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The Impact of Hula Project (1993-2018) on Nutrient Migrations

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Abstract

During the 1950s the Hula wetlands and old lake were drained and the land converted utilization to agriculture and ecotourism. As a result of the drainage, the Peat Soil was exposed to atmospheric oxygen. The geochemical environment was modified from reductive to oxidative and the Nitrogen in it was converted from Ammonium to Nitrate. Intensive migration of Nitrate from the Hula Valley induced a national concern of water quality deterioration in the lake which was dissipated when Nitrogen deficiency was developed in Lake Kinneret. Forty years after drainage the ecosystem structure was renovated (Hula Project, HP) aimed at agricultural management and nutrient migration reduction. The paper examines through evaluation of the ecological data record (1993-2018) the impact of hydrological changes, attributed to the HP implementation on nutrient dynamics within surface waters in the Hula Valley. It is suggested that soil moisture elevation by irrigation in summer reduced Phosphorus and enhanced Nitrate concentrations.

Keywords

Nitrogen, Phosphorus, Migration, Runoff, Peat Land, Headwaters

1. Introduction

The Kinneret Drainage Basin area is 2730 km^2 of which the Hula Valley is 200 km^2 (7.3%). Since the late 1950s Lake Kinneret and the Hula Valley have been a compatible interlock of anthropogenic achievement in the national economy, water supply, agriculture, nature protection and tourism management. The Kinneret catchment includes three major headwaters, Hazbani (Snir), Banias (Hermon) and Dan which combined into one Jordan river inflow into lake Kinneret. The mean annual discharge of Hazbani, Banias and Dan is 59, 59, and 216 mcm (10^6 m^3) respectively and the recent Jordan River is 357 mcm. River Jordan contributes about 63% of the Kinneret water budget and also conveys more than 70% of Kinneret nutrient inputs [1] [2] [3] [4] [5], (Glass and Miller unpublished data).

During 1953-1957 the Hula wetland and old lake Hula were drained and the natural habitat was converted into agricultural development. This fundamental modification of environmental structure was followed by changes in the eco-hydrological and nutrient migration dynamics. During 40 years of post-drainage management and inappropriate management, the need for ecosystem structure renovation induced the implementation of the Hula Project Proposal that was completed in 2006 [1] [2] [6]. Evaluation of scientific information and documented data records carried out during the post drainage and Hula Project implementation, (1993-2018) was carried out [1] [6] [7] [8] [9]. During the implementation of the HP, from 1993 and later on, intensive research and monitor program were carried out [1] [2] [6] [7] [8] [9]. The present paper is an attempt to open an insight into the impact of anthropogenic involvement on nutrient dynamics and its implication on their migrations. One of the Hula Project conclusions emphasized the need to increase soil moisture in summer by irrigation of cultivated and uncultivated land. As a result, a contract was agreed upon between the National Water Authority and the Regional Agricultural Municipal Company ("The Peat Convention"). This agreement ensured the enhancement of summer soil moisture through water pricing discounts for irrigation [1]. The present paper is aimed at the study of the resulted "Peat Convention" implementation on both ecosystems, the Hula Valley and Lake Kinneret: Removal of Phosphorus and harmless Nitrate migrations.

2. Methods

The data of nutrient concentrations and loads in river Jordan and Kinneret Headwaters were taken from periodical and annual reports published by the Monitor Unit Jordan Districts, Mekorot Ltd., Kinneret drainage Basin and Kinneret Limnological Laboratory, IOLR Ltd. [3] Kinneret Limnological Laboratory Data Base and annual reports and Kinneret Drainage Authority Interim Reports. Data about nutrient concentrations in the runoffs in the Hula Valley were taken from the "Hula Project", Migal, annual reports [1] [4]-[9]. Headwater River Discharges, (mcm, million cubic meters; 10^6 m^3): [10], Water Authority, State of Israel, Hydrological Service Department, Annual and Monthly reports; River Dan discharge, Unpublished Data, Water Organization, Upper Galilee Municipality, S. Glass and H. Miller.

3. Results

Figures 1-7 include Linear Prediction (w/CI; 95%) plots of correlations between seasonal (monthly) and annual (1993-2018) temporal nitrogenous, phosphorous matters and sulfate nutrients and month or Years. Results given in **Figure 1**, **Figure 2**, **Figure 4** and **Figure 7** indicate a significant decline of Nitrate (NO_3),

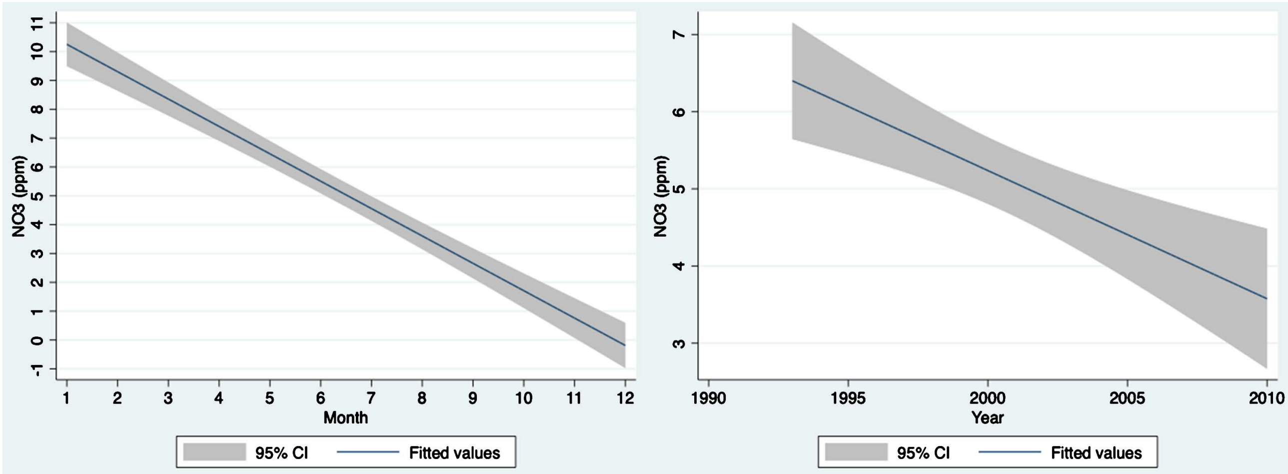

Figure 1. Linear Prediction (w/CI; 95%) plot of the correlation between monthly (left) and annual (1993-2018) (right) mean concentrations of NO_3 (ppm) and periodical time (month, year).

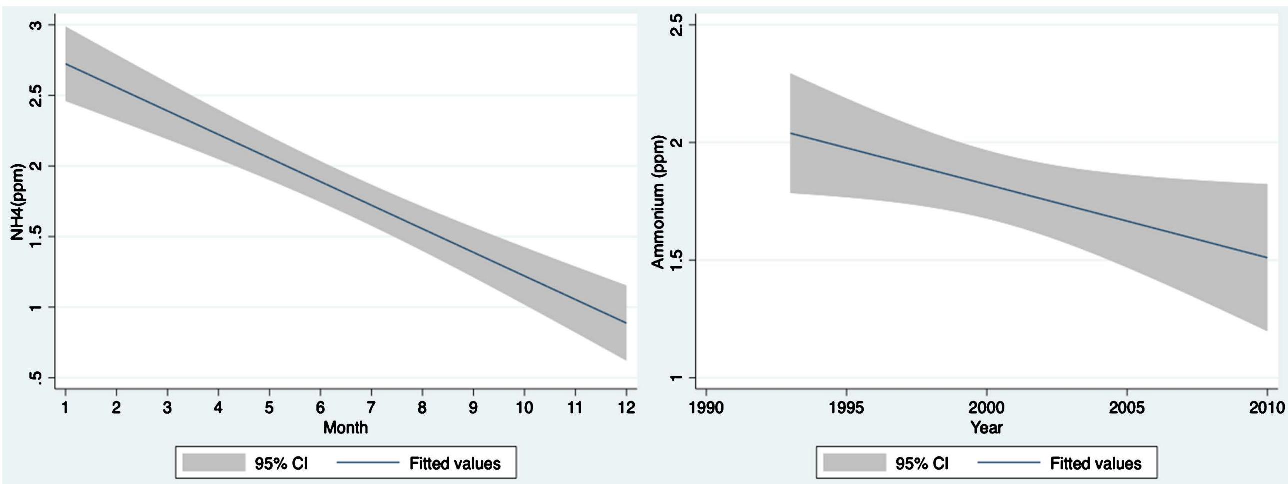

Figure 2. Linear Prediction (w/CI; 95%) plot of the correlation between monthly (left) and annual (1993-2018) (right) mean concentrations of NH_4 (ppm) and periodical time (month, year).

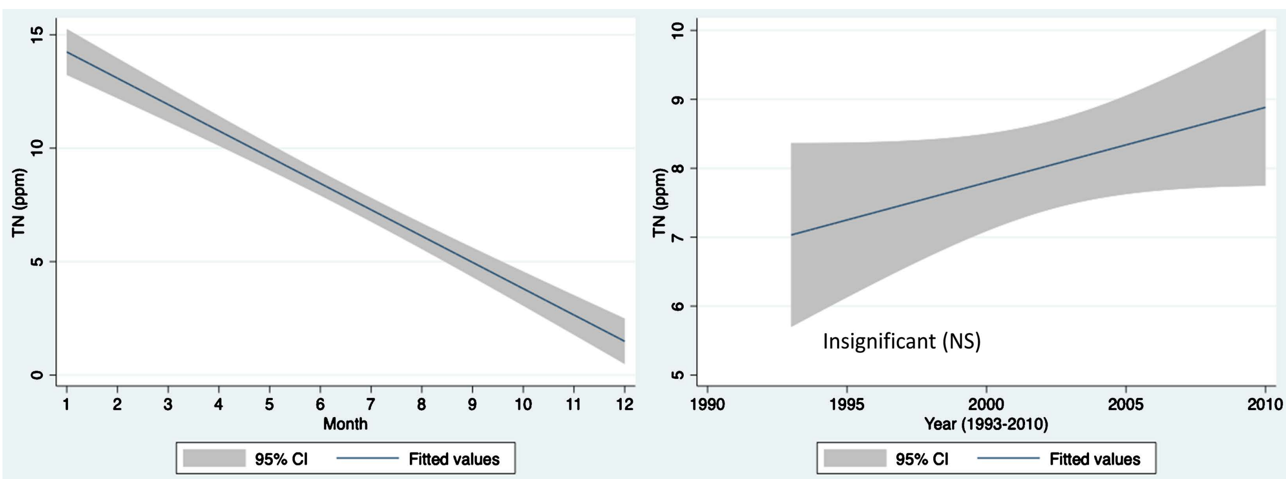

Figure 3. Linear Prediction (w/CI; 95%) plot of the correlation between monthly (left) and annual (1993-2018) (right, insignificant) mean concentrations of TN (ppm) and periodical time (month, year).

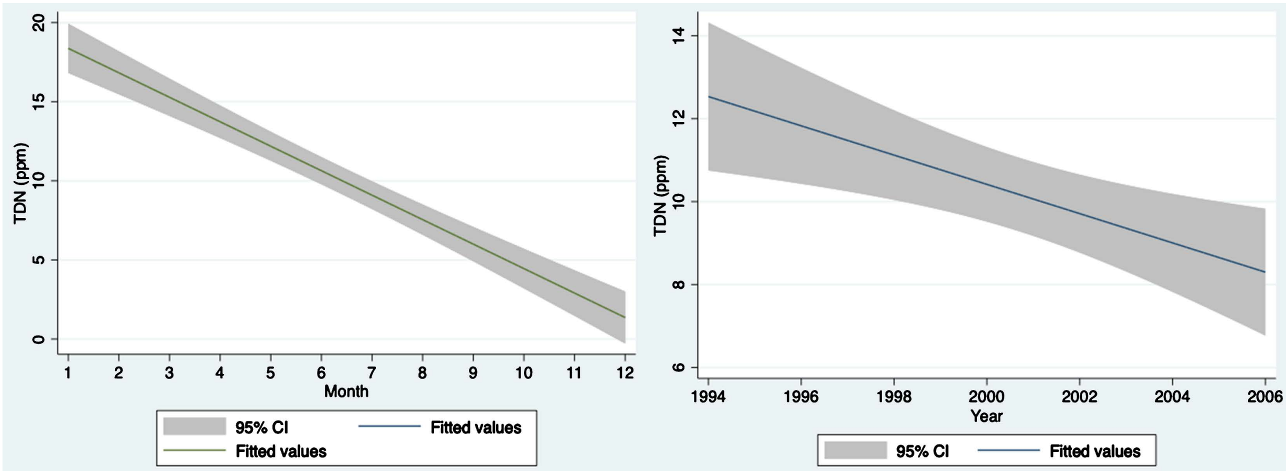

Figure 4. Linear Prediction (w/CI; 95%) plot of the correlation between monthly (left) and annual (1993-2018) (right) mean concentrations of TDN (ppm) and periodical time (month, year).

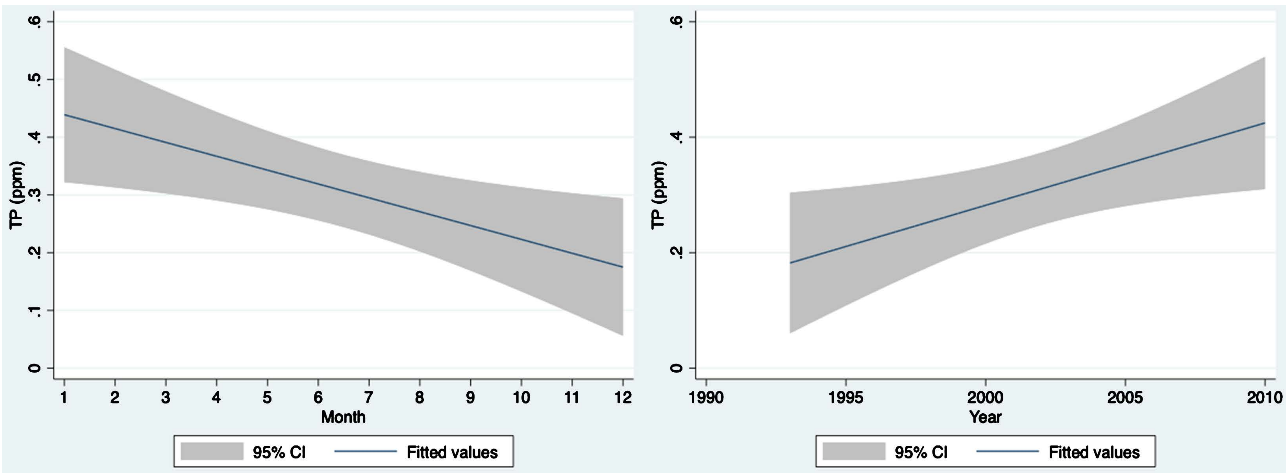

Figure 5. Linear Prediction (w/CI; 95%) plot of the correlation between monthly (left) and annual (1993-2018) (right) mean concentrations of TP (ppm) and periodical time (month, year).

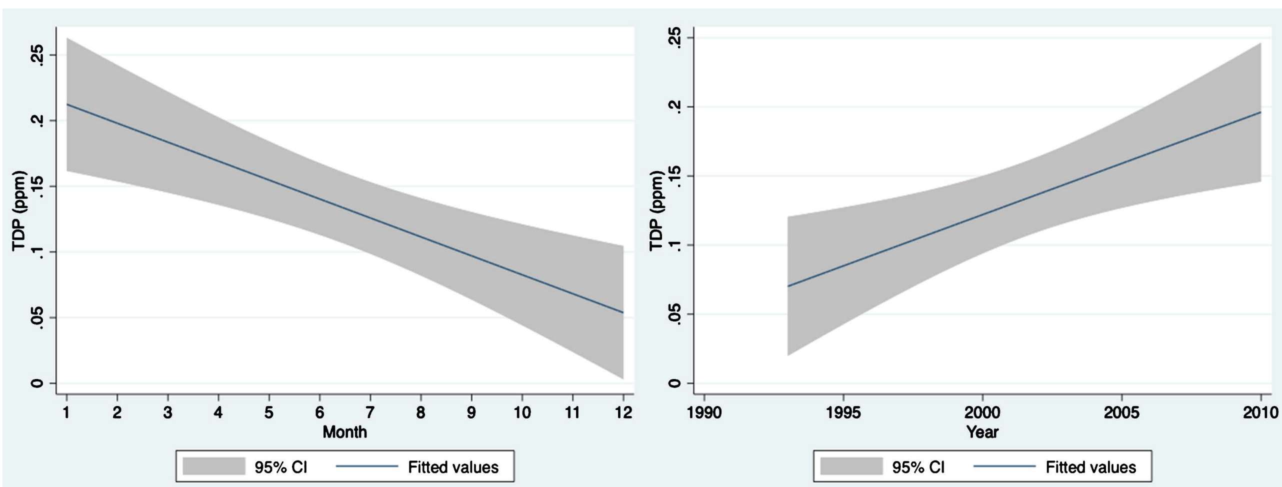

Figure 6. Linear Prediction (w/CI; 95%) plot of the correlation between monthly (left) and annual (1993-2018) (right) mean concentrations of TN (ppm) and periodical time (month, year).

Ammonium (NH_4), Total Dissolved Nitrogen (TDN), and Sulfate (SO_4) concentrations during spring-summer months respectively to rain and river discharge decrease. The correlative relations between nitrogenous matter concentrations and monthly and annual rain and discharge capacities are confirmed. The annual changes in TN concentration indicate exceptional but insignificant relations whilst the monthly change pattern is similar to the other Nitrogenous forms as well as Sulfate. The summer decline of TP and TDP is similar to the monthly pattern of nitrogenous matters resulting from being mostly dependent on local summer conditions. Major parts of Phosphorus sources within the Kinneret catchment are external to the Peat Land, and partly as dust deposition [11]. Therefore, the regional dryness trend enhances their temporal-annual concentration and consequently migration capacity (Figure 5 and Figure 6 annual changes).

The annual-temporal (1970-2018) changes in discharge capacities of the two major headwaters, Dan and Hazbani Rivers are given in Figure 8. Discharge stabilities in both rivers except for a recent decline in the Dan River are indicated

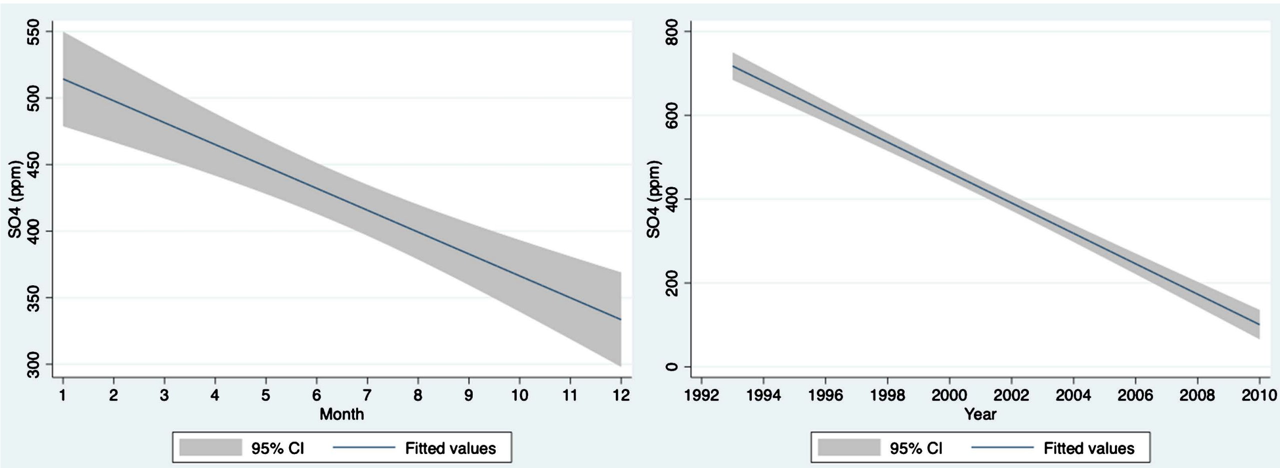

Figure 7. Linear Prediction (w/CI; 95%) plot of the correlation between monthly (left) and annual (1993-2018) (right) mean concentrations of SO_4 (ppm) and periodical time (month, year).

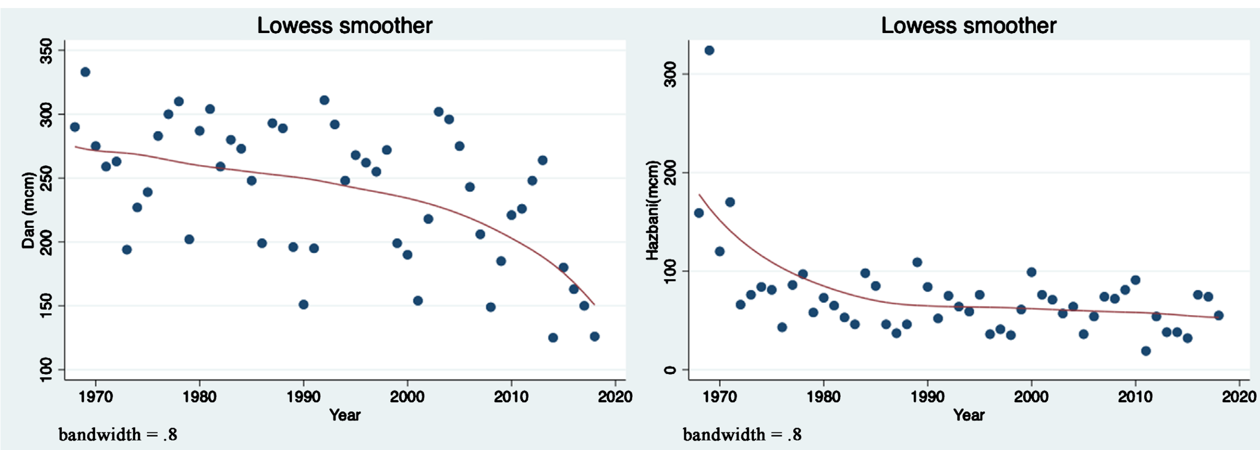

Figure 8. Lowess Smoother plot of the temporal (1968-2018) fluctuations of the Headwter (Dan-left, Hazbani-right) annual discharge (mcm/y).

(**Figure 8**). The recent decline of Jordan discharge expressed as Lowess Smoother and Linear Regression (w/CI 95%) plots are given in **Figure 9**. Pattern similarity of the temporal distribution of rain capacity (Dafna station, northern Hula Valley) indicates recent decline (**Figure 10**) by two plot methods: Lowess Smoother and Linear Regression (w/CI; 95%). The significant and obvious correlation between rain and Jordan discharge capacities is presented in **Figure 11**.

The temporal (1993-2018) three summer months, August-October changes of TP concentrations in surface waters in the Hula Valley are shown in **Figure 12** where distinct elevations occur during the drought period (2014-2018). The significant Linear (w/CI; 95%) Correlation between Jordan discharge and nitrogenous matters (TN, NO_3) and SO_4, and obviously with rain capacity (**Figure 11**), are presented in **Figure 13** and **Figure 14**.

4. Discussion

The impact of rainfall and river discharge capacities on nutrient migrations were

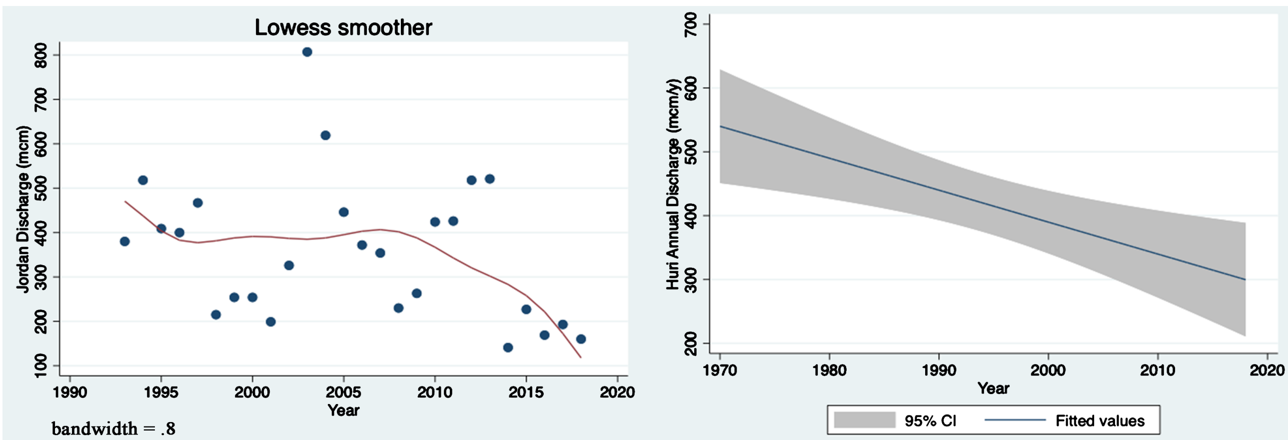

Figure 9. Temporal (1968-2018) fluctuations of the annual discharge (mcm/y) of River Jordan: Left-Lowess Smoother plot; Right-Linear Prediction (w/CI; 95%) plot.

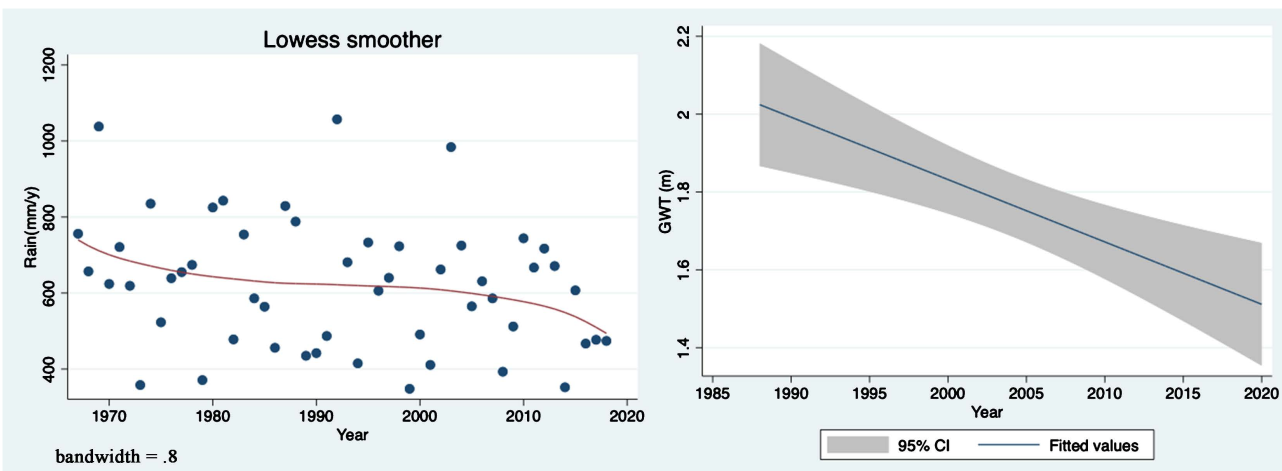

Figure 10. Temporal (1968-2018) fluctuations of the annual Rainfall (mm/y) (Dafna Station): Left-Lowess Smoother plot; Right-Linear Prediction (w/CI, 95%) plot.

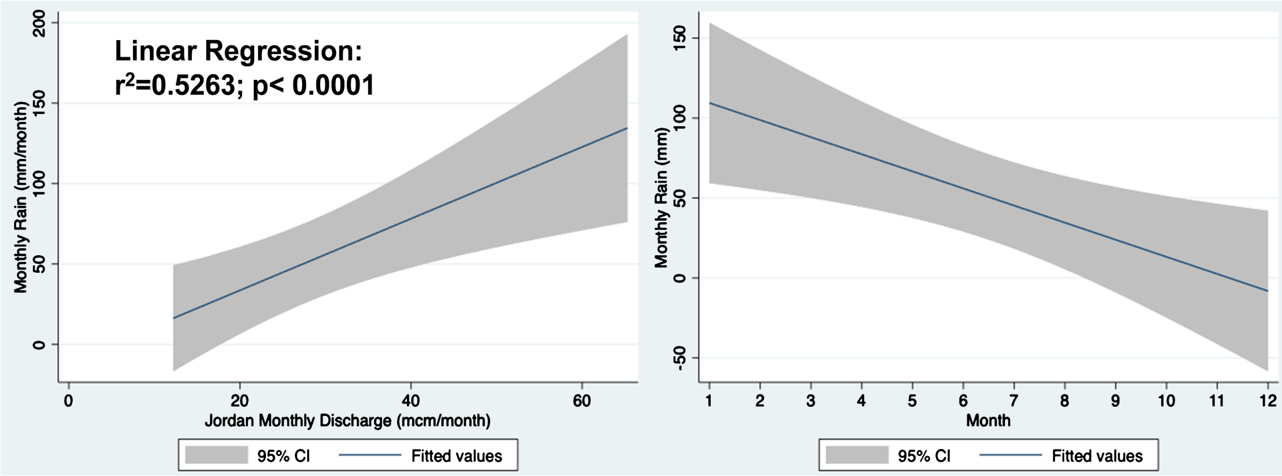

Figure 11. Linear Prediction Plot (w/CI; 95%) of the Correlation (LR: r^2 and p values are given) between monthly Rain (mm/month) and River Jordan discharge (mcm/month) (left) and the monthly temporal distribution of rain (mm/month) (right). If Jordan monthly discharge is converted to percentage of annual, significant linear correlation with monthly Rainfall (mm) was found: $r^2 = 0.5575$; $p = 0.0053$.

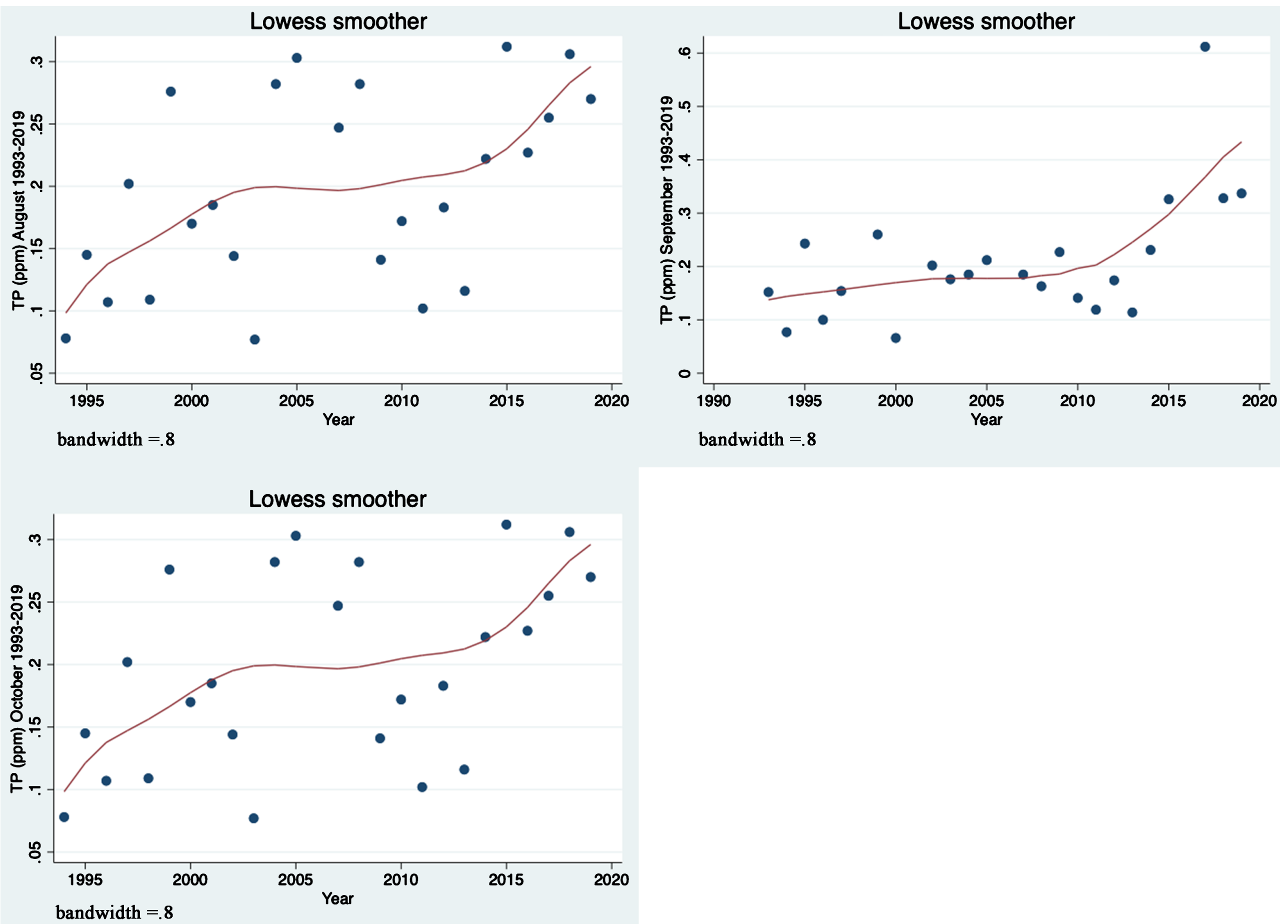

Figure 12. Lowess Smoother plot of the Temporal Changes of TP concentrations (ppm) in August (upper left), September (upper right) and October (lower) during 1993-2018.

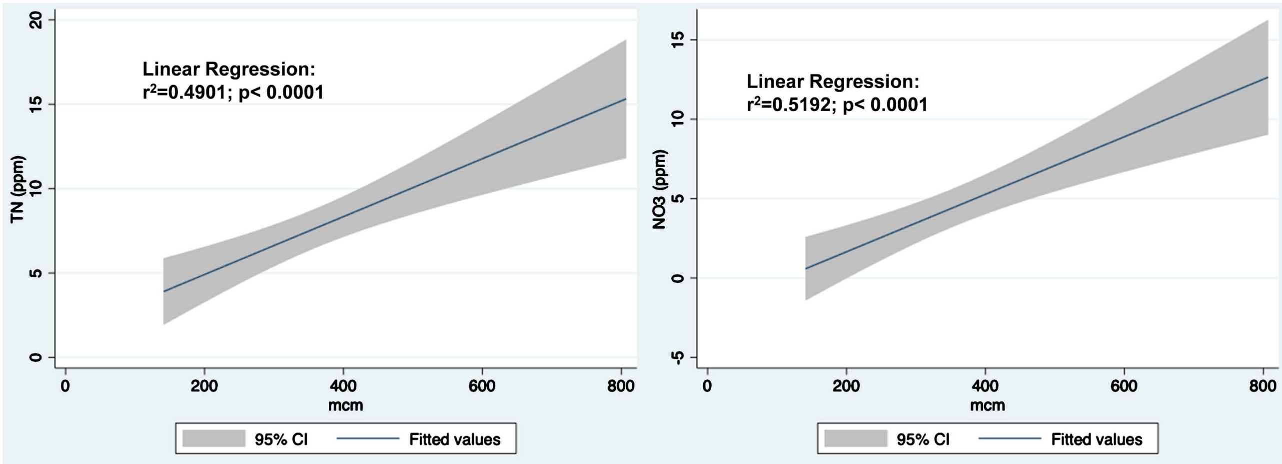

Figure 13. Linear Prediction Plot (w/CI; 95%) of the Correlation (LR: r^2 and p values are given) between annual means of TN concentrations (ppm) (left) and NO_3 (ppm) (right) and annual discharge of Jordan River.

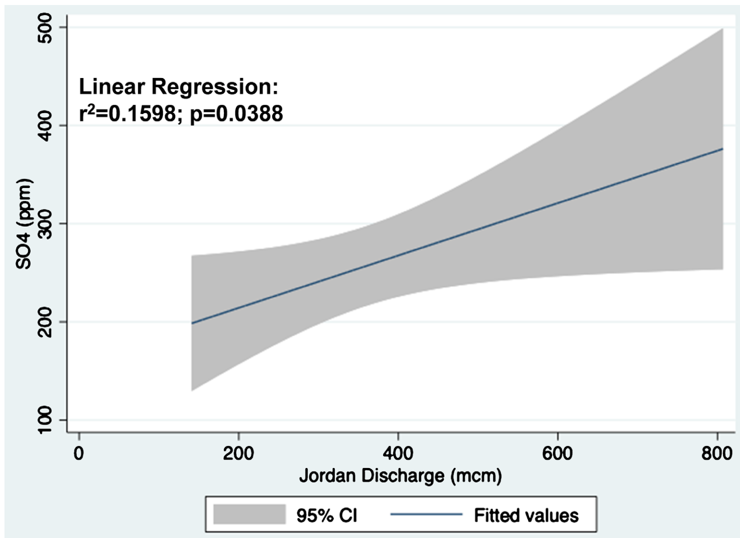

Figure 14. Linear Prediction (w/CI; 95%) of the correlation (LR: r^2 and p values are given) between annual concentrations (ppm) of SO_4 and the annual discharge of River Jordan.

widely documented (among others: [5] [6] [12]-[17]). A widely investigated topic was the processes of Phosphorus migration, of which the mechanism of fertilized P fixation and the natural bound of P to soil particles, followed by river discharge transportation [18] [19] [20] [21]. The dynamics of P fixation and bounding to soil particles is pH dependent was widely documented [18] [19] [20] [21]. Dissimilarity of P fixation and bounding to soil particles therefore exists between alkaline and acid soils where Redox potential is different [20]. P fixation is higher and availability is lower when soil moisture increases and pH is alkaline [22]. The variety of pedological characteristics including, texture, hydrological conductivity and geochemical features of soils in the Hula Valley was documented. Nevertheless, the soil pH is close but different in various soil types in the Hula Valley. The pH level in the Hula wetlands sediments prior to the drainage ranged between 7.3 and 7.5 [2] [23]. During post drainage period the pH of the drained area soil (app. 5000 ha) varied between 6.9 and 7.4 [24] [25] of which about 500 ha (10%) in the middle of the valley there was a block of acid peat soil where pH ranged between 3.7 and 6.3. As a part of the "Hula Project" proposal the acid peat block was partly (80 ha) covered by the newly created shallow lake Agmon-Hula and the rest of 420 ha was dedicated to an eco-touristic park. Documentation of pH range between 6.0 and 7.5 in Peat-Pore-Water and 8.0 - 8.2 in the water of reconstructed Jordan inflow into Lake Agmon-Hula whilst in Peat blocks drained waters (Canal Z) it was 6.5 - 7.5 and in Agmon-Hula waters 7.0 - 8.5 [26]. Conclusively, soil properties in the Peat-Land-Soil of the Hula Valley are mostly alkaline. Soil moisture decline accompanied by lower (acidic) pH value reduces P fixation and enhances its availability and therefore enhances migration [27]. Soil wetting increase of the alkaline Peat in the Hula Valley readily reacts with the high content of Calcium and the large proportion of P becomes bound to soil particles inducing a smaller fraction of P to be available for migration [2].

Long-term (1877-2023) rainfall data record confirmed periodical (1933-2023) enhancement in comparison with the 1987-1933 period [28]. Consequently, a decline of TP migration from the Hula Valley into Lake Kinneret was expected whilst after Hula drainage, during 1957-early 1990s the inputs of TP were enhanced, probably supported by Hula Valley's contribution. Rainfall enhancement normally supplies erosion P-products from the Kinneret catchment part which is external to the Hula Valley. Shortly after drainage, in the early 1960s, it was supported by P-products originating from effluents from newly developed fish breeding facilities (1700 ha ponds) and daily increment of 20 - 30,000 m^3 of raw domestic and dairy cattle sewage. As of the early 1990s the fishpond area was drastically restricted from 1700 to 350 ha and the sewage was totally removed into newly constructed 20 reservoirs where sewage was accumulated and reused for irrigation. Those anthropogenic operations restricted TP sources to be mostly erosion outside the Hula Valley and the geochemical P-product from the Peat-Land within the Hula Valley. Under those conditions, the alternate dynamics of TP fixation-availability migration are affected by an interchangeably flood-drought climate [1]. The TP migration was enhanced under dryness and declined.

The impact of unique geochemical conditions' existence during a long-term trend of precipitation decline was widely accepted. The temporal decline of headwaters and other small rivers in the Kinneret basin obviously enhanced dryness in the Hula Valley. Nevertheless, the catchment sources of most of the Phosphorus inputs into Lake Kinneret are not the Peat-Land-Soil but Hula Valley`s externals, by erosion and partly as dust deposition [11]. Dryness conditions inversely affect NO_3, SO_4 and P availabilities. P availability is enhanced and NO_3 and SO_4 are reduced. Soil moisture elevation enhances NO_3, and SO_4 migration and reduces P availabilities. Therefore the long-term decline of river discharge was followed by a decline of NO_3 and SO_4 release from the Peat Land Soil in the valley as well as diminishing erosion factor in the Hula Valley externals. The monthly mean concentrations of all nutrients indicated diminishment within the drained water from the Peat-Land-Soil. The decline of summer concentrations of all nutrients clearly reflects dependence on rain capacity and consequently on river discharges as well as with Peat Soil moisture. The opposite effect is exemplified by the long-term elevation of the GWT resulting from the implementation of the Hula Project conclusion. The mean (1988-2020) depth (32 boreholes monitoring) elevation of GWT by 0.5 m, from 2.02 to 1.5 m below the surface confirmed by Linear Correlation: $r^2 = 0.3246$ and $p = 0.0005$. This GWT elevation was the result of enhanced soil moisture elevation caused by the renovated Hula Project implementation. The moisture increase probably reduced P availability for migration. Increased soil moisture elevation affected the shallower depth of GWT. Nevertheless, the dominancy of the geochemical factor was emphasized later by water insufficiency (drought seasons) induced increase of TP concentration. During the 1993-2001 and 2002-2010 periods, TP mean concentrations were 0.232 and 0.499 respectively. A combination of two factors is responsible for the reduction of N and P concentrations in summer: 1) The insufficient water supply, which enhanced the dryness effect; 2) the geochemical factor which has an impact on N and P chemo-physical linkage to the soil particles. The total mean (1993-2018) concentration of nutrients (ppm) and significance (S) or insignificance (NS) correlation with Jordan River discharge (mcm) are given in **Table 1**.

It is suggested that the Nitrates and Phosphorus attachment factors to Peat soil particles are comprised of adhesive physical forces and geo-chemical bound. The linkage between NO_3-soil particles is dominated by the physical adhesion factor and that of the Phosphorus linkage by the geo-chemical factor. The detachment of NO_3 from the soil particles is therefore easily maintained but for Phosphorus availability, wettability is a sort of interference and dryness produces enhancement of it. For a prominent confirmation of the climate change impact, the multiannual means of River Jordan discharge and TP load inputs into Lake Kinneret are given in **Table 2**.

These data emphasize the significant impact of climate change, *i.e.* river discharge decline and consequently reduction of TP input loads. Moreover, the

Table 1. The total mean (1993-2018) concentration of nutrients (ppm) and significance (S) or insignificance (NS) correlation with Jordan River discharge (mcm).

Nutrient.	ppm	significance
TP	0.288	NS
TDP	0.102	NS
TN	7.68	S
NO_3	4.51	S
NH_4	1.84	NS
SO_4	259	S

Table 2. Periodical (1968-1993; 1994-2018) means of River Jordan discharge and TP load inputs into Lake Kinneret and percentage difference.

Period	Ton/Year	ppm	mcm
1968-1993	115	0.226	505
1994-2018	45	0.126	356
Difference (%)	70	44	30

temporal (1968-2018) changes analyzed by the linear regression, between annual means of TP concentrations (ppm) and loads(ton/year) and years resulted in significant reduction: $r^2 = 0.3806$ and $p < 0.0001$ for concentration changes, and, $r^2 = 0.4031$, and $p < 0.0001$ for loads.

5. Summary

The geochemical properties of Nitrogen and Phosphorus in the Hula Peat soil ecosystem are different, especially with regard to their fixation-availability relative capacities. The impact of soil moisture level on the drifting of P and N substances in peat soil is contradicted: Increasing moisture enhances and reduces N and P release from soil particles respectively. Wettability decline or dryness increase enhance P and diminish N release. The geochemical bound of Phosphorus to Peat Soil particles is breakable and transfer from fixation to available status is enhanced under dryness conditions, whilst attachment of NO_3 to Peat Soil particles is commonly weak and efficiently flushed by moisture enhancement. Therefore, river discharge reduction followed probably by Peat soil moisture decline enhanced P availability and its concentration in surface waters was increased but the total migrated capacity of P into Lake Kinneret declined as a result of the lower discharge. Conclusively, the P concentration in surface water enhances whilst input loads decline. The additional P resulting from dryness during the summer months of drought season is reflected by concentration increase. The seasonality impact of summer P enhancement confirms the temporal (1993-2018) elevation of P originating from the Peat Land Soil accompanied by a decline of river discharge. Therefore statistical linear regression between N forms concentration and river discharge are significant whilst insignificant with P forms. A practical management achievement is the enhancement of Peat-Soil moisture in summer which might probably reduce P and enhance NO_3 because P improves phytoplankton growth rate and the Kinneret ecosystem indicates N deficiency.

Conflicts of Interest

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

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