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Temporal, Spatial, and Hypsometrical Dispersion of Nutrients in the Hula Valley, Israel

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Abstract

Until 1957 most of the Hula Valley was occupied by swampy wetland covered by dense vegetation and old Lake Hula. Organic matter was accumulated in the bottom, decomposed under anoxic conditions creating Peat material. The wetland and the old lake were drained and the land-use was converted into agricultural development. Nutrients migrations from the Hula Valley through the headwater discharges carrying nutrients, where nitrogen enhancement is critical, significantly affecting water quality in down-stream Lake Kinneret. The fate of the Hula originated nutrients is partly known whilst fate of the others which might be probably a threat on the Kinneret water quality is unknown. The hypsometrical and spatial distribution of the Hula Valley originated nutrients within three depths level was indicated: shallowest level of surface water, intermediate level of underground water table and the deepest level of Lignite waters. The Hypsometrical and spatial distribution and regional origin of the nutrient in the Hula Valley was defined. Organic Nitrogen, Sulfate and Nitrates are mostly Hula Valley originated nutrients whilst most of the Phosphorus externally contributed to Lake Kinneret originate outside the Hula Valley. An underground north-south Hydrological gradient and nutrient migration along was indicated. It is suggested that an underground plastic barrier do not totally prevent horizontal nutrient migration. Hypsometrical downward migrated nutrients probably accumulate within the "Lignite" depth level. Management policy of increasing Peat Soil moisture, is recommended.

Keywords

Hula Valley, Kinneret, Nutrients, Runoff, Underground, Lignite

1. Introduction

1.1. Hydrological Anthropogenic Involvement

The drainage basin of Lake Kinneret (2730 km^2), of which 200 km^2 of the Hula Valley (7.3%), is part of the northern section of the Syrian-African Great Rift-Valley. The Hula Valley has undergone historical long-term attractive attention resulting from its geopolitical location and availability of transportive water routes, plenty of water, food production resources and suitable climate conditions. The geological history of the sedimentation process in the Hula Valley was widely documented [1]-[9]. The integration between human management and natural habitats within the Hula Valley was optimal since no drastic anthropogenic intervention was carried out [9]-[11]. Therefore, until 1957 most of the Hula Valley was covered by swampy shallow wetland waters and old Lake Hula (13.5 km^2 and mean depth 1.5 m) [10]-[12]. Emerged plant vegetation of *Cyperus papyrus* and *Phragmites australis australis* covered densely the swampy wetlands. Submerged plants were densely distributed within the swampy waters. Organic matter (60 - 80% content) was accumulated on the bottom of the swampy wetlands and decomposed under anoxic conditions creating Lignite-Peat material whilst the bottom sediments of the old Lake Hula were Calcium rich [1]-[9].

Throughout the Anthropocene the Hula Valley is a compatible interlock of anthropogenic achievement into national economy, water supply, agriculture, nature protection and tourism managements. The Kinneret catchment comprised of three headwaters, Hatzbani, Banyas and Dan, flowing southward down from Mount Hermon connected together with several other streams, and non-point runoffs, forming the Jordan River which contributes about 63% of the Kinneret water budget conveying about 70% of nutrient inputs loads. The Hula Valley was mostly covered by swampy wetlands and old Lake Hula which were drained and land-use was modified from natural environment to agriculture. During 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. Nevertheless, as a result of inappropriate methods of irrigation and decline of the Ground Water Table (GWT), heavy dust storms occurred frequently which resulted in subsidence of soil surface and blocking of drainage canals. Outbreaks of underground fire occurred frequently and Rodent population outbreak caused severe damage to agricultural crops. 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. A shallow Lake Agmon (0.2 average depth; 82 ha surface area) was created as a waste 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 leaking southward.

After the implementation of the Hula Project it was indicated that N and P loads removed by the Agmon-Hula system is minor: 1.0 - 2.0 tons TP and 25 - 30 tons TN annually [10] [11]. The principal cmponents of the Hydrologicl system in the Hula vlley are: Newly created shallow Lake Agmon-Hula (surface area—82 ha, mean depth—0.2 m), 90 km of renewed darainagee and water supply canals of which the principals are Canal Z, Canal Hula East (which convey Peat Soil Drained waters) and the reconstructed Jordan route. Calculated water balance (10^6 m^3/y) of Lake Agmon-Hula has indicated significant loss through infiltration: Total gain—11.3, total loss—8.5, water level increase—0.1, and −2.7 (24% of the inflow) loss through bottom infiltration of rich nutrient water and residence time of 2.8 days. Mass balance of Lake Agmon-Hula has indicated different fate of TN and TP: Higher TP outflow (1.2 t/y) than inflow (0.8 t/y) resulted by seasonal proliferation and degradation of submerged vegetation which utilize Phosphorus stored in bottom sediments. This positve balance exist in spite of particulate Phosphorus sedimentation and water P-mediated infiltration, whilst the opposite for TN: the lake effluent contain less TN (27.3 t/y) than the inflow (38.1 t/y). The reason for that is probably Nitrogen removal through de-nitrification, particulate Nitrogen sedimentation and infiltration. Consequently, Hypsometric Dispersion, of nutrients from surface and downward through the Ground Water Table and below is justified. Emphasizing an indication of north-south hydrological gradient and respective migration of nutrients from north to south in the Hul Valley.

1.2. Surface Runoff Waters

The water mass flows in the Hula Valley include surface water or runoff as aerial flood dispersed and folded within the canal system and as underground gathered in preferential pathways (tunnels, or free space). Surface water in the Hula Valley is all directed from north to south as the slope trait of the Graben. Nevertheless, Artesian water migration in the Hula Valley was concluded and even defined as the major underground water migration in the valley. Nevertheless, Artesian water migration was considerable in the northern and was not indicated in the southern valley region [13]. The indication of hydraulic gradient oriented North-South [11] is in agreement with earlier studies. The assumption of uplifted Artesian water in the Hula Valley was denied. Earlier studies about nutrient dynamics in the Hula Valley during post drainage period included surface water. The present paper is an attempt at evaluation of the nutrient dispersion in the Hula Valley within three Hypsometrical levels: surface water, underground level (Ground Water Table) and within the Lignite waters (5 - 150 m below surface) [14]. The capacities of Nitrogen and Phosphorus within the total volume (0 - 150 m) of the Hula-Peat-Soil-include shallow layers, runoff and GWT (6 m depth) where mass exchange occur periodically whilst significant portion of those nutrients are deeply buried forming Lignite. Significant part of Nitrogen, mostly as Nitrate and minor part of Phosphorus are exported. Lignite is a matter that was formed from Peat substance that exists commonly at the bottom of shallow productive swampy wetlands such as was in the Hula Valley during the Pre-drainage period (<1957). The Hula wetlands were densely plant-covered. Very high biomass of common emerged (among others: *Cyperus spp.*, *Phragmites spp.*, *Typha spp.*) and submerged plants (among others: *Potamogeton spp.*, *Nymphaea alba, Najas spp., Myriophyllum sp.*). The regional climate is tropical with annual mean daily air temperatures ranging between 18 - 22˚C. Organic matter that was intensively deposited and accumulated as Peat form on the Hula wetlands-swampy bottom, was degraded and decomposed through coalification stages of sub-bituminous, bituminous and finally produced brown coal or lignite. Geological investigations in the Hula Valley were previously carried out and guidelines features were: Picard [1] [2] defined the two interfingered facies of Gadot lacustrine and Hatzor alluvial in the southern part of the valley; the creation of Lake Hula before 30,000 years was suggested by Cowgill [5] [15]. The regional dimensions and spatial distribution of the lignite in the underground of the Hula Valley were previously studied [6]-[8] [14]-[19]. The geological history of the Hula Basin formation was documented by Horowitz [3] [4] and the impact of climatic conditions on the lake-water depth was published by Ehrlich [16]. The hydrological consequences were documented [20]. A comprehensive survey of the underground volume and location of Lignite in the Hula Valley was documented [6]-[8].

Although many earlier studies were carried out about soil features, nutrient geochemistry, spatial distribution of soil types as well as hydrological management and soil moisture conditions in the Hula Valley were not comprehensively accomplished. This paper is an attempt at spatial and Hypsometrical evaluation of nutrient migration within the Peat Soil Hula Land. The disadvantage of the presently available information is the lack of deep layer information. Partial cover pf this data deficiency is covered by two data sources that were documented in the Peat-Soil-Hula-Land: 1) An annual (2010) survey of the groundwater composition; 2) The Lignite and its water content composition survey that was carried out during the 1970's. The monitor program of quantitative and qualitative qualities of surface waters was long term routinely recorded. This paper is a tentative attempt at integration between those three documentations. All along the studies and surveys carried out in the Hula Valley an enigmatic issue accompanied their consequent conclusions: what is the fate off micro and macro-nutrient migrated from the Hula Valley: partial answers were evaluated from their role within the balances of inputs and cycling in Lake Kinneret. Nevertheless, the fate of partial portion of commonly distributed macro elemental nutrients within the upper layers of the Hula Valley soil cross section such as Phosphorus is not clearly known. The ecological nutrient fate hypothesis is that most of the Phosphorus is migrated downward to an unknown end-lock whilst major portion of the Nitrogen is involved within biogenic cycles in the Peat-Soil-Hula-Land and the limnological ecosystem of Lake Kinneret. This paper, include a summary of the available data and interpretation of the fate of nutrients migration with respect to hypsometrical distribution.

1.3. Stratigraphical Structure

Stratigraphic analyses in boreholes carried out in 1951, in the Hula Valley swamp [9] have indicated a 6-meter thickness of the upper Lignite layer and underneath 40 m thick layer comprised of silt-Calcareous, and deeper below 50 m thick Peat layer. Southern to the swampy-peat soil layer the soil is mineral [9]. Until 1957 the swampy water and the vegetation cover protected the sedimentation basin of the Lignite layer from atmospheric oxidation. In 1957 the Hula valley was drained and the Hula valley land was converted from swampy wetlands and old shallow lakes into agricultural development. The runoff waters and 0 - 5 deep underground waters were routinely monitored within the frame of the Hula Project proposal [10] [11]. As a result of the drainage, the upper Peaty-Lignite layer was exposed to oxidation which enhanced the chemical conversion of organic Nitrogen to Nitrate. During the seventies, a pre-visibility research project was carried out aimed at the tentative indication of energy production from Lignite resources in the Hula Valley [6]-[8]. Within the scope of this project, the pore water in the Lignite layers was analyzed [12]. The upper 150 m part of the Hula Valley filling sedimented matter includes layers of Clay-Marl, Peat-Lignite, Humic-Clay, and mixed Send-Pebbles [6]-[8] [13]. The analyzed stratigraphic section of sedimentation of the upper Peat layer included 0 - 10 m below the surface that was initiated about 2500 years ago [5]. Underneath this layer between 30 - 100 m below the surface, covering a major part of the valley, [3] [4] [14]-[16] is aged 35,000 years and lower there are more Lignite strata at 100 - 292 m below surface [5] [6]. The bottom of the sedimented matter bordered by Miocenic-calcareous rock is below 2781 m but was not precisely defined [13]. A comprehensive description of the upper (shallower) different soil types in the Hula Valley during the Post Drainage Era was widely documented (among others) [13] [17]-[27]. Three hypsometrical levels of water mass in the Hula Valley are considered: A) Upper-surface-runoff water; B) Medium-Underground, between surface and 6 meters deep; C) Deep-Lignite water, limited between 5 - 150 m deep. The objective of this study is to open wider historical and hypsometrical ranges of knowledge of nutrient resources in the catchment aimed at improvement of ecosystem management to protect Kinneret water quality.

2. Material and Methods

2.1. Study Area and Ground Water Table Sampling

Fourteen consecutive monthly (2 - 12, April excluded) (2010) underground (Ground Water Table, GWT) pumped water sampling was carried out in 14 boreholes in the Hula Valley (**Figure 1**) and chemical analysis was followed. An underwater hydraulic gradient sloping from north to south was indicated resulting higher level of GWT in the northern part of the Hula Valley. Lower amplitude of GWT fluctuations and a higher level in winter were recorded [10].

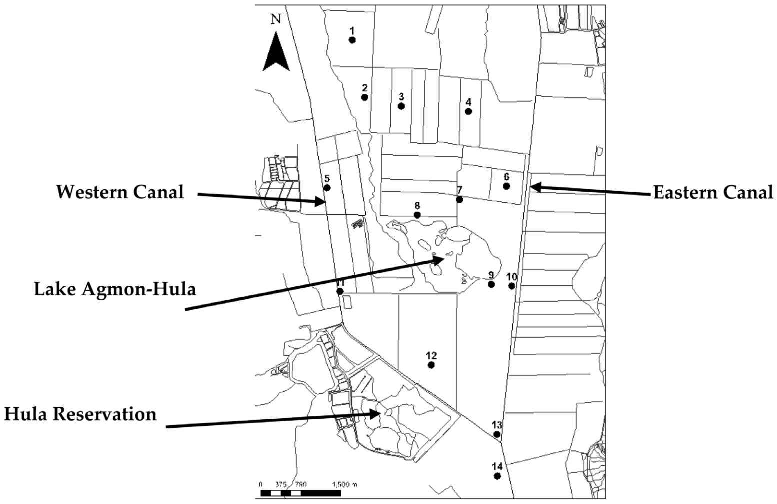

Figure 1. Ground water table drillings (boreholes) (numbered 1 - 14) distribution map in the Hula Valley.

2.2. Statistical Methods

Statistical evaluation was done using software of: STATA 17.0-Standard Edition, Statistics and Data Science, Copyright 1985-2021 StataCorp LLC, StataCorp, 4905 Lakeway Drive, 4905 Lakeway Drive, 800-STATA-PC, Stata license: Single-user perpetual, Serial number: 401706315938, Licensed to: Moshe Gophen, Migal. Three Statistical methods were utilized: Linear Prediction, Lowess Smoother and Linear Regression.

3. Results

3.1. Rainfall Regime

Seasonal distribution of rainfall (Dafna Station-Northern part of the Hula Valley) are given in Figure 2.

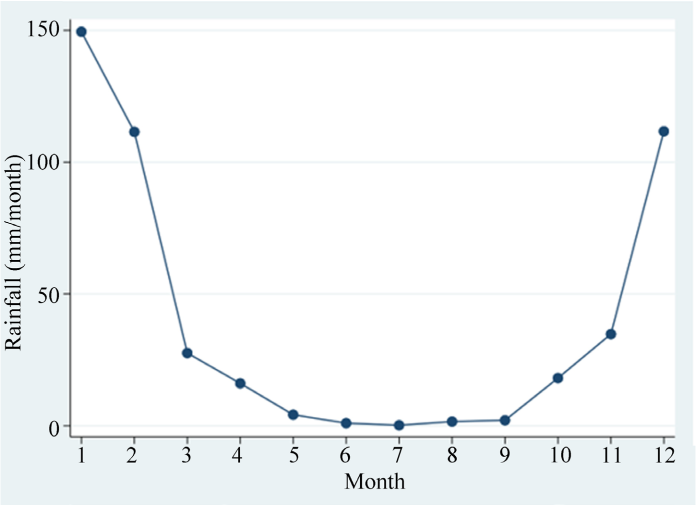

Figure 2. Monthly (2010) Rainfall (mm), average of Gadash, Kfar Blum and Dafna meteorological Stations In the Hula valley.

3.2. Soil Surface Subsidence

The grand total mean which includes all available data has indicated an average annual soil surface subsidence in the Hula Valley of 10 and 9 cm during the 1958-1964 and 1964-1965 periods respectively [17]. Consequently, shortly after the drainage (>1957) the rate of subsidence was high and diminished later (>1964). Measurements of soil surface subsidence carried out during the late 1990s confirmed a rate of 6 - 8 cm/year and slightly less later [18]. Conclusively during the post-drainage period (1958-present) soil surface, as the average for the entire Hula Valley (including marl soil with lower rate) in the Hula Valley, declined range is approximately 4 - 5 meters. The survey carried out during 1958-1964 indicated [17] the highest soil surface altitude of 67.19 whilst presently it is around 62.00 MASL in the central part of the valley. The horizontal and vertical distribution of nutrient concentrations in the uppermost soil level in the Hula Valley was intensively explored and aimed at appropriate management of agricultural fertilization requirements. The seasonal changes in the hydrological dynamics are highly affected by anthropogenic intervention and climatological condition changes. Soil properties in the Hula Valley are very versatile, such as content of $CaCO_3$ in the upper soil layer (0 - 16 m) in the southern part was defined as 40 - 80% and organic matter −7 - 17% of the dry matter, whilst lower $CaCO_3$ and higher organic matter content in the northern part of the valley [13].

Soil surveys carried out in the Hula Valley during pre-drainage, in 1945 [25] and 30 years after drainage in 1984-85 [26] [27] documented a soil surface subsidence of 3.5 m. The organic matter content (%) in the upper 2.5 meters of the Peat soil was diminished from 75 to 10 - 20% [26] [27] whilst marl-carbonate soil in the southern part of the valley which was covered by old Lake Hula contain 50 - 80% carbonates. Decomposition of organic matter in the peat soil enhanced underground fire. It has to be taken into account that dry peat soil dust was intensively eroded by wind which also enhanced the subsidence of surface level.

3.3. The Impact of Anthropogenic Involvement

During the last century, the Hula Valley has undergone significant ecological modifications: First—The Drainage (1957), Second—Raw Sewage removal and Fishponds restriction (the mid-1980s) and Third—Hula Reclamation Project (1994-2007). Nutrient migration that prevailed between the first and second phases is presented in **Table 1**.

Data shown in **Table 1** indicates a significant change that was carried out in the Kinneret watershed Prior to the sewage removal, fishpond restriction and Hula Reclamation Project when about 70% of TP input into Lake Kinneret originates from the Hula Valley whilst later on surface water in the Hula Valley as TP source became negligible within the total Kinneret input [29] and its content in deep groundwater and Lignite water (later in this paper) very low. Nevertheless, it is possible that TP migrates through the underground water flows within preferential spaces and drained into the Eastern and Western canals (**Figure 1**) and downstream into Lake Kinneret. Moreover, several sources of nutrients in the Kinneret drainage basin were not considered in Table 1: western headwaters fluxes from the Golan heights and eastern from Naftali ridge. The significant contribution of Nitrogen (mostly as NO_3) originating from the peat soil after Hula drainage is supported by (Table 1). The contribution of Ammonium and Organic Nitrogen and consequently TN were significantly reduced towards the end of the 1980s resulting in sewage removal and fishpond restriction whilst nitrates, which originate from oxidized peat soil during post-drainage, continued intensively. Conclusively it can be summarized that the Hula Valley presently contributes to Lake Kinneret mostly nitrogen. Annual means of major nutrient concentrations (ppm) in the GWT (14 boreholes) of major nutrient concentrations (ppm) are given in Table 2.

Table 1. Periodical (1967-1985) means of nutrient loads in ton/y, (SD): Ammonium-NH_4, Nitrate-NO_3, Organic Nitrogen-ON, Total Nitrogen-TN, Total Phosphorus-TP and Annual Discharge (10^6 m^3) in Kinneret headwaters (Dan, Banias and Snir), and River Jordan (at Huri station); Total Headwaters, and Hula valley contribution are given: Huri minus Total Headwaters Equals Hula valley contribution. (ton and %) [28].

Source	NH_4	NO_3	ON	TN	TP	Discharge
Dan	6 (3.4)	264 (36)	78 (32)	348 (3)	5.7 (1.3)	270 (32)
Banias	3.1 (1.4)	136 (36)	54 (26)	193 (59)	18 (10)	116 (36)
Snir	3.9 (2)	144 (59)	67 (41)	215 (9)	19 (12)	129 (64)
Jordan	63.1 (24.7)	1042 (569)	480 (192)	1584 (705)	119 (53)	530 (184)
Total Headwaters	13	544	199	756	43	515
Hula Valley (% of Jordan)	50.1 (80)	498 (48)	281 (59)	828 (52)	76 (69)	15 (3)

Table 2. Monthly means (14 boreholes) of nutrient concentrations (ppm) in GWT.

Month	NH_4	NO_3	TDN	TN	TP	TDP	SRP
2	14.5	144	132.3	148.6	0.204	0.075	0.152
3	47.2	219.7	127	138.5	0.58	0.3	0.29
5	40.7	116.6	107.7	122.1	0.398	0.266	0.358
6	48.3	234.7	135.3	92.2	0.47	0.245	0.335
7	56.6	263	133.5	151.1	0.417	0.286	0.305
8	51.9	167.4	104.6	125.9	0.442	0.257	0.361
9	80.6	56.3	97.9	89.1	417	0.278	0.314
10	70.2	38	79	100.6	0.403	0.171	0.239
11	86.5	79	85.8	376.2	0.393	0.104	0.193
12	38.4	331.3	174.3	195	0.143	−0.037	0.081

Results given in Table 2 indicate lowest concentrations of TN and TP in June.

Results in Table 3 indicate highest concentrations of TN and TP in GWT underneath heavy Peat soil.

Table 3. Annual (2010) means of nutrient concentrations (ppm) of GWT in 14 boreholes (See **Figure 1**).

Borehole	NH_4	NO_3	TDN	TN	TDP	TP	SRP
1	4.1	41.2	26.9	33.7	0.05	0.104	0.054
2	5.3	26.5	18.9	23.2	0.015	0.068	0.016
3	0.1	451.5	228.9	540.4	0.021	0.046	0.016
4	0.5	68.8	24.9	32.2	0.029	0.155	0.041
5	8.5	17.8	16.8	20.5	0.018	0.079	0.026
6	359.3	874.9	922.2	1116.9	0.062	0.256	0.072
7	103.1	12.5	92.6	127.6	0.885	1.362	1.151
8	56.3	26.6	61	75.1	0.24	0.648	0.428
9	32.3	108.1	76.2	80.6	0.122	0.403	0.156
10	16.5	94.7	61.5	66.9	0.042	0.105	0.04
11	45.2	2.6	80.4	97.3	0.051	0.306	0.098
12	1.4	89.7	51.3	57.7	0.096	0.211	0.104
13	21.7	38.6	40.5	44.1	0.096	0.258	0.127
14	116.5	100.4	91.4	210.8	0.991	1.294	1.215
Mean	55.1	139.6	128.1	180.5	0.194	0.378	0.253

3.4. The Underground Waters

Since the late 1990s a monthly record of the level of the Ground Water:

Table (GWT) depth is carried out in 14 borehole drillings (See Map, **Figure 1**) and during 2010 Chemical composition was recorded (**Tables 4-6**).

Table 4. Averages of TN, TP concentrations and TN/TP ratios in Lake Kinneret. River Jordan, Hula underground and Lignite waters.

Water Source	TN (ppm)	TP (ppm)	TN/TP Ratio
Kinneret	0.711	0.02	33.86
Jordan	2.587	0.17	14.87
Runoff Water: Hula Project	2.418	0.12	20.32
Underground waters	179.5	0.39	464.18
Lignite Waters	1022	5.87	174.1

Table 5. Elemental (TP, SO_4, NH_4, NO_3, TN, Cl) composition (ME) of Lignite water, Lake Agmon-Hula water and Underground (GWT) water [10] [11], lake Kinneret, and river Jordan [12] [19] [28]-[31].

Element	Lignite	Agmon[#]	Underground[*]	Kinneret	Jordan (Huri)
TP	0.21	0.004	0.02-south 0.002-north	0.001	0.01
SO_4	0.99	9.1-winter 3.6-summer	10.3	0.6	0.29
NH_4	26.9	0.004	4.6-south 0.2-north	0.1	0.01
NO_3	0.01	0.042	1.03-south 0.9-north	0.004	0.03

Continued

TN	70.6	0.205	13.8	0.04	0.21
Cl	2.3	1.4	0.72	7	0.47

[*]North, South—Underground boreholes are located northern and southern to the underground barrier; [#]Winter, Summer—sampling during winter and summer months; SO_4 parameter in underground waters was taken from Pore Water sampling [31].

Table 6. Ion concentrations (ppm) and EC (mS/cm) of Underground Water (GWT) sampled in four of Hula Valley regions: western (1), eastern (2), central (peat soil) (3), and southern (Transition soil: peat-marl) (4) and Southern (Marl) (5) (Modified from [13].

Region	Ca	Na	Mg	Cl	K	P	HCO_3	SO_4	EC
1	150	40	50	90	3.2	0.12	310	130	1.68
2	80	50	40	40	4.6	0.31	300	20	0.96
3	670	40	80	120	11	0.8	500	560	2.89
4	540	45	70	100	4.8	1	470	420	2.74
5	480	65	90	120	6.4	0.6	680	570	3

The Maximum-Minimum range of pH was 8.52 - 7.4;

The Maximum-Minimum range of Electric Conductivity (EC) was 8236 - 3752;

In boreholes Number 11, 12, 22 and 23 Sulfate was exceptionally high;

In boreholes Number 22 Nitrate was exceptionally high.

3.5. The Lignite Beds

Significant concern within the optional usage of Hula Lignite for Thermo-Electrical Production was due to its impact on the water quality in Lake Kinneret. Earlier studies [19] [28] [29] suggested the negative impact of Lignite waters on Kinneret water quality. Consequently, the Lignite water pumped in 23 borehole drillings was sampled and their compositions were analyzed accompanied by its potential microbial degradation [12]. All Lignite water samples were very rich in suspended matter. The following chemical parameters were indicated: Electrical Conductance (EC), pH, Chloride (Cl^-), Alkalinity, Sulfate (SO_4), Ammonium, Calcium, Magnesium, Sodium, Potassium, Organic Nitrogen, BOD and ATP.

Concentrations of Nitrate in Lignite waters removed from all boreholes ranged between 0.3 - 0.03 ppm whilst in borehole no. 17 an exceptionally high (3.9 ppm) was measured; pH values in all Lignite water samples varied between 7.4 - 8.5; sulfate concentrations in Lignite water samples removed from 15 boreholes (79%) was 5 ppm whilst 4 exceptions of 693, 308, 250, and 291 ppm in borehole number 17, 12, 3, and 9 respectively were documented (**Tables 7-12**) (**Figure 1**).

Table 7. Maximum, Minimum and total mean values (23 boreholes) (ppm) (µS) of nutrient concentrations analyzed in Lignite water.

Nutrient	Maximum	Minimum	Mean
Total C	122	45	80

Continued

Chloride	484	9	127
Kijeldhal	2230	104	988
Ammonium	919	86	378
Organic Nitrogen	1893	172	655
Nitrate	0.6	0.03	0.4
Total Phosphorus	23.5	0.45	6.5
Alkalinity[#]	5350	1900	3624
Calcium	407	53	293
Sulfate[*]	291	5	386
NO_3[&]	0.3	0.03	0.2
EC	7555	3509	3861

*13 Boreholes mean—5 ppm; 4 Boreholes Mean—386 ppm (μS). [&]Borehole 22 excluded; [#]As $CaCO_3$ in mg/l.

Table 8. Lignite Water Composition (ppm) and total average: Total Kijeldhal (Kijldhal T), Organic Nitrogen, Ammonium (NH_4), Nitrate (NO_3), Total Phosphorus (TP), Calcium (Ca), Sodium (Na), Magnesium (Mg), Chloride (Cl), and Total Carbon (C), in Each Borehole drilling and elemental total average [12].

Borehole	Kijeldhal-T	Organic-N	NH_4	NO_3	TP	Ca	Na	Mg	Cl	TC
1	1816	1081	735	0.3	0.96	401	247	350	61	71
2	1228	763	465	0.3	0.95	295	329	606	112	102
3	2230	1893	337	0.3	23.5	141	821	157	155	
4	1550	759	791	0.03	0.77	407	170	360	9	
5	1155	755	400	0.04	2.16	236	488	394	226	117
6	975	567	408	0.03	1.44	254	454	385	223	121
7	790	490	300	0.3	17.5	224	631	539	484	
8	1962	1043	919	0.5	4.75	246	232	236	20	85
9	740	654	86	0.03	11.16	74	700	82	9	
10	1062	851	211	0.3	13.25	171	748	451	320	122
11	1178	998	180	0.06	4	109	683	143	101	
12	770	272	498	0.3	4.25	295	371	293	68	83
13	1156	580	576	0.3	1.33	322	257	317	16	79
14	1050	745	305	0.3	0.45	183	341	324	80	
15	400	255	145	0.3	1.55	208	520	411	198	86
16	430	172	258	0.03	2.97	53	320	448	11	
17	624	500	124	3.9	10.25	232	488	242	73	45
18	104	39	64.8	0.03	6.13	112	593	87	213	65
19	119	35.5	83.5	0.04	4.13	105	532	116	219	68
Mean	1009	655	376	0.39	5.87	214	470	313	137	84

Table 9. Alkalinity (ppm $CaCO_3$) and Electric Conductivity (EC in μmhos/cm) in Lignite water and total average, in each Borehole [12].

Borehole	Alkalinity	EC
1	4720	7555
2	4740	7160
3	2900	5653
4	5350	6950
5	4440	3752
6	4380	6885
7	4190	6839
8	5250	8326
9	1950	6277
10	3620	4729
11	2890	4559
12	3930	6089
13	3920	6600
14	3110	5100
15	3200	5048
16	3470	4340
17	2020	3766
18	2000	3509
19	1900	3766
Mean	3604	5627

Table 10. Averaged composition (milliequivalent; ME, and %) summary of Anions, and Cations in Lignite water from 23 boreholes.

	ME (%)
Anions	
Chloride	3.3 (4.3)
Bicarbonate	72.6 (93.4)
Sulfate	1.8 (2.3)
Total	77.7 (100)
Cations	
Ammonium	26.9 (31.8)
Calcium	10.9 (12.9)
Magnesium	26 (30.7)
Sodium	20.3 (24)
Potassium	(0.6) (0.6)
Total	84.7

Table 11. Spatial Mean concentrations (ppm) of nutrients in the ground and Lignite waters [12] [13].

Nutrient	Ground Water	Lignite Water
Ca	384	214
Na	48	470
Mg	66	313
Cl	94	137
K	6	19.1
P	0.57	5.87
HCO_3	452	ND
SO_4	340	989
EC (mS/cm)	2.25	5.6

Soil surface subsidence as periodically measured immediately after drainage (1958-1964, and 1964-1965) [17] are given in **Table 12**.

Table 12. Annual Soil surface subsidence (cm) in the Hula Valley during two periods 1958-1964 and 1964-1965: Total aerial size of 6 (enumerated 1 - 6) surveyed blocks was 33.5 10^3 m^2 (dunam) in the central part of the valley at an altitude ranged between 67.19 and 65.76 MASL (meters above sea level).SDs (cm) ranged between 0.2 - 0.4 and 0.6 - 2.4 during 1958-1964 and 1964-1965 respectively [17].

Block No.	Annual subsidence (cm) 1958-1964	Annual subsidence (cm) 1964-1965
1	12	4
2	8	12
3	7	14
4	10	6
5	13	12
6	8	8

The seasonal (monthly) (Left side) and spatial distribution (**Figure 1**) (right side) of Phosphorus (ppb) and Nitrogen (ppm) form nutrients in the GWT are shown in **Figures 3-9**.

Results shown in **Table 2** and **Table 3** and **Figures 3-9** indicate the relation between nutrient concentrations, spatial distribution and climatic conditions (rainfall regime). The concentrations of P and N forms are dependents of both the geochemical type of bound to the peat soil particles and the rainfall regime impact on their flushing and migration from the uppermost peat soil depth into the GWT—the subterranean underground water. The difference between nitrogenous and phosphorous substances is prominently expressed in the **Figures 3-9** and **Tables 2-3**. Boreholes number 1 - 8 are located in the organic peat-soil northern to the underground plastic barrier [10] [11] and the southern boreholes are located in marl soil. Moreover, the northern boreholes are located where GWT altitude is higher than in the southern region creating the hydraulic gradient. A prominent exceptionally high concentration of all P and N nutrients was recorded in borehole numbers 6 and 7 (**Table 3**, **Figures 3-9**). Moreover, a personal communication (M. Peres, unpublished) reported about Sulfide smell that was commonly indicated from these boreholes but chemical

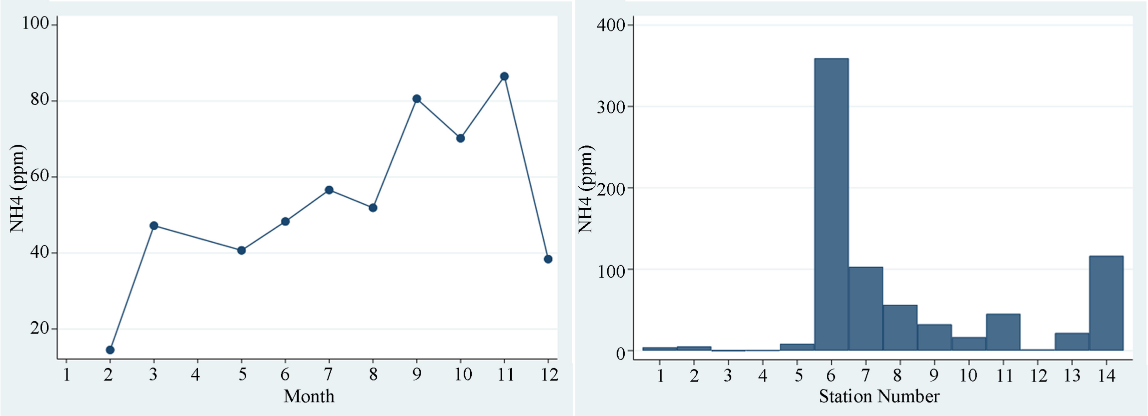

Figure 3. Monthly (left) and spatial (boreholes 1 - 14; right) distribution of.NH_4 (ppm) in the GWT waters.

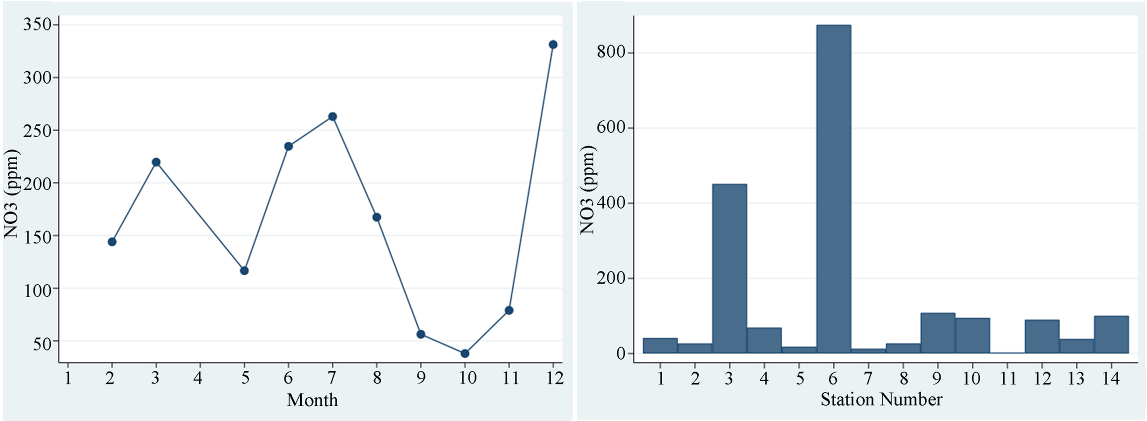

Figure 4. Monthly (left) and spatial (boreholes 1 - 14; right) distribution of. NO_3 (ppm) in the GWT waters.

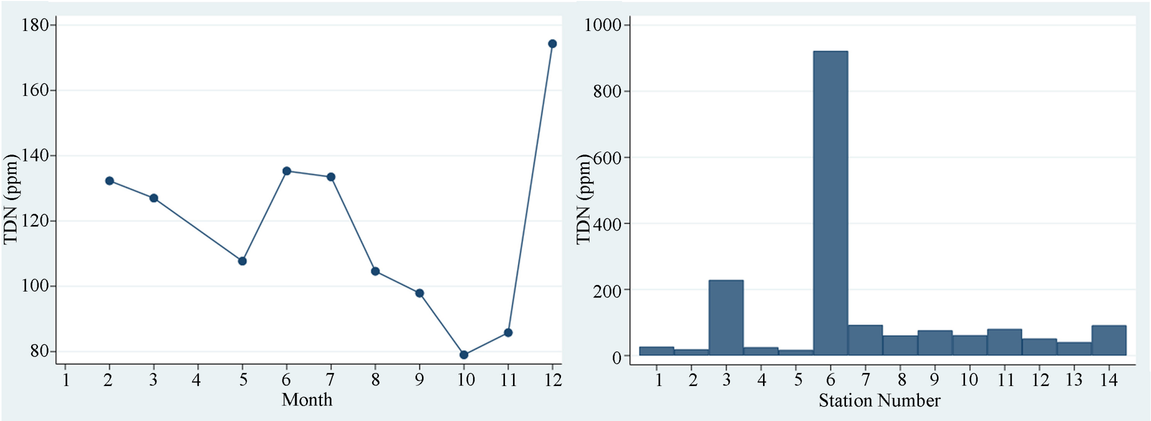

Figure 5. Monthly (left) and spatial (boreholes 1 - 14; right) distribution of. Total Dissolved Nitrogen (TDN) (ppm) in the GWT waters.

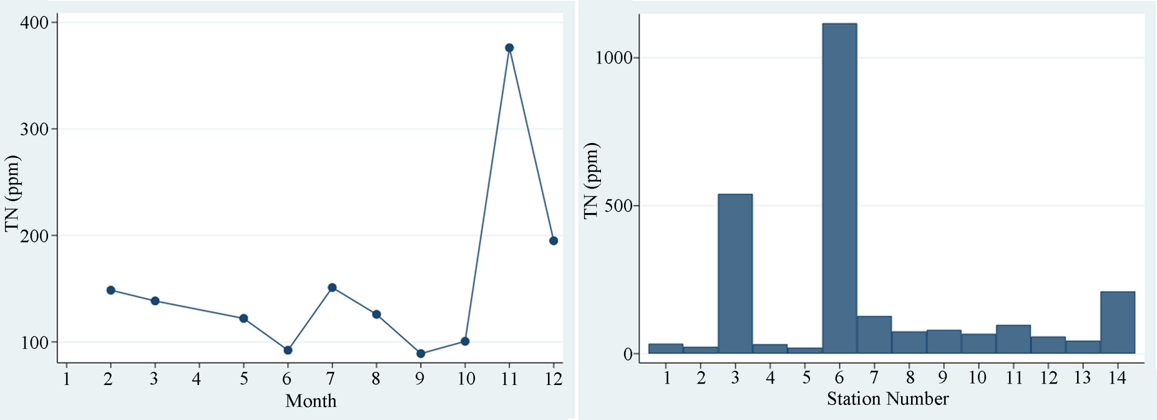

Figure 6. Monthly (left) and spatial (boreholes 1 - 14; right) distribution of. Total Nitrogen (ppm) in the GWT waters.

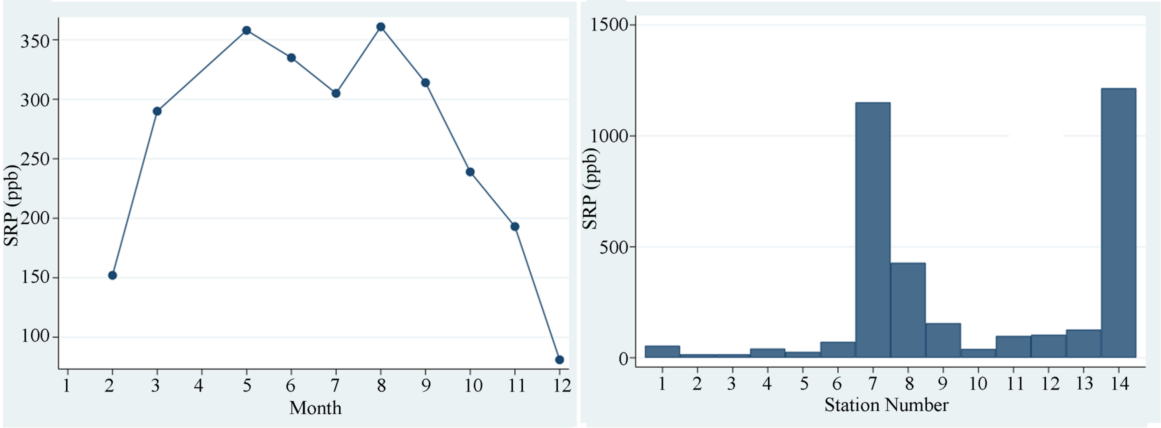

Figure 7. Monthly (left) and spatial (boreholes 1 - 14; right) distribution of. Soluble Reactive Phosphorus (SRP) (ppb) in the GWT waters.

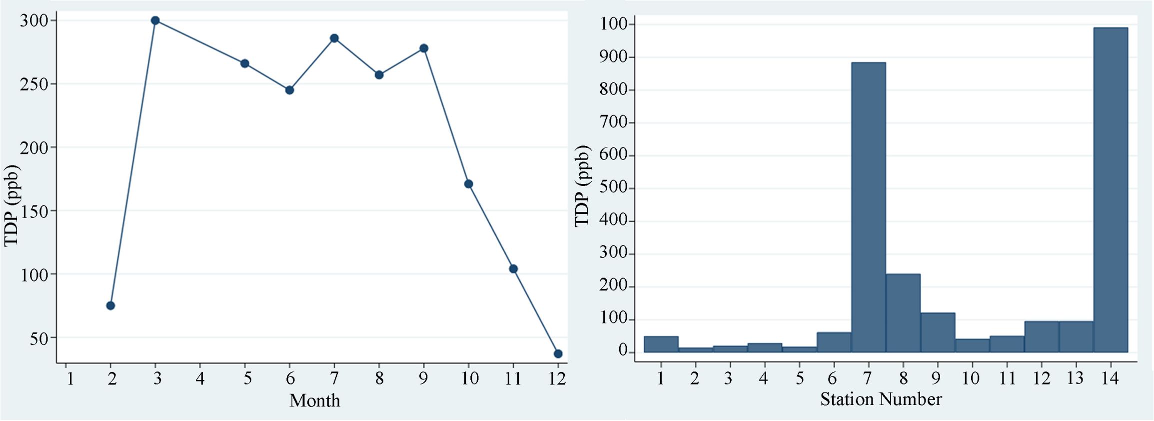

Figure 8. Monthly (left) and spatial (boreholes 1 - 14; right) distribution of. Total Dissolved Phosphorus (TDP) (ppb) in the GWT waters.

analysis was not recorded. It is suggested that in the vicinity around boreholes 6 - 7, there is an underground depression where the exchange rate of the subterranean perennial GWT accumulates and partial anoxia is developed, probably a slight subterranean Hula wetland "memorial" body of water. Results presented in **Figures 3-9** indicate nutrients migration within the underground waters (GWT) along the north-south hydraulic gradient [10]. An accumulation effect is indicated for all N and P nutrients except nitrates. Nitrates are efficiently drifted from the peat soil by surface waters and conveyed into river Jordan. The high increase of ammonium (**Figure 3**) is the result of both migration and denitrification. Temporal distribution of NO_3, TDN, SRP, and TDP in the underground waters (GWT) (**Figures 4-5**, **Figures 7-8**) indicates high concentrations in winter and low in summer [10] [11].

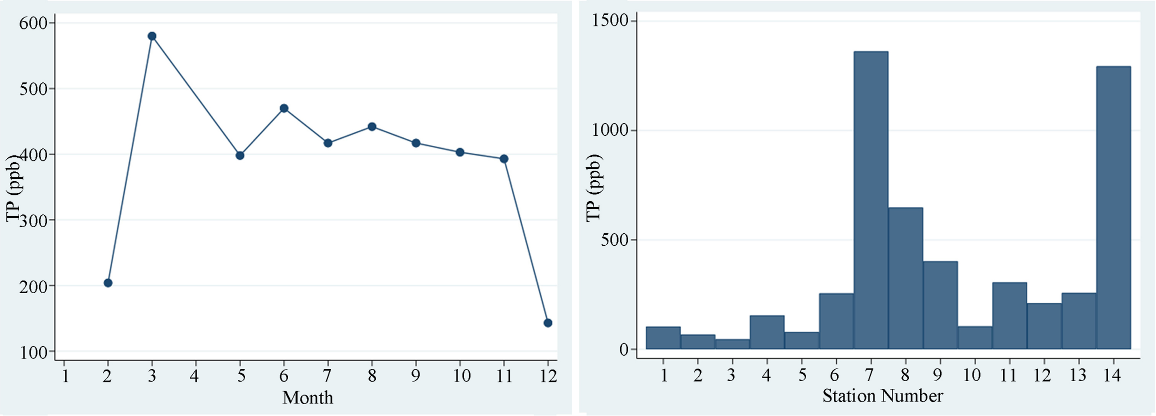

Figure 9. Monthly (left) and spatial (boreholes 1 - 14; right) distribution of. Total Phosphorus (TP) (ppb) in the GWT waters.

4. Discussion

The creation of the deposited bulk of high moisture Lignite initiated 60,000 years B.P. [7] [8]. The topographic areal slope of 0.5% [9] was permanently shallow and covered by swamps. The impact of those conditions induced a very low flow velocity which enabled the development of dense vegetation. Young renovation of plant matter replaced the older vegetation which was sedimented and decomposed under reductive conditions to become a Lignite [9]. A cross-section illustration through the Lignite bulk (length—7 km, width—1 - 3 km) indicates alternates of Lignite strata and lacustrine clays and marl thin layers and a few inter-deposited sandy varved sediments along the eastern side of the Lignite bulk [6] [7]. The main lignite complex which is interrupted by clay bed intercalations appears over most of the basin at depth intervals of 30 - 100 m (**Figures 10-11**) [6]-[9]. In the eastern part of the valley an additional lower lignite complex was indicated at a depth intervals varied between 100 and 160 m. However, along the same sequence in the western valley region, just a few meters of lignite bed layer thickness was indicated [6] [7].

The cross-section profile of the Hula Valley soil comprised of two "Lignite" layers: the upper one from surface to 5 - 7 m depth which is presently (after drainage, later than 1957) defined as "Peat Soil" and is not chemically pure Lignite matter, exposed to wetting-de-wetting moisture alternates regime and utilize as

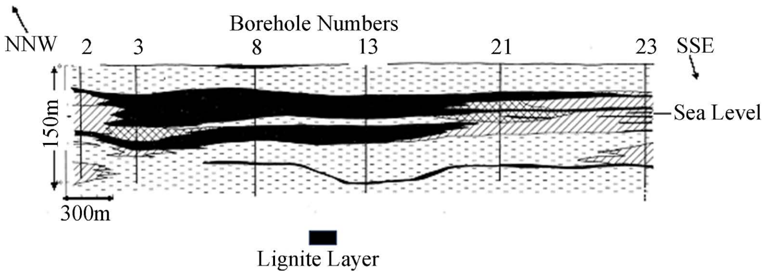

Figure 10. Cross-section illustration of the Spatial (See Borehole numbers, **Figure 11**), depth and thickness placement of the Lignite bed layer in the Hula Valley (Modified from [7]).

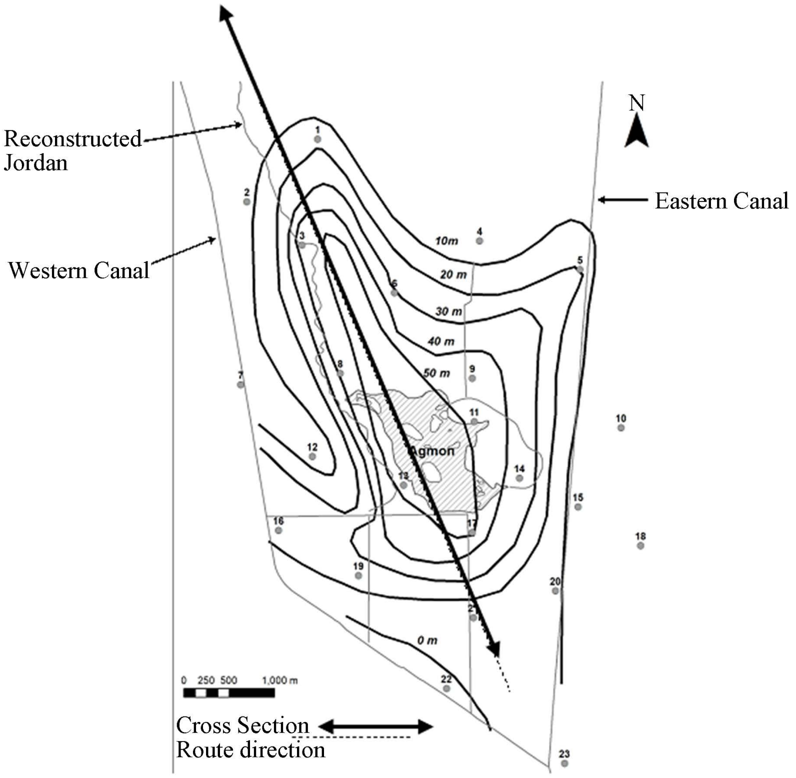

Figure 11. Isopachs contour of the Lignite beds thickness (0 m - 50 m) in the Hula Valley. Cross-section route direction (⟷) (**Figure 10**) and Borehole numbers (1 - 23) are indicated (Modified from [7]).

agricultural infrastructure. Besides moisture-dryness exchange and thermal changes, this layer is chemically oxidized and artificially fertilized. The lower one is much deeper, below 50 m in the center and the fringes become thinner. This deeper Peat layer was converted into Lignite [9]. During the early 1970s, it was proposed to utilize the deep Pure Lignite matter in the Hula Valley for the production of thermo-electricity. A pre-feasibility study of the location, capacity and chemical properties of the Lignite was carried out [6]-[9]. Twenty-four borehole drillings were carried out in the Hula Valley aimed at defining the Lignite size, aerial extension and depth. The mean of maxima depths (>5 m) of the boreholes was 148.2 m. The mean thickness of the Lignite layer varied between 4 - 54 m

(37% and 64% below and above 10 m respectively) averaging 23.4 m. The chemical properties of pore water which were squeezed out from lignite drilled cores, “Lignite Waters”, and its potential degradation were documented [12]. Technical information about the drilling methodology and Lignite Water sampling is given by [6] [7].

Results shown in **Table 4** & **Table 5** represent a high content of Nitrogen which was probably transferred from the sedimented Peat soil and Lignite into the water whilst Phosphorus contribution from the Peat and the Lignite into the water was lower. It probably reflects the strong geochemical bond of Phosphorus to the soil particles whilst the affinity of Nitrogen to Peat-Lignite particles when moisture is high is lower.

The Chloride concentrations in Lignite water are high in the northern and central whilst much lower in the southern and eastern boreholes. The low concentrations of Chloride in the Lignite waters as analyzed in the eastern-southern drillings are probably the result of dilution affected by the freshwater spring flows of Notera, Gonen, Divsha, Harofe and Dekel with additional seepage of Ein Zraot, Ein Pagim, Ein Ela, Ein Harofe, Ein Netz and Ein Dekel [23] [24]. Significant capacities of the nutrients especially, Ammonium, and Organic Nitrogen are “trapped” within the deeply buried Lignite matter and are probably eliminated from the Kinneret inputs. Moreover, results confirmed that a very small fraction of the organic matter (probably stable Humic compounds) is an available substrate to be utilized by bacteria [12]. Moreover, it was confirmed [12] that surface waters in the Hula Valley (Peat soil drainage) contain less than 10% of the Carbon content of Lignite waters and less the 12% of the Lignite water content is available to Bacteria. A summary of the chemical properties of Lignite matter includes a very low (<1) C/N ratio and unavailability to bacterial consumption, and low molecular weight of the organic Nitrogen which is unaffected by high pH. Physico-chemical successive processes induced by surface water flows within the Kinneret drainage basin through the Hula swampy wetlands, followed by biological and sedimentation activities induced by dense vegetation and particulate matter imports were not intensively investigated and a major part of the fate of material cycling, dynamics and allocated accumulation is therefore unknown.

The Peat soil in the Hula Valley is very rich in Sulfate and comparative concentrations (milliequivalent, ME) emphasize the dissimilarity between the drained Hula Peat soil and river Jordan waters, in comparison with Lignite waters, and Lake Kinneret as presented in **Table 5** & **Table 6**.

Results shown in **Table 5** indicate higher TP, TN, Cl (exclude Kinneret) and NH4, whilst lower concentration of NO_3 in Lignite water in comparison with the others. It should be considered that the increase of Chloride in Lake Kinneret is mostly affected by sub-lacustrine inputs.

Chemical analysis of the underground water table (GWT) has indicated significant nutrient concentration differences between Peat soil types in the western, eastern, and central valley regions compared to the peat-marl soil in the southern part of the valley (**Table 6**) [13].

The Lignite pore waters were found to be very poor in SO_4 and NO_3 (**Table 5**) content which indicates reductive conditions. Four boreholes (11, 12, 22, 23; **Figure 11**) contained exceptionally high concentrations of SO_4. The relative importance (by distribution) of anions and cations commonly known in freshwater lakes and rivers are very different from the Lignite water composition documented in the Hula Valley. The concentration ranges of nutrients (Max.-Min) are given in **Table 7**.

The high concentration of organic matter, especially organic nitrogen in the Lignite waters is prominent. Therefore, the ratio between the mean concentration of organic Carbon (mean-84.23 ppm) and organic Nitrogen (mean-655.95 ppm) in the Lignite waters is very low, 0.13. The ratio between total Carbon (TC) and total Nitrogen (TN) was found as 1 by Agron and Fleischer [29]. Results shown in **Table 3** indicate a very high mass ratio of TN/TP in the underground and Lignite waters compared to runoff waters of the Hula Project, Jordan and also in Lake Kinneret. It results from either high Nitrogen, low Phosphorus or both.

Results given in **Tables 8-11** indicate how much Lignite waters are different from commonly known freshwater composition and surface runoffs and underground waters in the Hula Valley as well as from Jordan and Kinneret waters: predominance (93.4%) of Bicarbonate among anions and the majority (31.8%) of Ammonium among Cations, and an almost complete absence of NO_3 and SO_4 probably a result of bacterial degradation [12]. The high equivalent concentration of HCO_3^- probably induces Bicarbonate as a molecular anion of Ca, Mg, NH_4, and Na carbonates [12]. The very little information known from the Hula swamps during pre-drainage indicates a total of 0.785 ppm of Ammonium [32]. Comparative rating scale by concentration (ME) importance of major elements are as follows: Common Freshwater: $HCO_3 > SO_4 > Cl$ and $Ca > Mg > K$ whilst in Lignite waters: $HCO_3 > Cl > SO_4$ and $NH_4 > Na > Ca > K$ and it is in Lake Kinneret: $Cl > HCO_3 > SO_4$ and $Na > Ca > Mg > K$.

Results shown in **Figure 12** and **Figure 13** indicate a gradual spatial decline from the northern to the southern parts of the Hula Valley of Ammonium, Total Kijeldhal, Total Carbon and Organic Nitrogen concentration in the Lignite water. This regional decline of nutrient concentrations is the opposite spatial trend of the underground waters.

Results given in **Figures 14-17** indicate no distinct spatial variability of the concentrations of Chloride, Sodium Potassium and total Phosphorus in the Lignite waters whilst Ca, and Mg, concentration decline as well as Alkalinity and Electric Conductivity values which significantly declined from North to South. Moreover, a comparative evaluation of spatial distribution of nutrient concentrations in the Underground water [13] and in Lignite water [12] indicates a decline of Ca in Lignite water whilst a significant increase of Na, Mg, Potassium, Total Phosphorus, Sulfate, and Electrical Conductivity in Lignite water. A process of nutrient accumulation in deep strata as Lignite layer at 100

- 150 m deep resulting in downward migration is therefore suggested. Total Phosphorus and the other P forms (TDP, SRP) concentration in Ground Water (**Table 3**) [13] are significantly lower than those measured in the Lignite Water—5.87 ppm confirm the trend of Phosphorus accumulation within the deep strata of the Hula valley. The annual load of total phosphorus varied during the last 70 years within the range of 80 - 120 tons (recently 33 t) whilst most of this P load source is not the Hula valley but other parts of the Kinneret drainage basin [29]. An annual contribution of 1.1 - 6.3 tons of Total Dissolved P (TDP) which is about 35 % of the total measured in the Jordan discharge originates from the Hula Valley [12] [13] [28]-[30]. The fate of the peat soil Phosphorus and other elements was intensively globally studied [13] [31]-[40]. These earlier studies concluded that Phosphorus contribution from the Hula Valley to the Kinneret inputs is between minority to negligible. Nevertheless, migration of the peat soil phosphorus was confirmed but was not clearly targeted, the depth of most locations was not defined. Adsorption of >2.0 gP/kg peat soil and 0.3 - 0.7 gP/kg marl soil and adsorption enhancement in deeper strata were documented [25] [38]. A prediction of a significant P flux rate from marl soil into underground water was documented [38]. The environmental fate of this underground water-mediated P is suggested to be

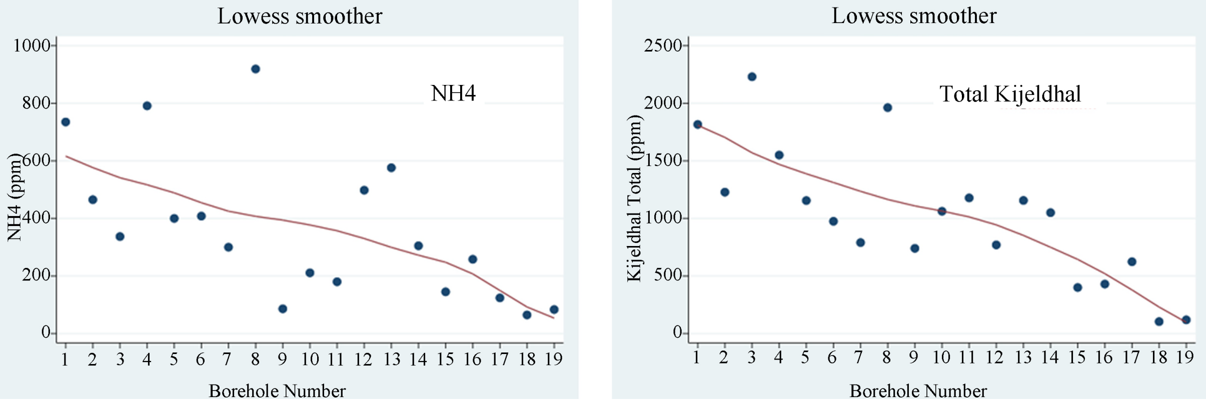

Figure 12. Spatial distribution of NH4 and Total Kijeldhal in Lignite water (Lowess Smoother; bandwidth = 0.8).

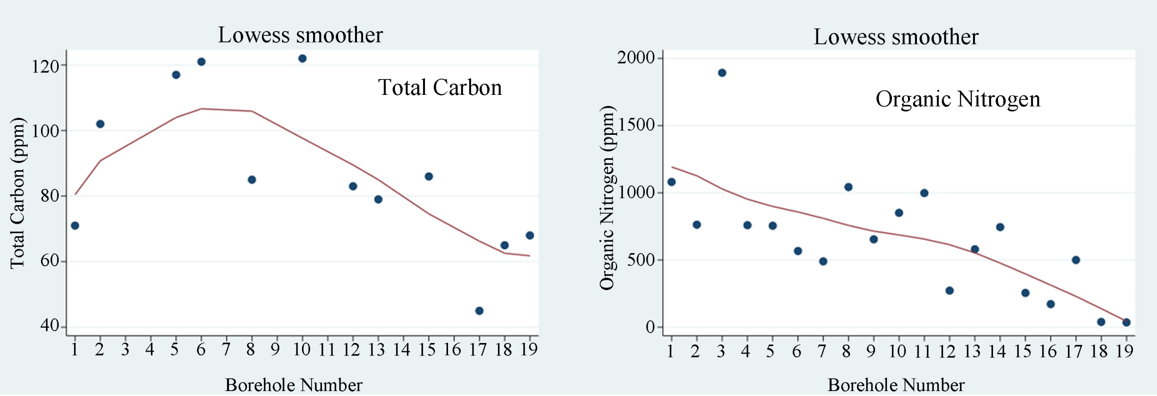

Figure 13. Spatial distribution of Total Carbon and Organic Nitrogen in Lignite Water. (Lowess Smoother; bandwidth = 0.8).

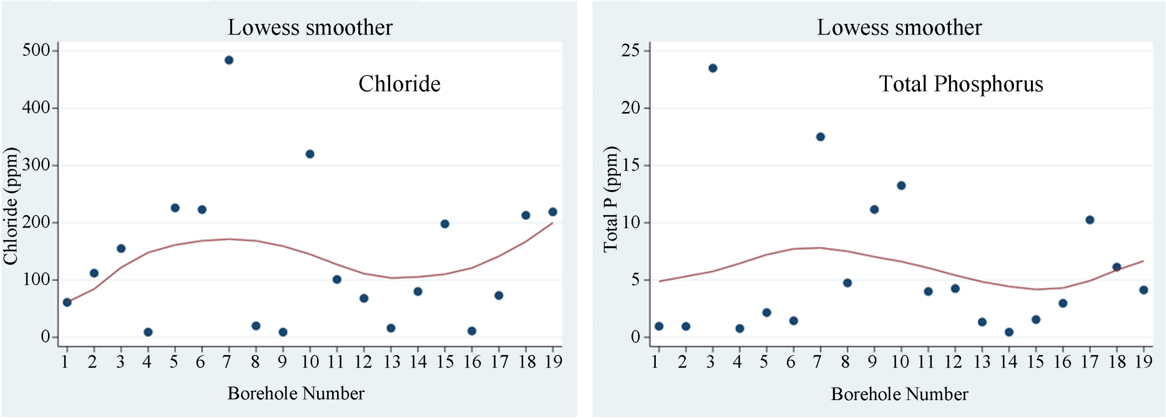

Figure 14. Spatial distribution of Total Phosphorus and Chloride in Lignite Water (Lowess Smoother; bandwidth = 0.8).

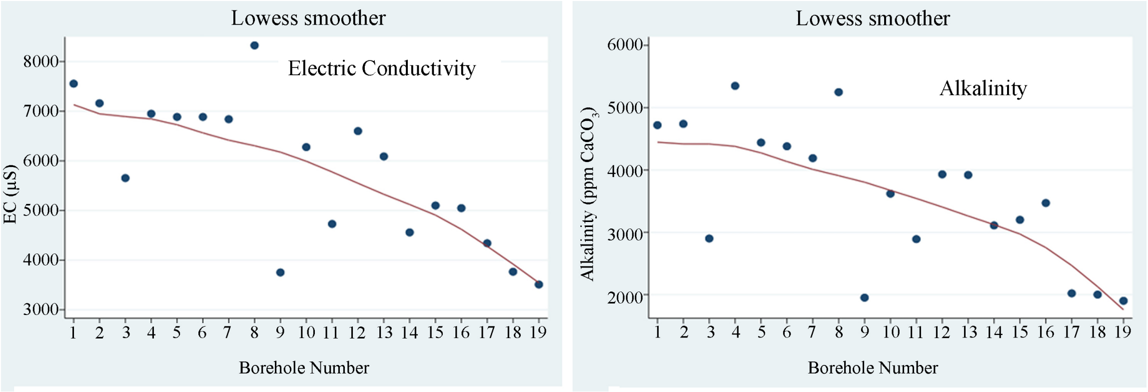

Figure 15. Spatial distribution of Electric Conductivity (µmhos/cm) and Alkalinity (ppm $CaCO_3$) in Lignite Water (Lowess Smoother; bandwidth = 0.8).

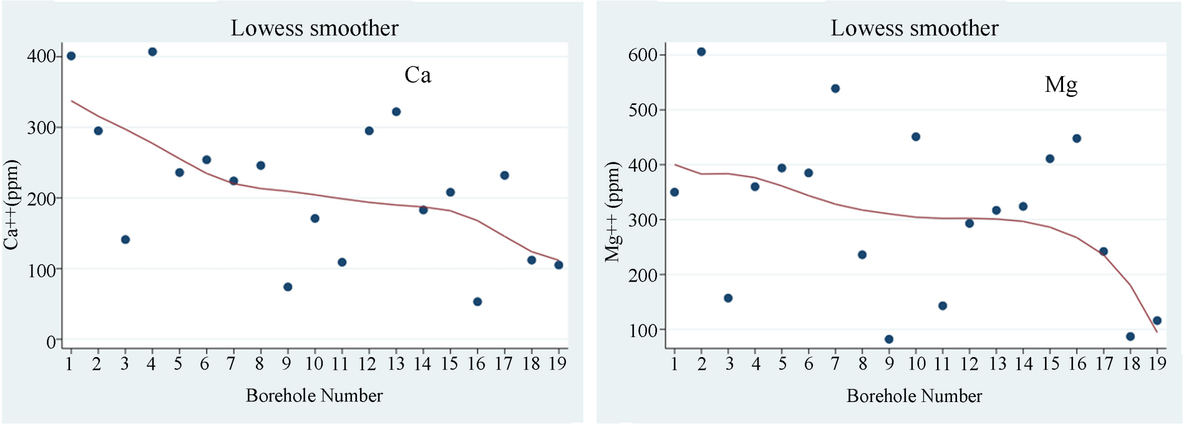

Figure 16. Spatial distribution of Cations (Ca^{++}, Mg^{++}) in Lignite Water (Lowess Smoother; bandwidth = 0.8).

downward migration into a very deep either limited or unlimited stock. Vast documentation as the outcome of a very long history of soil property investigation in the Hula Valley supported information about soil properties and agricultural management, fertilization included, and the results are closely ranged, for instance, carbonates content as—4.6 - 9.4% and 83.3% in Peat and marl respectively or 43%

and 5% organic matter content in Peat and Marl soil respectively.

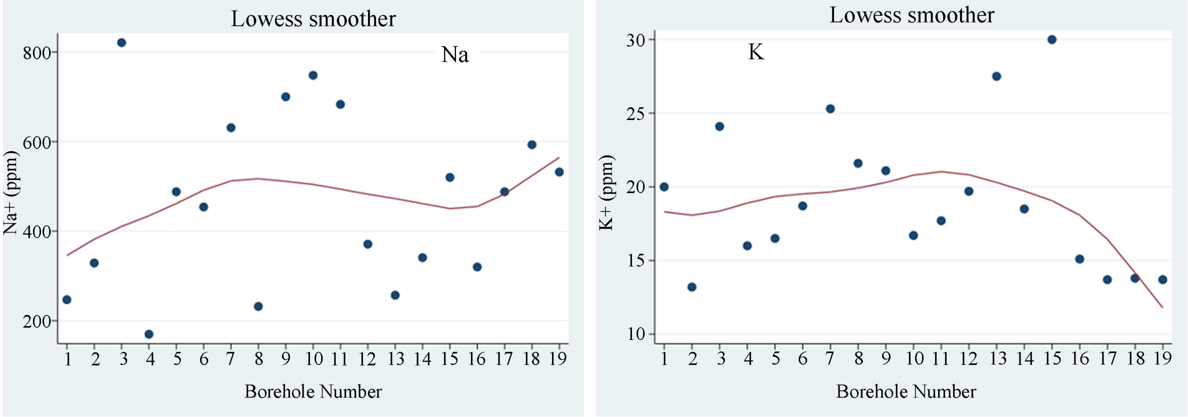

Figure 17. Spatial distribution of Cations (Na^+, K^+) in Lignite Water (Lowess Smoother; bandwidth = 0.8).

A conclusion is presented in other studies consider nutrient migration in the subterranean space as a potential factor of deterioration of surface waters. The present paper is attributed to a different approach which tentatively suggests that nutrient from the soil of the Hula Valley migrates mostly downward and to a lesser extent horizontally. The trend of downward cumulative nutrient migration is recognizable (Table 10).

5. Summary

Nutrient migrations in the Hula Valley were studied at three hypsometrical depths: Runoff, Underground waters and Lignite waters. Nutrient concentrations in Runoffs were modified after the Hula drainage and later anthropogenic management, Nitrogen as Nitrate was enhanced and Phosphorus was diminished. Changes within the Underground level are affected by hydrological North-South gradient and agricultural fertilization. During the long History of the Hula Valley existence, Lignite matter was formed and buried under recent sediments presently located at about 50 meters. Reductive forms of Phosphorus, Nitrogen and carbonates are accumulated in the Lignite matter. Minor part of the Peat-Soil originated Phosphorus is migrated through the Hula outflows into River Jordan and forwarded into Lake Kinneret. Significant portion of this Phosphorus is migrating Hypsometrically downward whilst the end-lock is unclear. Most of the water mediated Phosphorus that is migrated into Lake Kinneret originates from parts of the Kinneret drainage basin outside the Hula Valley. On the other hand significant portion of the Peat-Soil originated Nitrates migrate through the Jordan discharge into Lake Kinneret. Pre-caution alert of the Kinneret water quality deterioration followed the Hula drainage and further agricultural development was denied. Future recommendations include enhancing Peat-Soil wettability supported by summer extra irrigation water allocation legislated by the "Peat Convention", which is a contracted agreement between the farmer organization and the National Water authority. Among nitrogen and phosphorus supply from the catchment, the mostly affected water quality was found to be nitrogen. Since early 1990's nitrogen supply has significantly declined. It was one of the reasons for Kinneret water quality deterioration through replacement of the bloom forming Dinoflagellates Peridinium spp. dominance by Cyanobacteria. The status of the lake ecosystem shifted from sufficiency to insufficient nitrogen. Consequently, enhancement of nitrogen input is critical.

Authors' Contributions

M.G. and V.L-O cooperatively implemented data analysis, and conceptual evaluation; V.O. carried out the field measurements of GWT and surface mapping of the underground water migration; M.G. directed water chemistry; presentation design, computerization, and the preparation of the original draft and final version were carried out cooperatively. All authors have read and agreed to the published version of the manuscript.

Informed Consent Statement

Not applicable as the study does not involve humans or animals.

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 authors declare no conflict of interest.

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