

# Effects of Climatic Changes on Surface and Groundwater Resources in the Northwestern Part of Jordan

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**Abstract**— During the last 5 decades precipitation records in Jordan have shown a general decreasing trend. Such decreases have certainly their impacts on the availability of surface and groundwater, on soil moisture contents (green water) and on the surface and groundwater qualities.

In this article the impacts of decreasing precipitation on the availability of surface and groundwater will be analyzed.

The results show that a decrease in precipitation of 10% will result in the reduction of flood runoff by about 39%, and a reduction in groundwater recharge of 16% in rain rich areas receiving more than 500mm/yr increasing to 59% in areas receiving moderate precipitation of around 300mm/yr.

**Keywords**— climatic changes, evaporation calculation, surface and groundwater.

## I. INTRODUCTION

Precipitation (henceforth ppt) records in Jordan during the last 4-5 decades show a general decrease in the amount of ppt with the passage of time. The study area in the northwestern part of the country (Fig. 1) is a very important part of the country in what concerns surface and groundwater resources. The precipitation trends for that area and for Jordan as a whole are given in Figures (2-5). The main consequences of such decreases are:

- 1- Reduced flood flows.
- 2- Reduced groundwater recharge.
- 3- Reduction in soil moisture content (green water) and shorter periods of soils being wetted.
- 4- Increases in both surface and groundwater salinities.

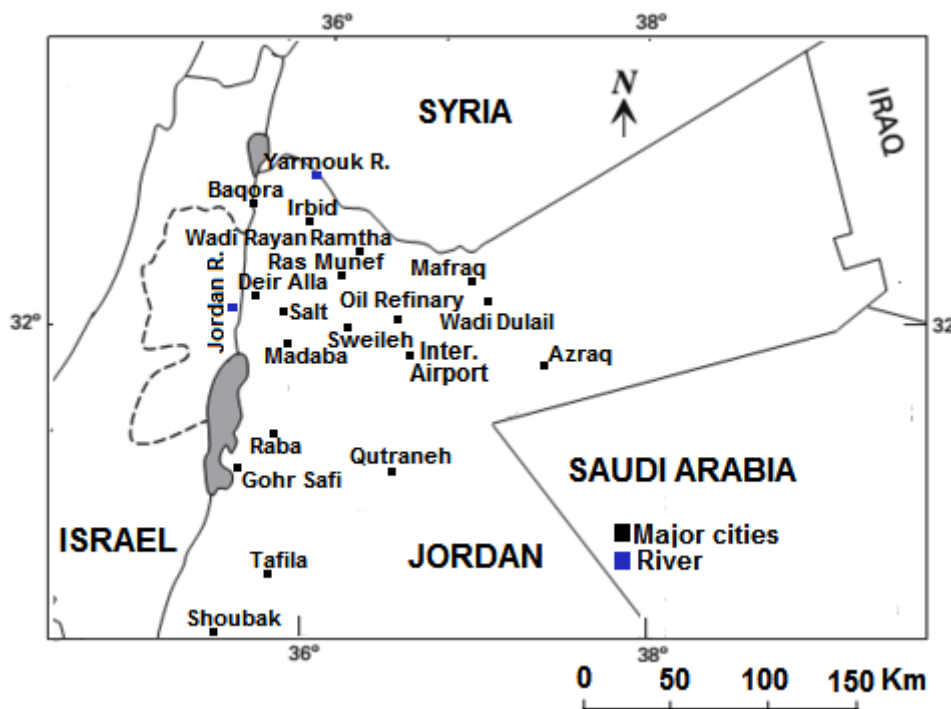


FIG. 1: LOCATION MAP OF THE STUDY AREA AND SOME OF THE RAINFALL STATIONS

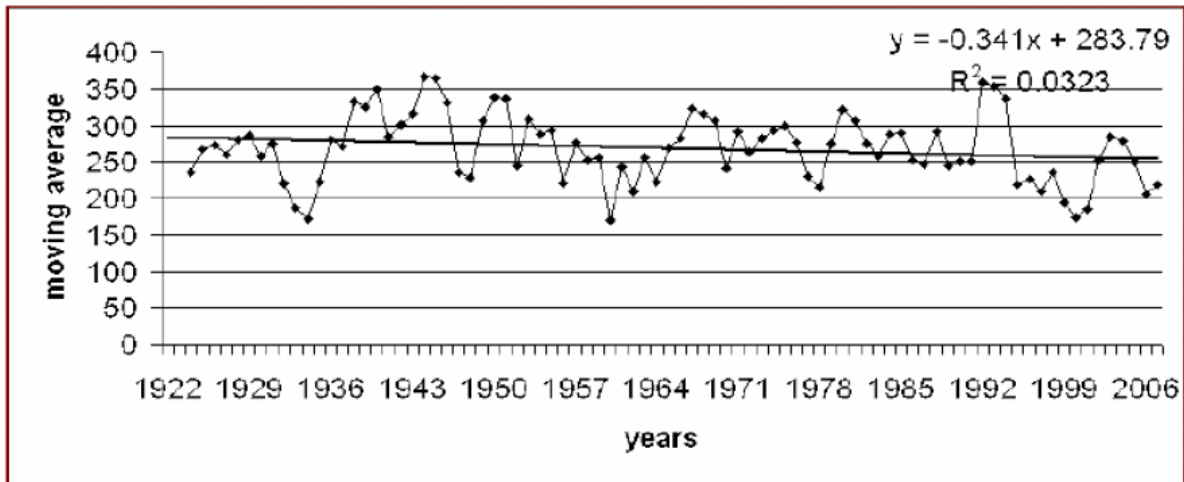


FIG. 2: ANNUAL RAINFALL IN AMMAN STATION (MM/YR.)

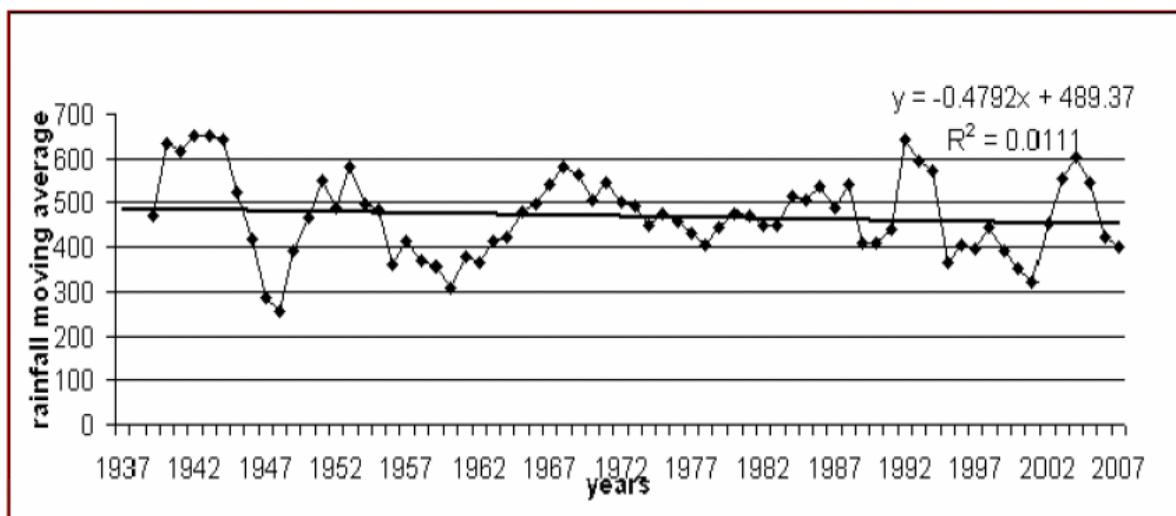


FIG. 3: ANNUAL RAINFALL IN IRBID STATION (MM/YR.)

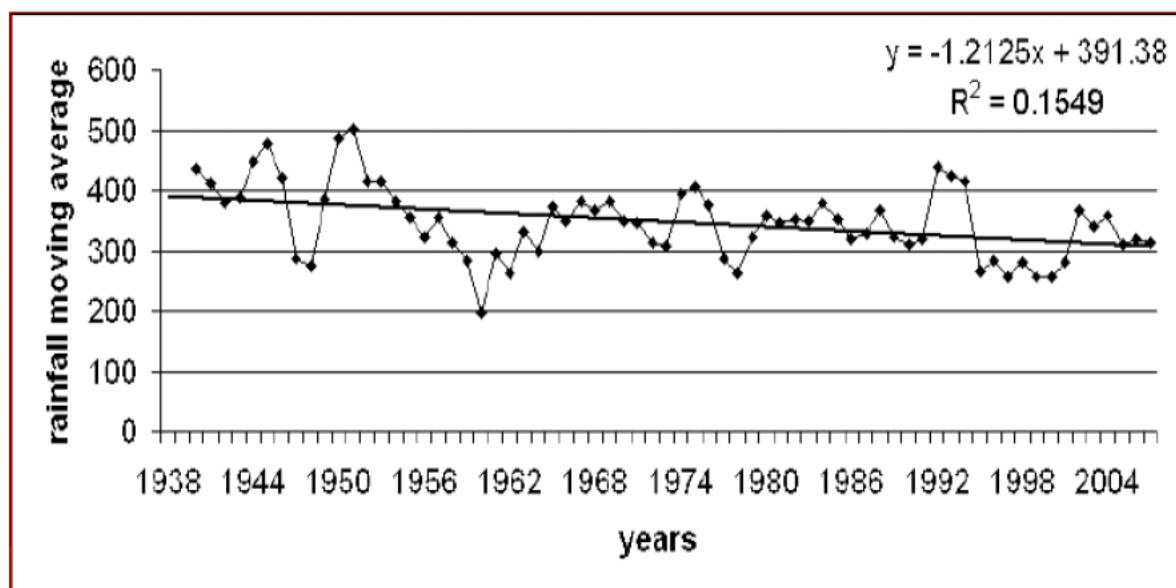
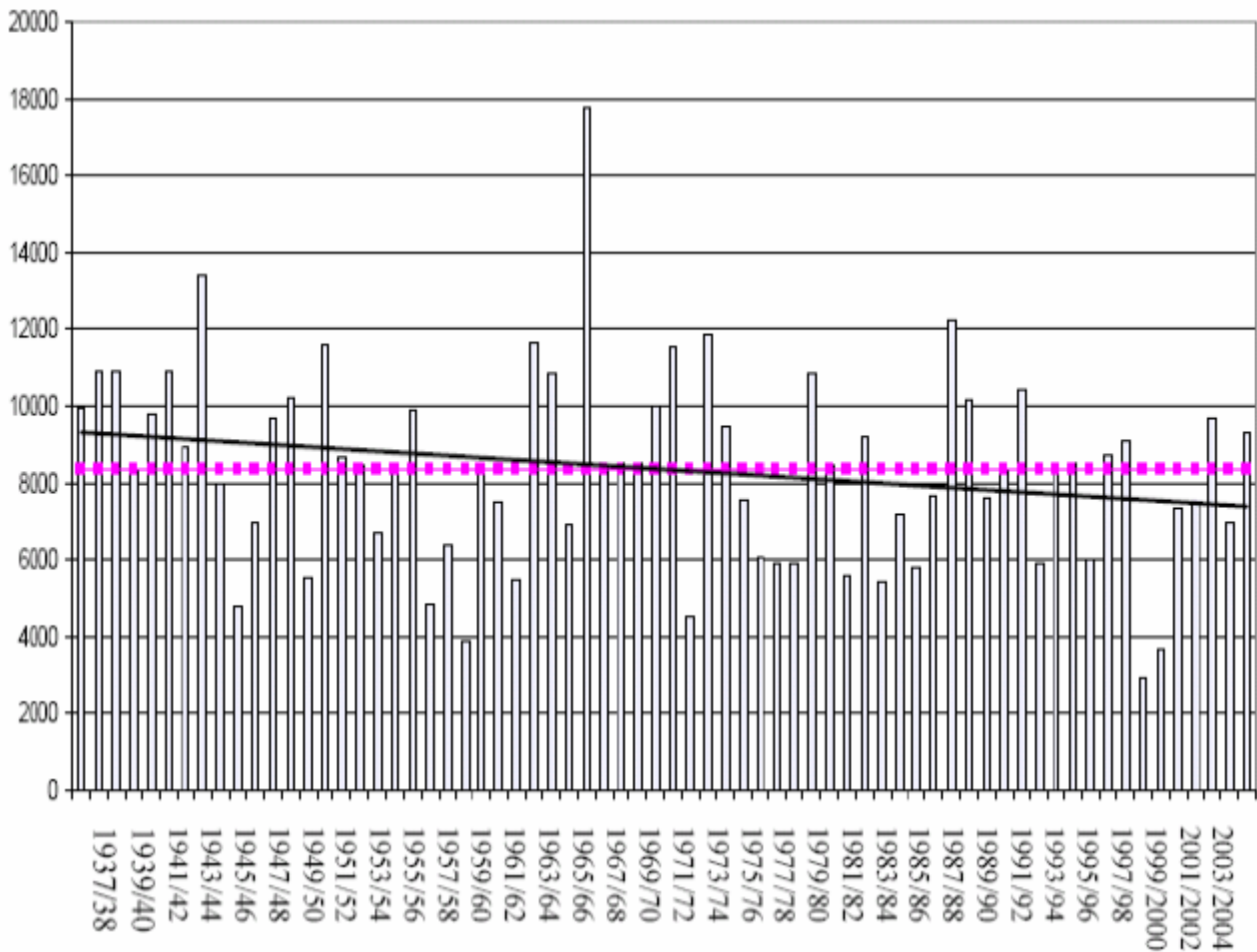


FIG. 4: ANNUAL RAINFALL IN MADABA STATION (MM/YR.)



**FIG. 5: TOTAL VOLUME OF PRECIPITATION OVER JORDAN FROM 1937/38 TO 2005/2006(MCM/YR.)**

These consequences have themselves further implications on discharge of springs, water supply, air relative humidity soil temperature etc.

As a result of all these effects rain fed agriculture will reduce, water supply will decline, existing dams will become oversized and generally investments in many projects will be lost or will reduce in value, with all the socioeconomic ramifications of all the above mentioned impacts.

In this article, the decreases in ppt in the northwestern parts of the country, which receive the highest amounts of ppt and hence the water richest areas in Jordan will be illustrated in the form of time series of representative rain gauging stations. After that, the impacts of the reduction in ppt rates on the quantities of surface and groundwater resource will be elaborated.

## II. REDUCTION IN FLOOD FLOWS

Decreasing ppt in an area reflects on flood flows as a result of two factors:

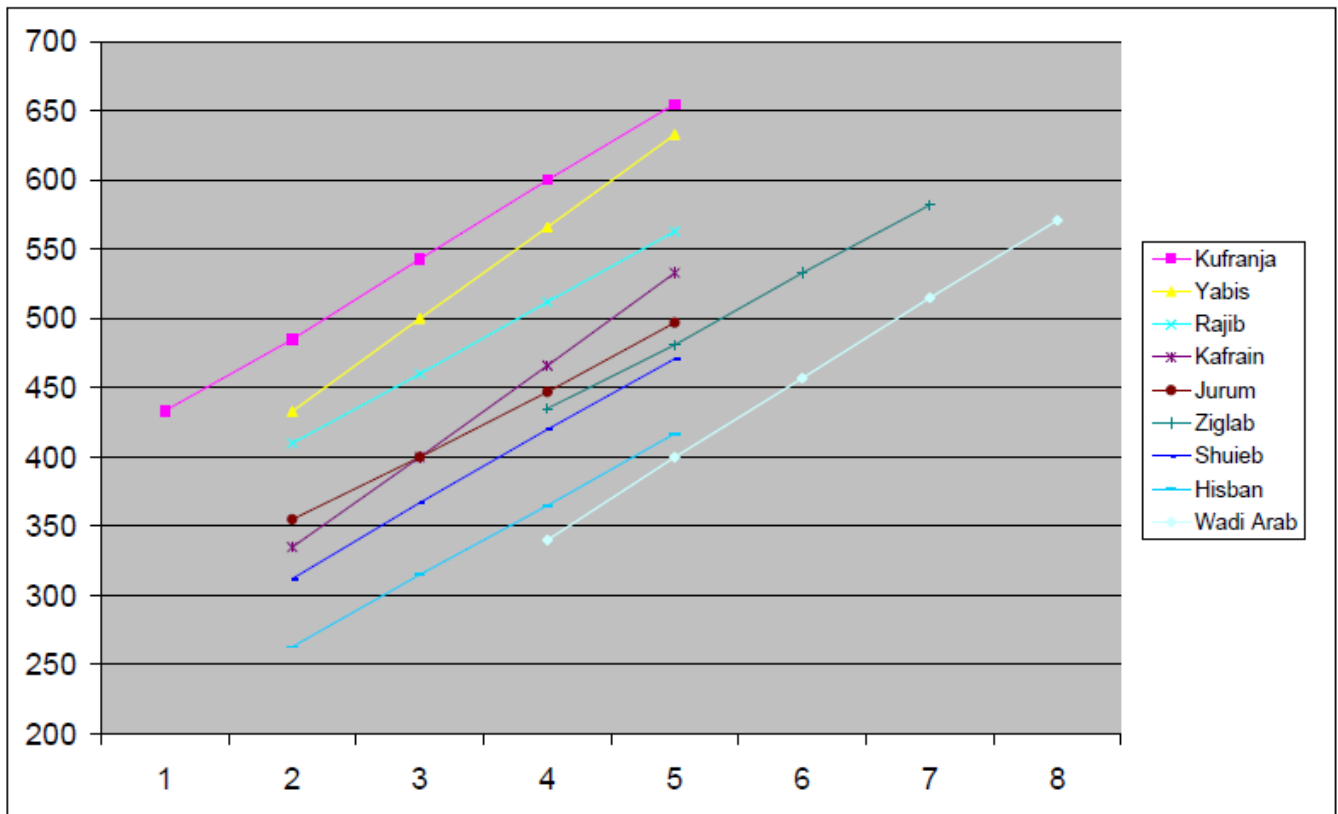
- 1- Decreasing flood flow amounts due to decreasing ppt according to the equation:

$$\text{Flood flow} = \text{ppt} \times \text{runoff ratio}$$

If ppt decreases, the flood flow decreases also.

- 2- Flood flow decreases as a result of the fact that the higher the ppt in an event or in the sum over a certain time period the higher the runoff / ppt ratio (Fig. 6).

The reduction in the flood runoff / ppt ratio in the northwestern part of Jordan can be deduced from Figure 6. In average it equals 0.8% (based on the NWMP 1977)



**FIG. 6: CORRELATION OF FLOOD RUN OFF/PRECIPITATION RATIO (IN %) AND RAINFALL AMOUNTS (MM/YR) FOR DIFFERENT CATCHMENTS IN THE STUDY AREA.**

#### LEGEND TO TABLES 1-7

**T** = Average monthly maximum daily temperature (centigrade)

**ppt** = Precipitation amount in a month (mm)

**Rh** = Relative humidity of the air at noon (%)

**Saturation air pressure** = vapor pressure of the air at saturation for a given temperature (Torr)

**Total evaporation** = total calculated evaporation for a specific month (mm)

**Flood runoff** = % of precipitation that runs off as flood flow based on actual flood runoff /precipitation measurements

**Net infiltration into soil** = ppt – runoff – evaporation in the considered month (mm)

**Soil retention (mm)** = amount of ppt, which the soil can hold after gravity drain.

**Net Recharge to the groundwater** = actual recharge amount into the groundwater (mm)

Precipitation over the area ranges from 312 mm/yr to 542 mm/yr with an overall weighted average of 456 mm/yr (DoM and WAJ open files).

Decreases in ppt by 10% result in direct reduction in flood flow by the same rate of 10%. This is a direct result of flood flow/ppt ratio.

The flood flow of the wadis in an average year sums up to 16.3 MCM, a 10% reduction equals 1.63 MCM /yr of that average flood flow.

The flood flow / ppt ratio decreases due to 10% decrease in ppt rates by 0.8% (Fig 6). That means, instead of a flood flow/ ppt ratio ranging from 0.0 to 5.22% with an average of 2.77%, the ratio, when ppt decreases by 10% will range from 0.8 to 2.87% with an average of 1.97%.

Accordingly, the second factor, which is the decrease in the flood flow/ ppt ratio itself will cause a reduction in the flood flow of  $(0.8 / 2.77) \times 16.3 = 4.7$  MCM/yr.

The total reduction equals then  $(1.63 + 4.7)$  6.33 MCM/yr out of 16.3 MCM/yr of the flood flow amounts of the 30s, 40s and 50s of the last century.

This is an average reduction of around 39% in the flood flow amounts.

### III. REDUCTION IN GROUNDWATER RECHARGE

Natural groundwater recharge is normally calculated from the water balance equation

$$P = E + Sr + I$$

P = Precipitation

Sr = Surface runoff

E = Evaporation

I = Infiltration to the groundwater or natural recharge

The calculation or measurement of both evaporation and infiltration give only approximations of quantities. Because evaporation in semi arid areas makes a high percentage of ppt amounts (60 - 99%), a small error in its measurement or calculation reflects strongly on the other water balance parameters especially infiltration and groundwater recharge.

Therefore a new approach for the calculation of actual evaporation will be adapted. The new approach is based on Dalton's (1502) equation:

$$E_D = c (e_s - e_a)$$

Where

$E_D$  = evaporation according to Dalton (1502)

$e_s$  = water pressure at the surface of water

$e_a$  = water pressure of the air

c = factor

Haude in 1952 developed that equation to:

$$E_H = f \cdot s$$

Where:

$E_H$  = Evaporation after Haude

f = A factor depending on the month of the year according to Haude (1952).

s = Saturation deficit of the air in mbar

### IV. BACKGROUND FOR THE CALCULATION OF EVAPORATION

1. After the dry season, evaporation can only start when rainfall begins and soil moisture becomes available for evaporation.
2. Evaporation can take place only as long as soil moisture is available in the capillary fringe of rocks and soils and that period in Jordan extends from November to April.
3. Moisture in soils and rocks exceeding the capillary fringe capacity either remains in the soil and/or rock or move downwards by gravity and capillary forces of the unsaturated rocks lying further beneath the top layer.
4. Soil and rocks are considered to contain water available for evaporation during the whole rainy season.
5. Water retention needs of soils and rocks down to the depth of the capillary fringe are considered as a part of the evaporation water amounts.
6. The recharge effective rainy season is November to March of each year and the evaporation effective season from November to April.

7. Monthly evaporation is calculated according to Haude (1952):

$$E_H = f.s$$

Considering the average monthly maximum daily temperatures and the relative humidity or saturation deficit of the air, the evaporation for the period of the year, when soil moisture is available for evaporation can be calculated (Tables 1-7). The calculated evaporation amounts resemble those of potential evaporation for the studied stations.

**TABLE 1**  
**WATER BALANCE FOR SALT AREA**

	Month/ parameter	Nov.	Dec.	Jan.	Feb.	Mar.	Sum	
1	Temp. C <sup>0</sup>	18.6	13.2	11.1	11.7	15.1		
2	ppt (mm)	51.9	105.9	140.2	119.6	94.6		
3	Rh. at noon %	61	70	74	73	65		
4	Sat.vap. p. (Torr)	16.1	11.4	9.9	10	12.9		
5	Total evaporation	50.6	27.4	20.7	19.9	46.5		
6	Flood runoff	1.3	2.6	3.5	2.3.	2.4		
7	Evap. + flood runoff	51.9	30	24.2	22.2	48.9		
8	Net infiltr. into soil	0	75.9	116	96.9	45.7	335	
9	Soil retention						48	
10	Net recharge to gr. w.							287
1	10% less ppt	46.7	95.3	126.2	107.6	85.1		
2	Flood runoff	1.2	2.4	3.2	2.7	2.1		
3	Evap. + flood runoff	51.8	29.8	23.9	22.6	48.6		
4	Net infiltr. into soil	0.0	65.5	102.3	85.0	36.5	289.3	
5	Soil retention						48	
6	Net recharge to gr. w.						241.3	
7	Reduction in net recharge						16%	

**TABLE 2**  
**WATER BALANCE FOR BAQURA AREA**

	Month/parameter	Nov.	Dec.	Jan.	Feb.	March	Sum	
1	Temp. C <sup>0</sup>	26.5	20.2	18.4	19.7	23.2		
2	ppt	45.1	80	93.5	74.8	56		
3	Rh. at noon %	62	71	74	74	70		
4	Sat.vap.p. (Torr)	26	17.7	15.9	17.2	21.3		
5	Total evaporation	77.2	41.1	33	32.8	82.6		
6	Flood runoff	0.5	0.8	0.9	0.8	0.6		
7	Evap. + flood runoff	77.7	41.9	33.9	33.6	83.2		
8	Net infiltr. into soil	0	38.1	59.6	41.2	0	139	
9	Soil retention						48	
10	Net recharge to gr. w.							90.9
1	10% less ppt	45.2	72	84.2	67.3	50.4		
2	Flood runoff	0.4	0.7	0.8	0.7	0.6		
3	Evap. + flood runoff	77.6	41.8	33.8	33.7	83.1		
4	Net infiltr. into soil	0.0	30.2	50.4	33.6	0.0	114.2	
5	Soil retention						48	
6	Net recharge to gr. w.						66.2	
7	Reduction in net recharge						27.1%	

**TABLE 3**  
**WATER BALANCE FOR THE UNIVERSITY OF JORDAN AREA**

	Month/parameter	Nov.	Dec.	Jan.	Feb.	March	Sum
1	Temp. C <sup>0</sup>	18.1	12.3	10.2	11.7	15.2	
2	ppt	48.5	94.8	116.9	105.1	85.1	
3	Rh. at noon %	58.1	67.4	70	65.7	59	
4	Sat.vap.p. (Torr)	15.6	12.1	9.4	10	13	
5	Total evaporation	49.1	31.4	22.6	24.8	54.7	
6	Flood runoff	0.9	1.7	2.1	1.9	1.5	
7	Evap. + flood runoff	50	33.1	24.7	20.7	56.2	
8	Net infilt. into soil	0	61.7	92.2	78.4	28.9	261
9	Soil retention						48
10	Net recharge to gr. w.						213
1	10% less ppt	43.7	85.3	105.2	94.6	76.6	
2	Flood runoff	0.7	1.3	1.6	1.4	1.1	
3	Evap. + flood runoff	49.8	32.7	24.2	26.2	55.8	
4	Net infilt. into soil	0.0	52.6	81.0	68.4	20.8	222.8
5	Soil retention						48
6	Net recharge to gr. w.						174.8
7	Reduction in net recharge						23%

**TABLE 4**  
**WATER BALANCE FOR WADI RAYYAN AREA**

	Month/parameter	Nov.	Dec.	Jan.	Feb.	March	Sum
1	Temp. C <sup>0</sup>	26.7	20.5	18.8	20.3	23.8	
2	ppt	35.4	62.8	71.6	58	44.4	
3	Rh. at noon %	68.5	77	78.9	77.1	72.8	
4	Sat.vap.p. (Torr)	26.3	18.1	16.3	17.8	22.1	
5	Total evaporation	64.7	33.9	27.4	29.8	61.4	
6	Flood runoff	0.9	1.6	1.8	1.5	1.1	
7	Evap. + flood runoff	65.6	35.5	29.2	31.3	62.5	
8	Net infilt. into soil	0	27.3	42.4	26.7	0	96.4
9	Soil retention						36
10	Net recharge to gr. w.						60.4
1	10% less ppt	31.9	56.5	64.5	52.2	40	
2	Flood runoff	0.6	1.0	1.2	1.0	0.7	
3	Evap. + flood runoff	65.3	34.9	28.5	30.8	62.1	
4	Net infilt. into soil	0.0	21.6	35.9	21.4	0.0	78.9
5	Soil retention						36
6	Net recharge to gr. w.						42.9
7	Reduction in net recharge						59%

**TABLE 5**  
**WATER BALANCE FOR IRBID AREA**

	Month/parameter	Nov.	Dec.	Jan.	Feb.	March	Sum
1	Temp. C <sup>0</sup>	20.6	15	13	14.8	17.1	
2	ppt	50.4	82.1	109.1	97.1	85.9	
3	Rh. at noon %	60.4	71.3	73.6	70.8	65.9	
4	Sat.vap.p. (Torr)	18.2	12.8	11.2	12.6	14.6	
5	Total evaporation	56.2	24.2	24.2	26.8	51.7	
6	Flood runoff	2.7	4.3	5.7	5.1	4.7	
7	Evap. + flood runoff	58.9	28.5	29.9	37.9	56.4	
8	Net infilt. into soil	0	54.5	79.3	66.2	29.5	230
9	Soil retention						48
10	Net recharge to gr.w.						182
1	10% less ppt	45	73.9	98.2	87.4	77.3	
2	Flood runoff	2.5	4.1	5.4	4.8	4.3	
3	Evap. + flood runoff	58.7	28.3	29.6	31.6	56.0	
4	Net infilt. into soil	0.0	45.6	68.6	55.8	21.3	191.3
5	Soil retention						48
6	Net recharge to gr. w.						143.3
7	Reduction in net recharge						21%

**TABLE 6**  
**WATER BALANCE FOR MADABA AREA**

	Month/parameter	Nov.	Dec.	Jan.	Feb.	March	Sum
1	Temp. C <sup>0</sup>	20.2	14.1	12.7	14.1	14.5	
2	ppt	37.4	64.1	84.1	74.4	61.4	
3	Rh. at noon %	61.5	71.3	74.3	70.4	63.9	
4	Sat.vap.p. (Torr)	17.7	12.1	11.1	12.1	15	
5	Total evaporation	53	28.2	22.6	26.2	56.8	
6	Flood runoff	1	1.8	2.4	2.1	1.7	
7	Evap. + flood runoff	54	30	25	28.3	58.5	
8	Net infilt. into soil	0	34.1	69.1	46.1	2.9	152
9	Soil retention						48
10	Net recharge to gr. w.						104
1	10% less ppt	33.7	57.7	75.7	67.0	55.3	
2	Flood runoff	0.8	1.4	2.1	1.9	1.5	
3	Evap. + flood runoff	53.8	29.6	24.7	28.1	58.3	
4	Net infilt. into soil	0.0	28.1	51.0	38.9	0.0	118
5	Soil retention						48
6	Net recharge to gr. w.						70
7	Reduction in net recharge						33%



**TABLE 7**  
**WATER BALANCE FOR DEIR ALLA AREA**

	Month/parameter	Nov.	Dec.	Jan.	Feb.	March	Sum
1	Temp. C <sup>0</sup>	27.2	21.2	19	20.3	23.7	
2	ppt	35.8	54.7	66.7	54.1	44.5	
3	Rh. at noon %	50.1	60.3	62.9	63.9	60.4	
4	Sat.vap.p. (Torr)	27.1	18.9	16.5	17.9	22	
5	Total evaporation	105	60.5	49.2	47.3	89.9	
6	Flood runoff	0	0	0	0	0	
7	Evap. + flood runoff						
8	Net infiltr. into soil	0	0	17.5	6.8	0	24.3
9	Soil retention						24
10	Net recharge to gr. w.						0.3

#### LEGEND TO TABLES 1-7

**T** = Average monthly maximum daily temperature (centigrade)

**ppt** = Precipitation amount in a month (mm).

**Rh** = Relative humidity of the air at noon (%).

**Saturation air pressure** = vapor pressure of the air at saturation for a given temperature (Torr).

**Total evaporation** = total calculated evaporation for a specific month (mm).

**Flood runoff** = % of precipitation that runs off as flood flow based on actual flood runoff /precipitation measurements.

**Net infiltration into soil** = ppt – runoff – evaporation in the considered month (mm).

**Soil retention (mm)** = amount of ppt, which the soil can hold after gravity drain.

**Net Recharge to the groundwater** = actual recharge amount into the groundwater (mm).

Stanhill (1969) gives for the open water surface of Lake Tiberias an evaporation rate of mm 283mm for the months November through March (Table 8). Worth mentioning is that Lake Tiberias site is the only site in the area where actual evaporation rates have been calculated and calibrated. In the present calculation, evaporation during the same time period from the land surface in Baqura station, a few kilometers to the south of Lake Tiberias sums up to 234.5 mm. Class A- Pan Evaporation for Baqura area for the same period is given in the NWMP (1977) of Jordan as 443mm. Evaporation after Stanhill is 64% and evaporation in the present study 55% of the Class A-Pan Evaporation. The discrepancy can be explained by the nature of the two evaporation surfaces one a land surface and the other an open water surface. By applying the ratios calculated above to the Class A-Pan evaporation figures given in the NWMP (1977) shows that the discrepancies between the calculated evaporation amounts in this study and those calculated using the ratios do not exceed a few percentages.

**TABLE 8**  
**LONG TERM AVERAGE MONTHLY EVAPORATION FROM LAKE TIBERIAS, MM/MONTH (STANHILL 1969)**

Nov.	Dec.	Jan.	Feb.	March	Total
71	59	52	43	58	283

The soil retention capability for water is very essential for the calculation of infiltration and groundwater recharge. To measure it 27 samples collected in cylinders were dried at 105°C. After that they were saturated with water by merging the cylinders containing the dry soil in water containers allowing water to enter them from the bottom to the top for 12 hours. After that they were allowed to drain by gravity after being covered with plastic sheets to minimize evaporation. Drainage stopped in most samples after less than two hours.

The water retention ranged from 16% to 28% with an average of 24% of the total soil volume. Soil thicknesses of 10, 15, and 20cm can hence hold 24, 36, and 48 mm of rain water respectively.

If the amount of rain exceeds these figures soil water will move further down by gravity to reach areas beyond the reach of capillary forces.

Therefore the amounts of 24, 36, and 48 mm of rain water are considered recharge ineffective rain. They are lost by evaporation or evapo-transpiration at a certain stage.

Soils in hydrologic terms serve as a water storage reservoir for evaporation. Therefore, decreasing precipitation will affect the saturation degree of the soil during the rainy season allowing herewith less water to move down from the soil horizon into the groundwater regimes.

A 10% decrease in precipitation will result in the study area in decreasing groundwater recharge rates as shown in Table (9).

**TABLE 9**

**DECREASES IN GROUNDWATER RECHARGE RATES AS A RESULT OF 10% DECREASE IN PRECIPITATION RATES**

Station/	Salt	Madaba	Jordan University	Irbid	Deir Alla	Baqura	Rayyan
<b>Present recharge mm/yr</b>	286.5	104.2	213.2	181.5	0.3	90.9	60.4
<b>Decrease in groundwater recharge</b>							
<b>in mm/yr</b>	46.7	34	38.2	38.7	0.0	24.7	17.1
<b>in % of total recharge</b>	16	33	23	21	0.0	27.1	59

## V. CONCLUSION

Climatic changes are expected to have their rigorous effects on precipitation amount and distribution, air temperature and humidity, which in turn will have appropriate impacts on the surface and ground water resources, soil moisture, water quality and socio-economics.

There are strong indications that climatic changes are affecting the amount of precipitation falling over the northwestern parts of Jordan, which have been showing decreasing trends of precipitation during the last few decades.

Flood runoffs of Wadis will be affected by two mechanisms, namely: first, as a result of runoff amounts being directly proportional to precipitation amounts and second as an indirect result of lower flood runoff/ precipitation ratios inherent in lower precipitation amounts. Such mechanisms will result in a flood runoff reduction in northwest Jordan of 39%, if the precipitation amount decreases by 10%.

The results show also that a decrease in precipitation of 10% will result in a reduction in groundwater recharge of 16% in rain rich areas receiving more than 500mm/yr increasing to 59% in areas receiving moderate precipitation of around 300mm/yr.

Countries in the MENA region should gradually become aware of the climatic processes affecting their surface and ground water resources with all the socio-economics and stability implications on these countries. That may trigger taking the necessary measures to alleviate the negative impacts.

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