

Seasonal and Spatio-Temporal Distribution of Nutrients in the Hula Valley after Drainage: A: Nitrogen

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Abstract

Among several soil types in the Hula Valley, the Peat soil occupies a significant part of the agricultural cultivation area. Nitrogen compounds comprise a significant constituent of the chemical components. Cultivation in the Hula Peat land is a critical achievement, whereas nitrogen migration downwards into Lake Kinneret is of national concern. Therefore, sites of nitrogen resource location and spatial and temporal dispersion changes of nitrogenic compounds are critical for the design of effective management strategies. A long-term record (1994-2024) of temporal and spatial concentration fluctuations in relation to climate (rain capacity) conditions was statistically reevaluated. The indicated results emphasized soil moisture as the principal factor affecting nitrogen dynamics. This paper represents descriptively a first-class importance of an environmental factor—the fate and consequently management design of the nitrogen dynamics in the Hula Valley beyond wetlands drainage. The natural climate conditions (rainfall) and anthropogenic (irrigation) fluctuations predominate the soil moisture and consequently the fate of nitrogen. Nitrogen dynamics include nitrification, denitrification, nitrogen-fixation, and other nitrogenic processes. Most of the Hula Valley is under agricultural management and the irrigation regime is therefore affected by management control and its design, including water allocation. The outcome of this paper is therefore beneficial for both cultivation and the prevention of pollutant leaking into Lake Kinneret.

Keywords

Peat Soil, Hula Valley, Nitrification, Denitrification, NO_3 , NH_4

1. Introduction

The ecological conditions reforms in the Hula Valley during the last 100 years

[1] initiated chemical processes where Nitrogen is significantly involved [2]: Ammonification, Nitrification, denitrification, redox reaction (oxidation, reduction), nitrogen fixation, and others. Nitrogen is one of the most common substances in peat soil, and it is a component of several compounds. During the pre-drainage period, Hula Valley swampy wetlands were densely covered with emerged and submerged vegetation. Suspended particles and plant debris settled and accumulated on the bottom, creating a massive deposit of organic matter under anaerobic conditions. The anaerobic conditions dictated the reductive formation of nitrogen compounds such as ammonium [3]. After drainage (1957), the organic matter content of the surface-shallowest layer was exposed to aerobic conditions. In deeper layers, aerobic conditions were gradually diminished and transferred into reductive anaerobic situations. It is therefore likely that complex interactions between Nitrogen compounds and oxygen or mixed environmental conditions are distributed hypsometrically within the Peat soil matter. The research on the impact of man-made changes on nitrogen cycles within the Peat soil in the Hula Valley is based on the evaluation of long-term records (1994-2024) of nitrogen compounds content in the Peat soil drained waters. The ecological studies that accompanied research of wetlands drainage and agricultural landscape conservation, particularly in Peat Land, are presently a worldwide common practice [4]-[10]. The objective of this study is aimed at spatial and temporal range definitions of Nitrogen involvement processes as supportive tools for the design of agricultural management accompanied by Kinneret water quality protection. Soil features in the Hula valley are highly varied and are divided into three major groups: mineral lake sediments, Peat and transitions in between. Peat soil samples (sampling Station No. 57) were collected from the outlet, which flows into Lake Agmon-Hula (LAH). These samples are the optimal presentation of the porewater content of the central Peat soil block. The porewaters within the eastern Peat soil block (sampling station No. 73) are optimally presented in the outlet of its drainage canal, which inflows into LAH.

2. Material and Methods

2.1. Sampling Methodology

Study Site (**Figure 1**):

The Hula Project (HP) territory (**Figure 1**) is part of the entire Hula Valley which constitutes part of the northern section of the Syrian-African Great Rift Valley. HP is bordered between 70 - 61 MASL altitudes and 33°06'12" North and 35°36'33" latitude coordinates.

Sampling Stations (**Figure 1**):

- 1) Underground (GWT) waters were sampled in the 14 boreholes.
- 2) The entrance of Canal Z into Lake Agmon-Hula (LAH). Canal Z conveys drained water from the Central block of Peat Soil.
- 3) The reconstructed Jordan entrance into Lake Agmon-Hula (LAH).

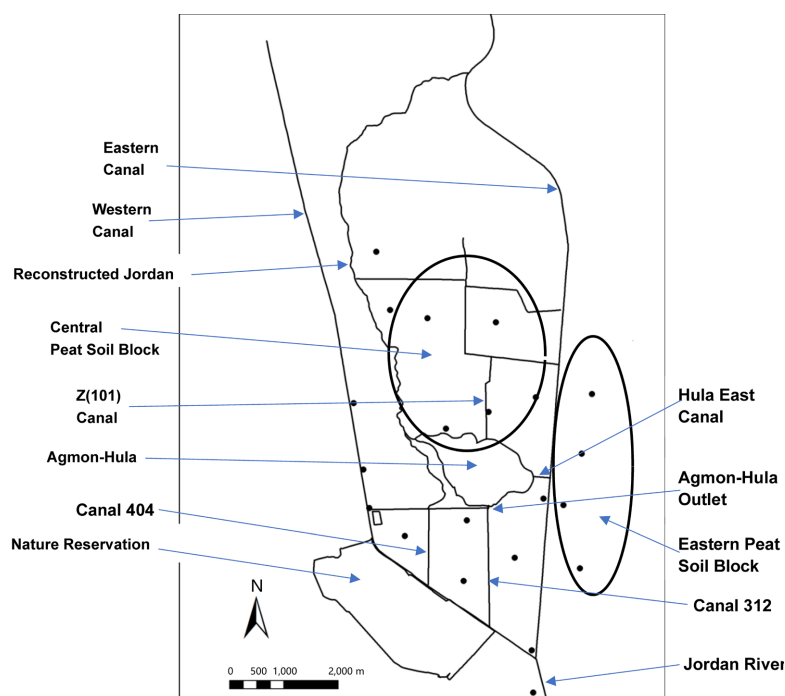


Figure 1. Chart map of the Hula Project territory: Inflow and drainage water lines and Peat soil blocks regions are outlined; Ecosystem compartments are arrowed; black dots are borehole drill locations for the underground water sampling.

2.2. Chemistry

Analysis of Nitrite, Nitrate and Ammonia that were carried out on sampled water. Nitrate analysis was carried out using the Cadmium Reduction (NED) method on a Millipore-filtered sample. Nitrite analysis was carried out by 4500-NO₂-Nitrite Colorimetry method, on Millipore filtered sample [11]. The analysis of ammonia was done using the Indophenol Method, which is based on the formation of a blue color resulting from the reaction between phenol and hypochlorite in the presence of ammonia [11].

The data was obtained from the Hula Project Monitor Program (1994-2024): Migal-Galilee Scientific Research Institute, Jewish National Fund and Israel Water Authority [12]-[18].

2.3. Statistical Methods

Statistical evaluation included the following methods: Quadratic and Linear Regressions (w/CI 95%) and scatter plots. Quadratic and linear regressions (w/CI 95%) are used for modeling relationships between variable distribution with a parabolic best-fit curve, as most likely relevant to the analyses presented in this paper.

2.4. PCA Analysis

Principal Component Analysis (PCA) is a dimensionality reduction technique used in exploratory data analysis for a multivariate Gaussian distribution. The vectors shown and the separate Biplot presentation provide a visualization of the data pre-

processing results. The data is linearly transformed into a new coordinate system such that the directions (principal components) capturing the largest variation in the data can be identified. PCA is used when variables are correlated with each other and it is desirable to reduce their number to an independent set. The first principal component can equivalently be defined as a direction that maximizes the variance of the projected data. PCA defines a new orthogonal coordinate system that optimally describes variance in a single dataset. The statistical evaluation was carried out using the software STATA 17.0—Standard Edition for Statistics and Data Science. Soil features in the Hula valley are highly varied and divided into three major groups: mineral lake sediments, Peat and transitions in between. Peat soil samples (sampling Station No. 57) were collected from the outlet, which inflows into LAH. These samples are the optimal presentation of the porewater content of the central Peat soil block. The porewaters within the eastern Peat soil block (sampling station No. 73) are optimally presented in the outlet of its drainage canal, which inflows into LAH.

3. Results

Table 1 presents the grand total averages (with SDs) of NO₂, NO₃ and Ammonia concentrations (ppm) measured at stations 48, 49, 57 and 73, based on routine sampling from 1994 to 2024.

Table 1. Grand total mean values of NO₂, NO₃ and NH₄ concentrations (ppm) measured in routinely collected samples in stations 48, 49, 57, 73: NO₂ during 1994-2006 and NO₃ and NH₄ during 1994-2024.

Nutrient/Period	Station	Average	SD	n
1994-2006				
NO ₂	48	0.046	0.251	120
NO ₂	49	0.158	0.485	105
NO ₂	57	0.149	0.176	157
NO ₂	73	0.055	0.094	94
1994-2024				
NO ₃	48	1.563	5.461	721
NO ₃	49	2.616	7.453	433
NO ₃	57	9.276	18.282	525
NO ₃	73	3.412	6.450	371
1994-2024				
NH ₄	48	0.162	0.390	564
NH ₄	49	1.454	2.570	484
NH ₄	57	3.315	6.618	519
NH ₄	73	1.011	1.833	400

Results presented in **Table 1** confirm the existence of a great stock of Nitrate in the Peat soil, especially within the central peat soil block. The high amplitude of concentration fluctuations is characteristic of a newly created and not yet stabilized ecosystem. Nevertheless, anaerobic conditions probably initiated ammonification and/or de-nitrification, which occasionally occur when high soil moisture is prolonged. The high level of nitrite concentration during 1994-2006 in LAH when organic matter accumulation was intensive in LAH and already exists in the peat soil (Stn.57) is probably due to anaerobic conditions and de-nitrification [17]-[19].

The seasonal and temporal distribution patterns (Linear regression w/CI 95%) of Nitrate and Ammonia within the Hula Project territory (stations 48, 49, 57, 73) are presented in **Figures 2-9**. The statistical significance of the plot is indicated on both sides of the trend line as NS (not significant) and S (significant).

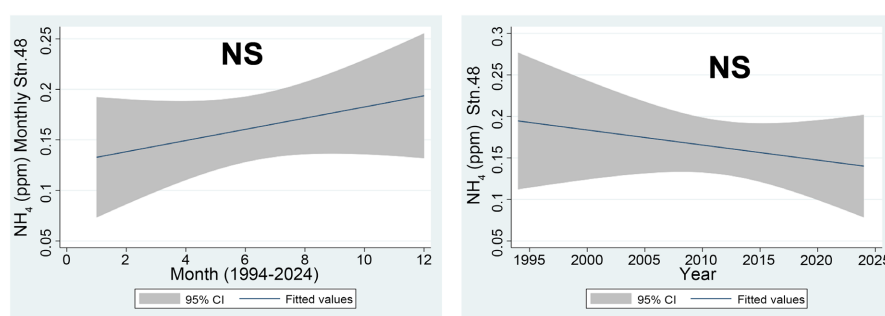


Figure 2. Liner Regression w/CI 95% plot of monthly (left panel) and annual means (1994-2024) (right panel) of NH_4 sampled in Station 48 (reconstructed Jordan), significances are indicated.

Results given in **Figure 2** confirm the existence of rather seasonal and temporal stable NH_4 concentration in the Jordan waters flow within the reconstructed route. The geochemical impact of the Peat soil medium on the Jordan waters composition while flowing through the short distance within Peat Soil medium into LAH is minor.

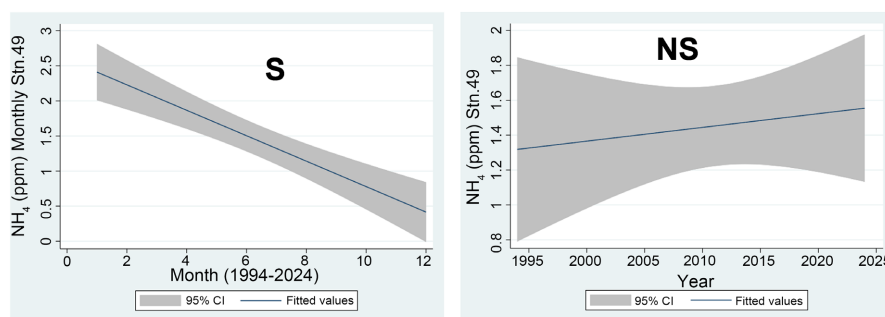


Figure 3. Liner Regression w/CI 95% plot of monthly (left panel) and annual means (1994-2024) (right panel) of NH_4 sampled in Station 49 (Lake Agmon-Hula outlet), significances are indicated.

The information given in **Figure 3** confirms significant seasonal changes, while also indicating insignificant temporal fluctuations. It is suggested that the differ-

ence between winter-spring and summer-fall is due to oxidation enhancement in summer, caused by photosynthetic activity carried out by the development of submerged vegetation growth.

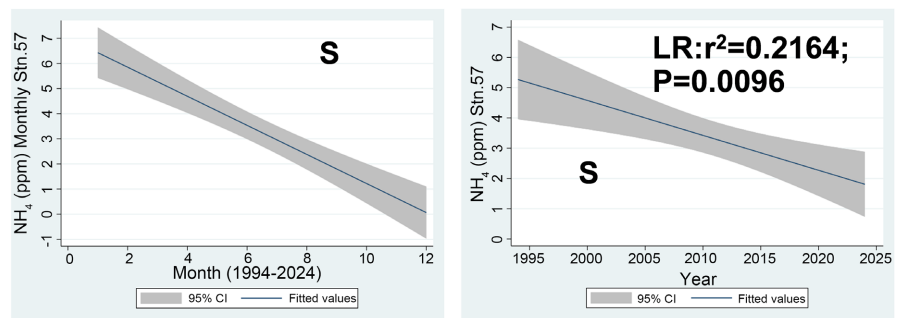


Figure 4. Liner Regression w/CI 95% plot of monthly (left panel) and annual means (right panel) (1994-2024) of NH_4 sampled in Station 57 (Peat Soil drainage), significances are indicated.

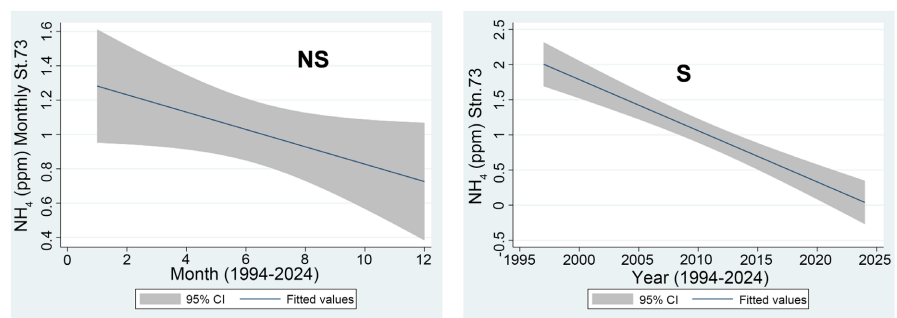


Figure 5. Liner Regression w/CI 95% plot of monthly (left panel) and annual means (right panel) (1994-2024) of NH_4 sampled in Station 73 (Drainage Canal Hula East), significances are indicated.

Results shown in **Figure 4** and **Figure 5** indicate a significant temporal decline of NH_4 concentrations in drained water from the central and eastern Peat soil blocks between 1994 and 2024. It is probably due to the enforcement of oxidative conditions resulting from the HP implementation.

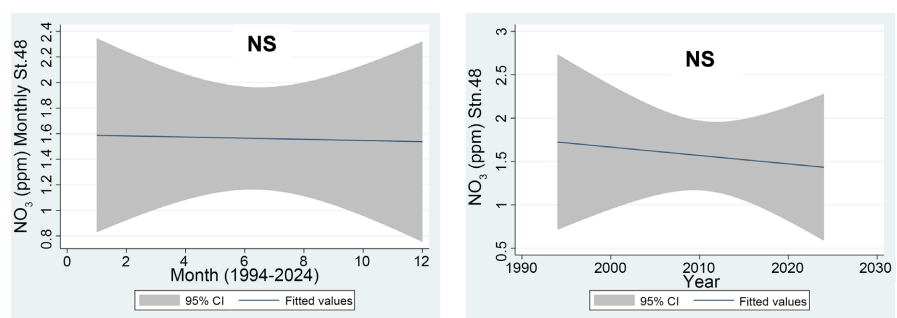


Figure 6. Liner Regression w/CI 95% plot of monthly (left panel) and annual means (right panel) (1994-2024) of NO_3 sampled in Station 48 (reconstructed Jordan) significances are indicated.

The information given in **Figure 6** confirms the seasonal and temporal stability of NO_3 concentration in Jordan waters.

The impact of the Peat soil medium on the Jordan water nitrate content while flowing through the short distance within the Peat Soil medium into LAH is negligible.

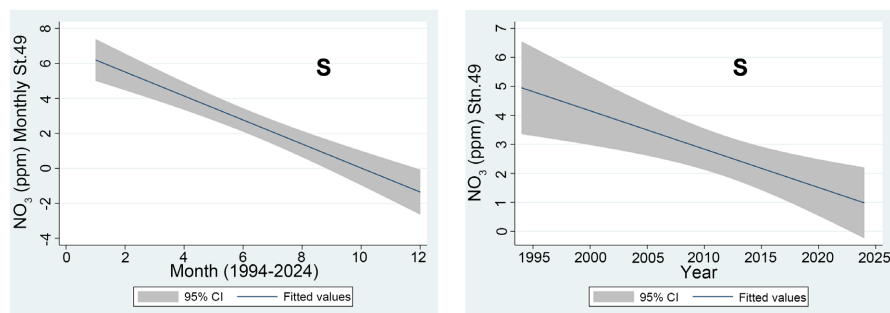


Figure 7. Linear Regression w/CI 95% plot of monthly (left panel) and annual means (1994-2024) of NO_3 sampled in Station 49 (Lake Agmon-Hula outlet), significances are indicated.

Results presented in **Figure 7** indicate a decline of nitrate concentration in the LAH's effluents in summer months when inflows carrying NO_3 are reduced. These inflows are the major suppliers of nitrates to LAH. The temporal decline is attributed to inflow reduction, resulting in a decrease in lake volume and surface area.

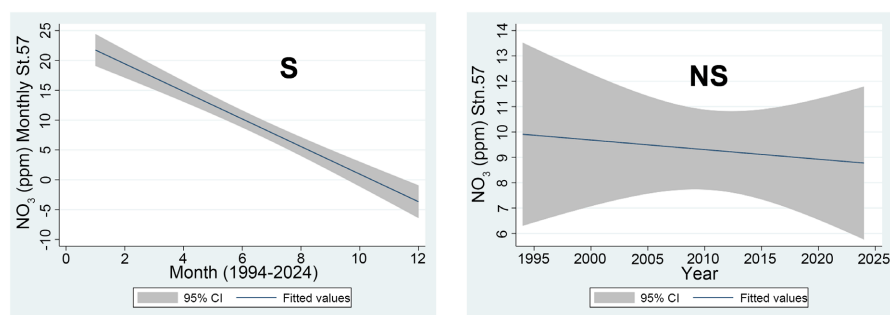


Figure 8. Linear Regression w/CI 95% plot of monthly (left panel) and annual means (right panel) (1994-2024) of NO_3 sampled in Station 57 (Peat Soil drainage), significances are indicated.

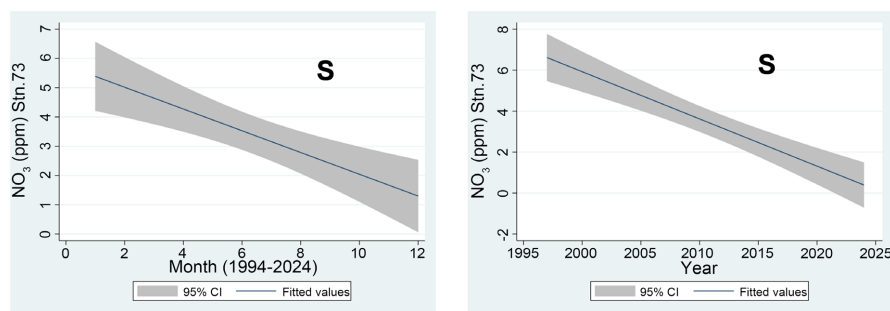


Figure 9. Linear Regression w/CI 95% plot of monthly (left panel) and annual means (right panel) (1994-2024) of NO_3 sampled in Station 73 (Drainage Canal Hula East), significances are indicated.

A distinct confirmation of the correlation between soil moisture and nitrate migration is given in **Figure 8**. As a result of the huge stock of nitrates in the central peat soil blocks, the impact of moisture reduction on the temporal migration pattern is minor.

Results given in **Figure 8** and **Figure 9** indicate a significant decline of NO_3 in summer when soil moisture declines and oxidative conditions enhance. Moreover, results shown in **Figure 10** indicate a direct positive correlation between concentrations of NO_3 and NH_4 in all stations (48, 49, 57, 73). The NO_3 decline is due to diminished moisture whilst the NH_3 decline is due to enhancement of oxidative condition.

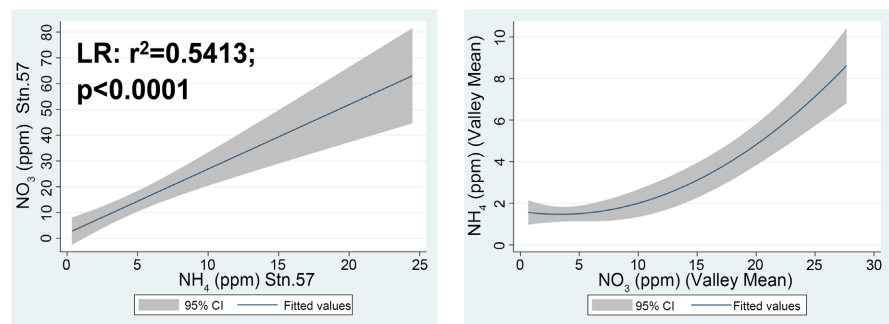


Figure 10. Annual mean (1994-2024) of NO_3 (ppm) Versus NH_4 (ppm): Left: Central Peat Soil Block (Stn.57); Right: Total Valley means.

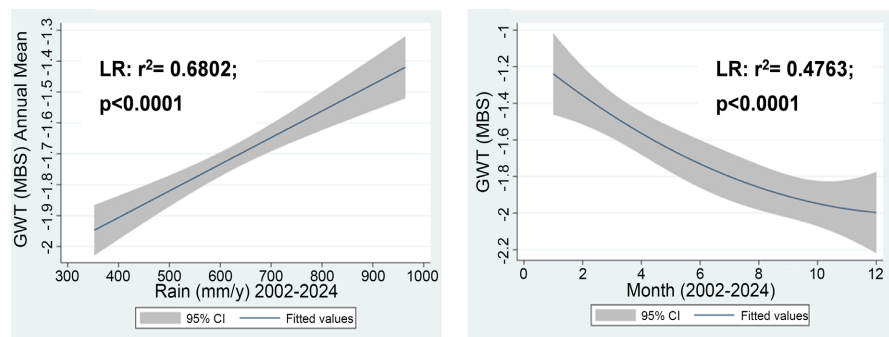


Figure 11. Right panel: Monthly changes of Total Valley Mean (1994-2024) GWT (Ground Water Table) depth (Meter Below Surface; MBS): Left Panel: Temporal changes of annual Total Valley Mean (1994-2024) GWT depth (MBS) in relation to annual rain capacity (mm/y, Dafna).

Results given in **Figure 11** indicate a close relation between rain intensity, and consequently soil moisture, and the GWT depth. The higher the rain intensity, the shallower is the GWT. Long-term elevated soil moisture might be an achievement of nitrogenic nutrient migrations, which probably encouraged the amplification of reductive conditions.

A brief conclusive summary of the result presentation includes the different impact factors on the fluctuations of nitrates in drained waters from the central and eastern peat block, LAH effluents, and the Jordan waters.

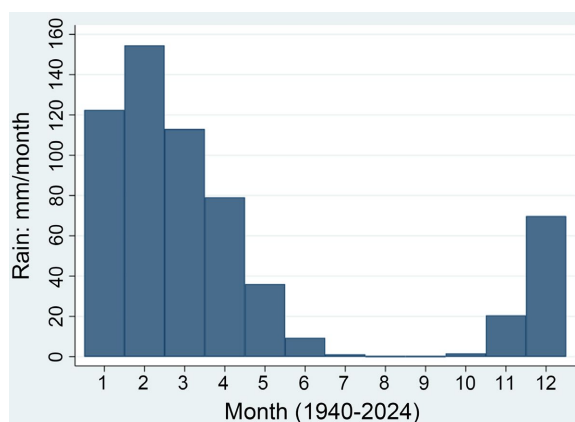


Figure 12. Monthly means (1940-2024) of Precipitation (Dafna, mm/y).

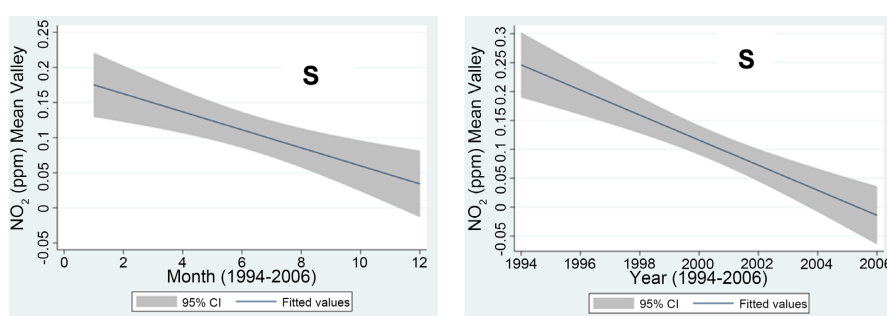


Figure 13. Linear Regression (w/CI 95%) plot (Significance (S) indicates) of seasonal (monthly) and Annual (1994-2006) changes of NO₂ concentrations (ppm) as valley means (48, 49, 57, 73 stations).

4. Discussion

Four major microbiological-chemical cycles of Nitrogen occur within the Peat soil in the Hula Valley: Nitrification, Denitrification, Ammonification and Nitrogen fixation.

4.1. Denitrification

Denitrification is a microbial reductive process where Nitrogen is converted to the final product of molecular N₂. The intermediate stages of this process include gaseous Nitrogen oxides. These microbial stages are carried out by different bacterial species (De-nitrifiers) and their rate of activity is not similar. Oxidation of organic matter (electron donor) is responded to by Nitrogen oxide reduction (electron acceptor) which is denitrifier respiration (source of energy). Therefore, metabolic energetic demands such as oxygen or organic matter substrate are minimal, and the process condition is anaerobic. Eventually, the preference order of Nitrogen oxide stages during the denitrification process is: NO₃ (Nitrate), NO₂ (Nitrite, Nitrogen dioxide), NO (nitric oxide), N₂O (nitrous oxide), N₂ (dinitrogen).

4.2. Nitrification

This is a microbiological process comprised of several stages that originated as

consumption of Ammonia (NH_3) and terminated as Nitrate (NO_3) production via intermediary nitrite (NO_2). The process of complete nitrification occurs through different bacterial species. The most common bottleneck (limiting factor) of the nitrification chemo-microbial chain of events is the rate of nitrite (NO_2) production. Other limitations are also predicted under substrate (organic matter, NH_3 contents), such as a reduction of availability, which is unpredictable in the Hula Peat soil, and the development of anaerobic conditions. Moreover, the rate of NO_2 is faster than NO_3 production. Therefore, the accumulation of NO_2 might be an indication of Nitrification's existence. The entire process of nitrification is an obligatory demand of aerobic conditions.

4.3. Ammonification

The high content of Ammonia (NH_3) in the Hula Peat soil originated through different processes: 1) Microbial and fungal decomposition of vegetation substances during the pre-drainage period of the Hula wetlands. 2) Denitrification during the post-drainage period. Ammonia production through direct reduction of nitrate to ammonia is also maintained by denitrifier bacteria (dissimilatory nitrate reduction to ammonium) (DNRA), where natural nitrogenic compounds are broken into ammonia. Nevertheless, most of the Ammonia content in the Peat soil originates from the ammonification of organic matter containing organic Nitrogen is likely.

4.4. Nitrogen Fixation

Nitrogen Fixation (NF) is a microbial process in which atmospheric dinitrogen (N_2) is converted into Ammonia (NH_3), catalyzed by the enzyme Nitrogenase. Several terrestrial Nitrogen-fixing bacteria are symbionts of vascular plants that occupy root system tissues. Alfalfa (*Medicago sativa*) of the legume Fabaceae family is well-known to host species. Alfalfa was intensively cultivated on the Hula Peat soil land but later was drastically reduced, resulting in frequent rodent (*Microtus socialis*) outbreak infestations. Nevertheless, a relation between Gypsum-sourced sulfate distribution and nitrogenase rate of activity was documented. Information about terrestrial nitrogen fixation is very scarce.

Nutrient migrations from the Hula Valley into Lake Kinneret through the Jordan River are a long-term subject of research. Shortly after the completion of the Hula drainage, the major concern about potential Kinneret water quality deterioration was directed to nitrates. The reason for that was the newly developed oxidative conditions within the drained Peat soil land. Nonetheless, optional opportunities for the increase of ammonium concentration in the peat soil were not highly considered. Lesser scientific attention was attributed towards the creation of anaerobic conditions accompanied by denitrification, and/or ammonification enhancement. Nitrogen fixation did not attract research during earlier stages, but it was enhanced in relation to the expanded cultivation of Alfalfa. Nitrogen processes became an intensive research issue during agricultural development and

the implementation of the reclamation project (Hula Project, HP, 2006) [1] [2]. Public awareness after drainage was directed to Nitrate migration whilst during the 1970s and early 1980s, organic nitrogen accompanied by Ammonia, Phosphorus and intestinal microbiota became major awareness factors. As a result, potential sources were managed: raw sewage was removed and fishponds were restricted from 1700 to 350 ha.

The fate of nitrogen within the Hula Valley ecosystem during the post-drainage period is indicated as a key factor in the management design. The development of geochemical transformations of Nitrogen forms is defined as simultaneously multidirectional. Thought-chained environmental conditions determine the potential outcome direction. In water that contains a high proportion of organic nitrogen, the ammonification process will predominate. The process of organic matter oxidation, mostly nitrification, dominated the nitrogen transformations after drainage. The produced nitrate is partly consumed and mostly migrated [5]. The most important inorganic forms of nitrogen in wetlands (or drained wetlands, as Hula Valley) are Ammonia (NH_3), Ammonium (NH_4), Nitrite (NO_2), Nitrate (NO_3), Nitrous Oxide (N_2) and dissolved or gas elemental Nitrogen (N_2). The Ammonia/Ammonium proportion depends on temperature and pH. Denitrification depletes and nitrification enriches atmospheric nitrogen. Nonetheless, denitrification accompanied the heterotrophic metabolism of bacteria under conditions of anoxia [5].

The chained sequence of rain capacity, headwater discharges, irrigation and water availability control soil moisture and consequently nitrogen migration. Another sequenced chain direction of aerobic/anaerobic reflecting oxygen availability determines nitrification or denitrification control [4] [5] [7] [8]. Moreover, the impact of the drainage, enhanced significantly the ecosystem's internal interactions and external consequences as well whilst during pre-drainage, the ecosystem was more stable [6] [9] [10] [20] [21]. The drainage resulted in the loading enhancement of nutrients in the Jordan River. The oxidative degradation of the peat was followed by aeolian and riverine transport of nutrients into Lake Kinneret. During the 1980s, the decline in the aeolian transport of dusty peat to LK was recorded [22] [23]. The fishpond restriction and sewage removal carried out during 1970-1980, in the Hula Valley resulted in the decline of the annual mean of organic-N in the Jordan (Huri, sampling station) from 1.3 to 0.4 ppm [22] [23].

Nitrogen transformations are operated by bacteria: nitrifiers, denitrifiers, ammonifiers, and nitrogen fixers, which are at different stages by different bacterial species. Protein-contained substances disintegrate through the ammonification process, where ammonium is the final product. Ammonia is oxidized by Nitrosomonas to nitrite, which is converted by Nitrobacter to nitrate. The backward process is operated by denitrifiers with the end product of molecular dinitro (N_2). The maintenance of the terrestrial denitrification process exists under anaerobic conditions by bacteria hosted in the roots of *Papilionaceae* (*Fabaceae*) plants. Nitrate (NO_3) is the end product of nitrification whilst Nitrite (NO_2) might be an

intermediate stage of both nitrification and denitrification [24]. Moreover, the rate of aquatic and terrestrial denitrification is similarly dependent on anaerobic conditions and nitrate availability. The higher is the nitrate available, the higher the power of the denitrification process. Aquatic nitrogen oxidation is progressed by free oxygen consumption and when it is used up, the oxygen demand for nitrate reduction is consumed and finally when this is out, the executive source of oxygen is reduced sulfate producing sulfide [24]. As of today, such full-chained processes producing very low concentrations of sulfide have rarely been documented in bottom sediments of LAH [17]-[19] [25].

The hypsometrical distribution of nutrients was defined for three depth levels [26]: the shallowest level of surface water, the intermediate level of the underground water table (GWT) and the deepest level of Lignite waters. Organic Nitrogen, Sulfate and Nitrates are mostly Hula Valley-originated nutrients whilst most of the Phosphorus contributed externally to Lake Kinneret which originates outside the Hula Valley. An underground north-south hydrological gradient and nutrient migration were indicated. Hypsometrical downward migrated nutrients probably accumulate within the “Lignite” level [26]. Information about the underground water dynamics in the Hula Valley was previously documented [27]. A vertical plastic sheet (4.5 m deep) was placed 2.8 km across the valley, dividing the underground space into northern-organic and southern mineral soil blocks. The groundwater table (GWT) in the northern part of the valley is shallower than in the south, and seasonal fluctuation amplitudes are smaller in the north. A higher level of ammonium was documented in the southern underground waters but not for Nitrate (NO_3) concentrations. Nutrient concentrations in the Southern underground waters were higher than those in the North partly because of mediated nutrient water migration. This migration occurred underneath and/or aside from the plastic barrier, driven by the hydraulic gradient as water moved from north to south [27].

The information about the temporal, seasonal and hypsometrical distribution of Nitrogen compounds in the Hula Valley prevailed from routine long-term (1994-2024) Hula Project monitor program in the sampling stations of Lake Agmon Hula (LAH) outlet (No. 49), drainage canal Z (No. 57), reconstructed Jordan (No. 48), Hula East which conveys drained water from the eastern block of Peat soil No.73), and Ground Water Table (GWT) pumped from 14 boreholes (Figure 1). The evaluation of the role of nitrogenic microbial-chemical process impact is the result of the interpretation of nitrogen species distribution, climate conditions, and the location of the sampling station.

The potential impact of N cycling in the Hula Peat soil and seasonal variations in N isotope composition have been documented in Lake Kinneret [28]. It is a useful methodology providing a biogeochemical tool for studying N cycling in lakes and ecological changes in N source and cycling in response to watershed land use changes and climate change [27] [28]. The interaction between deposited nitrogen and salinization in the tree (*Torreya grandis*) tissues that were studied

indicated that an increase in H_2O_2 in the leaves was induced by the elevation of salinity and moderate nitrogen enhancement can mitigate salt damage [29]. Those terrestrial and aquatic case studies of nitrogen conversion are likely relevant to the analysis of nitrogen dynamics in the Hula Valley.

Before the Hula drainage, the ecosystem maintained rather stable anaerobic conditions within the wetlands-swampy ecosystem [3]. The ecological Instability is induced mostly by precipitations and headwater river discharges and, to a lesser extent, by anthropogenic intervention such as fishery, livestock grazing and moderate commercialized removal of reed (*Typha domingensis*), including intentioned controlled fire. None of these ecological factors caused fundamental habitat changes. Therefore, under the existing anaerobic conditions, the majority of the ecosystem's nitrogen load was in the form of ammonia and organic nitrogen. After Hula drainage, the diversity of geochemical conditions was enriched and external (atmospheric and terrestrial) impact became more effective and intensive. This resulted in the occurrence of nitrogenic processes such as nitrification, denitrification, and later also nitrogen fixation through Alfalfa cultivation. The drainage expedited the elimination of factors of ecological stability in the newly created ecosystem, and the impact of climate change intensified. The positive relation between rain capacity and soil moisture and the depth of GWT-induced nitrogen dynamics fluctuations within the various habitats in the valley. Different habitats include Jordan waters, LAH, Pure Peat and other soil types such as transition-Peat and mineral soil [1] [2] [30] [31]. The occurrence of denitrification in wet Pure Peat soil became more frequent whilst the potential for nitrification in transition and mineral soil is higher.

Heterotrophic diazotrophs are potentially important agents in freshwater ecosystems and terrestrial cultivations of special plant species. The contribution of freshwater heterotrophic diazotrophs as free-living or aggregate-associated cells to total N_2 fixation in the Jordan River was recently documented [32]. Heterotrophic diazotrophs accounted for 25% to 56% of the total diazotrophs and were commonly found as free-living cells or attached to aggregates in the Jordan River.

The major load of nitrogen in the Hula Valley is accumulated in the central block of the Peat soil (Table 1). Nevertheless, internal interactions between ecological parameters within the LAH ecosystem are not different from those known in shallow lakes [20] [33]: The oxidation of the accumulated organic matter, as well as nitrification and denitrification, are dependent on dissolved oxygen (DO) content which is diffused from the atmosphere and by submerged vegetation photosynthesis. Nevertheless, a significant impact on the entire ecosystem is due to regional rain capacity dictating headwater discharges, soil moisture and accumulated organics in LAH. Heavier discharge enhances organic matter accumulation in the LAH whilst reducing DO content, which encourages denitrification. Although the supply of Jordan water (Station 48) mediated ammonia exhibits seasonal and temporal changes, these fluctuations are relatively minor (Figure 2). It is therefore likely that the impact of Peat soil on Jordan water nitrogen content is

minor. Unlike low fluctuated ammonia in the Jordan waters, its concentration in LAH highly fluctuates: significant summer decline (**Figure 3**) resulted from intensive oxidation of organic matter due to the enhancement of photosynthetic Oxygen produced by the biomass increase of submerged vegetation. Nevertheless, following the peak in vegetation biomass, plant tissues rapidly degrade, consuming excess oxygen and leading to partial anoxia. This is accompanied by denitrification and a subsequent decline in nitrate levels (**Figure 8**; Station 57). Most of the ammonia in the Hula Valley accumulates in the Peat soil of the central block, as confirmed by its content in drained water (**Figure 4**; Station 57). Evaluation of the long-term record of nitrogen migration in the Hula Valley justifies the conclusion about its correlation with soil moisture. During summer months (seasonal) or periods of low rainfall, reduced soil moisture and diminished drain capacity typically occur, followed by a decline in ammonia concentrations in Canal Z (**Figure 4**, Station 57). The impact of two factors is involved in the case of ammonia accumulation in the Peat Soil: The climate effect of rain-river discharges and soil moisture enhancement as an intermediate stage within the nitrification and denitrification process. The similar seasonal fluctuation patterns observed in NO_3 and NH_4 concentrations (**Figure 5** and **Figure 8**) in the drained waters of central and eastern Peat soil blocks further confirm that both factors are interconnected. The nitrate stock that accumulated in the central block of the Peat soil is very high and temporal climate change is therefore confounded (**Figure 8**) and not significant. The summer decline of nitrate in LAH (**Figure 7**) is due to both denitrification [8] [9] [20], and reduction of lake water mass, water body shrinkage, and inflows decline of mediated nutrients input. The summer decline of Nitrate concentration in the eastern Peat soil block drained waters is likely a result of soil moisture decline as well as reduced freshwater seepage and nitrate migration (**Figure 9**). Evaluation of ammonia and nitrate concentrations in drained waters throughout the entire valley (Stations 48, 49, 67, 73) confirms pattern uniformity of concentration changes (**Figure 10**). The response of nutrient migration patterns to climate changes confirms similarities. Moreover, the correlation between rain capacity and the depth of GWT confirms the impact of climate change on nitrogen form concentration dynamics in drained waters. During spring-summer-fall months, soil moisture declines and GWT deepens, whereas they rise during the rainy season (**Figure 11**, **Figure 12**).

4.5. Nitrite Distribution

The record of NO_2 samples analysis covers a shorter period of 1994-2006 (**Figure 13**). Since NO_2 is an intermediate stage in both nitrification and denitrification processes, relying solely on chemical analysis at a specific sampling point is insufficient. Additional environmental information is necessary to support and contextualize the findings. As previously indicated, nitrate migration within the Peat soil is dependent on soil moisture and therefore nitrite changes reflect nitrification and soil moisture fluctuations.

Conclusively, the sources, migration, and dynamic properties of nitrogen in the Hula Valley are crucial for the present and future hydrological and agricultural management design, especially under global climate changes and regional water scarcity. Beneficial properties include agricultural efficient production accompanied by Kinneret water quality protection. The control of factors of limitation, such as hydrology and nutrient resources, are located in neighboring countries, which are outside of this paper's scope.

5. Conclusions

The range of nitrification and denitrification processes in the Hula Peat soil is mostly affected by soil moisture, which also indirectly dictates oxidative conditions. The information presented in this paper contributes a partial response to two questions: 1) What is the fate of the nitrogenic substances in the Hula valley after drainage, and 2) What is the practical importance of the results? The response to the 1st question is given in the paper results, and discussion, and the outcome of the 2nd question is a recommendation for future wider and deeper research on the impact of peat soil moisture on nutrient dynamics in the Hula Valley.

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Author Contributions

The author carried out data analysis, and evaluation and the preparation of the original draft and final version.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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