livestock Grazing	Religious and Cultural
HIGH ALTITIDE WETLANDS	+	+	++	+++	+	+++
MIDHILLS WETLANDS	++	++	+++	++	++	+++
LOWLAND WETLANDS	+++	+++	+++	+	+++	+++

+ Low, ++ medium, +++ High

However, with the rapidly changing climate, these services will be compromised as climate change further aggravates the threat to the wetlands. Glacier retreat and snow melt have been recorded unpredictably faster than the past due to the rapid warming in Nepal (Shrestha and Aryal, 2011; Chaulagain, 2009). Since 1950 to 2011, 14.3±5.9 % of glaciers have retreated in the Sagarmatha region (Thakuri et al., 2013). Wetland ecosystems are more vulnerable and prone to alteration in quality and quantity of water supply due to changes in hydrological regime brought on by climate change (Khatri, 2014). In Nepal, predicted range shift of vulnerable species such as the relict Himalayan dragonfly (Tachamo Shah et al., 2012) and range shift of even biomes (MoPE, 2004; Zomer et al. 2014) is feared due to climate change. Likewise, infestation of invasive species is also triggered by warming climate (Rai and Scarborough, 2012).

1.3 Wetlands Inventory, Assessment and Monitoring

Despite having high biodiversity and livelihood values, wetlands have remained neglected resources until recently. Therefore, for conservation of wetland biodiversity, evaluation of ecosystem's function and values is necessary. Based on Ramsar Framework for Wetland Inventory (Resolution VIII.6), the working definitions for wetland inventory, assessment and monitoring have been incorporated as.

Wetland Inventory

Collection and/ or collation of core information for wetland management, including the provision of an information base for specific assessment and monitoring activities.

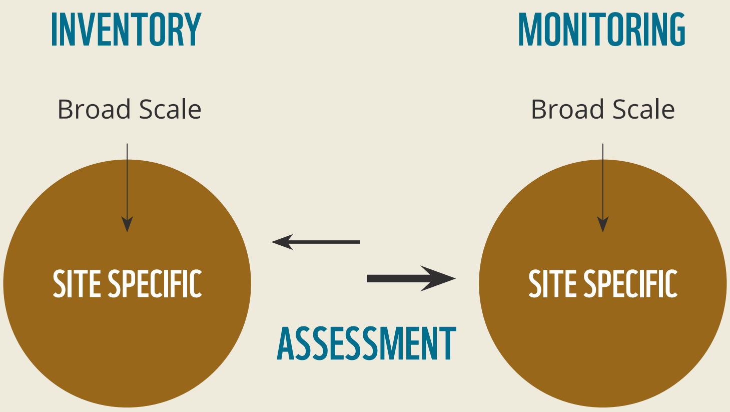
Wetland Assessment

Identification of status and threats to wetlands as a basis for collection of more specific information through monitoring activities.

Wetland Monitoring

Collection of specific information for management purposes in response to hypotheses derived from assessment activities, and the use of these monitoring results for implementing management.

Figure 2: Wetland inventory, assessment and monitoring concept



For the establishment of an integrated framework, all three elements should be linked and considered. Initially, wetland inventories are created for baseline information to describe the ecological characters of the ecosystem followed by assessment to evaluate the pressures and adverse changes in the ecological characters and finally monitoring to provide information on the extent of any changes and current status (Figure 2). When all three elements are incorporated, it provides identification of key features of wetland characters and provides data required for establishment of plans and policies to maintain and conserve the defined characteristic of a healthy wetland ecosystem. The data and information collected through inventory, assessment and monitoring are essential parts of an overall wetland management planning process, whether at the scale of defined wetland sites, or more broadly for mosaic wetlands, river basin, nationally and regionally.

1.4 Wetland Health Assessment in Nepal

Nepal lags a little behind in the health assessment area of wetlands. There hasn't been much work carried out to determine the overall health of a wetland with relation to every component of the ecosystem. Mostly water quality of rivers and lakes are assessed through physicochemical parameters and hardly through biological parameters. Physicochemical parameters such as pH, temperature, dissolved oxygen (DO), electrical conductivity, turbidity, total dissolved solids (TDS), nitrate, phosphate, *E-coli* etc. are measured. These parameters are compared to national or international permissible limits which suggest the state of water quality. As the quality of wetland is also determined by the life present in the ecosystem, the relation of these physicochemical parameters to wetland biodiversity is also evaluated. Most studies are carried on Ramsar sites such as Jagadishpur reservoir (Shah et al., 2011; Thapa and Saund, 2013; Baral et al., 2015; Chaudhary and Devkota, 2018), Bishazzari Lake (Niraula, 2012; Shrestha, 2017; Shakya et al., 2019), Koshi Tappu (Pandey et al., 2020; Regmi et al., 2021; Shrestha et al., 2021), Mai Pokhari (Sharma and Joshi, 2017; Pradhan et al., 2020), Rara Lake (Gurung et al., 2018; Lama et al., 2018), Gokyo (Sharma et al., 2010), etc.

Besides assessments of Ramsar sites, there have also been preliminary studies on physicochemical parameters and biodiversity of wetlands in and outside of protected areas (Kafle et al., 2009; Panthi et al., 2014; Kharel, 2018; Moravek et al., 2019). Wetland services and their respective threats that can alter the health of ecosystem have also been documented (Lamsal et al., 2014; Merriman et al., 2017)

© Karun Dewan

1.5 Need for Methodological Framework

There is inadequate information on the status and trends of wetland and its biodiversity in Nepal. Also, the methodology used for the assessment is not uniform throughout the literature. Therefore, for the conservation and sustainable management of wetland resources, timely and thorough wetland assessment and regular monitoring is critical. Such wetland assessment allows the establishment of a baseline data while regular monitoring detects change and trends over a period in the wetland ecosystems.

In Nepal, there have been various approaches established for the assessment of wetlands by government, intergovernmental and private sectors. For example, IUCN conducted a comprehensive inventory for lowland wetlands in Nepal in 1996. Similarly, the Conservation and Sustainable Use of Wetlands in Nepal (CSUWN) project has been a great example in terms of the various knowledge base products it has delivered. However, one important omission has been the lack of a methodological framework on wetland assessment and a manual for its implementation. Therefore, a national methodological framework for wetland assessment is needed as such the framework would record the state of wetlands in the country, prioritize management actions, help mitigating threats and associated stressors, and provide background information for declaring additional Ramsar sites as envisioned by National Ramsar Strategy and Action Plan (2018-2024).

So, an effective wetland health assessment framework would require a mechanism for national reporting, and associated assessment protocols, to ensure that data from different authorities are unbiased and comparable. A national framework for the assessment of wetland health would function not only as a quality control device for the local/provincial/federal-based programs, but permit a more informed prioritization process at the national level -identifying high conservation values, quantifying impacts and highlighting general trends.

WETLAND HEALTH ASSESSMENT
METHODOLOGICAL FRAMEWORK

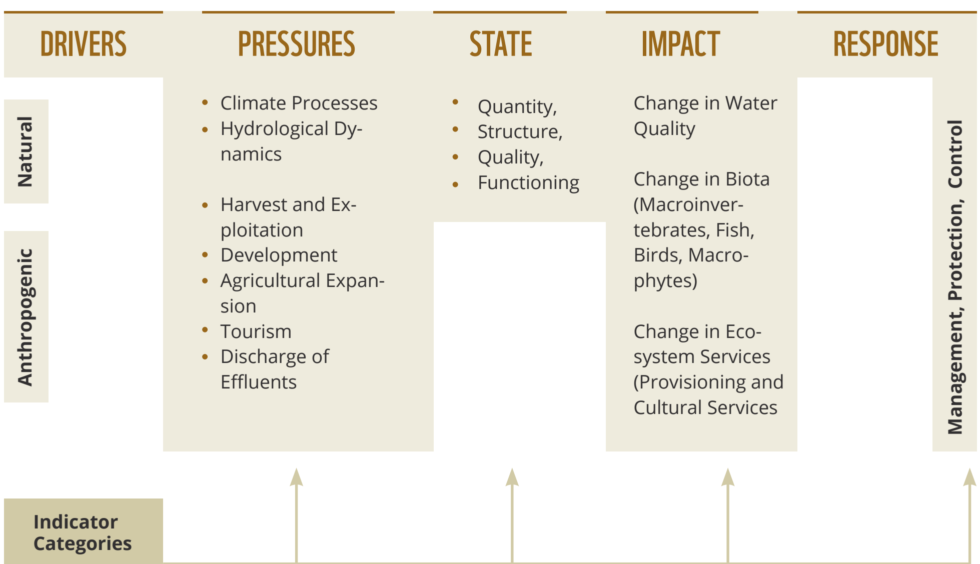
2.1 DPSIR framework

DPSIR (Driver/Driving Forces- Pressure- State- Impact- Response) framework was established by the Organization of Economic Cooperation and Development (OECD, 1993) and the European Environment Agency (EEA, 1995) to have knowledge about the anthropogenic causes for environmental degradation and to improve such degradation by encouraging and supporting decision making plans and policies. It essentially is a conceptual framework that gives an adaptive management tool for developing and showcasing cause and effect linkages (and feedbacks) of environmental issues and also emphasizes where the linkage can be broken down by management actions (Logan et al., 2020). It creates an organized structure to evaluate environmental issues of different spatial scales ranging from a watershed to global range (Carr et al., 2007). The framework provides an initial point for a common level of consensus and understanding between all the stakeholders as it creates a linking pathway between all the different drivers that sabotages the intrinsic functioning of the ecosystem (Saadati et al., 2013),

The framework is widely used and appreciated in various fields for its communicative power and flexibility. It is also multi-disciplinary and has an inclusive approach for all stakeholders participation (Logan et al., 2020). Therefore, in the context of wetland health report cards, DPSIR framework creates a structure that identifies and communicates the required indicators to address goals and objectives.

DPSIR framework (Figure 3) was prepared based on understanding the interaction between socio-economic developments as "Drivers" which exert or mitigate pressures on the environment. Such "Pressures" cause stresses on environmental status. "Impacts" describe the effect of the changed environment and its consequences on human health and economy (Smeets and Weterings, 1999). Accordingly, a number of "Responses" are recommended as a feedback loop to mitigate the environmental changes.

Figure 3: A schematic diagram of DPSIR-framework



Driver

Driving Forces/ Drivers refer to variables that are either natural or anthropogenic which are root causes of problems or exacerbates the existing environmental problems. Anthropogenic drivers are often the social, demographic and economic developments in societies, production patterns and the level of consumption. These drivers can develop and act regionally or globally which influence the sustainable use of resources, consumption and production of ecosystem services.

Pressure

Pressures are the direct human induced stresses on the ecosystem. They are a medium through which drivers are expressed and are linked with natural systems and socioeconomic activities. For example; over harvesting and exploitation; pollution- direct discharge from agriculture, aquaculture, and industries on the water body; changes in ecosystem's morphology- land reclamation and agriculture expansion; changes in hydrological regime- water diversion, abstraction, etc.

State

State is the form of all the biotic and abiotic components of the ecosystem. The pressure exerted by drivers leads to intentional or unintentional changes in the state of the ecosystem that are usually unwanted. When the state of an ecosystem is altered, it compromises the quality and quantity of human dependent resources. For example in wetlands, the agricultural or aquaculture discharge could trigger algae bloom and result in eutrophication which can alter the abundance of fishes.

Impact

Impact is the alteration brought on by the changed environment. Changes in the state of an ecosystem have environmental and social impact on the well-being of biodiversity and humans. For example alteration of various components of w ater quality due to eutrophication or invasive species can bring changes on the richness and abundance of aquatic biodiversity like macroinvertebrates, fish, macrophytes etc which in turn bring in changes in the ecosystem services provided by the wetland.

Response

The impact of state alteration triggers response by community or policy makers. It can affect any part of the series and reverse the effect of drivers, pressures, state or impact. Through regulation, prevention and mitigation, the drivers can be controlled.

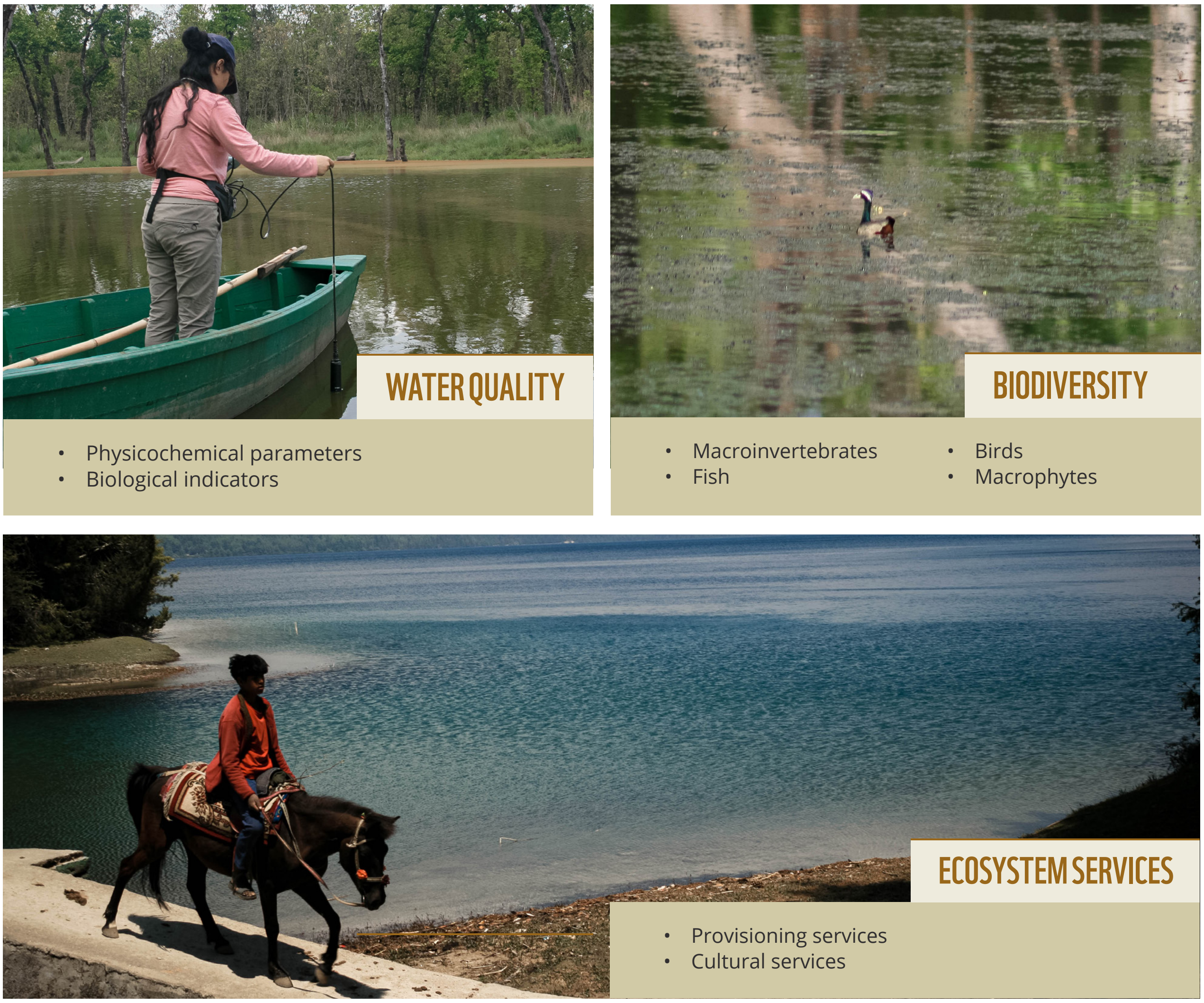
Rara Lake
© Deep Narayan Shah

Water Quality at Beeshazari Taal
© Deep Narayan Shah

ASSESSMENT PROCESS AND METHOD

The condition of a wetland reflects the integrated state of physical, chemical and biological characteristics of the wetland. Systematic identification and measurement of these features are critical for predicting the performance of particular functions of a wetland (Gopal, 2015). However, the assessment of all components such as hydrology, water chemistry, soils, flora and fauna is too expensive and time-consuming to be carried out in every wetland. Therefore, a methodological framework for assessing wetland health in Nepal has been developed based on the subset of the parameters that describe the wetland ecological status and represent biotic assemblages and ecosystem services of the wetland (Figure 4).

Figure 4: Components to evaluate health of wetlands



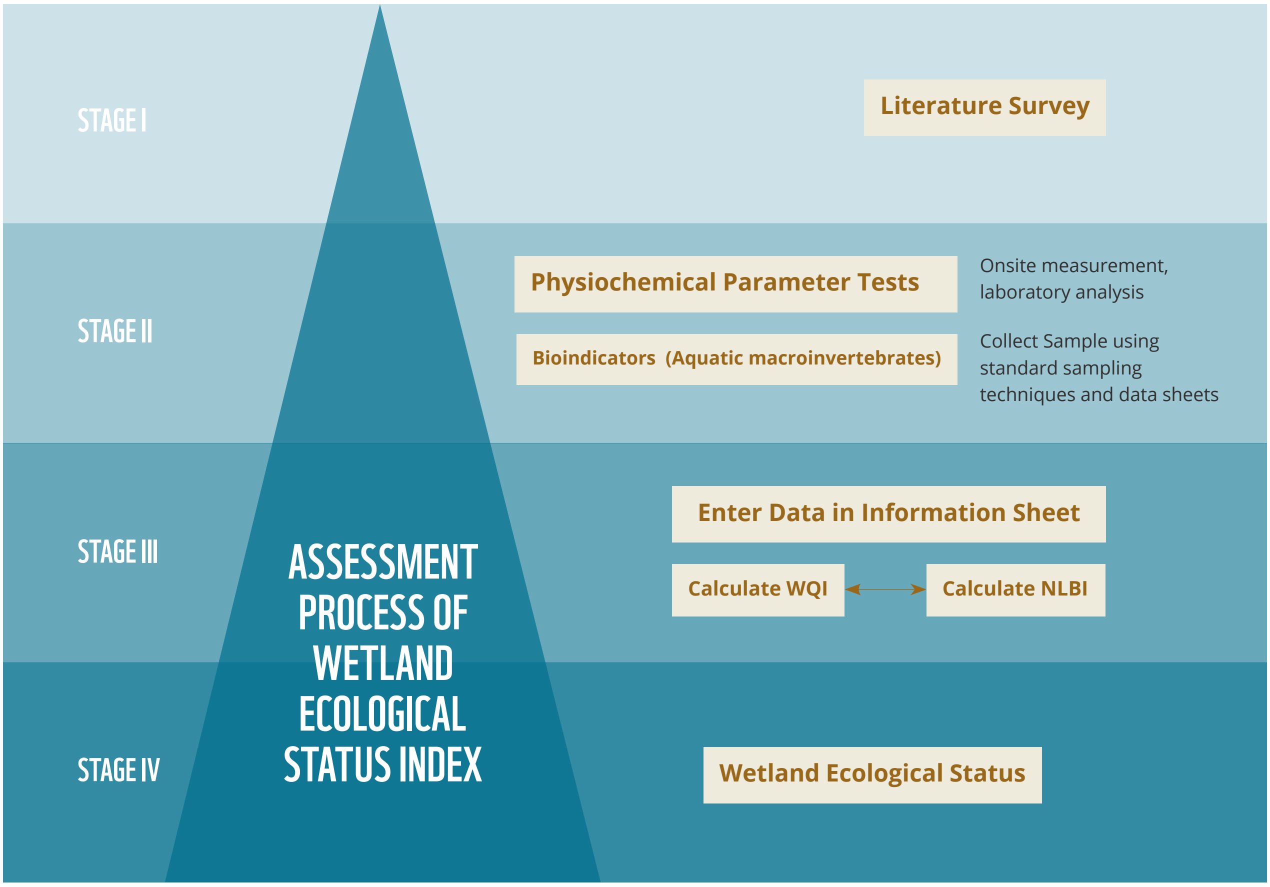
The developed methodological framework involves rigorous literature review, field observation, survey, field measurements, sample collection, laboratory analysis, local consultations, data analysis and result interpretation. Sophisticated field gears and standard protocol are necessary for sample collection and the generation of reliable data. Moreover, a skilled human resource in a specific field is required to collect, analyse and interpret the data.

3.1 Ecological Status Index

Ecological status of wetlands can be defined as the condition of water quality that supports aquatic communities inhabiting unimpaired water bodies (USEPA, 1990). Wetlands with good ecological status can support high biodiversity. Measurements of only physicochemical parameters tell the status of wetlands at the time of sampling but the study of organism distribution and composition of the wetlands presents a holistic picture of the wetland's status for a relatively long period of time. Therefore, an integrated index –"Wetland Ecological Status Index" has been developed to determine the ecological condition of a wetland. Aquatic macroinvertebrates are considered one of the robust groups to detect the impact of pollution, water level fluctuations, wetland morphological characteristics, etc. on wetland ecosystems (Shah et al., 2011; Gopal, 2015; Shrestha et al., 2021).

Determination of Wetland Ecological Status Index involves several processes such as literature review; onsite measurement of physicochemical parameters and aquatic macroinvertebrates sample collection; laboratory analysis of water chemistry and processing and determination of macroinvertebrates; data analysis and calculation on index value (Figure 5).

Figure 5: Schematic diagram of assessment process of Wetland Ecological Status Index



Here, Wetland Ecological Status Index is derived from the arithmetic mean of water quality index (i.e., physicochemical parameters) and Nepal Lake Biotic Index (i.e., presence and absence of macroinvertebrates) for a wetland (Figure 6).

Figure 6: List of physicochemical and Biological parameters to determine Wetland Ecological Status Index

WATER QUALITY INDEX

- **L - WQI: Water Quality Index**
  [Based on turbidity, water temperature, electrical conductivity, pH, oxygen saturation, chemical oxygen demand, total phosphorus, ortho-phosphate, nitrate, total nitrogen, nitrate]

BIOTIC INDEX

- **NLBI: Nepal Lake Biotic Index**
  [Based on the presence/ absence of macroinvertebrates as bio-indicator]

Measurement of physico-chemical parameters

Physico-chemical parameters such as pH, electrical conductivity, oxygen saturation (DO%), turbidity, water temperature need to be measured in a sites using portable digital probe while chemical oxygen demand, chlorophyll “a”, total nitrogen, nitrate, orthophosphate and total phosphorus are to be determined in a laboratory for which water samples need to be collected during field assessment (see Annex 1).

Sampling of aquatic macroinvertebrates

Aquatic macroinvertebrates is sampled using multi-habitat approach described by Tachamo Shah et al. (2015) (see Annex 2). The collected samples are transferred in a well labeled plastic container and a composite sample is made. The samples are preserved in 95% ethanol at a site and brought to a laboratory for further processing of samples, which includes sorting and determination of aquatic macroinvertebrates to the lowest taxonomic resolution.

Water Quality Index (WQI)

Water quality index (WQI) is a mathematical approach which aggregates data of two or more water quality variables (such as DO, pH, water temperature, conductivity, etc.) to produce a single number for classifying the water quality status of a water body (Figure 6). Choosing a suitable WQI is critical as it has to accurately evaluate the effects of anthropogenic disturbances such as eutrophication, organic pollution, habitat alteration, etc, on aquatic biota. Similarly, the selected water quality parameters should also be easily assessed in the field and in the least sophisticated laboratory at low cost. In this regard, Lagoon Water Quality Index (L-WQI, Taner et al., 2011) could be an appropriate method for determining water quality of wetlands as it was developed with vital and limited number of physico-chemical parameters and the parameters are feasible to carry out in the field and laboratory in low cost.

In L-WQI, percentage of oxygen saturation (DO, %), ratio of total nitrogen (TN) and total phosphorus (TP), chemical oxygen demand (COD, mg/L), pH, turbidity (NTU), and electrical conductivity (EC, µS/cm) are included. Dissolved oxygen (DO, %) is critical for the survival of aquatic organism and rely on water temperature and salinity. Chemical oxygen demand (COD) indicates the load of organic pollution especially from industrial discharge and domestic sewage into the water bodies. Redfield Ratio (TN:TP) represents the limiting nutrient in the aquatic ecosystem for the growth of algae (Wetzel, 2001). However, high concentrations of the nutrients may deteriorate water quality and make unsuitable habitats for many aquatic organisms due to eutrophication. Therefore, assessment of these parameters are important for assuring wetland water quality suitable for aquatic organisms. L-WQI is calculated using following formulas.

$$L\text{-}WQI=0.25C_{DO}+0.25C_{TS}+0.23C_{COD}+0.10C_{pH}+0.09C_{EC}+0.09C_{TRB}$$

Where, C represents the recorded value for each variable. TS is the trophic status condition which is determined according to TN/TP ratio (after Taner et al., 2011).

$$C_N = \begin{cases} \text{IF TN : TP} \geq 7.2, C_{NO_3} \\ \text{IF TN : TP} < 7.2, C_{O\text{-}PO_4} \end{cases}$$

$$C_{TS} = \min(C_N, C_{chl\text{-}a})$$

The L-WQI provides four classes: Excellent (100 – 75), Good (75 – 50), Fair (50 – 25) and Poor (25 – 0). The calculated index value is is tallied with a transformation table (Table 3).

Table 3: Transformation table from WQU values to status class.

Water Quality Index (WQI)	Status Class
100-75	1
75-50	2
50-25	3
25-0	4

Nepal Lake Biotic Index (NLBI)

Integration of Biological indicator such as macroinvertebrates is considered a robust approach for assessing aquatic ecosystem health. Application of macroinvertebrates as bioindicators in assessment of freshwater ecosystems are well established in Nepal. NLBI (Tachamo-Shah et al., 2011) has been developed for assessing standing water bodies in the country. NLBI is based on taxon tolerance score where taxon score ranges from 0 to 10 indicating very tolerant to sensitive to perturbations. NLBI is calculated as follows:

$$\mathbf{NLBI = \sum^{n}_{i=1} TTSi / n}$$

Where, n is the total number of scored taxa, and TTSi is the taxon tolerance score of i taxon.

The calculated NLBI values is tallied the transformation table to determine the respective status class (Table 4).

Table 4: Transformation table for determining status class based on macroinvertebrate presence and absence data.

NLBI	Status Class
6.10 – 10.00	1
4.91 - 6.09	2
4.00 - 4.90	3
0.00 - 3.99	4

Wetland Ecological Status Index (WESI) is calculated as the arithmetic mean of the respective status class of WQI and NLBI values.

$$\text{WESI}= \frac{\textbf{Status class of WQI + Status class of NLBI}}{\textbf{2}}$$

3.2. Biodiversity metric

The representative group of organisms such as aquatic macroinvertebrates, fishes, birds, and macrophytes of wetlands are to be assessed (Figure 7). In general, species richness and diversity measure in particular Shannon diversity index are sensitive to habitat alteration, pollution and disturbances in wetlands. Species richness and diversity index of each group are scaled up to make it compatible.

Figure 7: Biodiversity components for the assessment of Biodiversity metric

© Ram Devi Tachamo-Shah

© Ram Devi Tachamo-Shah

© Aditya Pal

© Ram Devi Tachamo-Shah

Aquatic macroinvertebrates

Aquatic macroinvertebrates are small aquatic animals that don't possess backbones and are visible through our naked eyes. They are mostly the aquatic larvae/nymphs of terrestrial insects and are often found attached at the bottom surface of rocks, sticks, vegetation, logs etc. They generally feed on smaller organisms like algae and other non-living substances and are a major food resources for fishes and other predators. They are the important source of energy in an aquatic food chain, therefore, the reduction of aquatic macroinvertebrates can persuade a bottom-up cascade. In aquatic ecosystem, macroinvertebrates are regarded to be the greatest biological indicators as they are highly sensitive organism, shows wide range of tolerance level to perturbation, comparatively long-life, have high abundance, and are accessible as cost effective way of sampling measure (Shrestha et al., 2021). Furthermore, they aren't that mobile which makes them incompetent to escape from perturbations and consequently, need to tolerate the impact of disturbance or climatic pressures.

Fish

Fishes are cold blooded aquatic vertebrates with gills. Fishes have been used as biological indicators as they reflect the condition of watershed since they are sensitive to any alteration in wide range of environmental factors. They have traditionally been used in assessment to classify different types of standing waters (Chovanec et al., 2003). The biodiversity in standing water bodies represent their trophic state, morphometry, oxygen and thermal stratification and littoral development. Depending on issues and indicator selected, fish meet the requirement to evaluate changes in communities in the environment with testing for causes and sources of problems.

Birds

Usually birds in a wetland ecosystem are the top predators and their diversity may change depending on habitat availability and food resources. Therefore, birds are used as indicators of changes that occurs at low trophic levels (Burger and Eichhorst, 2005). From species to community level, waterbirds have been studied to track environmental changes at short and long scales (Amat and Green, 2010; Rendón et al., 2008). Birds are studied as bioindicators of different conditions in wetlands such as fish abundance (Einoder, 2009) or eutrophication (Michelutti et al., 2009), pollution from agricultural runoff (Varo and Amat, 2008).

Macrophytes

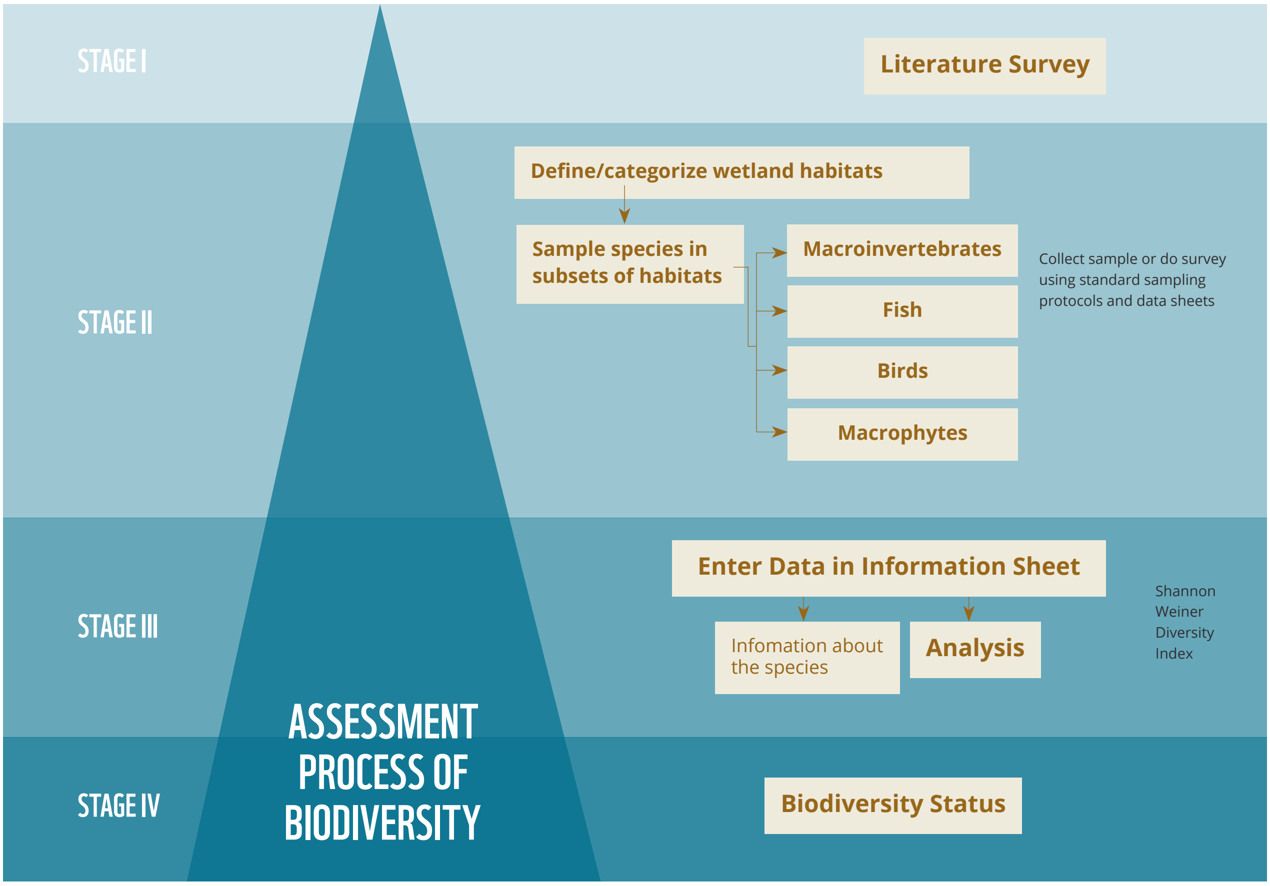
Macrophytes are aquatic plants that grow around water bodies and are either submerged, emergent or floating. They are at the bottom of detritivorous and herbivorous food chains as they are primary producers, which is a food source for bacteria, invertebrates, birds and fishes (Rejmánková, 2011). Furthermore, they provide shelter and serves as substrates for numerous invertebrates, amphibians, reptiles, fishes, etc. They respond to array of environmental conditions. Their presence and absence indicate the status of water bodies, food availability or morphometry condition of wetlands.

Macrophytes are sensitive to water level fluctuations, water quality, human disturbances etc, (Regmi et al., 2021, Pandey et al., 2020), therefore, they are regarded as bioindicators of wetland health. For example, diversity of macrophytes increase with good water quality and nutrient dynamics whereas diversity of macrophytes decline with poor water quality.

Assessment of Biodiversity

Existing information on target species' distribution, occurrence and ecological niche is compiled from relevant published and unpublished literature at initial stage before conducting field work (Figure 8). Sampling of each target biotic group are carried out from appropriate sections/habitats of a wetland following standard methods (see Annex 2 – aquatic macroinvertebrates; Annex 3 – fishes; Annex 4 – Birds; Annex – 5 macrophytes). Sample processing and taxonomic identification of species can be done following the literature listed in the respective annexes at stage II. Identified species can be entered in an excel spreadsheet for further analysis such as taxa/species richness and determination of Shannon diversity index at stage III. Finally at stage IV, biodiversity status is calculated.

Figure 8: Schematic diagram of assessment process of biodiversity



Species Richness

Species richness is the number of different species present in wetland ecosystem. Usually species richness increases with habitat diversity and area indicating the healthy wetland ecosystems (Shah et al., 2011; Regmi et al., 2021; Shrestha et al., 2021) while richness decline with nutrient enhancement, habitat deterioration and proliferation of invasive species (Pandey et al, 2020; Regmi et al., 2021; Shrestha et al., 2021).

Shannon wiener diveristy index (H)

The shannon-wiener diversity index (H) is a measure of diversity that combines species richness and their relative abundances. This index is simple and provides synthetic summary, because of which it is widely used in ecological studies across the globe. The value ranges from 0 to 4. In general, the values are documented between 1.5 and 3.5 in most ecological studies, and the value rarely reach to 4. The index increases as both the richness and the evenness of the biotic community increase. The Shannon wiener diversity index is calculated using following formula:


Fish Taxonomic Identification
Photo by Deep Narayan Shrestha

$$H' = -\sum pi \ ln \ pi$$

Where pi is the proportion of individual found species i
pi= ni/N where ni is the number of individuals in species i and N is the total number of individuals in the community.

Based on literature review and expert judgment, species richness and the Shannon weiner diversity index values are classified into four status classes (Table 5).

Table 5: Species richness and diversity index ranges for determining biodiversity status

Species Richness		Shannon Wiener diversity index	Status class
Macroinvertebrates, Macrophytes, Birds	**Fish**		
>15 taxa/ species	>10 species	>2	1
11-15 taxa/ species	6-10 species	~1.5- 2.0	2
6-10 taxa/ species	3-5 species	~1- 1.5	3
≤5 taxa/ species	≤2 species	<1.00	4

(Sources: Tachamo Shah et al., 2011; Tachamo Shah et al. 2018; Tachamo Shah et al., 2019; Pandey et al., 2020; Shrestha et al., 2021; Regmi et al., 2021)

For each biodiversity component, status class is determined by arithmetic mean of final status class of species richness and Shannon Wiener diversity index (Table 6)

Table 6: Calculation table for the determination of Biodiversity Status Class

Biodiversity Component	Status Class based on species richness [A]	Status Class based on Shannon Wiener diversity index [B]	Biodiversity Status Class [A]+[B]/2
Macroinvertebrates			
Fish			
Bird			
Macrophytes			

Biodiversity Index is calculated by dividing sum of individual status class of macroinvertebrates, fishes, birds and macrophytes by number of biodiversity component as expressed below.

$$\text{Biodiversity Index} = \frac{\sum_{i}^{n} N}{n}$$

N= Sum of individual biodiversity status class (macroinvertebrates, fishes, birds, macrophytes)
n= Number of biodiversity components

3.3 Ecosystem Services metric

Physical state of wetland

The direct and indirect benefits provided by natural environment to humans are ecosystem services. The ecosystem services are categorized into four groups: provisioning, regulating, supporting and cultural services (MEA, 2005). Provisioning services are the basic human needs that are obtained from an ecosystem such as; food, water, shelter, fuel, minerals, etc. Regulating services like carbon feedbacks, decomposition of waste, climate regulation is provided. Supporting services such as nutrient cycling, pollination etc. which are needed, or the functioning of another ecosystems is offered. Lastly, cultural services are the spiritual and aesthetic experiences for religious or recreation activities.

Wetlands have been regarded as the most productive ecosystem as they offer necessary services for human wellbeing (Maltby, 2006; Roy et al., 2012). Even though, the total coverage of wetlands occupies only 1.5% of earth's surface, they provide 40% of global ecosystem services (Zelder and Kercher, 2005). Wetlands provide us with several ecosystem services that not only support people globally and locally but also maintain biological diversity that prevent the consequences of climate change and environmental degradation (Barbier et al., 1997; Bhandari, 2003). Therefore, various ecosystem services assessments have been carried out applying different approaches (Lopez et al., 2009; Das et al., 2020; Thapa et al., 2020 or through index (Xu et al., 2005).

For wetland health assessment purpose, provisioning and cultural services are selected for evaluating the quality of ecosystem services as these services are easy to document and people perceive the changes occurred in these services quickly. Humans utilize the provisioning and cultural services offered by wetlands, which could make them either prone to overexploitation or unsustainably managed. Only some achievable indicators of provisioning and cultural services are considered for evaluation of the wetland health. A total of ten questions related to provisioning and cultural services are formulated for understanding the significance of wetlands to human beings (Table 6). Each question carries 10 percentage and a complete list provides 100 percentages. Since, some of the cultural services (e.g., number of visitors, types and numbers of cultural activities) do not directly depend on the quality of wetlands, therefore, low weightage (10 - 30% depending on the physiographic zones) has been given for the calculation of overall health status of wetlands.

Provisioning services

Provisioning services are the palpable products or goods attained from ecosystems such as food, freshwater, fuel, fiber, etc. Wetlands in Nepal provides an array of provisional services. Approximately 85% of Nepal's agrarian communities are dependent on wetlands resources for food, fodder, fiber, medicine, fishery, mine, gene, etc. (MoFE, 2018). The major food source dependent on wetlands is fisheries. About 10% of ethnic communities are dependent on wetlands. Another important services provided by wetlands is paddy which produces about 5.23 MT of rice each year (MoAD, 2017). Thus, assessment of provisioning services of wetlands is necessary as sustainable management enhances wetlands' productivity and improve the health of the ecosystem.

Fishing
Photo by Ram Devi Tachamo-Shah

Cultural services

There is huge cultural and religious significance of water bodies in Hinduism, Buddhism and Islam. Most of Nepal's rivers/ rivulets, ponds and lakes are considered holy. High-altitude lakes; Gosaikunda, Paachpokhari, Shey Phoksundo, Tillicho etc. are some of the famous destination for pilgrims to visit. Many Hindu rituals from cremation to celebration of festivals like Chhath, Agan Panchami, Naag Panchami etc, the wetlands have major part to play in such religious traditions. More than 100,000 pilgrims visit Shivaganga Tal of Bara annually in the month of Shrawan and Shivaratri (MoPE, 2018). Further, they have aesthetic/ecotourism, spiritual, recreational, inspirational, and educational values. It has inspired art and literature and contributed to the development of human knowledge. However, these non-material benefits remain un-quantified.

Chhath Puja
Photo by Dibakar Roy on Unsplash

Assessment of Ecosystem Services

The questionnaire related to provisioning and cultural services are structured into three sections: the first section captures general information; the second deals with information about provisioning services; and the third section details information on cultural service. A total of ten questions are formulated, five questions for each provisioning and cultural services (Table 7). Upon a positive answer to a question gets 10 percentages so if a wetland gets values for eight or more questions, the wetland is considered as high status in terms of ecosystem services. Depending upon the services provided, the status of wetland can be classified intofour status classes: 1, 2, 3 and 4 (Table 8).

The survey should include at least 15 key respondents or more considering wetland dependent communities, GESI, and other concerned stakeholders. The obtained score of each respondents are averaged to get the final score.

Table 7: Worksheet for the collection of ecosystem services information at the study wetland.

Responses "Yes" and "No" are valued as 10 and 0 respectively.

Name of the wetland:	**Province:**	**Municipality**	
Village:	**Latitude:**	**Longitude:**	**Altitude:**
Name of respondent:	**Education:**	**Occupation:**	**Ethnic group:**

	Provisioning Services	Responses		%
1	Do you get food resources including fish from the wetland?	Yes	No	
2	Is the water used for agriculture or drinking purpose?	Yes	No	
3	Do you harvest wetland fibers or fodder for household consumption or livestock?	Yes	No	
4	Is this wetland suitable habitat for birds?	Yes	No	
5	Is the wetland known for medicinal plant?	Yes	No	

	Provisioning Services	Responses		%
1	Does the wetland have temple/pilgrims in and around?	Yes	No	
2	Do the wetland get number of visitors per year over 5000?	Yes	No	
3	Do students visit for their field work or experiment each year?	Yes	No	
4	Does the wetland have any cultural significance?	Yes	No	
5	Does the wetland have recreational value?	Yes	No	

Table 8: Transformation table for number of ecosystem services to ecosystem class

Ecosystem services value (%)	Status Class
>80-100	1
>60-80	2
>30-60	3
10-30	4

Physical state of wetland

Maintaining or preservation of wetland characteristics across temporal scale assure the quality of ecosystem services to wildlife including human being and indicate the well-being of the wetlands. However, continuous exposure to disturbances could lead to changes in morphometry (such as shoreline characteristics, water depth) of the wetlands and deterioration of services. Changes in the quality of services or deviation of natural states of the wetlands' morphological characteristics thus could be indicators for the determination of wetland health (Table 9).

Data are collected using a combination of approaches that include focus group discussions, key informant interviews, field observation and measurements.

Table 9: Description of physical states of wetlands for status class

Status Class	Description
1	More than 75% of shoreline and surrounding vegetation are natural; No to minimal human disturbances.
2	50 - 75% of shoreline and surrounding vegetation is natural; Occasional disturbances.
3	25 - 50% shoreline and surrounding vegetation are natural; Regular disturbances.
4	Less than 25% shoreline is natural; No to some surrounding vegetation; Regular disturbances.

Assessment of Physical state

Ecosystem services metric is the final value obtained by averaging the status class of ecosystem services (Table 8) and physical states (Table 9) of the study wetland. The metric values are tallied with status classes that ranges from 1 to 4 (Table 10).

Table 10: Physical states of wetlands with respective to physical status class.

Naturalness and preservation of services	> 75%	50-75%	25-50%	> 25%
Status class	1	2	3	4

Ecosystem service metric is calculated by averaging the status class of ecosystem services and physical state of the wetland as expressed below.

$$\textbf{Ecosystem services metric} = \frac{\textbf{Status class of ecosystem services} \quad \textbf{Status class of physical state}}{\textbf{2}}$$

3.4 Wetland Health Status

Wetland Health Status provides conditions of wetland in terms of ecological quality, biological assemblages and their diversity, and ecosystem services. Wetland health is calculated from the developed multi-metric index that is determined by the combination of weighted wetland ecological status index (an index developed from water quality and macroinvertebrate based biotic index; NLBI), biodiversity metric, and ecosystem services metric (Table 11). The multi-metric index reflects the overall wetland health including ecological, biodiversity and ecosystem services status of the wetland.

Wetland Multi-metric Index (WMMI) = Sum of weighted index value.

The wetland health status includes 3 metrics considering 16 indicators from ecological quality, biodiversity and ecosystem services and categorizes wetlands into four status classes such as "Excellent"-1, "Good"-2, "Fair"-3, and "Poor"-4.

Table 11: Given weightage value based on wetland characteristics for physiographic zones

Wetland Assessment Components	Index Value	Weightage value for different physiographic zones (select one)			Weighted Index Value
		High Land	Mountain	Lowland	
Ecological Status (WQI and NLBI)		0.7	0.4	0.4	
Biodiversity (macroinvertebrates, fish, birds, macrophytes)		0.2	0.3	0.4	
Ecosystem services		0.1	0.3	0.2	

(Weightage value for different physiographic zones is based on expert judgment and stakeholder consultation meetings)

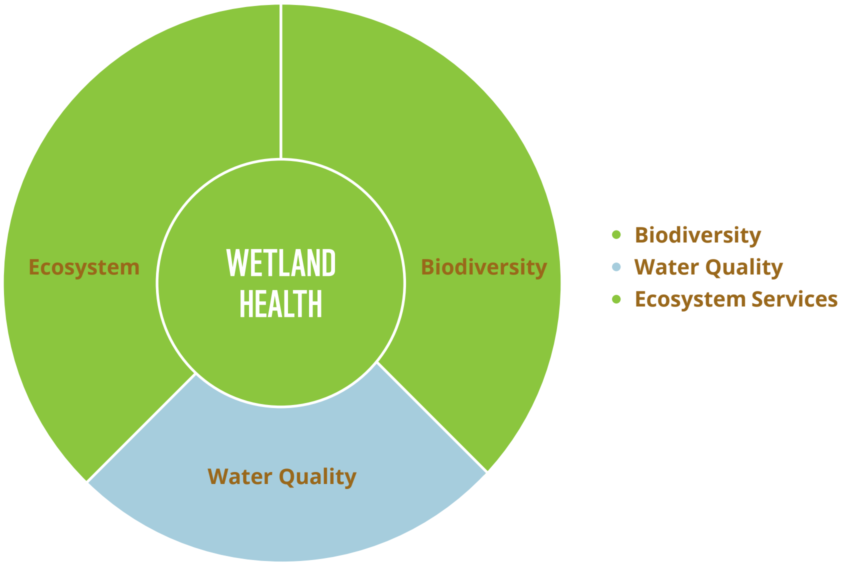
Table 12: Transformation table for wetland status class

Ecosystem services mean	Status class	Description	Color Code
≤ 1	1	Excellent	Blue
> 1 and ≤ 2	2	Good	Green
>2 to 3	3	Fair	Yellow
>3	4	Poor	Red

Presentation of wetland health status

The wetland health status is presented for each index or metric and overall wetland (Figure 9).

Figure 9: Presentation of wetland health report card for an assessed wetland



WETLAND HEALTH REPORT CARD

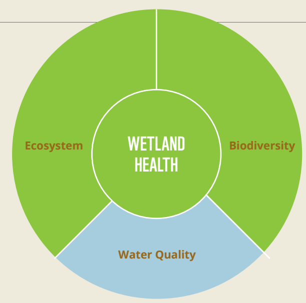
The health report card of a wetland ecosystem (Table 13) is an effective showcase to translate the complex information of data into simple format on the condition of the wetland ecosystem that is easily understandable by local stakeholders and non-technicians including policy makers.. The health report card is based on the DPSIR framework (Figure 1). The wetland health report card (Table 13) comprises of general information of wetland geographic position, physical states, dominant anthropogenic and natural stressors, wetland health status based on water quality, biodiversity and ecosystem services, and recommendations for restoring and preserving wetland resources and its natural state.

The development of health report card for a wetland will aid governmental bodies and conservation partners to better allocate resources for restoration and inform protection decisions.

Table 13: A template of wetland health report card

WETLAND HEALTH REPORT CARD		Map of the Wetland
Name of the Wetland		
General Information		**Photo of the Wetland**
Location		
Wetland area		
Land Use		
Wetland use		
Dependent population and Households		
Major threats (Natural and Anthropogenic stressors)		
Management regime		

WETLAND HEALTH				
Indicators	**Index**	**Score**	**Mean**	**Class**
Wetland Ecological	Water quality index			
	Biotic index			
Biodiversity	Aquatic macroinvertebrates			
	Fish			
	Birds			
	Macrophytes			
Ecosystem services status	Provisioning services			
	Cultural services			
Wetland health				
Wetland health Description				
Recommendation for restoration and preservation				



REFERENCES

Amat. J.A and green. A. J (2010) 'Waterbirds as Bioindicators of Environmental Conditions'. Biological Monitoring in Freshwater Habitats.

Bandari. B (2003) 'Module 1: Let Us keep our wetland healthy'. IGES, Hayama, Japan.

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

Baral. S., Khanal. R., Joshi. R., Bhatta. R., Paudel. A., Thapa. K., LaVelle. K and Poudyal. A (2015) 'Water Quality of Wetlands in Nepal: a Case Study of Jagadispur Reservoir Ramsar Site'. Jocabs Journal of Hydrology. Vol. 1 (2)

Burger . J and Eichhorst . B (2005) Heavy metals and selenium in grebe eggs from Agassiz National Wildlife Refuge in northern Minnesota. Environ Monitor Assess, vol. 107, pp :285–295

Cantonati. M., G. C., Jüttner. I and Cox. E.J (2001) 'Diatom assemblages in high mountain streams of Alps and the Himalaya'. Nova hedwigia vol. 123, pp:37-61

Carr. E.R., Wingard. P.M., Yorty. S.C., Thompson. M.C., Jensen. N.K and Roberson. J (2007) 'Applying DPSIR to Sustainable Development' International Journal of Sustainable Development and World Ecology, vol. 14, pp: 543-555

CCME (2001) Canadian water quality guidelines for the protection of aquatic life. CCME water quality index 1.0, User's Manual, Winnipeg, Manitoba, Canada

Chaudahary. R.K and Devkota. A (2018) 'Evaluation of Limnological Status of Jagadishpur Reservoir,

Chudamani and Karmacharya (2004) 'Quantitative analysis of macrophytes of beeshazar Tal, Chitwan, Nepal' Himalayan Journal of Sciences vol 2 (3)

Chaulagain. N.P (2009) 'Climate change impacts on water resources of Nepal with reference to the glaciers in the Langtang Himalayas'. Journal of Hydrology and Meteorology. Vol.6, pp:58-65

Chovanec. A., Hofer. R and Schiemer. F (2003) 'Fish as bioindicators'. Boindicators and Biomonitors, Elsevier Science Ltd.

Costanza. R., D'Arge. R., de groot. R., Farber.S., Grasso. M., Hannon. B., Limburg.K., Naeem.S., O'Nell. R. V., Paruelo. J., Raskin. R.G., Sutton. P and Belt. M. VD (1997). 'The value of the world's ecosystem services and natural capital.' Nature, vol. 387 (6630), pp: 253-260

Das. S., Pradhan. B., Shit. P. and Alamri. A. M (2020) 'Assessment of Wetland Ecosystem Health Using the Pressure–State–Response (PSR) Model: A Case Study of Mursidabad District of West Bengal (India)'. Sustainability vol. 12

Diwakar. J., Bajracharya. S and Yadav. U. R (2009) 'Ecological Stud of Ghodaghodi Lake'. Banko Janakari vol. 19 (3), pp: 18- 23

EEA (1995) Europe's Environment: the Dobris Assessment. Technical Report. European Environmental Agency, Copenhagen

Ghimire. N.P., Jha. S.K and Caravello. G (2013) 'Water Quality of High-Altitude Lakes in the Sagarmatha (Everest) National Park, Nepal' Journal of Environmental Protection vol. 4 (7), pp: 22-28

GON (2014) Nepal National Biodiversity Strategy and action plan 2014- 2020. Government of Nepal, Ministry of Forests and Soil Conservation, Kathmandu, Nepal.

Gurung. S., Gurung. A., Sharma.C.M., Jüttner. I., Tripathee. L., Bajracharya. R. M., Raut. N., Pradhananga. P., Sitaula.B.K., Zhang.Y., Kang. S and Guo. J (2018) 'Hydrochemistry of Lake Rara: A high mountain lake in western Nepal' Lakes and Reservoirs Research and Management.

Horton RK (1965) 'An index number system for rating water quality'. J Water Pollut Control Fed vol 37(3), pp: 300–306

Inskipp. C., Baral. H.S., Inskipp.T., Khatiwada. A.P., Khatiwada. .P., Poudyal. L.P., and Aim. R (2017). Nepal's National Red List of Birds. Journal of Threatened Taxa. Vol. 9 (1), pp: 9700-9722

IUCN (2004). A Review of the Status and Threats to Wetlands in Nepal. International Union for Conservation of Nature, Kathmandu, Nepal, pp 78

IUCN (2015) Biodiversity and Livelihood Assessment in Jagadishpur Reservoir Ramsar Site. International Union for Conservation of Nature, Lalitpur, Kathmandu, Nepal.

Kapilvastu District, Nepal'. International Journal of applied Science and biotechnology, vol. 6 (3) pp: 235-260.

Keddy. P.A (2010) Wetland Ecology: Principles and Conservation. United Kingdom, Cambridge: Cambridge University Press.

Kharel. M (2018) 'Preliminary Study on Birdlife of BetanaWetlnad, Belbari, Morang District, SE-Nepal' SOJ Vet Sci, vol 4 (3), pp: 1-6

Khatri. T.B., Shah. D.N., Tachamo Shah. R.D., Mishra. N (2010). 'Biodiversity of Koshi Tappu Wildlife Reserve: A post flood assessment'. Journal of Wetlands Ecology, vol. 4, pp: 69-82.

Kumar. R and Sharma. R.C (2019) 'Assessment of the water quality of Glacier-fed lake Neel Tal of Garhwal Himalaya, India'. Water Science vol. 33 (1), pp: 22-28

Laanbroek . H. J (2010) Methane emission from natural wet-lands: interplay between emergent macrophytes and soil microbial processes. A mini-review. Ann Bot , vol 105 pp: 141-153.

Lama. F., Thakuri. S., Ghimire. N. P and Malla. R (2018) 'Ecotone vgetation and water quality of Rara and Begnas Lakes, Nepal'. Himalayan Biodiversity, vol. 6 pp: 27-37.

Lamsal. P., Pant. K. P., Kumar. L and Atreya. K (2014) 'Diversity Uses, and Threats in the Ghodaghodi Lake Complex, a Ramsar Site in Western Lowland Nepal

Lamsal. P., Atreya. K., Pant. K.P., and Kumar. L (2017). People's dependency on wetlands: South Asia perspective with emphasis on Nepal. In Wetland Science, pp : 407-419

Logan. M., Hu. Z., Brinkman. R., Sun. S., Sun. X., Schaffelke. B (2020) 'Ecosystem health report cards: An overview of Frameworks and analytical methodologies' Ecological Indicators vol 113

Lopex. B.M., Bagghetun. E.G., Gonzalez. J.A., Lomas. P. L and Montes. C (2009) 'The Assessment of ecosystem services provided by biodiversity: Re-thinking concepts and research needs'. Handbook of Nature Conservation: Global, Environmental and Economic Issues , Nova Science Publishers

Maltby. E (2006) Wetland conservation and management: questions for science and society in applying the ecosystem approach. In: Wetlands: functioning, biodiversity conservation, and restoration. Springer, pp 93–116

MEA (2005). Ecosystems and human well-being: Wetlands and water synthesis, Washington, DC: World Resources Institute

Merriman. J. C., Gurung.H., Adhikari. S., Butchart. S.H., Khatri. T. B., Pandit.R.S., Ram. A.K., Thomas. D. H. L and Thapa. I (2017) 'Rapid ecosystem sevice assessment of the impact of Koshi Tappu Wildlife Reserve on Wetland benefits to local communities. Wetland Ecology and Management, vol 26, pp: 491-507

MoPE (2004). Initial National Communication to the Conference of the Parties of the United Nations Framework Convention on Climate Change. A report submitted to UNFCCC, pp: 181.

Moravek. J. A., Shrestha. M.B and Yonzon. S (2019) 'Baseline Biodiversity and Physiochemical surveys in ParkatiKunda and Surrounding Area in Rasuwa, Nepal' Journal of Threatened Taxa vol 11(6), pp : 13734–13747

Mountain Spirit (2003). Participatory Livelihood Fieldwork for Terai Landscape Strategic Plan.

National research council (1995) 'Ecology of wetland ecosystem'. Wetlands: Characteristics and Boundaries. Washington, DC: The National Academies Press, pp: 20-21

Neupane. P. K., Khadka. M., Adhikari. R. and Bhuju, D. R. (2010). 'Lake Water Quality and Surrounding Vegetation in Dry Churiya Hills, Far-Western Nepal.' Nepal Journal of Science and Technology, vol. 11, pp: 181–188.

Niraula. R (2012) 'Evaluation of the limnological status of Beeshazar Lake, a Ramsar site in Central Nepal'. Journal of Water Resource and Protection, vol. 4 (5)

OECD (1993) OECD Core Set of Indicators for Environmental Performance Reviews. Technical Report. Organization for Economic Cooperation and Development. Paris, France

Pandey, I. P., Shah, D.N. and Tachamo-Shah, R.D. (2020). Impact of invasive alien plant species on aquatic biodiversity of Koshi Tappu Wetlands: Ramsar Site, Nepal. Banko Jankari 30(2), 48-58.

Pant. R. R ., Dhakal. T. M., Thapa. L. B., Baral. U.B. dangol. A., Chalaune. T. B and Pal. K. B (2019) 'Water Quality Assessment of the Betkot Lake, Sudurpaschim Province, Nepal' North American Academic Research vol. 2 (12) pp: 36-62

Panthi.S., Dhakal. M., Thagunna. S.S and Thapa.B.B (2014) 'Status of wetland in Dhorpatan Hunting Reserve, Nepal'. Open Journal of Ecology, vol 4 (5)

Pokharel, S and Nakamura, M. (2010). Integrated Lake Basin Management for the Sustainable Conservation of Himalayan Lakes of Nepal. In: ILBM for the Sustainability of Himalayan Lakes. Proceedings of National Seminar.

Ramakrishna. R., Sadashivaiah. C and Ranganna. G (2009) 'Assessment of Water Quality Index for the Groundwter in Tumkur Taluk, Karnataka State, India' E-Journal of Chemistry, vol. 6 (2), pp: 523-530

Rai. A.K (2000) 'Limnological characteristics of subtropical Lakes Phewa, Begnas and Rupa in Pokhara Valley, Nepal' Limnology vol. 1, pp: 33-46

Rai. R.K and Scarborough. H (2012). 'Valuing the damage caused by invasive plant species in low income community in Nepal', SANDEE working paper no. 74-12 , pp: 40.

Rajbhanshi. K.G. (2013). Biodiversity and Distribution of Freshwater Fishes of Central Nepal Himalayan Region. Kathmandu, Nepal: Nepal Fisheries Society.

Rayamaghi. B (2009) Direct use of wetland resources to inhabitants in the buffer zone of Koshi Tappu wildlife Reserve.

Regmi, T., Shah, D.N., Doody, T.M., Cuddy, S.M. and Tachamo-Shah, R.D. (2021). Hydrological alteration induced changes on macrophyte community composition in sub-tropical floodplain wetlands of Nepal. Aquatic Botany, 173.

Rendón. M.A., Green. A.J., Aguilera. E and Almaraz P (2008) Status, distribution and long-term changes in the waterbird community wintering in Doñana, south-west Spain. Biol Conserv, vol 141, pp: 1371–1388

Roy. M.B., Roy. P.K., Samal. N.R., and Mazumdar. A (2012) Socio-economic valuations of wetland based occupations of lower gangetic basin through participatory approach. Environment and Natural Resources Research vol. 2(4) pp: 30

Saadati. S., Motevallian. S., Rheinheimer. D.E and Najafi. H (2013) 'Indicators for Sustainable Management of Wetland Ecosystems Using a DPSIR Approach: A Case Study in Iran' Conference: 6th International Perspective on Water Resources & the Environment conference

Shah, D.N., Tachamo-Shah, R.D. and Pradhan, B. (2011). Diversity and Community Assemblages of Littoral Zone Benthic Macroinvertebrates (BMI) in Jagadishpur Reservoir, Nepal. Nepal Journal of Science and Technology 12: 211-220.

Shakya. S., Yadav. P. K., Pant. D.R., Shakya. R.K., Shrestha. M., Pradhananga. A.R., Shrestha. P. K and Shakya. P. R (2019) 'Physico-chemical characterizations of surface water and underlying sediments and limnological status of Beeshazari Lake, a Ramsar site at Chitwan, Nepal. International Research Journal of Environmental Sciences, vol 8 (4), pp: 28-36.

Sharma. C. M., Sharma. S., Gurung. S., Jüttner. I., Bajracharrya. R.M and Pradhan. N. S (2010) 'Ecological studies on Gokyo wetlands, Sagarmatha National Park, Nepal'. In: P.K.Jha and I.Kjanal, Eds., Contemporary Research in Sagarmatha (Mt. Everest) Region, Nepal: An Anthology, Nepal Academy of Science and Technology, Kathmandu, pp: 139-154

Shrestha. A.B., and Aryal. R (2011). 'Climate change in Nepal and its impact on Himalayan glaciers'. Regional Environmental Change. Vol.11, pp: 65–77

Shrestha. N (2017) 'Faunal diversity and Water Quality of the Beeshazar Lake, Chitwan, Nepal'. Central Department of Zoology, Tribhuvan University, Kritipur, Kathmandu

Shrestha, S., Tachamo-Shah, R.D., Doody, T., Cuddy, S. & Shah, D.N. (2021). Establishing the relationship between benthic macroinvertebrates and water level fluctuation in subtropical shallow wetlands. Environmental Monitoring and Assessment, 193.

Singh and Singh (2007) 'Physico-chemical characteristics of Ghariyarwa pond of Birganj, Nepal in relation to growth of Phytoplankton's'. Nature Environment and Pollution Technolog y, vol. 6 (4), pp: 629-632

Subedi. N (2013). 'Effect of Mikania micrantha on the Demography, Habitat Use and Nutrition of Greater One Horned Rhinocerous in Chitwan National Park, Nepal.' Forest Research Institute University, Dehradun

Tachamo Shah. R. D., Shah. D.N and Domisch. S (2012). 'Range shifts of a relict Himalayan dragonfly in the Hindu Kush Himalayan region under climate change scenarios'. International Journal of Odonatology. Vol. 15 (3), pp: 209-222

Thakuri. S., Salerno. F., Guyennon. N., Viviano. G., Smiraglia. C., D'Agata. C., Tarttari. G (2013). 'Glacier response to climate trend and climate variability in Mt. Everest region (Nepal)'. American Geophysical Union, Spring Meeting 2013

Thapa. S., Wang. L., Koirala. A., Shrestha. S., Bhattarai. S and Wai. N. A (2020) 'Valuation of Ecosystem Services from an Important Wetland of Nepal: A Study from Begnas Watershed System '. Wetlands,

Thapa. J., and Saund. T (2013). Water Quality Parameters and Bird Diversity in Jagdishpur Reservoir, Nepal. 'Nepal Journal of Science and Technology', vol. 13(1), pp: 143-155

Xu. F.L., Zhao. Z. Y., Zhan.W. Zhao. S. S., Dawson. R and Tao. S (2005) ‘An ecosystem health index methodology (EHIM) for lake ecosystem health assessment’. Ecological Modelling. Vol 188, (2-4),pp:327-339

Upadhaya. S., Chalise. L and Paudel R. P. (2009). ‘High Altitude Ramsar Sites of Nepal’. The 126415799 Initiation, vol 3, pp: 135-148

Zomer. R.J., Trabucco. A., Metzger. M. J., Wang. M ., Oli. K.P and J. Xu (2014). ‘Projected climate change impacts on spatial distribution of bioclimatic zones and ecoregions within the Kailash Sacred Landscape of China, India. Nepal. Climatic Change. Vol.125, pp: 445–460

Zedler. J.B and Kercher. S (2005). Wetland resources: status, trends, ecosystem services and restorability. Annual Review of Environment and Resources, vol. 30, pp: 39

APPENDICES

Annex 1: Water quality parameters, measurement methods and the requirements.

SN	Parameters	Methods	Requirements
1)	Temperature		Thermometer / Multi parameter probe
2)	Turbidity		Multi parameter probe
3)	Electrical Conductivity		Multi parameter probe
4)	pH		Litmus paper, M Multi parameter probe multi-parameter probe
5)	Dissolved Oxygen		Multi parameter probe
6)	Total Phosphorus	UV-Visible Spectro-photometer at 880nm	• 1.76 % of Ascorbic acid • Sulphuric acid of 5N and 11N • Potassium persulphate • 4% Ammonium molybdate • Potassium antimonyl tartrate • Sodium Hydroxide 6N and 1N • Phenolphthalein
7)	Total Nitrogen	Macro- Kjeldahl method	Spectrophotometer
8)	Orthophosphate		Spectrophotometer
9)	Nitrate		Spectrophotometer

Collection of water sample

- Depending on size and feasibility take water samples from sections around different land use and habitat types covering the overall area of wetland.
- Collect water samples in High Density PolyEthene (HDPE) bottles up to wadeable depths with preservatives as needed. While water collection, a boat can be used or ensure that any bottom sediment disturbed by your feet is nowhere near the water you collect. Collect the sample by turning the bottle upside down and pushing it below the water surface. Once underwater, turn the bottle right way up and allow it to fill. Place the cap on while the bottle is underwater.
- Take 3 composite water sample from one spot and code with site code, date, time of sampling
- Analyse within 8 hours of collection, or preserve by freezing or by adding sulphuric acid to reach pH <2.

© Deep Narayan Shah

© Deep Narayan Shah

Annex 2: Macroinvertebrate sampling and processing techniques

Sampling Equipment

The following equipment are essentially required for sampling the macroinvertebrates:

- Hand/pond net (D-frame net; mesh size 500 μm), the frame attaches to a long handle (Fig. XX).
- Peterson grab sampler (Fig. XX)
- Waders or gumboots, depending on the depth of water
- Utility/work gloves
- Measuring tape
- White tray
- Bucket (max. 10 litre capacity)
- Air tight plastic sample containers (usually 500 – 1000 ml capacity)
- Vials, forceps, small plastic Petri dishes
- Preservative (Ethanol)
- Sample container labels
- Pen and pencil (waterproof)
- Field notebook
- Protocols
- GPS unit and spare batteries
- Magnifying glass
- Camera and spare batteries

Sampling Technique

- Divide the perimeter evenly into approximately 20 survey sites. Take one sample from each selected site. OR, divide the 20 sampling efforts among the 5 habitat types.
- In the littoral zone, a kick and sweep collection method is preferable. A standard D-frame kick net with a mesh of 500μm size is used.
- Ensure that the sampling net and bucket/sieve are clean.
- Approach the selected area slowly in order to minimize accidental disturbance.
- Start the sampling at a depth of 1-metre and slowly walk towards the shore. Bump the net against the submerged vegetation and other hard bottom substrate to dislodge and collect the organisms. The sampling can be standardized to time (e.g., 3 minutes at each site).
- For multi-habitat sampling, sample all inundated microhabitats at each site using D-frame net by jabbing the net into the wetland substrate and quickly sweeping upward. Make sure to collect aquatic macroinvertebrates from areas having emergent vegetation, aquatic macrophyte beds consisting of floating and/or submerged plants, and areas between vegetation hummocks.
- Transfer the sampled material to a white tray or bucket approximately half full of water. Wash or pick all animals off the net.
- Rinse and remove any unwanted large debris items (e.g., stones, sticks, leaves) that may not fit into the sample container or will absorb and diminish the effectiveness of the preservative.
- Transfer the sample to the sample container.
- Add enough ethanol so that the final concentration is about 70% ethanol.
- Label the specimen with appropriate code.

Laboratory Procedure

- Transfer the sample with preservative on a hand net and rinse with water.
- Place the rinsed sample on a white tray with sufficient amount of water for sorting.
- With the help of forceps pick the animals and sort it in their orders. Consider some subsampling methods if the number of invertebrates or the amount of extra material is too high. Subsampling methods include:
    - Dividing the sample into half, quarter or less. Multiply up to get the estimated total number in the sample;
    - In a gridded white tray, count the first 200 individuals then scan the remainder of the sample for rare taxa. Record how many grid squares were counted, then multiply up to get the estimated total number of individuals.
- Sort the animals based on their respective orders and place it in a petri dish filled with ethanol and water.
- Transfer the sorted animals in vials with their site code. (Use pencil or Waterproof pen)
- Fill the vials with ethanol.

Identification

- Transfer the sorted animal from vials to petri dishes.
- Place the petri dish under stereo-microscope for further identification.

Literatures for identification

- Aquatic macroinvertebrate Identification-key https://www.uwa.edu.au/science/-/media/Faculties/Science/Docs/Aquatic-macroinvertebrate-Identification-key2.pdf
- Dudgeon, D. (1999) Tropical Asian Streams: Zoobenthos, Ecology and Conservation, 1st edition. Hong Kong University Press, Hong Kong.
- Guide to Aquatic Invertebrates of the Upper Midwest (2004) (Available at https://dep.wv.gov/WWE/getinvolved/sos/Pages/UMW.aspx
- Nesemann, H.F., Tachamo-Shah. R.D and Shah. D.N (2013) Key to the larval stages of common Odonata of Hindu Kush Himalaya, with short notes on habitats and ecology. Journal of Threatened Tax 3 (9), 2045: 2060
- Nesemann, H., Sharma, S., Sharma, G., Khanal, S., Pradhan, B., Shah, D.N. & Tachamo, R.D. (2007) Aquatic Invertebrates of the Ganga River System, H. Nesemann.
- Tachamo-Shah, R. D., Shah, D.N and Sharma, S (2020) Rivers Handbook: A guide to the health of rivers in the Hindu-Kush Himalaya, Aquatic Ecology Centre, School of Science, Kathmandu University, Nepal.
- Shah, D. N., Sharma, S. and Tachamo-Shah, R. D. (2015). Rapid Assessment of Biodiversity, Benthic Macroinvertebrates. In Gopal, B. (eds) Guidelines for Rapid Assessment of Biodiversity and Ecosystem Services of Wetlands, Version 1.0. Asia□Pacific Network for Global Change Research (APN□GCR), Kobe, Japan, and National Institute of Ecology, New Delhi. 134 pages.
- Yule, C.M. & Sen, Y.H. [eds] (2004) Freshwater Invertebrates of the Malaysian Region. Academy of Sciences Malaysia, Kula Lumpur, Malaysia

© Ram Devi Tachamo-Shah

© Ram Devi Tachamo-Shah

Annex 3: Fish sampling and processing techniques

Sampling Equipment

- Cast Net, Traps, Hooks
- Preservative (10% formaldehyde)
- Sample container labels
- Pen and pencil (waterproof)
- Field notebook
- Protocols
- GPS unit and spare batteries
- Power glass
- Camera and spare batteries
- Measuring Scale
- Digital weighing machine

Sampling Technique

- Fish samples should be collected from all zones of water body.
- Sampling can be carried out using Nets, traps, hooks.
- Diversity of fish species caught during sampling should be identified on site. Use clove oil to anesthetize the fish during measurement and release them back to the wetland after identification of the species.
- Measurement of standard length, total length and weight are documented.
- In case of unidentified specimens, the specimen needs to be preserved in 10% Formalin or 70% ethanol in a large container so the shape of the specimen remains intact.

Literature list for identification

- Shrestha. T. K (2008) Ichthyology of Nepal A Study of Fishes of the Himalayan Waters. Himalayan Ecosphere. Kathmandu. Nepal
- Mishra. S.K (2012)Hill Stream Fishes Along the Indo Nepal Border. Mittal Publications, New Delhi
- Gopal, B. (Editor). 2015. Guidelines for Rapid Assessment of Biodiversity and Ecosystem Services of Wetlands, Version 1.0. Asia-Pacific Network for Global Change Research (APN-GCR), Kobe, Japan, and National Institute of Ecology, New Delhi. 134 page
- Fish Species in Nepal. Available at: https://www.fishbase.in/identification/RegionSpeciesList.php?resultPage=3&c_code=524&SortBy=family#

Date:	**Water Body Name:**	**Sampling Site**	**Site Code:**
Method:	**Start time of Sampling**	**End time of Sampling**	**Sampling Duration:**

S.N	Species	Standard Length (cm)	Total Length (cm)	Weight (gm)	Fin Sample (Y/N)	Voucher Specimen (Y/N)	Photo (Y/N)	Sample ID

© Ram Devi Tachamo-Shah

© Susan Pradhan

Supplementary table: Taxa tolerance score for the determination of Nepal Lake Biotic Index, Phylum, Classes and Orders are given in bold letters, Genus and Species are in italic letters (Source: Tachamo-Shah et al., 2011)

TAXON	TOLERANCE SCORE (TS)	TAXON	TOLERANCE SCORE (TS)
Ephemeroptera		Polypedilum sp. (Chironomidae)	4
Baetidae	6	Dolichopodidae	2
Caenis sp.	3	Ephydridae	1
Trichoptera		Limoniidae	8
Ecnomidae	3	Muscidae	2
Lepidostomatidae	7	Sciomyzidae	8
Leptoceridae	6	Stratiomyidae	4
Molannidae	6	Tabanidae	4
Coleoptera		Tipulidae	7
Chrysomelidae	8	Lepidoptera	
Curculionidae	5	Pyralidae	8
Dryopidae	10	Decapoda	
Dytiscidae	5	Atyidae	6
Gyrinidae	7	Caridina (cf. nilotica)	7
Hydrophilidae	6	Palaemonidae	6
Noteridae	5	Macrobrachium spec.	6
Scirtidae	10	Isopoda	
Odonata		Corallanidae	7
Aeshnidae	6	Tachaea spongillicola (Stebbing, 1907)	7
Coenagrionidae	5	Mysidacea	
Corduliidae	5	Mysidae	8
Gomphidae	4	Gangemysis assimilis	8
Libellulidae	3	Decapoda	
Protoneuridae	8	Potamidae	9
Heteroptera		Himalayapotamon spec.	9
Belostomatidae	7	Parathelphusidae	6
Corixidae	2	Amphipoda	
Gerridae	4	Talitridae	8
Helotrephidae	9	Platorchestia platensis	8
Hydrometridae	6	Araneae	
Mesoveliidae	6	Hydracarina sp.	7
Micronectidae	3	Spinicaudata	
Nepidae	4	Cyclestheriidae	7
Notonectidae	3	Cyclestheria hislopi (Baird, 1859)	7
Pleidae	4	Haplosclerida	
Veliidae	8	Spongillidae	7
Diptera		Cheilostomata	
Ceratopogonidae	5	Lophopodidae	8
Chironomidae (red)	1	Lophopodilla carteri (Hyatt, 1866)	8
Chironomidae not red	5	Plumatellidae	7
Culicidae	2	Tricladida	
Diamesinae (Chironomidae)	8	Planariidae, Dugesia sp.	6
Microtendipes sp. (Chironomidae)	4	Nematoda	2

TAXON	TOLERANCE SCORE (TS)
Haplotaxida	
Naididae	6
Aulophorus carteri (Stephenson, 1931)	7
Aulophorus flabelliger (Stephenson, 1931)	8
Aulophorus furcatus (O. F. Müller, 1773)	7
Aulophorus hymanae (Naidu, 1963)	8
Aulophorus indicus (Naidu, 1963)	7
Aulophorus michaelseni (Stephenson, 1923)	7
Aulophorus tonkinensis (Vejdovsky, 1894)	8
Chaetogaster limnaei bengalensis (Annandale, 1905)	5
Dero nivea (Aiyer, 1930)	6
Nais bretscheri (Michaelsen, 1899)	6
Nais communis (Piguet, 1906)	6
Nais pardalis (Piguet, 1906)	7
Nais simplex (Piguet, 1906)	5
Pristina cf. biserrata (Chen, 1940)	6
Pristina breviseta (Bourne, 1891)	6
Pristinella acuminata (Liang, 1958)	6
Pristinella jenkinae (Stephenson, 1931)	6
Pristinella menoni (Aiyer, 1929)	6
Pristina synclites (Stephenson, 1925)	6
Stylaria fossularis (Leidy, 1852)	6
Tubificidae	2
Aulodrilus limnobius (Bretscher, 1899)	9
Aulodrilus pigueti (Kowalewski, 1914)	6
Aulodrilus pluriseta (Piguet, 1906)	4
Branchiodrilus hortensis (Stephenson, 1910)	5
Branchiodrilus semperi (Bourne, 1890)	6
Branchiura sowerbyi (Beddard, 1892)	2
Limnodrilus claparedeanus (Ratzel, 1868)	4
Limnodrilus hoffmeisteri (Claparede, 1862)	2

TAXON	TOLERANCE SCORE (TS)
Limnodrilus profundicola (Verill, 1871)	3
Limnodrilus udekemianus Claparede, 1862)	4
Enchytraeidae	7
Megascolecidae	
Amynthas corticis (Kienberg, 1867)	7
Lumbriculida	
Lumbriculidae	8
Lumbriculus variegatus (O.F.Muller, 1774)	8
Arhynchobdellida	
Salifidae	3
Barbronia weberi (Blanchard, 1897)	4
Salifa (Herpobdelloidea) lateroculata (Kaburaki, 1921)	5
Haemadipsidae	8
Haemadipsa sylvestris (Blanchard, 1894)	8
Hirudinidae	7
Hirudinaria manillensis (Lesson, 1842)	8
Poecilobdella granulosa (Savigny, 1822)	8
Rhynchobdellida	
Glossiphoniidae	4
Alboglossiphonia heteroclita (Linnaeus, 1761)	4
Alboglossiphonia pahariensis	5
Alboglossiphonia weberi (Blanchard, 1897)	4
Batracobdelloides reticulatus (Kaburaki, 1921)	4
Placobdelloides multistriatus (Johansson, 1909)	7
Placobdelloides fulvus (Harding, 1924)	4
Bivalvia	
Unionidae	6
Lamellidens jenkinsianus jenkinsianus (Benson, 1862)	6
Lamellidens marginalis	8
Lamellidens narainporensis (Preston, 1912)	6
Corbiculidae	5
Corbicula striatella (Deshayes, 1854)	4
Sphaeriidae	5

TAXON	TOLERANCE SCORE (TS)
Musculium indicum (Deshayes, 1854)	4
Pisidium annandalei (Prashad, 1925)	9
Pisidium atkinsonianum (Theobald, 1876)	8
Pisidium clarkeanum dhulikhelensis (Nesemann & Sharma, 2005)	6
Pisidium clarkeanum (G. & H. Nevill, 1871)	4
Pisidium nevllianum (Theobald, 1876)	5
Amblemidae	7
Radiatula caerulea (Lea, 1831)	6
Radiatula lima (Simpson, 1900)	7
Radiatula occata (Lea, 1860)	7
Gastropoda	
Bithyniidae	5
Digoniostoma cerameopoma (Benson, 1830)	5
Digoniostoma pulchella (Benson, 1836)	5
Gabbia orcula (Frauenfeld, 1862)	5
Lymnaeidae	4
Galba truncatula (O.F. Müller, 1774)	8
Lymnaea acuminata (Lamarck, 1822)	4
Radix luteola (Lamarck, 1822)	4
Radix ovalis (Gray, 1822)	4
Thiaridae	4
Brotia costula (Rafinesque, 1833)	7
Melanoides pyramis (Hutton, 1850)	4
Melanoides tuberculatus (O.F. Müller, 1774)	4
Thiara lineata (Gray, 1828)	4
Thiara scabra (O.F. Müller, 1774)	5
Planorbidae: Planorbinae	4
Gyraulus convexiusculus (Hutton, 1849)	4
Gyraulus euphraticus (Mousson, 1874)	4
Gyraulus labiatus (Benson, 1850)	5
Hippeutis umbilicalis (Benson, 1836)	4
Segmentina calatha (Benson, 1850)	4
Segmentina trochoidea (Benson, 1836)	5
Planorbidae: Bulininae	
Camptoceras lineatum (Blanford, 1871)	7
Indoplanorbis exustus (Deshayes, 1834)	4
Physidae	2
Physa (Haitia) mexicana (Phillipi, 1889)	2
Viviparidae	6
Bellamya bengalensis	6
Idiopoma dissimilis	6
Ampullariidae	4
Pila globosa (Swainson, 1822)	4

Annex 4: Bird survey techniques

Sampling Equipment

The following equipment are essentially required for Bird survey:

- A binocular
- GPS unit and spare batteries
- Camera and spare batteries
- Compass, Clipboard, pencil and eraser
- Small notebook for making your own notes of special events seen
- Protocol
- Bird field guide
- Lens tissue to clean the binocular lens and glass
- Flagging tape or strips of colored material
- Cassette recorder, cassette tape and spare batteries to record unknown bird calls (optional)

Sampling Technique

- Depending on the area and land use type, set the number of transects along the wetland area.
- Estimate the distance interval for observation and between transects.
- Use fixed count method for the survey of birds within certain radius.
- Scan birds early in the morning and during evenings
- Spend 10-15 minutes in each plot .Binocular shall be used while documenting birds
- Use a field guidebook, Birds of Nepal (Grimmet et al. 2016) for identification of species
- Record unfamiliar calls and take photographs of unidentifiable species for further identification with the experts.

Literatures for Identification

- Grimmet .R., Inskipp.C.,Inskipp.T and Baral. H.S (2016) Birds of Nepal. Bloomsbury Publishing
- Bird Conservation Nepal (2018). Birds of Nepal: An Official Checklist, Kathmandu, Nepal.

Date:	**Survey Area :**	**Site code:**
Start Time:	**Finish Time:**	**End time of Sampling**

S.N	Name of Spe-cies	Species Code	Habitat prefer-ence	X Distance interval	Zone	Easting	Northing	CITIES	IUCN	Photo (Y/N)

Bird Watching © Omkar Bhatta

Indian Pond Heron © Aditya Pal

Annex 5: Macrophytes sampling and processing techniques

Sampling Equipment

The following equipment are essentially required for sampling macrophytes:

- Plastic bags
- Rake
- GPS unit and spare batteries
- Camera and spare batteries
- Rubber boat/ Paddle boat
- Plant cutter, and a knife
- Quadrat
- Rubber gloves

Sampling Technique

- A stratified random sampling should be conducted in site. However, an entire area of a wetlands can be surveyed if the area is small and wadeable.
- Based on the water regime collect macrophytes from different zonation along the water depth gradient.
- All kinds of macrophytes; Free floating, Submerged and Emergents can be collected and identified in the field by walking across it and wading into shallow waters.
- Pull macrophytes using a rake with a long handle if Free floating, floating leaved or submerged plants growing in an area cannot be easily reached.
- Sample macrophytes at 3 locations per site.
- The distribution of different taxa can be visually inspected and indicated on the map in wetlands with a large deep water area and where macrophytes only appear in a relatively restricted littoral zone.

Literatures for Identification

- Biswas, K. and C.C. Calder. (1937) Handbook of common water and marsh plants of India and Burma. Health Bulletin 24. Manager of Publications, Delhi.
- Gopal, B. (Editor). 2015. Guidelines for Rapid Assessment of Biodiversity and Ecosystem Services of Wetlands, Version 1.0. Asia-Pacific Network for Global Change Research (APN-GCR), Kobe, Japan, and National Institute of Ecology, New Delhi. 134 pages

Site ID:	**Date:**
Location:	**Water body name:**
Water level: High/Med/Low	**GPS waypoint:**

S.N	Species	Observed Rep[1]	Observed Rep[2]	Observed Rep[3]	Fin Sample (Y/N)
		Depth (cm) :	Depth (cm) :	Depth (cm) :	
		Substrate:	Substrate:	Substrate:	
		% open water:	% open water:	% open water:	
		Type	Type	Type	

© Deep Narayan Shah

WWF

NEPAL