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Nitrogen and Phosphorus Removal from Lake Kinneret Inputs

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Abstract

The Hula Valley was drained in 1957. The land use was modified from natural wetland and old shallow lake ecosystems to agricultural development. About half of the drained land area was utilized for aquaculture. Population size was enhanced and the diary was developed intensively resulting in the enhancement of domestic and husbandry sewage production that increased as well. The natural intact Hula Valley-Lake Kinneret ecosystem was heavily anthropogenically interrupted: The Hula was drained and Kinneret became a national source for domestic water supply. Some aspects of the environmental and water quality protection policy of the system are presented. The causation and operational management implications for the reduction of Nitrogen and Phosphorus migration from the Hula Valley are discussed. Drastic (81%) restriction of aquaculture accompanied by sewage totally removed achieved a reasonable improvement in pollution control which was also supported by the Hula Project. The implications of anthropogenic intervention in the process of environmental management design are presented.

Keywords

Hula Valley, Jordan, Kinneret, Nitrogen, Phosphorus, Peat Soil, Fish Ponds, Sewage Removal

1. Introduction

The Hula Valley (between 200 and 60 MASL altitudes) comprising app.7% of the Kinneret Drainage Basin (2730 km^2) is part of the Northern section of the Syrian-African Rift Valley. Within the Anthropocene era, the Hula Valley is a compatible interlock of anthropogenic achievement in the national economy, water supply, agriculture, nature protection and tourism management. The Kinneret catchment comprised of three headwaters, Hatzbani, Banyas and Dan, flowing southward down from Mount Hermon and connected together with several other streams, and non-point runoffs, forming the Jordan River [1] [2] [3]. The River Jordan contributes about 63% of the Kinneret water budget and also convey more than 70% of nutrient inputs. Until the late 1950s the Hula Valley was mostly covered by swampy wetlands and old Lake Hula which were drained and land use was modified from the natural environment to agriculture. The agricultural development included field crops, orchards and fish breeding aquaculture.

For 40 years, the drained area was successfully cultivated and the agricultural products were economically produced and nutrient flux into Lake Kinneret did not thoroughly threaten its water quality. Nonetheless, as a result of inappropriate management, drainage canals were blocked; irrigation methods were not suitable for optimal soil structure protection and Ground Water Table (GWT) declined. Consequently, the soil structure of the upper layers (0 - 0.5 m) deteriorated and heavy dust storms occurred frequently which resulted in subsidence of the soil surface and blocking of drainage canals [4]. Due to unsuitable agricultural management, outbreaks of underground fire occurred frequently. Rodent population outbreak caused severe damage to agricultural crops and the stability of drainage canal banks. Part (500 ha) of the drained area, that was most severely deteriorated which made it impossible for beneficial maintenance and thus, was not cultivated [5]. Consequently, a reclamation project, the "Hula Project", was proposed and implemented. The Hula Project, included increasing soil moisture by elevating GWT, changing the irrigation system and renewing the hydrological canal system throughout the entire valley. Ninety km of drainage canals were reconstructed and a shallow Lake Agmon (0.2 average depth; 82 ha surface area) was created as a wastewater collector and recreational site. A plastic sheet (4 mm thickness) was placed vertically (0 - 4.5 m) along 2.8 km, crossing the valley, to prevent underground nutrients from leaking southward. The present Hula Valley management is a package deal between three sectors: 1) The land owner (farmer) for the Hula Valley area is a source of income for them; 2) Water managers who are responsible for the protection of the Kinneret water quality supplied for domestic usage; and 3) the "greens" Nature ecologists [5]-[10].

The Hula drainage in relation to the national drinking water resource, Lake Kinneret, gave an ominous warning: a significant enhancement of Nitrate loads migration through river Jordan is supposed to be associated with water quality deterioration. Moreover, without a distinct remedy Lake Kinneret might be unsuitable for drinking water supply, recreation and fish habitats as an object for commercial fishery. The public start to concern about water quality in the Lake Kinneret ecosystem and the continuation of serving as an essential resource for drinking water supply, fishery, and recreation. Consequently, a limnological environmental intensive research carried out by the Kinneret Limnological Laboratory (KLL) and Mekorot, Water Supply Company was established. A case study of Lake Washington, Seattle, [11] guided the Kinneret management authorities. Although KLL and Mekorot maintained a scientific role, a credit accompanied by intensive collaboration was given to the political level of water managers by which a national agency, "Kinneret Drainage Authority" was formed to improve pollution control and Lake management. The collaboration between the scientific and political Kinneret agencies became a model of scientific usage in public policy. It was pointed out that an increase of fish aquaculture and domestic and dairy sewage production in the Hula valley would result in deterioration of the Kinneret water quality. Nevertheless, Peat soil exposure to atmospheric oxidation resulted in the Hula drainage followed by agricultural development might enhance Nitrogen inputs into Lake Kinneret as well. Consequently, essential research was given to define the importance priorities should be given either to aquaculture and sewage or peat soil agriculture for the design of management efforts.

Three case studies exemplify the close collaboration between limnologists and governmental water managers in the practical design of the Kinneret ecosystem:

1) Nitrate inputs enhancement created public awareness and publical "noise". The invited report concluded eutrophication submitted as three volumes memorandum was calmed down by scientific analysis ("Bob Davis" Case). 2) Subsidized removal of unwanted fish enhanced zooplankton biomass in the lake "Sardin Dilution" Case. 3) Scientific recommendation to lower water level below 214.5 BSL aimed at water withdrawal from lake Kinneret to rescue irrigation of Avocado orchards during exceptional drought regime.

This paper describes a case study where progressed implementation of scientific recommendations is promoted by fruitful collaboration with a civilian-public organization of The Kinneret Authority. An ecological study about the impact of removal of domestic and dairy raw sewage into storage reservoirs and reuse for irrigation, on water quality protection in Lake Kinneret is presented in this paper. Moreover, conversion of land use in the Hula valley from fishpond into orchard and field crops accompanied by agricultural management initiated a reduction of Nitrogen and Phosphorus supply from the Hula valley into the Kineret aimed at Kinneret water quality protection as well [12].

2. Material and Methods

The data sources about nutrient concentrations and loads in river Jordan and Kinneret Headwaters were periodical and annual reports published by the Monitor Unit Jordan Districts, Mekorot Ltd., Kinneret drainage Basin [1] [2]; Kinneret Limnological Laboratory, IOLR Ltd. Data Base and annual reports [13]; Kinneret Drainage Authority Interim Reports; Nutrient dynamics in the Hula Valley runoffs from Hula Project, Migal, annual reports (1995-2018) [6] [8] [9] [10]. River discharges are given in mcm (million cubic meters) = 10^6 m^3; Nutrient data is given in concentration (ppm) or loads (Tons).

3. Results

Annual Nitrogen (NO_3 and Total) contribution by the Peat Land Soil area in the

Hula Valley (calculated) and in the Jordan discharge (Huri) (measured) during 1962-1981 are shown in **Table 1**.

The data presented in **Table 1** were documented during 24 years after Hula drainage (1957) and prior to the fish-ponds restriction and sewage removal projects that were implemented during the late 1970s and early 1980s. Analysis of Linear Regression between the rain capacity (mm) (independent) and nitrate load inputs (ton) (dependent parameter) indicates a significant relation between rainfall capacity and Nitrate flush from the Peat soil in the Hula Valley (r^2 = 0.5996: p = 0.0002). Data in **Table 1** indicates that during 24 years after the Hula Drainage the NO_3 migration from the Peat soil comprised only 25% and 50% of the TN and NO_3 recorded at Huri respectively, and NO_3, 51% of the TN measured at Huri. Taking into account that until the late 1970s total fish-pond area in the Hula Valley was 1700 ha whilst in the late 1980's, 350 ha (80% decline) it is therefore suggested that a significant contribution of Nitrogen was supported by fishpond effluents.

Table 1. Annual (Hydrological Year: October through next September) input (ton/year) of NO_3 and TN contributed from Peat soil and measured at Huri Station [1]; and Rainfall (Dafna Station); nd, No Data [1].

Rain	Peat NO_3 (Ton)	Huri NO_3 (Ton)	Huri TN (Ton)	Year
622	315	nd	nd	1962/63
590	137	nd	nd	1964/65
479	23	nd	nd	1965/66
756	352	nd	nd	1966/67
657	389	1085	1565	1967/68
1038	3084	nd	4250	1968/69
624	143	748	1257	1969/70
721	315	1205	1836	1970/71
619	46	708	1171	1971/72
358	12	423	700	1972/73
835	987	1581	2118	1973/74
523	29	524	1138	1974/75
639	24	659	1293	1975/76
655	55	799	1528	1976/77
674	129	806	1512	1977/78
371	1	365	675	1978/79
825	643	1464	2240	1979/80
843	698	nd	nd	1980/81
657 (169)	410 (723)	864 (391)	1637 (914)	Mean (SD)

Sub-tropical climate dominating the Hula region is characterized by short wet cold winters and long dry and hot summers, The seasonal distribution (winter-summer) of nutrient migrations therefore reflects rainfall and river discharge dynamics. The rainy season in the Hula Valley lasts between October and March. Nitrate flushing and migration dynamics therefore depend upon rain and river discharge dynamics resulting in significant difference between winter and summer as shown in **Table 2**.

Results in **Table 2** indicate nitrate migration from the Kinneret drainage basin in winter comprises about 80% of the annual load recorded in River Jordan (Huri Station).

The Nitrate supported from the Peat Land Soil in relation to the total Kinneret input as documented in a study carried out during the 1970s [1] [2] is shown in **Table 3**.

Results given in **Table 3** indicate the following: winter comprised 55% of the annual loads; Josef loads comprised 27% of Huri loads in winter resulting probably Hula Valley contribution being more than 70% in winter, probably fishponds and sewage sources; nevertheless, annual contribution from Peat Land is 41% of the totally documented in Huri.

The role of Nitrate contributions by the Hydrological resources in the Kinneret Basin from 1969-1981 prior to the implementation of the fishpond restriction and sewage removal projects are given in **Table 4**.

Table 2. Annual (October-September) and seasonal (December-April) loads of NO_3 (Tons) measured in River Jordan (Huri Station) between 1969-1980 prior to the fishpond restriction and the sewage removal project implementations [1] [2].

Huri NO_3 Winter (Ton)	Huri NO_3 Annual (Ton)	Year
513	748	1969/70
895	1205	1970/71
476	708	1971/72
261	423	1972/73
1363	1581	1973/74
361	524	1974/75
446	659	1975/76
520	799	1976/77
555	806	1977/78
239	365	1978/79
1188	1464	1979/80
1233		1980/81
671 (378)	844 (385)	Mean (SD)

Table 3. Seasonal (Flood season: December-April) (Flood, annual) and spatial (Josef, Huri, Peat land soil) Nitrate loads (Ton) distribution recorded at River Jordan stations (Huri, Josef) and Peat Land during 1971-1980. Huri Station value contains total annual nutrient content (Ton) migrated from the Kinneret Drainage basin including Hula Valley; Josef Station located on River Jordan discharge at the top northern point of the Hula Valley beyond the headwaters meeting point containing total nutrient loads originated northern to the Hula Valley. Full information for 1972/73.1978/79, is missing when Peat Land Soil contribution was approximated as negligible [1] [2].

Year	Huri Flood	Huri Annual	Josef Flood	Peat Flood	Peat Annual	Others	Huri Annual
	(t/flood)	(t/Year)	(t/flood)	(t/flood)	(t/year)	(t/flood)	(mcm)
1971/72	73	476	23	37	46	13	270
1973/74	1220	1363	208	914	987	98	376
1974/75	112	361	75	29	29	8	478
1975/76	90	446	63	17	24	10	557
1976/77	98	520	50	41	55	7	575
1977/78	168	555	68	93	129	7	276
1979/80	916	1188	242	643	743	31	633
Mean(SD)	382 (477)	701 (400)	104 (85)	253 (368)	287 (402)	25 (33)	452 (147)

Table 4. Annual (1969-1981) Nitrate loads (T/Y) migration through River Jordan (Huri), Hazbani, Banias, Dan (Headwaters); small rivers and runoffs (Others) and contributed by Peat Land Soil (Peat) [1] [2].

Year	Huri	Headwaters	Peat	Others
1969/70	513	260	143	110
1970/71	895	302	414	179
1971/72	476	233	46	197
1972/73	261	168	12	81
1973/74	1363	306	987	70
1974/75	361	240	29	92
1975/76	446	308	24	114
1976/77	520	307	55	158
1977/78	555	354	129	72
1978/79	239	170	1	68
1979/80	1188	418	743	128
1980/81	1233	401	698	134
Mean(SD)	671 (395)	289 (80)	273 (348)	117 (44)

Results in **Table 4** represent the percentage composition of annual Nitrate migration after the drainage and before the fish pond restriction and sewage removal projects. Nitrate loads migration into the Jordan River (Huri) through Headwaters, Peat Land Soil effluents and other rivers plus runoffs are 43%, 41% and

16% respectively. The high contribution of Nitrate from the Peat Land Soil during this period emphasizes its importance for the evaluation of Nutrient dynamics in the Hula Valley after the drainage and before project implementations of sewage removal, aquaculture restriction and Hula Project.

Results given in Figure 1 indicate temporal decline of River Jordan discharge since the early 1980s and a short periodical (2014-2018) decline in rainfall.

The Data shown in Figure 2 represent a significant correlation between rain capacity as measured in the northern part of the Hula Valley and the discharge in the Jordan River (Huri).

The results shown in Figure 3 indicate significant trend of Nitrate migration enhancement from the Peat Land Soil in relation to the increase of rain capacity.

Results shown in Figure 4 indicate minor decline in Nitrate load migrations from 2014-2018 resulting by decline in rain capacity and a significant correlation between migrated loads (Ton) and concentration (ppm) of Nitrates within the Jordan River discharge.

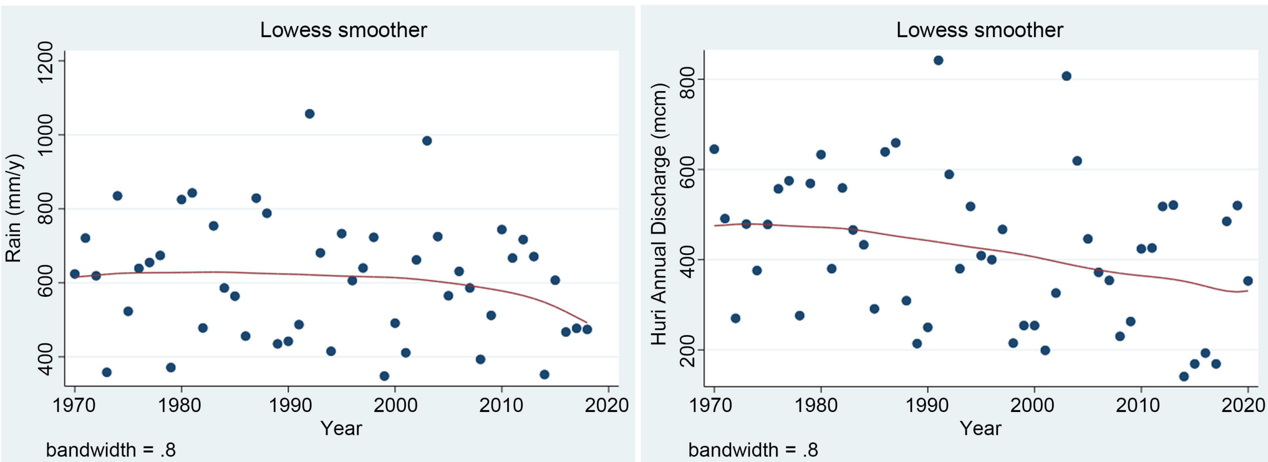

Figure 1. Temporal (1970-2018) distribution of rainfal (mm/y) (left panel) (Dafna Station), and Annual discharge (mcmy) of River Jordan (right panel) [13].

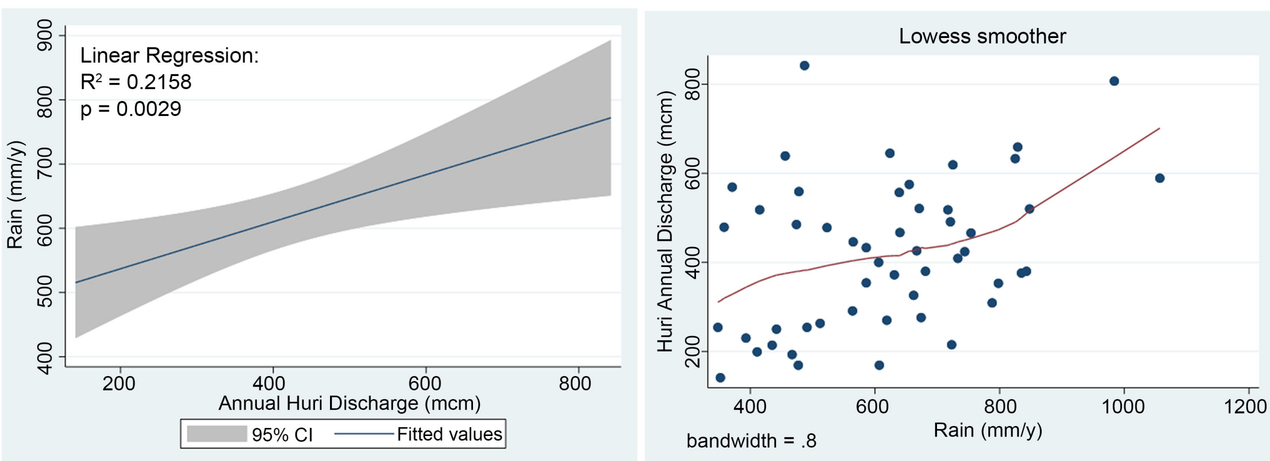

Figure 2. Linear Prediction (W/CI) (left) (r^2 and p values of LR are given) and Lowess Smoother plot (right) between annual discharge in river Jordan (mcm) (Huri) and Rain (mm/y) [13].

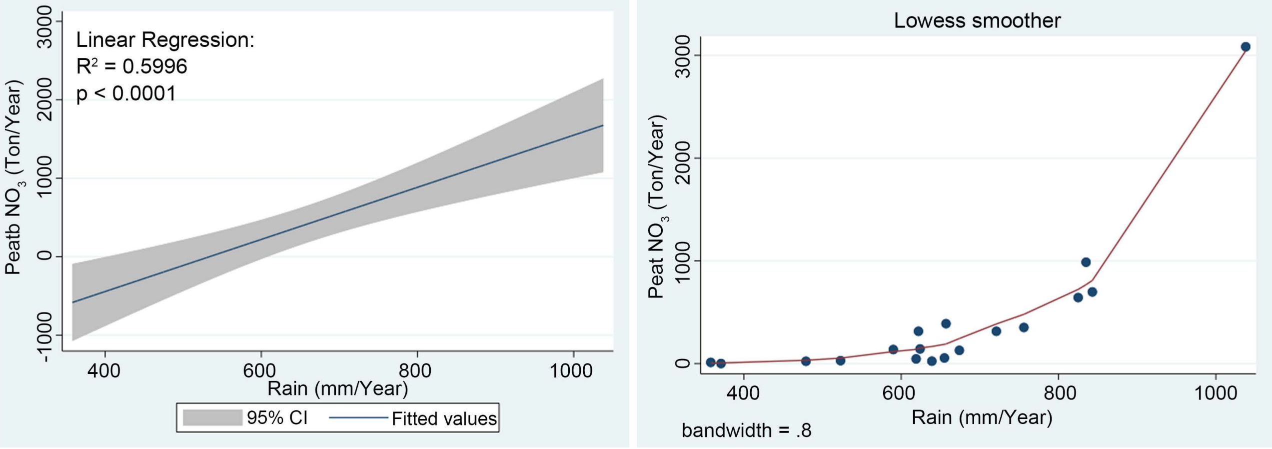

Figure 3. Linear Prediction (W/Cl) (r^2 and p values of LR are given) between annual means of the concentrations of Nitrate originated from the Peat land soil and rain (mm/y)(left) and Lowess Smoother distribution plot of the relations between Nitrate loads migrated from the Peat soil land in the Hula Valley (Ton/Year) and annual rain (mm/Y) (right) during 1963-1981 [1].

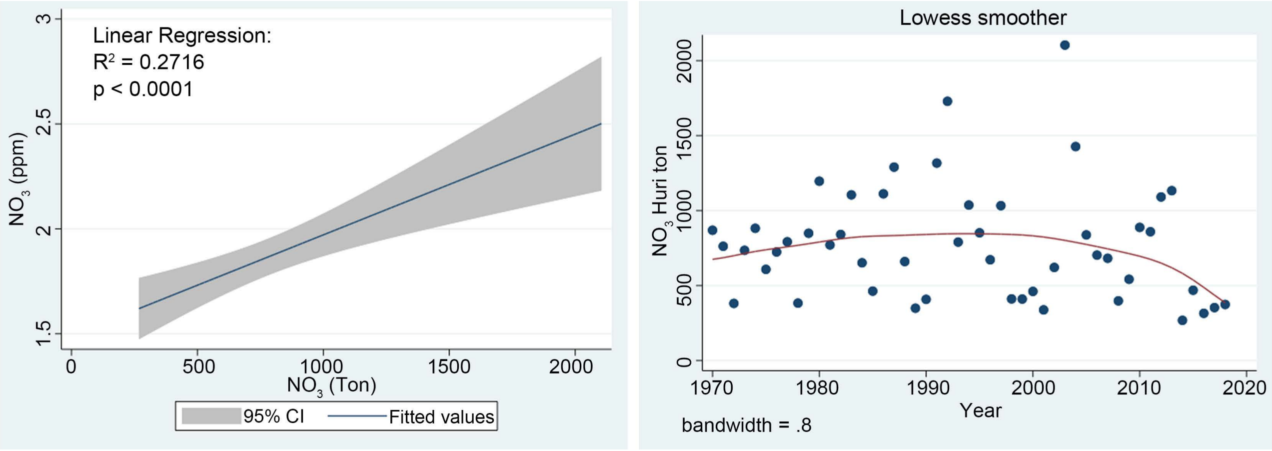

Figure 4. Linear Prediction (W/Cl) (r^2 and p valuesof LR are given) between annual mean concentrations (ppm) and Nitrate (Ton/Year) (left) and temporal distribution (Lowess Smoother plot) of annual loads of Nitrate recorded at Huri station (right) during 1970-2018 [13].

Results presented in **Figures 5-9** indicate decline of migrated nutrients through the Jordan River discharge that originated from domestic and diary sewage as well as effluents of fish ponds: Ammonium (NH_4), Total Nitrogen (TN), Organic Nitrogen (NORG) Total Phosphorus (TP) and Total Dissolved Phosphorus (TDP). The distribution of their concentrations and loads is significantly correlated with the river Jordan discharge capacity. Moreover, temporal changes in load contents clearly show the trend of decline from late 1970s-the early 1980s.

Periodical Terms of TP Migration from the entire Kinneret catchment emphasizing the Hula Valley

1) 1968-1985: Post Drainage - Pre aquaculture restriction and Sewage Removal:

Evaluated data [2] of headwater (Hazbani, Banias, Dan) and River Jordan discharges and TP concentrations and loads enabled an insight into the dynamics

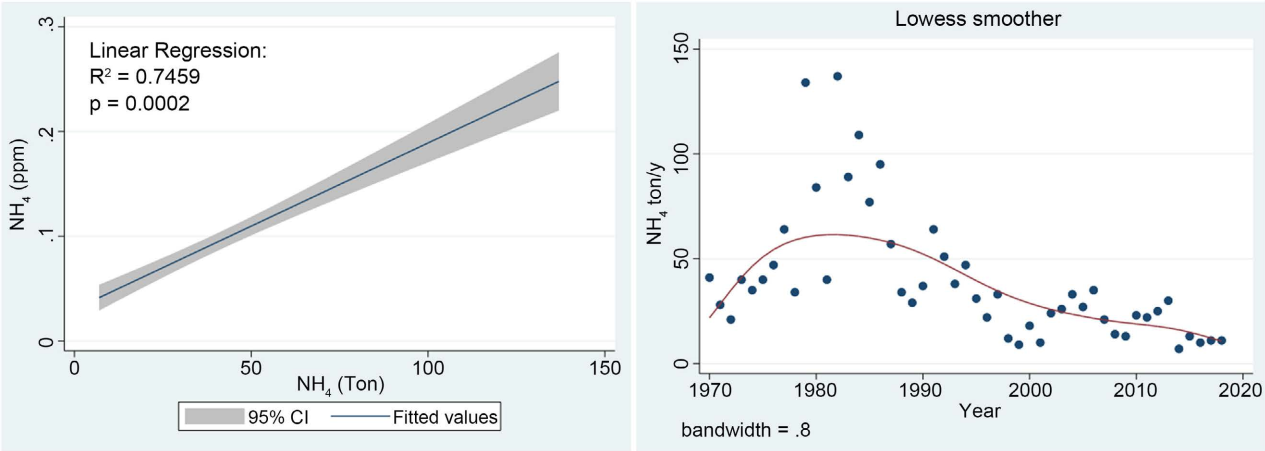

Figure 5. Linear Prediction (W/Cl) (r^2 and p values of LR are given) between annual mean concentrations (ppm) and loads (Ton/Year) of ammonium (left) and temporal distribution (Lowess Smoother plot) of annual loads of Ammonium recorded at Huri Station (right) during 1970-2018 [13].

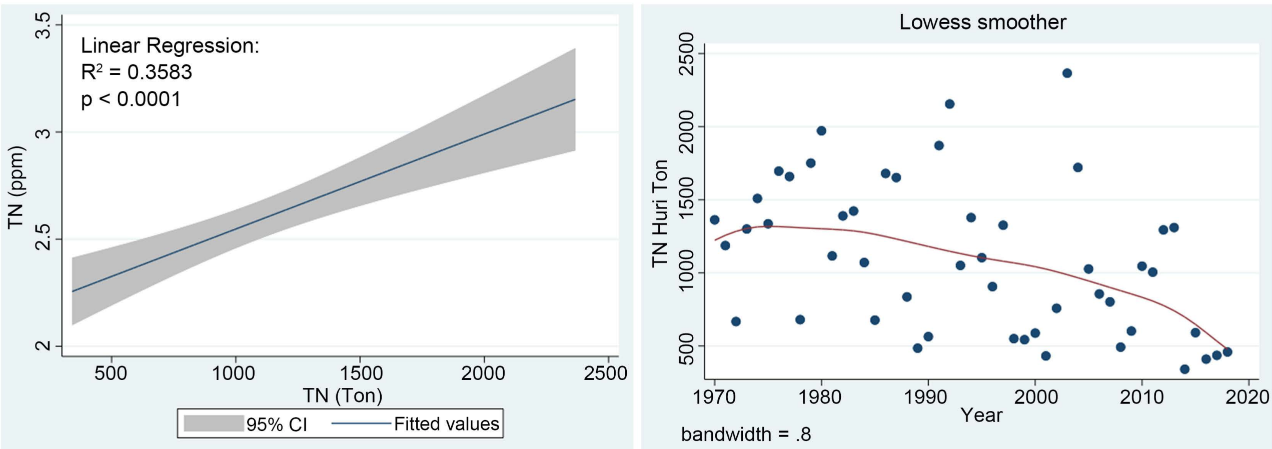

Figure 6. Linear Prediction (W/Cl) (r^2 and p values of LR are given) between annual mean concentrations (ppm) and loads (Ton/Year) of Total Nitrogen (TN) (left) and temporal distribution (Lowess Smoother plot) of annual loads of Total Nitrogen recorded at Huri Station (right) during 1970-2018 [13].

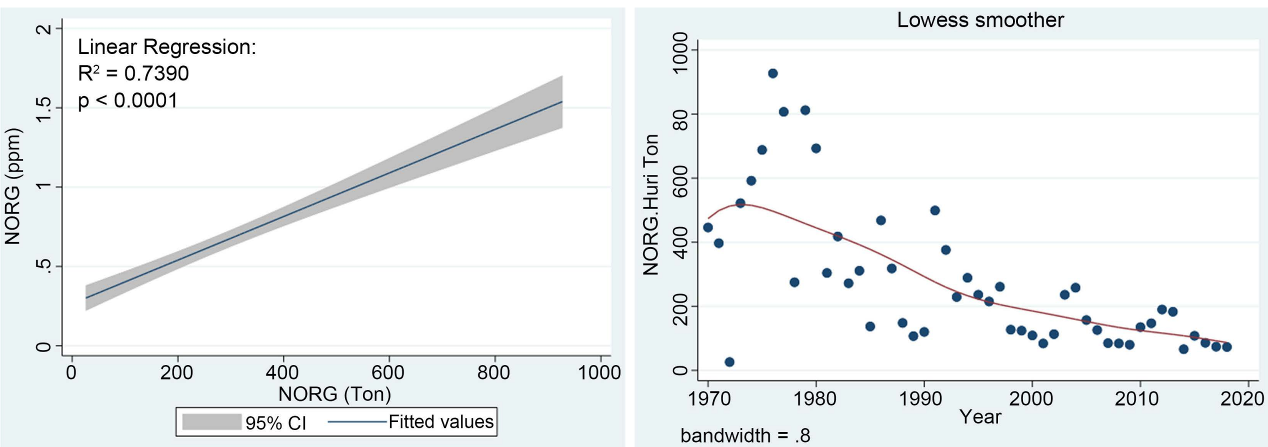

Figure 7. Linear Prediction (W/Cl) (r^2 and p values of LR are given) between annual mean concentrations (ppm) and loads of Organic Nitrogen (NORG) (Ton/Year) (left) and temporal distribution (Lowess Smoother plot) of annual loads of Organic Nitrogen recorded at Huri Station (right) during 1970-2018 [13].

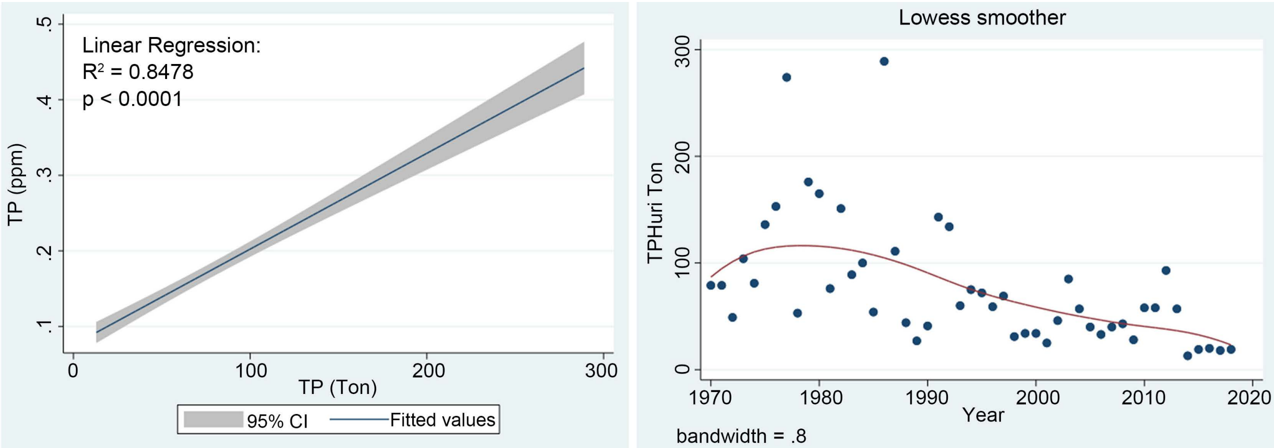

Figure 8. Linear Prediction (W/Cl) (r^2 and p values of LR are given) between annual mean concentrations (ppm) and loads of Total Phosphorus (TP) (Ton/Year) (left) and temporal distribution (Lowess Smoother plot) of annual loads of Total Phosphorus recorded at Huri Station (right) during 1970-2018 [13].

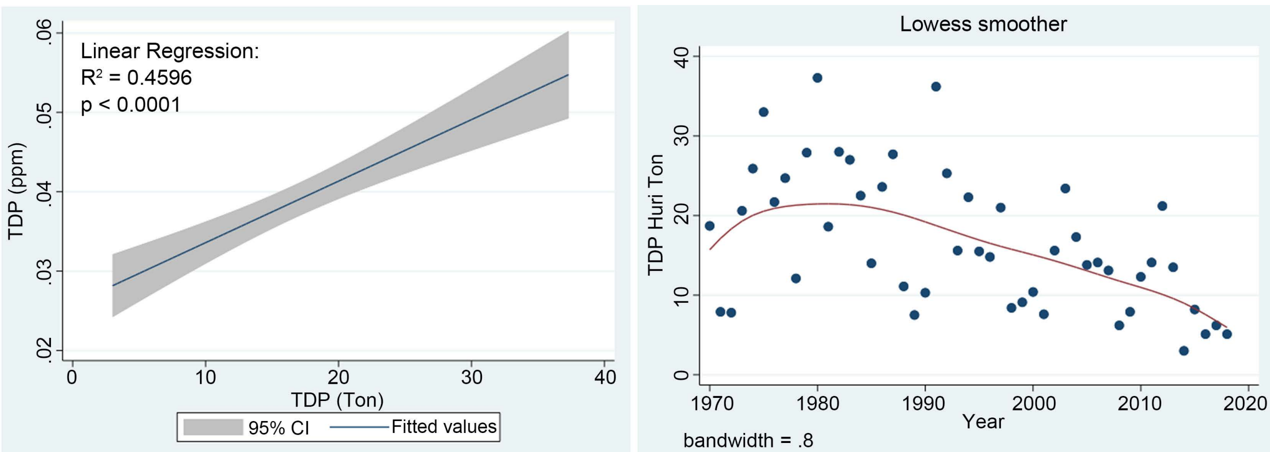

Figure 9. Linear Prediction (W/Cl) (r^2 and p values of LR are given) between annual mean concentrations (ppm) and loads of Total Dissolved Phosphoprus (TDP) (Ton/Year) (left) and temporal distribution (Lowess Smoother plot) of annual loads of Total Dissolved Phosphorus recorded at Huri Station (right) during 1970-2018 [13].

of Phosphorous migration during post-Hula drainage and pre-aquaculture restriction and sewage removal operation. The annual (1968-1985) discharge (mcm), mean TP concentrations (ppm) and annual loads (ton/year) in Jordan (Huri) and the headwater (Dan, Hazbani, Banias) are given in **Table 5** [2].

Subtraction of Headwater load from Jordan load resulting in 77 tons of TP attributed to the contribution of the Hula Valley which includes surface runoffs and other small rivers on both sides of the mountain slopes eastern and western of the Hula Valley and fish-ponds and raw sewage effluents within the valley.. Nevertheless, it is clear that TP contributed by the Hula Valley is high due to the contribution of fishpond effluent and untreated domestic and dairy raw sewage released into rivers crossing the Hula Valley. It is confirmed by the very low TP concentration in the high (515 mcm) headwater discharges (0.080 ppm).

2). The entire Period of 1968-2018

For the evaluation of the impact of aquaculture restriction and sewage removal projects carried out during the 1980s, the entire period was split into two periods, before and after the projects implementation: A) 1968-1993 and B) 1994-2018 (Table 6).

Results given in Table 6 indicate sharp distinct lower TP lads and concentrations in Period B which is due to load capacity (Ton: 61%) and concentration (ppm: 44%) whilst climate change is reflected in the reduced Jordan discharge (mcm: 30%). Therefore it is suggested that the TP decline in Period B is partly due to the aquaculture and sewage removal project implementation and partly attributed to the river discharges decrease.

Data shown in Figure 10, Figure 11 indicates a distinct decline of TP migration from the Kinneret basin into Lake Kinneret and the temporal fluctuations of TP in the Jordan discharge for the entire period of 1968-2018 (see Figure 8, right panel).

Table 5. The annual (1968-1985) discharge (mcm), mean TP concentrations (ppm) and annual loads (ton/year) in Jordan (Huri) and the headwater (Dan, Hazbani, Banias).

Parameter	Jordan (Huri): Headwaters and others)	Headwaters (Dan, Hazbani, Banias)
Discharge*	530	515
TP concentration (ppm)	0.221	0.080
TP Annual Load (ton/year)	119	43

*The Jordan discharge includes three headwaters and other minor contributions.

Table 6. Annual and periodical means of Total Phosphorus (TP) migration (tons and ppm) in River Jordan (Huri) during 1968-1993 (A) and 1994-2018 (B). The absolute and percentage (%) differences (ton, ppm) are given. River Jordan discharge is given in mcm.

Period	Ton/Year	ppm	mcm/y
1968-1993	115	0.226	505
1994-2018	45	0.126	356
Decline	70	0.1	149
%	61%	44%	30%

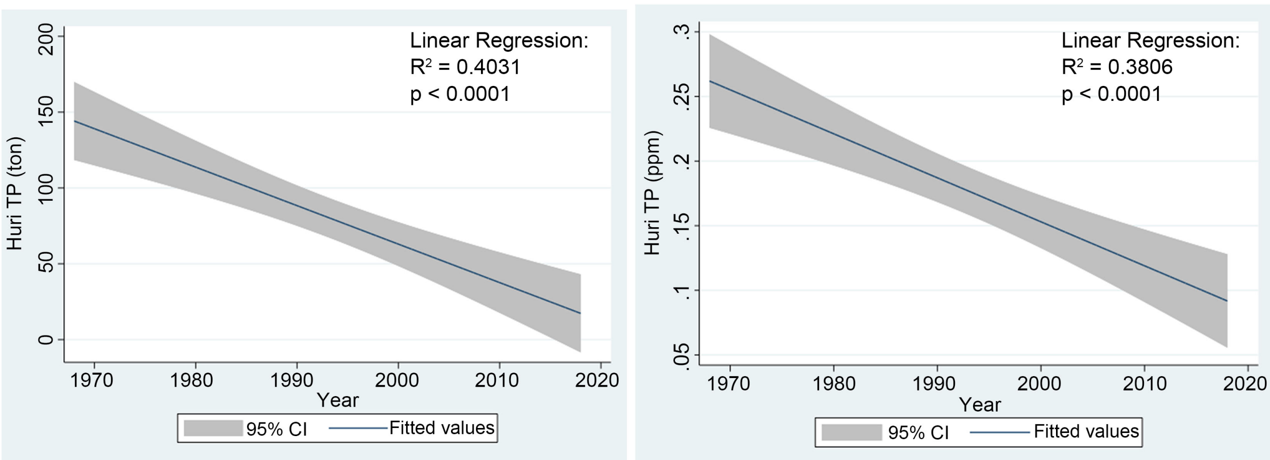

Figure 10. Linear Prediction (W/CI) between annual means of TP load (T) (Left) and concentration (ppm) (right) in Jordan river discharge during 1968-2018 [2] [13]. Linear Regression (r^2 and p values are given) are presented.

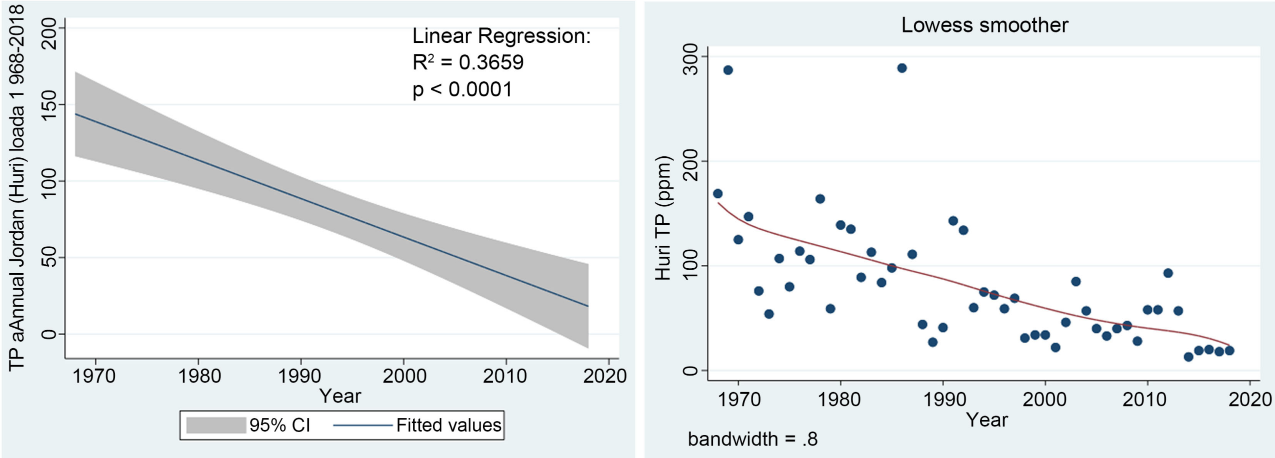

Figure 11. Linear prediction (W/CI) (r^2 and p values of LR are given) between annual TP load (T) (left) and years Lowess Smoother (right) in Jordan River discharge during 1968-2918 [2] [13].

4. Discussion

Several prominent environmental modifications resulted from the Hula drainage, among others, are the conversion of the dominant Nitrogen input into Lake Kineret where Nitrate replaced Ammonium; The development of aquaculture and dairy in the valley; Regional population enhancement which was accompanied by an increase of sewage production. Those anthropogenic involvements enhanced the contribution of Organic Nitrogen and Phosphorus to Lake Kinneret. Consequently, elimination of these pollutant sources was likely, designed and implemented. The overall balance of nutrient load export from the Hula Valley declined accompanied by Kinneret nitrogen stock reduction although Nitrate migration was increased. Moreover, available quantitative information about Ammonium and other nutrients migration from the Hula Valley before drainage is very minor [14]. Nevertheless, the higher affinity of Ammonium than that of Nitrate for planktonic algal production is well known [15]. It is therefore suggested that the impact of Ammonium on phytoplankton growth in Lake Kinneret before drainage was not lower and probably even higher than under the present conditions. It is not the outcome of Ivory Tower or egghead scientist epithets. In our case it is a misleading consideration for the reality of ecological trait: The Hula was drained, the natural ecosystem was devastated, but national population dispersion and agricultural food production were improved and enhanced. Accompanied ecological obstacles were eliminated and deterioration of Kinneret water quality was prevented. "Ivory tower" and "Egghead" limnologists help people to understand and cooperate in solving problems of Kineret water quality resulting from Hula drainage. The Kinneret ecosystem, namely water quality deterioration did not pose a threat due to the Hula drainage nevertheless domestic and dairy raw sewage and fish-ponds effluents do. Therefore those risks were anthropologically eliminated and positively resulted.

It is suggested that nutrient loads migrated from the Hula Valley towards Lake Kinneret are highly correlated with hydrological dynamics. The more water is discharged the higher the nutrient concentration and load. Nevertheless, the nutrient composition, especially Nitrogen and Phosphorus, is strongly affected by anthropogenic involvement. The Hula drainage induced the replacement of Ammonium by Nitrates which was later declined due to reduction in Jordan discharge (climate change). The sewage (domestic and dairy) removal and restriction of fish breeding aquaculture enhanced the decline of different forms of Nitrogen and Phosphorus. Shortly after the Hula drainage 1700 ha of the drained land was utilized for commercial fish breeding in constructed ponds. The management of it included the diversion of headwater discharge through the newly constructed fish pond by continuous winter flow aimed at increasing water temperature in the ponds. Consequently, these waters were intensively loaded with nutrients and the pond effluents were directed into Lake Kinneret. Prior to the implementation of the sewage removal project in the late 1980's-early 1990's, about 25,000 - 30,000 m^3 of raw sewage were daily fluxed into Lake Kinneret. The pollutants within the raw sewage were removed into newly constructed reservoirs resulting in a significant decline of TP, TDP, Organic Nitrogen, Ammonium and TN migration. The implementation of the Hula Project, including renovated Hydrological and agricultural regulations supported an additional impact on the reduction of migrated nutrients from the Hula Valley downward to Lake Kinneret. The conversion of 1700 ha of fishpond into field and orchard crops, the removal of sewage, and partial rehabilitation of natural conditions required strong public backing. A model for public discussion integrated with scientific support came from Lake Washington, Seattle, USA, where a known limnologist, Prof. W.T. Edmondson carried out a similar case (not without dissimilarities) and started a struggle in 1955 [11]. Scientific evidence combined with public-political involvement aimed at lake water quality protection. As one of the first steps forward a survey of the Peat Land Soil feature in the Hula Valley was carried out [16]. The pedological information supported by this survey opened the gate for field and orchard crops and even Fishpond land use which was found later as a source of pollutants. The immediate initiation of a scientific monitor program and limnological research in Lake Kinneret and its drainage basin and the establishment of long-term data records about the impact of nutrient migrations on the water quality in the national drinking water supply, Lake Kinneret, had been given a management tool to water managers. One of the early management decisions was to convert fishpond land use in the Hula Valley into field and orchard crops and to remove sewage. Sewage removal instruction was integrated with the design of reuse of the accumulated sewage for irrigation mostly outside the Kinneret catchment. Those conclusions were successfully implemented. The conversion of Fishpond into field crops and the removal of sewage effluents are likely a tackle the gap of reduction of TP migration from the Hula valley during the post drainage and Hula Project implementation to protect water quality in Lake Kinneret and agricultural management.

The appropriate management of the Hula Valley aimed at both Kinneret water quality protection and the efficient utilization of the Hula Peat Land initiated the achievement of the Hula Project. Therefore, the potential impact of the implemented Hula Project on Nutrient migration is the cardinal interest of water managers. A high correlation was found between nutrient concentrations (ppm) and load capacities (Ton). Concentration and load are dependent factors, the same as, discharge and load factors whilst concentration and discharge are supposed to be independent. Nevertheless, a significant correlation was indicated between those two independents, discharge and concentration. It is therefore suggested that the reason for those relations exists in the Kinneret drainage basin outside the Hula Valley, in the dynamics of the Headwaters, smaller rivers and runoffs. The erosive force of the water dynamic is dominant, and increasing discharge creates erosion enhancement (dissolved and particulate) and consequently-nutrient concentration. The major source of Nitrate migration into Lake Kinneret is the Peat Load Soils in the Hula Valley, which overlaps the Hula Project territory (app 2900 ha). Linear regression analysis of temporal fluctuations of NO_3 concentration Vs time during 1993-2018 was found insignificant but significantly correlated with rain intensity. The Peat soil wettability is the dominant factor but not necessarily the river discharge. A significant correlation ($r^2 = 0.3834$; $p = 0.0010$) was found between NO_3 concentration in the effluents of the Hula Project territory and those in the Jordan River (Huri) during 1993-2018. Consequently, it is suggested that the nitrate migration from the Peat Land Soil is a dominant source for the Kinneret Nitrate supply. There is a significant correlation between Nitrate (NO_3 Vs TN: $r^2 = 0.4758$; $p < 0.0001$) and obviously with Total Nitrogen (NO_3 Vs Rain: $r^2 = 0.3050$; $p < 0.0001$) concentration in the Hula Project effluents and Rainfall intensity resulting from breakable linkage of NO_3 with soil substances (particles). Nitrate migration from Peat Land Soil source has an impact on River Jordan Nitrate loads whilst TP-rainfall relations are statistically insignificant. Most of the NO_3 migration occurs during the rainy season and is minor in the summer months in spite of irrigation activity. The implementation of the Hula Project was initiated during the early 1990s when loads and concentrations of TP, TDP, and Organic Nitrogen in Jordan discharge were declining whilst before the mid-1980s these nutrients exhibited high levels. Consequently, the ecological changes observed in the Hula Valley after the drainage included modification of migrated Nitrogen from Ammonium to Nitrate resulted in by newly oxidative soil environment and Kinneret water quality did not deteriorate [5]. The most effective anthropogenic involvement after the Hula Drainage is due to sewage removal and fishpond restriction whilst removal of Nitrogen other than NO_3 and P nutrients through the Agmon Hula system of the Hula Project is negligible [12]. The Hula Project significantly improved the agricultural management and the efficiency of water utilization as well as recreational conditions and nature protection [5]. The correlations between annual mean concentrations of NO_3, TN and TP in the Jordan Discharge (Huri) and the Agmon-Hula effluents since the implementation of the Hula Project (1993-2018) are as shown in **Table 7**.

Table 7. The correlation coefficients (r^2, p values) between annual mean concentrations of NO_3, TN and TP in the Jordan Discharge (Huri) and the Agmon-Hula effluents since the implementation of the Hula Project (1993-2018).

Site	Parameters	r^2 Value	p Value	Significance
Jordan (Huri)	NO_3	0.3935	0.0006	S
HP	NO_3	0.5192	<0.0001	S
Jordan (Huri)	TN	0.2415	0.0108	S
HP	TN	0.4901	0.0001	S
Jordan (Huri)	TP	0.0035	0.7746	NS
HP	TP	0.095	0.1256	NS

The correlation results emphasize the impact of Nitrate contribution by the Peat soil (Agmon-Hula effluents), originated in the Peat soil, on the Jordan water content whilst there is no similar effect on the TP migration. That is probably because the dominant contribution of TP is an outsourcing origin, not in the Hula Valley [17]. Data about N&P nutrient migrations from sewage produced in the Kinneret Drainage Basin and from Fishponds were not routinely monitored. Nevertheless, sporadic data are available [12] [18] [19]: Eighteen reservoirs with a total volume capacity of 4.1mcm were constructed in the Kinneret catchment for sewage collection. During 1996-2007 an annual removal of 83 tons of TN (concentration ranged between 11 - 27 ppm) through the reservoirs operation whilst through the Agmon Hula effluents (Hula Project System) the annual removal of TN was ranged (Max. - Min.) between 11 and 48 tons (concentration range 4.6 - 8.7 ppm). Moreover, during 2000-2005 an annual removal of 3.3 - 5.5 tons of Ammonium through the Agmon-Hula effluents (mean concentration 1.4 ppm) whilst an annual mean of Ammonium migration through the Jordan was 21 tons. During the period of post-drainage and prior to the implementation of the sewage removal project (<1986) 70.2 tons of Ammonium and 718 tons of Nitrates were migrated annually into Lake Kinneret through the Jordan discharge [12]. The very few data about the chemical features of the swampy waters in the Hula Valley before drainage [14] (Jordan annual discharge of 650 mcm) indicates probably an annual potential migration into River Jordan of 293 and 117 tons of Free Ammonia (Gaseous NH_3) and Albuminoid Ammonia (Organic Nitrogen) respectively. Conclusively, with regard to the contribution of Ammonium from the Hula Valley, the drainage resulted in a distinct decline of Ammonium and total nitrogen which were further diminished as a result of sewage removal and aquaculture restriction and later additional reduction was the result of the Hula Project implementation. The oxidized peat became a Nitrate-rich source which is probably less effective in phytoplankton growth rate.

Although introducing science into public policy where conflicts of interest are likely [11], shortly after the Hula drainage awareness initiated a disputed issue public: Does Nitrogen migration (mostly Nitrate) from the drained Peat Land

Soil might be risky for the quality of Lake Kinneret water. As a response to the invited consultation a three volumes report was submitted to the national water authority of Israel summarized as (quote): "…There is an extremely serious problem…protect the lake from complete degradation…" [20] Scientific evaluation of ad hoc available limnological information revealed distinct negative responses scientists (Limnologists) and the case was closed.

5. Summary and Conclusion

The Hula Valley was drained during the 1950s and the land use was converted to agriculture and recreational tourism. Primarily, the newly developed land use included fish breeding in constructed ponds. Regional population size was enhanced and the industrial diary as well which implies intensive sewage production. The desire for Kinneret water quality protection implies aquaculture restriction and sewage removal. Collected sewage was conveyed into 18 newly constructed reservoirs and was reused for irrigation outside the Kinneret drainage basin. Supplemental investment aimed at environmental improvement was the Hula Project (HP). HP concluded fishpond restriction and replacement of aquaculture by field crops. These restrictions (81%) together with sewage removal were very effective in pollutant migration control and the Hula Project significantly improved agricultural management. The already implemented management policy in the Hula Valley is following design: maintain high levelm of the GWT and prevent summer dryness by irrigation. Agreement between the land owners and the National Water Authority resulted the "Hula convention" which ensure summer irrigation of cropped and non-cultivated Peat-Soil land against water pricing reduction induced positive support. Nevertheless, accompanied enhancement of Nitrate migration is not risky since lake Kinneret is under Nitrogen insufficiency.

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Data Availability Statement

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

Conflicts of Interest

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

References

[1] Geifman, Y. (1981) The Monitor Ring System: Ntrate Contribution from the Peat Land Soil. Interim Report, Mekorot Water Supply Company Ltd., Drainage Basin Unit, Jordan District; 16 p. (In Hebrew)

[2] Geifman, Y., Shaw, M., Dexter, H. and Sarusi, F. (1987) The Kinneret Watershed Jordan and Headwaters Loads Investigation: 8 Supplemental Chapters. Mekorot Water Co. Ltd., Jordan District, Watershed Unit, Nazareth, 150 p.

[3] Gophen, M. (2006) The Lake Kinneret Drainage Basin: Headwater Discharges, Hydrology and Nutrient Dynamics in the Hula Valley Wetland. In: Krecek, J. and Haigh, M., Eds. *Environmental Role of Wetlands in Headwaters*, Vol. 63, Springer, Berlin, 233-236. https://doi.org/10.1007/1-4020-4228-0_20

[4] Gophen, M., Meron, M., Orlov-Levin, V. and Tsipris, Y. (2014) Seasonal and Spatial Distribution of N & P Substances in the Hula Valley (Israel) Subterranean. *Open Journal of Modern Hydrology*, **4**, 121-131. https://doi.org/10.4236/ojmh.2014.44012

[5] Gophen, M. (2023) Agriculture, Recreation, Water Quyality and Nature Protectionin the Hula Valley, Israel. Springer Geography, Berlin. https://doi.org/10.1007/978-3-031-23412-5

[6] Gonen, E. (Ed.) (2007) Hula Project Annual Report. Jewish National Fund (Keren Kayemet LeIsrael) Migal-Scientific Research Institute and Israeli Water Authority. 133.

[7] Levanon, D. (2023) Chapter: Forward: Agricultural Development and Soil Deterioration after the Hula Drainage. In: Gophen, M., Ed., *Agriculture*, *Recreation*, *Water Quality and Nature Protection in the Hula Valley*, *Israel*, Springer Geography, Berlin.

[8] Barnea, I. (Ed.) (2008) Hula Project Annual Report. Jewish National Fund (Keren Kayemet LeIsrael) Migal-Scientific Research Institute and Israeli Water Authority, 159 p.

[9] Barnea, I. (Ed.) (2008-2018) Hula Project Annual Report. Jewish National Fund (Keren Kayemet LeIsrael) Migal-Scientific Research Institute and Israeli Water Authorit.

[10] Gophen, M. and Levanon, D. (Eds.) (1994-2006) Hula Project Annual Reports. Migal-JNF (KKL). (1994-2005 in Hebrew, 2006 in English)

[11] Edmondson, W.T. (1991) The Uses of Ecology Lake Washington and Beyond. University of Washington Press, Seattle and London, 331 p.

[12] Gophen, M. (2022) Dramatic Change in the Kinneret Phytoplankton Community Structure—Peridinium Out, Cyanobacteria in (POCI): Perennial or Disposable. *Water*, **14**, 2583. https://doi.org/10.3390/w14162583

[13] LKDB (1970-2022) Kinneret Limnological Laboratory, IOLR, Ltd. Annual Reports, Haifa.

[14] Dimentman, Ch., Bromely, H.J. and Por, F.D. (1992) Lake Hula, Reconstruction of the Fauna and Hydrobiology of a Lost Lake. Publications of the Israel Academy of Sciences and Humanities, 170 p (Brief Summary in Hebrew 24 p).

[15] Serruya, C. (1978) Part Three: The Planktonic Communities. In: Kinneret, L., Ed., *Monographiae Biologicae*, Dr. Junk bv Publishers, The Hague-Boston-London, Vol. 32, 185-204. https://doi.org/10.1007/978-94-009-9954-1

[16] Yaari-Cohen, G., Paldi, C., Mozes, G. and Harpaz, A. (1971) A Survey of Peat Soils in the Hula-Valley, Israel. Part A. Water & Drainage Authority, Upper Galilee; Ministry of Agriculture, Soil Department, Kiriat Shemona. 37 p. (In Hebrew) (Eng-

lish Summary).

[17] Gophen, M. (2021) Effects of Climate Conditions on TP Outsourcing in Lake Knneret (Israel). *Climate*, **9**, 1-24. https://doi.org/10.3390/cli9090142

[18] Meron, M., Peres, M., Gershon, G., Torchinski, C., Alpert, R., Melman, G. and Shalit, M. (2008) Upper Galilee Reservoirs Monitoring Program. Interim Report (1996-2007). Upper Galilee Municipality Kiryat Shmone, 40 p. (In Hebrew)

[19] Green, P. (2005) Annual Activity Report, 2005. Interim Report, 20 p. (In Hebrew)

[20] Davis, R.J. (1973) Investigation of the Pollution Problem of Lake Kinneret. Special Interim Report, Water Commissionaire, Israeli National Water Authority, Tel Aviv., Vol. 3, 138 p.