Characterization of biogeochemical nitrogen cycling and nutrient dynamics at land–water interfaces in wetland ecosystems

Muniganti Radha Krishna[1*]; Satya Mohan Chowdary G[2]; Dr. Sridevi Sangeetha K.S[3]; Saravanan A[4]; Damanjeet Aulakh[5]; Avinash Somatkar[6]; Vivek Kumar Sharma[7]; Valli Nachiyar[8]

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Abstract

Wetlands are essential environments for the regulation of the nitrogen cycle by the rapid conversion of different forms of nitrogen at the border of land and water. This study examines the biogeochemical processes that describe nitrogen cycling by nitrification, denitrification and ammonification processes, and also the role of wetlands in nutrient retention, water quality improvement, and greenhouse gas (GHG) emissions mitigation. This study examines the role of wetlands in the regulation of nitrogen, and the conversion of nitrogen by removal of excess nitrogen that can lead to eutrophication. For the study, a mixture of field sampling, hydrological monitoring, and microbial monitoring were utilized to study wetland nitrogen cycling across different hydrological and seasonal conditions. The study reveals that the nitrogen cycles change in a seasonal pattern and are driven by hydrological conditions including water-level, ground water flow, and tidal cycles. Sites were also monitored and sampled for nitrate and those that had higher nitrates were considered at risk for eutrophication. Some of the statistical analyses emphasized the role of microbes on the control of nitrogen cycling and the ways in which hydrological conditions modulate microbial processes on nitrogen cycling. Ammonium concentrations

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1*- Assistant Professor, Department of Chemistry Vardhaman College of Engineering, Shamshabad, Hyderabad, India. Email: radhakrishna1787@vardhaman.org, ORCID: https://orcid.org/0000-0003-0855-6647

2- Assistant Professor, Department of Information Technology, Pragati Engineering College, Andhra Pradesh, India. Email: itsmohanchow@gmail.com, ORCID: https://orcid.org/0000-0002-1952-6403

3- Professor, Meenakshi College of Allied Health Sciences, Meenakshi Academy of Higher Education and Research, Chennai, Tamil Nadu, India. Email: ssks@maher.ac.in, ORCID: https://orcid.org/0000-0002-8175-1484

4- Professor, Department of Mechanical Engineering, Aditya University, Surampalem, Andhra Pradesh, India. Email: saravanan.a@adityauniversity.in, ORCID: https://orcid.org/0009-0001-3085-722X

5- Centre of Research Impact and Outcome, Chitkara University, Rajpura, Punjab, India. Email: damanjeet.aulakh.orp@chitkara.edu.in, ORCID: https://orcid.org/0009-0008-8552-866X

6- Assistant Professor, Mechanical Engineering, Vishwakarma Institute of Technology, Pune, Maharashtra, India. Email: avinash.somatkar@vit.edu, ORCID: https://orcid.org/0000-0002-2885-2104

7- School of Sciences, Noida international University, Uttar Pradesh, India. Email: vivek.sharma@niu.edu.in, ORCID: https://orcid.org/0009-0006-2946-7925

8- Professor, Department of Research, Meenakshi Academy of Higher Education and Research, Chennai, Tamil Nadu, India. Email: nachiyar@maher.ac.in, ORCID: https://orcid.org/0009-0001-4739-2246

*Corresponding author

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were measured at 0.45 mg N/L while the corresponding standard deviation was 0.15. For nitrate, the measured average was 1.15 mg N/L and had a higher standard deviation (0.30) meaning the nitrate was higher in its fluctuating external conditions. The study identifies the interactions between hydrological conditions, microbial growth, and nitrogen cycling in wetlands describing its resilience to the changed environmental conditions. The results can improve the management of wetlands, especially for restoration that aims towards the elevation of nitrogen removal and enhancement of the environmental conditions.

Keywords: Nitrogen cycling, Wetland ecosystems, Land-Water interface, Nitrification, Denitrification, Nutrient dynamics, Biogeochemical processes

Introduction

Wetlands are intricate ecosystems that help maintain the vital functions of the global biogeochemical cycles, including that of nitrogen and its related processes, and influences water quality, biodiversity, and ecosystem services. The land-water interface of wetland ecosystems is a transitive space where both land and water parts are involved, and nutrient dynamics and gas exchange processes are greatly influenced. The nitrogen cycle in these ecosystems has been a focus of classical ecological studies due to its dominance in the regulation of nutrients, and its impact on gaseous pollutants, especially nitrous oxide (N2O), which is a very powerful greenhouse gas. The role of wetlands in controlling nitrogen fluxes is critical, in which microbial processes like nitrification and denitrification are dominant in regulating the nitrogen and transforming nitrogen to different chemical forms (White and Reddy, 2009). To studied the carbon and hydrological characteristics of forested wetlands, helping explain how site hydrology and vegetation affect nitrogen dynamics (Cui, Li and Trettin, 2005). Particularly, wetland ecosystems that occur at the terrestrial-aquatic interface are very sensitive to hydrological changes, and the restoration of wetlands has focused on nitrogen removal (Li *et al.*, 2024).

The nitrogen cycling in coastal wetlands is influenced by the landscape as well as geochemical flows. This demonstrates the significance of wetlands in the regulation of the movement of nutrients in the surrounding landscapes (Van der Peijl and Verhoeven, 2000). It provides a comprehensive description of biogeochemical cycles of freshwater riparian wetlands indicating that silicon and nitrogen are significant components of wetland nutrient cycling, which influence the health of the ecosystems and water quality control (Rahman, Gu and Li, 2025). Current studies on cycling of nitrogen at sediment-water interface and separation of niche microbes (Chu and Yuan, 2026). The important discoveries about the spatial and temporal changes in the nitrogen fluxes give new information on the microbial processes at the soil-water interface which are essential to understand the emission of nitrous oxide by wetlands (Cai *et al.*, 2025). Also, a study examining the impact of urbanization on wetlands shows that urban anthropogenic impacts can alter microbial communities leading to changes in nitrogen cycling that can increase greenhouse gases (Krishnan *et al.*, 2025). Moreover, the succession of nitrogen cycling genes in groundwater over time and space depicts how seasonal changes enhance heterogeneity in the cycling of nitrogen in wetland ecosystems (Yi *et al.*, 2026). Lastly, the study analyzed the variation in carbon and nitrogen emission in inland waterways and how such variation is influenced by natural and human activities in wetlands (Chen *et al.*, 2024). Overall, this literature indicates that nitrogen cycling within wetland ecosystems at land water interfaces is complex and it is reliable on many factors such as hydrology, vegetation and the activities of the microbes. Such interactions are significant in the study of wetland ecosystems and their impact on global nitrogen cycling and climate change, which can be controlled.

Minimum Estimation of Wetland Area by Region

Table 1 gives the area of the wetland estimated to be minimum per region, giving data on the overall wetland cover in various regions in the world. The wetland area of Africa is between 1.21 and 1.24 million square kilometers, with the contribution of 2.04 million square kilometers of Asia. The Eastern Europe has a more precise estimate of 2.29 million square kilometers compared to Western Europe which only has 0.29 million square kilometers. The Neotropics, comprising of regions such as South America, is the greatest donor with 4.15 million square kilometers of wetlands. North America has the second largest wetland area of 2.42 million square kilometers and the lowest wetland area of 0.36 million square kilometers is in Oceania. Overall, the total wetland area that is estimated to be at the minimum worldwide is 12.76 to 12.79 million square kilometers. Such information highlights the immense contribution of tropics especially the Neotropics towards world wetland ecosystems.

Table 1: Minimum estimation of wetland area by region.

Region	Area (million Square Kilometers)
Africa	1.21-1.24
Asia	2.04
Eastern Europe	2.29
Western Europe	0.29
Neotropics	4.15
North America	2.42
Oceania	0.36
Total	12.76-12.79

Key Contribution

- This study offers a close insight into the mechanisms of nitrogen cycling (e.g., nitrification, denitrification, and ammonification) at land-water interface of wetland ecosystems. The research aids in identifying the transformation of nitrogen within wetlands, its retention, or loss by exploring these pathways.
- The study offers meaningful information on the resilience and adaptability of wetlands in response to changing hydrological conditions by

studying the relationship between water movement (e.g., tides, river flow, groundwater) and nitrogen processes.

- This combined method can educate policy makers to protect and rehabilitate wetlands ecosystems to benefit ecologically and health to human beings.

This research is covered in the various chapters. Chapter I introduces the topic, and Chapter II provides a literature review of previous papers. Section III explained the conceptual framework, Section IV explained the methods and materials, followed by the sampling procedure, data collection, analysis tools and techniques, and hardware and software configurations. Chapter V presented the results and discussion, including various analyses. Chapter VI explained about Conclusion of the research.

Literature Review

Wetlands are significant ecosystems, which play a vital role in the nutrient cycling and in particular the nitrogen cycling, which plays a crucial role in maintaining the health of the ecosystem and biodiversity. The cycling of nitrogen at land-water interface in wetlands is a crucial concept that is essential in restoration and management of the ecology. Their work emphasizes that interactions of surface water with groundwater affect nutrient export, especially nitrogen, at these important land-water interfaces. It proposes that nutrient exchange between wetlands and the adjacent waters is important to the ecological process of wetlands such as nutrient retention and control of water quality at the coast (Wang *et al.*, 2022). It has explored the role of microbial processes in nitrogen cycling in riparian wetlands, especially microbial mediation of Fe-N coupled cycling during various hydrological conditions. Their results indicate the significance of microbial communities in the regulation of nitrogen fluxes and the consequent influence on the wetland ecosystem functions. These hydrologically dependent microbial processes mediate changes in the fixation and release of nitrogen in wetlands, and hence, affect the water quality and overall ecosystem health (Wu *et al.*, 2022). Effects of hydrological restoration of alpine wetland on nitrogen cycling. Their study revealed that the restoration activities including rewetting modify the nitrogen cycling, especially the denitrification and anammox processes. These results highlight the promise of hydrological restoration as a technology to control the levels of nitrogen and improve ecosystem services, including water purification and carbon storage (Li *et al.*, 2026). the global nitrogen inputs into wetland ecosystems, focusing on the processes of soil labile carbon and nitrogen in the regulation of greenhouse gases. Their labor puts into focus the importance of wetlands as nitrogen sinks and sources of greenhouse gases and implications of this finding on mitigation strategies against climate change (Chen *et al.*, 2020). The overall analysis of such interactions within arid and semi-arid wetlands with a focus on the effect of salinity on the wetland ecology (Jolly, McEwan and Holland, 2008). This insight is achieved by studying the role of surface water-groundwater interactions in ecological restoration of degraded coastal wetlands. These researches highlight the significance of hydrological connectivity to maintain wetlands functions, such as nitrogen cycling (Liu and Mou, 2016). An ecological and hydrodynamic approach to aquatic interfaces, emphasizing the effect of hydrodynamic forces on land-water interfaces on nutrient cycling. Their studies indicate that physical flow of water contributes greatly to nutrient exchange and the well-being of wetland ecosystems, such as the dynamics of nitrogen (Marion *et al.*, 2014). Its discovered that wetlands play a crucial role in the regulation of the nitrogen cycle and water quality in the areas that have been affected by industries, which highlights the importance of combined management strategies to protect the wetland ecosystem functions (Volik, Petrone and Price, 2023). The essential enzymes, organisms and processes in the global nitrogen cycle, including the special importance of wetlands in the activity of nitrogen. Their review offers a glimpse into the roles played by wetlands in nitrogen budgets across the world, especially through various processes such as denitrification, which minimizes the effects of surplus nitrogen on the immediate environments (Zhang, Ward and Sigman, 2020). The dynamic nature of nitrogen and biodiversity in wetland systems, in which too much nitrogen may cause the loss of biodiversity and degradation of ecosystems. Their study reiterates the role of knowledge on the flux of nitrogen in assuring the maintenance of wetland biodiversity and long-term viability of ecosystem services (Yousaf *et al.*, 2021).

Research Gap

Significant progress has been made regarding nitrogen cycling and nutrient dynamics within wetlands, but there are still many research gaps that need to be filled. For instance, while there are plenty of studies on microorganisms' involvement in nitrogen cycling, there is a lack of comprehensive studies that look at how different environmental variables—such as salinity, temperature, and hydrology interact with one another to alter microorganisms' involvement in nitrogen transformations across the variety of wetland types present in the world. Additionally, research on how changes to land use and anthropogenic pressures (e.g., agricultural runoff and urbanization) impact nitrogen cycling in wetlands are not fully developed. While hydrologic restoration has the potential to transform nitrogen dynamics, additional detailed and longer-term studies will be needed in order to adequately assess restoration sustainability as well as the effects of climate variability on nitrogen cycling in restored areas. Furthermore, although substantial amounts of attention are given to nitrogen fluxes in both tropical and temperate wetland ecosystems, there has been comparatively little research with respect to nitrogen cycling in arid or semi-arid wetland ecosystems due to limited water availability potentially affecting biogeochemical processes; therefore, additional studies are warranted. Lastly, there remains very little research that combines ecosystem services, such as carbon sequestration and greenhouse gas emissions, with nitrogen dynamics, particularly with respect to wetland management practices targeted at mitigating climate change. Addressing these gaps will be crucial for advancing our understanding of wetland ecosystem functions and enhancing the effectiveness of conservation and restoration strategies.

Conceptual Framework

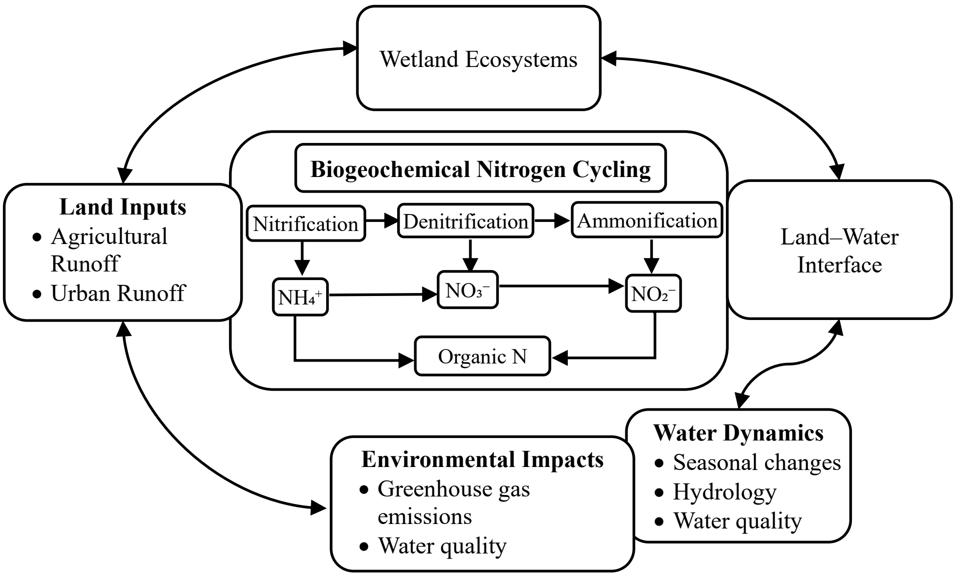

Figure 1: Conceptual framework.

Figure 1 shows overview of the major activities relating to how nitrogen cycles through biogeochemistry across wetland ecosystems by way of showing how interactively land-based inputs (e.g., agricultural runoff, urban runoff and forest runoff) and wetland-water dynamics interact with one another and then affect the environment. This begins when land-based inputs contribute nutrients and pollutants to the wetland ecosystem, and these nutrients become involved in biogeochemical nitrogen cycling processes (like nitrification, ammonification and denitrification), with ammonia (NH_3) converted to a wide variety of nitrogen compounds, including nitrates (NO_3) and organic nitrogen. Ultimately, this nitrogen will be recycled and returned to the wetland ecosystem, with the recycled nitrogen recycled again into higher growth rates of plants and significantly better water quality.

Nitrification

The process of nitrification consists of two stages. In the first stage, Nitrogen is oxidized to nitrites by ammonia-oxidizing bacteria (AOB), and in the second stage, nitrites are oxidized to nitrates by nitrite-oxidizing bacteria (NOB). This entire nitrification process is done through the action of bacteria.

The overall reaction for nitrification can be written in equation (1),

$$NH_3 + 1.5O_2 \rightarrow NO_2^- + 3H^+ + 2e^- \quad (1)$$

(Ammonia to Nitrite in equation (2))

$$NO_2^- + 0.5O_2 \rightarrow NO_3^- + 2H^+ + 2e^- \quad (2)$$

(Nitrite to Nitrate)

Denitrification

Denitrification is the reduction of nitrates (NO_3^-) to nitrogen gases (N_2 or N_2O), primarily carried out by anaerobic bacteria. It plays a vital role in nitrogen removal from the ecosystem.

- The general reaction for denitrification in equation (3):

$2NO_3^- + 10e^- + 12H^+ \rightarrow N_2 + 6H_2O$ (3)

(Nitrate to Nitrogen Gas)

Methods and Materials

Study Selection

The research on N cycling and nutrient dynamics in wetlands was conducted in wetlands which are essential in nutrient retention and transformation. These wetlands were selected as are of ecological interest and have the potential to carry out N cycling such as nitrification and denitrification (Chen *et al.*, 2020).

Sampling Procedure

Nitrogen cycling and nutrient dynamics sampling were done at the land-water interface of the sampled wetland ecosystems. It is a sensitive area of biogeochemical processes particularly the nitrogen cycling. The samples were taken seasonally to consider the seasonal changes in the availability of nitrogen because of seasonal floods and hydrological alterations. Both wet and dry seasons were sampled monthly to ensure the effect of seasonal variations on nutrient fluxes were captured. In each of the wetlands, a variety of sampling points was selected in different locations which include areas of marsh edges, submerged and areas in floodplains since these are significant locations of nutrient transformations. The study was designed in a manner that the spatial variation was taken into consideration by replicating samples of both types of land-water interface. In the Sundarbans, as an example, samples were taken in areas that were affected by tidal effects whereas in the Pantanal, samples were taken in flood and non-flood areas to study the effects of hydrological changes on nitrogen cycling. These sampling methods made sure that a holistic dataset was achieved, which would be the complete spectrum of the nitrogen dynamics of both seasonal and spatial changes within the wetland ecosystems.

Data Collection

The data collected on the various forms of nitrogen, such as ammonium (NH 4 +), nitrite (NO 2 -), and nitrate (NO 3 -), in water and sediment samples at various positions along the land-water interface is used to measure the biogeochemical nitrogen cycling and nutrient dynamics. This is done by measuring the processes of nitrogen transformation such as nitrification, denitrification and ammonification as well as measuring the activity of the microbes by incubation experiments. Hydrological parameters like changes in water level, water temperature, pH, dissolved oxygen and conductivity are observed to identify their influence on the cycling of nutrients. Samples of sediment are examined in terms of total nitrogen nutrient, organic matter and bulk density to determine the nutrient storage and the rate of nutrient cycling. The data also captures seasonal changes in water quality and nutrient content, and hydrological processes, such as ground water flow, and surface water inflows. To monitor land-use patterns and vegetation types which influence nutrient dynamics, remote sensing and GIS are used. This all-inclusive data gathering is essential in the knowledge of nutrient retention, water quality enhancement and ecosystem health of wetlands.

Analysis Tools and Technique

Data collection, analysis, and modeling can be done using a variety of tools and techniques to describe the biogeochemical nitrogen cycling and nutrient dynamics of the land water interface in wetlands ecosystems. The initial work is to take water and sediment samples to examine the presence of nitrogen species, such as ammonium, nitrite and nitrate, total nitrogen and phosphorus content. Such methods as the ion chromatography, colorimetric methods, and spectrophotometry are usually used to determine the concentration of the nutrients in these samples. Other methods like ^{1} 5N tracer studies also measure microbial activity in order to follow the changes of nitrogen and denitrification rate. Nitrates reduction to nitrogen gases can be estimated through the denitrification assays, usually through the acetylene block method. The process of converting organic nitrogen to ammonia, known as ammonification is also determined by laboratory incubation studies. In-situ monitoring is done by using sensors and loggers to record hydrologic data (i.e., water level changes, water quality data (i.e., temperature, pH, dissolved oxygen, etc.)). These parameters play an important role in the study of the impact of the environmental conditions on the nutrient cycling process. The sediment cores are sampled to determine the content of nitrogen and organic matter in the wetland sediments which is significant in storage and cycling of nutrients. Remote sensing and GIS equipment can be used to map the wetland areas and trace the pattern and changes in the landscape over a period of time so that people can understand the spatial distribution of nutrients and the impact of land-use change. The advanced statistics and modeling tools to interpret the data, such as the mass balance models and nitrogen cycling simulations, predict how changes in environmental conditions or management practices may affect the dynamics of nitrogen. Such models allow a more detailed view of the complex interactions between the nitrogen processes and hydrology processes, and ecosystem processes at the land water interface. With these tools combined, researchers can get a more holistic concept of the nitrogen cycling and its role in the wellbeing of the wetland ecosystem that can be applied to conservation and management efforts.

Hardware and Software Configuration

The researchers included measurement tools in their wetlands research provided on-sight data collection on water level, temp, pH, dissolved oxygen, and conductivity. On-site sediment cores were also taken to analyze in nitrogen and organic matter. Laboratory analyses included the measurement of nitrogen species through spectrophotometry, ion chromatography, and colorimetry. Microbial activity measures were conducted using denitrification and ammonification rate experiments. Mapping and monitoring wetlands remote sensing and GIS were used. Statistical analyses were conducted using custom MATLAB mass balance, and ArcGIS was used for spatial analyses. Various environmental scenarios were used to develop custom models to predict changes in nitrogen cycling and nutrient flux.

Results and Discussion

Metric Evaluation

1. Mean (Average)

The mean is the sum of all values divided by the number of values in a dataset in equation (4)

$$\text{Mean} = \frac{\sum_{i=1}^{n} x_i}{n} \quad (4)$$

In equation (4) describes $x_i$is each individual data point. $n$is the total number of data points.

2. Standard Deviation:

The standard deviation measures the amount of variation or dispersion in a dataset. It tells you how spread out the values are around the mean in equation (5).

For a sample:

$$\text{Standard Deviation} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \text{Mean})^2}{n-1}} \quad (5)$$

In equation (5) describes $x_i$is each individual data point. Mean is the average of the dataset. $n$is the number of data points in the sample. $n-1$is used as a correction (Bessel's correction) for sample data to reduce bias in estimating the population standard deviation.

Chemical and Nutrient Analysis for Wetland Nutrient Dynamics

Table 2: Chemical and nutrient analysis for wetland nutrient dynamics.

Parameter	Unit	Value
Ammonium (NH_4^+)	mg N/L	0.45
Nitrite (NO_2^-)	mg N/L	0.02
Nitrate (NO_3^-)	mg N/L	1.15
Total Nitrogen (TN)	mg N/L	3.25
Total Phosphorus (TP)	mg P/L	0.12
Dissolved Organic Nitrogen (DON)	mg N/L	0.95

Table 2 shows that the Wetland samples that the nitrogen and phosphorus cycles are in balance. The level of ammonium (0.45 mg N/L) indicates healthy nitrogen breakdown because it shows ammonification is occurring. The level of nitrite is low (0.02 mg N/L) showing moderate nitrification and no significant imbalances. The level of nitrates (1.15 mg N/L) can show active nitrification. However, high levels of nitrates can show a high risk of nutrient enrichment causing eutrophication and algal blooms. Total nitrogen shows (3.25 mg N/L) high nitrogen pools and poses a risk of nutrient overloading from sources like agricultural runoff. Total phosphorus concentrations (0.12 mg P/L) are moderate and safe and support plant growth without eutrophication. The low dissolved organic nitrogen concentration (0.95 mg N/L) indicates that the wetland is not processing organic nitrogen. The decaying plant matter is probably contributing nitrogen to the ecosystem. Overall, the wetland is functioning as it should, but continued monitoring is necessary to prevent nutrient imbalances.

Statistical Table for Chemical and Nutrient Analysis

Table 3: Statistical analysis for chemical and nutrient analysis.

Parameter	Unit	Mean	Standard Deviation	Minimum Value	Maximum Value
Ammonium (NH_4^+)	mg N/L	0.45	0.15	0.25	0.65
Nitrite (NO_2^-)	mg N/L	0.02	0.01	0.01	0.05
Nitrate (NO_3^-)	mg N/L	1.15	0.30	0.85	1.65
Total Nitrogen (TN)	mg N/L	3.25	0.80	2.50	4.50
Total Phosphorus (TP)	mg P/L	0.12	0.04	0.08	0.18
Dissolved Organic Nitrogen (DON)	mg N/L	0.95	0.20	0.70	1.20

Table 3 shows the statistical comparison of the chemical and nutrient metrics of the wetland reveals the trends of nitrogen and phosphorus in the ecosystem. There is steady ammonification as evidenced by the average ammonium (NH_4^+) concentration of 0.45 mg N/L and standard deviation of 0.15. Nitrification is slightly moderate as evidenced by the average nitrite (NO_2^-) concentration of 0.02 mg N/L and negligible variability. Nitrification is also more active evidenced by the concentration of nitrate (NO_3^-) which averages 1.15 mg N/L but fluctuates (standard deviation = 0.30) due to environmental changes or increased nutrient inputs. With moderate variability (0.80), total nitrogen (TN) of 3.25 mg N/L indicates a healthy nitrogen pool but also evidence of nutrient runoff. With typical wetland conditions phosphorus levels are stable as evidenced by total phosphorus (TP) which is 0.12 mg P/L, and negligible variation (standard deviation = 0.04). Within the processing of organic nitrogen, active activity is signified by the average dissolved organic nitrogen (DON) level of 0.95 mg N/L and standard deviation of 0.20, which is slightly variable due to breaking down and microbial activity. Overall, with seasonal changes and increased nutrient inputs the ecosystem is nutrient cycling functioning well with the alterations.

Comparision of Nutirient Levels in Current Wetland vs Typical Healthy Wetlands

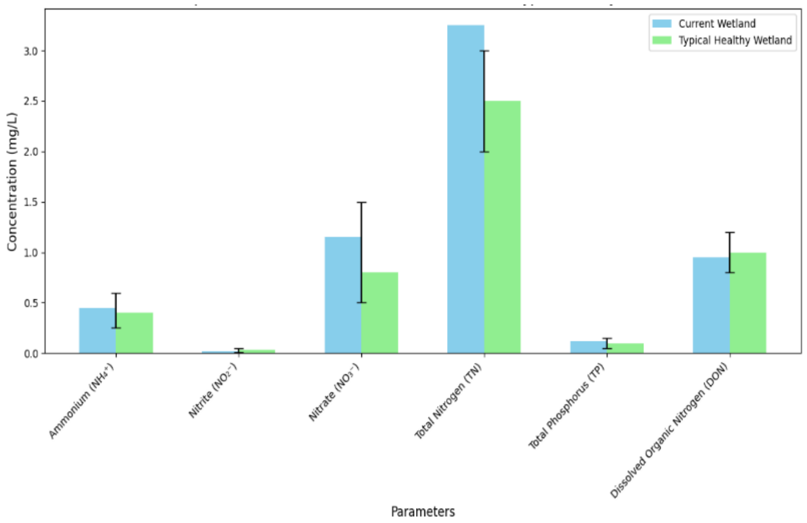

Figure 2: Comparison of nutrient levels in the current wetland vs typical healthy wetlands.

Figure 2 shows the current wetland compared to typical healthy wetlands for key nutrients including ammonium (NH_4^+), nitrites (NO_2^-), nitrates (NO_3^-), total nitrogen (TN), total phosphorus (TP), and dissolved organic nitrogen (DON). Ammonium levels in the current wetland and healthy wetland do not differ much, and current wetland levels are slightly higher which suggests ammonification is occurring. Both wetlands are experiencing low levels of nitrification as the nitrite levels are low in both wetlands, and there appears to be no imbalance. Nitrate levels are higher in the current wetland (1.15 mg N/L) than in healthy wetlands (0.80 mg N/L), which indicates that both nitrification and nutrient enrichment are occurring, and planning is needed as further increases in nutrient levels may lead to eutrophication. Current wetland Total Nitrogen (3.25 mg N/L) and Total Phosphorus levels are 2.50 mg N/L which suggests current wetlands may be receiving nutrient loading from agricultural runoff. Total phosphorus levels in both wetlands are similar which suggests there is no risk of phosphorus enrichment and/ or eutrophication in the current wetland. DON levels are stable, and slightly lower in the current wetland (0.95 mg N/L). The current wetlands NO_3 and total N levels may indicate that the healthy wetlands are also impacted by nutrient enrichment, and planning is required to prevent eutrophication.

Discussion

Analysis of nutrients in the wetland ecosystem shows that cycling of nitrogen and phosphorus is occurring in the typical range for wetlands. However, some parameters are suggestive of nutrient enrichment, particularly in total nitrogen (TN) and nitrate (NO_3^-) concentrations. For example, the ammonium (NH_4^+) concentration of 0.45 mg N/L is within the expected range. That concentration correlates to ammonification, where nitrogen in organic form is converted to ammonium. In addition, the concentration of nitrite (NO_2^-) of 0.02 mg N/L indicates moderate (healthy) nitrification is occurring, and healthy microbial activity is also present at the land water interface. Nitrate concentration of 1.15 mg N/L is also higher than the (natural) background level of 0.80 mg N/L. Therefore, nutrient enrichment is happening in the wetland ecosystem. Also, agricultural runoff may be increasing the nitrogen content of the wetland. That could lead to the risk for eutrophication (nutrient enrichment) and harmful algal blooms. TN (total nitrogen) concentration of 3.25 mg N/L demonstrates the size of the nitrogen pool, but moderate variability of TN concentration is present. The variability may be due to the runoff as well as wastewater discharges. Conversely, total phosphorus (TP) concentration of 0.12 mg P/L is in range observed in healthy wetlands. That TP concentration designates that there is no worrying risk of eutrophication in the wetland ecosystem. Plus, the dissolved organic nitrogen (DON) concentration of 0.95 mg N/L identified an active organic nitrogen processing in the wetland that is happening through the microbial decomposition of the plant material and organic matter. Analysis of the current wetland compared to healthy wetlands reveals that ammonium, nitrite, and phosphorus concentrations are similar, but nitrate and total nitrogen are higher, indicating nutrient loading. This underscores the importance of monitoring external nutrient sources to control the risk of nutrient imbalances and possible future eutrophication. The wetland has adequate functioning in nutrient cycling, but the nitrogen levels indicate that managing external nutrient inputs is critical for water quality.

Conclusion

This study sheds light on the complexity and dynamism of nitrogen cycles at the interfaces between land and water in wetland ecosystems. The results emphasize the importance of wetlands as regulators of nitrogen fluxes required for maintaining water quality, biological diversity, and ecological stability. Nutrient analyses indicated that mean concentration of ammonium was 0.45 mg N/L (standard deviation = 0.15). This observation indicates active ammonification process within wetlands. In addition, nitrate concentrations recorded were 1.15 mg N/L (standard deviation = 0.30). Although this result indicates nitrification processes, it also shows potential for enrichment of nutrients, leading to eutrophication in future if nothing is done. Total nitrogen concentrations of 3.25 mg N/L with standard deviation of 0.80 show healthy status of nitrogen pool. However, the data also suggest potential enrichment of nutrients, most likely from agricultural activities. Low levels of nitrite concentrations (0.02 mg N/L) suggest moderate nitrification while phosphorus concentrations (0.12 mg P/L) are within the expected range of healthy wetlands. The results presented above clearly indicate functioning wetlands; however, enrichment of nutrients poses some threats to wetlands if no measures will be taken. This study has also indicated the importance of seasons and hydrology. The knowledge that is derived from this study will help formulate better approaches for wetland restoration, especially those aimed at improving the nitrogen removal process. Through overcoming the limitations presented by nutrients brought in externally and other environmental factors, it will be possible to ensure that the ecological functions of wetlands remain sustainable. In the future, it would be useful to explore the effects of anthropogenic activities like urbanization and agriculture on the nitrogen cycle, as well as how wetlands can help combat climate change.

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