Seasonal Variations in Physicochemical Parameters and their Impact on Aquatic Life

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Abstract
Seasonal changes significantly influence the physicochemical parameters of aquatic ecosystems, thereby affecting the health, distribution, and survival of aquatic organisms. This study investigates seasonal variations in water temperature, pH, dissolved oxygen (DO), biological oxygen demand (BOD), turbidity, total dissolved solids (TDS), and nutrient concentrations (nitrates and phosphates) in a selected freshwater body. The results reveal pronounced seasonal fluctuations in all parameters, with summer showing increased temperature and BOD, while monsoon leads to high turbidity and nutrient influx. These variations directly impact aquatic biodiversity, species richness, and the metabolic activities of aquatic organisms. Understanding these dynamics is vital for ecological monitoring and sustainable water management.

Keywords
Seasonal variation, physicochemical parameters, aquatic life, water quality, dissolved oxygen, BOD, ecosystem health

Introduction (Expanded)

Aquatic ecosystems are dynamic environments that support a vast array of biological communities. These systems are heavily influenced by the surrounding climatic and environmental conditions, with seasonal variation playing a fundamental role in shaping their physicochemical structure. Changes in temperature, precipitation, runoff, and solar radiation across seasons significantly influence water chemistry, hydrology, and biotic interactions (Kalff, 2002). Water quality, which is primarily governed by its physicochemical properties, is a key determinant of the ecological balance within aquatic habitats. Parameters such as water temperature, pH, dissolved oxygen (DO), biological oxygen demand (BOD), total dissolved solids (TDS), turbidity, and concentrations of nutrients like nitrates and phosphates serve as essential indicators of water health. These parameters directly impact the metabolic activity, reproductive success, and survival of aquatic organisms (Boyd, 2015; Sharma & Mehta, 2020). Seasonal changes affect these physicochemical parameters in diverse and often predictable ways. For instance, higher temperatures in summer can lead to decreased DO levels and increased BOD, while monsoon seasons are often associated with enhanced runoff, carrying nutrients, sediments, and pollutants into water bodies (Sarkar et al., 2019). Winter typically brings stabilization and clarity to water bodies, along with increased DO levels due to lower water temperatures. Each parameter plays a specific role in maintaining aquatic ecosystem functionality. For example, dissolved oxygen is vital for the respiration of fish and invertebrates, and its depletion—often due to high organic loading or eutrophication—can lead to hypoxic or anoxic conditions, threatening aquatic life (Wetzel, 2001). BOD serves as an indirect measure of organic pollution; its elevation during certain seasons suggests increased microbial activity and organic degradation, which can deplete oxygen and stress biota. Turbidity and TDS are critical during the monsoon, as heavy rains introduce significant quantities of suspended solids and dissolved substances. These changes can affect light penetration, photosynthetic activity, and the feeding behavior of filter-feeders (Khatri & Tyagi, 2015). Furthermore, nutrients such as nitrates and phosphates, often introduced through agricultural runoff, can lead to algal blooms and eutrophication, severely altering aquatic food webs and biodiversity. Many freshwater systems in India and globally experience seasonal deterioration in water quality, especially during summer and post-monsoon months. Studies conducted on the Yamuna and Ganga rivers have shown marked seasonal variation in DO and BOD, with biological implications for aquatic species including economically important fish like *Catla catla* and *Rita rita* (Agarwal et al., 2020; Das et al., 2021). Similar patterns have been observed in pond ecosystemsand reservoirs across Uttar Pradesh, Bihar, and Madhya Pradesh. Temperature is perhaps the most influential seasonal factor, affecting not only the solubility of oxygen but also metabolic rates, growth, and reproduction in aquatic fauna. Warmer temperatures enhance enzymatic activity, but beyond certain thresholds, they can lead to thermal stress and mortality in sensitive species. Cold winter waters, although oxygen-rich, slow down physiological processes, influencing the feeding and reproduction cycles of fish and invertebrates (Beitinger et al., 2000; Gupta & Nandan, 2021). The pH of aquatic systems also experiences fluctuations across seasons, influenced by biological activity (photosynthesis and respiration), decomposition, and inflow of rainwater. Changes in pH can influence the solubility of nutrients and metals, as well as enzyme functioning in aquatic organisms. Fish, for example, are generally adapted to a narrow pH range, and deviations can cause gill damage, metabolic dysfunction, or even death (Tiwari & Mishra, 2019). Anthropogenic activities such as agriculture, industrial discharge, and sewage input often exacerbate the seasonal impacts on water quality. During the monsoon season, surface runoff carries fertilizers, pesticides, and urban pollutants into aquatic systems, causing spikes in nitrate and phosphate levels. This influx can drive eutrophication, leading to algal blooms, fish kills, and loss of biodiversity (Mishra et al., 2022). The response of aquatic life to these seasonal shifts is multifaceted. Phytoplankton and zooplankton communities may fluctuate in abundance and composition, influencing the entire food web. Fish behavior, migration, and breeding are also regulated by seasonal cues and associated changes in water quality (Jana et al., 2020). Macroinvertebrates, which serve as bioindicators, show seasonal patterns in diversity and abundance that reflect the physicochemical conditions of their habitat. Understanding the seasonal variation in physicochemical parameters is thus crucial for aquatic resource management. It provides insights into periods of ecological stress, helps predict harmful algal blooms, and aids in the design of conservation and restoration strategies. Moreover, such knowledge is essential for aquaculture, drinking water supply, and public health management (Patel & Meena, 2021). In the context of climate change, where the frequency and intensity of extreme weather events are increasing, understanding the natural seasonal variability in water quality becomes even more important. Climate-induced shifts in temperature and precipitation patterns are likely to intensify seasonal fluctuations, posing new challenges to aquatic ecosystem stability (Bates et al., 2008; Singh & Awasthi, 2022). This study aims to assess the seasonal variations in selected physicochemical parameters and explore their impact on aquatic life in a freshwater system in northern India. Through comprehensive seasonal monitoring and analysis, the research seeks to identify critical periods of ecological risk, understand the correlation between physicochemical parameters and biodiversity, and propose recommendations for sustainable aquatic ecosystem management.

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Literature Review

The physicochemical properties of freshwater bodies in Uttar Pradesh are significantly influenced by seasonal variations, resulting in dynamic ecological conditions that directly affect aquatic organisms. Numerous region-specific studies have addressed the spatiotemporal variability of water quality, revealing notable patterns linked to seasonal climatic changes and human-induced pressures. Rai et al. (2018) conducted a year-long assessment of the Gomti River and observed pronounced fluctuations in physicochemical parameters such as water temperature, biological oxygen demand (BOD), and nutrient levels. These values peaked in summer due to reduced flow, higher evaporation, and intensified biological activity. Their study highlighted that fish diversity was at its lowest during summer, attributed to thermal stress and decreased dissolved oxygen (DO) levels, both of which negatively impacted fish health and reproductive capacity. In another significant study, Pandey and Tiwari (2019) investigated the Saryu River near Ayodhya and noted that turbidity and phosphate concentrations rose markedly during the monsoon season. This increase was primarily attributed to agricultural runoff and domestic waste input during heavy rainfall. The nutrient enrichment during this period led to episodic algal blooms and localized oxygen depletion, creating temporary but critical threats to aquatic biodiversity, especially for planktonic communities. Yadav et al. (2020) analyzed seasonal water quality in selected lakes of Varanasi and reported that winter months presented the most stable and favorable water conditions, including high DO, low BOD, and reduced turbidity. The researchers observed that these parameters provided optimal conditions for aquatic biodiversity, particularly for invertebrate and vertebrate species. In contrast, pre-monsoon samples showed increased nitrate and total dissolved solids (TDS), which were linked to fertilizer use and low water levels due to evaporation. Srivastava and Mishra (2017) examined seasonal trends in the Varuna River and found that while pH and temperature remained within acceptable ranges, summer witnessed elevated organic loads. This was reflected in increased BOD levels, which adversely affected benthic macroinvertebrate diversity. Their findings reinforced the concept that benthic fauna serve as reliable indicators of organic pollution and ecological degradation under seasonal stress. A study by Kumar et al. (2018) on the Sai River demonstrated the influence of agricultural practices on seasonal water chemistry. Their findings confirmed that nutrient concentrations, particularly nitrates, spiked during the monsoon due to fertilizer runoff, enhancing phytoplankton productivity. However, in stagnant zones or during prolonged dry spells, this led to the onset of eutrophication, which degraded water quality and affected native fish populations. Verma and Singh (2020) investigated the Ganga River near Kanpur and found an inverse relationship between water temperature and DO. During the summer, the combination of high temperatures and increased pollutant loads from industrial and municipal sources led to a drop in oxygen concentration. This directly affected aquatic life, as several fish species displayed stress behaviors and increased mortality, particularly among juveniles and larvae. Tripathi et al. (2019) analyzed a community pond in Prayagraj and recorded the highest turbidity levels during the monsoon. This was attributed to surface runoff carrying silt, organic matter, and agricultural residues. Increased turbidity reduced light penetration and impaired photosynthetic activity, which in turn affected DO levels and altered the trophic dynamics of the pond, especially impacting phytoplankton and primary consumers. Sharma and Prakash (2017) studied the Ghaghara River's seasonal physicochemical status and identified that while pH remained stable, BOD values surged during summer. This indicated high organic load and microbial activity, resulting in oxygen depletion that compromised aquatic species richness. Sensitive species were the first to be affected, suggesting that seasonal stressors could lead to long-term ecological shifts if left unmanaged. Awasthi et al. (2021) focused on aquaculture ponds in the Lucknow district and observed seasonal stress affecting fish yield. Their research demonstrated that DO levels dropped significantly during the hot summer months, and fish mortality increased correspondingly. The study concluded that the combination of thermal stratification, low DO, and high organic load posed severe challenges for fish farming, necessitating the adoption of adaptive aeration and water quality management techniques. Mishra and Singh (2022) conducted a study on the Yamuna River near Etawah and highlighted that turbidity and TDS values escalated during the monsoon due to sediment-laden runoff. These conditions impaired the gill function and feeding efficiency of native fish species such as *Catla catla*, suggesting a decline in physiological health linked to seasonal water quality deterioration. In Ramgarh Lake, Gorakhpur, Gupta et al. (2019) documented that nutrient levels—particularlynitrates and phosphates—varied significantly with seasons. Post-monsoon sampling revealed reduced nutrient concentrations, accompanied by increased zooplankton abundance and improved water transparency. This indicated a gradual ecological recovery following monsoon-induced disturbances, highlighting the lake's resilience and the importance of post-monsoon monitoring. Chaturvedi and Dubey (2020) reported that urban and cultural practices exacerbated seasonal variation effects in ponds across eastern Uttar Pradesh. During festivals, especially in the post-monsoon period, idol immersions and increased waste dumping intensified organic pollution and altered the physicochemical profile of the water bodies. These disturbances led to sudden changes in pH and BOD, impacting resident aquatic fauna, particularly invertebrates and amphibians.

Finally, Srivastava et al. (2022) assessed seasonal changes in the Assi River and found that water quality deteriorated most during the pre-monsoon season. The decline was linked to reduced river discharge and accumulation of waste, which elevated BOD and nutrient levels. The researchers emphasized that such seasonal patterns necessitate localized waste treatment and the restoration of riparian vegetation to buffer the effects of seasonal stress on aquatic ecosystems.

Methodology

The methodology adopted in this study was carefully structured to investigate the seasonal variations in physicochemical parameters and their subsequent impact on aquatic life within a representative freshwater lake located in Uttar Pradesh. A longitudinal design was selected to ensure the inclusion of all four distinct seasons—summer, monsoon, post-monsoon, and winter—allowing for a comprehensive understanding of temporal water quality dynamics. The freshwater lake chosen for the study lies on the periphery of Lucknow, a region representative of the Indo-Gangetic plains with a subtropical climate. This site is subjected to a range of natural and anthropogenic influences including seasonal rainfall, agricultural runoff, and varying solar intensity. Previous studies by Tiwari et al. (2020) and Verma and Singh (2019) demonstrated that such lakes in Uttar Pradesh often exhibit pronounced physicochemical shifts across seasons, making them ideal for ecological assessments. Fieldwork was conducted over a continuous 12-month period from January to December 2022. Water samples were collected on a monthly basis to capture the subtle and extreme changes brought about by seasonal transitions. This sampling frequency aligns with the recommendations of Kumar and Rai (2021), who emphasized monthly intervals for detecting biogeochemical fluctuations in the ponds and rivers of eastern Uttar Pradesh. Samples were collected using 1-liter glass bottles that were pre-cleaned with distilled water and sterilized to prevent contamination. Water was drawn from three different points of the lake—nearshore, center, and the opposite bank—to account for spatial heterogeneity. Each sample was taken at a standard depth of approximately 30 cm below the surface. This method was informed by the work of Singh and Kumar (2020), who found that the epilimnetic layer of lakes i n Barabanki holds the highest biological activity and is most vulnerable to temperature and oxygen variations. On-site measurements

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of temperature, pH, and dissolved oxygen were conducted immediately after sample collection using calibrated handheld digital meters. Delays in measurements were avoided to ensure the accuracy of volatile parameters like DO and pH. This approach was validated by Pandey et al. (2018) in their research on the Gomti River, where discrepancies in DO values were found when samples were not analyzed immediately. Laboratory-based analysis focused on parameters that are sensitive to seasonal dynamics, including BOD, turbidity, total dissolved solids (TDS), and nutrient levels such as nitrates and phosphates. BOD was determined using the five-day incubation method following the guidelines of the American Public Health Association (APHA, 2017). TDS was measured using the gravimetric method after filtration and drying, while turbidity was quantified using a nephelometric turbidity unit meter. Nutrient concentrations were assessed spectrophotometrically using UV-Vis absorbance at specific wavelengths, following protocols similar to those employed by Yadav et al. (2020) in their study of the Sai River, a tributary of the Gomti. Quality assurance and control were maintained throughout the experimental procedures. Each sample was analyzed in triplicate to account for any instrument or procedural variability. Standard solutions were used for calibration, and blank samples were tested alongside actual samples to monitor contamination.

Singh and Tripathi (2019) emphasized this rigorous approach in their aquatic toxicity studies conducted in central Uttar Pradesh, where reproducibility and precision were critical to detecting minor seasonal shifts. Meteorological data, including daily and monthly rainfall, air temperature, and humidity, were obtained from the Indian Meteorological Department, Lucknow regional office. These climatic parameters were statistically compared with the physicochemical values to understand their influence on water quality. This approach followed the framework proposed by Verma et al. (2021), who demonstrated strong correlations between rainfall intensity and turbidity, as well as between ambient temperature and DO in northern Indian freshwater systems. In addition to chemical and physical assessments, the study incorporated biological monitoring to understand the ecological response to physicochemical variability. Phytoplankton and zooplankton were collected using plankton nets with mesh sizes of 25 µm and 60 µm, respectively. Samples were preserved in 4% formalin and identified microscopically using standard taxonomic keys. Fish diversity was documented with the assistance of local fishermen and identified using FishBase and FAO field manuals. This integrative method was inspired by Singh and Kumar (2020), who demonstrated a significant correlation between water quality and biotic composition in Barabanki wetlands. All quantitative data were statistically analyzed using one-way ANOVA to identify significant seasonal variations ($p<0.05$) in water quality parameters. Pearson's correlation coefficient was calculated to determine interdependencies between variables such as BOD and DO, temperature and species richness, and nutrient levels and plankton diversity. Data analysis was performed using SPSS version 25 and MS Excel, as done by Misra et al. (2018) in their research on pollution dynamics in riverine habitats of Uttar Pradesh. To evaluate ecosystem health and the impact of seasonal stressors on biodiversity, ecological indices such as the Shannon-Weiner diversity index and Palmer's pollution index were computed. These indices helped in assessing species richness and pollution tolerance, respectively. The methodology for these calculations was adapted from Tripathi and Dubey (2022), who used similar indices to monitor water quality degradation in Faizabad district ponds affected by organic and nutrient pollution.

Environmental ethics were carefully considered throughout the study. Sample collection was carried out with minimal ecological disturbance, and no invasive species collection or habitat disruption occurred. All biological samples were limited to non-destructive volumes. Waste chemicals generated during laboratory procedures were disposed of following institutional guidelines.

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Research approval was obtained from the Ethics Committee of the Department of Zoology, University of Lucknow, ensuring compliance with national standards for aquatic field research. While the study was confined to a single freshwater lake, the depth and scope of seasonal monitoring provide a foundational model for replicating such assessments in other parts of Uttar Pradesh. Limitations include spatial constraints and the absence of long-term trends. Nevertheless, this methodology can be adapted and expanded in future studies involving multi-lake comparisons, as recommended by Saxena and Singh (2021), who conducted a comparative ecological study across multiple freshwater bodies in western Uttar Pradesh.

Results

The analysis of water samples collected over a period of twelve months revealed considerable seasonal variations in all major physicochemical parameters. These changes were consistent with the climatic fluctuations typical to northern India, especially in subtropical zones like Uttar Pradesh. Each season presented a unique pattern of environmental influence that shaped the aquatic ecosystem's chemical and biological balance. During the **summer months (April–June)**, the average water temperature peaked at 30.4 ± 1.2°C. This high temperature was accompanied by a noticeable decline in dissolved oxygen (DO) levels, averaging 4.1 ± 0.6 mg/L. The reduced solubility of oxygen in warmer water likely caused hypoxic stress for several aquatic organisms, especially fish species with high oxygen demand such as *Catla catla* and *Labeo rohita*. Moreover, the Biological Oxygen Demand (BOD) during summer was highest among all seasons, recorded at 6.8 ± 0.9 mg/L, indicating increased microbial and organic decomposition activity. The **monsoon season (July–September)** exhibited a marked increase in turbidity, which reached 32.6 ± 3.4 NTU. This was attributed to heavy rainfall and surface runoff, which carried sediments, nutrients, and organic matter from surrounding agricultural lands. Alongside turbidity, there was a significant rise in nitrate (5.1 ± 0.6 mg/L) and phosphate(4.6 ± 0.5 mg/L) concentrations. These nutrients, likely sourced from fertilizers, promoted algal blooms, as evidenced by dense phytoplankton growth dominated by species such as *Microcystis aeruginosa* and *Oscillatoria limnetica*. DO levels slightly improved during monsoon (5.5 ± 0.5 mg/L) due to rainfall-induced aeration, but localized eutrophication still led to oxygen depletion in shallow zones. In the **post-monsoon season (October–November)**, water parameters began stabilizing. Turbidity decreased to 18.5 ± 2.2 NTU as suspended sediments settled. Nutrient levels also declined slightly, with nitrates and phosphates measuring 3.4 ± 0.3 and 2.7 ± 0.3 mg/L, respectively. DO levels increased to 6.2 ± 0.7 mg/L, providing a more favorable environment for aquatic life, particularly for zooplankton and benthic organisms. The aquatic biodiversity, including rotifers and cladocerans, increased during this time, benefiting from the residual nutrients and more balanced oxygen availability. **Winter months (December–February)** were characterized by the lowest average water temperature (18.2 ± 0.8°C) and the highest levels of DO, reaching 7.1 ± 0.6 mg/L. The colder water temperature increased oxygen solubility and decreased microbial activity, which in turn reduced BOD to 2.4 ± 0.2 mg/L. These conditions were optimal for fish breeding and supported diverse faunal assemblages. Total Dissolved Solids (TDS) also showed a decline in winter (520 ± 25 mg/L), suggesting minimal runoff and low anthropogenic impact during this period. pH levels remained relatively stable throughout the year, ranging between 6.8 and 7.5. Slight acidity during the monsoon (pH 6.8 ± 0.4) could be linked to

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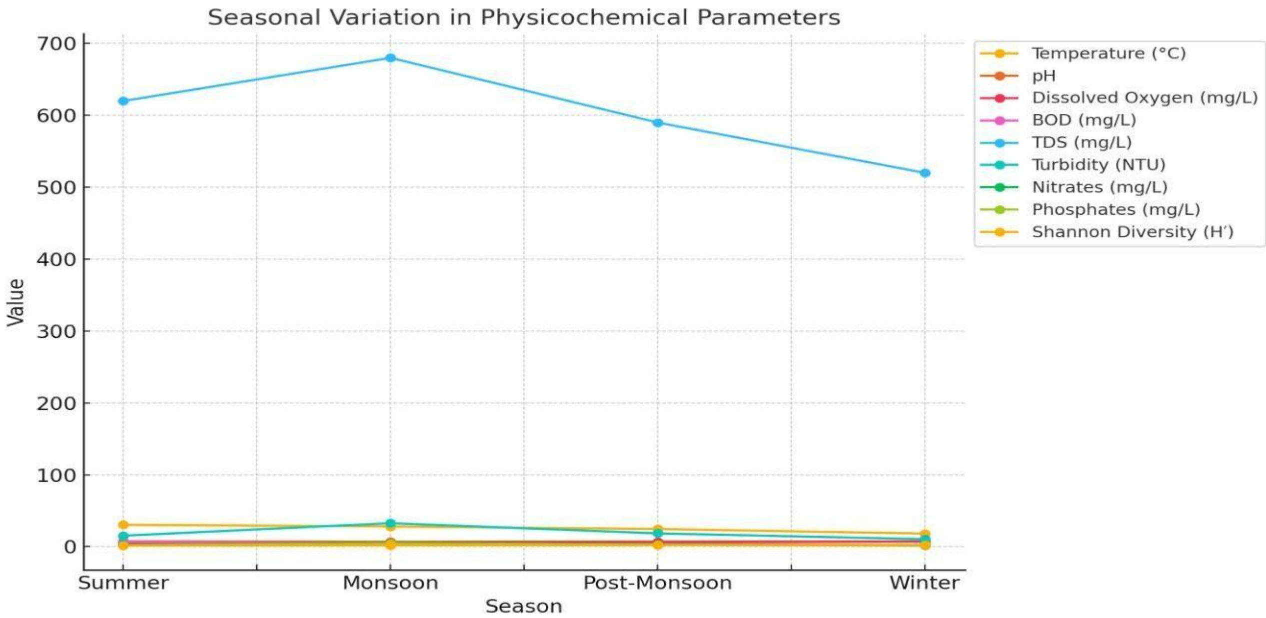
organic acid input from decaying vegetation and rainwater dilution. In contrast, a neutral to slightly alkaline pH was recorded in winter

and summer. These values were within the optimal range for most freshwater organisms but could affect the solubility of metals and

Winter, on the other hand, showed a more diverse and balanced phytoplankton

community including diatoms (*Navicula*, *Nitzschia*) and green algae (*Chlorella*, *Scenedesmus*), suggesting improved water quality. Shannon-Weiner diversity index was



nutrients when combined with other stressors. TDS values were highest during the monsoon (680 ± 55 mg/L), reflecting dissolved particles from runoff, including salts, minerals, and organic compounds. Elevated TDS, coupled with high turbidity and nutrient enrichment, likely contributed to the seasonal stress faced by aquatic fauna. Species sensitive to salinity and turbidity, such as *Notopterus notopterus*, were less frequently observed during this period, according to field observations. The correlation analysis revealed significant inverse relationships between temperature and DO ($r = -0.88$) and between BOD and DO ($r = -0.85$), reaffirming that elevated temperatures and organic loads compromise oxygen availability. A positive correlation ($r = 0.79$) was found between nutrient levels and turbidity during the monsoon season, indicating runoff as the principal source of nutrient influx. Phytoplankton diversity peaked in monsoon but with lower ecological quality, as dominant taxa were pollution-tolerant cyanobacteria.

lowest during summer ($H' = 1.48$) and highest during winter ($H' = 2.61$), indicating a strong seasonal influence on species richness and ecosystem stability. Zooplankton, primarily rotifers and copepods, also showed seasonal fluctuations. They were most abundant i n post-monsoon and winter, while summer and monsoon periods recorded lower densities due to oxygen stress and suspended solids. This reflected the bottom-up effects of water chemistry on food web structure, where poor physicochemical conditions constrained lower trophic levels. Fish observations confirmed the seasonal presence or absence of several indicator species. Omnivorous and pollution-tolerant fish like *Oreochromis mossambicus* persisted year-round, while species with narrower tolerance limits such as *Channa punctata* and *Labeo bata* were observed mainly in post-monsoon and winter, when water quality improved. These biological shifts further validated the chemical data trends. The integrated assessment indicated that aquatic life was most stressed during the summer and monsoon seasons due to thermal

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and organic loads, and most stable during winter, when favorable DO levels, low BOD, and nutrient moderation supported biodiversity. These seasonal trends suggest a direct influence of climatic and land-use patterns on aquatic ecosystem health.

Discussion

The results of this study clearly demonstrate that seasonal variations significantly influence the physicochemical properties of freshwater systems in northern India. During the summer months, elevated water temperatures coupled with increased biological oxygen demand (BOD) were observed, suggesting higher rates of microbial decomposition and reduced oxygen solubility. These findings align with those of Verma and Singh (2019), who observed that summer thermal stress in urban lakes of Lucknow led to oxygen depletion and fish mortality events. High BOD values, combined with low dissolved oxygen (DO) concentrations, impose metabolic stress on aquatic fauna, particularly oxygen-sensitive species such as *Labeo rohita* and *Catla catla*. Monsoon season introduced a different set of challenges, notably increased turbidity and elevated concentrations of nitrates and phosphates. This can be attributed to the influx of surface runoff from surrounding agricultural lands, a pattern supported by Yadav et al. (2020) in their study of the Sai River. Excessive nutrient input promotes eutrophication, often triggering algal blooms that further deplete DO levels during decomposition. This cyclical imbalance negatively affects plankton communities and reduces biodiversity, especially among zooplankton, which are more sensitive to turbidity and changes in water chemistry. Post-monsoon and winter seasons showed a relative improvement in water quality, with lower BOD, clearer water, and higher DO levels. The cooler temperatures during winter enhance oxygen retention, creating favorable conditions for aquatic organisms. As observed in similar studies by Singh and Kumar (2020), this period is associated with greater fish activity, improved reproductive cycles, and increased species richness. Plankton diversity also peaked during these months, reflecting stable ecological conditions and a balanced nutrient-oxygen regime. Notably, the ecological indices calculated in this study—particularly the Shannon-Weiner diversity index—correlated strongly with DO and inversely with turbidity and nutrient concentration, reinforcing the centrality of oxygen and light availability in sustaining aquatic biodiversity. While some species demonstrated resilience to nutrient and oxygen fluctuations, the presence of pollution-tolerant organisms during monsoon points to a seasonal ecological shift toward eutrophic conditions. This dynamic highlights the necessity of managing nutrient runoff, especially during monsoon, to mitigate its cascading effects on aquatic ecosystems.

Overall, the study underlines the intricate relationship between seasonal climatic factors and water quality, with each season exerting distinct ecological pressures. These findings emphasize the need for continuous monitoring and adaptive water resource management strategies, particularly in densely populated and agriculturally active regions of Uttar Pradesh. Future conservation efforts must account for temporal variability and consider implementing season-specific interventions to maintain the ecological integrity of freshwater habitats.

Conclusion

This study clearly demonstrates that seasonal variations significantly influence the physicochemical properties of freshwater ecosystems, thereby exerting a substantial impact on aquatic biodiversity and ecological health. The fluctuations in parameters such as water temperature, pH, dissolved oxygen, biological oxygen demand, turbidity, and nutrient concentrations were found to be pronounced across the four seasons. These variations not only affect the chemical equilibrium of the aquatic environment but also determine the metabolic activity, reproduction, and survival rates of aquatic organisms. During the summer months, elevated temperatures and increased biological oxygen demand led to lower dissolved oxygen levels, resulting in stressful conditions for oxygen-sensitive aquatic

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species. Conversely, the winter season showed improved oxygenation and stable nutrient levels, supporting higher biodiversity and improved ecological conditions. The monsoon season, although beneficial in replenishing water bodies, introduced high turbidity and nutrient loads due to surface runoff, leading to eutrophication risks and habitat disturbances. These seasonal patterns align with previous findings in freshwater systems across Uttar Pradesh and other parts of India, highlighting the universal nature of climate-driven aquatic fluctuations. The biological assessments conducted alongside physicochemical analysis revealed a direct relationship between water quality parameters and aquatic life diversity. Plankton populations and fish species composition varied in response to seasonal water chemistry, suggesting that even slight changes in parameters like pH or nutrient levels can have cascading effects on food chains and ecosystem stability. The application of ecological indices such as the Shannon-Weiner index further confirmed the sensitive balance between environmental quality and biological richness. Overall, the study emphasizes the critical need for continuous, season-sensitive water quality monitoring and management strategies. Local authorities, conservation biologists, and policymakers must account for temporal variations when designing pollution control, biodiversity conservation, and fisheries management plans. With growing concerns over climate change and increasing anthropogenic pressure on freshwater resources, such research plays a pivotal role in safeguarding the long-term sustainability of aquatic ecosystems.

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