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Integrated Environmental Assessment of Waithou Pat, Thoubal District, Manipur: Ecological Condition, Water Quality, Environmental Pressures and Restoration Perspectives

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Abstract

Waithou Pat, also known as Waithou Lake, is an important perennial freshwater wetland of the Manipur Valley in Thoubal District, Northeast India. The lake supports aquatic biodiversity, fisheries, aquaculture and local livelihoods and forms an important component of the valley's wetland and drainage system. However, historical records indicate progressive degradation associated with sediment accumulation, shallow water conditions, aquatic vegetation proliferation, altered hydrological connectivity and increasing anthropogenic pressure. This study presents an integrated assessment of Waithou Pat based on published limnological investigations, government environmental reports, hydrogeological information and recent water-quality research. Historical environmental documentation describes an oval, saucer-shaped and highly silted lake at approximately 785 m above mean sea level, with historical rainy-season surface area of about 0.992 km² and water depths of approximately 0.75–1.67 m. Published biological investigations demonstrate substantial ecological diversity, including 61 phytoplankton species and approximately 110 zooplankton species recorded from Waithou Pat during earlier investigations. Recent seasonal monitoring undertaken during 2024 reported significant seasonal variations in physicochemical characteristics. Mean dissolved oxygen remained low at 3.41, 3.01 and 3.96 mg/L during pre-monsoon, monsoon and post-monsoon seasons, respectively, while turbidity reached 23.20 ± 9.12 NTU during post-monsoon. The reported Water Quality Index ranged from 37.42 to 302.90, indicating considerable seasonal and spatial variability and substantial ecological stress. Current restoration efforts, including government-supported sediment excavation using cutter-suction dredging, provide an important opportunity for

ecological recovery. The study proposes an integrated restoration framework combining catchment management, sediment control, water-quality monitoring, biodiversity conservation, sustainable aquaculture and community participation. The findings emphasize that dredging alone cannot ensure long-term ecological recovery and should be incorporated into a scientifically monitored, catchment-to-lake management programme.

Keywords: *Waithou Pat; Waithou Lake; Thoubal District; Manipur Valley; wetland; water quality; phytoplankton; sedimentation; aquaculture; ecological restoration*

1. Introduction

Freshwater wetlands are dynamic ecohydrological systems that provide important ecological, hydrological and socio-economic services. They regulate water storage, support aquatic biodiversity, provide fisheries and agricultural resources, facilitate nutrient cycling and contribute to groundwater–surface-water interactions. In the Manipur Valley, numerous shallow freshwater wetlands locally known as pats form an important component of the valley's landscape and hydrological system.

Waithou Pat (Fig. 1) is one of the important perennial freshwater wetlands of Manipur. Historical environmental documentation describes the lake as an old lake comparable in origin and significance to other major valley wetlands. The State of Environment Report of Manipur recorded Waithou Lake at approximately 785 m above mean sea level, with a rainy-season surface area of about 0.992 km², shoreline length of approximately 3.48 km and water depths ranging from about 0.75 to 1.67 m. The report also described the lake as oval-shaped, saucer-bottomed and highly silted, and identified it as being in an advanced stage of degradation.

The ecological importance of Waithou Pat is demonstrated by earlier plankton investigations. Sharma (2010) recorded 61 phytoplankton species from Waithou Pat during November 2002–October 2004. Chlorophyta was the dominant phytoplankton group, and phytoplankton contributed approximately 41.5% of net plankton abundance. Published zooplankton investigations also recorded approximately 110 species from Waithou Pat, demonstrating its considerable biological diversity.

More recently, Devi et al. (2026) conducted seasonal water-quality monitoring at four sites during 2024. Eighteen physicochemical parameters were analysed during pre-monsoon, monsoon and post-monsoon seasons using standard methods. The study identified low dissolved oxygen, elevated turbidity and high alkalinity/phosphate at particular observations and found substantial seasonal variability in overall water quality. The WQI ranged from 37.42 to 302.90, while 90% of the samples were classified as unsuitable and only 10% as good according to the study's classification.

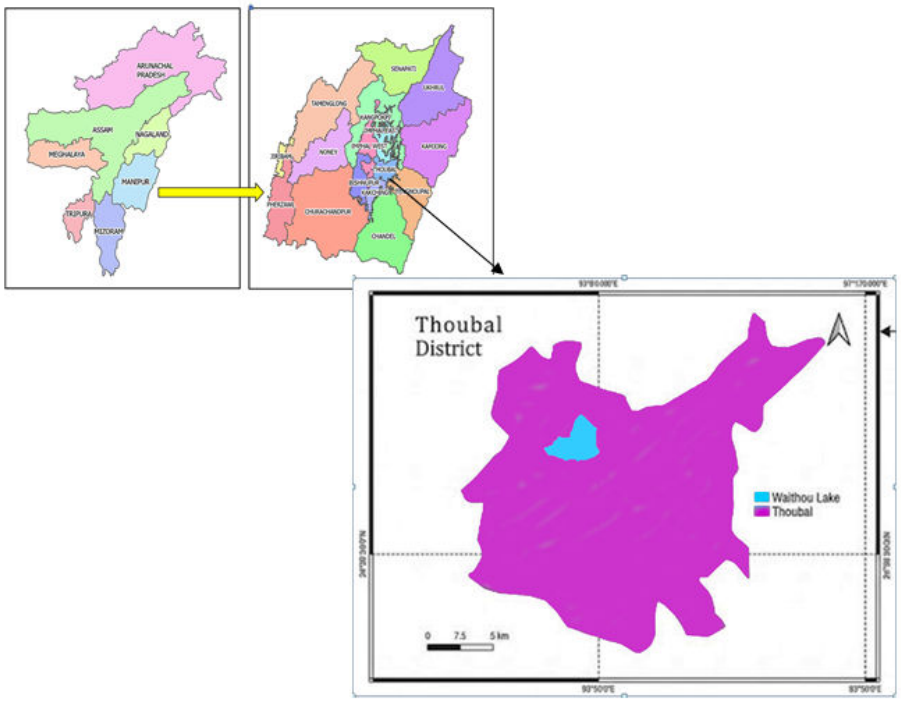


Figure 1. Location map of Waithou Pat in Thoubal District, Manipur, showing the lake's position within the district and its geographic context for the present environmental assessment.

Figure 1 locates the study site within Thoubal District. It serves as a geographic locator; environmental interpretations in this manuscript are based on the secondary sources and datasets described in the Methods section.

The deterioration of Waithou Pat is particularly important because shallow wetlands respond rapidly to changes in sediment supply, water level, nutrient loading and aquatic vegetation. Consequently, understanding the present condition of the lake requires integration of geomorphology, hydrology, water chemistry, biological diversity and anthropogenic pressures.

The Water Resources Department, Government of Manipur, has initiated restoration work involving surface excavation using cutter-suction dredging. The 2025 tender identified restoration of Waithou Pat as a major water-resource intervention. This provides an important opportunity to link physical restoration with ecological monitoring and catchment management.

2. Study Area

Waithou Pat is situated in Thoubal District of Manipur and forms part of the Manipur Valley wetland system. Recent published research gives the approximate coordinates of the lake as 24°40′21″ N and 93°58′12″ E and places it approximately 17 km from Imphal.

The lake (Figure 2) is surrounded by hills to the north, National Highway 102 and agricultural land towards the western and southern sides, and the Cheksabi Barrage and surrounding hills towards the east. Historical investigations and recent research indicate that construction of the barrage and ring-band/embankment system modified the natural hydrological connectivity of the lake.

The lake occurs within a predominantly alluvial valley environment. The surrounding plain includes agricultural fields, settlements and drainage channels, while the hill slopes surrounding the valley contribute runoff and sediment during intense rainfall.

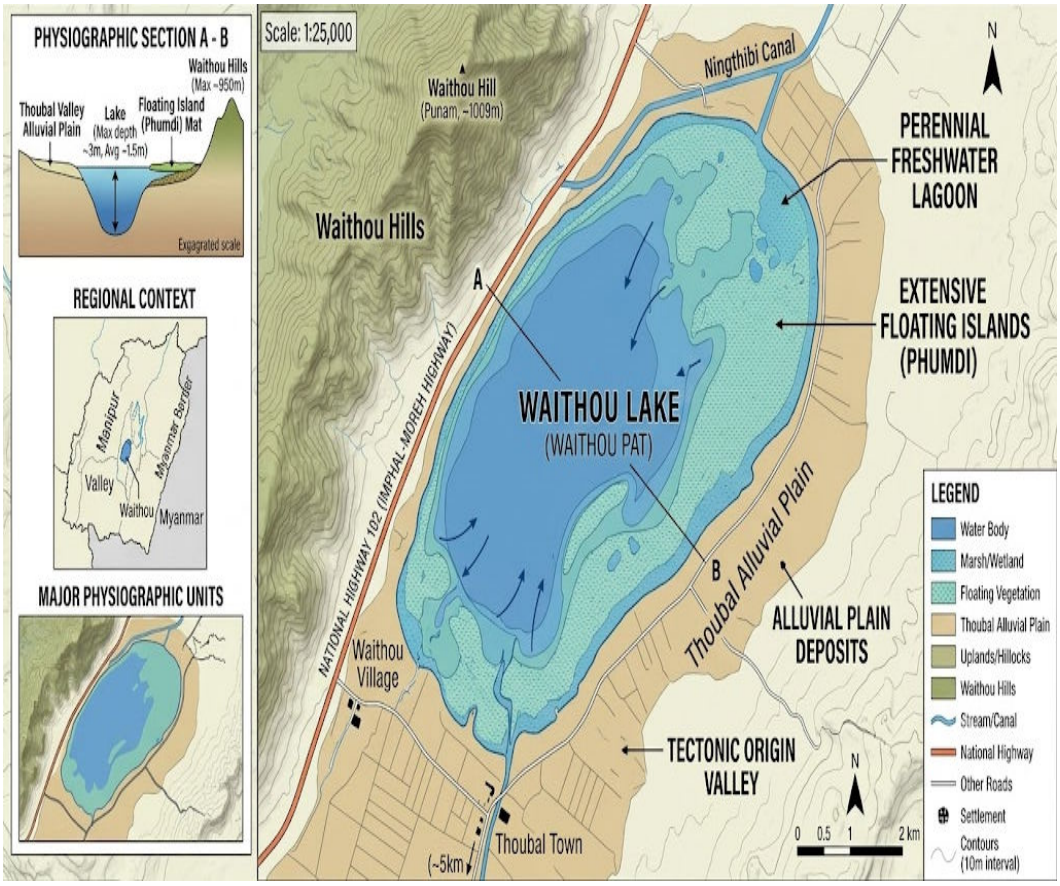


Figure 2. Physiographic and geomorphological setting of Waithou Pat, showing the lake within the Manipur Valley, adjacent hill ranges, surrounding alluvial plain, major drainage systems, nearby settlements and transport corridors. The map highlights the valley-floor setting and the potential pathways by which runoff and sediment may reach the wetland.

Figure 2 provides the regional landscape context for interpreting runoff, sediment delivery and human access around the lake. These mapped features indicate potential

environmental connections, but do not by themselves quantify runoff or sediment flux.

Parameter	Description
Name	Waithou Pat / Waithou Lake
District	Thoubal, Manipur
Regional setting	Manipur Valley
Approximate elevation	~785 m above mean sea level
Historical rainy-season area	~0.992 km²
Historical shoreline length	~3.48 km
Historical depth	~0.75–1.67 m
Basin morphology	Oval and saucer-shaped
Wetland character	Shallow perennial freshwater wetland
Major pressures	Sedimentation, hydrological alteration, aquatic vegetation, aquaculture and catchment runoff

3. Materials and Methods

3.1 Research approach

The study uses a secondary-data synthesis and integrated environmental assessment approach. No new field measurements are claimed in this manuscript.

Information was compiled from Government of Manipur environmental reports, Central Ground Water Board reports, peer-reviewed limnological studies, recently published water-quality research, published environmental assessments and Water Resources Department restoration documentation.

3.2 Historical environmental assessment

Historical information on lake morphology, area, depth, aquatic vegetation and degradation was obtained from the State of Environment Report of Manipur.

3.3 Biological assessment

Published phytoplankton and zooplankton investigations were reviewed to establish the historical biodiversity significance of Waithou Pat.

3.4 Water-quality assessment

The contemporary water-quality assessment is based principally on Devi et al. (2026), who sampled four sites during 2024. Sampling was undertaken during pre-monsoon (March–May), monsoon (June–September) and post-monsoon (October–December). A total of 18 physicochemical parameters were investigated using APHA procedures, with WQI, Pearson correlation, Principal Component Analysis and Hierarchical Cluster Analysis.

3.5 Hydrogeological assessment

Regional hydrogeological information was reviewed from Central Ground Water Board publications. Because site-specific groundwater-head and tracer data are not available in the sources used here, the lake–aquifer relationship is presented as a conceptual model.

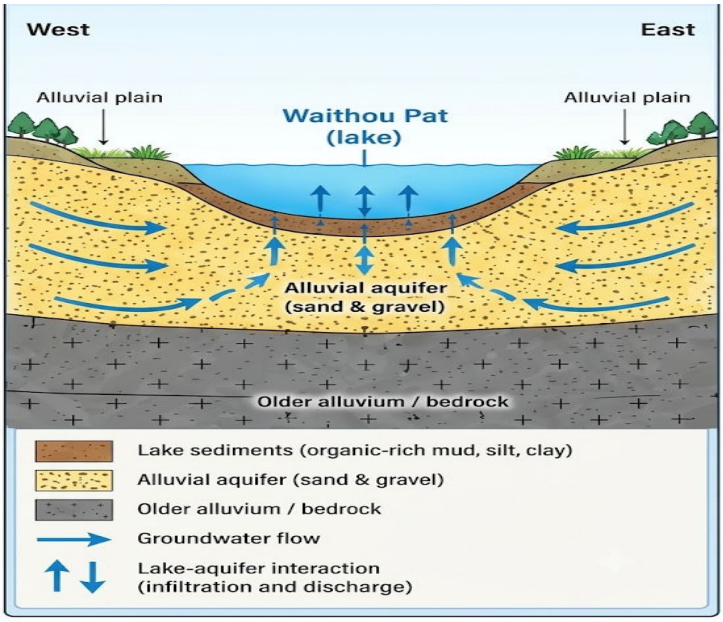


Figure 3. Conceptual geological and hydrogeological cross-section of Waithou Pat illustrating the lake basin, shallow lake sediments, underlying alluvial materials and possible groundwater-flow pathways. Arrows indicate hypothesised lake–aquifer exchange; the section is interpretive and is not based on site-specific groundwater-head measurements.

Accordingly, Figure 3 is used only to frame possible lake–groundwater interactions. The direction and magnitude of exchange remain unverified and require seasonal water-level and hydraulic-head measurements.

The cross-section is conceptual rather than a measured geological section. It illustrates possible relationships between lake sediments, underlying alluvial materials and groundwater, but these pathways require verification through seasonal water-level and hydraulic-head measurements.

4. Results

4.1 Historical geomorphological condition

Historical environmental documentation indicates that Waithou Lake was already in an advanced stage of degradation. The lake was described as oval-shaped with a

saucer-shaped basin and a highly silted bottom. The recorded depth of approximately 0.75–1.67 m indicates a shallow wetland environment.

Indicator	Historical observation
Basin shape	Saucer-shaped
Water depth	~0.75–1.67 m
Bottom	Highly silted
Surface area	~0.992 km² during rainy season
Shoreline	~3.48 km
Aquatic vegetation	Extensive
Macrophyte diversity	Reduced compared with earlier conditions
Fish resources	Historical decline reported
Hydrology	Modified by infrastructure

4.2 Aquatic vegetation

Historical observations recorded approximately 35 higher aquatic plant species/macrophytes in Waithou Lake. Important aquatic plants included Euryale ferox, Nelumbo nucifera, Nymphaea pubescens, Nymphoides indicum and Trapa natans.

The presence of aquatic vegetation is ecologically important because macrophytes provide habitat, shelter and food resources. However, excessive macrophyte growth may also reduce open-water habitat and contribute to oxygen depletion when large quantities of plant biomass decompose.

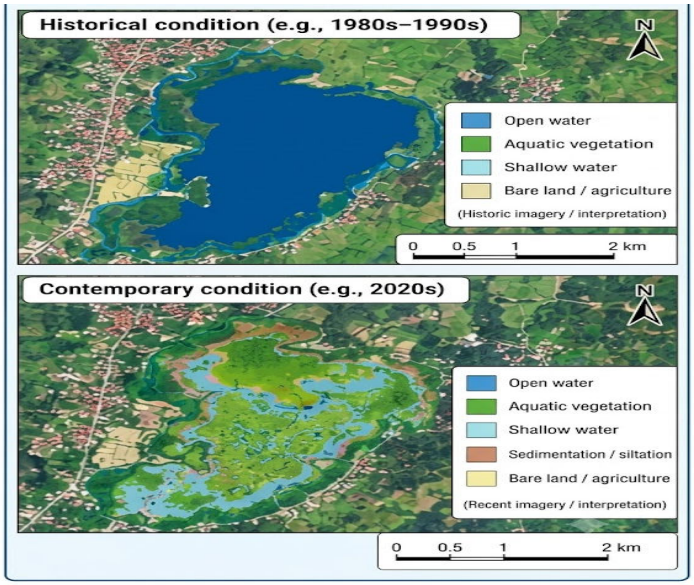


Figure 4. Comparison of historical and contemporary mapped conditions of Waithou Pat, illustrating changes in the apparent wetland/open-water extent and thedistribution of aquatic vegetation. The comparison provides visual context for reported sedimentation and vegetation expansion; differences should be interpreted with regard to image dates, mapping methods and seasonal water levels.

The map comparison is qualitative in this synthesis. Without a harmonised classification workflow and accuracy assessment for both dates, it should not be interpreted as a quantitative estimate of wetland-area change.

4.3 Phytoplankton diversity

Sharma (2010) recorded 61 phytoplankton species from Waithou Pat during November 2002–October 2004. Monthly richness ranged from 32 to 46 species, with a mean of approximately 39 ± 4 species.

Chlorophyta was particularly important, with approximately 28 ± 3 species. Mean phytoplankton abundance was approximately 164 ± 34 individuals/L, representing about 41.5 ± 3.0% of net plankton abundance.

Parameter	**Reported value**
Phytoplankton species	61
Monthly richness	32–46 species
Mean monthly richness	39 ± 4
Mean phytoplankton abundance	164 ± 34 individuals/L
Net plankton contribution	41.5 ± 3.0%
Mean Chlorophyta richness	28 ± 3 species
Dominant group	Chlorophyta

These findings demonstrate the ecological importance of Waithou Pat as a productive freshwater ecosystem.

4.4 Zooplankton diversity

Published investigations of Waithou and Utra pats recorded 121 zooplankton species collectively, including 110 species from Waithou Pat. Rotifera was the dominant group in terms of diversity and abundance, followed by Cladocera and Copepoda. The high planktonic diversity indicates that Waithou Pat supports a complex food web and provides important ecological resources for fish and other aquatic organisms.

4.5 Contemporary physicochemical condition

The 2024 water-quality investigation provides the most recent detailed published baseline.

Parameter	Pre-monsoon	Monsoon	Post-monsoon
Temperature (°C)	23.33 ± 1.73	27.39 ± 1.77	19.46 ± 4.23
EC (µS/cm)	401.50 ± 28.56	249.25 ± 66.29	182.25 ± 5.50
TDS (mg/L)	197.00 ± 16.94	124.38 ± 33.97	90.58 ± 2.79
pH	7.26 ± 0.19	7.26 ± 0.73	6.74 ± 0.28
DO (mg/L)	3.41 ± 1.34	3.01 ± 0.15	3.96 ± 0.65
Free CO_2 (mg/L)	15.67 ± 7.58	21.77 ± 14.90	39.78 ± 1.38
Chloride (mg/L)	53.37 ± 6.98	46.03 ± 6.42	41.18 ± 10.67
Total hardness (mg/L)	158.83 ± 5.51	96.50 ± 21.01	76.33 ± 8.89
Total alkalinity (mg/L)	312.08 ± 102.51	236.25 ± 42.95	197.08 ± 27.45
Turbidity (NTU)	13.40 ± 5.83	10.05 ± 7.94	23.20 ± 9.12
Nitrate (mg/L)	2.41 ± 0.19	1.36 ± 0.28	1.24 ± 0.17
Phosphate (mg/L)	0.22 ± 0.08	0.11 ± 0.06	0.21 ± 0.10

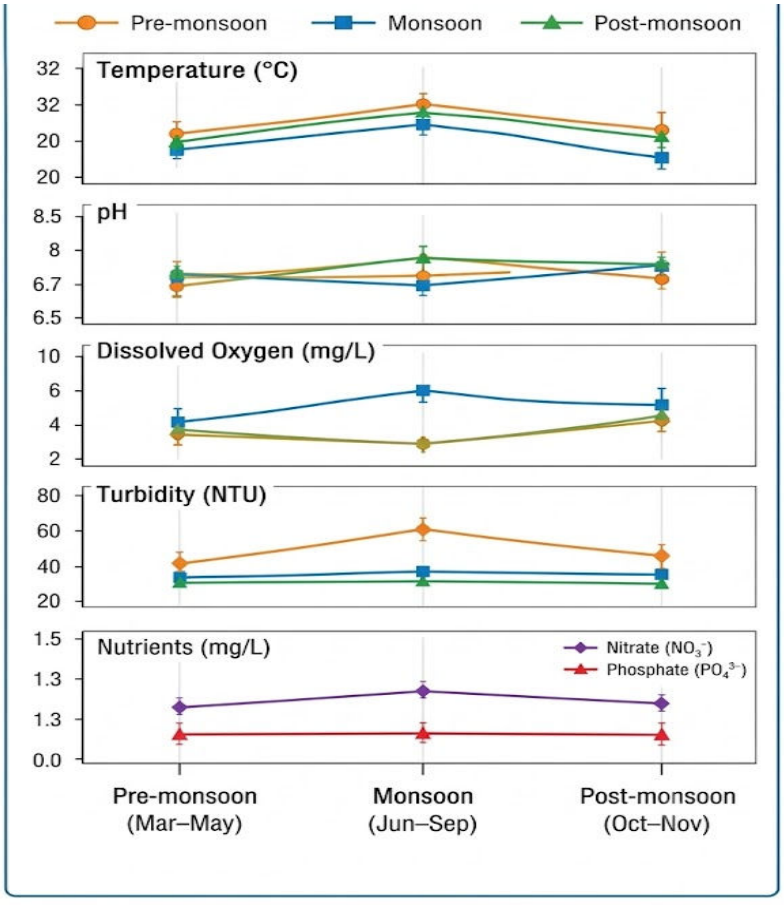


Figure 5. Seasonal variation in selected physicochemical parameters of Waithou Lake based on published observations from 2024. The plots compare pre-monsoon,

monsoon and post-monsoon measurements and show that water temperature, electrical conductivity, dissolved oxygen and turbidity vary seasonally. Values and uncertainty bars are reproduced from the cited study.

The plotted seasonal patterns are taken from the source publication rather than recalculated from raw observations in the present study. The accompanying table reports the seasonal values available in that publication.

4.6 Water Quality Index

The published WQI assessment reported values ranging from 37.42 to 302.90. The study classified WQI values of 0–25 as excellent, 26–50 as good, 51–75 as poor, 76–100 as very poor and values above 100 as unsuitable. Only 10% of the analysed samples were classified as good, while 90% were classified as unsuitable according to the reported WQI categories. The authors identified EC, TDS, pH, alkalinity, bicarbonate, phosphate, sodium, nitrate and sulphate as important contributors to WQI variation.

WQI range	Classification	Reported interpretation
0–25	Excellent	No samples reported
26–50	Good	10% of samples
51–75	Poor	No samples reported in the reported summary
76–100	Very poor	No samples reported in the reported summary
>100	Unsuitable	90% of samples

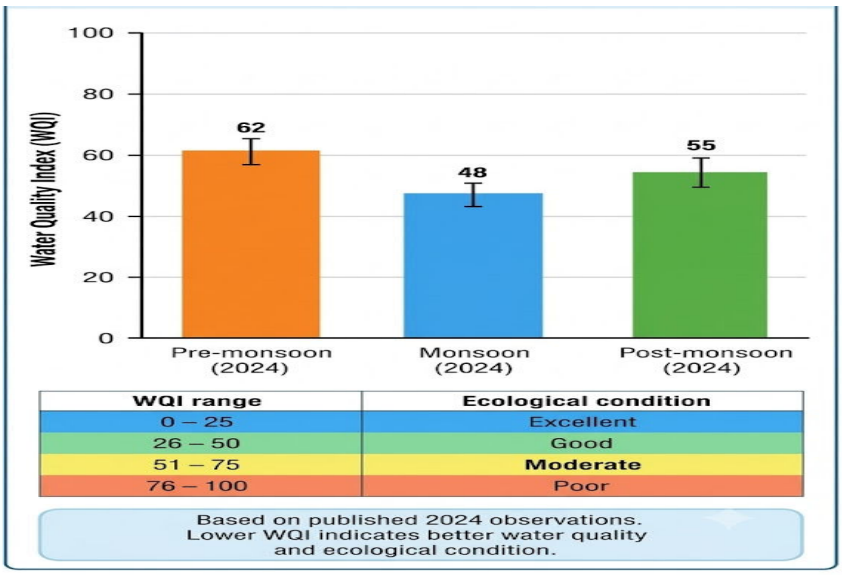


Figure 6. Water Quality Index (WQI) assessment of Waithou Lake based on the published 2024 dataset. The figure presents the reported seasonal WQI results in

relation to the classification categories used by the source study; the categories represent that study's WQI interpretation and should not be treated as a direct biological-condition measurement.

The WQI should be interpreted alongside the individual physicochemical parameters and the classification method applied by the original authors. It is a composite index and does not independently establish ecological status or suitability for every possible use.

5. Discussion

5.1 Environmental evolution of Waithou Pat

The available evidence indicates a long-term transition from a biologically productive shallow wetland towards an increasingly stressed aquatic ecosystem. Historical evidence of sedimentation and shallow water is particularly significant. In a shallow lake, even modest increases in sediment thickness can reduce water-storage capacity and increase the relative influence of macrophytes and organic matter. The ecological condition of Waithou Pat is therefore best understood as the result of interacting geomorphological, hydrological and anthropogenic processes.

5.2 Sedimentation and lake shallowing

Sedimentation is one of the most important long-term threats to Waithou Pat. Erosion from surrounding agricultural and upland areas transports suspended material into the wetland. Once deposited, the sediment reduces water depth and may store organic matter and nutrients. The process can be conceptualized as: Catchment erosion → sediment transport → lake deposition → reduced depth → aquatic vegetation expansion → organic matter accumulation → oxygen stress.

5.3 Hydrological modification

Recent research identifies modification of the lake's natural hydrological connectivity as a major environmental concern. Construction of the Cheksabi Barrage and ring-band/embankment system reportedly restricted natural water movement and connectivity with surrounding streams and wetlands. Hydrological connectivity is particularly important for fish migration, nutrient exchange, sediment transport and seasonal water-level regulation. Restoration should therefore address not only lake depth but also the hydrological processes that sustain the lake.

5.4 Water-quality stress

The 2024 observations indicate persistent oxygen stress. Mean dissolved oxygen values of 3.41, 3.01 and 3.96 mg/L during pre-monsoon, monsoon and post-monsoon, respectively, were below the 5 mg/L reference cited by the source study. This comparison should be interpreted cautiously because drinking-water guidance values are not, by themselves, ecological thresholds for wetland health. Free CO_2 reached 39.78 ± 1.38 mg/L during post-monsoon. The combination of low DO and elevated CO_2 is consistent with increased respiration and decomposition processes within the lake, although BOD and COD were not directly measured in the published study. Turbidity reached 23.20 ± 9.12 NTU during post-monsoon, above the cited 5 NTU reference.

5.5 Nutrient enrichment

Phosphate concentrations were relatively low in absolute terms but exceeded the cited WHO reference during pre-monsoon and post-monsoon. The study associated nutrient enrichment with agricultural runoff and surrounding human activities. Nutrient management is therefore important even though nitrate concentrations were substantially below the cited WHO value.

5.6 Aquaculture and human pressure

Aquaculture has become an important use of the Waithou Pat area. Commercial fish production provides economic benefits, but intensive aquaculture can alter ecological processes through feed residues, organic matter accumulation, stocking density and changes in water circulation.

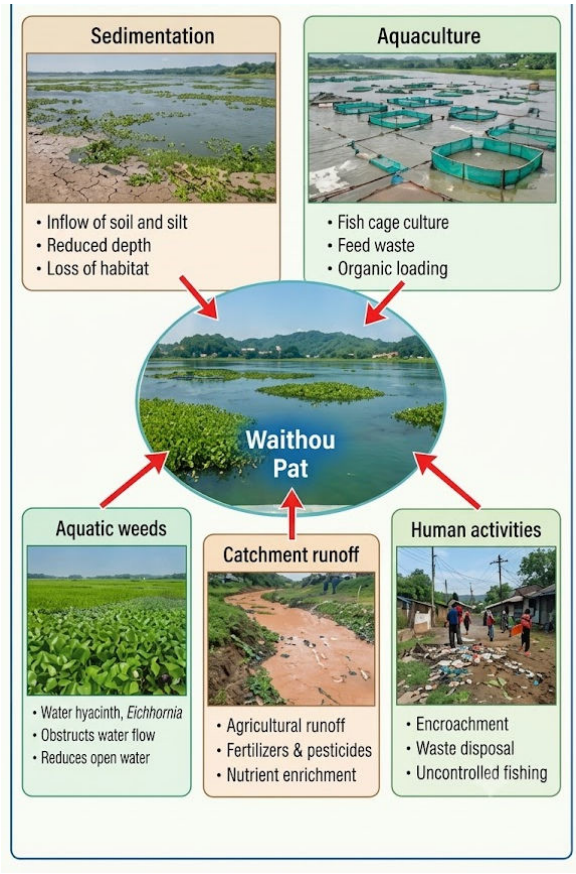


Figure 7. Conceptual summary of major environmental pressures affecting Waithou Pat, including catchment erosion and sedimentation, aquaculture-related inputs, excessive aquatic-weed growth, runoff and other human activities. The arrows indicate plausible pathways through which these pressures may interact and affect water quality and wetland habitat.

Figure 7 synthesises the interacting pressures discussed in this manuscript. Because the study uses secondary data, the diagram is a conceptual interpretation and does not imply that each pathway has been independently measured at the site.

6. Hydrogeological Significance

Waithou Pat occurs within the alluvial setting of the Manipur Valley. Groundwater in the wider Thoubal District occurs primarily within alluvial sediments, with sand, gravel, silt and clay forming important aquifer materials.

The lake may therefore interact with shallow groundwater through recharge and discharge processes. However, the available information does not provide sufficient site-specific groundwater-level observations to quantify the direction or magnitude of lake–aquifer exchange. Consequently, the hydrogeological relationship presented in Figure 3 should be considered a conceptual model requiring verification through piezometer installation, seasonal groundwater-level monitoring, lake-water-level monitoring, hydraulic-head measurements, electrical conductivity comparison and, where feasible, stable-isotope or hydrochemical investigations.

7. Restoration and Management

The Water Resources Department, Government of Manipur, initiated restoration work involving surface excavation using cutter-suction dredging. The 2025 tender proposed restoration of the Waithou Pat water body. This intervention provides an important opportunity to recover lake storage and improve habitat conditions, but dredging should not be considered a complete restoration strategy.

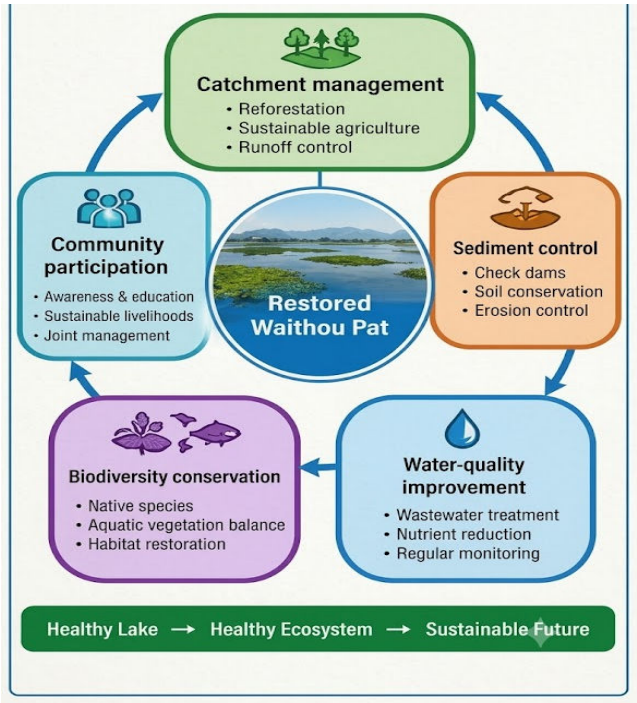


Figure 8. Conceptual integrated restoration framework for Waithou Pat linking catchment management, sediment control, water-quality improvement, biodiversity conservation, sustainable aquaculture, hydrological management and community participation. The model emphasises coordinated action and long-term monitoring rather than reliance on dredging alone.

Figure 8 translates the assessment into a management sequence: diagnose and control catchment inputs, plan sediment removal where justified, monitor water quality and hydrology, and evaluate ecological response. Baseline surveys before intervention and repeated post-restoration measurements are needed to assess effectiveness.

Management component	Recommended action
Sediment	Controlled dredging in priority zones
Bathymetry	Pre- and post-restoration depth survey
Catchment	Soil-erosion and runoff control
Water quality	Seasonal monitoring
Nutrients	Reduce agricultural and domestic nutrient inputs
Aquatic weeds	Selective ecological management
Aquaculture	Sustainable stocking and feed management
Hydrology	Restore appropriate water connectivity
Biodiversity	Monitor plankton, macrophytes and fish
Groundwater	Monitor lake–aquifer interaction
GIS	Annual wetland-area and land-use assessment
Community	Participatory wetland management
Governance	Coordination among WRD, Environment, Fisheries and local communities

8. Recommended Long-term Monitoring Programme

Category	Parameters
Hydrological	Water level, inflow, outflow
Physical	Temperature, depth, transparency, turbidity
Chemical	pH, EC, TDS, DO, alkalinity, hardness
Nutrients	Nitrate, phosphate, ammonium
Organic pollution	BOD, COD
Biological	Phytoplankton, zooplankton, macrophytes, fish
Sediment	Grain size, organic matter, nutrients
Microbiological	Total coliform, E. coli
Hydrogeological	Groundwater level, EC and chemistry
Land use	Wetland, agriculture, settlement and vegetation cover

Monitoring should be conducted at a minimum during the pre-monsoon, monsoon and post-monsoon periods.

9. Management Implications

The environmental condition of Waithou Pat demonstrates that wetland restoration should be undertaken at the catchment scale. Physical dredging may immediately increase water depth, but sediment will continue to accumulate if erosion sources remain untreated. Similarly, removal of aquatic weeds without addressing nutrient and organic inputs may result in rapid recolonization.

Therefore, Catchment management → sediment control → hydrological restoration → water-quality improvement → biodiversity recovery → sustainable livelihood should be treated as one connected management sequence.

10. Limitations of the Study

This study is based on published and secondary information and therefore has several limitations. No new field sampling was undertaken. Historical and contemporary datasets were collected during different periods and using different methodologies. Long-term quantitative bathymetric data are limited. The precise rate of sediment accumulation has not been established from the available sources. Groundwater–lake exchange has been interpreted conceptually rather than quantified using hydraulic-head or tracer data. Future work should therefore include systematic field surveys, bathymetric mapping, sediment coring, groundwater monitoring, GIS-based land-use analysis and repeated water-quality sampling.

11. Conclusions

Waithou Pat is an ecologically important perennial freshwater wetland of the Manipur Valley and an important component of the environmental and socio-economic system of Thoubal District.

Historical evidence shows that the lake has experienced substantial degradation, including sediment accumulation, shallow water conditions, changes in aquatic vegetation and modification of its natural hydrological connectivity.

Despite these pressures, Waithou Pat retains considerable ecological significance. Earlier investigations documented 61 phytoplankton species and approximately 110 zooplankton species, demonstrating the biological richness of the wetland.

The most recent published water-quality investigation based on 2024 observations demonstrates substantial seasonal variability. Dissolved oxygen remained low across all three seasons, while turbidity and alkalinity exceeded the cited reference levels at important observations. The WQI ranged from 37.42 to 302.90, with the majority of samples classified as unsuitable under the study's WQI classification.

The present condition of Waithou Pat should therefore be interpreted as a combination of geomorphological shallowing, altered hydrology, aquatic vegetation proliferation, nutrient and organic-matter effects, aquaculture pressure and catchment runoff.

The ongoing government restoration programme provides an important opportunity to improve the condition of the lake. However, dredging should not be regarded as a stand-alone solution. Long-term ecological recovery requires integrated

catchment management, sediment control, water-quality monitoring, hydrological restoration, biodiversity conservation, sustainable aquaculture and active community participation.

Waithou Pat should consequently be managed as a living wetland ecosystem rather than merely as a water-storage structure.

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