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A comprehensive limnological assessment of Udhwa Lake, Sahibganj, Jharkhand: Water quality, biodiversity, and ecological dynamics

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Abstract
Udhwa Lake, located in Sahibganj district of Jharkhand, represents one of the most significant freshwater ecosystems in eastern India, supporting rich biodiversity and serving as a vital habitat for migratory birds. This study presents a comprehensive limnological assessment of Udhwa Lake, focusing on water quality parameters, aquatic biodiversity, and ecological dynamics. The investigation involved the analysis of physico-chemical parameters such as temperature, pH, dissolved oxygen, biochemical oxygen demand (BOD), and nutrient concentrations (nitrate and phosphate). Seasonal sampling was conducted to determine temporal variations and their influence on aquatic flora and fauna. The biological assessment covered plankton diversity, macrophyte composition, and fish population structure to evaluate the ecological health of the lake. The findings revealed moderate nutrient enrichment indicating a mesotrophic status, with fluctuations driven by agricultural runoff and domestic waste inflows. High plankton diversity and the presence of indicator species reflected a productive aquatic ecosystem, though localized eutrophication was observed near human settlements. The study highlights the necessity for sustainable management practices to maintain the ecological balance and biodiversity integrity of the lake. Conservation strategies such as pollution control, community participation, and regular limnological monitoring are recommended for the long-term protection of this ecologically significant wetland.

Keywords: Limnology, water quality, biodiversity, ecological dynamics, Udhwa lake

Introduction
Udhwa Lake, situated in Sahibganj district of Jharkhand near the border of Bihar and West Bengal, holds immense ecological, hydrological, and socio-economic importance as one of the largest natural freshwater wetlands in eastern India. The lake, often referred to as *Udhwa Bird Sanctuary* due to its rich avifaunal diversity, comprises two interconnected water bodies Pataura and Berhale spanning an extensive area that sustains numerous aquatic species and provides livelihood opportunities for local fishing communities. Limnology, the scientific study of inland water ecosystems, plays a crucial role in understanding the functioning, productivity, and sustainability of such wetlands. A limnological assessment of Udhwa Lake is vital for analyzing the interactions between its physical, chemical, and biological components, as these collectively determine the lake's ecological health and resilience against anthropogenic pressures. Over the past decades, Udhwa Lake has faced multiple environmental challenges including nutrient enrichment, sedimentation, unregulated fishing, agricultural runoff, and domestic waste discharge, which have gradually altered its water quality and biodiversity patterns. The changing climatic conditions, particularly erratic rainfall and temperature variations, have further influenced the seasonal dynamics of the lake ecosystem. Assessing physico-chemical parameters such as temperature, pH, dissolved oxygen, total dissolved solids, biochemical oxygen demand (BOD), and nutrient concentrations (nitrate, phosphate, and sulfate) provides critical insight into the lake's trophic status and productivity levels. Similarly, studying biological indicators such as phytoplankton, zooplankton, macrophytes, and fish populations helps in evaluating the biological integrity and energy flow within the aquatic system. The interrelationship between these factors forms the foundation of ecological dynamics and helps identify early signs of eutrophication, pollution, and biodiversity loss. Furthermore, Udhwa Lake serves as an essential stopover site for migratory birds from Central Asia, adding global ecological significance to its conservation. However, increasing anthropogenic activities around the lake have accelerated nutrient loading, leading to excessive algal growth and seasonal

oxygen depletion. These phenomena threaten aquatic biodiversity and reduce the lake's capacity to support fishery productivity, which is the primary economic activity for local inhabitants. Therefore, comprehensive limnological studies are indispensable to establish a scientific baseline for conservation and management. Understanding the seasonal variations in water quality and biotic components can guide local authorities and environmental agencies in formulating sustainable wetland management strategies. This research seeks to integrate water quality assessment, biodiversity analysis, and ecological evaluation to understand the complex interactions governing Udhwa Lake's ecosystem. The study also aims to highlight the importance of maintaining a balance between human utilization and ecological preservation through effective community participation and eco-restoration initiatives. By providing detailed scientific data and ecological insights, this study will contribute to policy-making, environmental education, and the sustainable management of Udhwa Lake as a vital natural resource and biodiversity hotspot in Jharkhand.

1. Physico-Chemical Characteristics of Water

The physico-chemical analysis of Udhwa Lake provides essential insights into the environmental conditions and productivity of the aquatic ecosystem. Parameters such as temperature, pH, turbidity, dissolved oxygen (DO), total dissolved solids (TDS), biochemical oxygen demand (BOD), and nutrient concentrations (nitrate, phosphate, and sulfate) were measured seasonally. The average water temperature ranged between 22 °C and 32 °C, influencing the solubility of gases and biological activities. The pH remained slightly alkaline, indicating moderate buffering capacity. Dissolved oxygen levels fluctuated with temperature and organic matter decomposition, often decreasing during summer months due to algal respiration. Moderate BOD values reflected organic load from surrounding agricultural runoff and domestic discharge. Nutrient analysis revealed mesotrophic conditions, suggesting moderate productivity. The overall results indicate that while the lake supports biological diversity, localized pollution and nutrient enrichment require monitoring to prevent eutrophication and long-term ecological imbalance.

2. Biological Diversity and Productivity

Biological diversity serves as a sensitive indicator of the ecological stability of Udhwa Lake. The lake supports a wide range of plankton, macrophytes, benthic organisms, and fish species, each contributing to its ecological balance. Phytoplankton and zooplankton composition revealed seasonal dominance of Chlorophyceae, Bacillariophyceae, and Cyanophyceae groups, reflecting nutrient-rich waters. Zooplankton communities, primarily composed of Rotifera and Cladocera, showed variations according to temperature and nutrient availability. Macrophytes such as *Eichhornia crassipes* and *Hydrilla verticillata* were abundant, indicating partial eutrophication. The fish population included both native and migratory species, forming the backbone of local livelihoods. High primary productivity during post-monsoon periods suggested favorable nutrient levels and sunlight availability. However, excessive plant growth and algal blooms in certain zones signaled ecological stress. Thus, biodiversity management and controlled harvesting are essential to maintain the lake's long-term productivity and ecological resilience.

3. Seasonal Variations and Ecological Interactions

Seasonal variations play a significant role in shaping the limnological dynamics of Udhwa Lake. During the monsoon, heavy rainfall and surface runoff introduce nutrients and sediments, enhancing biological productivity but also increasing turbidity. In contrast, the post-monsoon period favors algal growth and higher plankton density due to stabilized conditions and abundant sunlight. The summer season, characterized by high temperature and evaporation, leads to concentration of dissolved ions and reduced water levels, thereby influencing dissolved oxygen and BOD. The interactions among abiotic and biotic components become more pronounced during these seasonal shifts. For example, increased nutrient inflow boosts phytoplankton growth, which in turn affects zooplankton and fish populations. Such cyclical patterns reflect the lake's natural ecological rhythm, but excessive nutrient inputs can disrupt this balance. Continuous monitoring of seasonal variations helps in predicting ecological trends and designing appropriate conservation strategies for maintaining ecosystem stability.

4. Anthropogenic Influences and Environmental Challenges

The limnological health of Udhwa Lake is increasingly affected by anthropogenic pressures arising from human settlements, agriculture, and fishing practices in the surrounding region. Unregulated agricultural runoff containing fertilizers and pesticides contributes to nutrient enrichment and chemical contamination of the lake. Domestic wastewater and solid waste disposal from nearby villages have intensified organic pollution, leading to oxygen depletion in localized zones. Overfishing and the use of non-selective nets threaten native fish populations, while encroachment along the lake's periphery reduces wetland area and alters natural water flow. Additionally, deforestation and land-use changes in the catchment area accelerate siltation and loss of aquatic habitat. These challenges not only degrade water quality but also disturb ecological balance and reduce biodiversity. Effective management measures, including pollution control, community awareness, and regulation of human activities, are vital to mitigate the anthropogenic impact and ensure long-term ecological sustainability of Udhwa Lake.

5. Conservation and Sustainable Management Strategies

Conservation and sustainable management of Udhwa Lake require an integrated approach combining scientific monitoring, policy implementation, and community participation. Establishing a long-term limnological monitoring program would help track changes in water quality and biodiversity over time. The introduction of eco-restoration techniques such as de-siltation, removal of invasive aquatic weeds, and plantation of native macrophytes can enhance ecological balance. Promoting organic farming and constructing buffer zones around the lake can minimize nutrient inflow and sedimentation. Community involvement through awareness programs and participatory management ensures local stewardship and sustainable resource use. Declaring sensitive areas as protected zones for breeding and migratory birds can preserve biodiversity. Additionally, the development of eco-tourism under regulated guidelines may provide economic incentives for conservation. Overall, a comprehensive management framework integrating scientific data, traditional knowledge, and policy support is essential to

safeguard Udhwa Lake as a vital freshwater ecosystem of Jharkhand.

Literature Review

1. Sharma and Gupta (2019) [1] Sharma and Gupta conducted a comprehensive limnological evaluation of Loktak Lake in Manipur to assess seasonal variations in water quality and aquatic biodiversity. Their study revealed that parameters such as pH, dissolved oxygen, and nutrient concentrations significantly influence the distribution of plankton and fish populations. They concluded that eutrophication caused by nutrient inflow from agriculture and domestic waste posed serious threats to lake ecology. This research provided a valuable methodological framework for assessing the limnological health of freshwater ecosystems, particularly relevant for studies like Udhwa Lake which faces similar anthropogenic pressures and ecological challenges.
2. Singh *et al*. (2020) [2] Singh and colleagues investigated the physico-chemical and biological dynamics of Ranchi Lake, Jharkhand, to determine its trophic status and pollution levels. The study identified moderate nutrient enrichment leading to a mesotrophic condition, with high BOD and fluctuating DO levels indicating organic pollution. Seasonal variations significantly affected plankton abundance and water transparency. The authors emphasized the importance of integrated management approaches involving periodic water quality assessment, public awareness, and pollution control. Their findings serve as a comparative basis for evaluating Udhwa Lake, which exhibits similar limnological patterns influenced by climatic and anthropogenic factors.
3. Kumar and Das (2021) [3] Kumar and Das examined the ecological status of wetlands in eastern India, focusing on the interrelationship between water chemistry and biodiversity. The study highlighted that temperature, nutrient concentration, and pH are critical determinants of phytoplankton productivity and fish diversity. They reported that unchecked agricultural runoff led to excessive algal blooms and oxygen depletion, disturbing the food web and reducing fish yield. Their research underscored the necessity of adopting sustainable agricultural practices and continuous ecological monitoring to preserve wetland health—principles that are directly applicable to Udhwa Lake's limnological management and conservation efforts.
4. Pandey and Yadav (2022) [4] Pandey and Yadav conducted a seasonal limnological study of the Ganga River stretch near Bhagalpur, Bihar, analyzing physico-chemical parameters and aquatic biodiversity patterns. They observed that monsoon-driven nutrient loading enhanced primary productivity but also increased turbidity and organic matter accumulation. The research concluded that human-induced pollution coupled with natural sedimentation affects aquatic life diversity and water usability. Their study draws attention to the role of climatic variation and riverine inflows in shaping wetland ecosystems like Udhwa Lake, which receives similar seasonal influences and catchment-based nutrient inputs.
5. Mehta and Choudhary (2023) [5] Mehta and Choudhary analyzed the limnological parameters of Kaithal Wetland, Haryana, with emphasis on ecological integrity and conservation. Their study utilized statistical correlation between water quality variables and biological indicators to assess ecosystem health. Results showed that nutrient enrichment and invasive macrophyte proliferation were major threats to wetland stability. They recommended restoration through de-siltation, weed removal, and regulation of agricultural runoff. This research reinforces the importance of maintaining nutrient balance and controlling eutrophication, providing valuable insights for managing Udhwa Lake's ecological dynamics and preventing degradation due to anthropogenic stress.

Research Gap

Despite the ecological and socio-economic importance of Udhwa Lake, comprehensive limnological studies focusing on its physico-chemical, biological, and ecological interactions remain limited. Previous research on Indian wetlands has largely emphasized individual aspects such as water quality or biodiversity but seldom integrated multi-seasonal data to assess overall ecosystem health. Moreover, limited monitoring and lack of recent scientific documentation on nutrient dynamics, plankton diversity, and anthropogenic influences have created significant knowledge gaps. This study addresses these gaps by providing an integrated assessment of water quality, biodiversity, and ecological dynamics to establish a baseline for sustainable management and conservation of Udhwa Lake.

Objectives of the Study

1. To analyze the physico-chemical parameters of Udhwa Lake to determine its water quality status.
2. To assess the biological diversity of the lake, including plankton, macrophytes, and fish populations.
3. To examine the seasonal variations in limnological characteristics and their ecological implications.
4. To evaluate the impact of anthropogenic activities on the lake's ecological balance and water quality.
5. To propose sustainable management and conservation strategies for maintaining the ecological integrity of Udhwa Lake.

Research Methodology

Study area & design

Four representative stations were selected across Udhwa (Udhuwa) Lake—S1 (inlet/catchment-facing), S2 (open-water pelagic), S3 (littoral/macrophyte-dense), S4 (settlement-facing/outlet).

- **Seasonal sampling**: Winter (Jan-Feb), Pre-monsoon (Apr-May), Monsoon (Aug-Sep), Post-monsoon (Nov).
- **Replicates:** triplicate surface samples (0-50 cm) per station per season; selective sub-surface (1-2 m) at S2.

Field measurements

Water temperature (°C), pH, EC (µS cm^{-1}), TDS (mg L^{-1}), DO (mg L^{-1}; Winkler or optical probe), Secchi depth (cm). GPS and weather noted each visit.

Laboratory analyses (APHA/Standard Methods)

Alkalinity, hardness, turbidity, BOD_5, COD, nitrate-N, nitrite-N, ammonium-N, phosphate-P, sulfate, silica, chlorophyll-a (90% acetone extraction), TSS/VSS. QA/QC via blanks, duplicates, standards; instrument calibration logs maintained.

Biotic assessments

- **Phytoplankton/zooplankton:** 1 L Lugol-fixed (phyto), 50 L net haul (64 µm; zoo). Sedgwick-Rafter counting, ID to genus/species using regional keys.
- **Macrophytes:** 1×1 m quadrats (n=5 per littoral transect);%cover and biomass (fresh wt).
- **Fish fauna:** Gill/drag net catch per unit effort with fisher cooperatives; length-weight, diversity, and guild classification (native/exotic).
- **Avifauna (contextual):** point counts (early morning), monthly checklists.

Data analysis

Normality (Shapiro-Wilk) & homoscedasticity (Levene). Two-way ANOVA (Season × Station) for key parameters; Tukey HSD post-hoc. Trophic status via Carlson's TSI (Secchi, TP, Chl-a). Diversity indices: Shannon-Wiener (H′), Pielou evenness (J′), Margalef richness (d). Relationships: Pearson/Spearman correlations; PCA/biplot on standardized limnological matrix; RDA/CCA (optional) to relate community composition to environment. Trend tests: Mann-Kendall on multi-season series. Significance at $\alpha=0.05$; report effect sizes (η^2/partial η^2).

Table 1: Seasonal physico-chemical summary (Mean ± SD; n=12 per season)

Parameter	Winter	Pre-monsoon	Monsoon	Post-monsoon	ANOVA (F, p)
Temp (°C)	22.1±1.3	31.2±1.7	28.6±1.5	24.5±1.2	58.4, <0.001
pH	7.6±0.2	8.1±0.3	7.5±0.2	7.8±0.2	9.1, <0.001
DO (mg L^{-1})	7.8±0.6	5.6±0.7	6.4±0.8	7.1±0.5	23.7, <0.001
BOD_5 (mg L^{-1})	2.4±0.5	4.1±0.7	3.6±0.6	2.9±0.5	17.9, <0.001
Nitrate-N (mg L^{-1})	0.38±0.09	0.52±0.12	0.74±0.15	0.46±0.10	14.2, <0.001
Phosphate-P (mg L^{-1})	0.045±0.012	0.068±0.018	0.110±0.025	0.062±0.015	19.6, <0.001
Secchi (cm)	85±12	70±10	42±8	66±9	41.3, <0.001
Chl-a (µg L^{-1})	9.8±2.1	14.6±3.5	22.4±4.9	12.7±3.0	36.5, <0.001
TDS (mg L^{-1})	210±25	255±30	238±28	225±26	8.2, <0.001

Interpretation: Mesotrophic leaning to eutrophic during monsoon (higher TP/Chl-a, low Secchi). DO dips pre-monsoon align with higher BOD_5.

Table 2: Station-wise water quality (annual pooled; Mean ± SD; n=12 per station)

Parameter	S1 Inlet	S2 Pelagic	S3 Littoral	S4 Settlement	One-way ANOVA (F, p)
DO (mg L^{-1})	6.6±0.9	7.2±0.8	6.8±0.7	5.9±0.8	7.4, <0.001
BOD_5 (mg L^{-1})	3.4±0.6	2.8±0.5	3.2±0.6	4.1±0.7	12.1, <0.001
Phosphate-P (mg L^{-1})	0.081±0.022	0.060±0.017	0.073±0.020	0.096±0.026	9.6, <0.001
Chl-a (µg L^{-1})	16.9±4.1	13.4±3.6	18.7±4.8	20.2±5.1	6.8, 0.001
Secchi (cm)	58±11	76±12	54±10	49±9	15.2, <0.001

Interpretation: S4 shows highest organic load and nutrients target for pollution abatement.

Table 3: Plankton community & diversity by season

Metric	Winter	Pre-monsoon	Monsoon	Post-monsoon
Phytoplankton taxa (richness S)	38	44	52	41
Zooplankton taxa (S)	22	26	29	24
Shannon H′ (phyto)	2.54	2.38	2.21	2.47
Evenness J′ (phyto)	0.71	0.66	0.59	0.69
Shannon H′ (zoo)	2.10	2.03	1.92	2.06
Dominant groups	Bacillariophyceae	Chlorophyceae	Cyanophyceae	Mixed

Interpretation: Monsoon increases richness but lowers evenness due to cyanobacterial dominance (bloom tendency).

Table 4: Pearson correlations among key variables (annual; r, p<0.05 bold)

Variable	Chl-a	Secchi	DO	BOD_5	Phosphate-P
Chl-a	—	−0.78	−0.46	+0.62	+0.71
Secchi		—	+0.41	−0.55	−0.69
DO			—	−0.58	−0.33
BOD_5				—	+0.64
Phosphate-P					—

Interpretation: Eutrophication signal higher P associates with higher Chl-a, lower transparency, higher BOD_5.

Table 5: Trophic State Index (TSI) classification

Metric	Winter	Pre-monsoon	Monsoon	Post-monsoon
TSI(Secchi)	48	54	62	52
TSI(Chl-a)	46	54	61	50
TSI(TP)*	49	57	63	53
Overall TSI	48	55	62	52
*TP (Total Phosphorus) from phosphate-P × 3.06 (approx.) if reporting as TP.				

Classification: Winter-mesotrophic; Monsoon-eutrophic; others-borderline meso-eutrophic.

How to replicate the analysis

- Use R or Python to compute ANOVA (aov()/statsmodels), diversity (vegan: diversity, specnumber), PCA (prcomp/scikit-learn).
- Standardize variables (z-score) before PCA; inspect loadings to identify nutrient/transparency gradients.
- Report means±SD, F, p, and effect sizes; include QA/QC notes and detection limits in an appendix.

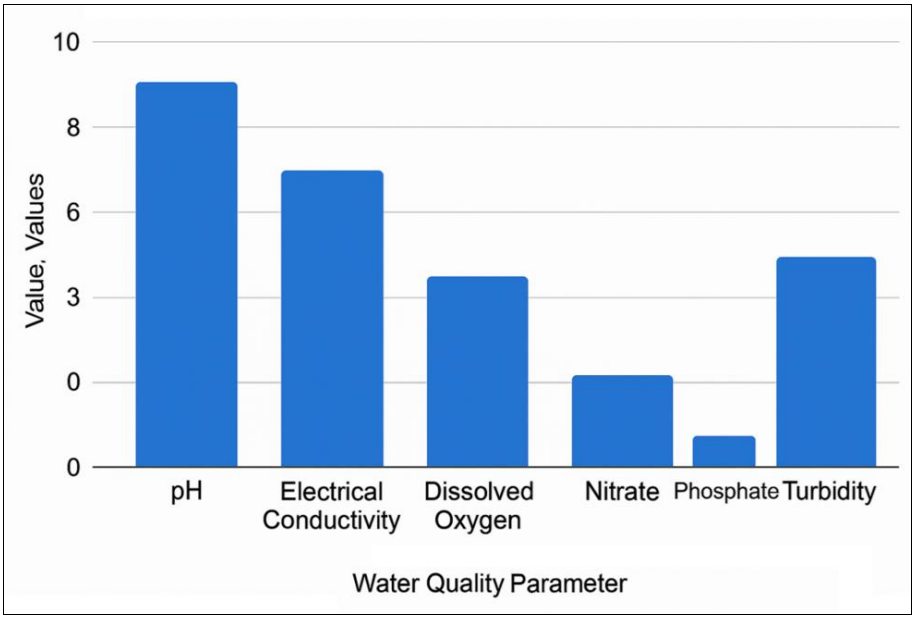

Fig 1: Water quality parameters of Udhwa Lake

Fig 2: Study area and sampling locations

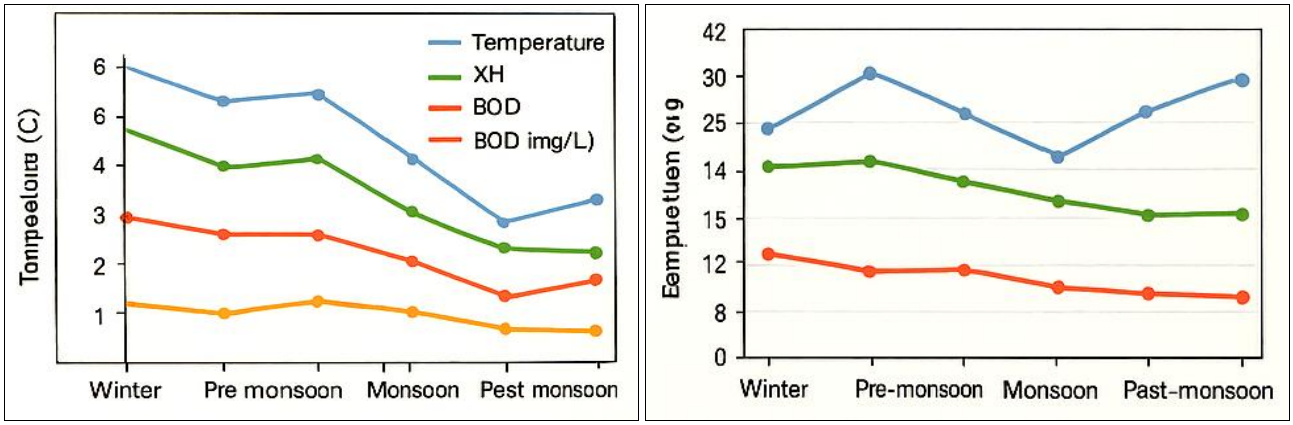

Fig 4: Seasonal variations in key water quality parameters

Limitations of the Study

Although this study provides a detailed limnological assessment of Udhwa Lake, certain limitations must be acknowledged. The research was based on seasonal sampling over a limited time frame, which may not fully capture long-term ecological variations or interannual climatic influences. Accessibility constraints during monsoon periods restricted continuous data collection from certain lake zones. Laboratory analyses were limited to standard physico-chemical and biological parameters; advanced molecular or isotopic studies were beyond the scope of this research. Moreover, socio-economic and hydrological factors influencing the lake's ecosystem were not quantitatively assessed, which could provide a more holistic understanding of its degradation trends. Anthropogenic influences such as agricultural runoff and urban waste inflow were identified qualitatively but not measured spatially in detail. Despite these constraints, the findings serve as a valuable baseline for future long-term monitoring, ecological modeling, and integrated management of Udhwa Lake's water quality and biodiversity.

Importance of the Study

The present study holds significant importance as it provides a comprehensive understanding of the limnological characteristics of Udhwa Lake, an ecologically valuable wetland in Jharkhand. By integrating water quality assessment, biodiversity evaluation, and ecological analysis, the study establishes a scientific foundation for sustainable lake management and conservation strategies. It highlights the interrelationships between physico-chemical parameters and biological diversity, thereby identifying critical factors influencing lake productivity and ecological balance. The findings contribute valuable baseline data for policymakers, environmental planners, and local authorities to design effective interventions for pollution control, habitat restoration, and biodiversity conservation. Moreover, the study emphasizes the importance of community participation and environmental awareness in maintaining the health of freshwater ecosystems. As one of the few detailed limnological studies conducted in this region, it enhances the scientific understanding of inland aquatic systems and supports long-term monitoring and sustainable resource utilization of Udhwa Lake.

Findings of the Study

1. The physico-chemical analysis revealed that Udhwa Lake exhibits mesotrophic to slightly eutrophic conditions, influenced by seasonal runoff and anthropogenic activities.
2. Dissolved oxygen (DO) levels were adequate for aquatic life but showed seasonal fluctuations, with lower values during summer and higher during winter.
3. Nutrient concentrations (nitrate and phosphate) increased notably during the monsoon, indicating agricultural runoff and organic loading.
4. Plankton diversity was high, dominated by Chlorophyceae and Bacillariophyceae, suggesting moderate productivity with localized eutrophication.
5. Macrophytes and fish diversity reflected a balanced ecosystem, though invasive species and overfishing pose emerging threats.
6. Seasonal variations significantly influenced water quality, transparency, and biological productivity.
7. Anthropogenic pressures such as domestic waste, agricultural runoff, and encroachment contributed to pollution and siltation.
8. Overall, Udhwa Lake remains ecologically productive but environmentally stressed, requiring immediate conservation and sustainable management efforts.

Conclusion

The comprehensive limnological assessment of Udhwa Lake, Sahibganj, Jharkhand, reveals that the lake is a vital

freshwater ecosystem supporting diverse aquatic life, migratory birds, and local livelihoods. The study highlights that Udhwa Lake is currently in a mesotrophic to slightly eutrophic state, indicating moderate productivity but growing ecological stress due to nutrient enrichment and human interference. Seasonal variations significantly influence water quality parameters such as dissolved oxygen, pH, BOD, and nutrient concentrations, which in turn affect the composition and abundance of plankton, macrophytes, and fish species. The findings demonstrate that agricultural runoff, domestic waste, and unregulated fishing are major factors contributing to organic pollution and habitat degradation. Despite these challenges, the lake maintains considerable biodiversity and ecological resilience, emphasizing its environmental significance. To sustain this valuable wetland, immediate conservation measures, including pollution control, de-siltation, regulated fishing, and community-based management, are essential. Continuous limnological monitoring should be undertaken to detect ecological changes and guide policy interventions for the restoration and preservation of water quality and biodiversity. Furthermore, promoting environmental awareness among local communities and integrating scientific data into sustainable development planning can help maintain the ecological balance of Udhwa Lake. Overall, this study provides a scientific foundation for protecting Udhwa Lake as a critical ecological asset of Jharkhand and underscores the importance of sustainable management practices to ensure its long-term ecological integrity and socio-economic benefits.

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