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A Review on Water Quality Assessment in Local Wetlands Using Physiochemical Parameters

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ABSTRACT

Wetlands are essential freshwater ecosystems that possess significant ecological importance. Wetlands are crucial for the provision of a variety of services such as water purification, groundwater recharge, regulation of floods, nutrient cycling, and carbon storage, apart from providing habitats to many aquatic species. However, human activities such as urbanization, agricultural runoff, industrial discharge, and sewage have recently resulted in deterioration of the wetlands. Traditional approach of water quality monitoring involves the measuring of parameters like temperature, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), electrical conductivity (EC), total dissolved solids (TDS), nutrients, and microbial parameters. Although these parameters are important for providing information about the chemical properties of water bodies, they are not adequate for showing the impact of these water quality parameters on aquatic organisms' biology. In this context, this paper seeks to assess the water quality in wetlands with the use of physiological indicators along with traditional monitoring methods. A PRISMA-based literature review has been conducted using peer-reviewed articles, standard literature on limnology and environmental guidelines. The review also assesses the contribution of physiological indicators such as fish respiration behaviour, operculum activity, gasping respiration, condition factor, feeding behaviour, and reproduction along with other biological indicators namely plankton, benthos, amphibians, and aquatic macrophytes towards the determination of wetlands' ecological health. Lastly, the paper also reviews the utility of Water Quality Index (WQI) and biomonitoring methods in wetland assessment. The review suggests that combining physiological, biological, and chemical parameters is a better alternative to assess the health of wetlands than depending on traditional water chemistry alone. Finally, education gaps in long-term monitoring, seasonal assessment, and studies on indicators have been identified and beneficial recommendations for the future work have been made.

Introduction

Wetlands are known to be one of the most productive and biologically diverse ecosystems in the world, acting as bridges between terrestrial and aquatic areas. Wetland ecosystems perform a range of ecological functions such as water purification, nutrient retention, groundwater recharge, and flood control (Mitsch & Gosselink, 2015; Convention on Wetlands, 2021). Wetlands also have significant socioeconomic function because they provide support for fisheries, agricultural activities, livestock, recreation, and domestic water supply for millions of people worldwide. However, wetlands face considerable destruction and degradation at an unprecedented scale in response to urbanization, industrialization, agricultural expansion, climate change, and land-use practices (Dudgeon *et al*., 2006; Zedler & Kercher, 2005).

Local wetlands, including ponds, marshes, floodplain wetlands, oxbow, irrigation tanks, and seasonal bodies of water, are very vulnerable because they typically receive a lot of untreated domestic waste, agricultural runoff, industrial discharges, and solid waste. These human impacts alter the physicochemical and biological characteristics of wetlands leading to eutrophication, depletion of dissolved oxygen, loss of biodiversity, habitat fragmentation, and decline in ecosystem services (Bassi *et al*., 2014; Gopal, 2013). Given that local wetlands are usually vital for many aquatic species such as fish, amphibians, aquatic invertebrates, birds, and planktonic organisms, their preservation is of great importance for freshwater biodiversity and sustainable management of resources.

It is widely considered that, among variousThe water quality has been evaluated traditionally based on the assessment of the physicochemical properties of water that include water temperature, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), electrical conductivity (EC), total dissolved solids (TDS), turbidity, nutrients and alkalinity (APHA *et al*., 2023; Chapman, 1996). The parameters play an important role in determining the chemical nature of the aquatic environment, and therefore, have a wide application in environmental monitoring and legislation, however, physicochemical indicators tend to indicate the water quality at a specific time only and ignore the accumulated biological effects of environmental effects over time (Wetzel, 2001).

The recent developments in freshwater ecology underline the necessity of the inclusion of the biological and physiological reactions of aquatic organisms in the assessment of water quality. The physiological parameters give the direct evidence of how aquatic organisms react to the environmental changes and impact of the pollutants. Fish respiratory behavior, opercular movement, surface breathing, feeding behavior, reproduction, condition factor, oxidative stress, enzyme activity and histopathological changes are considered to be the efficient biological indicators of ecological disturbance (Froese, 2006; Le Cren, 1951). The changes in the composition of plankton, macroinvertebrates, populations of amphibians, and aquatic plants are also important indicators of long-time ecological changes due to degradation of water quality and habitat (Bonada *et al*., 2006; Lampert & Sommer, 2007). Thus, physiological indicators serve as a complement to the water chemistry.It is rumored that lower levels of dissolved oxygen can lead to increased activity of gills, respiration from the surface of the water, loss of feeding behavior in the fish, and their deaths. Similarly, high ammonia concentrations can affect processes like osmoregulation as well as impair the function of the gills (U.S. Environmental Protection Agency [EPA], 2018. Excessive nutrient enrichment can also promote harmful algal blooms that will change the communities of plankton, reduce light penetration, and trigger hypoxia, which is harmful for aquatic animals (Smith & Schindler, 2009). Therefore, physiological responses can serve as warning signals for environmental stress and signal the onset of environmental degradation. Particularly, biological monitoring is important because biological communities reflect the effects of various environmental factors over time. Fish assemblages, micro-invertebrates, plankton, and amphibians react to the changes related not only to the water chemistry but also to the quality of habitat, changes in hydrology, and land disturbances (Karr, 1981; Karr & Chu, 1999). Thus, it is possible to receive a more complex picture of the health of the ecosystem by integrating biological indicators with chemical monitoring. In the last few decades, the Water Quality Index (WQI) has emerged as a powerful summary of different water quality variables and has been used to ease the communication of scientists, environmental managers and policymakers (Brown *et al*., 1970; Tyagi *et al*., 2013). However, it should be kept in mind that the WQI results should be interpreted very cautiously since they may not reflect serious ecological problems like oxygen depletion, ammonia poisoning, and contamination by microorganisms. Although a lot of studies were conducted on big rivers and wetlands that are recognized all over the world, a small number of them have studied the local wetlands. These ecosystems are often left without any monitoring in spite of their great importance for ecology and economy. As far as they are concerned, most studies pay attention to physico-chemical characteristics, while physiological responses and indicators of biology are rarely used. This is a drawback since it does not allow to evaluate the ecological health properly.

The purpose of the review is to analyze the existing literature and research on water quality in local wetlands and to focus on the physiological parameters as indicators of ecosystem health. The paper covers the study of the traditional physico-chemical indicators, biological indicators, biomonitoring, and Water Quality Index approaches. It also indicates key gaps in the research and outlines the perspectives of future research in the area of wetlands.

Review Methodology

This review utilized a methodical narrative review technique developed based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines to provide transparency and reproducibility during literature research, analysis, and synthesis. While the current study is not a quantitative meta-analysis, the principles of the PRISMA method have been enabled to increase the methodological transparency of the study and avoid any possible biases in the review process.

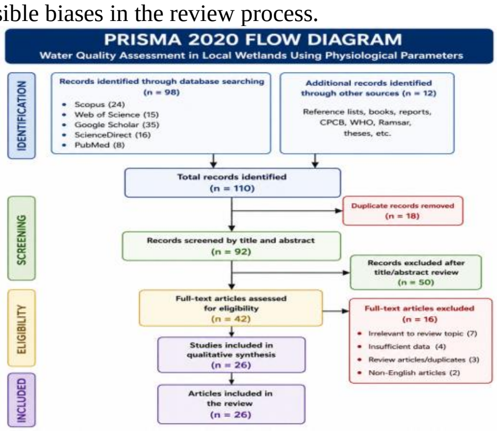

Figure 1. PRISMA 2020 flow diagram illustrating the literature search, screening, eligibility assessment, and study selection process used for this review on water quality assessment in local wetlands using physiological parameters.

In this study, a thorough literature search was carried out using prominent scientific databases including Web of Science, Scopus, PubMed, Google Scholar, ScienceDirect, SpringerLink and Wiley Online Library. In addition, knowledge was taken from official publications of various organizations such as Central Pollution Control Board (CPCB) in India, Ministry of Environment, Forest and Climate Change (MoEFCC), Convention on Wetlands (Ramsar), World Health Organization (WHO), and U.S. Environmental Protection Agency (EPA).

The search strategy involved the use of keywords and Boolean operators like “wetland water quality," "physiological parameters," "water quality assessment," "freshwater wetlands," "biomonitoring," "fish physiology," "dissolved oxygen," "Water Quality Index," “macroinvertebrates," "plankton," “eutrophication," "aquatic ecosystem health," and "wetland conservation."

Studies were included in our search if they (i) report about freshwater wetlands (ponds, lakes, marshes or floodplain wetlands), (ii) evaluate physico-chemical or biological features of water quality; (iii) are published in peer-reviewed journals and recognized organizations; and (iv) are written in English language. Exclusion criteria comprised the studies focusing on marine ecosystems or wastewater management processes without any ecological aspect, conference abstracts, unpublished reports and repeated publication.

The process of gathering literature information from these sources involved the screening of papers by title and later body of study. In addition, duplicate publications were removed prior to judgment about their eligibility. The gathered information included the location of studies, types of wetlands studied, the parameters and methods analyzed in the studies.

Finally, qualitative synthesis method was used in processing the information on the studies retrieved from the sources.

3. Physico-Chemical Parameters for Water Quality Assessment in Local Wetlands

The physico-chemical attributes of water play an important role in wetland health evaluation because they affect aquatic animals, ecological processes, and ecosystem functioning. The quality of the water depends on the interactions between the hydrological conditions, climatic conditions, watershed features, biological activity, and human activities. Monitoring of these factors is important in assessing the ecological health of wetlands and in determining their pollution, eutrophication, and habitat degradation impacts(Wetzel, 2001; Chapman, 1996) (Figure 2).

3.1 Water Temperature

Water temperature is one of the most essential environmental parameters when it comes to aquatic ecosystems. It affects metabolic functions, oxygen solubility, microbial decomposition, photosynthesis, and nutrient cycling. It also has an impact on growth, reproduction, migration, and survival of aquatic life. Increased temperature of water reduces the amount of dissolved oxygen while the metabolic needs of water life grow, making fish and other water living organisms more vulnerable to stress (Wetzel, 2001).

In shallow wetlands, seasonal variations of temperature are particularly strong due to shallow depth and long period of sun exposure. Increased summer temperature often leads to algal bloom, increased microbial respiration, and oxygen depletion while winter temperatures usually contribute to increased oxygen concentration and decreased biological demand for oxygen. Therefore, measurement of water temperature has to be carried out simultaneously with the measurement of dissolved oxygen.

3.2 Hydrogen Ion Concentration (pH)

The acidity and alkalinity of water can be determined by its pH value that significantly influences the biological and chemical processes within wetlands. The optimum pH levels allow the majority of freshwater species to survive in this range which is estimated to be from 6.5-8.5 pH units. Any pH shifts of this range will have serious consequences for many significant physiological processes, such as breathing, osmoregulation, enzyme activity (APHA *et al*, 2023). Any changes in pH will also affect the toxicity of solutes. One of the instances of that would be queuing up for un-ionized ammonium (NH3) which becomes harder than ionized ammonium (NH4+) in alkaline and warm waters (U.S. EPA, 2018). Thus, pH should be closely associated with ammonia and temperature in a water body and not considered separately.

3.3 Dissolved Oxygen (DO)

According to the universal perception oxygen is one of the central indicators of aquatic ecosystem health because it is the basis for respiration for fish, macroinvertebrates, zooplankton, and aerobic microorganisms. Oxygen concentrations in wetlands change on a daily basis because of photosynthesis, respiration, diffusion of air, and decomposition outputs (Wetzel, 2001).

Freshwater wetlands with good health are supposed to keep within the range of DO levels which do not fall below 5 mg L^{-1}; otherwise when the DO levels have been low for a long period, e.g. below 3 mg L^{-1}, the physiological stress of the fish, various behavior changes, and even reduced reproduction may take place. Measurements of dissolved oxygen in the morning are of special importance because of its low values at that period that is provided by the respiration which took place overnight.

3.4 Biochemical Oxygen Demand (BOD)- Biochemical Oxygen Demand is the amount of oxygen used by microorganisms in the decomposition of organic matter that can decompose. When BOD concentration is high, this means that the water body has been polluted by domestic wastewater, animal waste, runoff from agricultural areas, decaying of plants, or industrial waste (Chapman, 1996). High BOD value reduces the amount of dissolved oxygen, which poses danger to fishes and other organisms that require oxygen for life. Thus, BOD is used as an indirect measure of organic pollution, but it cannot be used alone to determine the source of pollution.

3.5 Chemical Oxygen Demand (COD)-COD, or Chemical Oxygen Demand, measures oxygen requirements needed to chemically oxidize both bio-degradable and non-bio-degradable organic material present in the water. COD values generally tend to be more than Biological Oxygen Demand or BOD, because chemical oxygenation also refers to substances that cannot be decomposed by micro-organisms.

High COD values may imply that water is polluted with industrial effluents, household wastes, agricultural chemicals, or organic material accumulated in water. COD and BOD should be used together for better interpretation and identification of pollutants, as well as for achieving a better understanding of the sources of pollutants and management of wetlands.

3.6 Electrical Conductivity (EC) and Total Dissolved Solids (TDS)-An index of total dissolved solids (TDS) is a measure of the total amount of dissolved ions in water. Electrical conductivity (EC) is also an indicator of TDS, as it measures how conductive water is due to the number of ions present in water.

High readings of either EC or TDS in water can result from the use of agricultural fertilizers, discharge of sewage, industrial effluents, groundwater supply, mineral leaching, and evaporation in dry periods. Initial levels of EC and TDS are not indicative of pollution, but in the long term, increased values may imply an anthropogenic cause or salinity stress affecting freshwater organisms.

3.7 Turbidity and Water Transparency-Turbidity is the measure of the amount of suspended solids such as clay, silt, plant and animal plankton, and debris. An increase in turbidity results in reduced light penetration which has an effect on both primary production and visual feeding by fish.

Transparency is often quantified using a Secchi disc and indicates the clarity of water. Decreased transparency is often an indicator of sediment and organic matter runoff, algae blooms, and other impacts of eutrophication. Regular turbidity and transparency measurements provide significant information about watershed erosion and water pollution.

3.8 Nutrient Concentrations-Nitrogen and phosphorus are vital nutrients that determine the level of aquatic primary production. Yet, too much of those substances can lead to eutrophication, formation of noxious algal blooms, poor water transparency, and drastic changes in dissolved oxygen levels.

Enrichment of local wetlands with nitrates and phosphates is due to the use of fertilizers in agricultural production, livestock waste, discharge of untreated wastewater and urban runoff. Long-term accumulation of nutrients, however, leads to domination of cyanobacteria, decreases biodiversity and affects food web interactions. Hence, monitoring of the release of nutrients becomes a necessary task for understanding the trophic level of the environment.

3.9 Ammonia-Ammonia is considered to be one of the most harmful nitrogen compounds that affect freshwater lifeforms. It is a byproduct of degradation of organic materials, fish metabolism, agriculture, wastewater discharge and fertilizer losses. The toxicity of ammonia is affected significantly by pH and water temperature. In alkaline conditions, the amount of non-ionized ammonia (NH_3) increases. Exposing fish and aquatic invertebrates to ammonia results in gill damage, weakening respiration, decreasing growth and behavior changes, as well as mortality. Therefore, ammonia tests have to be conducted in combination with the measurement of pH and temperature.

3.10 Microbial Indicators

The microbiological parameters contain important information on sanitary quality of water. The total coliforms, fecal coliforms, and Escherichia coli are commonly used as the indicators of fecal pollution caused by the discharge of sewage, livestock activities, or open defecation. Microbial indicators determine health risks for the public; however, they also indicate human disruptions in wetland ecosystems. The high counts in bacteria correlate with the high input of nutrients, usage of oxygen, and worsening of natural conditions.

To obtain accurate microbiological data, quality assurance and sterile sampling methods are important.

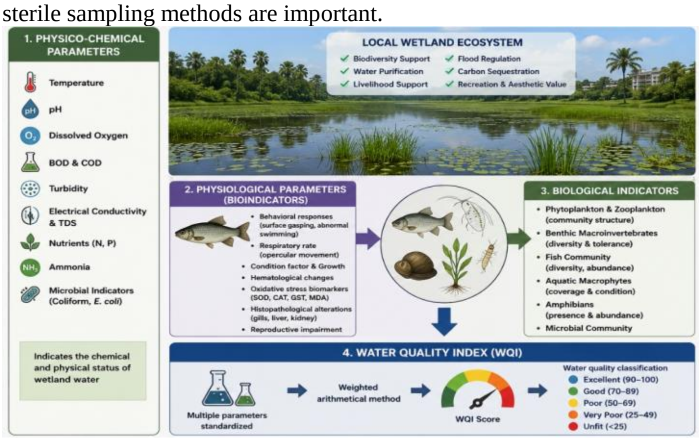

Figure 2. An illustration shown Interaction between Physiological parameters and biological indicators

3.11 Integrated Interpretation of Physico-Chemical Parameters- One factor cannot capture the full extent of wetland ecosystem health. Rather, a combination of factors needs to be examined together, as the physical, chemical, and biological functional processes interact with each other continuously. For instance, the rise of temperature decreases the solubility of oxygen, while increased BOD is causing substantial oxygen depletion. Furthermore, nutrient enrichment results in a rise of algal blooms that increase daytime oxygen through photosynthesis, as well as causing hypoxia in the night (Figure 2).

Thus, it becomes clear that an integrated assessment using temperature, pH, DO, BOD, COD, EC, TDS, turbidity, nutrients, ammonia, and microbiological indicators for the wetland health evaluation is more precise than isolated measurements. It is possible to achieve even better results if the traditional parameters are studied alongside physiological and biological indicators.

4. Physiological Parameters as Bioindicators of Wetland Water Quality- One factor cannot capture the full extent of wetland ecosystem health. Rather, a combination of factors needs to be examined together, as the physical, chemical, and biological functional processes interact with each other continuously. For instance, the rise of temperature decreases the solubility of oxygen, while increased BOD is causing substantial oxygen depletion. Furthermore, nutrient enrichment results in a rise of algal blooms that increase daytime oxygen through photosynthesis, as well as causing hypoxia in the night (Figure 2). Thus, it becomes clear that an integrated assessment using temperature, pH, DO, BOD, COD, EC, TDS, turbidity, nutrients, ammonia, and microbiological indicators for the wetland health evaluation is more precise than isolated measurements. It is possible to achieve even better results if the traditional parameters are studied alongside physiological and biological indicators.

5. Biological Indicators of Wetland Water Quality-Biological indicators are organisms that indicate the ecological condition of water bodies through their occurrence, diversity, and abundance. However, biological populations are deemed to provide better assessment of water quality as they reflect the impact of environmental changes over extended periods (Karr & Chu, 1999).

Phytoplankton and zooplankton are considered to be effective biological indicators because they are affected by the nutrient input and organic contamination. For example, the increase in nutrient load causes algae masses to form, the loss of light penetration through the water body, and plankton community changes. Benthic macroinvertebrates, such as insect larvae, mollusks, and annelids, are also widely used in the biomonitoring process due to the fact that pollution-sensitive species are replaced by the pollution-tolerant ones in polluted habitats (Bonada *et al*., 2006). Fish communities provide useful information on the habitat quality and ecological condition. When there are changes in the species richness, quantity, composition, and structure, this implies that the environment may be suffering from chronic stress.

Aquatic macrophytes can also be used a biological indicators of the ecological condition as they respond to the concentrations of nutrients, sediment properties, and hydrology. The knowledge of biological indicators in the context of physiochemical and physiologic variables provides a complete assessment of the wetland system condition. This in turn helps to establish the extent of ecological degradation and to make scientific decisions aimed at wetland preservation and sustainable use.

6. Water Quality Index (WQI): An Integrated Approach for Wetland Assessment-The Water Quality Index is a common means of assessing the water quality, which integrates different physical and chemical parameters and represents their value through a single numerical expression. The main parameters that are usually taken into account are pH, dissolved oxygen, biochemical oxygen value, chemical oxygen value, total dissolved solids, electrical conductivity, turbidity, nitrates, phosphates and some microbial indicators (Brown *et al*., 1970; Tyagi *et al*., 2013). Therefore, Water Quality Index minimizes complex water quality information and allows researchers, environmental administrators and politicians to understand the ecological situation of wetlands.

According to the Water Quality Index values, water quality can be classified into the following groups: excellent, good, poor, very poor or unsuitable for drinking and for aquatic species. Such a classification helps to trace the level of pollution of wetlands and to improve the approaches to their conservation and monitoring of ecosystem quality. Although Water Quality Index proves to be a helpful means of communication and management, it still entails certain drawbacks. First, it is based on certain physical and chemical indicators and doesn't describe the biological and physiological reactions of organisms. Thus, it is recommended to use Water Quality Index together with biological measures to achieve better results.

Conclusion

Wetlands are important ecosystems that have freshwater, and provide wildlife with environmental services as well as water purification, nutrient cycling, control of floods, and climate regulation. The analysis of wetland water quality is very important for maintaining ecological integrity and providing sustainable ecosystem management. Conventional physical and chemical indicators, including pH, dissolved oxygen, biochemical oxygen demand, nutrients, and conductivity can provide the desired information on water quality; however, they cannot completely depict the biological effects of ecological stress. Some physiological indicators, including fish behavior, condition factor, biomarkers of oxidative stress, blood changes, and histopathological changes, act as sensitive indicators of pollution. Biological indicators, including plankton, macroinvertebrates, aquatic plants, and amphibians help establish long-term ecological conditions.

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Conflict of Interest

The author declares that there are no conflicts of interest regarding the publication of this review article.

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