Training Manual

Integrated Wetland Management

Module 3

Water Quality for Wetlands Conservation and Wise use

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Authors

Ravi Prakash (Lead)
Harsh Ganapathi
Suchita Awasthi
Ritesh Kumar

Design and illustrations

Shruti Pillai
shruti.pillai202@gmail.com

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• Message •

Dear Readers,

Wetland water quality is affected through various ecological, geological, and hydrological changes that take place in the wetland ecosystem. There is a change in nutrient fluxes in the system as most of the nutrients either get sedimented or are absorbed by emergent, submerged, or free-floating macrophytes. The flow of nutrients in the water also depends on water level fluctuations due to changes in hydrological regimes. When wetlands are used beyond their carrying capacity there are changes in the water quality and that is why we talk about conservation and wise use which is not only beneficial to the present generation but can be made sustainable for future generations too.

Wetlands have great significance as they charge aquifers, conserve moisture, act as pollution filters, and are habitats for biodiversity. When the world's population has increased many times freshwater withdrawal has increased due to massive urbanisation, growing dependence on irrigated agriculture, and higher standards of living. In this context, availability of water for meeting multiple requirements is a major challenge to the world. As our world faces many environmental challenges wetlands have to be saved from degradation due to overuse for human consumption. In this module, we would like to present knowledge and tools to address such issues.

The present module provides a comprehensive guidance on water quality. The module provides clues to the need for water quality, practical techniques for water quality monitoring, and effective strategies needed for water quality monitoring. It provides global examples of good practices available on water quality needed for healthy wetland management. This module will be useful for conservationists, managers, policymakers, researchers, and normal citizens. By promoting the wise use and sustainable management of wetlands we can do a little service to have healthier wetlands for a sustainable future.

This module forms an integral component of the efforts of Wetlands International South Asia(WISA) to help managers and equip them with the tools and knowledge needed to conserve wetlands. Our goal is to equip them with the tools and knowledge necessary to conserve wetlands in a holistic, organized, and efficient manner. We are hopeful that this initiative will contribute significantly to the enhancement of knowledge, skills, and values essential for effective water and wetland management.

I look forward to receiving your suggestions for further improvements to the modules.

Dr Sidharth Kaul
President
Wetlands International South Asia
February 2, 2025

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• Learning Outcomes •

- Appreciate the role of water quality in wetlands ecosystem
- Learn how wetland water quality gets affected by human activities and natural processes
- Learn how wetland water quality can be monitored
- Understand specific interventions through which water quality can be managed in wetlands

Acronym

AAS	Atomic Absorption Spectroscopy
BOD	Biological Oxygen Demand
BWQC	Biological Water Quality Criteria
CPCB	Central Pollution Control Board
CWs	Constructed Wetlands
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DDE	Dichlorodiphenyldichloroethylene
EC	Electrical Conductivity
EKW	East Kolkata Wetlands
EIA	Environment Impact Assessment
GHGs	Greenhouse Gases
GC	Gas Chromatography
GCMS	Gas Chromatography-Mass Spectrometry
HCH	Hexachlorocyclohexane
HF	Horizontal Flow
IoT	Internet of Things
IS	Indian Standard
IUCN	International Union for Conservation of Nature
IBA	Important Bird Areas
MoEFCC	Ministry of Environment, Forest and Climate Change
MPN	Maximum Probable Number
MF	Membrane Filter
NH	National Highways
NGT	National Green Tribunal
NWQMN	National Water Quality Monitoring Network
NMCG	National Mission for Clean Ganga
P/R	Production/ Respiration

1 Wetland water quality- an introduction

1.1 What are wetlands?

Wetlands are transitional areas between aquatic and terrestrial ecosystems where the water table is usually at or near the surface, or water covers the land. The Ramsar Convention, an intergovernmental treaty for wetlands conservation and its wise use defines wetlands as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters".

Wetlands can be natural such as river floodplains, lakes, lagoons, mangroves, peatlands, and coral reefs as well as human-made such as fish and shrimp ponds, farm ponds, irrigated agricultural land, salt pans, reservoirs, gravel pits, sewage farms, and canals. These wetlands are often interconnected and work as a larger hydrological and ecological system. Figure 1.1 illustrates different types of wetlands and their connectivity within the landscape.

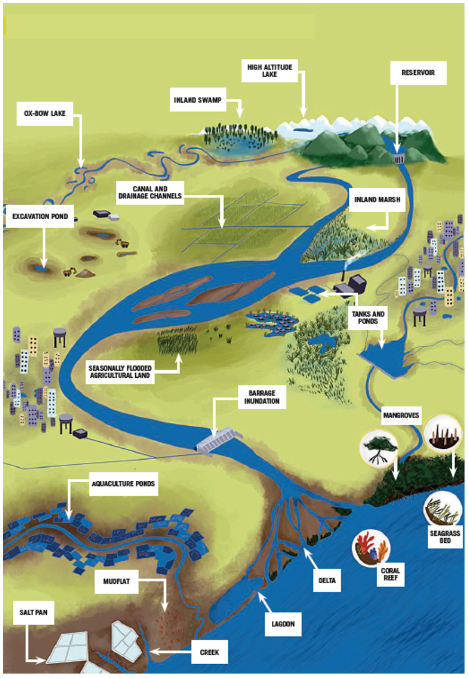


Figure 1.1 : Types of wetlands (credit: WISA Library)

1.2 Wetlands wise use

Wetlands are managed for their wise use. The Ramsar Convention defines Wise Use as 'maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development'.

Ecological character is the "sum of the ecosystem components, processes, and services that characterize the wetland at any given point in time". Figure 1.2 elaborates on interactions between different components of the ecological character of wetlands.

Ecosystem approach is a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way. The Convention on Biological Diversity has adopted the Malawi Principles for the implementation of ecosystem approach (See Box 1)

Sustainable development is a development that meets current human needs while preserving the environment and without compromising the ability of future generations to meet their own needs.

Development is not the aim of every wetland. Where wetland development is inevitable, it has to be done in a manner that befits 'sustainable development'. Thus, the wetland wise use aims at ensuring that wetlands provide their ecosystem services not only at present but also in the future. Thus 'preservation', protection', and 'conservation' much form a part of wetland wise use.

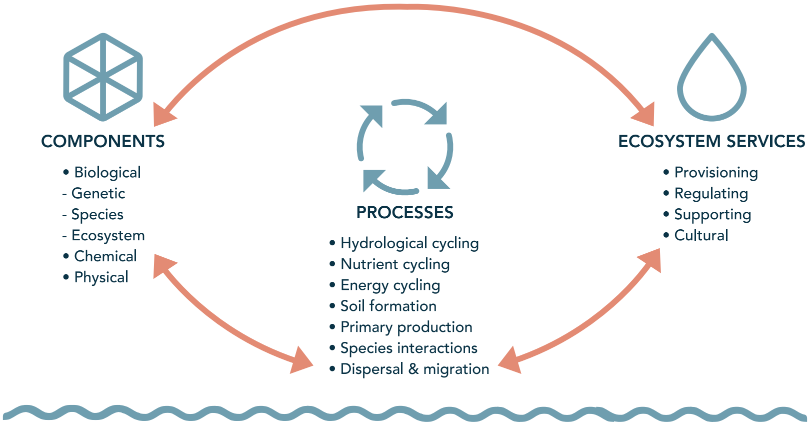


Figure 1.2 : The ecological character of wetlands

Box 1.1 : Malawi Principles for implementation of ecosystem approach

The Malawi Principle of the ecosystem approach to biodiversity management represents a significant milestone in the global conservation efforts. The principle was introduced during the Workshop on the Ecosystem Approach held in Lilongwe, Malawi, in January 1998. The essence of the Malawi Principle revolves around recognizing that sustainable management of biodiversity requires a holistic approach, taking into account the intricate relationships between living organisms and their environments. It emphasizes the need to consider social, economic, and cultural factors alongside ecological considerations in conservation efforts. This principle underscores the importance of involving local communities and stakeholders in decision-making processes to ensure that biodiversity conservation is both effective and equitable. The following are twelve principles adopted for the implementation of the ecosystem approach:

Principle 1: The objectives of management of land, water and living resources are a matter of societal choices

Principle 2 : Management should be decentralized to the lowest appropriate level.

Principle 3 : Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems.

Principle 4 : Recognizing potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context.

Principle 5 : Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach.

Principle 6 : Ecosystem must be managed within the limits of their functioning.

Principle 7 : The ecosystem approach should be undertaken at the appropriate spatial and temporal scales.

Principle 8 : Recognizing the varying temporal scales and lag-effects that characterize ecosystem processes, objectives for ecosystem management should be set for the long term.

Principle 9 : Management must recognize the change is inevitable.

Principle 10 : The ecosystem approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity.

Principle 11 : The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices.

Principle 12 : The ecosystem approach should involve all relevant sectors of society and scientific disciplines.

Water is the key determinant of the wetland ecosystem components and processes; its quality plays a crucial role in maintaining the ecological character. For instance, wetland species such as plants and animals derive nutrients from the water and are directly susceptible to water quality changes. Similarly, wetland processes such as nutrient cycling, soil formation, primary production, species interactions, dispersal, and migration are also dependent on wetland water quality characteristics. For instance, lack of nutrients in water may deprive the growth of aquatic plants, and habitats for species like water birds, fishes, and other animals. This can lead to the migration of these species to another favorable habitat. Moreover, water quality also determines the extent of ecosystem services that humans can derive from wetlands. Services such as water purification, soil formation, food production, raw material extraction, and recreation are driven by the water quality of wetlands (Refer to section 1.6 for more information on how water quality influences wetland ecosystem).

The ecosystem approach of integrated management of land, water, and living resources requires certain water quality standards. Conversely, maintenance of water quality within the wetland demands integrated management of these three components at the catchment scale. For instance, land use within the catchment requires a certain standard quality of water from wetlands. This in turn affects the quality of water received by the wetland after its use. Also, for achieving sustainable development, access to water of desired quality is the core mandate. This again emphasizes the importance of water quality within the framework of wise use .

1.3 What is wetland water quality?

Wetland water quality is the physical, chemical, and biological characteristics of water within the wetland. Their degree of variation from a natural undisturbed state provides a measure of degradation and the necessity of management intervention. Wetland water quality closer to its natural undisturbed state is considered to be better.

Water quality indicators are a set of physical, chemical, and biological properties of wetland water that are indicative of the characteristics of water. These indicators are measured to provide an understanding of wetland ecosystem health. These indicators, although assessed separately, are interdependent and often interact with each other (see Figure 1.3).

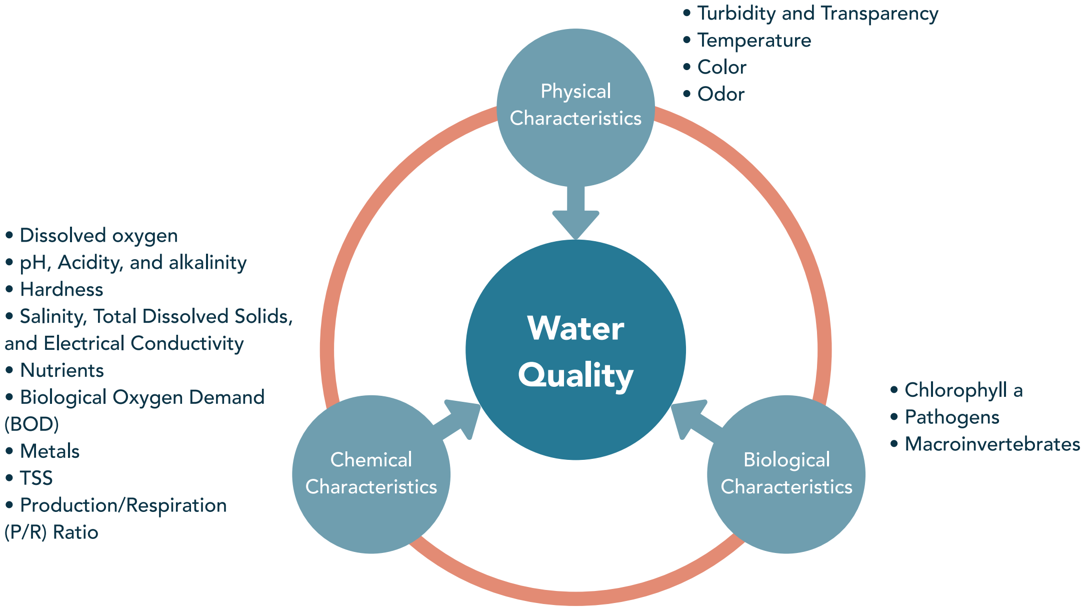


Figure 1.3 : Wetland water quality components

1.3.1 Physical indicators

Physical indicators are properties that are perceptible by the human senses of sight, touch, hear, taste, and smell. Physical indicators of wetland water include turbidity, transparency, temperature, and color. Table 1.1 represents the different physical indicators and their role in the wetland ecosystem.

Table 1.1 : Physical indicators of wetland water quality and its significance in the wetland ecosystem

Indicator	What it indicates	Significance in wetland ecosystem
Turbidity and Transparency	• Turbidity indicates the presence of suspended particulate matter in the water column. Cloudy-looking water indicates high turbidity which can be due to the presence of particulate matter such as silt and clay, organic and inorganic matter, and living or dead microscopic organisms, suspended in water. • Transparency indicates the extent of visibility in wetland water. Turbid water reduces visibility and leads to reduction in transparency in wetlands.	• Highly turbid water may hinder light penetration leading to decreased photosynthetic processes. • Turbidity may lead to an increase in water temperature as suspended particles have a higher heat-absorbing capacity than clear water. • Turbidity may affect predator-prey relationships as the ability of both prey and predator to detect each other gets impaired in highly turbid water. • Excessive turbidity can lead to clogging of the respiratory systems of aquatic fauna.
Temperature	• Abrupt changes in temperature can be an indicator of disturbances in the wetlands. • Temperature differences may also indicate stratification - a process of forming distinct thermal layers at different depths in wetlands. • High water temperature can also be an indicator of thermal pollution mostly caused by the discharge of industrial wastewater. Water inflow such as rainfall, surface runoff or groundwater also has an impact on temperature.	• The temperature of the water affects the presence of dissolved oxygen in the wetland, which is crucial or the survival of aquatic species. In general, as the water temperature increases, the level of dissolved oxygen decreases. • Temperature has an impact on metabolic processes in wetland plants and animals. Usually, metabolism is high in warmer water. • In fishes, the reproductive stage i.e. spawning and embryo development is the most temperature-sensitive period. • Temperature also affects ammonia levels and the rate of photosynthesis in wetlands. Ammonia volatilization (release of ammonia from water) increases with an increase in temperature.
Color	• Color in wetland water can be due to inorganic ions such as iron, manganese, humus and peat, plankton and other vegetation • True color is the color of the water after the removal of turbidity, whereas apparent color in wetlands water is due to soluble substances as well as suspended matter.	• Presence of color can hinder sunlight penetration in wetlands • Photosynthetic processes within the wetlands are only possible in the presence of light. • The presence of primary producers (that acquire energy from sunlight) is directly affected by light, which in turn affects the population of consumers via the food chain.
Odor	• Odor in wetlands can be due to natural as well as human-made sources. Natural sources of odor in wetlands include the presence of algae, protozoa, crustacea, actinomycetes, etc. Human-made sources of odor are domestic and industrial discharge into wetlands. Agricultural runoff also leads to odor in wetlands. For instance, a high nitrogen load can lead to the release of ammonia gas through volatilization.	• Odor due to anthropogenic sources can indicate degradation of wetland ecosystem health due to high pollution load. • Release of hydrogen sulfide (rotten egg-like smell) indicates anoxic condition (lack of oxygen) in wetlands

1.3.2 Chemical indicators

Water is an excellent solvent, as it dissolves a range of chemicals, including trace metals, organics, common ions, and biodegradable organics. Chemical indicators are used to indicate the chemical constituents of the wetland water. Table 1.2 represents the different chemical indicators and their role in the wetland ecosystem.

Table 1.2 : Chemical Indicators of wetland water quality and its significance in the wetland ecosystem

Indicator	What it indicates	Significance in wetland ecosystem
Dissolved oxygen	• Dissolved oxygen indicates the balance between oxygen-consuming processes (such as respiration, and aerobic decomposition) and oxygen-releasing processes (such as photosynthesis and diffusion from the atmosphere).	• Most aquatic species require oxygen for respiration. A low level of dissolved oxygen may be fatal for aquatic organisms, and create phenomena such as fish kills. • Dissolved oxygen influences the solubility of chemicals such as metals and nutrients in the water via redox reactions. • Anaerobic conditions (lack of oxygen) may support the growth of the species that can thrive on very low dissolved oxygen levels.
pH, Acidity, and Alkalinity	• pH indicates the presence of hydrogen ion concentration in water. It is measured on a scale of 0-14, where 7 is considered to be neutral. pH > 7 indicates wetland water is alkaline and < 7 as acidic.	• Wetland species are adapted to a certain range of acidity and alkalinity. Acidity or alkalinity above the tolerance limit of the species can have detrimental effects on its health and can even lead to mortality. • The solubility of metals and nutrients is directly dependent on the acidity of the water. Lower pH solubilizes metals and increases their biological availability eading to additional stresses among aquatic organisms. • An excess amount of alkalinity can lead to the release of ammonia gas which is again toxic to wetland species.
Hardness	• Hardness is the indicator of calcium (Ca) and magnesium (Mg) ions present in the water.	• Hardness impacts the bioavailability of toxic metals as well as nutrients in wetlands. The toxicity of many metals decreases with increasing water hardness. • Hard water usually is alkaline with a high acid buffering capacity. Therefore, wetlands with hard water are more resistant to acidification.
TDS	• Total Dissolved Solids is a measure of the total amount of solids present in the wetland including inorganic salts as well as dissolved organic matter. Major ions that contribute to total dissolved solids are calcium, magnesium, potassium, chloride, fluoride, carbonate, sodium, sulphate, and others.	• As the TDS constitutes dissolved organic matter, the presence of it is essential for wetland flora and fauna. • Dissolved nutrients such as nitrate and phosphate are crucial for sustaining life in wetlands. • High TDS may indicate the introduction of pollution to the wetland.

Indicator	What it indicates	Significance in wetland ecosystem
Salinity and Electrical Conductivity	• Salinity indicates the concentration of total dissolved salts and hence determines the difference between 'freshwater' and 'saline' water.Freshwater has a salinity of 0.5ppt or less, Brackish water present in estuaries can have salinity level between 0.5-30 ppt depending on their proximity to river inflows or ocean. Marine water has average salinity level of 35ppt. • EC indicates the ion concentration in wetland water. The higher the ion concentration higher the electrical conductivity of the water. • Freshwater usually has an EC level of less than 600 µS/cm. Brackish water has an EC level of 600-6000 µS/cm and saline water has > 6000 µS/cm of EC level.	• Salinity can alter the species composition, causing an increase in the population of salinity-tolerant species as compared to salinity-sensitive species. A higher salinity can lead to the extirpation of salinity sensitive species. • Changes in salinity can provide migration cues to communities such as fishes • Although species adapted to naturally saline water can tolerate small fluctuations in salinity, higher fluctuation can cause migration, reduced growth, or even lead to mortality. Species that are sensitive to salinity, can be affected adversely by small fluctuations.
Nutrients	• Nutrients are an indicator of the concentration of useful elements such as nitrogen and phosphorus vital for sustaining aquatic life. These are linked with wetland productivity including both primary as well as secondary productivity.	• Nutrients, especially nitrogen and phosphorus are vital for the survival of wetland species and occur in various forms in wetland ecosystems. They play a critical role in the construction of living tissues and metabolic processes. • High levels of nutrients can lead to excessive algal and cyanobacterial growth. This leads to eutrophication of the wetland, causing depletion of dissolved oxygen levels in the wetland.
Biological Oxygen Demand (BOD)	• BOD indicates the amount of oxygen required by microorganisms to decompose the organic matter present in water.	• In wetlands, BOD indicates the presence of organic matter. The higher the BOD, the higher will be the oxygen required to degrade the organic matter. It has a direct effect on the level of dissolved oxygen available for aquatic species. A higher BOD usually is associated with lower levels of DO.
Metals	• The presence of excessive metals indicates pollution in wetlands. • Heavy metal presence can be due to the discharge of industrial wastewater. It can also indicate acidification in the wetland, as metals can be released in water from the wetland bed in an acidic environment.	• Metals in a balanced amount are essential for the growth of wetland flora and fauna. • Excessive amounts of metals can lead to impaired health of wetland flora and fauna. • It can also lead to birth defects and can even lead to mortality. • Excessive metals can alter the floral and faunal composition of wetlands.

Indicator	What it indicates	Significance in wetland ecosystem
Total Suspended Solids (TSS)	• TSS indicates the mass of sediments suspended in the wetland water. Silt and clay are the most common suspended matter present in wetland water.	• Increased suspended sediment levels decrease light penetration in water and allow water to absorb more heat energy, increasing water temperatures.
Production/Respiration (P/R) Ratio	• P/R ratio is the indicator of primary productivity i.e. the process by which primary producers such as plants and algae make their own food by using inorganic sources and sunlight. P/R > 1 indicates good health of the wetland ecosystem, however, excessive value can indicate eutrophication. P/R=1 indicates a stable state and P/R < 1 shows unstable condition.	• Extremely high value of P/R indicates eutrophication which can cause depletion of dissolved oxygen levels leading to mortality in wetland species. • Low P/R < 1 leads to starvation of plants, as in this case energy consumed by respiration exceeds the energy produced by photosynthesis.
Oil and Grease	• Oil and grease include fats, oils, waxes, and other related constituents. Oil and Grease are used mainly as an indicator of pollution specifically industrial pollution.	• The presence of oil and grease within wetlands can give rise to the formation of surface films and the deposition of contaminants along shorelines. This phenomenon has the potential to engender environmental degradation, thereby precipitating adverse ecological consequences. Furthermore, the introduction of oil and grease into surface or groundwater systems can pose inherent risks to human health. Moreover, oil and grease compounds have the propensity to disrupt both aerobic and anaerobic biological processes, thereby culminating in a diminution of the efficiency of wastewater treatment protocols.

1.3.3 Biological and Microbiological indicators

Biological and microbiological indicators are indicative of the biotic ecosystem components of the wetland. Key indicators used to describe the biological and microbiological indicators of wetland water quality include chlorophyll a, pathogens, and macroinvertebrates. The composition of fish, waterbirds, and plant species may also serve as bioindicators of wetland water quality. However, these can be influenced by a range of factors other than those related to wetland sites. Table 1.3 represents the different biological indicators and their role in the wetland ecosystem.

Table 1.3 : Biological Indicators of wetland water quality and its significance in the wetland ecosystem

Indicator	What it indicates	Significance in wetland ecosystem
Chlorophyll a	• Chlorophyll a is the indicator of primary productivity and nutrient levels in the wetlands and is typically used as an indicator of algae in wetlands	• Chlorophyll a is the main light-capturing substance enabling photosynthesis in the plant, algal, and cyanobacterial cells. It is present in all green algae, diatoms, and some bacteria. High levels of chlorophyll a can be indicative of nutrient enrichment and the potential for algal and cyanobacterial blooms and related impacts.

Indicator	What it indicates	Significance in wetland ecosystem
Pathogens	• Presence of infectious microorganisms such as bacteria, viruses, protozoans, fungi, and parasites can cause disease or illness in wetland species as well as in humans.	• The presence of pathogens can impair species' health causing disease and illness. It can even lead to mortality leading to wetland biodiversity loss. • Pathogens such as E. coli indicate anthropogenic pollution including fecal contamination. This can have an adverse impact on the health of humans as well as wetland species.
Macroinvertebrates	• Benthic macroinvertebrates indicate the status of the biological diversity of wetland water as they are a critical part of the aquatic food chain. • The Saprobic and Diversity index are used for indicating the population and diversity of macroinvertebrates in wetlands	• Macroinvertebrates are a good indicator of wetland water quality, as they are the most sensitive to pollution and have different tolerance levels depending on the species. • The presence of least-tolerant or sensitive species of macroinvertebrates indicates good water quality, whereas tolerant species are indicative of poor water quality.

1.4 Ways in which wetlands influence water quality

1.4.1 How do wetlands function?

Wetlands as a multifunctional ecosystem provide numerous hydrological functions such as flow regulation, water recharge and storage, sediment retention, and purification through biogeochemical processes. During the wet period, it helps buffer excess water preventing flood, and in the dry period, it maintains the river and stream flow with the gradual discharge of stored water. Wetlands by dissipating the stream energy reduce the flow of water. Reduction in flow favors multiple ecohydrological processes such as increased water retention, groundwater recharge, and evapotranspiration. Retention of water for a longer period increases the interaction of biotic and abiotic components leading to multiple biogeochemical processes, such as nutrient cycling, soil formation, settlement, and filtration of suspended particles.

Water retained in the wetlands provides an opportunity for the settlement of suspended particles and other physical, biological, and chemical processes to occur. Biological processes that help in water purification in wetlands include microbial degradation of organic matter and plant uptake. Chemical processes that enhance water quality are the adsorption of materials in the plant roots and debris, oxidation and reduction of nutrients, and UV degradation through sunlight penetration. Filtration of suspended particles through plant roots, and settlement are physical processes that aid in water purification in wetlands (see Figure 1.4).

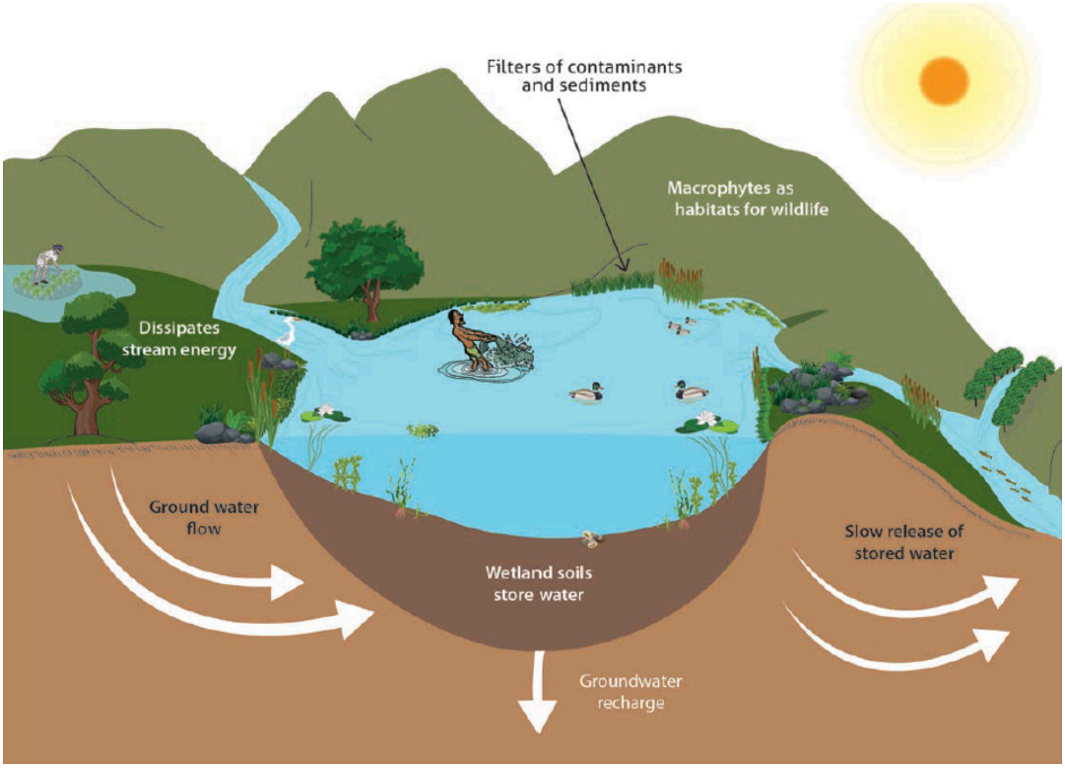


Figure 1.4 : Functions of wetland (credit: WISA Library)

1.4.2 The ways in which wetlands influence water quality

Wetlands are often termed as "kidneys of the ecosystem" as they perform water purification through multiple physical, chemical, and biological processes. These processes occur simultaneously within all three substrates of the wetlands i.e. soil, water, and vegetation (see Table 1.4 and Figure 1.5).

Table 1.4 : Different ecosystem processes leading to water quality improvement in wetlands

Process types	Process and implication for water quality	Examples
Physical	**Filtration** • Wetland plants help in filtering the pollutants through their root systems called the rhizosphere. **Sedimentation** • Sedimentation takes place due to water retention in the wetland. It leads to the removal of suspended particles as well pathogens attached to it.	• Suspended particles get trapped in between the roots. • Suspended particles such as suspended organic matters, metals, and even pathogens get settled down due to reduced flow in the wetlands.

Process types	Process and implication for water quality	Examples
Biological	**Microbial degradation** • Aerobic (in the presence of oxygen) and anaerobic(in the absence of oxygen) decomposition of organic matter by microorganisms.	• Oxidation and reduction of nitrogen compounds in water take place with the help of nitrifying and denitrifying bacteria.
	Plant uptake • Plant uptake, also called phytoremediation, takes place through the root system of hydrophytes in wetlands. It removes nutrients as well as metals from the wetland water.	• Heavy metals such as chromium, lead, arsenic, etc are removed by the macrophytes through root uptake. Nutrients especially, phosphorus and nitrogen are vital for the growth of macrophytes.
Chemical	**Adsorption and Precipitation** • Adsorption is a process in which molecules in the water get attached to the solid particles in the wetlands. Precipitation is the process of converting metals to insoluble forms.	• Metals get adsorbed on the sediment surface and get precipitated at the wetland bed. Phosphorus adsorption in the sediments plays an important role in nutrient cycling in the wetlands.
	Photodegradation • Photodegradation is a process of direct alteration of materials by light. In wetlands, the natural degradation of various pollutants takes place through sunlight.	• Photodegradation of pesticides is a crucial removal mechanism that occurs in the wetland system.Pathogens are inactivated directly through the heat received from sunlight.
	Volatilization • Volatilization is a direct conversion of chemicals from liquid or solid-state to gaseous . In wetlands, volatilization is facilitated by energy from sunlight.	• In highly alkaline conditions, ammonia gets volatilized from aqueous to gaseous form, leading to a reduction in nitrogen in wetlands. Volatile Organic Compounds(VOCs) are also removed through this mechanism.

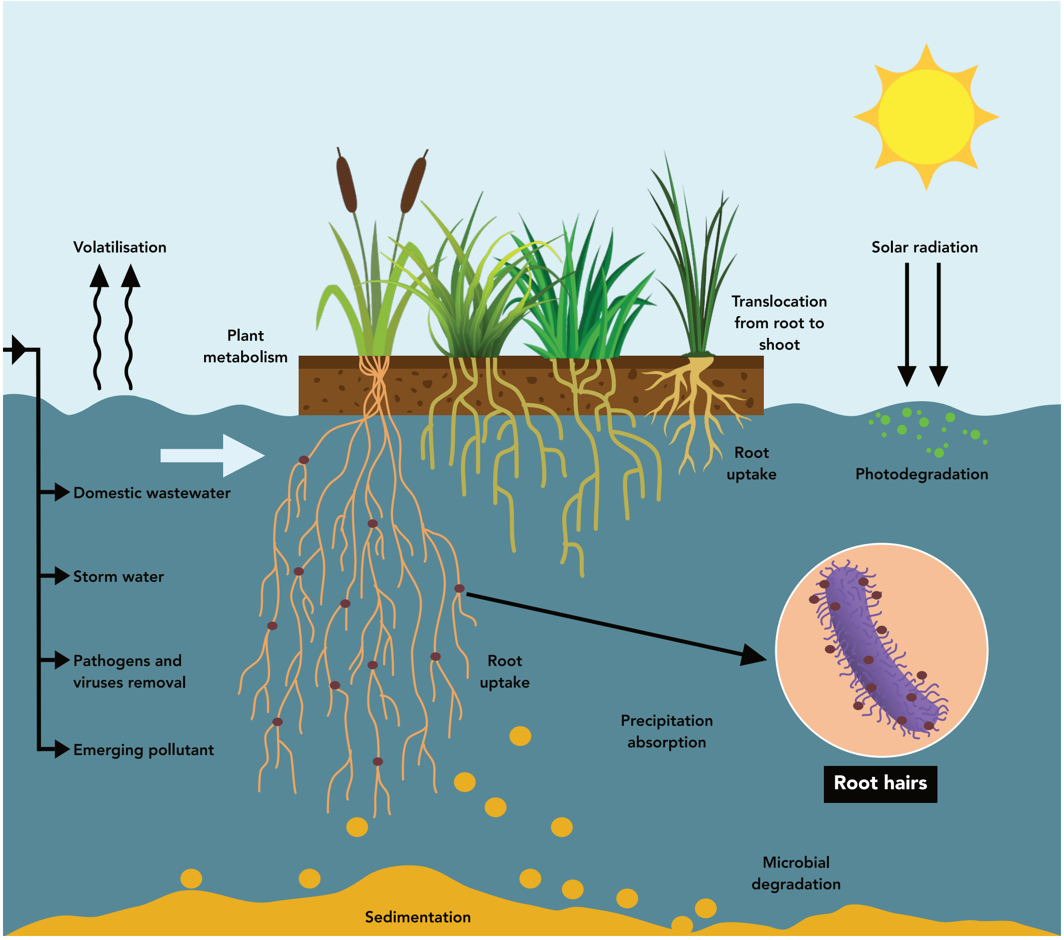


Figure 1.5 : A schematic diagram indicating various ecosystem processes in an inland wetland leading to water quality improvement

Box 1.2 : EKW - a natural wastewater treatment system for Kolkata city

East Kolkata Wetland, a Ramsar site in India, is located on the eastern fringe of the Kolkata Metropolitan City and has a spread of over 12,500 hectares. Due to its significance in treating enormous amounts of wastewater discharged by Kolkata city, it has often been termed as 'Kidney of Kolkata'. It supports the world's largest wastewater-fed aquaculture. The wetlands are interconnected through the channels and contain over 260 shallow fish ponds, locally known as "Bheri". Each hectare of the shallow wetland has the ability to remove 237 kg of BOD per day. As the Bheri are shallow, the vertical circulation of water allows the growth of algae which helps in nutrient uptake. Solar radiation, which is about 250 Langleys days, supports photosynthetic processes to occur, augmenting reoxygenation for efficient BOD and pathogen/fecal coliform reduction. The major factors that play a role in water treatment are shallow ponds acting as a stabilization pond, water hyacinth absorbing heavy metals, and sunlight penetration to the bed leading to efficient photosynthetic processes for bioremediation. As the nutrient-rich effluent traverses a complex network of fish farms, and horticultural and agricultural systems within the East Kolkata Wetlands, it undergoes a gradual purification process, wherein nutrients are efficiently extracted and redirected to support various agricultural outputs.

The anaerobic ponds with a depth of 2-5 meters with a retention time of 1-5 days remove solids, BOD, and pathogens. The facultative fish ponds with depth varying from 1-5 meters removes maximum pollutants including BOD, nutrients, heavy metals, pathogens, and others. The final stage of treatment takes place in a maturation pond removing residual pollutants (see Figure 1.6).

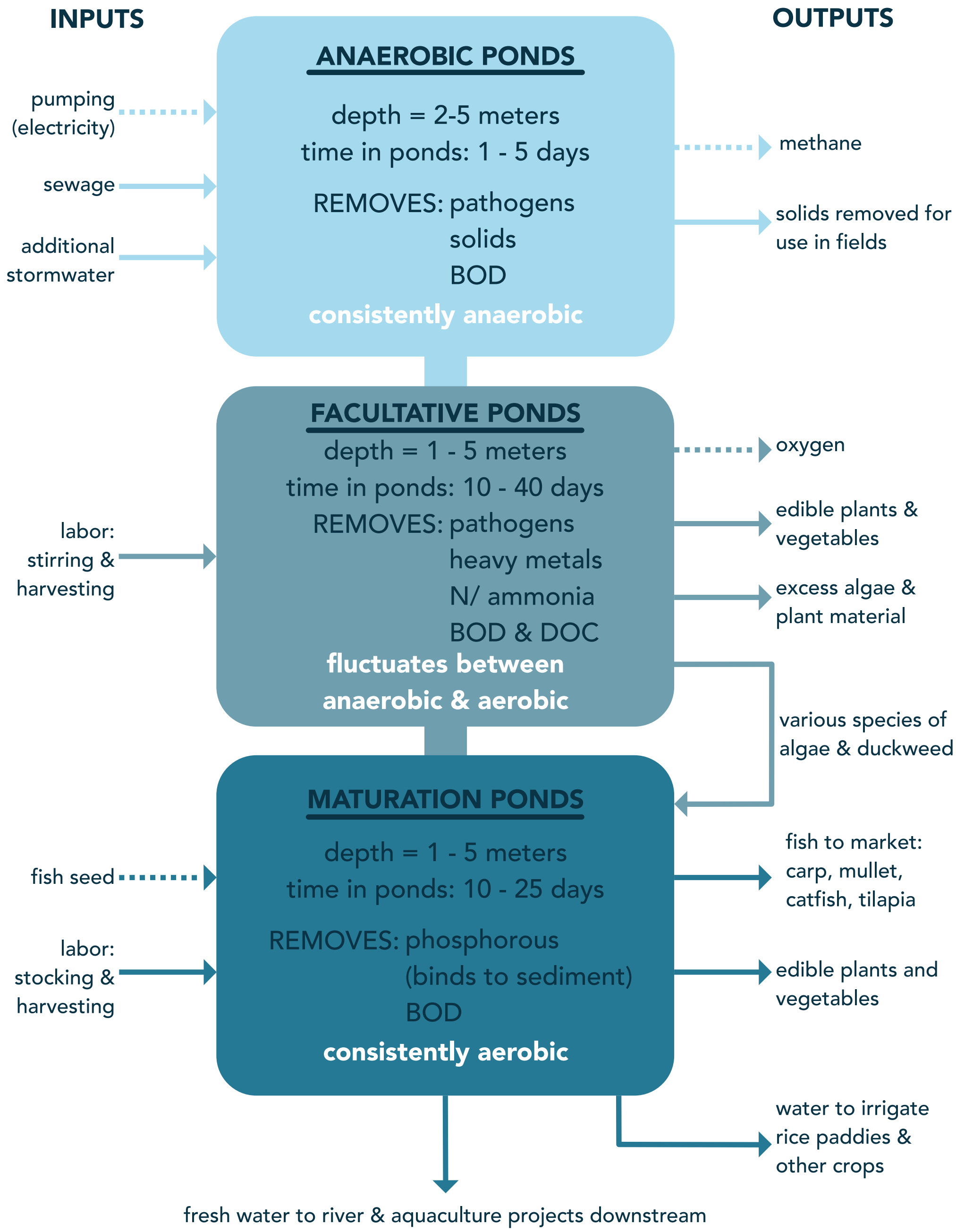


Figure 1.6 : A schematic diagram of treatment processes in EKW (Source: Scenario Journal; Stephanie Carlisle)

1.5 Determinants of wetland water quality

The water quality of wetlands is majorly determined by a) natural and physical settings and b) anthropogenic influences on the wetland.

1.5.1 Natural and Physical setting

Wetland water quality is affected by natural phenomena primarily through ecological, hydrological, and climatic influences. Natural processes leading to changes in water quality include weathering of rocks, evapotranspiration, depositions due to wind, leaching from the soil, run-off due to hydrological factors, precipitation, and biological processes in the aquatic environment. Some of the major natural factors that affect water quality in wetlands are discussed in Table 1.5 below:

Table 1.5 : Influence of natural and physical setting on wetland water quality

Natural and Physical setting elements	Relationship with water quality	Examples
Location	Climatic and geographical attributes of the location affect the water chemistry of wetlands, especially salinity, metal concentration, acidity, and alkalinity.	An inland wetland without outflows when exposed to high evaporation rates may lead to a high accumulation of salts making the wetland saline. This explains the high salinity in high-altitude wetlands.
Weathering of rocks	The geology of the wetland bed affects the soil or sediment quality of the wetland. It also regulates groundwater-surface water interactions leading to the transfer of natural minerals and metals. It can also lead to geogenic contamination.	Heavy metals like arsenic present in the bedrock of the wetlands can be transferred if the wetland is groundwater-fed.
Hydrological Regime	The physical, biological, and chemical processes taking place in the wetland are governed by the natural patterns of water presence and absence, in terms of timing, duration, frequency, extent and depth, and variability.	In dry periods, when sediments are exposed to air, phosphorus tends to bond with iron and aluminum through the process of adsorption and precipitation. This leads to a decrease in phosphorus availability for plants, algae, and bacteria.
Source of water	Wetland water quality is reflected by the quality of the source of the water. Wetlands fed by surface water such as rivers and sea have water quality similar to that of the source.	Groundwater-fed wetlands usually have high conductivity with pH ranging from neutral to alkaline as compared to rain-fed wetlands which have low pH and conductivity.

Natural and Physical setting elements	Relationship with water quality	Examples
Floods and droughts	Reduced flow resulting from droughts can cause an increase in the concentrations of dissolved minerals and a decrease in the load of solid material carried by the inlet into the wetland. The reverse is true of floods; high flows generally dilute the concentrations of dissolved organics and minerals, and flush new sediments from flood plains, increasing the sediment load.	Droughts can induce salinity in inland wetlands due to high evaporation of water and accumulation of salts. Conversely, dilution due to flood water reduces salinity.
Biological factors	Through the process of photosynthesis, wetland plants produce oxygen and consume carbon dioxide, nitrogen, and phosphorus in the water. The decay process of plants is carried out by associated microorganisms consuming oxygen and releasing carbon dioxide. Change in the balance between growth and decay can result in a change in the ecosystem and its water quality.	Excessive growth and decaying of plants debris can cause reduction in dissolved oxygen in wetlands.

Box 1.3 : Sambhar Lake - India's largest inland saline wetland

Sambhar lake in Rajasthan, designated a Ramsar site in 1990 and also an Important Bird Area (IBA), is famous for harboring flamingoes. The lake is formed out of a natural depression and is surrounded by the Aravalli Hills. The largest inland salt lake in the country located 100 km north-west of Jaipur has been a major source of salt. The lake bed of Sambhar is richly silted in salts and turns the water naturally salty. The lake is part of a closed drainage basin that has no water outflow. Thus, all the salts that are received in the wetland get accumulated causing water to become saline. In addition, Sambhar is located in the semi-arid region of Rajasthan where summers are extremely hot and dry with a high evaporation rate. A combination of these reasons increases the salinity of the lake naturally. However, in recent times, anthropogenic activities such as the diversion of water meant for the lake for salt mining activities have aggravated the hypersalinity, a condition of excessive salt presence in the wetland. The hypersalinity observed in the Sambhar brine can be attributed to the gradual evaporation of freshwater within a semi-arid climatic context. Furthermore, the essential chemical constituents required for the formation of such hypersaline brine originate from the catchment rocks (Sinha, 2014).

Sambhar lake- an inland saline wetland in India (Photo Credit : Sambhar Heritage)

1.5.2 Anthropogenic Influences

Rapid urbanization and exponential increase in population are putting direct stress on wetlands water quality. In India around 72% of the total wastewater generated is getting discharged without any prior treatment. Domestic, industrial as well as agricultural waste discharged to the wetlands deteriorates the water quality drastically. Moreover, fragmentation and conversion of wetlands for other uses leads to disruption of the hydrological regime leading to wetland pollution. Various anthropogenic activities that affect the wetland water quality are discussed in Table 1.6 below:

Table 1.6 : Influence of anthropogenic activities on wetland water quality

Anthropogenic influences	Relationship with water quality	Examples
Agricultural run-off	Run-off during events such as rainfall leads to the discharge of nutrients from agricultural fields into wetlands. Nutrients, such as phosphorus and nitrogen provide important resources for living organisms in the wetland and their availability often directly controls growth or survival.	Increased nutrient loading leads to excessive growth and decay of plants (such as algae) depleting oxygen for other species, such as fish; a process called eutrophication. In several inland wetlands, the first monsoon flush leads to a spike in nutrient loads, and the consequent lowering of dissolved oxygen levels may lead to fish kills.

Anthropogenic influences	Relationship with water quality	Examples
Release of untreated domestic wastewater	Municipal wastewater mainly comprises suspended and dissolved organic and inorganic solids. Organic substances include carbohydrates, lignin, fats, soaps, synthetic detergents, proteins, and their decomposition products. All these components are a major source of pollution in wetlands.	Domestic water usually contains high organic matter, which when discharged to the wetlands, gets degraded by microbial activities. Microbial degradation consumes dissolved oxygen making it unavailable for wetland species.
Release of industrial effluents	Untreated wastewater from industrial facilities such as power plants, paper mills, pharmaceutical manufacturers, semiconductor fabrication plants, chemical plants, petroleum refineries, bottling facilities, and processes such as mining and drilling, all contribute to poor water quality in wetlands.The discharged pollutants from untreated industrial wastewater can alter broad wetland water quality characteristics, such as temperature, acidity, salinity, or turbidity of the receiving wetland.	Food and agriculture industry discharges wastewater with high organic content leading to high biological oxygen demand in the wetlands. However, wastewater from metal manufacturing and processing industries. leather manufacturing industries and metal ore mining industries contribute to heavy metal presence in wetlands.
Dumping of solid waste	Leachates from the solid wastes get into wetlands which leads to changes in their water quality characteristics.	Solid waste dumped around wetlands often causes high nitrate levels in wetland water due to leaching. If the solid wastes contain electronic wastes, then it can cause heavy metal pollution in the wetland.
Conversion and Fragmentation	Conversion and fragmentations of wetlands leads to change in water availability which in turn affects the concentration of chemical constituents.	Conversion of wetlands into agricultural fields can lead to the discharge of excess nutrients in the wetlands leading to algal bloom. Fragmentation of wetlands alters its natural hydrological regime which in turn affects the water availability and quality.
Fire	Runoff containing ash created resulting from fire can affect the wetland water chemistry. Also, it increases the water temperature ultimately leading to various water quality problems. It can affect the nutrients levels, dissolved oxygen, and even ions.	Increase in water temperature due to fire, can lead to the release of dissolved oxygen causing the mortality of aquatic species.
Introduction of invasive species	Invasive species or non-native species affect the water quality through multiple pathways such as by affecting the water availability, increasing soil erosion, and affecting the nutrient level.	Overgrowth of invasive plants can alter the nutrient cycling by increasing organic matter decomposition.

Anthropogenic pollution can either be a point or nonpoint source of pollution. A point source is a single, identifiable source of pollution, such as a pipe or a drain that discharges into the wetland. Industrial wastes and discharges from wastewater treatment plants are commonly discharged into wetlands in this way. Nonpoint source pollution, unlike pollution from point sources, comes from many diffuse sources and thus their impacts are not easily attributed to a single source.

Box 1.4 : Impacts of Chemical Pesticides on Wetland Species - the case of Sarus Crane in Uttar Pradesh, India

The Sarus Crane is one of the most iconic and charismatic bird species found in wetland ecosystems across Asia. Known for its majestic appearance and distinctive call, the Sarus Crane holds a special place in the hearts of bird enthusiasts, conservationists, and the local communities living in proximity to the wetlands. Wetlands are vital habitats for the Sarus Crane playing a central role in the life cycle and survival of this iconic bird species. These unique ecosystems provide a range of essential resources and environmental conditions that make them particularly well-suited to meet the needs of Sarus Cranes throughout their lives. Wetlands provide abundant food supplies to these species including aquatic plants, insects, crustaceans, and small vertebrates. It also provides nesting and roosting sites for Sarus Cranes as it safeguards them from land-based predators.

A resident of India, it is the tallest flying bird in the world and has been classified as Vulnerable in the latest IUCN Red List. There has been a continuous decrease in the population of Sarus Cranes in Southeast Asia. In 2020, a study was conducted by the Salim Ali Centre for Ornithology and Natural History (SACON) to assess the status, distribution, and threats to the population of Sarus Crane in Uttar Pradesh. The study specifically assessed the impact of pesticides on the species. Samples of eggs were analyzed to understand the impact of pesticides on breeding outcomes. It was found that DDE, HCH, and Chlorpyrifos were the most frequently found pesticides in the egg samples. Chlorpyrifos residues in eggs have proven implications in the reproduction process as its metabolite is a proven reproductive toxicant. Detection of varying levels of chlorpyrifos in the vital organs including the brain has been observed, which can also cause mortality due to loss of orientation leading to a collision with power lines and eventual electrocution. During the study, a total of 22 incidents of mortality involving 24 individuals were recorded. Out of these, 21 deaths were observed due to electrocution and 3 due to suspected monocrotophos poisoning which is an organophosphate insecticide .

Sarus Cranes at Keshopur-Miani community reserve (Photo Credit : Gitanjali Kanwar)

Box 1.5 : Impact of pollution on wetlands - The case of fire and froth in Bellandur and Varthur Lakes, Bengaluru, India

Bellandur lake, situated in the southeastern part of Bengaluru, India is the largest lake in the city. The lake forms a catchment of about 148 square kilometers and water from the lake flows east to Varthur Lake, eventually reaching the Pinakini River basin downstream. Around 40% of Bengaluru's sewage is discharged into the catchment of these two lakes. Apart from the discharge of municipal sewage and industrial wastewater, solid waste dumping is also common in these lakes.

In recent times, these lakes have caught global attention but for all the wrong reasons. Incidents of the lakes catching fire and foams shattering on the adjacent roads have been reported several times. This usually happens during pre-monsoon and monsoon when there is heavy wind and rainfall. The wastewater coming into these lakes brings in a variety of dissolved organic compounds and synthetic detergents. The major source of synthetic detergents is domestic households where the surfactants are used for washing clothes. Many industries upstream of the Bellandur and Varthur lake have also been observed discharging synthetic surfactants. Uncontrolled discharge of phosphate-rich detergents has led to several frothing incidents in the lakes. The phosphorus entering the wetland system either gets absorbed by plants or gets settled in the sediments. Frothing takes place when phosphorus-containing sediments get churned during high flow, supported by strong winds. There has been an incident of foam catching fire due to the presence of highly flammable higher hydrocarbons and organic polymers, mainly attributed to the discharge from industries around these lakes (Ramachandra et al, 2017).

Fire and froth at Bellandur lake (Photo Credit : DCP Traffic East / Twitter)

Box 1.6 : Impact of solid waste dumping on water quality of Deepor Beel, Assam

Deepor Beel, the only Ramsar site of Assam, is a freshwater floodplain wetland situated at the southern bank of the River Brahmaputra. It is located around 10 km from the capital city, Guwahati. The wetland supports 200 species of birds, of which 70 are migratory. It has been included in the list of Important Bird Areas (IBA) by Birdlife International since 2004. The wetland was originally connected to the river through another lake named Sola Beel.

However, anthropogenic activities such as the construction of buildings, railway tracks, and national highways (NH-37) led to the disruption of the network (Niti Aayog, 2008).

Despite having numerous ecohydrological importance, one of the sides of the wetland was assigned as a dumping site for the capital city. The low-lying dumping site is directly connected and acts as a source of pollution to the Beel. Numerous studies have shown the detrimental effect of leachate, coming from solid waste, on the water quality of the Beel. The presence of heavy metals above the permissible limit in the leachate as well as in water and a high level of BOD has indicated the adverse effect of solid waste dumping. Moreover, the presence of pollutants has led to the occurrence of the highest percentage of tolerant species of insects (Choudhury and Gupta, 2017).

Solid waste dumping in Deepor Beel (Photo Credit : Indiawaterportal.com)

Box 1.7 : Microplastics - an Emerging Contaminant adversely impacting wetland ecosystem

Microplastics are small plastic particles that are typically less than 5 millimeters in size, often much smaller, and they can take various forms such as fragments, fibers, or microbeads. These particles originate from the fragmentation and breakdown of larger plastic items, like bottles, bags, and packaging, as well as from the degradation of synthetic materials used in textiles and personal care products.

The proliferation of microplastics, an emerging contaminant stemming primarily from anthropogenic activities, has cast a concerning shadow over the delicate wetland ecosystem, greatly impacting its aquatic life. These minute plastic particles find their way into wetlands through various pathways such as runoff from urban areas, industrial discharges, and even the breakdown of larger plastic debris. As they enter wetland waters, these persistent pollutants are consumed by a diverse range of aquatic organisms including fish, invertebrates, and even microscopic plankton.

The consequences are multi-fold, as the presence of microplastics can lead to physical harm, internal damage, and even altered feeding behaviors in these species. Additionally, the absorbed toxins present on the surface of microplastics can leach into the surrounding water, further exacerbating the contamination of wetland ecosystems. This cumulative impact not only disrupts the delicate balance of wetland food chains but also poses potential threats to the broader environment and human health as the toxins move up the food chain. Urgent measures are needed to curb the influx of microplastics into wetlands, safeguarding the vitality of these crucial habitats and the intricate web of life they support.

In India, multiple studies have shown the presence of microplastics in wetlands and its adverse impact on the ecosystem. A study by Rajeswari et al.,2023 assessed microplastic pollution in Kolvai Lake, Tamil Nadu, and found that there was an abundance of microplastic in the system leading to a decreased population of zooplankton. These findings suggested that microplastics built up in wetland environments can have severe concerns because of their capacity to infiltrate the food web. Similarly, Li et al.,2023 studied the impact of microplastics in coastal wetlands. The study assessed sources of microplastics in Kayamkulam estuary, Kerala, and found that sewage discharge, aquaculture and ocean navigation, tidal or wave actions, atmospheric deposition, and surface runoff were the main sources of microplastic pollution.

Plastic pollution in wetlands (Photo Credit : Ravi Prakash; WISA)

1.6 The need to maintain wetland water quality

Maintaining water quality is an essential element of Wetlands Wise Use. Abrupt fluctuations in water quality with reference to its natural state can lead to an adverse change in its ecological character. The impact of water quality on each component of wetland ecological character has been discussed below:

Table 1.7 : Influence of water quality on the ecological character of wetlands

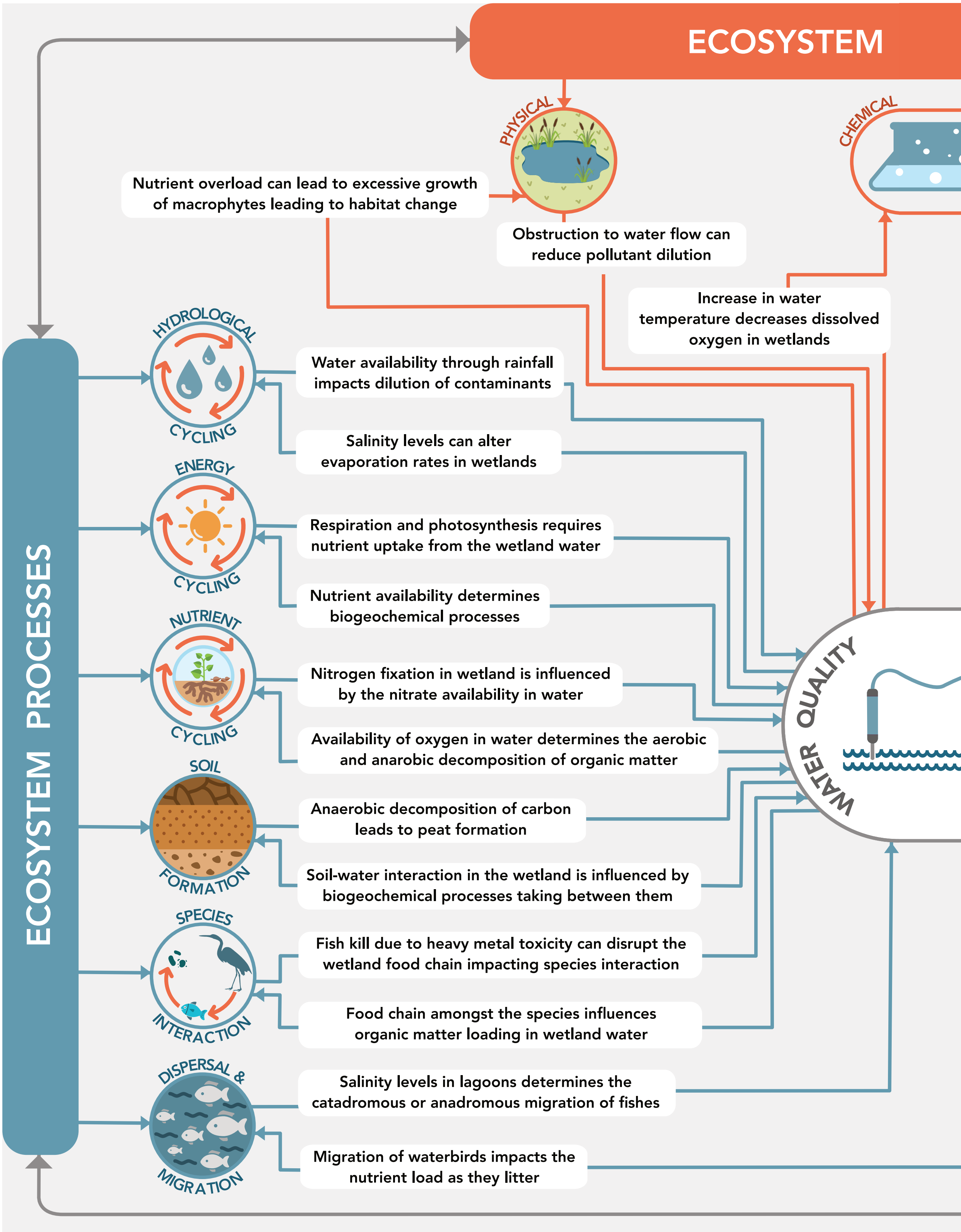
Wetland ecological character element	Influence of water quality on the element	Examples
Wetland ecosystem components		
Biological		
Genetic	• Water pollution in wetlands can lead to genotoxicity in aquatic species. Elements such as metals, and pesticides enter into the body and get bio-accumulated and biomagnified leading to impairment of genetic character.	• Heavy metals such as cadmium and arsenic damage the gene in fishes as they bioaccumulate inside their tissue.
Species	• Water quality impacts the composition, growth, and reproduction of wetland species. Elements such as nutrient availability, presence of dissolved oxygen, salinity, and pH levels are critical for the survival of species. Fluctuation in water quality characteristics alters the species composition of wetlands.	• Less nutrients can limit the growth of native vegetation in wetlands whereas excessive nutrients can support the growth of weeds (invasive species).
Ecosystem	• Water quality shapes the wetland ecosystem through its effects on the genetic information of species as well as the species itself.	• Salinity in water can lead to the presence of more salt-tolerant species and less salt-sensitive species, leading to a unique saline ecosystem.
Chemical	• Chemical elements of wetland ecosystems such as the chemical composition of water and sediment inherently are decided by the water quality characteristics.	• Sediment quality gets affected by the settlement of suspended solids in water. Decomposition and accumulation of organic material shape the sediment formation.
Physical	• Physical components of the wetland ecosystem include its drainage channels, water, sediments etc. Changes in water quality affects the physical regime by processes such as accumulation of organic and inorganic debris , siltation, soil formation, species growth etc.	• Growth of hydrophytes can alter the drainage regime of the wetland by clogging it. For instance, growth of water hyacinths due to excess nutrients can clog the inflow of the wetlands.

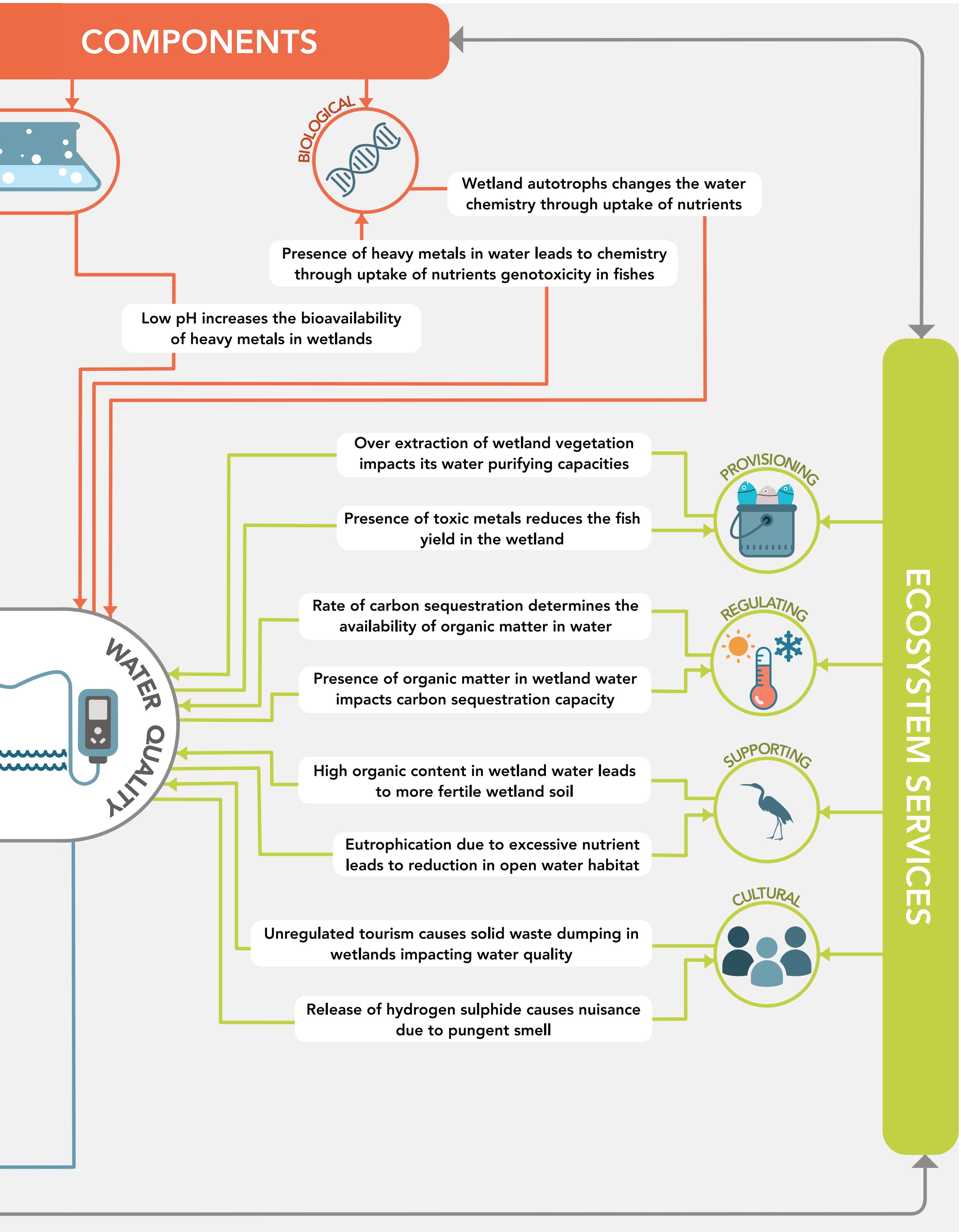
Wetland ecological character element	Influence of water quality on the element	Examples
Wetland ecosystem processes		
Hydrological cycling	• Water chemistry affects hydrological cycling by increasing or decreasing the evapotranspiration rates in wetlands. Emission and absorption of greenhouse gasses due to decomposition and accumulation of organic matter also affect the climate including rainfall patterns.	• Salinity usually decreases the evaporation rates of wetland water as it reduces the water vapor pressure and hence reduces its free energy.
Energy cycling	• Energy cycling can be affected by the nutrient availability in the wetland system. Energy transfer from producers to consumers is a function of the water chemistry of the wetland.	• Nutrient availability affects the energy cycling by impacting the wetland food chain. Less nutrients available in the wetland affects the population of primary producers which in turn impact the population of consumers.
Nutrient cycling	• Water quality can influence the extent at which nutrient cycling takes place in the wetlands. Availability of nutrients is dependent on water quality indicators such as pH and presence of metals.	• Presence of metals such as iron binds with nutrients in acidic situations reducing its bioavailability to the organisms.
Soil formation	• The chemical constituents of water directly impact the quality of soil formed within the wetland. The amount of organic matter in water and nutrients influences the soil formation process within wetlands.	• Presence of high organic matter in the wetland water leads to peat formation.
Primary production	• Rate of primary productivity is directly dependent on nutrient availability. Other indicators such as temperature and turbidity also determine the extent of primary production in wetlands.	• Highly nutrient rich water can lead to an increase in vegetation and algal growth.
Species interaction	• Deteriorated water quality can hinder the predator-prey relationship. It can cause food resource depletion leading to high competition.	• Turbidity can affect the species composition of the wetland by altering the predator-prey relationship.
Dispersal and Migration	• Dispersal and migration of wetland species depend majorly on food availability and also on the provision of favorable conditions for breeding and spawning. Water quality is the determining factor for food availability as it depends on nutrient availability. Moreover, the pH of the water plays an important role in migration.	• Catadromous fishes migrate from saltwater to freshwater for spawning. Conversely, anadromous fishes migrate from freshwater to salt water for spawning.

Wetland ecological character element	Influence of water quality on the element	Examples
Wetland ecosystem services		
Provisioning	**Water supply** • Supplying water from wetlands requires certain standards depending on its use. The presence of contaminants can hinder water supply from wetlands. **Food provision** • Wetlands species that are used as a food source by humans can directly absorb pollutants present in the water impacting the quality and quantity of the food produced. **Biomass extraction** • Reduction in vegetation and animals stocks due to water quality deterioration can ultimately impact the amount of biomass that can be extracted from the wetland	• Water quality deterioration such as the presence of microbial contamination is undesirable for water supply, especially for drinking water purposes. • Presence of heavy metals in water can be absorbed by the plants and animals of the wetland. Human consumption of these contaminated foods can be harmful as well as lethal in a few cases. • Reduction in native vegetation due to eutrophication reduces the amount of extracted raw material.
Regulating	**Water purification** • Presence of toxicants in water can hinder the water purification services of wetlands. The plants and microorganisms involved in purification can be affected by the presence of toxicants above the threshold level **Climate regulations** • Water in wetlands can act as a sink as well as a source of greenhouse gasses depending on the water quality status.	• Loss of hydrophytes due to the presence of toxicants above the threshold level can limit nutrient uptake reducing the water purification capacity of wetlands. • Decomposition of organic matter in wetland water releases GHGs. Deposition of organic matter in the benthic zone of wetland acts as a carbon sink.
Supporting	**Habitat Provision** • Water quality impacts the extent and type of habitat.	• Excessive nutrients lead to the proliferation of water hyacinth decreasing the open water habitat.
Cultural	• Pollution can impact the recreational capacity of the wetland by affecting the wetland species as well as through physical factors such as odor, appearance, etc.	• Release of hydrogen sulfide gas from the water stinks like rotten eggs which can create hindrance in recreational activities.

Figure 1.7 represents the general interactions between water quality and the ecological character of wetlands. The influences of water quality and elements of ecological character have been shown through examples.

Figure 1.7 : A schematic diagram representing interaction between water quality and ecological character of wetlands





COMPONENTS
BIOLOGICAL
Wetland autotrophs changes the water chemistry through uptake of nutrients
Presence of heavy metals in water leads to chemistry through uptake of nutrients genotoxicity in fishes
Low pH increases the bioavailability of heavy metals in wetlands
Over extraction of wetland vegetation impacts its water purifying capacities
Presence of toxic metals reduces the fish yield in the wetland
Rate of carbon sequestration determines the availability of organic matter in water
Presence of organic matter in wetland water impacts carbon sequestration capacity
High organic content in wetland water leads to more fertile wetland soil
Eutrophication due to excessive nutrient leads to reduction in open water habitat
Unregulated tourism causes solid waste dumping in wetlands impacting water quality
Release of hydrogen sulphide causes nuisance due to pungent smell
WATER QUALITY
PROVISIONING
REGULATING
SUPPORTING
CULTURAL
ECOSYSTEM SERVICES

Local users extracting raw material from Udhwa wetland influencing its water quality (Photo Credit : Ravi Prakash; WISA)

2 Monitoring wetland water quality

Effective monitoring of wetland water is essential for preserving these vital ecosystems. It serves as an early warning system for pollution, enabling timely intervention to protect the delicate balance of wetland habitats. Regular assessments of ecological health and biodiversity help inform conservation strategies, ensuring the resilience of wetland ecosystems. Monitoring also plays a crucial role in evaluating restoration initiatives and controlling the spread of invasive species, contributing to the overall success of conservation efforts. Beyond ecological considerations, monitoring supports informed policy-making, aids in understanding the impacts of climate change on wetlands, and promotes human health by ensuring the safety of water sources. Additionally, the data generated through monitoring serves as a valuable educational tool, fostering community engagement and enhancing public awareness of the importance of wetland conservation. In essence, comprehensive monitoring is integral to sustaining the ecological, social, and economic functions of wetlands for current and future generations.

2.1 Setting monitoring purpose and objectives

Water quality monitoring programmes should be guided by a clear understanding of purpose, feasibility, and end-use. Objective identification helps in selecting the relevant indicators that need to be monitored. For instance, if the objective is to understand the impact of agricultural runoff on the wetland, indicators such as nutrients and dissolved oxygen should be of utmost priority.

Water quality monitoring objectives should be designed in such a way that it is economically and practically feasible.

Box 2.1 : Wetland Inventory, Assessment and Monitoring

The Ramsar's Framework for Wetland Inventory (Resolution VIII.6) defines wetland inventory, assessment and monitoring as follows:

• **Wetland Inventory** : the 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** : the identification of the status of, and threats to, wetlands as a basis for the collection of more specific information through monitoring activities.

• **Wetland Monitoring** : the 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.

The ultimate objective of the monitoring design should be to minimise the cost without sacrificing the desired information to the level of precision. Scoping and designing of wetland water quality monitoring programmes should be based on clear scientific understanding of issues, relevant background information, monitoring objectives, desired outcomes, appropriate methods and the dynamics and characteristics of wetland water systems. Figure 2.1 shows the strategy for monitoring wetland water quality.

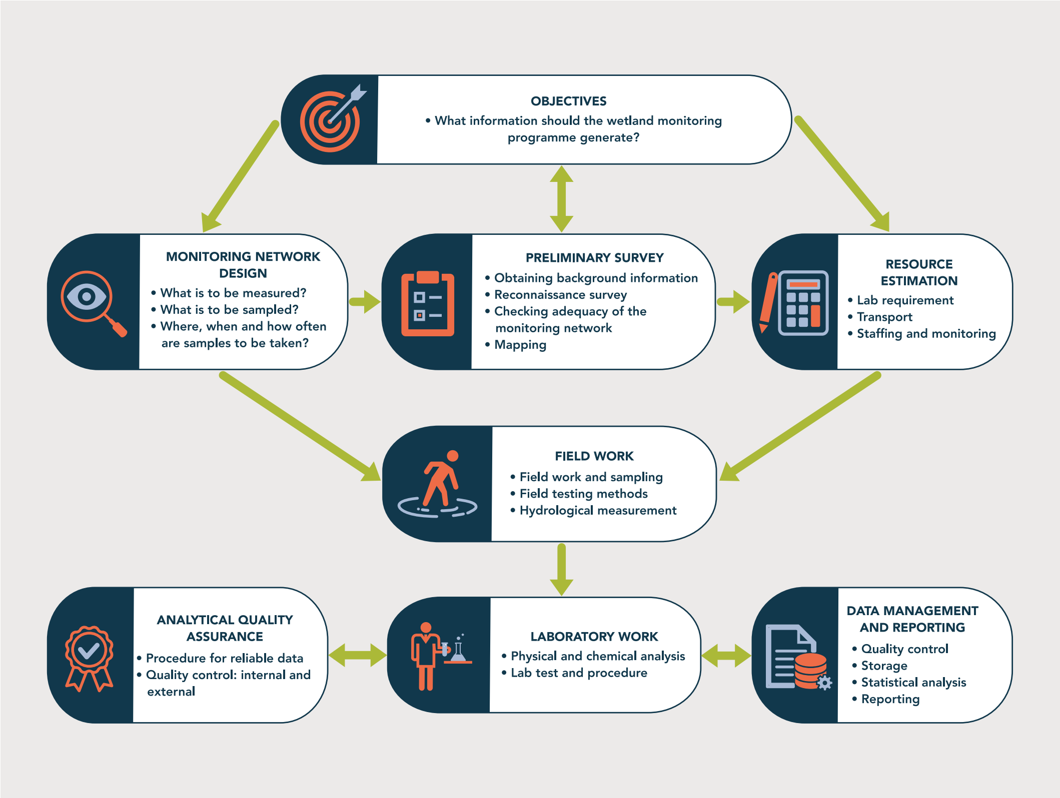


Figure 2.1 : Wetland water quality monitoring strategy

Adapted from Water Quality Monitoring - A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes (UNEP/WHO)

Setting up objectives for which water quality monitoring is to be done provides the guidance for developing a water quality monitoring system in place. Following are a few examples of defining indicators according to the objective. Similarly, different indicators can be chosen according to the objective defined.

Table 2.1 : Objective based wetland water quality monitoring system

Objectives	Proposed monitoring system
To assess the suitability of wetland water for propagation of wildlife and fisheries	• **Priorty Indicators**- pH, temperature, dissolved oygen, nutrients, pesticides • **Frequency**- Monthly • **Location**- Across the wetland
To understand the influence of industrial wastewater on wetland	• **Priorty Indicators**- Heavy metals, temperature, BOD, COD, TDS • **Frequency**- Monthly • **Location**- Preferably at the discharge point
To assess the portability of wetland water for domestic use	• **Priorty Indicators**- Pathogens, BOD, Heavy metals,TDS, TSS • **Frequency**- Monthly • **Location**- Preferably at the water abstraction point
To assess the impact of non-point sources of pollution such as agriculture	• **Priorty Indicators**- Nutrients, SAR, Electrical Conductivity, Pesticides • **Frequency**- Quarterly • **Location**- Across the wetland
To understand the feasibility of wetland for recreational use	• **Priorty Indicator**s- Total Coliforms, pH, Dissolved Oxygen, Biochemical Oxygen Demand • **Frequency**- Quarterly • **Location**- Section of wetland being used for recreation

2.2 Measuring water quality indicators

There are few indicators that require in-situ measurement such as pH, conductivity, transparency, turbidity. Other indicators can be tested in NABL accredited water quality testing laboratories. Indicators such as dissolved oxygen, total dissolved solids, can be tested by both methods.

Table 2.2 : Measuring physical indicators

Water quality indicators	Equipments required	Laboratory	In-situ	Resources
Turbidity	• Testing kit with meter and probe or Nephlometer	Yes	Yes	• IS 3025 • Test kit manual
Transparency	• Secchi disc		Yes	• Test kit manual
Temperature	• Mercury in-glass Thermometer	Yes	Yes	• IS 3025 • Test kit manual
Color	• Visual method or Water samples for lab	Yes	Yes	• IS 3025 • Test kit manual
Odour	• Physical method		Yes	• IS 3025
Conductivity	• Conductivity meter • Testing kit with meter and probe		Yes	• Test kit manual

Table 2.3 : Measuring chemical indicators

Water quality indicators	Equipments/ methods required	Laboratory	In-situ	Resources
Dissolved oxygen	• Winkler modified method • Testing kit with meter and probe	Yes	Yes	IS 3025/ Test kit manual*
Total dissolved solids	• Gravimetric method • Testing kit with meter and probe	Yes	Yes	IS 3025/ Test kit manual
Total suspended solids	• Gravimetric method	Yes		IS 3025
Sodium	• Flame photometry method • Testing kit with meter and probe	Yes	Yes	IS 3025/ Test kit manual
Potassium	• Flame photometry method • Testing kit with meter and probe	Yes	Yes	IS 3025/Test kit manual

Water quality indicators	Equipments/ methods required	Laboratory	In-situ	Resources
Calcium	• Flame photometry method • Testing kit with meter and probe	Yes	Yes	IS 3025/Test kit manual
Magnesium	• EDTA Titrimetric • Testing kit with meter and probe	Yes	Yes	IS 3025/Test kit manual
Carbonate as CaCo3	• Titrimetric method	Yes		IS 3025
Bicarbonate as CaCo3	• Titrimetric method	Yes		IS 3025
Chloride	• Argentometric titration method	Yes		IS 3025
Sulphate	• Turbidimetry method	Yes		IS 3025
Fluoride	• Colorimetry • Test kit with Ion meter	Yes	Yes	IS 3025/ Test kit manual
Iron	• Atomic Absorption Method • Phenanthroline method • Testing kit with meter and probe	Yes	Yes	IS 3025/ Test kit manual
Boron	• Curcumin method • Testing kit with meter and probe	Yes	Yes	IS 3025/ Test kit manual
pH	• pH strip • Testing kit with meter and probe or water samples for lab	Yes	Yes	IS 3025/ Test kit manual
Acidity	• Indicator method • Potentiometric method	Yes		IS 3025
Alkalinity	• Indicator method • Potentiometric method	Yes		IS 3025
Arsenic	• Cold vapour AAS • Testing kit with meter and probe	Yes	Yes	IS 3025
Mercury	• Cold Vapour AAS	Yes		IS 3025
Ammonical Nitrogen (NH4-N)	• Colorimetry	Yes	Yes	IS 3025/Test kit manual
Nitrite + Nitrate-N	• Colorimetry	Yes		IS 3025
Total Phosphate	• Colorimetry	Yes		IS 3025
Orthophosphate	• Colorimetry	Yes		IS 3025
Pesticides and other organics	• GC, GCMS	Yes		

Table 2.4 : Measuring biological indicators

Water quality indicators	Equipments required	Laboratory	In-situ	Resources
Chlorophyll a	Frozen filter paper for lab	Yes		• EPA manual
Total Coliforms	MPN or MF method	Yes	Yes	• IS 1622
Fecal coliform	MPN or MF method	Yes	Yes	• IS 1622
Macroinvertebrates	Visual method/samples for lab	Yes		• CPCB guidelines on biomonitoring • As per the method of testing used for particular indicator

*Test kit manual refers to the manual provided by the manufacturing company
*For further details on water quality monitoring refer to CPCB guidelines for water quality monitoring and BIS manuals :

https://cpcb.nic.in/openpdffile.php?id=UmVwb3J0RmlsZXMvTmV3SXRlbV8xMTZfR3VpZGVsaW5lc29mIHdhdGVycXVhbGl0eW1vbml0b3JpbmdfMzEuMDcuMDgucGRm

https://www.services.bis.gov.in:8071/php/BIS/PublishStandards/published/standards?commttid=MzUx

In-situ water testing kit (Photo Credit : Jal-Tara)

Box 2.2 : Isotope Hydrology - An innovative technique for water quality monitoring

Isotope hydrology is a powerful and innovative technique used for water quality monitoring in wetlands. It involves the study of isotopic variations in water molecules, which can provide valuable insights into the sources, movement, and behavior of water in wetland ecosystems. Isotopes are atoms of the same element that have the same number of protons but different numbers of neutrons. In water, the most commonly studied isotopes are deuterium (2H) and oxygen-18 (18O). These isotopes can vary in abundance depending on the source and history of the water.

Isotope hydrology can help identify the sources of water in wetlands. Different water sources, such as precipitation, surface water, groundwater, and anthropogenic inputs, have distinct isotopic signatures. By analyzing the isotopic composition of wetland water, researchers can determine the contributions of various water sources. It can be used to trace the movement of water within wetlands. This is especially useful for understanding the flow paths, residence times, and exchange processes within wetland ecosystems. Isotopic data can help characterize the hydrological dynamics and connectivity of wetland systems. Isotope hydrology is sensitive to seasonal variations in wetland water, such as evaporation and recharge patterns. The isotopic composition of water can change over time due to these processes, and monitoring these variations can provide important information about wetland hydrology.

Apart from assessing water flows, isotopes can be used to track the movement of nutrients (e.g., nitrogen and carbon) in wetlands. By studying isotopic ratios of these elements, researchers can gain insights into nutrient cycling processes, including uptake, transformation, and release within wetland ecosystems. It can be used to assess the impact of human activities on wetland water quality. It can help identify contamination sources, track pollutant transport, and assess the effectiveness of wetland restoration efforts. For instance, Liao et al., 2022 assessed sources of Nitrate in a Karst wetland, Southwest China, using isotope studies. The study used nitrate isotopes (15N-NO3 and 18O-NO3) to trace nitrate movement in the wetland. Another study by Choi et al.,2020 traced nitrate using stable isotope δ15N in Chydorus sphaericus (OF Müller), to investigate hydrological characteristics and nutrient states in artificial wetlands near the Nakdong River, South Korea.

The information obtained through isotope hydrology can be valuable for wetland conservation and management. It can guide decisions related to wetland restoration, habitat preservation, and water resource management. It provides a deeper understanding of wetland hydrology, sources of water, nutrient dynamics, and the impacts of human activities. By incorporating isotope analyses into wetland management and research, we can better preserve and protect these ecologically significant ecosystems.

3 Setting water quality targets for wetland management

Sustainable wetland management entails conserving its species, communities, ecosystem processes and the services they provide. Water in a wetland may be subjected to various types of uses such as for drinking, recreation, fisheries, agriculture, and industry. Among these types of uses, there is one use that demands the highest level of water quality or purity, and that is termed as 'Designated Best Use' in that stretch of the wetland. Each of these designated uses has a different defined chemical, physical and biological standards necessary to support that use. For example, higher standards for drinking water are required compared to those used in agriculture. This classification can assist wetland managers to set water quality targets and design suitable management programs for various wetlands.

Targets for water quality depend on the specific objectives that need to be achieved for wetlands conservation and management. For example, if the focus is to protect the wetland species, the target should be designed such that it takes into account the water quality needs of the species considered. If the priority is to maintain drinking water quality, then targets should define the concentration of indicators such as BOD, coliforms, nutrients among others. Therefore, specific water quality targets should be set to achieve particular objectives.

3.1 Setting target for wetland species and ecological communities

Wetland species include plants, birds, animals, and microorganisms that are directly dependent on the wetland ecosystem. These species require certain favorable water quality, for their growth and survival. Adequate amount of food supply including nutrients, available dissolved oxygen, and absence or adequate presence of toxic elements are some of the essential wetland water quality criteria for species survival. For instance, chemical elements like zinc, boron, manganese, and copper are essential for aquatic organisms but only at trace concentrations. Similarly, nutrients such as nitrogen and phosphorus are essential for survival and the growth of wetland species however they become toxic in excess concentration.

As discussed in chapter 1, water quality indicators are usually interdependent. Hence one indicator can affect the concentration of others. For example, an increase in wetland temperature is related to a decrease in dissolved oxygen. Similarly, the toxicity of a few elements such as zinc, lead, and copper gets exaggerated by a decrease in dissolved oxygen levels in the wetlands.

Hence wetland species can be susceptible to a particular indicator both directly and indirectly through other indicators.

Owing to the diverse physical, chemical, and biological characteristics, it is not possible to set a standard value for water quality indicators for wetland species. However, certain ranges within which species thrive have been established through various studies. For instance, the criteria value of dissolved oxygen for the proper functioning of wetland species usually ranges from 5-6 mg/l for warm water and 6.5-9.5 mg/l for cold water (WHO,1996). Similarly, a pH range of 6.5 to 9 has been observed to be most appropriate for the sustenance of fish communities. In India, the Designated Best Use criteria provided by CPCB suggest three water quality indicators for the propagation of wildlife and fisheries:

- **pH** - 6.5 to 8.5
- **Dissolved Oxygen** ≥ 4 mg/l
- **Free Ammonia (as N)** ≤ 1.2 mg/l

Box 3.1 : Biological Water Quality Criteria (BWQC) of the Central Pollution Control Board

BWQC is a biomonitoring protocol developed by the CPCB to assess the health of surface water bodies. Table presents the criteria to analyze the range of saprobic and diversity scores of the benthic macroinvertebrate families with respect to water quality. The saprobic score represents the average sensitivity of the families of macro-invertebrates towards pollution. A high saprobic score reflects high DO and low biodegradable organic matter whereas, the opposite condition is indicated by a low score. The diversity score is derived through different characteristics of a community such as the number of existing taxa (Richness), the distribution of individuals equally (Evenness), and the total number of existing individuals. The Biological Water Quality class is assigned based on the saprobic and diversity scores indicating the status of water quality.

Currently, the scorecard has been used for river water quality monitoring. The tool has been adopted for the biological water quality assessment of River Ganga and its tributaries under the Water Quality Monitoring (WQM) project sponsored by the National Mission for Clean Ganga (NMCG). However, it can be potentially adopted for inland as well as coastal wetlands for monitoring pollution due to the abundance of macroinvertebrate population.

(Source: CPCB)

To know more about BWQC,

See:https://cpcb.nic.in/openpdffile.php?id=UmVwb3J0RmlsZXMvMTM0NV8xNjM4NTM1MzczX21lZGlhcGhvdG80MzIzLnBkZg==

BIOLOGICAL WATER QUALITY WITH RESPECT TO RANGE OF DIVERSITY AND SAPROBIC SCORE

Range of Saprobic Score(0-10)	Range of Diversity Score (0 -1)	Water Quality	Biological Water Quality Class	Indicator colour
7 and more	0.2-1.0	Clean	A	Blue
6-7	0.5-1.0	Slight Pollution	B	Light Blue
3-6	0.3-0.9	Moderate Pollution	C	Green
2-5	0.4-less	Heavy Pollution	D	Orange
0-2	0-0.2	Severe Pollution	E	Red

3.2 Setting target for wetland ecosystem processes

Carbon Cycle

The carbon cycle within the wetland ecosystem decides the dynamics of sequestration and release of greenhouse gases carbon dioxide and methane into the atmosphere. Anaerobic decomposition of organic matter releases methane as well as carbon dioxide whereas aerobic decomposition releases only carbon dioxide. As the different processes in wetlands are dynamic and take place at the same time, a combination of anaerobic and aerobic decomposition occurs. Figure 3.1 illustrates the role of oxygen in the overall carbon cycle in the wetland ecosystem.

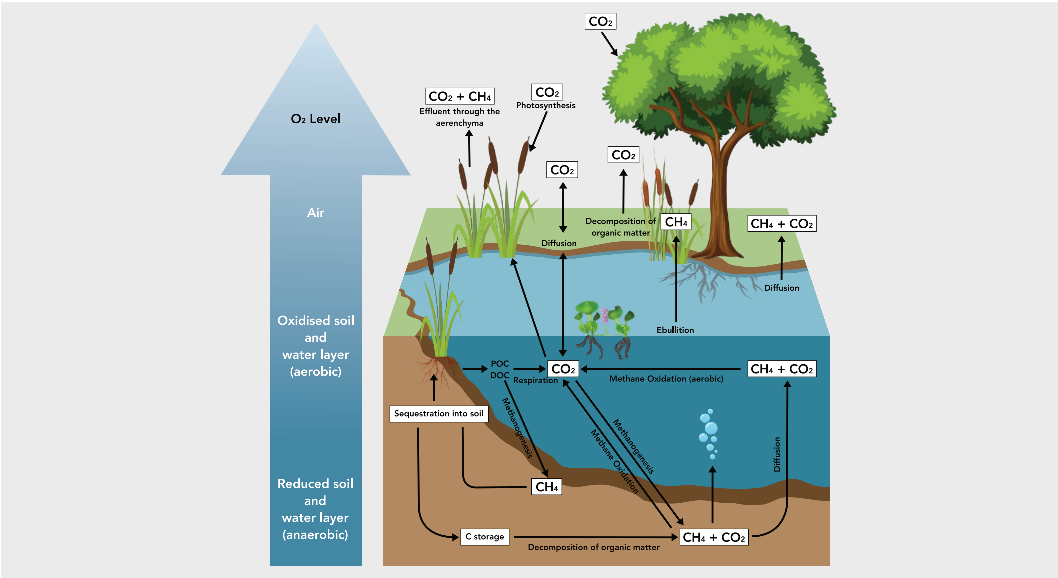


Figure 3.1 : Role of dissolved oxygen in the release of greenhouse gases (CH4 and CO2) from wetland ecosystem (Adapted from Limpert et al.)

Nutrient cycling

Nutrient cycling in wetlands mainly includes the phosphorus cycle, nitrogen cycle, and carbon cycle. These cycles take place in wetlands through various biogeochemical processes. Water quality is a major factor in the nutrient cycle as it contains these nutrients either in precipitated form or dissolved form. Anthropogenic activities disrupt these cycles by adding excess nutrients to the system. Excess of nutrients leads to eutrophication in wetlands which can lead to mortality in wetland species. As anthropogenic phosphorus can be controlled through the prevention of its uses in agriculture, households as well as in industries, it becomes the limiting factor in the wetland ecosystem. Therefore, the target setting for nutrient cycling requires regulating the amount of phosphorus in the environment (see Figure 3.2).

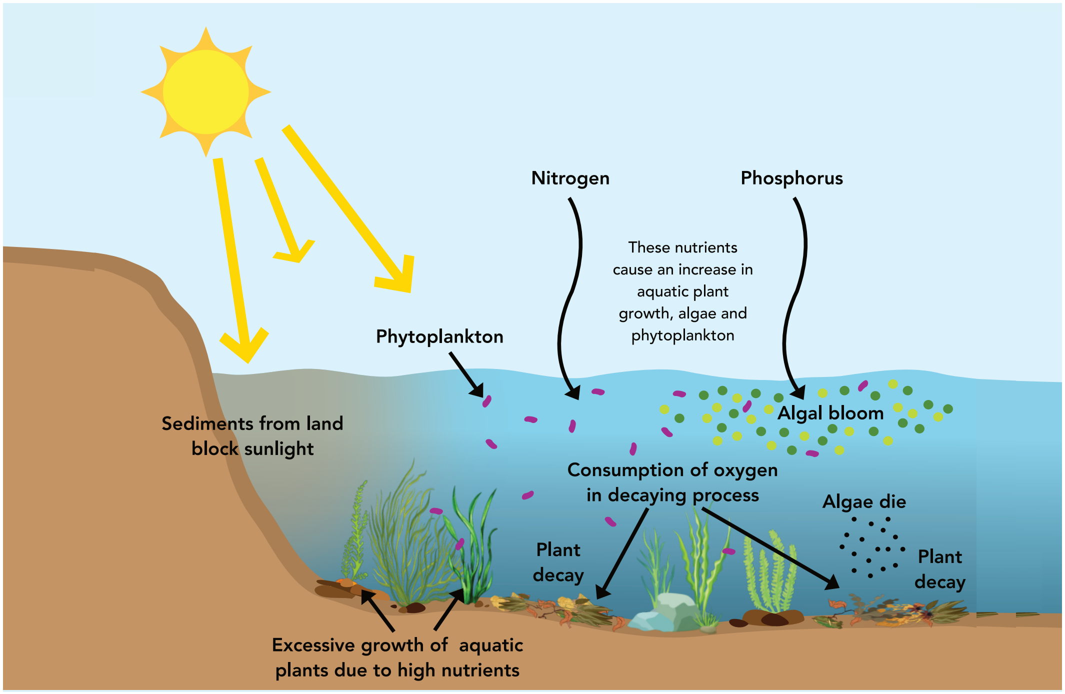


Figure 3.2 : Eutrophication due to excessive nutrient loading into the wetland

Dispersion and Migration

Water quality indicators are major factors that influence the dispersion and migration of wetlands species. Unsuitable conditions lead to the migration of species to the favourable environment. Moreover, certain species require specific water characteristics during the different stages of their life cycles. For instance, anadromous fishes migrate from saltwater to a freshwater environment and catadromous fishes migrate from freshwater to saltwater for spawning (see Figure 3.3). Therefore, for setting wetland water quality targets related to dispersion and migration, the focus should be given to the provision of favorable environmental conditions for these processes to take place.

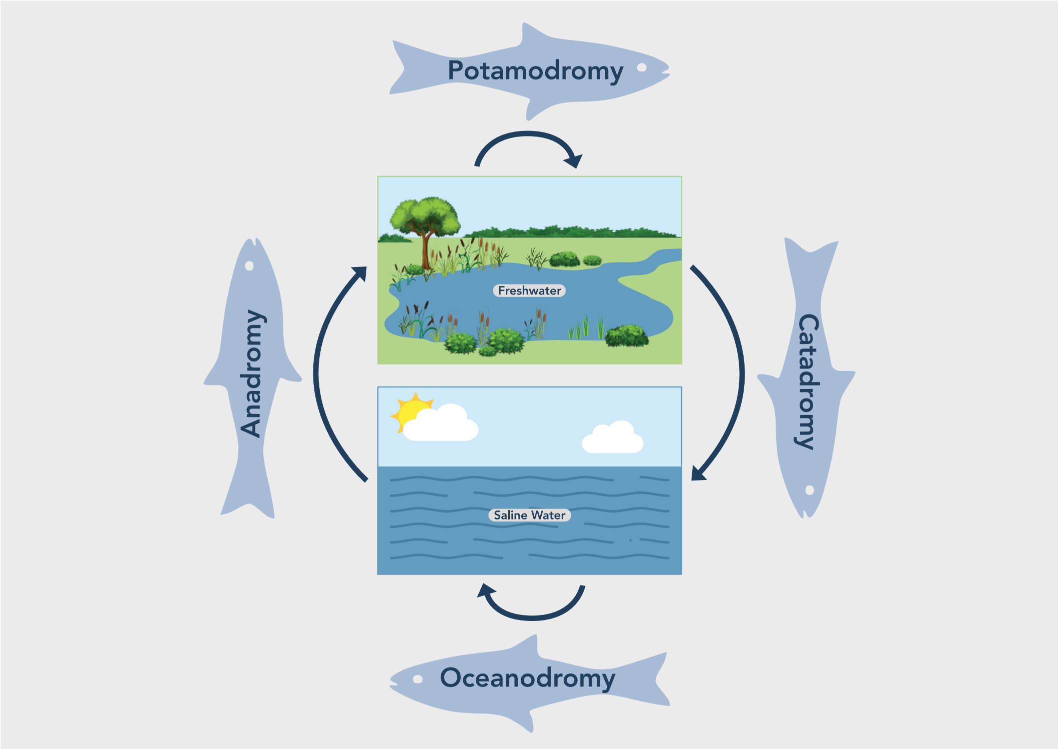


Figure 3.3 : Spawning migration of different fishes in relation to salinity level (Adapted from Tamario et al.)

3.3 Setting target for ecosystem services

The wetland ecosystem services derived by humans require the maintenance of certain water quality criteria. These services are often translated in terms of the designated best use of the wetland water such as drinking water supply, irrigation, livestock, recreation, etc.

3.3.1 Drinking water supply

Drinking water supply requires the highest standard of water quality. Targets related to drinking water quality depend on the available treatment processes. For instance, if the wetland water is provided with the conventional treatment systems (treatment with three stage systems of physical, chemical, and biological removal of pollutants) including disinfection, then the standard of the wetland water quality will be set lower compared to that without any treatment. However, while setting targets for wetlands where water is directly being used for consumption, targets for drinking water without any treatment should be emphasized. This is imperative, especially in developing countries like India where large populations are dependent directly on the wetlands for drinking water sources. The best use criteria for drinking water (with and without conventional treatment), as specified by CPCB, include indicators such as Total coliform, pH, dissolved oxygen, and Biochemical Oxygen Demand (BOD).

Best-use criteria for drinking water source after conventional treatment and disinfection:

- **Total Coliforms** ≤ 5000 MPN/100ml
- **pH** 6-9
- **Dissolved Oxygen** ≥ 4 mg/l
- **Biochemical Oxygen Demand** (5 days 20°C) ≤ 3 mg/l

Best-use criteria for drinking water source without conventional treatment but after disinfection:

- **Total Coliforms** ≤ 50 MPN/100ml
- **pH** 6.5-8.5
- **Dissolved Oxygen** ≥ 6 mg/l
- **Biochemical Oxygen Demand** (5 days 20°C) ≤ 2 mg/l

3.3.2 Irrigation

One of the important ecosystem services that humans derive from wetlands is the supply of water for irrigation. Wetland water quality affects agricultural productivity by causing the accumulation of salts in the root zone of the crops, or by reducing the permeability of the agricultural soil due to the leaching of the salts. Wetland water containing pathogens can hinder the growth of the crops. Moreover, the consumption of crops containing pathogens can lead to gastrointestinal issues as well as other illnesses in humans. Criteria for irrigation water use often consider indicators such as crop tolerance to salinity, phytotoxicity to trace elements such as boron, heavy metals, and pesticides, and the Sodium Absorption Ratio (SAR). Global criteria for irrigation water quality have been established by the Food and Agriculture Organization (FAO) of the United Nations. Moreover, in India CPCB has set the standard for water quality specifically for irrigation purposes.

CPCB Best-use Criteria for Irrigation:

- **pH** 6.0-8.5
- **Electrical Conductivity at 25°C** < 2250 µmhos/cm
- **Sodium absorption ratio maximum** 26
- **Boron** < 2 mg/l

3.3.3 Livestock

Wetlands species including plants and animals have been a source of food supply for the livestock. Hence any quality indicator that affects the wetland species has direct as well as indirect effects on livestock. Moreover, the consumption of poor-quality water containing pathogens or any toxic elements can be fatal. Indicators of concern include high levels of trace metals, pathogens, nitrates, sulfates, salinity, among others. As most of the livestock are then consumed by humans, water quality criteria for livestock have direct implications for human health as well. Even though there are no specific standards available for wetland water quality for livestock, given the human-livestock relationship, the human-centric criteria should be taken into consideration while setting the targets.

3.3.4 Recreational use

Recreational use of wetland water includes bathing, eco-tourism, swimming, and other water-sports activities. Therefore, water quality criteria for recreation should be aimed at protecting human health from direct and indirect contact. This includes protection from pathogens that have the potential to cause illnesses such as gastrointestinal problems, and ear, eye, or skin infections. Criteria for recreational use include public health indicators such as exposure to fecal coliforms and other microbiological indicators. CPCB has specifically emphasized setting targets for bathing in Best-use criteria.

Outdoor bathing (organized):

- **Total Coliforms** ≤ 500 MPN/100ml
- **pH** 6.5-8.5
- **Dissolved Oxygen** ≥ 5 mg/l
- **Biochemical Oxygen Demand** (5 days 20°C) ≤ 3mg/l

4 Interventions for achieving wetland water quality targets

As discussed in the previous chapter, wetland water quality targets are determined by their ultimate use. There is no single intervention that can lead to achieving wetland water quality targets. Instead, a holistic approach of multiple interventions can have the desired results. Understanding the cause of pollution and planning interventions accordingly gives sustainable results in the long run. Examples of interventions to achieve wetland water quality targets include pollution abatement through different treatment infrastructures, especially nature-based solutions like constructed wetlands, floating wetlands, bioswales, etc. The second type of intervention includes managing the water regime of the wetlands which can help in maintaining the naturalness of the water quality within the wetland. The third type of intervention includes having EIA and other regulatory mechanisms to regulate wastewater discharge in the wetland and take strict action against those who do not adhere to the regulation. Integrated management and inter-sectoral coordination are important for overall sustainable management and wise use of wetlands. Having proper monitoring arrangements and capacities of stakeholders to monitor their wetlands plays a crucial role in achieving desired targets.

4.1 Pollution abatement

Pollution abatement refers to measures through which reduction of pollutants is achieved. This can be either done through technological interventions or by taking preventive measures. Technological interventions for pollution abatement include establishing gray-green infrastructure for the removal of pollutants. Preventive measures include sustainable production systems and source prevention.

Grey-Green infrastructure

Grey infrastructure for pollution abatement includes centralized as well as decentralized sewage treatment plants (STPs). These are systems specifically constructed to remove pollutants through various physical, chemical, and biological processes. Physical processes include skimming, screening, direct filtration, etc. Chemical processes mainly involved in STPs are adsorption, precipitation, and disinfection. Common biological methods for wastewater treatment are aerated lagoons, trickling filters, rotating biological contactors, anaerobic digestion, and biological nutrient removal. Green infrastructure that helps in treating wastewater includes constructed wetlands, bioswales, retention and detention ponds, in-situ water treatment systems, etc. The major pollution abatement mechanisms in these systems are plant uptake, microbial degradation, photodegradation, sedimentation, adsorption, and filtration. The individual impact of this infrastructure may not be adequate to cope with current pollution standards. Therefore, the integration of grey-green infrastructure is required to mitigate the pollution impact.

Sustainable production systems

Sustainable crop production systems, livestock and aquaculture plays an important role in pollution abatement. Limiting and optimizing the type, amount and timing of pesticide and fertilizers application is one of the crucial steps of sustainable crop production. Establishment of protection zones within the farmlands can also restrict pollutants to escape to nearby wetlands. Sustainable irrigation schemes and technologies such as drip and sprinkler irrigation can reduce the outflow of pollutants to the receiving wetlands by reducing the discharge.

4.2 Managing water regimes

Hard engineering approaches such as construction of dams and barrages for water regulation have disrupted the natural water regime. This has not only led to disconnectivity between different waterscapes but also has led to deterioration of water quality due to disruption of environmental flow. Environmental flow is the minimum flow required to maintain the ecological health of aquatic ecosystems and to promote socio-economic sustainability. Managing water regimes through which sustainable environmental flow can be assured is one of the solutions for wetland water quality management. Redeveloping the lost connectivity between various waterscapes including wetlands can aid in achieving water quality targets.

Box 4.1 : Restoring the hydrological regime of Chilika

Lake Chilika, situated on the eastern coast of India, is the largest coastal lagoon in the region. It has been officially recognized as a Wetland of International Importance, designated as a Ramsar Site under the Convention on Wetlands since 1981.

From 1950 to 2000, Lake Chilika faced a period of rapid deterioration primarily due to an increase in sediment accumulation from its catchment areas and reduced connectivity with the sea. This resulted in significant negative impacts such as a decline in fisheries, the proliferation of invasive weeds, and a decrease in the lagoon's size and water volume. These changes had far-reaching consequences on the local communities, particularly those dependent on fishing activities for their livelihoods.

In 2000, a significant hydrological intervention was executed by opening a new outlet to the Bay of Bengal. This intervention yielded positive outcomes, including the restoration of optimal salinity levels, increased fish catch, a reduction in invasive species, and an overall enhancement of water quality. These improvements facilitated the recovery of resources, thereby considerably enhancing the livelihoods of the communities dependent on the lake.

The successful outcomes of the restoration initiatives prompted the Government of India to request the Ramsar Convention Bureau to consider removing Lake Chilika from the Montreux Record. In 2002, this request was granted based on the recommendations of a Ramsar Advisory Mission. The remarkable achievements of the restoration efforts were also acknowledged through the Ramsar Wetland Conservation Award and the Evian Special Prize, both conferred upon the Chilika Development Authority in 2002.

Opening of the mouth at Chilika to restore salinity gradient (Photo Credit : WISA Library)

4.3 Constructed wetlands

Constructed wetlands (CWs) are engineered systems that replicate the properties and processes of natural wetlands specifically wastewater treatment. The major components of CWs are filter material (Substrate), vegetation, excavated basin, and inlet-outlet system. It mimics the natural biogeochemical processes of natural wetlands such as nutrient uptake, filtration, settlement, oxidation, etc, but in a controlled environment. Constructed wetlands are usually decentralized in nature, meaning they can be constructed locally at the pollution source and do not have mandatory requirements for large sewer networks like conventional treatment systems.

Pollutant removal mechanisms of constructed wetlands include plant metabolism, sedimentation, filtration and adsorption, and bacterial degradation (see Table 4.1).

Suspended solids in the constructed wetlands are removed by the process of sedimentation and filtration. Similarly, soluble organic matter is removed by biological degradation either aerobically (in the presence of oxygen) or anaerobically (in the absence of oxygen). Phosphorus removal takes place in the CWs through adsorption, precipitation, biotic assimilation, and plant uptake. Processes involved in nitrogen removal in the

CWs system are ammonification followed by nitrification, denitrification, adsorption, plant uptake, and ammonia volatilization. Similarly, metals are removed by plant uptake, microbial oxidation, reduction, adsorption, complexion, and precipitation. Removal of pathogens in the wastewater occurs through sedimentation, filtration, UV irradiation, natural die-off, predation, or even by excretion of antibiotics from the roots of macrophytes.

Table 4.1 : Removal mechanism of constructed wetlands

Wastewater constituents	Proposed monitoring system
Suspended Solids	• Sedimentation • Filtration
Soluble organics	• Aerobic microbial degradation • Anaerobic microbial degradation
Phosphorous	• Matrix sorption • Plant uptake
Nitrogen	• Ammonification followed by microbial nitrification • Denitrification • Plant uptake • Matrix adsorption • Ammonia volatilization (mostly in SF system)
Metals	• Adsorption and cation exchange • Complexation • Precipitation • Plant uptake • Microbial Oxidation /reduction
Pathogens	• Sedimentation • Filtration • Natural die-off • Predation • UV irradiation (SF system) • Excretion of antibiotics from roots of macrophytes

(Source: UN-HABITAT)

4.3.1 Types of constructed wetlands

Constructed wetlands are characterized according to various classifications such as the type of macrophytes being used, flow pattern of the water, configuration, type of substrate used, type of wastewater loading, and level of treatment required. Figure 4.1 shows the classification of constructed Wetlands and their type.

Among these classifications, CWs according to the flow type have been discussed. According to the flow type, CWs can be classified into Horizontal and Vertical flow types.

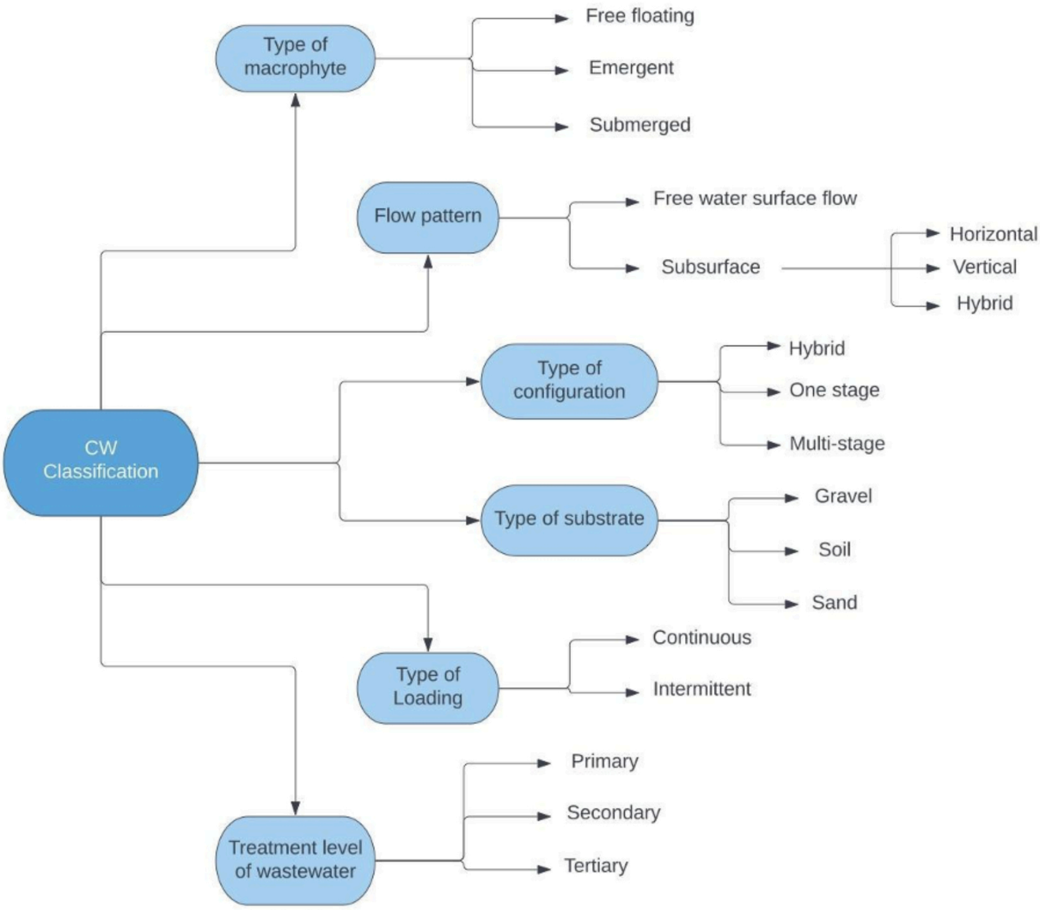


Figure 4.1 : Classification of Constructed wetlands (credit: Sneha Parul)

4.3.1.1 Horizontal Flow (HF) type CWs

Horizontal Flow types constructed wetlands are systems in which the flow direction of the wastewater is more or less horizontal. In the HF-type systems, the rhizosphere is the zone of aerobic decomposition of organic matter. Horizontal flow wetlands can effectively remove the TSS and BOD. Removal of nitrogen is limited in HF-type CWs as oxygen supply is constrained in such systems.

4.3.1.2 Vertical Flow type CWs

In the vertical flow systems, the water flows from the top to the bottom of the wetland intermittently. The water slowly percolates and passes through the system of the rhizosphere and substrate media. The water received at the bottom of the wetland is then collected through the drainage system. As the bed drains freely and intermittently in these systems, this leads to natural aeration of the bed hence providing oxygen to the next batch of wastewater fed to the wetland. The oxygen transfer through this process of diffusion is higher compared to the oxygen transfer by plants. Vertical flow type CWs are preferred over Horizontal ones, as the high oxygen transfer leads to high nitrogen removal through nitrification. Moreover, they are also compact in size as compared to HF types and more efficient in removing BOD and even pathogens.

4.3.1.3 Hybrid

In a few circumstances, a hybrid system that involves both horizontal and vertical flow of wastewater is used. Although oxygen transfer is greater in vertical flow systems, there are some benefits that can be achieved by using horizontal systems such as better solid removal capacity, less susceptibility to clogging, etc. Hence hybrid systems are used to derive the benefits of both systems. The hybrid system can have arrangements in which VF systems are followed by HF systems or vice-versa.

4.3.2 Advantages and disadvantages of constructed wetlands

Constructed wetland has emerged as an alternative or addition to conventional wastewater treatment systems. There are numerous advantages of using CWs such as cost efficiency, easy O&M, eco-friendliness, and multi-functionality. However, there are certain limitations associated with its use. These include the requirement for large areas, and knowledge requirements related to wetland ecology and functions. There is also a need for regular harvesting of biomass for the proper functioning of the system.

4.3.2.1 Advantages

- Cost efficient compared to the conventional wastewater treatment systems.
- Easy to operate and maintain
- Energy-efficient as the system does not need fossil fuels for operation.
- Provides multiple ecosystem services apart from purification such as recreation, fisheries, biomass production and even water supply

4.3.2.2 Disadvantages

- Larger area requirement leading constraints in terms of availability and affordability
- Requires knowledge of wetland ecology

- Require periodic harvesting of biomass
- Optimization of systems becomes difficult when various wastewater gets mixed

Box 4.2 : Use of constructed wetlands for the revival of Jakkur Lake

Jakkur is one of the largest lakes in the grid of human-made lakes in the city of Bengaluru and is located in the northeastern part of the city. Unplanned development in the area surrounding the lake had led to solid waste filling its feeder channels. This choked the natural watershed so much that the lake resembled a dumping yard. The lake receives water from many inlets with some mixed with domestic sewage. A constructed wetland system was designed to receive treated wastewater from a nearby STP and domestic sewage from the surrounding areas. The naturally treated wastewater from the wetland was then released into the lake. The constructed wetland covers approximately 7 acres in the northern part of the lake and accounts for approximately 4.4% of the total lake area. The constructed wetland system consists of Typha planted at the inlet and on the edge of the wetland, followed by Alligator weed and Water Hyacinth. Fishermen at the lake maintain the wetland and the lake by harvesting the plants as required. At present, the constructed wetlands have been very effective in removing organics and nutrients. Raw sewage is diluted with the treated wastewater and the remaining treatment takes place in the constructed wetlands .

Jakkur lake, Bengaluru: A wetland revived through a constructed wetland system (Photo Credit : Mongabay)

4.4 EIA and regulatory systems

Environment impact assessment is the process of evaluating the likely socio-environmental impacts of a proposed project or development. This is done taking into account the socio-economic, cultural, and human health impacts. A decision-making tool, EIA compares various alternatives for a project and seeks to identify the one that represents the best combination of economic and environmental costs and benefits. EIA systematically examines both beneficial and adverse consequences of the project and ensures that these effects are taken into account during project design. Apart from EIA, there are several other regulatory tools for water quality management in India. On national and state levels, we have several policies and regulations like the Water (Prevention and Control of Pollution) Act, 1974 to regulate pollution discharges and restore water quality of our aquatic resources including the prescription of monitoring activities. Under the Water Act, of 1974, pollution control boards were created, which are responsible for the implementation of its provisions. Table 4.2 shows the overview of Acts and Regulations for the protection of water quality in wetlands in India.

Table 4.2 : Overview of Acts and Regulations for protection of water quality in wetlands in India

1974	Water (Prevention and Control of Pollution) Act	Prevention and control of water pollution in maintaining or restoring the wholesomeness of water through the establishment of pollution control boards (central & state level) for implementation
1977	Water Cess Act, 1977	Water Cess Act, 1977 was adopted to strengthen the Pollution control Boards financially, to promote water conservation. This Act empowers the Central Government to impose a Cess on water abstracted from natural resources by industries and local authorities
1986	Environment Protection Act	Provision of protection and improvement of the environment in a broader sense, including the human environment. The EPA empowers the Government to set national standards for ambient environmental quality and controlling discharges to regulate industrial locations, to prescribe procedures for hazardous substance management, and to collect and disseminate information regarding environmental pollution. The Act provides for severe penalties for those who fail to comply with or contravenes any provision of the Act
1989	Manufacture, Storage, Import of Hazardous Chemicals Rules	The Manufacture, Storage, Import of Hazardous Chemicals Rules, 1989 and its amendments under EPA, 1986 has identified the responsibilities of various stakeholders for management of chemicals and containment of spillage
1998	The Bio-medical waste (Management & Handling) Rules	The Bio-medical waste (Management & Handling) Rules, 1998 are likewise directed at institutions that generate and bio-medical wastes in any form
1999	The Municipal Wastes (Management & Handling) Rules	The Municipal Wastes (Management & Handling) Rules,1999 fix responsibilities to every municipality responsible for the collection ,segregation, storage, transportation and disposal of municipal wastes

1989	The Hazardous Wastes (Management and Handling) Rules	The Hazardous Wastes (Management and Handling) Rules, 1989 and its subsequent Amendment 2000 were created to provide 'cradle-to grave' or comprehensive guidance to the generators, transporters and operators of disposal facilities among others, and monitoring norms for State governments
2017	Wetlands (Conservation and Management) Rules	Regulatory framework for conservation and management of wetlands in India. The rule prohibits discharge of untreated wastewaters to the notified wetlands from industries, cities, towns, villages and other human settlements.
2019	Coastal Regulation Zone notification	Preservation of coastal areas and marine waters together with safeguarding livelihoods of traditional fisherfolk communities.

One of the important provisions of the Water Act, 1974 is to maintain and restore the 'wholesomeness' of our aquatic resources. The Central Pollution Control Board (CPCB) is an apex body in the field of water quality management in India. For rational planning of any water quality management programme, CPCB needs to know the nature and extent of water quality degradation To define the level of 'wholesomeness to be maintained or restored a system of water use classification was developed. Under this system water uses are classified in 5 classes. Table 4.3 represents the standards set by CPCB for designated best use criteria of surface water which includes wetlands:

Table 4.3 : Designated best use criteria by CPCB

Designated Best Use	Class of Criteria	Criteria
Drinking water source without conventional treatment but after disinfection	A	• Total Coliforms ≤ 50 MPN/100ml • pH 6.5-8.5 • Dissolved Oxygen ≥ 6 mg/l • Biochemical Oxygen Demand (5 days 20°C) ≤ 2mg/l
Outdoor bathing (organized)	B	• Total Coliforms ≤ 500 MPN/100ml • pH 6.5-8.5 • Dissolved Oxygen ≥ 5 mg/l • Biochemical Oxygen Demand (5 days 20°C) ≤ 3 mg/l
Drinking water source after conventional treatment and disinfection	C	• Total Coliforms ≤ 5000 MPN/100ml • pH 6-9 • Dissolved Oxygen ≥ 4 mg/l • Biochemical Oxygen Demand (5 days 20°C) ≤ 3 mg/l
Propagation of Wildlife and Fisheries	D	• pH 6.5-8.5 • Dissolved Oxygen ≥ 4 mg/l • Free Ammonia (as N) ≤ 1.2 mg/l

Designated Best Use	Class of Criteria	Criteria
Irrigation, Industrial Cooling, Controlled Waste disposal	E	• pH 6.0-8.5 • Electrical Conductivity at 25°C < 2250 µmhos/cm • Sodium absorption ratio maximum 26 • Boron < 2 mg/l
	Below E	• Not meeting A, B, C, D and E criteria

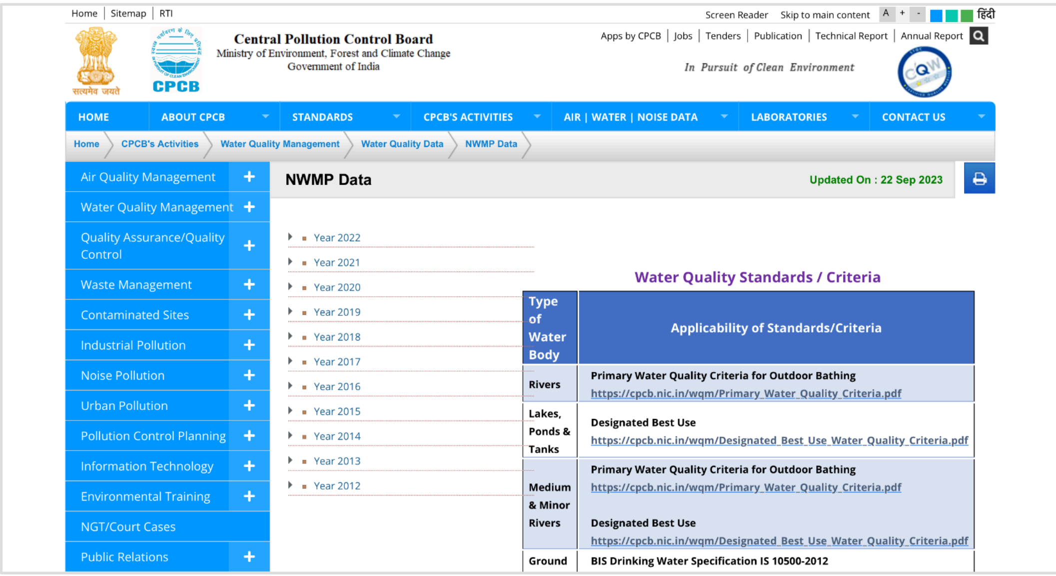
As the treated wastewater from wastewater treatment plants gets directly discharged into the wetlands, their quality impacts the overall wetland health. Therefore, to prevent wetland pollution MoEFCC has come up with discharge standards for wastewater treatment plants. Looking into the severity of pollution status, the National Green Tribunal (NGT) passed an order in 2019 establishing more strict regulations for discharging wastewater. Table 4.4 shows the discharge standards set by MoEFCC and NGT order.

Table 4.4 : Overview of WWTP discharge standards into inland wetlands

Parameters	General norms (1986) (MoEFCC, 1986)	Draft norms (2015) (MoEFCC, 2015)	MoEFCC notification (2017) (MoEFCC, 2017)	NGT order (2019) (NGT, 2019)
BOD (mg/l)	30	10	30 (20 for metro cities)	10
COD (mg/l)	250	50	-	50
TSS (mg/l)	100	20	100 (50 for metro cities)	20
pH	5.5-9	6.5-9	6.5-9	5.5-9
TN (mg/l)	100	10	-	10
Ammoniacal nitrogen as N (mg/l)	50	5	-	-
Free ammonia (mg/l)	5	-	-	-
Nitrate (mg/l)	10	-	-	-
Dissolved phosphate as P (mg/l)	5	-	-	1
Faecal coliform (MPN/100 ml)	-	<100	<1000	<230

Box 4.3 : National Water Quality Monitoring Programme by CPCB

The Central Pollution Control Board (CPCB), in conjunction with the State Pollution Control Boards (SPCBs) operating within various states, as well as the Pollution Control Committees (PCCs) situated in Union Territories, has instituted a comprehensive initiative known as the National Water Quality Monitoring Network (NWMP). The primary objective of this undertaking is to systematically evaluate the prevailing water quality within various water resources. This network serves the dual purpose of ascertaining the state of water quality and streamlining efforts geared toward the anticipation, prevention, and management of pollution in wetlands. Presently the network comprises around 4484 water quality monitoring stations on surface and groundwater. Monitoring of done on a monthly, quarterly, half-yearly, and yearly basis. The monitoring Programme considers parameters such as Temperature, Dissolved Oxygen, pH, Electrical Conductivity, BOD, Nitrate, Fecal Coliform and Total Coliform.



Webpage of CPCB showcasing water quality data under the NWMP over the years

4.5 Integrated management and inter-sectoral coordination

Wetlands are impacted by various developmental activities taking place in different sectors within its catchment (see Figure 4.2). For instance, tourism beyond the carrying capacity of the wetland can have an adverse impact on its health especially its water quality as more and more waste gets generated. Similarly, unsustainable water allocations under water resources management for different human uses such as for energy generation, agriculture, and others can have adverse impacts on the wetland. Therefore, prior to any development intervention at the landscape level, it is imperative to assess its implication on wetland health especially on water quality. On the other hand, healthy wetlands can contribute to achieving outcomes for various sectors. For instance, the maintenance of water quality is imperative for fish production enhancing the fisheries sector.

An integrated approach to wetland management through the convergence of multiple sectoral inputs can play an important role in maintaining wetland water quality.

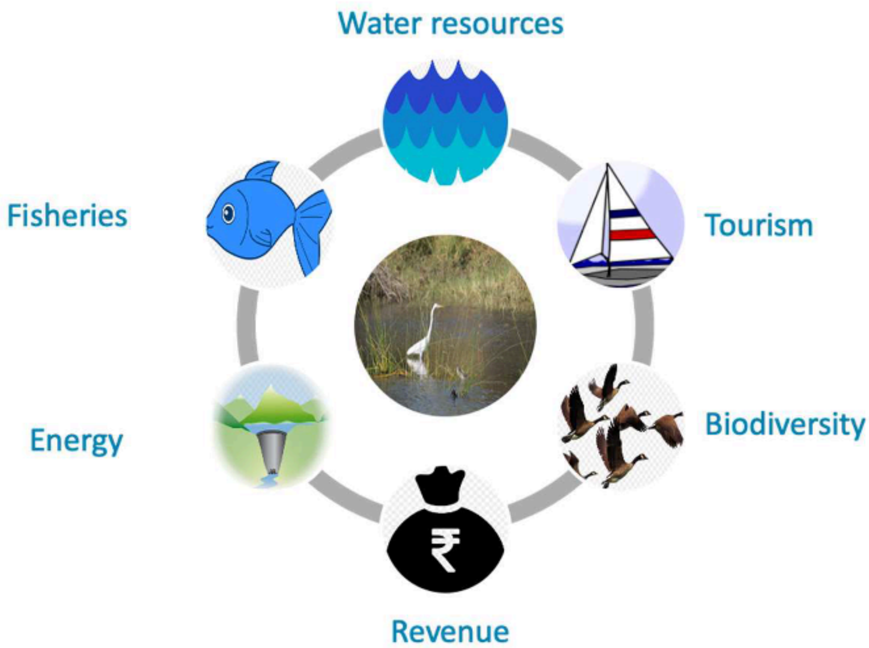


Figure 4.2 : Integrated Wetland Management and inter-sectoral coordination (credit: WISA Library)

4.6 Water quality monitoring systems

Smart solutions for monitoring water pollution are getting more and more significant these days with innovations in sensors, communication, and Internet of Things (IoT) technology. IoT-based Smart Water Quality Monitoring (SWQM) has the potential to eradicate errors in sampling and laboratory analysis as it can provide real-time data on water quality. These interventions at the catchment scale have the potential to address water quality issues in wetlands. Monitoring at different spatial scales such as river, stormwater inflow, and dams monitoring also contributes to achieving wetland water quality targets as a part of catchment management. Figure 4.3 represents one of IoT models for monitoring the water quality of wetlands.

Apart from the application of advanced technologies for monitoring, it is equally important to involve the community in the monitoring programmes. The participatory approach to water quality monitoring has been looked at as a potential tool for achieving water quality targets. A network of Wetland Mitra (Friends of wetlands) who are motivated volunteers working to conserve wetlands can lead the participatory water quality monitoring programmes.

Details on the concept of Wetland Mitra is available here:

https://indianwetlands.in/uploads/S_4.2_Module_4_Wetlands_Mitra.pdf.

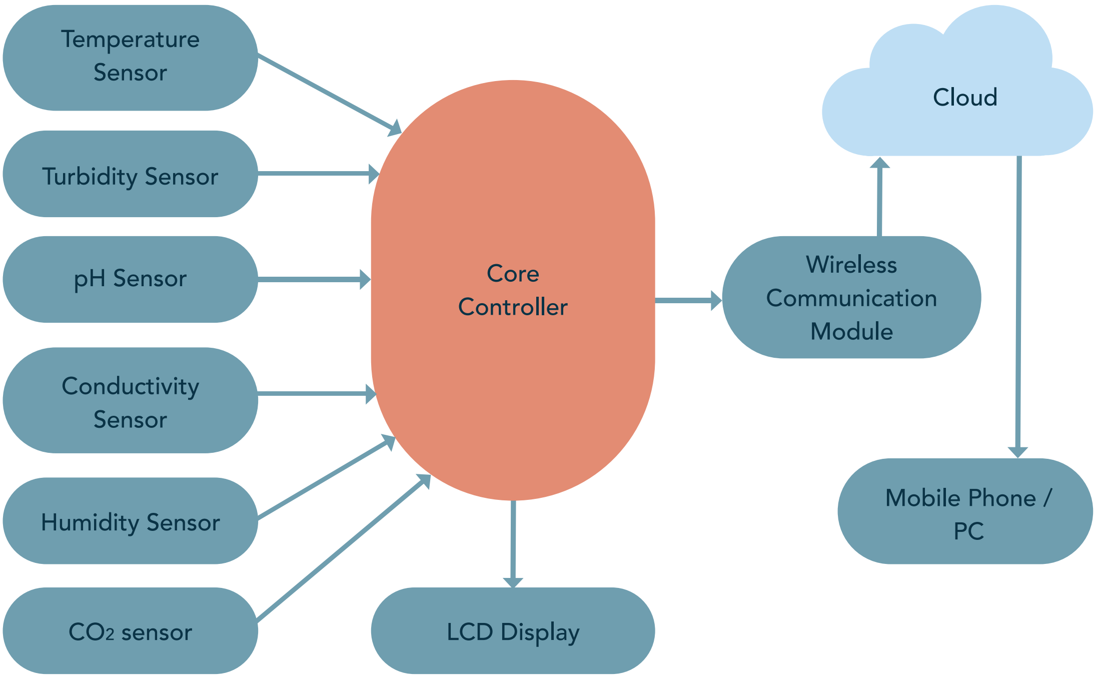


Figure 4.3 : Real-time water quality monitoring system framework

Box 4.4 : Participatory wetland water quality monitoring

Numerous mobile-based applications and easy-to-use technologies have been developed for monitoring water quality using citizen science. The involvement of stakeholders in the collection of water quality data not only helps in understanding the interventions required but also promotes awareness regarding the need for the protection of wetlands from various sources of pollution. A participatory approach to water quality monitoring also creates a sense of belongingness among the wetland users which in turn aids in wetland conservation. Secchi disk and Forel-Ule (FU) color scale are some common equipment that have been used to measure the optical properties of wetlands, which are indicators of biological activities, sediment load as well as pollution in the wetlands. However, the use of sophisticated equipment requires prior training and hands-on experience.

The State Wetland Authority of Kerala has been working on getting data on wetlands water quality through a participatory approach. The water quality assessment is being done by the local citizen who has been provided with login credentials of the portal to regularly feed the results online on https://wiams.kerala.gov.in. This has been done for prominent wetlands of the state such as Sasthamkotta, Ashtamudi, and Vembanad.

Local wetland user measuring water quality at Vembanad-Kol wetland complex, Kerala (Photo Credit : Scroll.in)

4.7 Capacity development

Capacity development in the context of wetland water quality management refers to awareness and capacity to understand the role of water quality in wise use of wetlands. Different stakeholders may have different capacity development needs, for example:

A) Wetlands managers - Knowledge of biogeochemical processes in wetlands, monitoring needs, adverse impacts of different pollution sources

B) Local users- Impact of over-extracting wetland resources, participatory approach of wetland water quality monitoring

C) Engineers and planners- Decentralized wastewater treatment systems, importance of maintaining hydrological regime for wetland water quality

Wetland health card

A standard wetland health card has been developed by the Ministry of Environment Forest and Climate Change as a tool for the assessment of wetland health (see Figure 4.4). It is prepared from the qualitative and quantitative assessments based on rapid surveys and monitoring of the wetlands. The wetland health assessment includes multiple components like area, hydrology, catchment, biodiversity, and governance. The hydrology and catchment component includes water quality parameters such as BOD, DO, etc. This provides an approximate idea of wetland water quality. The health card is beneficial for different stakeholders such as wetland managers, users, research organizations, state forest departments, state pollution control boards, etc.

Standard Frame-work of of Health Report Card developed by MoEFCC for rejuvenation of 100 wetlands of the country

Features	Indicator	Desired Value	Actual Value	A	B	C	D	E	Score
Area	% wetland converted to non-wetland use since 2000	0%		0%	1-5%	6-10%	11-20%	More than 20%	
Hydrology and Catchments	Ratio of number of natural inlets choked and diverted to total number of natural inlets	<0.2		0-0.2	0.3-0.4	0.4-0.6	0.7-0.8	More than 0.8	
	Ratio of number of natural outlets choked and diverted to total number of natural outlets	<0.2		0-0.2	0.3-0.4	0.4-0.6	0.7-0.8	More than 0.8	
	Biological Oxygen Demand	Between 3-6 mg/l		80-100% sample meet the criteria	60-80% sample meet the criteria	40-60% sample meet the criteria	20-40% sample meet the criteria	Less than 20% sample meet the criteria	
Biodiversity	% wetland area covered by invasive macrophytes	<10%		<10%	11-20%	21-30%	31-40%	More than 40%	
	Annual waterbird count as a proportion of average count of last 5 years	0.7		More than 0.7	0.6-0.7	0.5-0.6	0.4-0.5	less than 0.5	
Governance	Clearly demarcated wetlands map	Wetlands map prepared and approved by CWLW		Wetlands map prepared and approved by State	Wetland map prepared and under consideration of State Wetlands Authority	Wetlands map preapred but not placed in State Wetlands Authority	Wetlands map under preparation	Wetlands map not prepared	
	Wetlands management plan	Management plan prepared and approved by CWLW		Management plan prepared and approved	Management plan prepared and submitted to SWA	Management plan prepared, not submitted to SWA	Management plan under preparation	No manage-ment plan	
	Wetlands Notification	Wetlands notified under WPA		Final notification under extant regulation	Draft notification	Regulation under process	Regulation planned, process initiated	No regulation	

Figure 4.4 : Wetland Health report card developed by MoEFCC

• Group Exercise •

Visit a wetland near you and answer the following questions:

A) What are the pollution sources of water in the wetland? Is it natural or anthropogenic in nature? (Insert pictures, if any)

B) Are there any direct pollution sources in the wetland? (Insert pictures, if any)

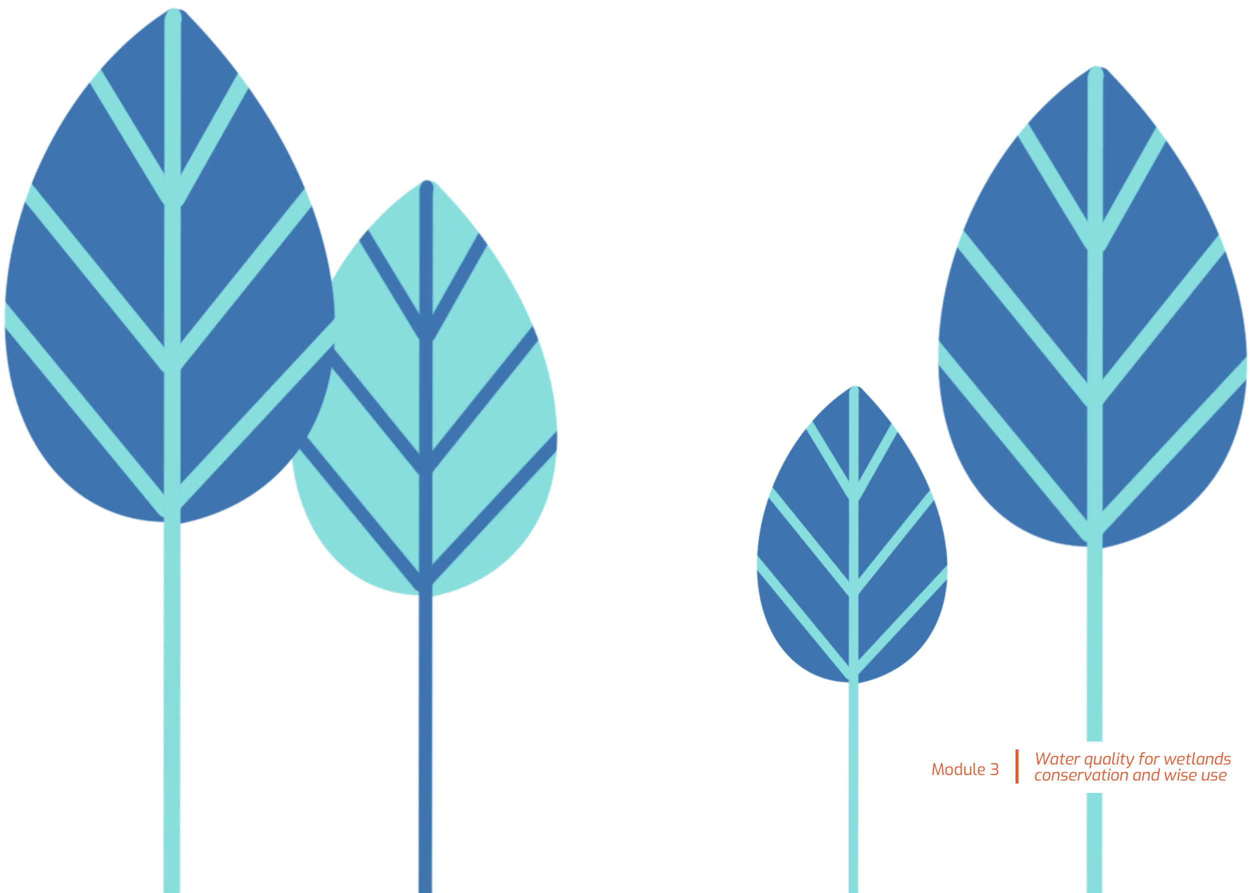
C) Are there any wastewater treatment plants treating the inflow of water prior to the discharge?

D) Observe the physical indicators of the wetland water such as color, transparency, and odor, and draw inferences from it. (Insert pictures, if any)

E) Propose measures for maintaining water quality through various interventions discussed in the manual.

F) What is the institutional arrangement in the area to tackle wetland pollution

G) Draft a wetland health card for the wetland



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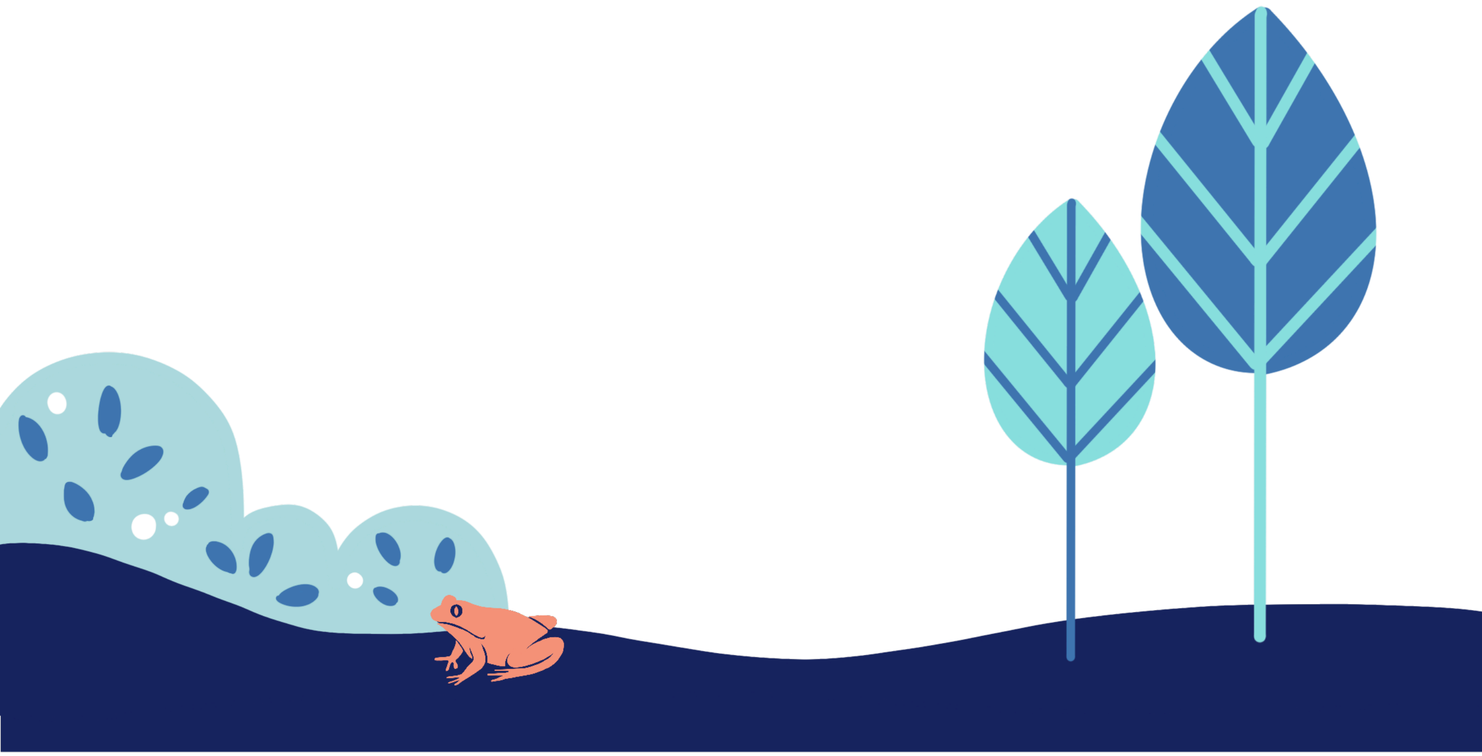

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Wetlands International South Asia
Module No.003, Ground Floor
NSIC Business Park
Okhla Industrial Estate
New Delhi – 110020
India

Email: wi.southasia@wi-sa.org
URL: https://south-asia.wetlands.org

Wetlands International
@WetlandsInt
Wetlands International