CHAPTER 2

REVIEW OF LITERATURE

2.1 THEORITICAL REVIEW

Wetlands are ecosystems that exist in various climates, spanning a broad spectrum of latitudes and elevations across the globe. These ecosystems are distinguished by the presence of water within and above the underlying layer for a significant portion of the period in which plants grow, which can be either permanently or periodically saturated in the ground. The water can have varying levels of salinity, ranging from fresh to brackish or saline. It can be either stagnant or free-flowing, and it can originate from different sources such as surface water bodies like rivers, lakes, or oceans, or solely from direct precipitation over the area, or even from groundwater discharge. The surface water quality of a wetland is determined by its environmental characteristics, such as its landscape, topography, geology, and vegetation, along with climatic factors and anthropogenic influences that shape its physical and chemical characteristics[1].

Wetlands harbours rich biodiversity ranging from only a few to an extensive range of diverse species, varying in size from microscopic to gigantic flora and fauna. The integration of all these biotic and abiotic components offers significant advantages to the health of the environment, biodiversity, and well-being of human beings. Wetland areas have played a crucial role in human history since they have served as vital water sources, contributing to the growth and development of different civilizations. Moreover, some societies worldwide attribute a substantial degree of cultural and spiritual significance to them. Thus, natural wetlands serve as hotspots for biodiversity, providing ecological functions like flood and water control, water purification, carbon sequestration, storm prevention, groundwater recharge, nutrient and waste absorption, and supporting fisheries. These functions, in another way, provide other benefits like protection or support of economic activities and property[2]. In addition to being utilized for recreation and water transportation, their various resources can be exploited for agriculture, fishing, hunting, wood products, and water supply[3]. They play a critical role in climate change too. Wetlands store significant amounts of carbon in their vegetation and soils, playing a vital role in regulating the global climate by reducing atmospheric CO_2 levels. Through their role as natural water filters, wetland areas contribute to the improvement of water quality in rivers and lakes further downstream by capturing pollutants, sediments, and important nutrients. Wetlands, in addition to being useful for maintaining biodiversity, offer essential habitats for the breeding, feeding, and nesting of an array of species, including a significant number of rare and endangered plant and animal species.

2.2 WETLAND FUNCTIONS AND SERVICES

In the year 2023, Eyvaz and Albahnasawi[4] presented a comprehensive overview of the most important characteristics, functions, and values of wetland ecosystems, as well as their global distribution, threats, and the challenges that they face in terms of conservation and management. The Millennium Ecosystem Assessment (2005)[5] elaborates well on the various ecosystem services provided by wetlands, which are categorized into four categories—provisioning, regulating, cultural, and supporting services. These services cater to the varied requirements of humanity and other living organisms on Earth, and they contribute to the preservation of a harmonious ecosystem. Finlayson et al. (2005)[6] also examined the ecosystem services provided by various types of wetlands and highlighted significant variations between them. However, defining the ecosystem services of wetlands and assigning them a tradable value still poses a challenge[7].

1) A value for an ecosystem function is significantly more difficult to assign than a value for its structural attributes;

2) The appropriate indicators or metrics to evaluate functions are as challenging to select as the appropriate methodologies to quantify them;

3) There is neither sufficient data nor a proper framework to analyze it.

4) The value of the service depends on its scale and magnitude in each specific geographical location; and

5) Uncertainties rise as one project goes further into the future since many ecosystem services reflect non-linear processes.

2.3 WATER QUALITY

Water in its liquid state is essential for the survival of living organisms on Earth. All living organisms, regardless of their shape and size, require water throughout their lifespan, whether they live in a terrestrial or aquatic setting. But for species that live in water, things like pH, turbidity, dissolved oxygen, salinity, electrical conductivity, nutrient levels, and harmful substances in the water are very important for their survival and show how good the water is. These features directly or indirectly affect various water-related processes, and their presence in natural and wastewater is influenced by the physical, chemical, and biological activities happening in water bodies.

Several researchers investigated the physico-chemical and biological characteristics of water and lakes, rivers, and ponds across the globe. Some studies to be mentioned like, surface water quality in Tehran[8]; plankton diatoms in Bass island area of Lake Erie[9]; bacteriological aspects of pollution in the Jukaskei- Crocodile river system in the Transvaal, South Africa[10]; bacteriological characteristics of water in the river Nida, Poland[11]; spatial distribution of the phytoplankton in a Lake Lanao, Philippines[12]; water quality monitoring in the Rous River catchment, NSW, Australia[13];water quality monitoring in the Rous River catchment[14]; river water quality Shibetsu River, Shibetsu area and Bekkanbeushi River, Akkeshi area[15]; seasonal variations in water quality Odiel River in South West Spain (Olias et al., 2004)[16] and Hickel (1973)[17] conducted limnological investigation in lakes of Pokhara Valley, Nepal.

Substantial numbers of reports are available on the ecological studies of river and lake ecosystems in India. Banerjee et al. (1999)[18] studied the surface water quality of the Brahmani river system in Odisha by applying statistical tools; Patil and Panda (1997) [19] conducted limnological studies on abiotic factors of a freshwater fish tank in Bibinagar, Andhra Pradesh; Bhuvaneswaran et al. (1999)[20] examined the water quality of the Adyar River in Chennai; Chandra et al. (1996)[21] monitored the quality of the Ramganga waters of Bareilly; Rao et al. (1994)[22] investigated sewage pollution in the high-altitude Ooty Lake; Singh et al. (1994)[23] investigated surface and groundwater quality of Kawar Lake area, Begusarai, Bihar; Munawar (1970)[24] studied freshwater ponds of Hyderabad; Patil and Sen (1983)[25] studied various water quality parameters in a high-altitudinal reservoir, Shillong, Meghalaya; Rao (1972)[26] conducted an ecological study of three freshwater ponds in Hyderabad; Zutshi and Khan (1977)[27] conducted a limnological investigation of two subtropical lakes; and Zutshi and Vass (1973)[28] studied variations in the water quality of some Kashmir lakes. Several physico-chemical parameters of water of different water bodies were studied by different scientists. Zutshi et al., (1980)[29] investigated physico-chemical and biological features of water of the lake of lower Siwalik Himalayas and high mountains of the Kashmir Himalayas; Chakravarthy et al., (1959)[30] studied physico-chemical conditions of the river Yamuna at Allahabad; Chatterjee (2000)[31] examined physico-chemical studies of water quality of the river Nunia of West Bengal; Das et al., (1997)[32] examined seasonal variation in physicochemical parameters in the Mahanadi estuary; Dasgupta and Purohit (2001)[33] conducted physico-chemical parameters to examined the status of surface and groundwater quality of Mandiakudar in Orisha; Desai, et al., (1995)[34] examined physicochemical characteristics of Khandepar river, Goa; Gambhi (1999)[35] studied physico-chemical and biological characteristics of water of Maithon Reservoir of Jharkhand.

Misra et al. (1975)[36] examined diurnal variations in physicochemical factors at Padamsagar reservoir during the premonsoon period of the year; Naik and Purohit (1996) [37] looked at the physical and chemical properties of some community ponds in Rourkela; Singh et al. (1999)[38] studied the physical and chemical features of water in the upper parts of the Damodar River; and Singh and Gupta (2004)[39] examined the physical and chemical properties of the Yamuna River water.

Climate elements such as temperature and precipitation influence seasonal variations in water quality. These variations are further intensified by both human activities and natural processes, as documented by Vega et al. (1998)[40] and Barakat et al. (2016)[41]. Through the examination of these factors, scientists and environmentalists are able to evaluate the overall state of aquatic ecosystems, assess the appropriateness of water for different purposes, and identify possible contaminants. According to Khatri and Tyagi (2014)[1], water quality is determined by comparing the physical, chemical, and biological characteristics of the water to a set of standards. This procedure allows for the determination of whether the water is safe for environmental use or consumption.

Factors such as the overall hardness and pH levels can have an impact on the quality of drinking water. Divalent cations, primarily calcium and magnesium, cause the overall hardness of water, which we measure in terms of equivalent calcium carbonate. Water hardness is often classified into two categories: calcium hardness and magnesium hardness. Hard water can result in the accumulation of scale in plumbing systems when it is heated or its pH level rises[42]. Additionally, it may lower the effectiveness of soaps and detergents. On the other hand, severe pH levels can induce gastrointestinal problems in human health (WHO, 2011)[43].

Drinking water should possess a pH level ranging from 6.5 to 8.5. According to Boyd (2000)[44], fish and other aquatic organisms flourish within the particular pH range of 6.5 to 9 and necessitate sufficient levels of dissolved oxygen (DO). Dissolved oxygen refers to the oxygen concentration in aquatic environments. A minimum level of approximately 4 mg/L is necessary for the survival of living organisms. Fishes experience fatality when the dissolved oxygen (DO) content reaches 3 mg/L, as stated by Novotny (2002)[45]. On the other hand, Bunn et al. (2010)[46] utilized the daily variation in DO levels as a measure of stream health. A low concentration of dissolved oxygen in water signifies contamination and plays a crucial role in water quality assessment, pollution reduction, and treatment procedures. The dissolved oxygen concentration in a saturated solution changes depending on the temperature of the water and the elevation.

Turbidity measures how much water loses its transparency due to the existence of organic matter, tiny particles, sediment, phytoplankton, non-organic materials, colored organic compounds, algae, and other small organisms[47]. Suspended particles help to increase turbidity through absorption of light, while nutrients promote phytoplankton growth, which also absorbs light and consequently leads to an increase in turbidity [48]. Suspended particles absorb or scatter downwelling light, causing turbidity in the water column[49]. Electrical conductivity (EC) is a quantitative assessment of water's capacity to transmit electric current, which indicates the presence of ions in the water. It serves as a significant measure of the quality and salinity of water. Elevated electrical conductivity values indicate increased concentrations of dissolved salts, which can have a negative impact on both plant growth and soil qualities[50]. Conductivity is directly proportional to the concentration of dissolved ions[44]. Shallow lakes can use the electrical conductivity of their water as an indicator of pollution. It is directly related to the total dissolved solids (TDS) present in the water, which in turn reflects the concentration of pollutant ions in the lake water[51]. On the other hand, salinity is the measure of the amount of dissolved salts in water. It may adversely influence the structure of soil, the growth of plants, and life in aquatic environments. Saline water commonly arises from natural phenomena or human actions such as irrigation and industrial discharges[52]. Increased salinity levels can result in soil degradation and decreased agricultural output[50]. The alkalinity of water is a crucial factor, as productivity is directly linked to alkalinity due to the correlation between alkalinity, pH, and carbon availability. According to Moyle (1949)[53], waters having total alkalinity concentrations between 0 and 50 mg/L are typically less productive than those having concentrations between 50 and 200 mg/L.

2.4 WETLAND CARBON SEQUESTRATION

Since water saturation creates anaerobic conditions, wetland ecosystems are so productive that they can generate enormous amounts of organic matter and store it in the soil in a semi-decomposed state (Gorham, 1991 [54]; Collins and Kuehl, 2001 [55]; Mitsch and Gosselink, 2007 [56]). It has been reported that wetlands are good sequesters of carbon and estimated to contain 350-535 Gt of carbon corresponding to 25-30% of the world's organic soil carbon [54], and wetlands in tropical climate regions exhibit the highest carbon sequestration rates. Microbes sequester carbon as organic matter, decompose it, and then release it back into the atmosphere. Microbial growth and metabolism carry out the decomposition; they obtain energy from the oxidation of organic substances through the use of electron acceptors in metabolic pathways. For deeper understanding of carbon sequestration in wetlands, it is necessary to understand the factors that affect carbon decomposition and mineralization. The sequestration of carbon by wetlands depends on the scale and magnitude of each geographical location[57]. Researchers find that tropical wetlands have a higher capacity to store carbon compared to wetlands in temperate and cold regions. Humid tropical wetland in Costa Rica was found to accumulate 255 g C m^{-2} per year in the past 42 years, which is 80% more than a similar temperate wetland in Ohio that accumulated 142 g C m^{-2} per year over the same period[58]. Sequestration of carbon also varies widely depending on the wetland hydrogeomorphic type and landscape position[59]. Soil organic matter-decomposing microbes emit carbon in the form of CO_2 and CH_4 during the decomposition process. So, if the decomposition process can be regulated, the emission of greenhouse gases can also be regulated. For this, the presence of newly synthetic compounds ranging from simple halogenated hydrocarbons to complex polymers in wetland soils, which are slowly degradable, is of great concern[60][7].

Microbial activities that decompose organic matter depend on substrate availability and temperature, as well as oxygen[7]. The way organic matter breaks down is slowed down by the physical protection of organic particles in clumps, a shortage of nutrients that limits microbial activity, and a high amount of hard-to-break-down organic compounds like lignin, which leads to more organic matter building up in the soil[61][62][63]. During the decomposition of organic matter, microbes leave behind some recalcitrant compounds that they cannot further degrade efficiently[64][65]. The more recalcitrant the compounds are, the more enzymes are required to degrade them. The energetic cost for the microbial community increases as they break down recalcitrant compounds into simpler, more degradable units[7]. Anaerobic conditions also limit enzyme activity, as microbes like phenol oxidase, which can degrade recalcitrant phenolic organic compounds, cannot degrade further due to lack of oxygen, thus reducing the decomposition of soil organic matter.

Changes in wetland equilibrium, such as in hydrological regime, could increase soil aeration, thereby increasing degradation. Wetlands with sulphur prevent solubilization of carbon, thereby protecting degradation of soil organic matter; that is why saline and brackish wetlands are more efficient in sequestering carbon compared to freshwater wetlands[66][7]. The wetland's vegetation and flooding duration should be managed to enhance the wetland's inherent capacity to store carbon and therefore maintain other valuable wetland functions and ecosystem services[59].

Accretion rate, or deposition rate of sediment, is one of the main factors for measuring carbon sequestration in wetlands. For this purpose, there are some commonly used methods: a) soil dating, b) direct measurement, and c) use of Net Ecosystem Exchange (NEE). Soil dating is used for determining long-term accretion rates. The most common method is radiometric dating using 137Cs and 210Pb[67]. In direct measurement, marker horizons, the sediment trap method, and the sediment erosion table (SET) are used. Marker horizons are made using clay or brick dust, glitter, sand, and feldspar[64][68][69][70]. In the sediment erosion table, a set of adjustable pins is used for measuring the height of sediment. Higher carbon sequestration rate is seen at intermediate accretion rate[7].

Despite the grave worry about the role wetlands play in global carbon sequestration, little study has been done on wetlands because of a lack of fundamental knowledge, information regarding carbon turnover, and temporal dynamics in the global carbon cycle.

There has been some research on wetland carbon sequestration in India. Researchers found a high annual carbon stock in the tropical mangrove forest of Sundarban. Accumulation of carbon in plant biomass was 4.71–6.54 Mg C ha^{-1} a^{-1}, and carbon sequestration in live biomass and sediment was found to be 1.69 Mg C ha^{-1} a^{-1} and 0.012 Mg C ha^{-1} a^{-1}, respectively[71]. Another study in two wetlands of Pondicherry reported that the presence of calcium carbonate affects the presence of organic carbon, while the presence of phosphate facilitates organic matter content in sediments[72]. This evidence indicates that the presence of other compounds influences the organic matter content in the sediment. Types of vegetation also affect carbon sequestration in wetlands. Pal et al. (2017)[73] reported the carbon sequestration efficiency of different wetland macrophytes in Kolkata. It was observed that 1.17 kg C m^{-2} yr^{-1} of carbon was captured by marginal aquatic plants, out of which 0.74 kg C m^{-2} yr^{-1} was captured by *Phragmites karka, Eichhornia crassipes* and *Typha angustifolia*.

In the mangroves of the coastal region of Gujarat, the carbon sequestration potential of soil (5.87 million tons) was found to be greater than that of mangrove plants (2.24 million tons) [74]. High concentrations of anions like fluorine, chlorine, phosphate, and sulphate have both positive and negative impacts on carbon sequestration. Variations in concentrations of these anions influence the assimilation, mineralization, and sequestration of carbon in the wetland soil[75]. Aquaculture ponds have the potential of burying carbon in their sediment. India has approximately 0.79 million hectares of aquaculture ponds that have the potential to sequester 0.6-1.2 TgC.yr^{-1} [76]. No studies on carbon storage in wetland sediments have been reported from the wetlands of Northeast India except Kangabam et al. (2016)[77]. The study was done in Loktak Lake, where they reported that the soil organic carbon density of Loktak Lake up upto a depth of 10 cm was 0.7-6.57 kg/m^2, with a total carbon sequestration potential of 204,181 tonnes per year.

2.5 VEGETATION IN WETLANDS

There were studies on vegetation analysis on aquatic macrophytes in different wetlands. Studies on the Loktak Lake revealed that around 86 macrophytic plant species were distributed across the lake in different seasons of the year. Dominant species include *Eichhorinia crassipes, Euryale ferox, Nelumbo nucifera, Nymphea pubescence, Nymphoides indicum* and *Trapa natans*. Among the species, 13 macrophyte species were found to be present whole year including *Ceratophyllum demersum, Eichhornia crassipes,* *Euryale ferox, Hydrilla verticillata, Nymphoides cristatum, Pistia stratiotes, Potamogeton crispus, Salvinia cucullata, Salvinia natans, Trapa natans, Urticularia exoleta, Urticularia flexuosa* and *Vallisnaria spiralis*[78][79]. Around 89 species of plants were available in and around phumdis (floating mats)[80]. *Phragmites karka*, *Oryza sativa*, *Zizania latifolia*, *Cynodon spp*., *Limnophila spp*., *Sagittaria spp*., *Saccharum latifolium*, *Erianthus pucerus*, *Erianthus ravennae*, *Lersia hexandra*, and *Carex spp*. are some of the important Phumdis vegetation[79][81]. It was also found that dominant species like *Alternanthera philoxeroides, Cyrtococcum accrescens, Echinocloa stagnina, Fagopyrum simosum, Mikania micrantha, Oenanthe javanica* and *Zizania latifolia* were found throughout the year (Devi and Sharma 2008)[80].

A total of 45 macrophyte species, categorized into 9 groups, were identified through vegetation mapping in 100 lakes of Upper Bavaria[82]. The study also found that abrupt shifts in the macrophyte index could be observed, possibly caused by unidentified wastewater inflows or diffuse sources within the lakes. The Dodi tal lake's littoral zone was found to have a significant proliferation of aquatic macrophytes. The substantial growth of these macrophytes during the spring and summer seasons may be linked to the large number of tourists visiting the area during this time[83]. The growth rates of four macrophytes species that are commonly found in Danish streams were found to be saturated at *in situ* concentrations of inorganic nitrogen and phosphorus, according to a study conducted in a nutrient-rich stream with open-water nutrient concentrations[84]. Additionally, the study discovered that the plants' needs could be met by leaf nutrient uptake alone. A study conducted by Kumar et al. (2022)[85] assessed the nutritional composition of freshwater-cultured macrophytes and found that they are abundant in minerals, as well as n-6 and n-3 polyunsaturated fatty acids (PUFAs). The chemical composition of water chestnut (*Trapa natans*) in terms of essential minerals, proteins, lipids, carbohydrates, vitamins, dietary fibers, secondary metabolites, and antioxidant properties was documented in studies conducted by Ismail et al. (2008)[86], Aleksic et al. (2018)[87], and Mazumdar (1985)[88]. Climate change poses a threat to aquatic-terrestrial ecotones, and the deterioration of the emergent aquatic macrophyte zone would have significant ecological impacts on freshwater, wetland, and terrestrial ecosystems[89]. Lesiv et al. (2020)[90] investigated the ecological properties and functions of macrophytes that are found in aquatic environments. It has been reported that a wide variety of macrophyte species are utilized in a variety of human activities, such as the bioindication of water quality, phytoremediation of contaminated water bodies, and the treatment of wastewater. Based on a literature analysis, it is evident that wetlands are experiencing a rapid decline in total area, despite their vital roles to functions such as hydro-ecological processes, biodiversity and bioresources, and climate change mitigation. Land use change plays a significant role in driving climate change by impacting the levels of greenhouse gasses. Examining wetland areas throughout time is crucial for assessing any changes in wetland size and recognizing their impact on the structural and functional aspects of wetlands. Understanding the role of wetlands in storing carbon for a long time and lowering the concentration of atmospheric carbon to mitigate global warming would be made easier with an estimation of the rate of carbon sequestration and their mechanism in wetlands researched with appropriate methods.

Understanding the critical function of wetlands, it is equally crucial to address threats that adversely impact these invaluable services that we mankind received throughout the year. Wetlands are susceptible to pollution due to their widespread use for wastewater disposal, effectively functioning as a repository for waste. As mentioned earlier the health of the wetlands is being threatened by a number of human-caused factors, including pollution, invasive species, urbanization, increased agricultural production, and climate change. Both anthropogenic activities and natural processes influences the quality of surface water in a region[91][92]. Hence, monitoring of water quality is of utmost importance in the management of water resources at the national level, as well as at the local and regional levels. However, in order to get the desired results that are aligned with the work's objectives, it is crucial to establish a suitable method for sample collecting and a laboratory protocol for analysis. Collecting and analyzing data on different water quality factors at different spatial and temporal scale not only helps maintain water quality but also greatly aids in conservation management. Conservation activities encompass international treaties, national regulations, and community-driven initiatives at local level. Efficient conservation strategies encompass the implementation of legal safeguards, active involvement of the community, and rigorous scientific investigation. Wetlands are crucial for maintaining biodiversity, managing water resources, regulating climate, and providing recreational opportunities for humans. Therefore, it is imperative to protect and restore wetlands in order to achieve sustainable development and services.

2.6 LAND USE AND LAND COVER (LULC) CHANGES IN WETLAND AREAS

Wetlands are valuable ecological resources that play an essential role in the ecosystem of the region, but they are increasingly subjected to various types of LULC changes[93]. Common LULC changes in wetland areas include conversion to agricultural land, which has been observed in numerous wetlands globally[94]. Built-up areas have increased over time due to population growth and infrastructure development, which occupy portions of wetlands and lead to their fragmentation and degradation[94]. Natural vegetation in wetlands has shown a steady decline, as evident in studies of various wetland systems. Flooded vegetation and water bodies in wetlands also experience changes due to alterations in hydrological conditions, often related to climate change and human activities[93]. In some cases, land conversion has transformed wetlands into urban areas through the encroachment upon agricultural land and vegetation cover[95].

Urbanization, essential for modernization, impacts wetland ecosystems by altering hydrology, water quality, and climate. Increased population and industrial activities lead to greater land use and impervious surfaces, disrupting wetland formation and changing their biotic and chemical properties[96].

Converting wetlands to agricultural land significantly reduces carbon sequestration capacity, with intact wetlands storing over twice the carbon of converted farmlands[97]. Cultivation releases large amounts of carbon, transforming wetlands from carbon sinks to carbon sources[98,99]. This conversion also depletes organic carbon in both soil and vegetation, primarily due to drainage, which accelerates decomposition and carbon loss[97].

Vegetation type greatly influences carbon sequestration in wetlands, with the Typha genus showing the highest rates of sequestration[100]. Tree species sequester more carbon than emergent plants, suggesting that integrating trees into wetland designs could enhance carbon storage. Aboveground plant carbon ranges from 49.23 g C m^2 in converted grazing lands to 2066.17 g C m^2 in undisturbed wetlands, emphasizing the need to preserve natural vegetation. Carbon sequestration increases with aboveground biomass and soil moisture but decreases with higher soil temperature[98].

2.6 RESEARCH GAP

Wetlands are recognized as critical ecosystems for carbon sequestration, yet significant gaps persist in understanding the underlying processes, particularly in regions where wetlands are abundant but understudied, such as northeastern India. While global research highlights the need to investigate carbon sequestration potential across diverse wetland types, the wetlands of this region remain largely unexplored. The absence of standardized methodologies for quantifying carbon storage and sequestration rates further limits the ability to make accurate comparisons across different geographic regions. Moreover, long-term monitoring of wetland carbon dynamics is essential to assess the impacts of climate change and land use practices, but such efforts are lacking in this region.

Specifically, limited information exists on carbon turnover and temporal dynamics within wetland sediments in Loktak Lake, a prominent freshwater ecosystem and Ramsar site in northeastern India. Existing studies have largely overlooked the combined influence of water quality variations, sedimentation rates, and land use/land cover (LULC) changes on carbon storage in wetland sediments. The absence of data on the effects of physiochemical changes in water, alongside LULC alterations, limits the comprehensive understanding of carbon sequestration dynamics. Moreover, sedimentation rates, a key determinant of carbon burial efficiency, have not been accurately quantified, leading to uncertainty in estimating the long-term carbon storage potential of these wetlands. Additionally, the contribution of plant types to carbon stocks has been inadequately assessed, despite evidence suggesting that vegetation plays a significant role in enhancing carbon sequestration in wetland ecosystems[73].

Addressing these critical gaps through a comprehensive investigation that integrates the analysis of water quality dynamics, sedimentation rates, LULC changes, and vegetation patterns in Loktak Lake will provide a more nuanced understanding of its carbon storage potential. Such insights will not only advance scientific knowledge of carbon dynamics in wetland ecosystems but also inform the development of evidence-based conservation practices and policy frameworks aimed at preserving and enhancing the carbon sequestration capacity of wetlands in the region.

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