American Journal of Water Science and Engineering
2021; 7(4): 165-178
http://www.sciencepublishinggroup.com/j/ajwse
doi: 10.11648/j.ajwse.20210704.14
ISSN: 2575-1867 (Print); ISSN: 2575-1875 (Online)

Ecological Consequences of Climate Condition Changes (CCC) in Lake Kinneret Watershed

Gophen Moshe, Meron Moshe, Tsipris Yosef, Orlov-Levin Valerie, Peres Moti

Migal-Scientific Research Institute, Kirya Shmone, Israel

Email address:
Gophen@Migal.org.il (G. Moshe)

To cite this article:
Gophen Moshe, Meron Moshe, Tsipris Yosef, Orlov-Levin Valerie, Peres Moti. Ecological Consequences of Climate Condition Changes (CCC) in Lake Kinneret Watershed. *American Journal of Water Science and Engineering*. Vol. 7, No. 4, 2021, pp. 165-178.
doi: 10.11648/j.ajwse.20210704.14

Received: November 24, 2021; **Accepted**: December 14, 2021; **Published**: December 24, 2021

Abstract: The Hula Valley which is part of the Lake Kinneret watershed (2730 km^2) in northern Israel is part of the Syrian–African Great Rift Valley. During mid-1980`s-2017 changes in the climate condition (CCC) were recorded in the watershed: Dryness symptoms of rainfall and headwater river discharges have been declining and air temperature has been increasing. The most recent periodical dryness (drought) was recorded in 2014–2019. Although the Hula Valley comprises only about 10% of the entire drainage basin, it is a significant environmental regional component contributing pollutants which is utilized for agricultural cultivation and eco-tourism infrastructure. Until the late 1950s, this valley was covered by swampy wetlands and a shallow old Lake Hula of mean 1.5 m depth and 13 km^2 surface area. The valley was drained and converted for agricultural development. The objective of this paper is an evaluation of long-term record of the CCC consequences within the Hula Valley: Headwater discharges, precipitation, air temperature, underground water table (GWT), wind regime (velocity, direction), evaporation, relative humidity, and solar radiation. A partial of CCC within the Hula Valley was confirmed, mostly temperature increase, water deficiency, and ground water table (GWT) lowering. Results indicates that the impact of CCC threatened the optimal appropriate maintenance of the valley. Conclusive future perspectives of supplemental water supply from lake Kinneret to the Hula Valley combined with enhancement of desalinized sea water input into the lake that might improve Hula Valley management and the Kinneret water quality are discussed.

Keywords: Kinneret Watershed, Hula Valley, Climate Conditions Change

1. Introduction

The Hula Valley in northern Israel is part of the Syrian–African Great Rift Valley. The total area of the Kinneret drainage basin is 2730 km^2, of which 73% are in the Israeli territory and the Hula Valley area is 200 km^2. Running water input into Lake Kinneret comes through three major headwater rivers: Hatzbani (Snir), Banyas (Hermon), and Dan, which flow from the Hermon Mountain region and several other smaller rivers. The merging of these three major headwater rivers creating River Jordan. The Jordan River contributes about 63% of the Kinneret water budget and more than 50% of the total external nutrient inputs into Lake Kinneret. Until 1957, the Hula Valley was covered by the shallow Lake Hula (mean depth 1.5m) and swamps. In the early 1950s, the Lake Hula and its adjacent swampy areas were drained and converted into arable land. Consequently, more than 6500 ha of natural wetlands were converted for agricultural development. Beneficial crops were produced but not without difficulties. For 40 years the repurposed wetlands were successfully cultivated and agricultural products (mostly cotton, corn, alfalfa, and vegetables) were economically produced, and nutrient flux into Lake Kinneret did not threaten the lake's water quality. Nevertheless, due to inappropriate management, drainage canals were blocked, irrigation methods were not suitable for optimal management and soil fertility protection, resulting in the lowering of the ground water table (GWT) and decline in crop production. The soil of the upper layers (0–0.5m) became oxidized and its texture deteriorated, heavy dust storms became frequent, and the soil surface subsided (7–10 cm/year). From 1990 to 1997, the Hula Valley underwent a reclamation project, the Hula Reclamation Project (HRP). The reclamation project involved increasing the soil moisture by elevating the ground water table (GWT), altering the irrigation methods, renewing the drainage system in the entire valley, and creating a new shallow lake called Agmon-Hula. A plastic sheet of thickness 4 mm, crossing the valley in an east-west direction, was placed vertically (0–4.5 m) over a distance of 2.8 km to prevent the leaking of nutrient-rich underground water into Lake Kinneret. Since the mid-1980s, changes in the climate condition (CCC) in the Lake Kinneret have been documented. Regional climate conditions in the Hula Valley was also evaluated. The climatological record was monitored in a standard meteorological station, named "Gadash," which is located in the central part of the Hula Valley. The data is recorded automatically at the station from 1988. The objective of this paper is to evaluate the regional impact of changes in the climate condition of the Hula Valley.

2. Material and Methods

2.1. Data Sources

The GWT, and climatological information from the Hula Valley (2000-2020) were provided by the Hula Project Data Base in Migal- scientific research institute [1-5]. Y. Tsipris, V. Orlov-Levin and M. Meron are responsible for the data collection, instrumentation maintenance and evaluations. Information about the three headwater rivers and Jordan River discharge (1970–2018) (mcm/y; 10^6 m^3), were provided by Israel Hydrological Service-of the National Water Authority; Mekorot, Water Supply Co. Kinneret-River Jordan monitoring Unit [6]; Water Works Organization -Upper Galilee Municipality, (H. Milard responsible). Long term record (1940-2020) of rainfall and air temperature were documented in the meteorological station-Israeli National Meteorological Service, in Dafna, M. Peres responsible. Within the frame of the Hula Reclamation Project (HRP) implementation a monthly and biweekly monitor of chemo-physical parameters was carried out [1-3]. Among recorded parameters, water in-and outputs were documented. Monthly & Annual water and nutrient mass balances were computed. Example of The lake Agmon-Hula water budget for the year of 2001 is given in Table 1.

Water budget of Lake Agmon-Hula during 2001given in Table 1 indicates annual input and output of 8918X10^3 and 7804X10^3 m^3 respectively. Taking into account that during 2001, prior to the extreme drought (2014-2018) Agmon-Hula surface area was 110 ha (1100X10^3 m^2) the 1114 remnant between input (Hula East, Canal Z, Reconstructed Jordan, Rain and WL increase) and output (Lake Agmon-Hula outlet, Evaporation) is due to infiltration through the bottom sediments of about. 2.5L per m^2 per day. The major source of water input to lake Agmon-Hula is the drainage of irrigated water through Canal Z and the reconstructed Jordan whilst most of the output is evacuated via outflow canal.

Table 1. *Lake Agmon-Hula Monthly Water Balance (10^3 m^3 month $^{-1}$) during January – December 2001.*

Month	Hula East	Reconstructed Jordan	Canal Z	Agmon Outflow	Agmon WL Change	Rain	Evapo-transpiraion
1	80	60	90	280	-22	87	94
2	60	0	0	60	88	117	87
3	90	4	620	40	22	8	175
4	60	0	650	620	0	6	233
5	20	150	720	440	44	7	265
6	20	220	1000	680	-33	0	298
7	10	11	1350	690	-22	0	293
8	10	360	410	740	-55	0	274
9	10	40	780	680	-22	0.2	233
10	90	106	180	470	-44	30	176
11	40	230	200	120	121	54	135
12	0	609	0	670	88	164	51
Annual	490	1790	6000	5490	165	473.2	2314

2.2. Statistical Methods

Three regression methods were performed (STATA 17): 1) fractional polynomial regression of continuous covariates, a form of parsimonious parametric modeling (Published in Applied Statistics 43: 429–467), 2) linear regression with confidence interval percentage (95%) (STATA17), and 3) LOWESS Smoother (0.8 Bandwidth), which provides weighted scatterplot smoothing.

2.3. Mapping of Subterranean Water Distribution

Distributional mapping of subterranean waters were carried out by incorporation of Ground Water Table (GWT) record and Inverse Distance Weighting (IDW) which is a deterministic method for multivariate interpolation with a known scattered set of recorded GWT depth. The assigned values to unknown points of GWT depths are calculated with a weighted average of the values available at the known points [7].

3. Results

Air temperature measured 10 cm and 2m above soil surface in Gadash Station (middle part of the Valley) during 2000-2020 and in Dafna station (Northern part of the valley) during longer term of 1946-2020 (daily Maximum, Minimum and mean) are presented in figures 1-4.

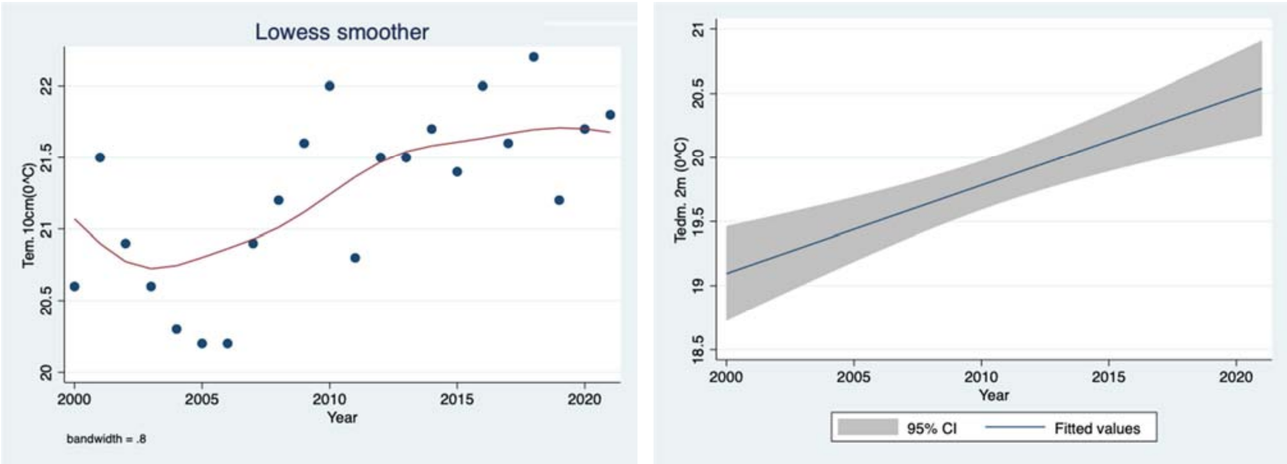


Figure 1. *Annual (2000-2020) Means of daily averages of air temperature fluctuations in Gadash Station (Hula Valley) measured at 10 cm above soil surface during 2000-2021: Left: LOWESS Smoother (band width 0.8); Right: Linear Regression (CI 95%).*

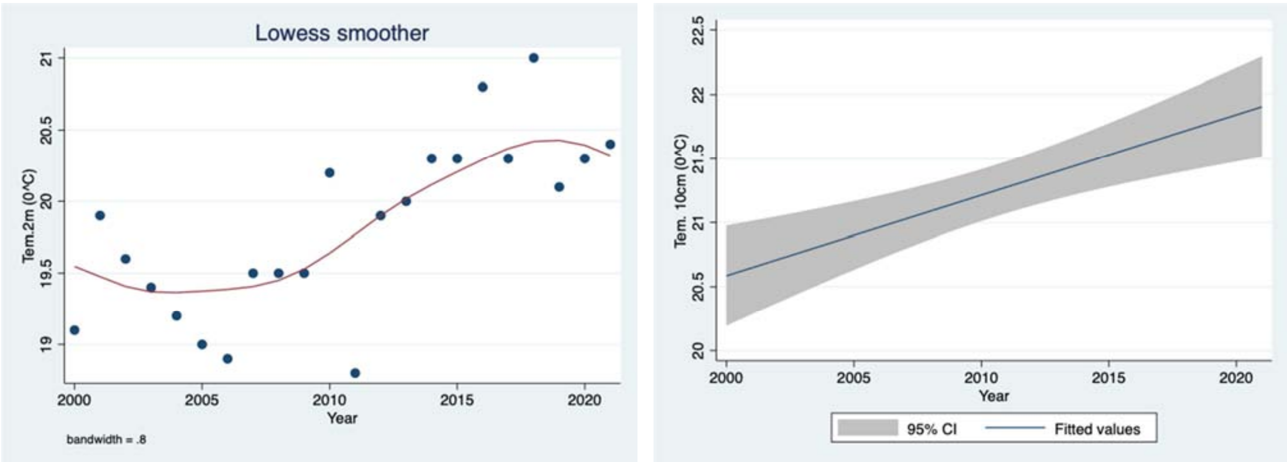


Figure 2. *Annual (2000-2020) means of daily average of air temperature fluctuations in Gadash Station (Hula Valley) measured at 2.0 m above soil surface (Standard Meteorological Station) during 2000-2021: Left: LOWESS Smoother (band width 0.8); Right: Linear Regression (CI 95%).*

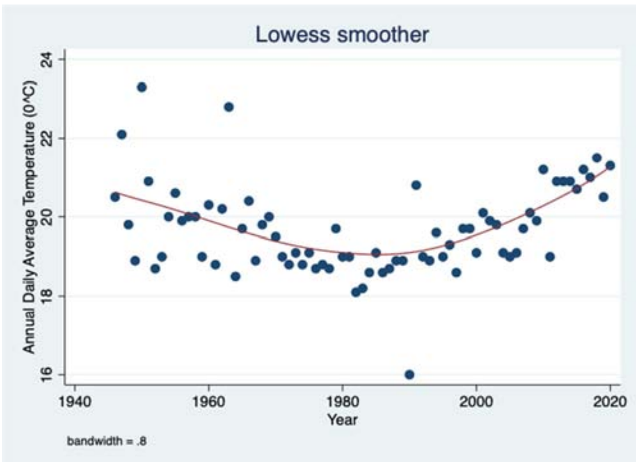


Figure 3. *Annual averages of Daily mean (=Max.+Min./2) air temperature fluctuations (LOWESS Smoother, band width 0.8); in Dafna Meteorological Station (northern Hula Valley) during 1946-2020.*

Results shown in Figures 1-3 indicates air temperature elevation in the Hula Valley (Gadash Station) during the last 21, years air temperature decline Dafna (northern Hula Valley) during 1946 – 1980 (Figure 3), and increase later (1980-2020) (Figure 3).

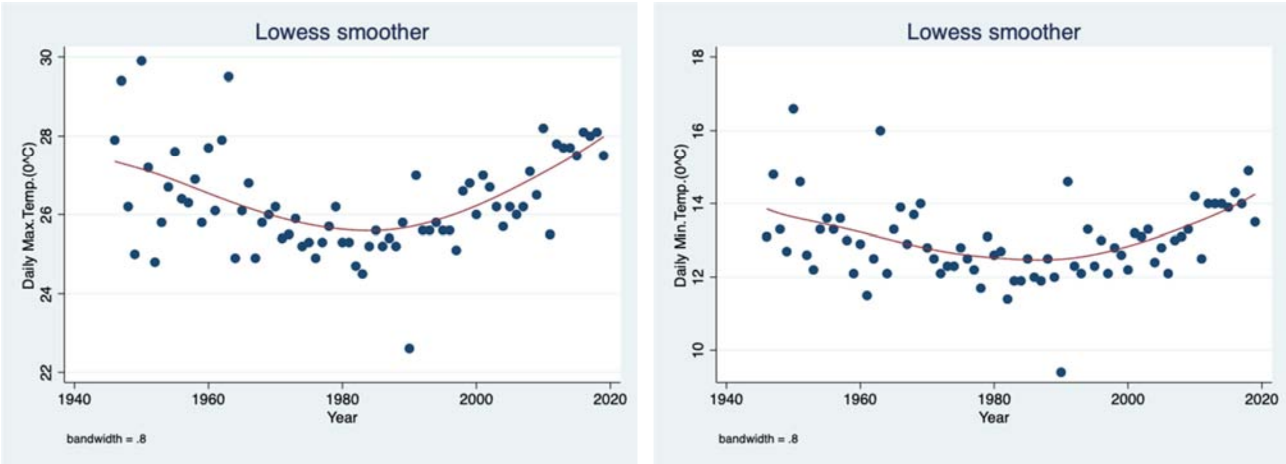


Figure 4. *Annual Averages of daily Maximum (left) and Minimum (right) air temperature fluctuations (LOWESS Smoother, band width 0.8); in Dafna Meteorological Station (northern Hula Valley) during 1946 – 2020.*

Results given in Figure 4 indicates temperature decline during 1940-1980 and increase later on. The Climate conditions during the Anthropocene era in the Kinneret drainage basin were affected by both anthropogenic intervention of the Hula drainage (during the 1950's) and natural parameters. Prior to the drainage the majority of the Valley was covered by water (swamps and old lake Hula) and dense aquatic vegetation. Beyond the drainage land surface was partly uncovered or seasonal agricultural crops. Albedo factor of bare soil surface is lower than water covered surface. Warming of Hula land surface beyond drainage was higher resulted by reduced heat reflection and higher surface absorption. Whilst prior to drainage Albedo, which is the % of reflected heat from absorbed sun energy was higher and above air temperature became colder.

Evaluation of wind velocity (m/s) and direction (Azimuth) data as are given in Figures 5, 6. (in the Hula Valley measured in the Gadash Meteorological Station during 2000 – 2021 (through September) Are given in Figures 5-8 and in tables 1-3. Wind velocity and Azimuth direction were recorded continuously every 10 minutes and daily, monthly and annual averages were computed.

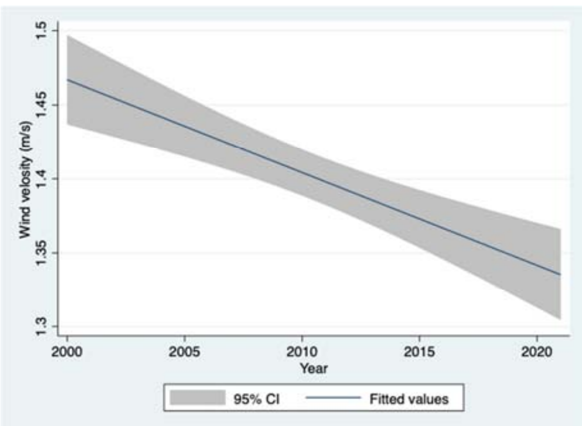


Figure 5. *Linear regression (95% CI) between annual Wind velocities values and years (2000 – 2021 (through September) recorded at the Gadash Meteorological Station located in the middle of the Hula Valley.*

Results in Figure 5 indicates temporal decline of Wind Velocity. Moreover, as shown in Figure 6, the temporal trend of wind velocity decline was accompanied by close correlation with wind direction fluctuations: the more westerly directed the higher was the velocity.

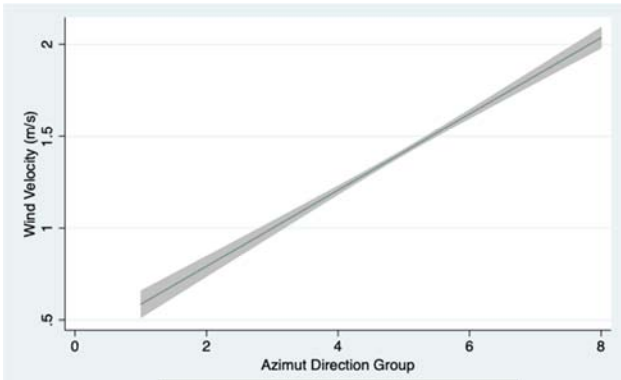


Figure 6. *Linear regression (95% CI) between Wind velocity (m/s) and direction (Azimuth 0°-360°). Direction were sorted in 8 groups as follows (Table 1).*

Data given in Figure 6 and Table 2 indicates higher wind velocity.

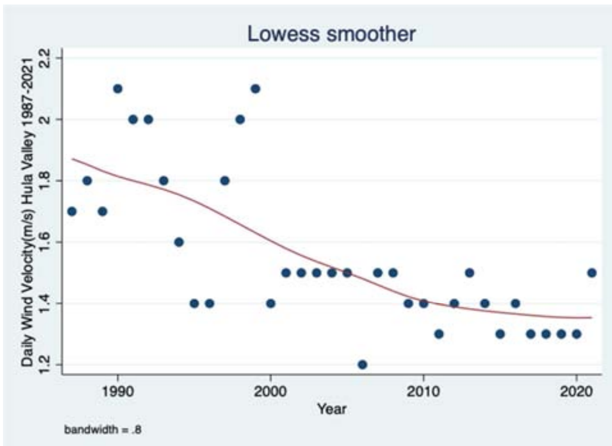


Figure 7. *Annual means of averaged Daily wind velocity m/s during 1987-2021.*

Results given in Figure 7 indicates high velocities prior to the 2000`s and lower but fairly stable wind speed fluctuations during the 2000`s which correspond to periodical temperature increase (Figures 3, 4).

Moreover, wind directions were stably restricted within a certain range of Azimuth as shown in Table 3.

Results given in Table 2 indicates the wind direction dominance range between 160 – 240, in other words, ranged between West and South. Consequently, windy-conveyed air-born nutrients migration is aimed at the opposite location of Lake Kinneret. Moreover, the most frequent wind direction was ranged between 161° – 240°, i.e. demarcated between Eastern-Southern and south-western. Consequently, negligible air-born particle towards Lake Kinneret opposing the most frequent wind direction in the Hula Valley.

Table 2. *Wind Directions frequencies as number of days with daily averaged Azimouth recorded in the Hula Valley (Gadash Meteorological Station) grouping (1-8) Azimuth compilation: 1=0 – 89 (North – East); 2=90-130 (North-Northern-South); 3=131-160 (East-Eastern-South); 4=161-180 (South-Southern-East); 5=181-210 (West-Western-South); 6=211-240 (South-Southern-West); 7=241-270) (West-Western-Southern); 8=241-312 (West-Northern-North).*

Group	Azimuth Range (°)	Number of Days included	Frequency (%)
1	0-89	5	0.1
2	90-130	30	0.4
3	131-160	229	3.0
4	161-180	1505	19.4
5	181-210	4541	58.4
6	211-240	11`03	14.24.0
7	241-270	313	0.5
8	271-312	49	

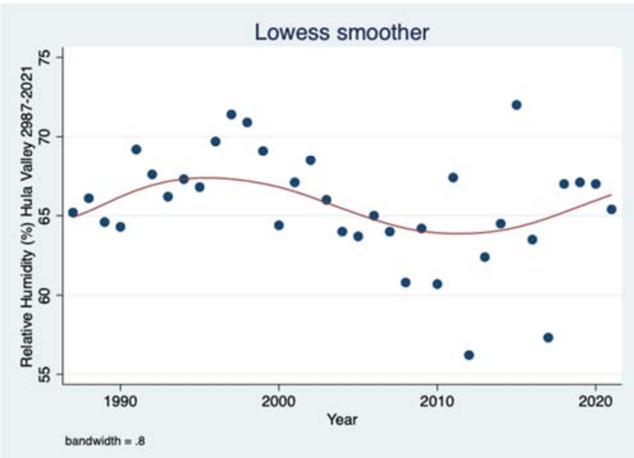


Figure 8. *LOWESS Smoother (band width 0.8) plot of annual means of Relative Humidity (%) (RH) in the Hula Valley (Gadash Station) during 1987-2021.*

Date presented in Figure 8 indicates respective relation t the Temperature fluctuations (Figures 3, 4). Decline of air temperature correspond to increase of RH values and vise versa.

Results shown in Figure 9 indicates a clear increase of the daily maximum wind velocity during 2019-2021 when range of precipitation was also, simultaneously, elevated and wind direction slightly changed towards westerly (Figure 8).

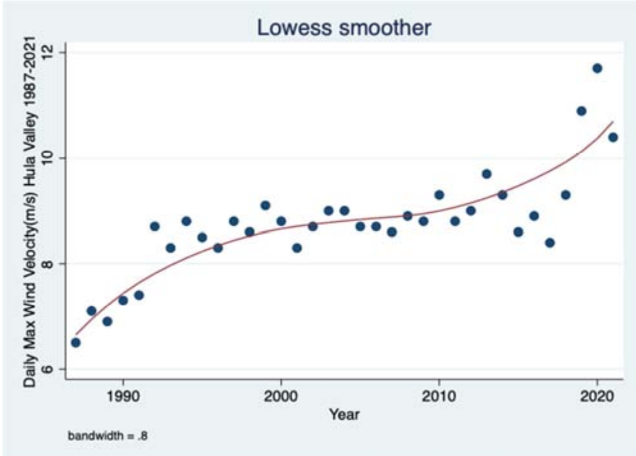


Figure 9. *Annual (2000-2021) means of Monthly (1-9) daily Maximal Wind velocity (m/s).*

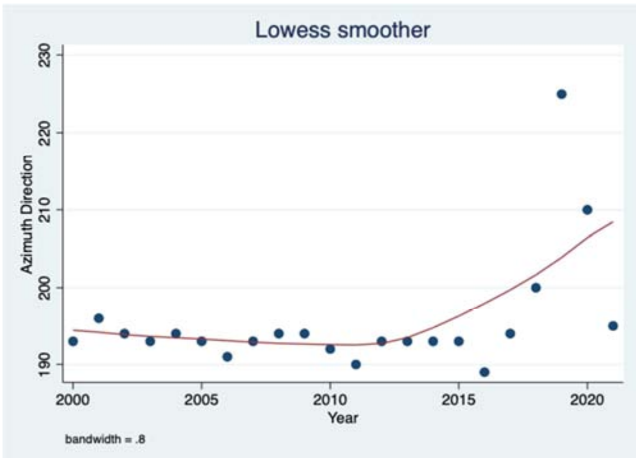


Figure 10. *Annual (2000-2021) Averages of daily mean wind direction (Azimuth).*

Results given in Figure 10 indicates dominant Azimuth wind direction range of 190-195 and clear westerly change (200-220) during the rainy years of 2018-2020.

Table 3. *Percentage annual (2000-2021) composition of number of days with daily means of wind direction sorted by three Azimuth groups of the following: 90-180, 180-270 and 270-312.*

Azimuth 270-312	Azimuth 180-270	Azimuth 90-180	Year
0	81	19	2000
1	85	14	2001
0.3	79	20.3	2002
0.3	82.3	18	2003
0.5	79.5	20	2004
0.5	77.5	22	2005
0	74	26	2006
0.3	81	18.7	2007
0	77	23	2008
0	79	21	2009
0.3	74.7	25	2010
0.3	73	26.7	2011

Azimuth 270-312	Azimuth 180-270	Azimuth 90-180	Year
0.3	81	18.7	2012
0.3	78	21.7	2013
0	82	18	2014
0	77	223	2015
0	72	28	2016
0.3	77	22.7	2017
0.3	71.7	28	2018
10	88	2	2019
14	63	23	2020
8	58	34	2021

Results given in Table 4 indicates dominance of 180-270 Azimuth range (South-West), negligible direction of West-North (270-312) and the enhancement of West-North direction during the rainy years of 2019-2021.

Data of depth fluctuations of the Ground Water Table (GWT) in the Hula Valley are presented in Figures 12-16.

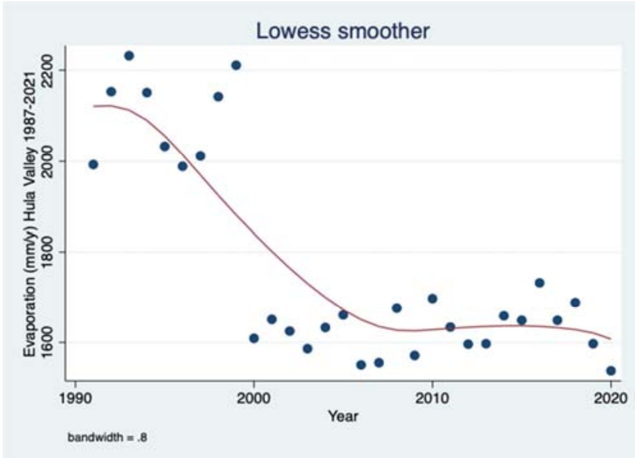


Figure 11. LOWESS Smoother (and width 0.8) plot of annual means of daily measurements of evaporation (mm/year) (Penman) during 1987-2021/ Results in Figure 11 indicates respective relation between low level of wind velocity (Figure 9) and high rate of evaporation and vise versa during the 2000`s.

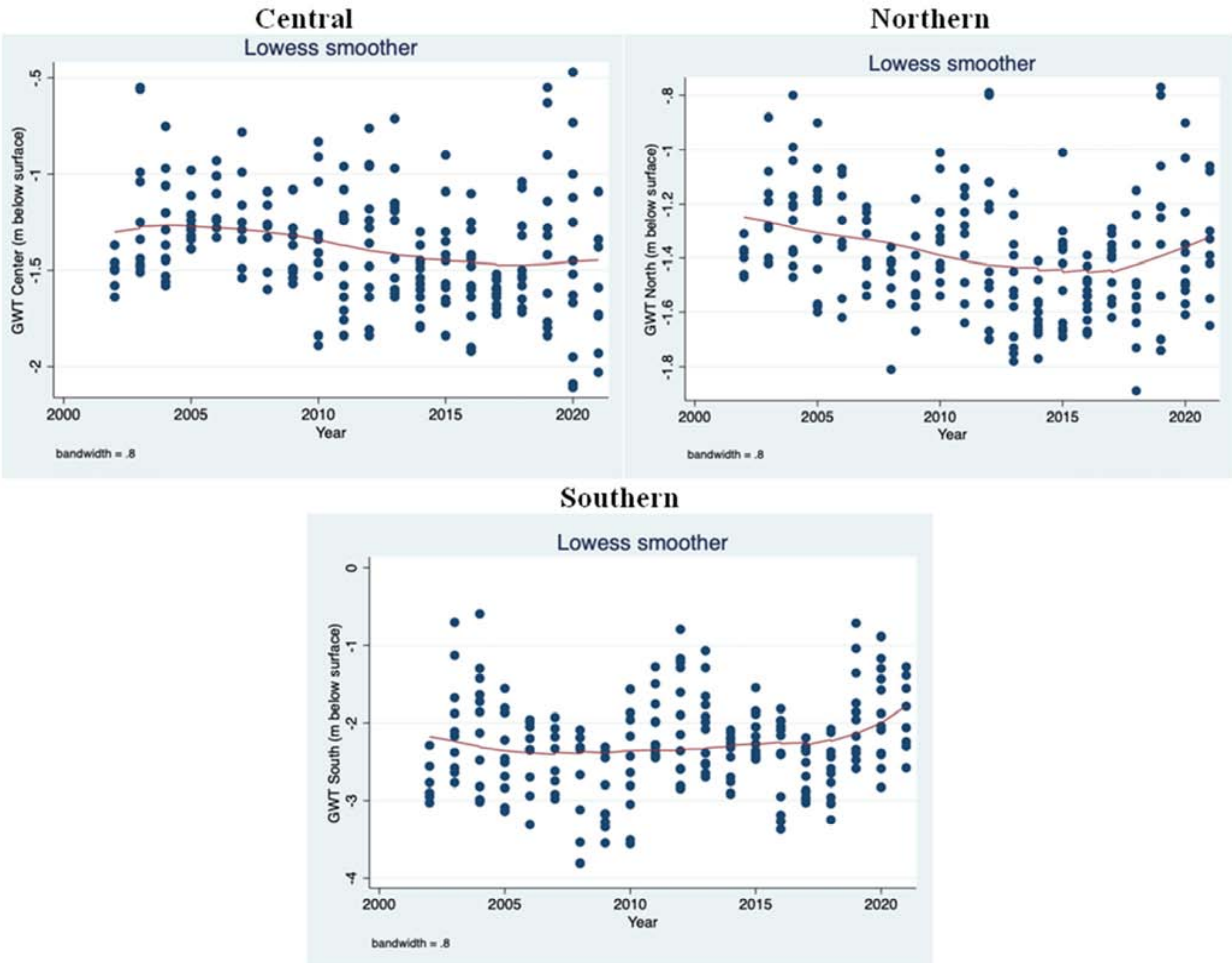


***Figure 12.** Annual changes (LOWESS Smoother band width 0.8) of Ground Water Table (m below soil surface) during 2002-2021in the Northern, Central and Southern parts of the Hula Valley.*

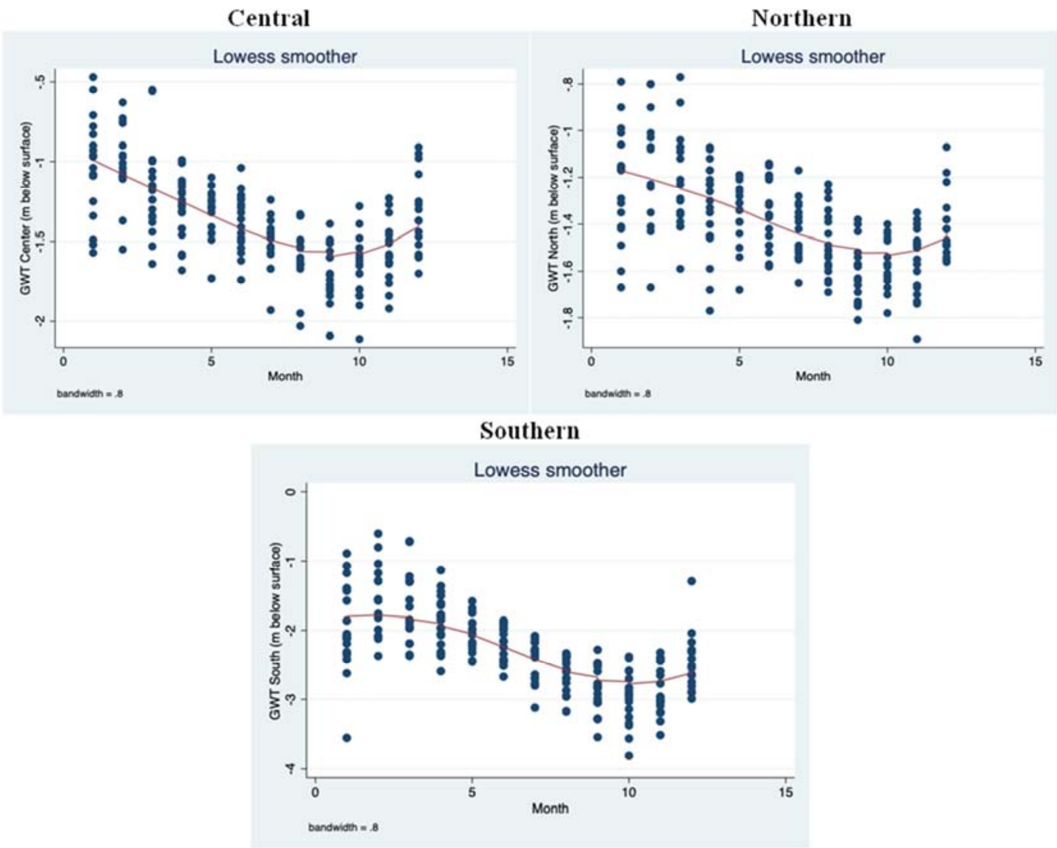


Figure 13. *Monthly changes (LOWESS Smoother band width 0.8) of Ground Water Table (m below soil surface) during 2002-2021in the Northern, Central and Southern parts of the Hula Valley.*

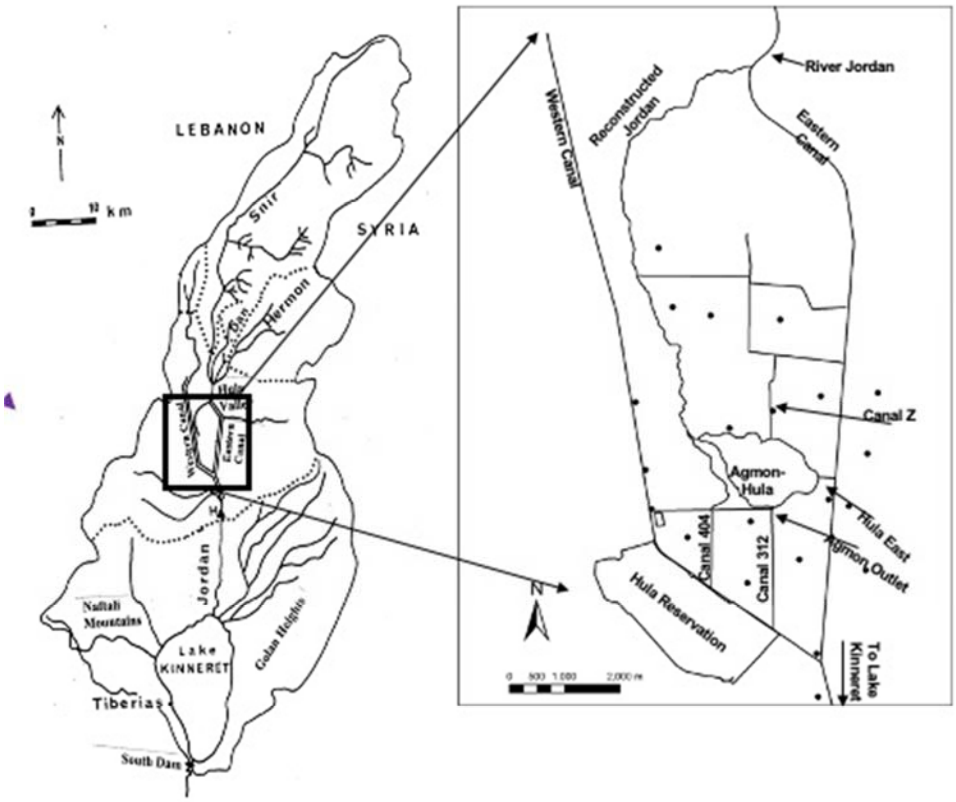


Figure 14. *Geographical map of the Lake Kinneret Watershed; Dan, Snir and Hermon headwaters Are indicated; The Hula Valley Is squared; local basins boundaries are indicated (dotted lines); Drills for GWT monitor are indicated (black dotted).*

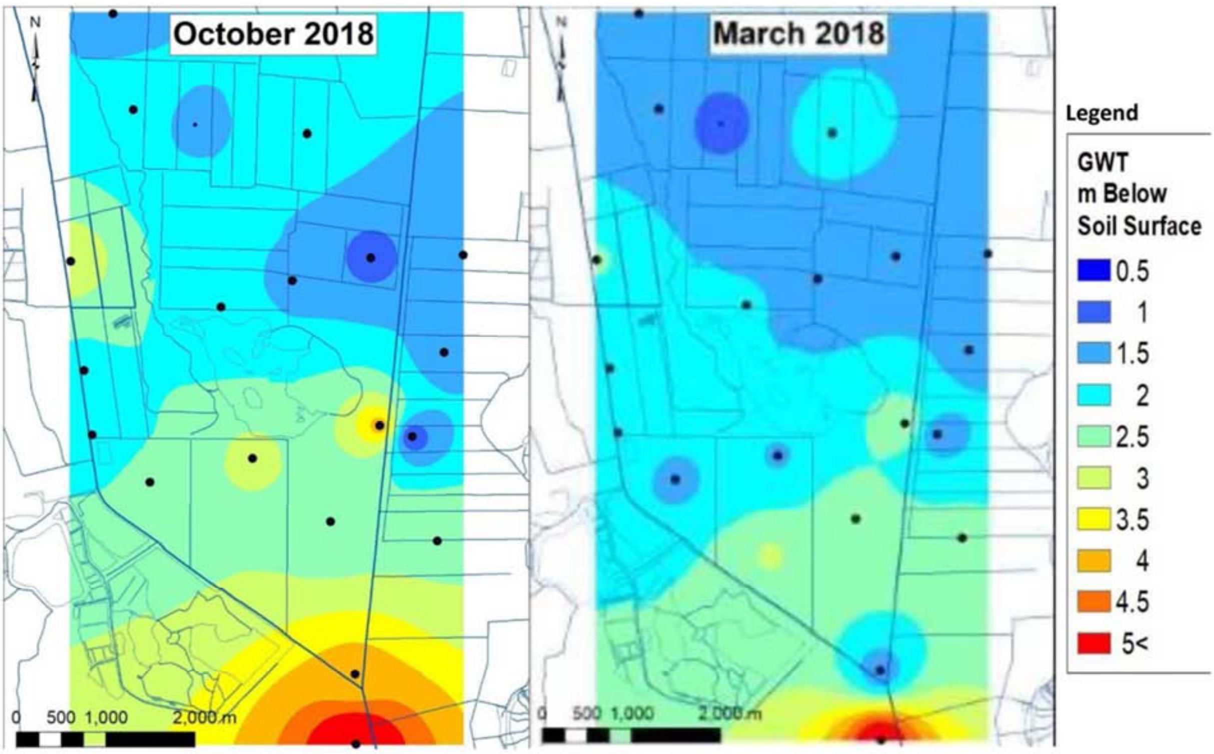


Figure 15. *Aerial mapping of GWT depth distribution in the Hula Valley during October and March (2018) "dry" year (256 mm) Black dots are GWT monitored bore-hole.*

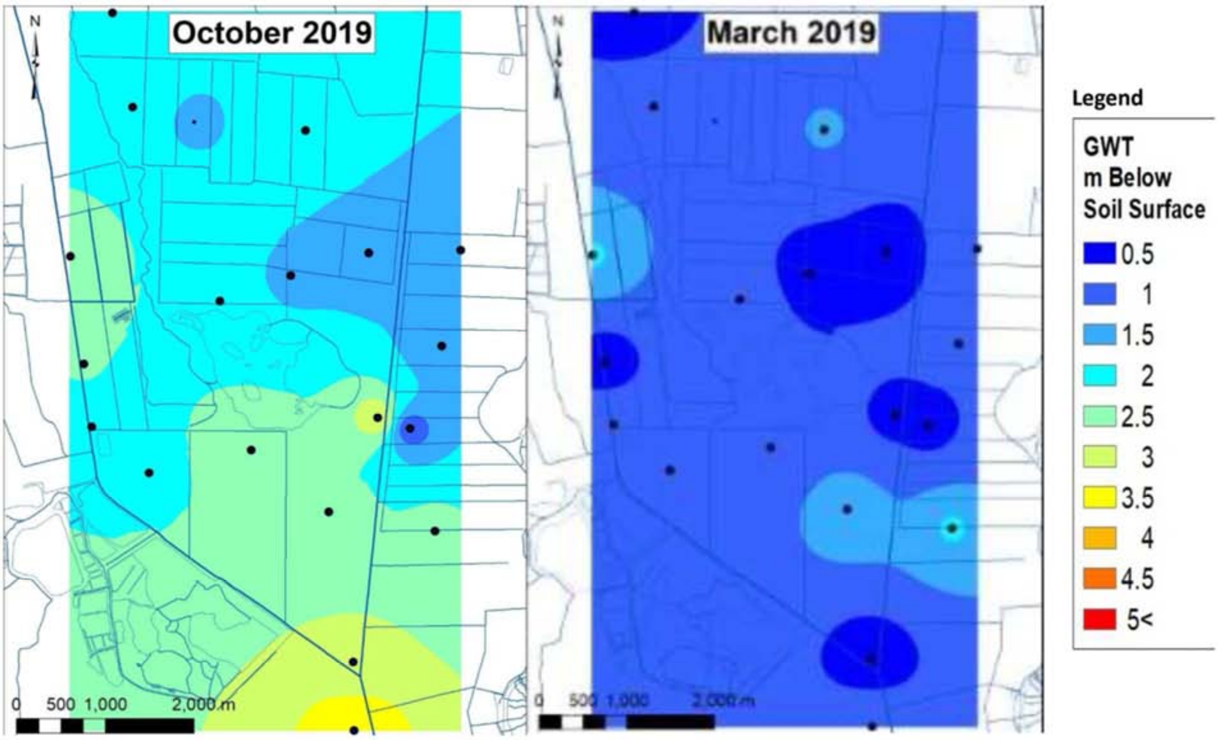


Figure 16. *Aerial mapping of GWT depth distribution (see upper panel) in the Hula Valley during October and March (2019)"wet" year (1089 mm) Black dots are GWT monitored bore-hole.*

Results presented in Figures 15, 16, indicates significant difference of regional GWT distribution: high in the northern part of the Valley and lower in the south creating Hydrological gradient. Moreover, the higher is the soil moisture (heavy rain) the shallower is the GWT as well as the deeper level in the southern valley region.

The discharge data of three headwater rivers, Dan, Hazbani and Jordan are shown in Figure 17:

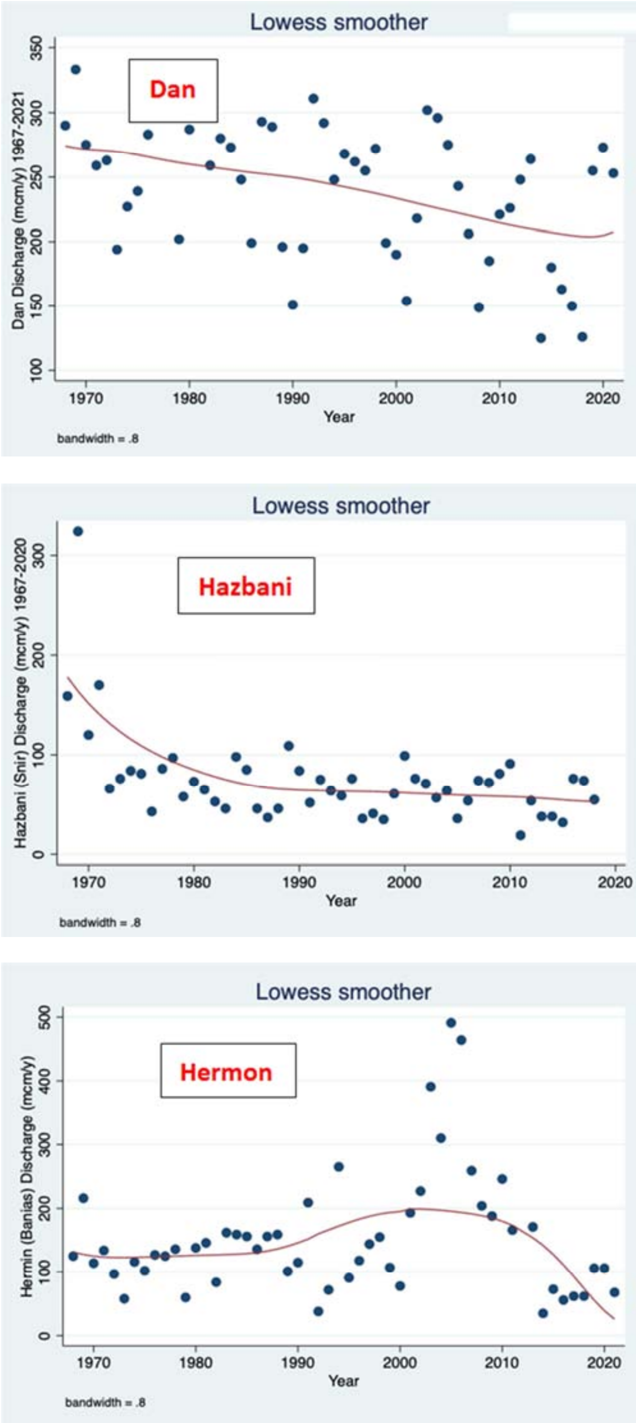


Figure 17. *Annual discharge (mcm/y; 10^6 m^3/year) of the three major Headwater rivers: Dan, Hazbani (Snir) and Banias (Hermon) during 1968-2021.*

Results in Figure 17 confirm an indication of discharge decline in headwater rivers.

The recent dryness trend conditions in the Kinneret watershed is indicated in Figures 17, 18as decline of river discharges. The rainfall increase during 1987-2021 in the Hula Valley (Figure 19) is inversely related to the entire watershed trend of decline. It is suggested that it is the result of local (Hula Valley) microclimate effect of the west wind enhancement.

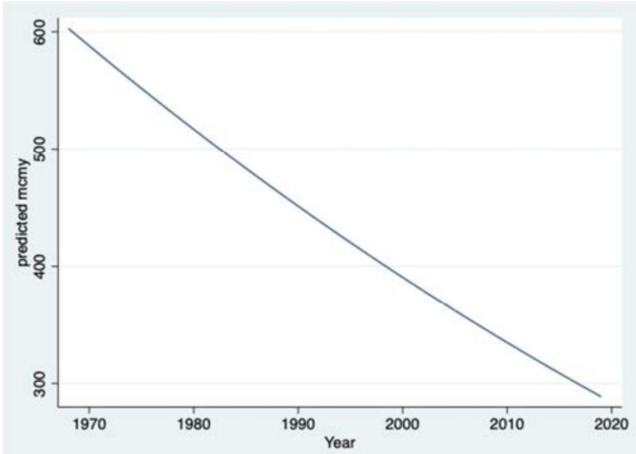


Figure 18. *Fractional Polynomial Regression between Years and annual Jordan River Discharge (mcm/y) during 1968 – 2019.*

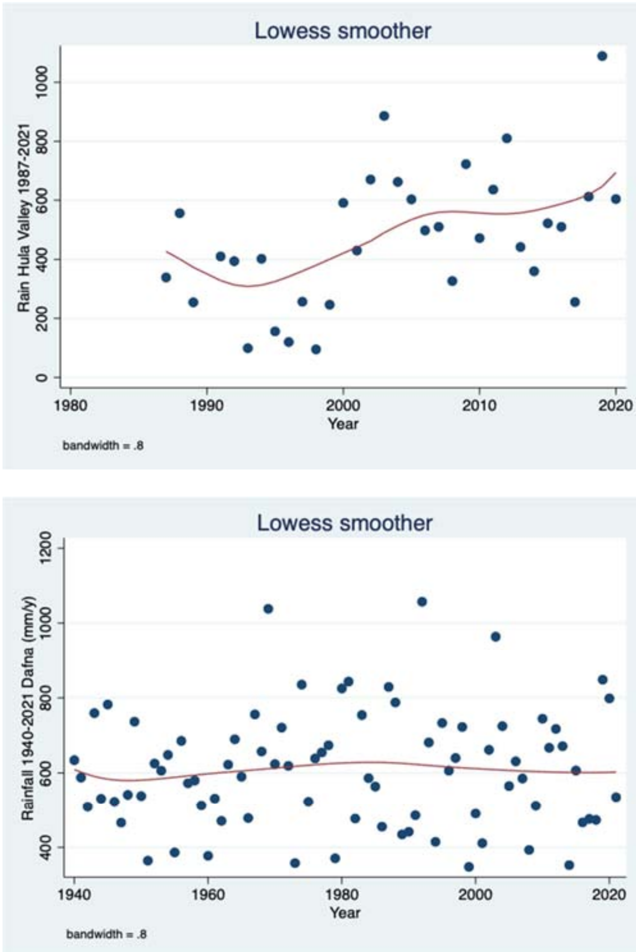


Figure 19. *LOWESS Smoother (band width 0.8) plot of Annual Rainfall (mm/y) in Dafna Station (northern Hula Vallley) during 1940-2021, and in Gadash Station (center Hula Valley) during 1987-2021. Whilst clear increase is documented in the middle part of the Hula Valley, the trend in the northern part of the Valley is stable.*

Data about ranges of Rain, Relative Humidity, Radiation and relation between Rain and Wind direction are given in Figures 13-16 and Table 5.

For better understanding the regional status of the Hula Valley periodical and daily records of major climatological parameters were evaluated. Periodical (2000-2021) record of total radiation (WJ/m2) for each month were evaluated. Results of that analysis indicates significant radiation decline and increase during January- February and May-June respectively. In all other months there were no significant change of radiation level. It is therefore concluded that as based on Radiation data climate changes in the Hula Valley are fairly stable. (Table 5)

Table 4. *Represent monthly changes of Relative Humidity.*

Month	RH (%)	Wind Direction (Azimuth)	Total Radiation in MJ/m^2/day (10^3 Kcal/m^2/day)	
1`	77	191	8.6	(2.1)
2	75	194	11.5	(2.7)
3	70	195	16.4	(3.9)
4	63	195	21	(5.0)
5	56	197	25.6	(6.1)
6	58	199	28.2	(6.7)
7	60	198	27.6	(6.6)
8	61	200	25.1	(6.0)
9	61	202	21	(5.0)
10	60	195	16	(3.8)
11	64	188	11.4	(2.7)
12	75	190	8.4	(2.0)

(%), averaged wind direction (Azimuth) and total radiation (MJ/m^2/day) recorded in the Gadash station during 2000-2021.
MJ=10^6 Joules=239 Kcal

Data shown in Table 4 indicates normal monthly flow of sun radiation. The monthly development of Wind direction confirm dominant (1-10 months) westerly winds and a slight eastern change of the typical east winds (Sharkiye) in November. Two factors has an impact on the monthly changes of Relative Humidity: 1) west winds inject humid air (77-70%) penetration (December-Jan.-Mar.) and 2) irrigation management during summer months. Consequently it is suggested that changes of climate conditions expressed as air temperature elevation, and decline of precipitations and river discharge developed in the northern part of the Kinneret watershed slightly affected indirectly Hula Valley.

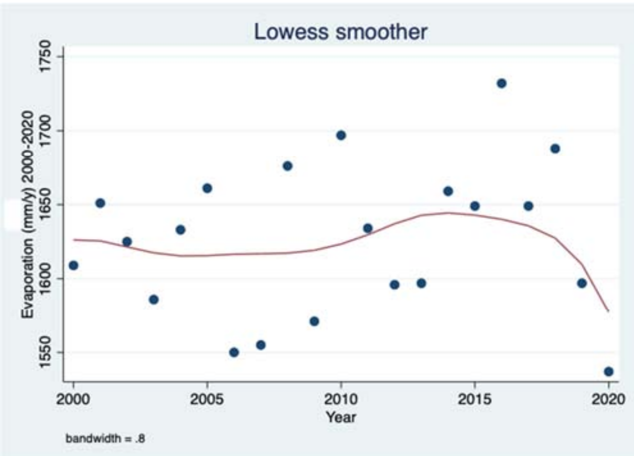


Figure 20. *Temporal changes of annual Evaporation (mm/y) during 2000-2021 in the Hula Valley (Gadash Station).*

Results given in Figure 20 indicates lower level of Evaporation during high rainfall capacity and intensification 2012-13 and 2019-20.

Results given in Figures 1-4 indicates a fairly stable climate in the Hula Valley with the exceptional three years, 2018-2020. The close relations between maximal daily recorded westerly gust wind and rainfall are presented in Figure 21.

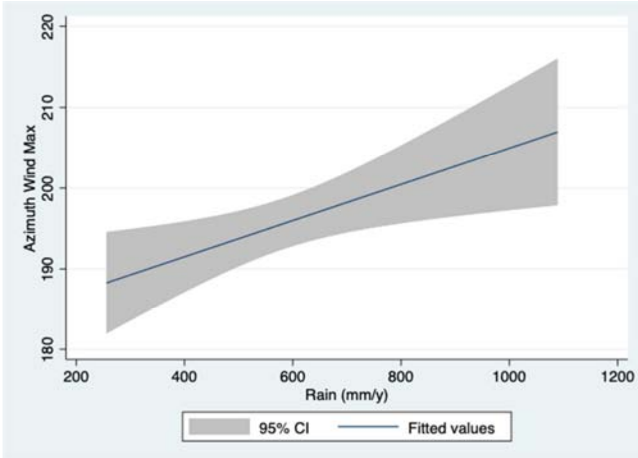
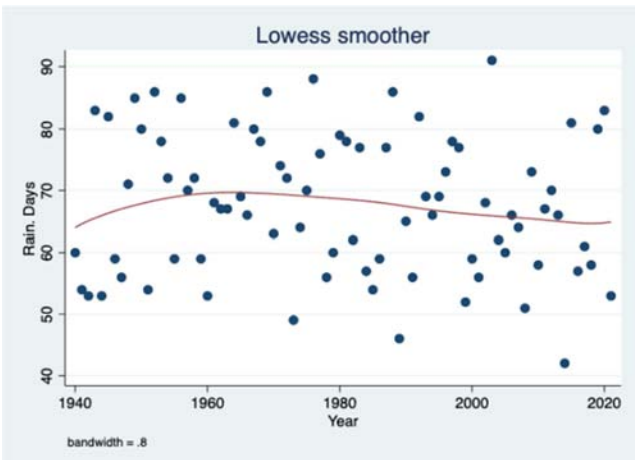


Figure 21. *Maximal daily recorded westerly gust wind direction (Azimuth) and annual (2000-2020) rainfall (mm/y) are presented in Figure 20.*

Results given in Figure 16 and Table 5 confirm the positive correlation between Rainfall intensity and South-Westerly (Azimuth 195-210) wind direction, high level of relative humidity (RH) and low radiation (cloud cover). The increase of RH in winter (Jan.-Mar) is due to the South-westerly cold and moist wind direction and lowered in springtime. The increase of RH in summer is probably due to local domain impact if irrigation. The daily course of Radiation changes represent normal conditions in the Northern Hemisphere. Nevertheless, temporal evaluation (2000-2020) of monthly means of radiation indicated significant decline and increase in winter (Jan.-Feb.) and in summer (May-Jun.) respectively.

The Impact of Climate Condition Changes on Rain Distribution.

Results in Figure 21 indicates decline of rain days number since mid-1980's.



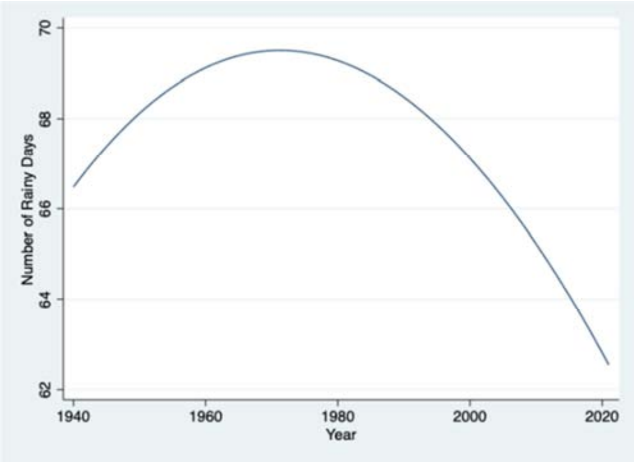


Figure 22. *Rain events distribution: the annual number of rainy days during 1940-2019 (LOWESS Smoother of (bottom page 10) and Fractional Polynomial Regression (Dafna Station).*

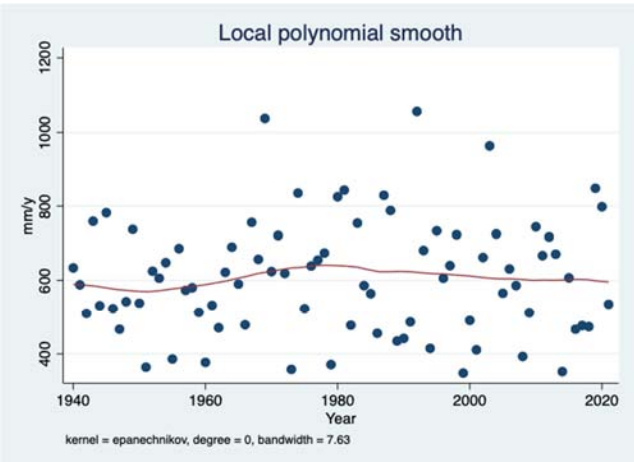


Figure 23. *Temporal distribution of annual rain (mm/y) in Dafna Station during 1940-2021: LOWESS Smoother.*

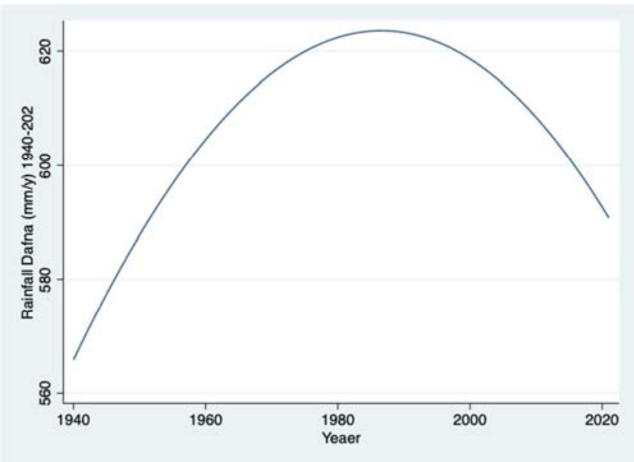


Figure 24. *Temporal distribution of annual rain (mm/y) in Dafna Station during 1940-2021: Fractional Polynomial Regression (right).*

Results given in Figure 22 indicates a minor decline of Rain gauge in the Northern part of the Hula Valley (Dafna). Temporal changes of Rain capacity indicates a slight increase during 1940-1970 and decline later. The rainfall measures as decade averages is given in Table 6.

Table 5. *Decade averages of Rainfall capacities during 1940-2018 (Dafna Station).*

Period	Mean Rainfall (mm/y)
1941-1950	598
1951-1960	536
1961-1970	648
1971-1980	622
1981-1990	617
1991-2000	618
2001-2010	621
2011-2018	554

The results given in Table 5 indicates an averaged increase of 50 mm/y (8.3%) during 1941-1970 and averaged decline of 68 mm/y (10.9%) during 1971-2018. Givati et al. [8] documented a significant impact of low level rainfall on the recharge of underground aquifers and consequently on river runoff discharge. The climate condition changes in the Kinneret watershed is relevance to those statements: During the periods of 1940-1979 and 1980-2018 mean annual rain capacity was similar (596 and 595 respectively). Nevertheless distribution of rainy days events and the daily capacity was different: 69 and 65 rainy days per year during earlier and later periods respectively. Rain capacity per day was 8.6 and 9.2 during 1940-1979 and 1980-2018 respectively. An indication of the significance decline of rainfall capacities is summarized in Table 6.

Table 6. *Temporal distribution of Precipitation capacity in northern Hula Valley (Dafna Station): Seasonal (decade) average of total capacity (mm/y), number of rainy days (No./y) and capacity per day (mm/d).*

Period	Precipitation (mm/y)	Number of Rainy days	Rain/Day (mm/d)
1941-1950	598	68	8.8
1951-1960	536	69	7.8
1961-1970	648	73	8.9
1971-1980	622	69	9
1981-1990	617	66	9.3
1991-2000-	618	68	9.1
2001-2010	621	65	9.6
2011-2021	608	69	8.8

Results in Table 6 indicates lower number of rainy days and higher capacity per rainy day during 1980-2021 period which is considered as a symptom of climate condition changes. It should be considered that as previous Hydrological research [8] documented a consequent prediction of a rain capacity decline which generate significant reduction of underground aquifer recharging followed by river runoff discharge reduction (Figures 24, 25). The dryness trend initiate rain diminish but capacity enhancement which create lower discharge.

The decline of discharge is clearly presented in Figure 25.

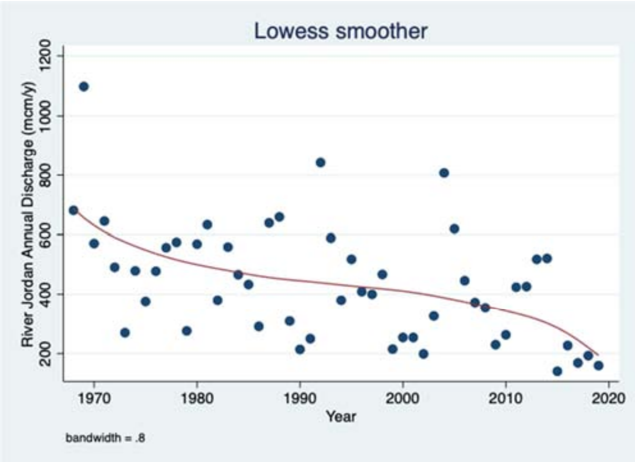


Figure 25. *Annual discharges of River Jordan (Huri Station) during 1970 2019.*

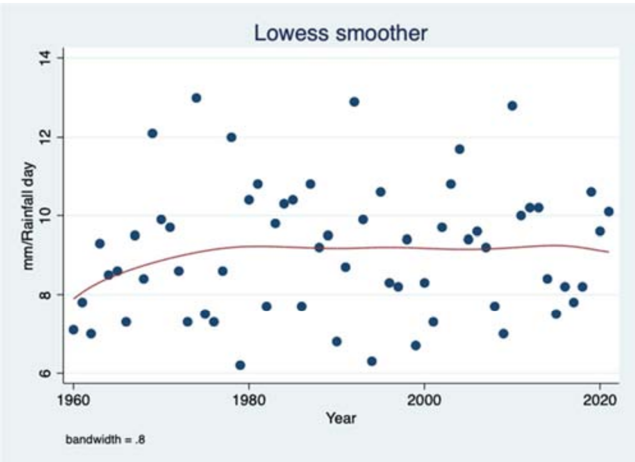


Figure 26. *Annual value of Daily Rain capacity (mm/rani day) calculated as annual rain per number of rainy days (Dafna Station).*

The data given in Figure 26 indicates increase of mean daily rain capacity since early 1980's.

Results given in Table 6 indicates lower number of rainy days since 1980 whilst daily capacity was enhanced.

4. Discussion

Changes in climate conditions are highly discussed internationally and nationally. The publicity of this issue is critical for the entire human society. The most critical implications of climate change include environmental policy, water scarcity and food production. Therefore, local consequent constraints are of national concern, and water supply as correlated to agricultural food production in the Hula Valley prioritized. A critical part of the history of the Hula Valley management includes the drainage and HRP implementations. Moreover, the ecological linkage between the Hula Valley and Lake Kinneret, which is the national source of drinking water, gives it a national significance. Consequently, evaluation of temporal changes in climate conditions (CCC) of the Hula Valley is crucial for regional and national agricultural and water supply management design. This paper is focused on climatological features of the Hula Valley. Reduction of rainfall capacity in the Kinneret watershed and river discharges and increase in regional air temperature was confirmed. The natural water supply to Lake Kinneret and the Hula Valley diminished. The Hula Valley was anthropogenically converted for agriculture and eco-tourism from swamps and shallow lakes (HRP). Nevertheless, not as like in the entire Kinneret watershed region, the micro-regional-climate conditions of the Hula Valley ecosystem, including the RH, air temperature, wind velocity and direction, and radiation, were not abruptly modified. The economic success of the HRP is documented in an evaluation of the project carried out by Znovar et al. [9]. Znovar [9] found a significant improvement in the agricultural revenue as well as environmental conditions. The soil moisture increased and the ground water table (GWT) was elevated, dust storms and rodent outbreak significantly declined, and tourism development was very successful, which was confirmed by the attraction of 500,000 visitors who annually (2010-2021) came to watch 50000 (56000 presently) migratory cranes for five months in the Hula Valley [10]. Nevertheless, a threat of deterioration in these achievements might be attributed to CCC with respect to enhanced scarcity of water. The recent 5 years of drought (2014–2018) increased the intensity of water scarcity, resulting in GWT depression and temperature elevation. These factors have led to difficulties in obtaining optimal crop yield. Agricultural crop yield is dependent on natural ecological conditions and human anthropogenic management. Among natural parameters, CCC are crucial. The principal objective of the HRP was to achieve a suitable procedure of crop cultivation, irrigation, and sufficient water allocation, which would ensure a shallower GWT, enhanced soil moisture, and a full-year cycle of "soil green cover" policy. The HRP 10-year anniversary report [9] highlights the successful achievements of the project. To ensure the continued success of the project and prevent incidences of drought, the Hula Valley requires additional water allocation. A trend of change in regional CCC has been reported, which is expressed as precipitation and river discharge decline accompanied by regional temperature elevation. Regional water scarcity will directly undermine the success of the HRP. Nevertheless, climate conditions within the restricted Hula Valley domain were fairly stable. Although the annual (2000–2020) means of air temperatures (10 cm and 2 m from the soil surface) (Figures 1, 2), relative humidity (Figure 8; Table 5) and radiation data represent a fair level of stability (Table 4), the regional dryness (Figures 17, 18, 25) negatively affected the achievements of the HRP. Water scarcity enhanced GWT deepening and increased demands for water for irrigation. Water scarcity is a cardinal issue with regional and national significance: how much water is required and its source? Two options are presently disputed by national water managers: direct supply from desalinization plants and Lake Kinneret pumping withdrawal. The second option includes, obviously, deposition of products of desalinization into Lake Kinneret and allocation of lake waters to the Hula Valley. Here, in a study about climate change, we expose a cardinal and actual confrontation of local and national water management design with the consequences of global warming conditions. Moreover, the relation between wind velocity and direction in the Hula Valley indicates the normal pattern of Eastern–South–West dominance of wind direction (Tables 3, 4, 5; Figures 5, 6, 9, 10, 21). Results of daily maximum gust wind direction indicate also the normal regional pattern of west wind in summer months and rain contribution in winter months. Conclusively, the climate conditions within the Hula Valley domain were not significantly modified in the period 2000–2020. Nevertheless, since the mid-1980s, regional changes in climate conditions have occurred in the Kinneret watershed, which have had national and regional implications for water management. Critical changes in climate conditions have led to drought and, consequently, water scarcity, accompanied by temperature increase over the entire watershed [11, 12]. Water scarcity is exemplified by the following percentage comparative reductions between the average for 1967–1985 and 2015, when water scarcity was maximal:

Percentage reduction in annual discharges of the three major headwaters:

River Dan	33%
River Banias (Hermon)	21%
River Hazbani (Snir)	52%
River Jordan (Huri)	60%

The elevation of temperature enhanced evapotranspiration (ET) (Figures 11, 20), which required additional water flux, but dryness prevented this. Agriculture management can confound water scarcity by irrigation but water allocation was diminished as a result of climate change. Rainfall, wind velocity, and RH increased in the years 2018–2020 (Figures 9, 19, 26). In the 1990s, evaporation (Penman) was higher when the velocities of winter west winds carrying humidity and rain were lower (Figure 11). Wind velocities increased in the 2000s (Figure 9). Then west winds enhancement introduced humidity (air moisture) and "Penman" evaporation diminished (Figure 19). This increased velocity of the west wind led to penetration of rain and air moisture and RH elevation, which is also a CCC`s symptom. The trend of Dryness is confound within the Hula Valley by summer irrigation, resulting decline of evaporation during 2019-2021 in the Hula Valley (Figures 11, 20).

Another potential impact of the CCC`s on the ecosystem is presented in Figures 12–16. The lowered GWT is an obvious consequence of dryness. The hydraulic gradient in the Hula Valley undergrounds has been previously documented [4]. Figures 12–16 represent the GWT decline and spatial distribution of subterranean water capacities, indicating the impact of changes in climate condition and dryness. Results given in Figures 12–16 represent the long-term moisture impact on the dynamic trend of the GWT amplitude of depth fluctuations. The Hula Valley is divided into three regions: Northern, Central and Southern. The underground gradient of decline in hydrological pressure from North to South has been documented [4]. The Northern and Central soil is organic, whilst the Southern soil has a mineralogical trait. Therefore, higher availabilities of preferential water path capacities in the southern region affect the GWT depth less when wettability changes. In the Northern region, the changed GWT depth amplitude between dryness-wettability alternate produce significant change of water content resulting pronounced GWT summer decline. Results given in Figures 15, 16 indicate the effective impact of the alternation between dryness and wettability; dryness (from 2003 to 2017) and wettability (in 2018 and 2019) are reflected by lowering and elevation of the GWT depth, respectively.

The dominant wind direction recorded in the Hula Valley ranges between Azimuths of 160 and 240 (Figure 6, Table 4), i.e. south–southern–west–western. These are both the daily (mid-day–early evening) regional common summer west wind and the winter infrequent west wind, which insert high humidity and rain, and as the west wind velocity is higher the direction is more westerly (Figure 6). Nevertheless, temporal changes (Figures 6, 7) indicate lower wind velocities in the 2000s as a consequence of changes in CCC, but relative humidity (RH) represents just 10% of amplitude fluctuation (Figure 8). Although temporal records of daily mean wind velocities do not indicate significant fluctuation, the record of exceptional maximal velocities of irregular gust west wind storms shows a significant increase of 6 m/s in recent years (Figure 9). This increase is a symptom of irregular rain/windy storm events of changes in climate conditions with consequent slight deviation of wind direction towards the west (Figures 10, 21, Table 6). A prominent reflection of CCC is shown in Figure 21 as a decline in the number of rainy days since 1980, with the rain capacity slightly diminished (Figure 24). The impact of CCC is emphasized (Figure 26, Table 6), where since the 1980s the rain capacity per day has been enhanced from 8.6 to 9.2 mm/day and the number of rainy days declined from 69 to 65 per year.

Moreover, results given in Table 4 indicate that normal and common daily fluctuations of total radiation existed throughout the entire period of 2000–2021. Total radiation values varied between 2.0×10^3 and 6.7×10^3 Kcal /m^2/day, which were slightly higher than those measured in Lake Kinneret [13]. The Lake Kineret altitude is below the sea level and radiation is partly absorbed and attenuated (dissipated), causing lower values than those documented in the Hula Valley (60–180 m above sea level). Conclusively, radiation was probably not affected and/or modified by CCC.

Air temperature elevation and water scarcity lowered the GWT in the Hula Valley and enhanced the demands for additional water allocation aimed at keeping soil moisture to prevent texture deterioration. The result was initiation of a national debate about water management, combined with reinforcement of Kinneret water quality protection contributed by sea water desalinization policy, and agricultural development in the Hula Valley. The recent three rainy years slightly alleviated some ecological difficulties. Future perspectives suggested desalinization enhancement supporting freshwater to Lake Kinneret and completion water allocation to the Hula Valley through pumping withdraw

Kinneret water.

A temporal evaluation of the rain capacity data throughout the entire period of 1940–2021 indicates that during the periods 1940–1979 and 1980–2020, there were 75% and 63% respectively of rainfall capacity between 450 and 750 m. In other words, rainfall capacity in 1940–1979 was higher than that in the latter period. Moreover, the long-term record of air temperature clearly confirms that temperature in the Kinneret watershed has increased since the mid-1980s. The challenge of management under an ecological disordered system is the present achievement: temperature increase enhances demands water for irrigation but resources are reduced. The prominent response is therefore intensification of supplemental water supply from desalinization production.

5. Conclusion

An increase of drought frequency was documented during the 2000`s but earlier they were not uncommon. The major change in climate condition in the 2000s was a non-dramatic decline in the rain capacity, as well as in the headwater river discharges. A fairly slight decline in the headwater (Dan, Hazbani, Snir) discharges is shown in Figure 17. Nevertheless, due to the overall (including Golan Heights) reduction in the rainfall capacity in the Kinneret watershed and the total Kinneret river system input, the Jordan River discharge significantly reduced (Figures 18, 25). Although the major trend of rainfall decline was confirmed for the entire Kinneret watershed, partial dissimilarity was recorded within the Hula Valley, where the amount of rainfall represent a present slightly increase (Figure 19). The ecological CCC status of the Hula Valley is therefore defined as a variation of the entire watershed ecosystem.

References

[1] Gophen, M., and D. Levanon, (eds) 1993-2006 Hula Project, Annual Reports: Migal-Sientific Research Institute, Jewish National Fund (Keren Kayemet LeIsrael), US Forestry Service International Project, Israeli Water Authority. Gonen, E.(ed) 2007. Hula Project Annual Report, Jewish National Fund (Keren Kayemet LeIsrael) Migal-Scientific Research Institute and Israeli Water Authority, 133 p.

[2] Barnea, I.(ed) 2008, Hula Project Annual Report, Jewish National Fund (Keren Kayemet LeIsrael) Migal-Scientific Research Institute and Israeli WaterAuthority159, p.

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

[4] Gophen, M., M. Meron, V. Orlov-Levin, & Y. Tsipris, (2014), Seasonal and spatial distribution of N & P substances in the Hula Valley (Israel) subterranean. Open Journal of Modern Hydrology; 4, 121-131. http://dx.doi.org./10.4236/ojmh.2014.44012.

[5] Gophen, M, M. Meron, V. Levin-Orlov, Y. Tsipris, and M. Peres, Climate Change, Regional Water Balance and Land Use POlicy, in the Watershed of Lake Kinneret (Israel). Open Journal of Ecology, 10, 200-224, https//doi.org/10.4236/oje..2020.104014.

[6] Geyfman, Y., M. Shaw, H. Dexter and F. Sarusi, 1987. The Kinneret Watershed Jordan and Headwaters loads investigation: 8 supplemental chapters; Mekorot Water Co. Ltd. Jordan District, Watershed Unit, Nazereth, 150 p.

[7] Shepard, D. (1968). "A two-dimensional interpolation function for irregularly-spaced data". Proceedings of the 1968 ACM National Conference. pp. 517–524. doi: 10.1145/800186.810616.

[8] Givati, A., Goillaume, T., Rosenfeld, D., and Paz, D. 2019, Climate change impacts on streamflow at the upper Jordan River based on an ensemble of regional climate models; Journal of Hydrology: Regional Studies 21: 92-109; DOI: 10.1016/j.ejrh.2018.12.004.

[9] Znovar Oved Gobi Ltd.: Shacham, G, H. Tsaban, Y. Avnimelech, and A. Ofer, 2011, Hula Project 2nd Stage, Development Program, Chapter: Opinion about Agricultural, Water consumption, Environmental and Touristic changes in the Hula Valley. Interim Report 31 p. (in Hebrew).

[10] Gophen, M. Hydrology and Cranes (*Grus grus*) Attraction Partnership in the Management of the Hula Valley—Lake Kinneret Landscape. *Hydrology* 2021, *8*, 114. https://doi.org/10.3390/ hydrology8030114.

[11] Gophen, M. 2020, The Impact of Climate Change on the River Jordan-Lake Kinneret (Israel) Ecosystem; Journal of Earth Science and Climatic Change; 105. DOI: 10.46715/jescc2020.1000105.

[12] Gophen, M. 2021, Effects of Climate Conditions on TP Outsourcing in Lake Kinneret (Israel); Climate, 9, 142, pp 1-24. https://doi.org/10.3390/cli.9090142.

[13] Neumann, J., and G. Stanhill. 1978. Chapter: The general meteorological background; in: Lake Kinneret Monographiae Biologicae, (C. Serruya ed.) Volume 32, Dr. W. Junk bv Publishers The Hague-Boston-London 1978. Pp 49-59.