The Impact of Climate Change on the Aridity Index in Jordan: Integrating Statistical Models and Geographic Information Systems[*]

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Abstract

This study aims to determine the impact of climate change on the Aridity Index in Jordan based on long-term climatic records of a 51-year period. The effect of the change in the monthly and annual general trend of both temperature and precipitation is reflected in the change in the values of DE Martonne's Aridity Index (Iar-DM). This is done by integrating statistical methods and geographic information systems (GIS) in addition to creating maps of climatic classifications for Jordan، according to Iar-DM, based on (GIS). The percentage of wet years in which the amount of rain exceeded the general average for the first period 1970-1982 was 62%, and the dry years in which the average temperature exceeded the general average for the same period was 8%. However, for the last fourth period, 2008-2020, the percentage of drought years in which rainfall was less than the general average was 100%, and the dry years in which the average temperature exceeded the general average also amounted to 100% for the same period. As well, the percentage the arid and semi-arid climatic regions reached 92.2% of the total area of Jordan, while the humid and semi-humid climatic regions constituted only about 7.2%.

Keywords. Aridity Index, Climate Change, Drought, GIS, Jordan, Statistical Modeling.

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الملخص العربى

أثر التغير المناخي على مؤشر الجفاف في الأردن: بالتكامل بين النماذج الإحصائية ونظم المعلومات الجغرافية

تهدف هذه الدراسة إلى تحديد تأثير تغير المناخ على مؤشر الجفاف في الأردن بناءً على السجلات المناخية طويلة الأمد لمدة ٥١ عامًا. حيث ينعكس تأثير التغير في الاتجاه العام الشهري والسنوي لكل من درجة الحرارة وهطول الأمطار على التغير في قيم مؤشر الجفاف (Iar–DM). ويتم ذلك من خلال دمج الأساليب الإحصائية و نظم المعلومات الجغرافية(GIS) ، بالإضافة إلى لاعداد خرائط للتصنيفات المناخية للأردن وفقًا لـ Iar–DM، بناءً على (GIS). حيث بلغت نسبة السنوات الرطبة التي تجاوزت فيها كمية الأمطار المتوسط العام للفترة الأولى ١٩٧٠–١٩٨٢ ٦٢٪ ، وبلغت السنوات الجافة التي تجاوز فيها متوسط درجة الحرارة المتوسط العام لنفس الفترة ٨٪. أما بالنسبة للفترة الرابعة الأخيرة ٢٠٠٨–٢٠٢٠ ، فقد بلغت نسبة سنوات الجفاف التي كان هطول الأمطار فيها أقل من المعدل العام ١٠٠٪ ، كما بلغت سنوات الجفاف التي تجاوز فيها متوسط درجة الحرارة العام ١٠٠٪ لنفس الفترة . كما بلغت نسبة الأقاليم المناخية الجافة وشبه الجافة ٩٢,٢٪ من إجمالي مساحة الأردن ، في حين شكلت المناطق المناخية الرطبة وشبه الرطبة حوالي ٧,٢٪ فقط.

كلمات مفتاحية: مؤشر الجفاف ، التغير المناخي ، الجفاف ، نظم المعلومات الجغرافية ، الأردن ، النمذجة الإحصائية.

Introduction

There have been a recurrence of drought and extreme climatic phenomena in the temperate regions of the Asian continent. As a result, the number of rainy days is expected to decrease in the Mediterranean basin accompanied by clear reductions in the number of snow days (IPCC 2007: P173). The Arab countries are among the countries most affected in the world by rising temperatures and decreasing rainfall, with their continuous suffering from drought and water scarcity (AFED 2009: P75). Also, most climate models expect that there will be a decrease in the number of winter rains in most regions of the Mediterranean basin, Rainfall is expected to decrease over large areas of the basin at a rate estimated to be (10% - 40%) by the year 2100. Furthermore, the expected results of climate change in the Middle East is more decreasing rainfall and increasing drought (Issar 2006: P120). Expectations indicate a change of (+ 4%) in latent evaporation, (+5%) in water deficit and a decrease (1%) in water surplus in the northern regions of Jordan (Al-Sababhah et al. 2020: P155). As a result of the changes that will occur in the rates of temperature and rainfall, the arid and semi-arid regions of the world will suffer increasing scarcity in available water resources in the present and the future (Al-Sababhah and Hazaymeh 2019: P467). Correspondingly, soil moisture associated with rainfall can be considered an important measure in the sectors of agriculture, forestry, and water, where the temporal and spatial variation of soil moisture is directly related to rainfall (Kumar et al. 2009: P267; Almagbil et al. 2019: P1-2). As a guide to climate change in dry regions, the aridity index is one of the most important criteria to be studied and monitored, the reason is that arid and semi-arid regions in the world suffer from an increasing shortage of available water sources, low agricultural land productivity, and high rates of evapotranspiration (Al-Sababhah and Al-Omari 2019: P191). Additionally, rainfall and temperature are important indicators of drought conditions determined by the adoption of international institutions and government criteria in studying and monitoring the consequences of climate change (Sharma 2007: P2053). Hence, De Marton's aridity index (Iar-DM) can be considered one of the common methods for conducting climatic and botanical classifications for different regions (Forootan 2019: P163; Zambakas 1992). Where; many studies have used Iar-DM in different regions of the world in climatic classifications, and as an indicator of change in rainfall and temperature rates. Actually, there is a possibility to determine the long-term general annual trends of both temperature and rainfall in order to analyze the general trend of Iar-DM rates (Falah 2012; Buric and Ivanovic 2018). The drought index or the socalled actual value of rainfall affects soil productivity, as it is related to determining the water needs of agricultural crops. Moreover, the ability of the soil to retain moisture is very weak, especially if this is associated with dry regions that suffer from low rates of rainfall and extreme temperatures, in addition to the importance of this in planning and managing water resources in the arid and semi-arid regions of the world (Sharaf 1985; Al-sababhah 2020: P85). It is to be noted that, the estimation of rainfall effectiveness depends on the interception of vegetation cover, surface runoff, the actual water storage capacity in the soil (AWC), and evaporation from the soil and plants (Mls 1980: P305; Vallet et al. 2013: P3947). The actual value of rainfall is the part of the total rainfall on which plants depend to meet their water needs for irrigation purposes (Bos et al. 2009; Babu et al 2015: P15; Obreza and Pitts 2002: P212).

This work aims to study and analyze the relationship between Iar-DM and climate change in Jordan based on statistical methods and GIS by determining the long-term annual general trend of monthly and annual rates of temperature and precipitation, and annual general trends of Iar-DM rates. Actually, the climatic conditions in Jordan are characterized by variation in terms of both rainfall and temperature, which creates a clear variation in Iar-DM or the amount of soil water retention. The importance of this study is manifested in developing a method that can, by focusing on the change in Iar-DM associated with climate change, have an impact on the productivity of agricultural soils in a country that suffers mainly from low rainfall and lack of available water resources, which may result in a shortage of food. The study is also important because it may help decision-makers to take serious measures and develop realistic solutions to a problem that is exacerbated by the passage of years, specifically with the continuous migrations of neighboring countries like Palestine, Syria, and Iraq to an agriculturally poor country like Jordan. Finally, comparing the current study with other studies that studied climate change, in integrating statistical models and GIS in assessing the impact of climate change on the aridity index, by answering the question: Is there an effect of climate change on the drought index in Jordan?

Materials and methods

Study Area

Jordan is situated in the southeastern part of the Mediterranean Sea and has an arid and semi-arid climate with high temporal and spatial variability due to some local factors like the presence of topographical differences and location in relation to the path of depressions coming from the Mediterranean Sea and others directions. The area is about 89300 km2 and is located between 29°10' to 33°22' north and 34°51' to 39°20' east. In terms of topography, Jordan has a complex terrain with elevations varying between (-453) m in the eastern part of the Dead Sea basin and 1854 m above sea level in southern Jordan. Figure 1a. Climatologically, the area is dominated by an arid and semi-arid climate regime, where the long-term analysis of temperature shows that the area’s average temperature is approximately 18.7°C, with mean annual minimum and maximum temperature of 12.9 °C and 26.3 °C, respectively. Figure 1b; period 1970-2020 (JMD 2020). Also, the long-term analysis of rainfall showed that the area receives approximately 262.5 mm annually (i.e., 26 mm minimum to 570 mm maximum. Figure1c; period 1970-2020.

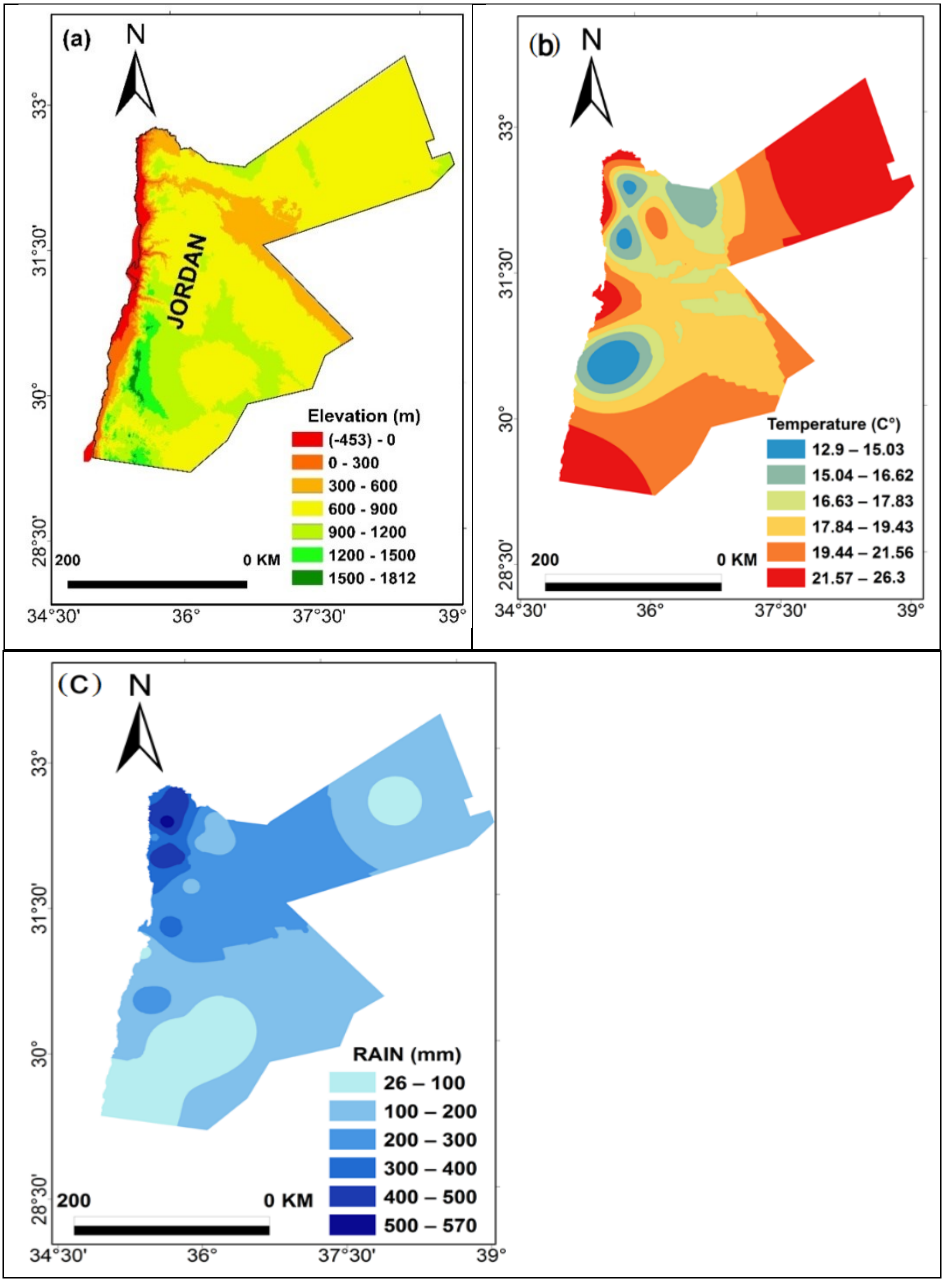


Figure 1 (a)Study Area, Elevation (m) (b)Temperature (C°) (c) Rainfall (mm)

Source: Author by Arc GIS10.7

Data

The data sets used in this assessment in the long-term (1970-2020), - with the exception of some stations scattered over most of Jordan, constitute the monthly and annual rates of rainfall and temperature for 19 climatic stations. Figure 2.

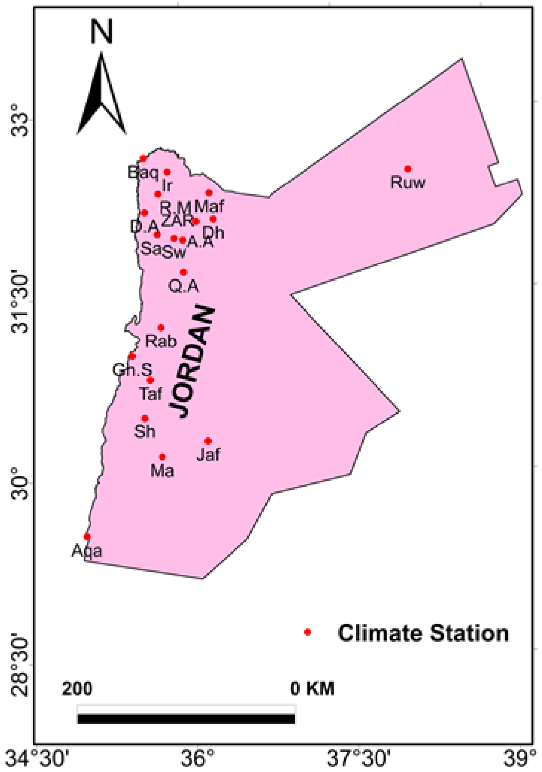


Figure 2 Distribution of climatic used stations in the study area

The data is provided by the Jordan meteorological department and the Ministry of Water and Irrigation. Table 1.

Table 1 List of climatic stations used in this study

Climate Station	WMO NO	Lat (N)	Long (E)	Ele (m)	Distance to Sea (Km)	Years
Ras Muneef (RM)	40257	´2٢º32	٤´4º35	900	82	1970-2020
Irbed (IR)	40255	32°33'	35°51'	560	86	1970-2020
Baqura (Baq)	40253	32°39'	35°37'	(-228)	69	1970-2020
Mafraq (Maf)	40265	٢٢´º32	١٤´º36	666	126	1970-2020
Ruweshid (Ruw)	40250	32°30'	38°11'	675	203	1970-2020
Aqaba (Aqa)	40340	29°34'	34°59'	15	210	1970-2020
Swaillih (Sw)	40269	31°60'	35°53'	1020	102	1970-2020
Amman.A.P (A.A)	40270	31°59'	35°59'	725	110	1970-2020
Q.A.Airport (Q.A)	40272	31°44'	35°58'	711	113	1970-2020
Rabah (Rab)	40292	31°15'	35°44'	920	127	2000-2020
Salt (Sa)	40268	٠٢´º32	´43º35	1050	93	1970-2020
Deir Alaa (D.A)	40285	١٤´º32	٣٦´º35	(-260)	75	1970-2020
Maan (Ma)	40310	30°11'	35°43'	1110	190	1970-2020
Shoubak (Sh)	40300	30°31'	35°34'	1360	155	1970-2020
Jafer (Jaf)	40305	30°19'	36°9'	850	223	1981-2020
Tafellih (Taf)	40298	30°50'	35°38'	1215	143	2000-2020
zarqa (ZAR)	40288	٠٨´º32	´05º36	542	121	2000-2020
Dhulil (Dh)	40267	٠٩´º32	´11º36	562	133	2000-2020
Ghour Safi(Gh.S)	40296	31°01'	35°28'	(-373)	83	2000-2020

Source: Jordan meteorological department

This work is also based on two remote sensing datasets obtained: (i) Landsat-8 surface reflectance data freely available from the United States Geological Survey (USGS) during 2014-2016; and (ii) ASTER GDEM data freely available from NASA.

DeMartonne's aridity index (Iar-DM)

Due to the importance of studying the actual value of rainfall. Climatologists, botanists, and hydrologists have tried to find mathematical bases to estimate the drought index for the purpose of studying the relationship between actual rainfall sufficiency and geographical distribution of vegetation cover.

The De Martonne drought index (Iar-DM) is one of the frequently used indicators of

Climate aridity (De Martonne 1926). It is calculated from the ratio of annual precipitation (Rsrg) and average annual temperature (tsrg) increased by 10 (Ducić and Anđelković 2004: P420):

$$\mathrm{Ig} = Rsrg/(tsrg + 10^{\circ} \qquad (1)$$

The drought index can be calculated for each month separately, but the formula

Is slightly changed:

$$\mathrm{Im} = 12Rsrm/(tsrm + 10^{\circ} \qquad (2)$$

On the basis of Iar-DM results of monthly and annual temperatures and rainfall in Jordan, classifications can be determined for climatic regions. Table 2.

Table 2 Classification of climatic regions - Iar-DM

Climatic Region	**Value of (Iar-DM)**
Arid	Less than 5
Semi-Arid	5-10
Semi-Humid	10-20
Humid	20-30
High-Humid	٣٠More than

Source: DeMartonne E (1926)

General trend of temperature, precipitation, Iar-DM

The regression equations obtained from these parameters show that there are curved lines describing the correlation between Iar-DM, temperatures and rainfall, according to the following equation:

$$\mathrm{Y} = Xa + b \qquad (3)$$

Where Y is the expected value (temperature, rain, drought index), a is the amount of change in the studied phenomenon, and b is the value of Y at time X. Furthermore, when studying the time series, the value of the pre-time value of the start time of the time series is zero, (Humaidan et al. 2006).

Further, the statistical significance of the change in the curvature of the general trend of the climatic phenomenon with respect to the zero value that assumes that there is no change, and the importance of changing the averages of its values statistically during time, were examined by testing the statistical significance of the regression equations of temperature, rain, and Iar-DM during certain periods, depending on Linear regression analysis in SPSS.

Pearson's correlation coefficient between time(years), temperature, rainfall, and Iar-DM

A correlation matrix is used to show all possible correlation coefficients between all variables. the matrix is useful in showing how strongly each independent variable is related to the dependent variable at different lag times. Therefore, a correlation matrix was set up, USING Pearson’s correlation coefficient between time (years), temperature, rainfall, and Iar-DM, as in the following equation (Humaidan et al. 2006):

$$r_p = \frac{n\Sigma xy-(\Sigma x)(\Sigma y)}{\sqrt{(n\Sigma x^2-(\Sigma x)^2)(n\Sigma y^2-(\Sigma y)^2)}} \qquad (4)$$

The value of the correlation coefficient ranges between (-1,1), where x represents the independent variable (temperature, rain, Iar-DM years), y the dependent variable (temperature, rain, Iar-DM) as well, according to required relationships, and n number of years.

Statistical relative comparisons

The method of statistical relative comparisons was used to distribute the study time into the periods (1970-1982), (1983-1995), (1996-2007), and (2008-2020) for stations with long-term climatic records (1970-2020). As for the al-jafr station, the study period was divided into three periods (1980-1993), (1994-2006), (2007-2020), and the other stations represented by Tafileh, Rabbah, Zarqa, and Dhulil into two periods (2000-2009), (2010-2020). This is to measure the changes in both temperature and rainfall rates and compare them to the change in Iar-DM.

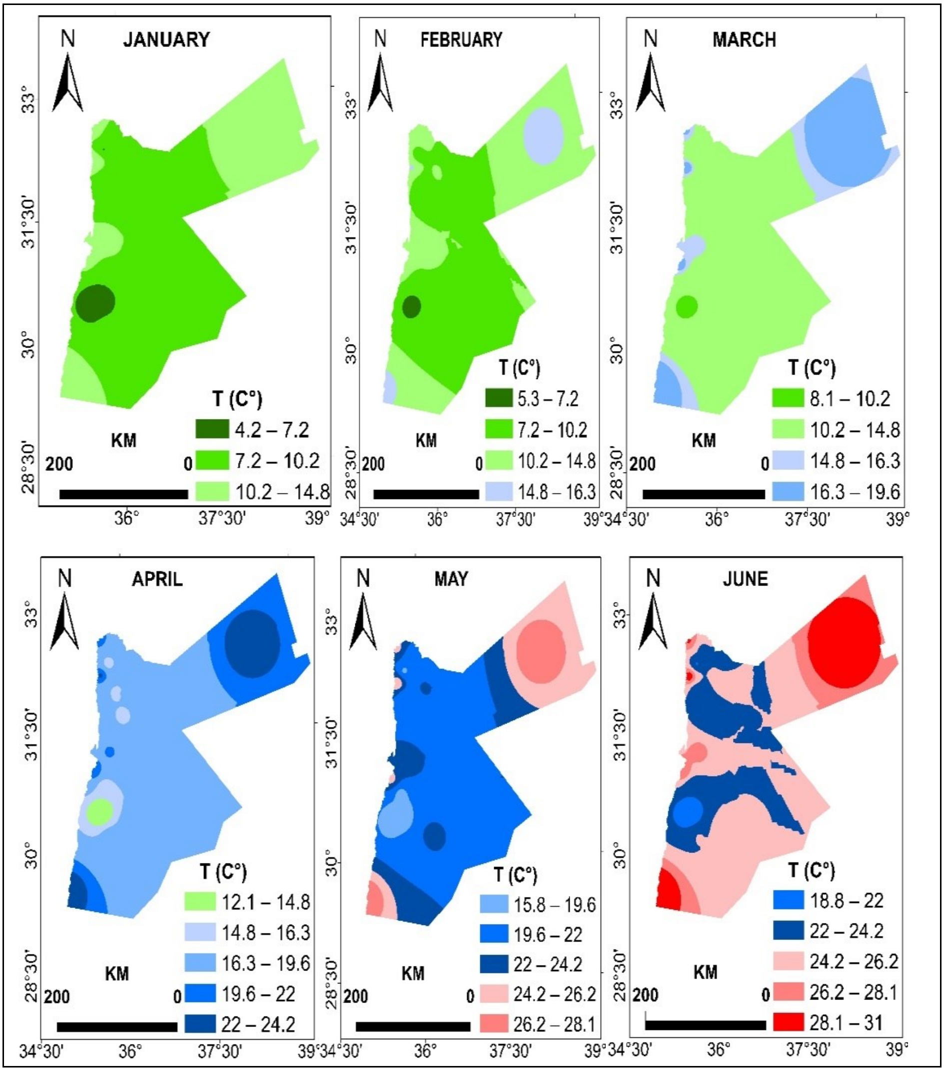
Procedures and techniques

The study relied on (GIS) to create thematic maps related to monthly and annual changes in rainfall, temperature, and Iar-DM, in addition to preparing the climatic classification maps necessary for the study. The Interpolation inverse distance weighted (IDW) method was also used as an ideal method in data prediction (Feng and Chen 2012: P209). in order to estimate the distribution of rainfall, temperature, and Iar-DM rates for the 19 climatic stations during the period 1970-2020.

Results and Discussion

Monthly distribution of rates: temperature, rainfall, and Iar-DM

Temperature is the main meteorological parameter that determines the climatic character of an area. In Jordan, the average temperature during (1970-2020) was approximately 18.73°C, where the hottest months ere July and August with climatic average temperatures of 27.25 °C and 27.2 °C, respectively. As for stations, the highest average temperature was recorded in Al-Ruwaished, northeastern Jordan, for the month of July, which was 32.6° C, and the lowest temperature recorded in Shobak in the southern highlands was 4.2° C in January. Figure 3.


JANUARY
N
T (C°)
4.2 – 7.2
7.2 – 10.2
10.2 – 14.8
KM
200
0
FEBRUARY
N
T (C°)
5.3 – 7.2
7.2 – 10.2
10.2 – 14.8
14.8 – 16.3
KM
200
0
MARCH
N
T (C°)
8.1 – 10.2
10.2 – 14.8
14.8 – 16.3
16.3 – 19.6
KM
200
0
APRIL
N
T (C°)
12.1 – 14.8
14.8 – 16.3
16.3 – 19.6
19.6 – 22
22 – 24.2
KM
200
0
MAY
N
T (C°)
15.8 – 19.6
19.6 – 22
22 – 24.2
24.2 – 26.2
26.2 – 28.1
KM
200
0
JUNE
N
T (C°)
18.8 – 22
22 – 24.2
24.2 – 26.2
26.2 – 28.1
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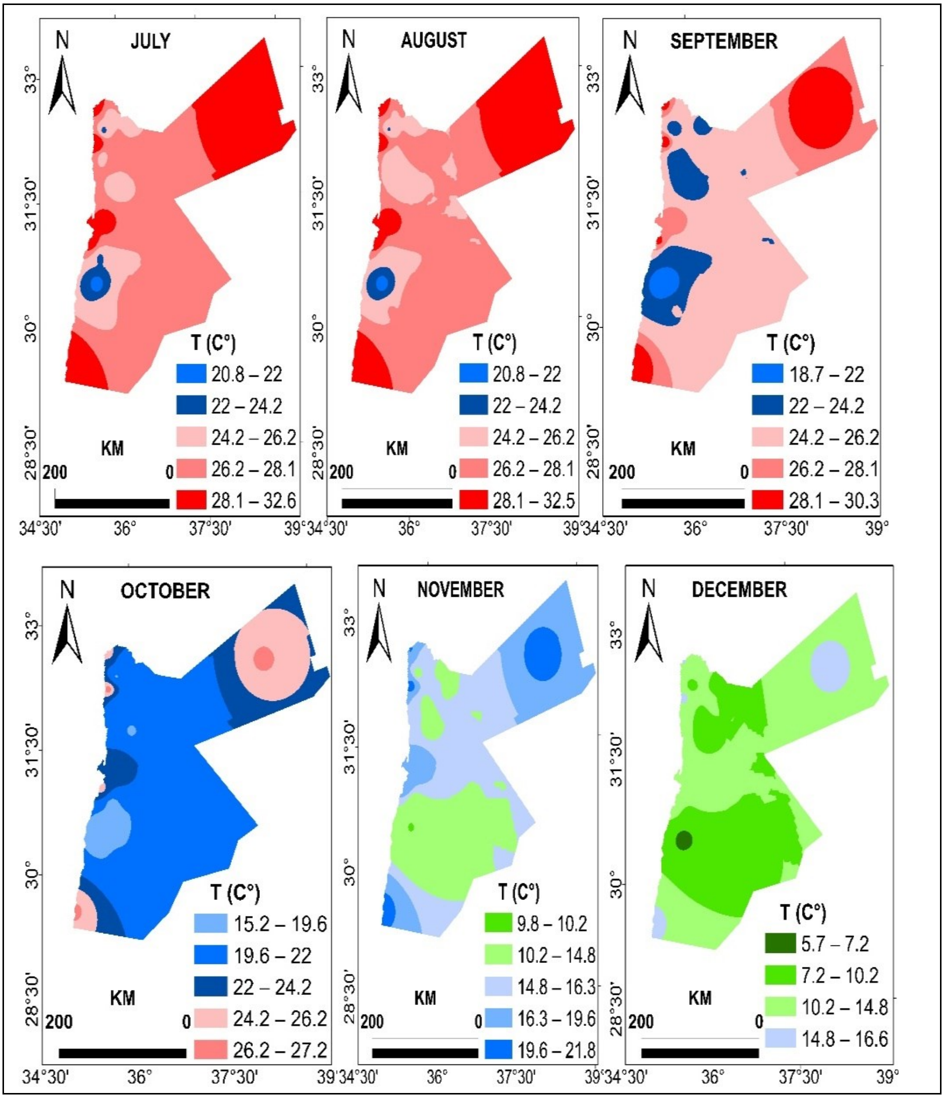
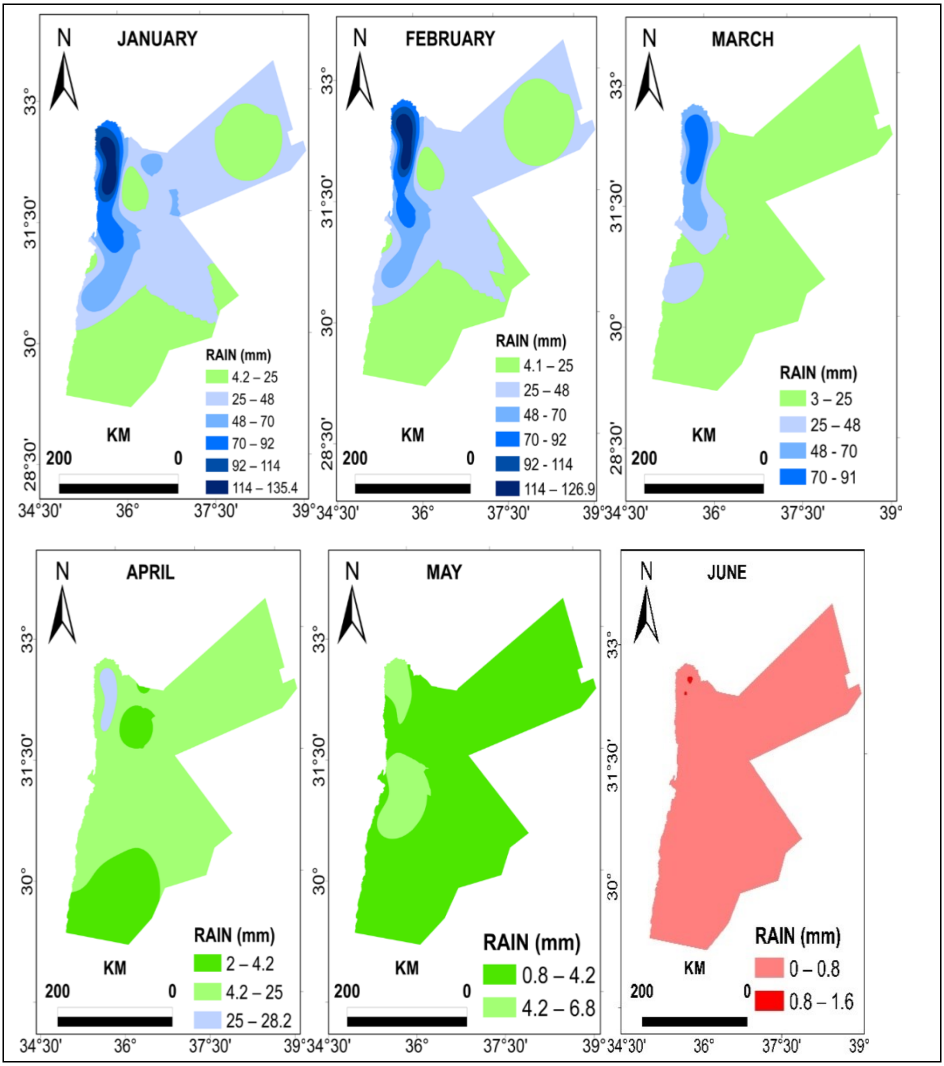


Figure 3 Monthly distribution of temperatures during (1970-2020)

Source: Author by Arc GIS10.7

Figure 4, below depicts the mean annual rainfall for 51 years (1970–2020). The average rainfall in Jordan (1970-2020) was 261.3 mm. In detail, the highest monthly rainfalls were recorded in January, February, and December, 57.4 mm, 52.5 mm, and 42.8 mm, respectively; however, the average rainfall does not include the months from June to September which was without rainfall. It is to be noted that no significant volume of rainfall was recorded in these months during the study period, as it was only less than 1 mm in a few stations. One can also observe the high variability of precipitation varying from 135.4 mm in Al- Salt in the center of Jordan in January, and 126.9 mm in Ras Munif, northern Jordan, in February to almost no rainfall in some deserted stations.



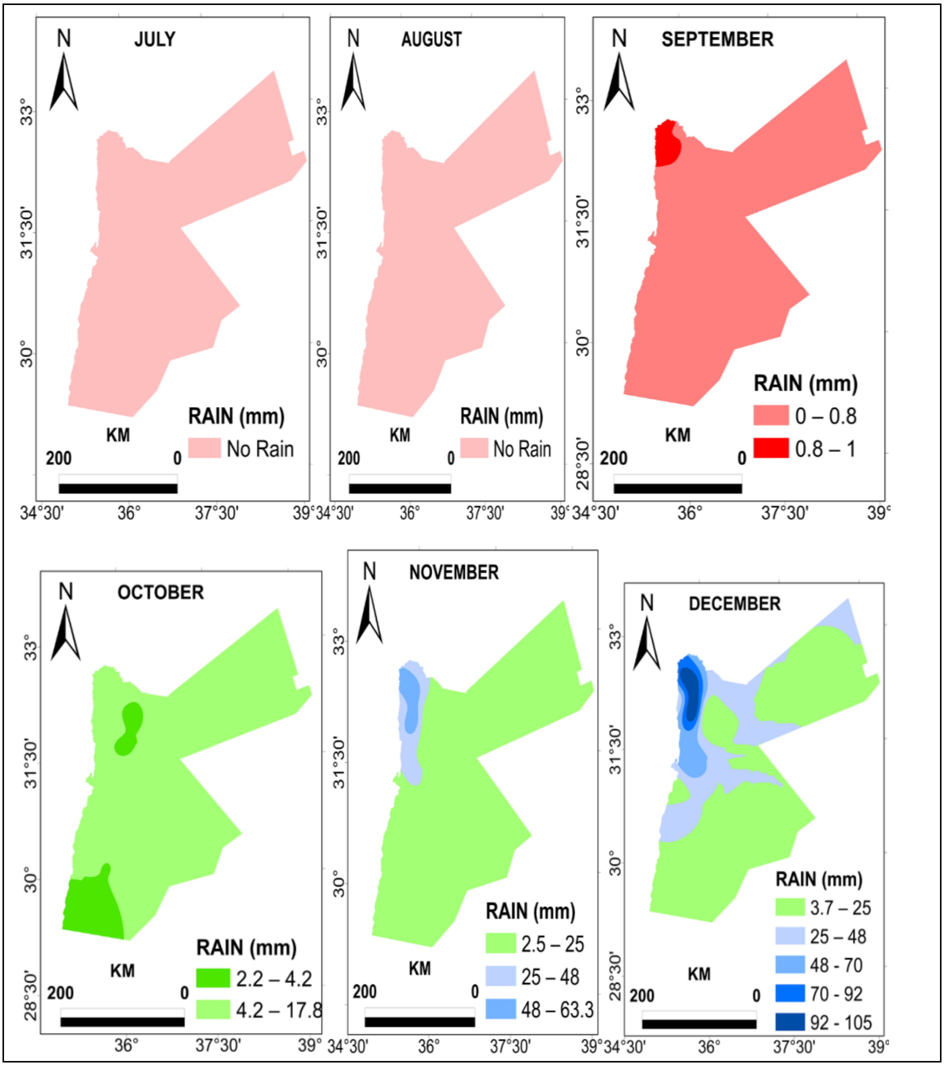
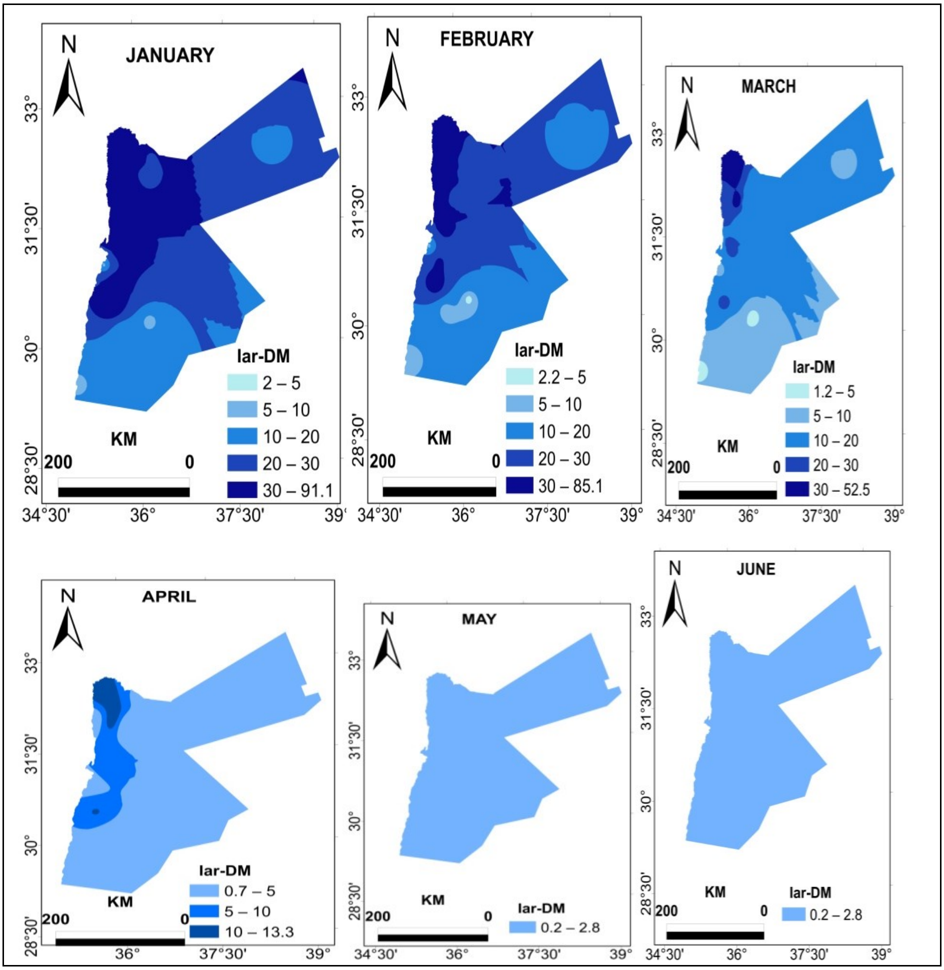


Figure 4 Monthly distribution of rainfall during (1970-2020)

Source: Author by Arc GIS10.7

Based on the above, there is a logical relation between monthly average changes in temperature and rainfall in Iar-DM values in Jordan, where the annual rate of Iar-DM was 9.4 for the period 1970-2020. This indicates that the climatic classification of Jordan based on Iar-DM is semi-arid. Iar-DM values show clear temporal and spatial variability. In fact, the values reached the highest monthly average in

January, February, and December, at 36.9,31.9, and 25, respectively. The lowest monthly rate for Iar-DM was in July and August at approximately 0.005, and then in June and September, at approximately 0.07. As for spatial variability, the highest monthly rate of Iar-DM was recorded in Ras Munif, northern Jordan, at about 91.1 in January, and zero in all Jordan for the four months from June to September. This corresponds to the Rainfall distribution. The wettest and least warm months from December to February recorded the highest Iar-DM values, while the warmest and least humid months from June to September recorded the lowest Iar-DM values for the period under study. Figure 5.



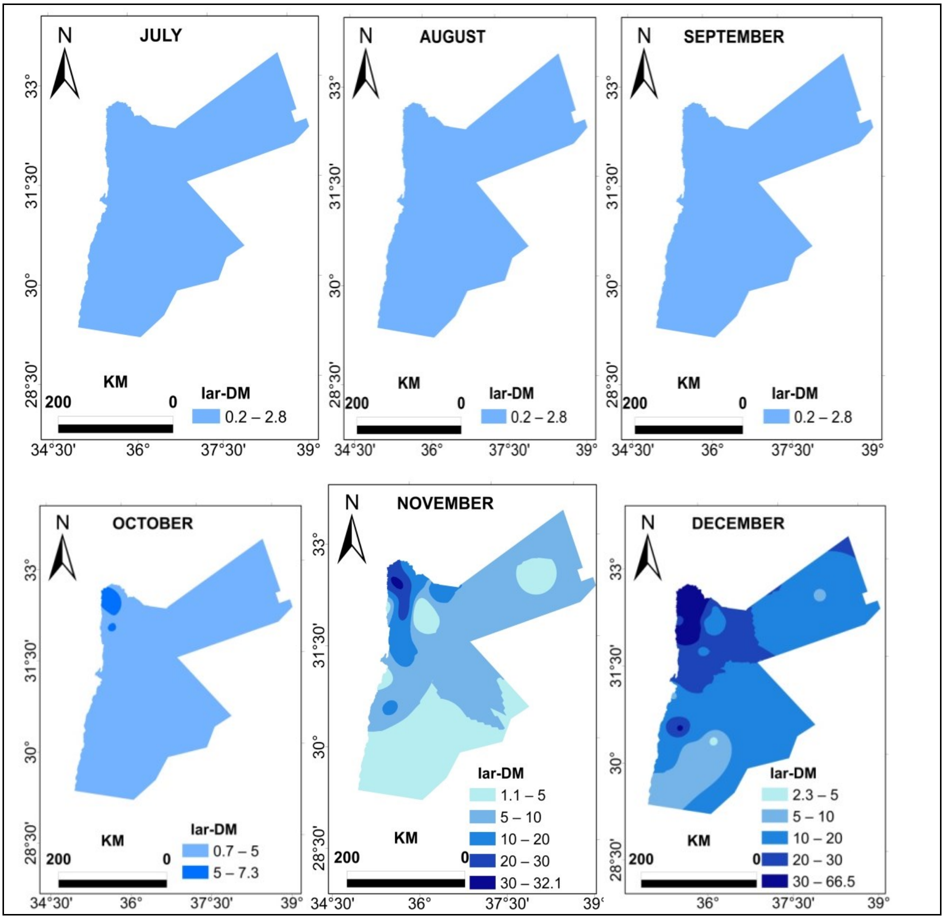


Figure 5 Monthly distribution of Iar-DM during (1970-2020)

Source: Author by Arc GIS10.7

3.2 General trend of rates: temperature, rainfall, and Iar-DM

The use simple regression coefficient analyzing the general trend of averages for temperature, rainfall, and Iar-DM during (1970-2020) in Jordan. Indicates a general trend toward an increase in the average temperature. Where (X) is 26 years, meaning that 1995 represents the base year in the process of future prediction of the temperature rate. Therefore, the average temperature in Jordan in 2030 is expected to be approximately 19.04°C, with an increase of 0.34°C, over the current rate of 18.7°C. Figure 6a. Simple regression also indicates a general trend towards a decrease in the rainfall rate for the same period, where (X) is 26 years as well, meaning that 1995 is the base year in the future forecasting process. So, the rainfall rate in Jordan is expected to drop to 242 mm by 2030, meaning a decrease of 19.3 mm from the current rate of 261.3 mm. Figure 6b. Hence, the increase in the general trend of temperature, relative to the decrease in the general trend in rainfall. It will inevitably lead to a general trend of decreasing Iar-DM. As a result, the value of Iar-DM for 2030 is expected to reach 8.46, decreasing by 0.94 from the current rate of 9.4. Figure 6c.

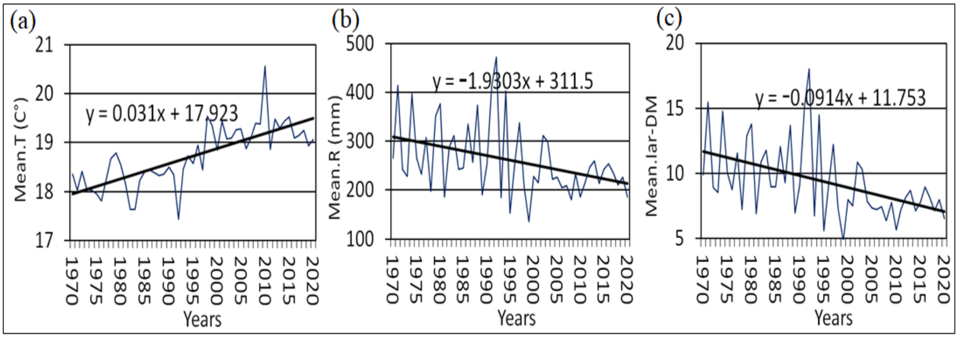


Figure 6 General trend of rates: (a)Temperature (C°), (b) Rainfall (mm),)c) Iar-DM

Source: Author by SPSS

By dividing the study period into four periods (1970-1982, 1983-1995, 1996-2007, 2008-2020), we find a variance in the general trend of temperature, rainfall, and Iar-DM in Jordan during 1970-2020. The first and second periods 1970-1982 and 1983-1995 are characterized by a decrease in the average temperature at18.2°C, and 18.3°C, with a decline of respectively, 2.8% and 2.3%, compared to the annual average temperature of 18.7°C. As for the general trend of rainfall and Iar-DM, these two periods witnessed a noticeable increase in the rates, especially in the second period (1983-1995), where the percentage of average rainfall rise is 12.7% compared to the annual average of 261.3 mm: the same is true for Iar-DM, with a 15.5%

increase compared to the annual Iar-DM average. As for the third and fourth periods (1996-2007 and 2008-2020), the general trend is towards an increase in average temperature and a significant decrease in rainfall rate and the Iar-DM rate, specifically in the fourth period, in which the rate of increase in average temperature was 3.3% with an increase of 0.6 ° C, compared to the annual average this was associate with a decrease of 14.9% and 19.9% in rainfall and Iar-DM rates, respectively. Table 3.

Table ٣ Changes in the Rates and Amount of Rainfall, Temperature, Iar-DM

for Different Periods During 1970-2020

Period	Variables	rate	Change to Mean (1970-2020) (%)	Change Amount to Mean (1970-2020)
(1970-2020)	T (C°)	18.7	-----	-----
	R (mm)	261.3	-----	-----
	Iar-DM	9.4	-----	-----
(1970-1982)	T (C°)	18.2	-2.8	-0.5 (C°)
	R (mm)	288.8	+10.6	+27.5(mm)
	Iar-DM	10.7	+14.6	+1.4
(1983-1995)	T (C°)	18.3	-2.3	-0.4(C°)
	R (mm)	294.6	+12.7	+33.3(mm)
	Iar-DM	10.8	+15.5	+1.5
(1996-2007)	T (C°)	19.1	+2	+0.4(C°)
	R (mm)	237.6	-9.1	-23.7(mm)
	Iar-DM	8.3	-11	-1
(2008-2020)	T (C°)	19.3	+3.3	+0.6(C°)
	R (mm)	222.4	-14.9	-38.9(mm)
	Iar-DM	7.5	-19.9	-1.9

Source: Author by SPSS

Undoubtedly, the extent of change in the general trend of temperature, precipitation, and Iar-DM is very clear. Relying on the equation of the simple regression line and its graphic representation confirms these facts. Figure 7a shows the variation in the temperature rates for the four periods. Figure 7b, shows the clear change in rainfall rates, and Figure 7c, illustrates the same for Iar-DM rates.

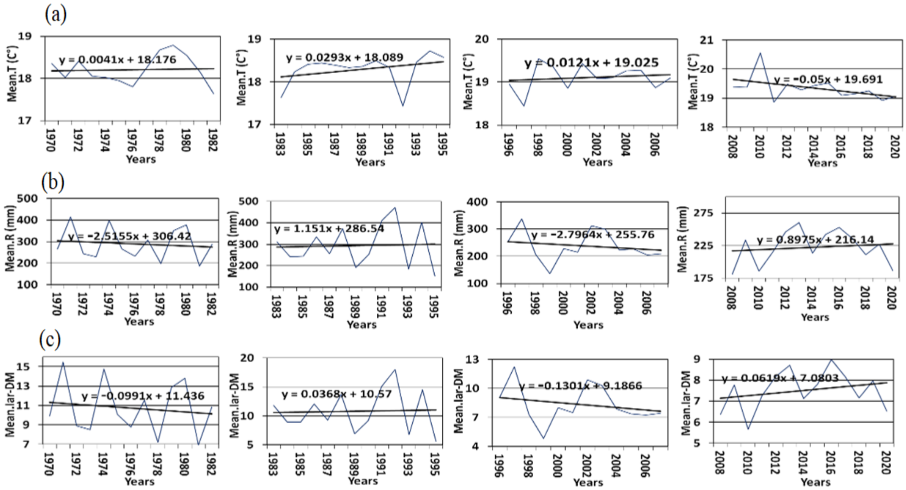
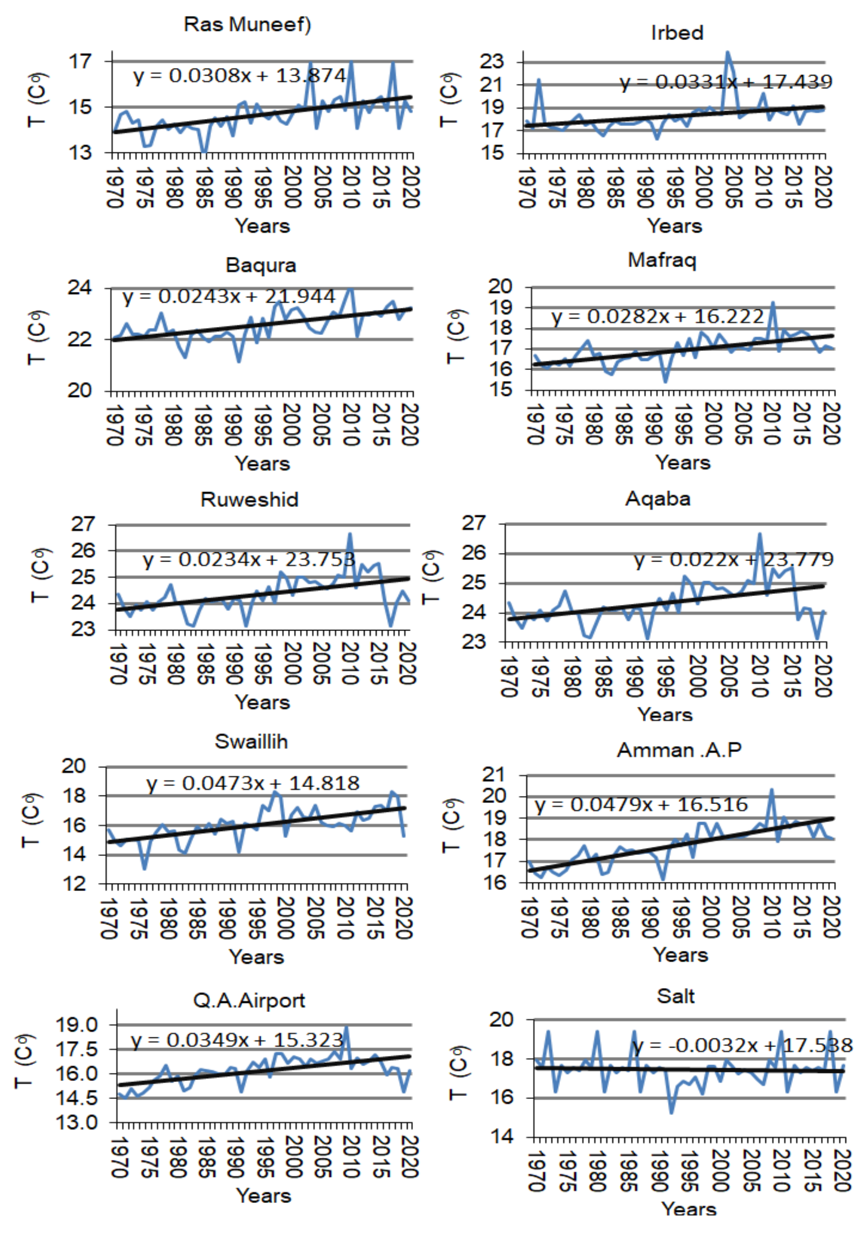


Figure 7 Changes in the general trend of rates: (a) Temperature (C°), (b) Rainfall (mm), (c) Iar-DM for different periods during 1970-2020

Source: Author by SPSS

If we consider that the change in the general trend is related to spatial variations, for the four periods. We find that the first and second periods (1970-1982 and 1983-1995) witnessed a decrease in the average temperature and an increase in the average temperature during the other two periods (1996-2007 and 2008-2020) in most of the stations covering the study area. To illustrate, the average temperature in Ras Munif in northern Jordan, which represents the semi-humid climate, was 14.7° C for the whole period 1970-2020, distributed over the four study periods at, respectively (14.2° C, 14.4° C, 15° C, 15° C) with an increase which reached 0.34°C for the two periods 1996-2020, compared to the general average. As for Al-Ruwaished in Eastern Jordan, which represents a very arid region, the third period 1996-2007, witnessed an increase of 0.36°C, and the fourth an increase of 0.42°C, compared to the 24.4°C general average temperature for this station. The situation is not much different in the central regions of Jordan. For instance, at Queen Alia Airport, the average temperature increase in the fourth period 2008-2020, was about 0.93°C compared to the general average of 16.42°C. As for Southern Jordan, the increase during the fourth period 2008-2020 was about 0.76°C in Ma'an, compared to the general average temperature of about 17.7°C. Figure 8.


Ras Muneef)
y = 0.0308x + 13.874
T (C°)
13
15
17
Years
Irbed
y = 0.0331x + 17.439
T (C°)
15
17
19
21
23
Years
Baqura
y = 0.0243x + 21.944
T (C°)
20
22
24
Years
Mafraq
y = 0.0282x + 16.222
T (C°)
15
16
17
18
19
20
Years
Ruweshid
y = 0.0234x + 23.753
T (C°)
23
24
25
26
27
Years
Aqaba
y = 0.022x + 23.779
T (C°)
23
24
25
26
27
Years
Swaillih
y = 0.0473x + 14.818
T (C°)
12
14
16
18
20
Years
Amman .A.P
y = 0.0479x + 16.516
T (C°)
16
17
18
19
20
21
Years
Q.A.Airport
y = 0.0349x + 15.323
T (C°)
13.0
14.5
16.0
17.5
19.0
Years
Salt
y = -0.0032x + 17.538
T (C°)
14
16
18
20
Years
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

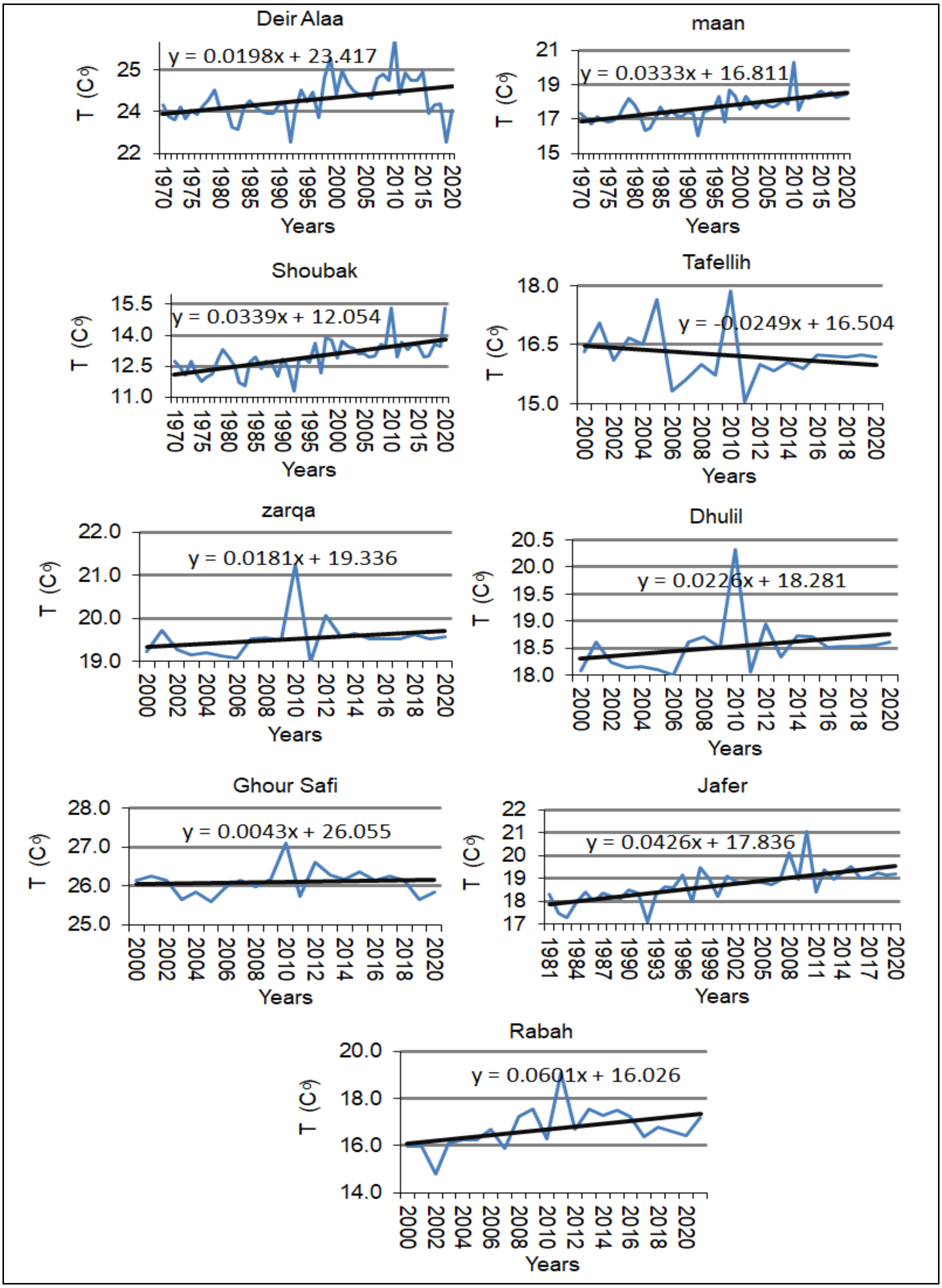
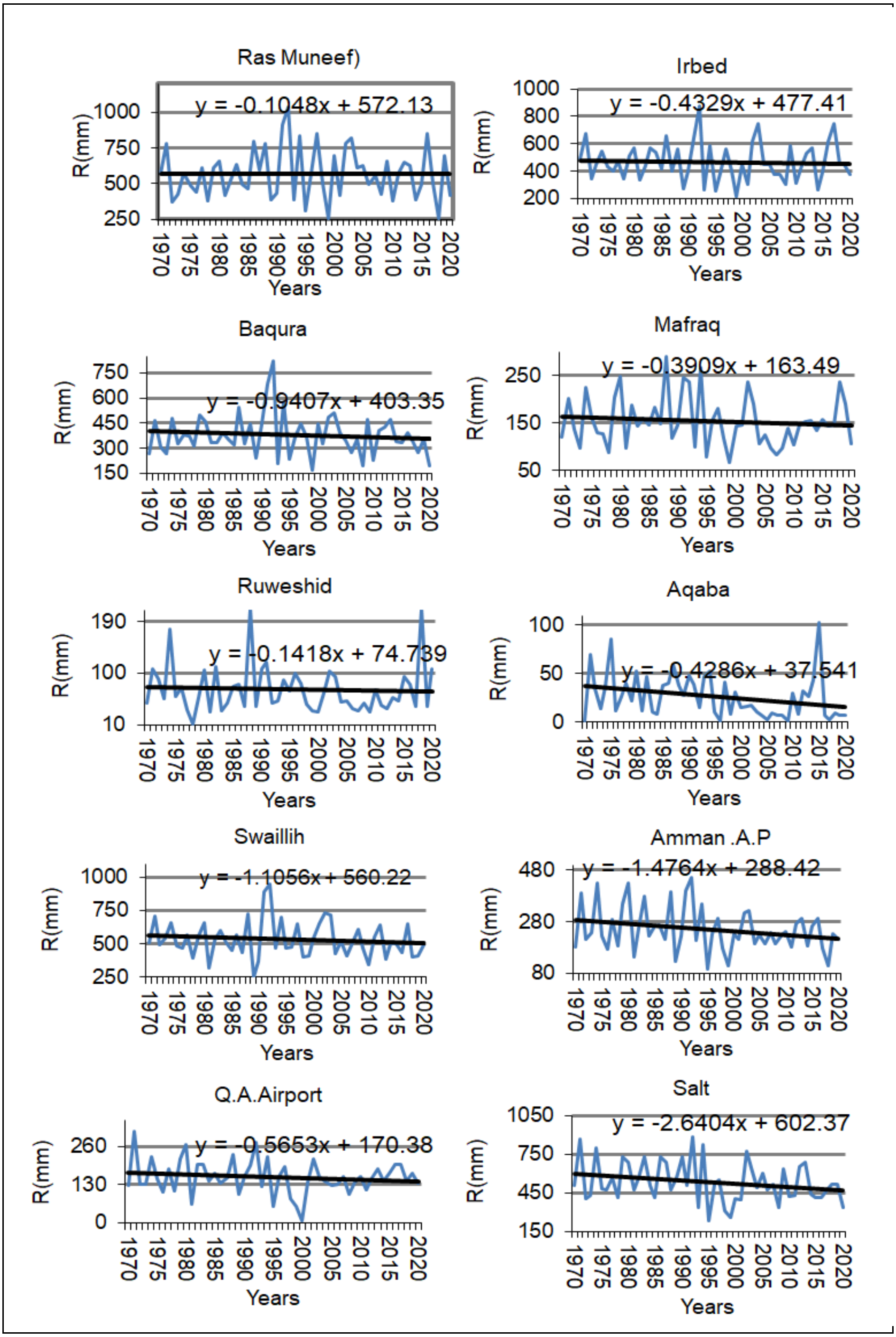


Figure 8 Changes in the General Trend of Temperature Rates Related to Climatic Stations for Different Periods During 1970-2020

Source: Author by SPSS

By analyzing the change in the general trend of rainfall for the climatic stations during the four study periods, we find that the first and second periods (1970-1982 and 1983-1995) witnessed an increase in rainfall, which was more clear in the second period. Conversely, the third and fourth periods (1996-2007, 2008-2020) show a decrease in the rainfall rate, and more accurately, in the fourth period, in most of the stations covering the study area. In RasMunif in northern Jordan, the average rainfall amounted to 570 mm for the whole period 1970-2020, and the highest increase was recorded during the second period, with an increase of 9% oer the annual average, as the average rainfall for this period amounted to 622 mm: meanwhile, the fourth period witnessed a decrease of 5% from the annual average. In Mafraq in eastern Jordan, there was a decrease of 13% and 2% during the third and fourth periods, respectively, from the annual average of this station. The same applies to the Salt station in central Jordan, which witnessed a decrease of 9.4% and 7.4%, respectively, compared to the annual rate. In the south of Jordan, Shoubak witnessed a significant decrease in the rainfall rate for the third and fourth periods of 18% and 19.6%, respectively, compared to the annual rate. Figure 9.


Ras Muneef)
y = -0.1048x + 572.13
R(mm)
1000
750
500
250
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Years
Irbed
y = -0.4329x + 477.41
R(mm)
1000
800
600
400
200
Years
Baqura
y = -0.9407x + 403.35
R(mm)
750
600
450
300
150
Years
Mafraq
y = -0.3909x + 163.49
R(mm)
250
150
50
Years
Ruweshid
y = -0.1418x + 74.739
R(mm)
190
100
10
Years
Aqaba
y = -0.4286x + 37.541
R(mm)
100
50
0
Years
Swaillih
y = -1.1056x + 560.22
R(mm)
1000
750
500
250
Years
Amman .A.P
y = -1.4764x + 288.42
R(mm)
480
280
80
Years
Q.A.Airport
y = -0.5653x + 170.38
R(mm)
260
130
0
Years
Salt
y = -2.6404x + 602.37
R(mm)
1050
750
450
150
Years

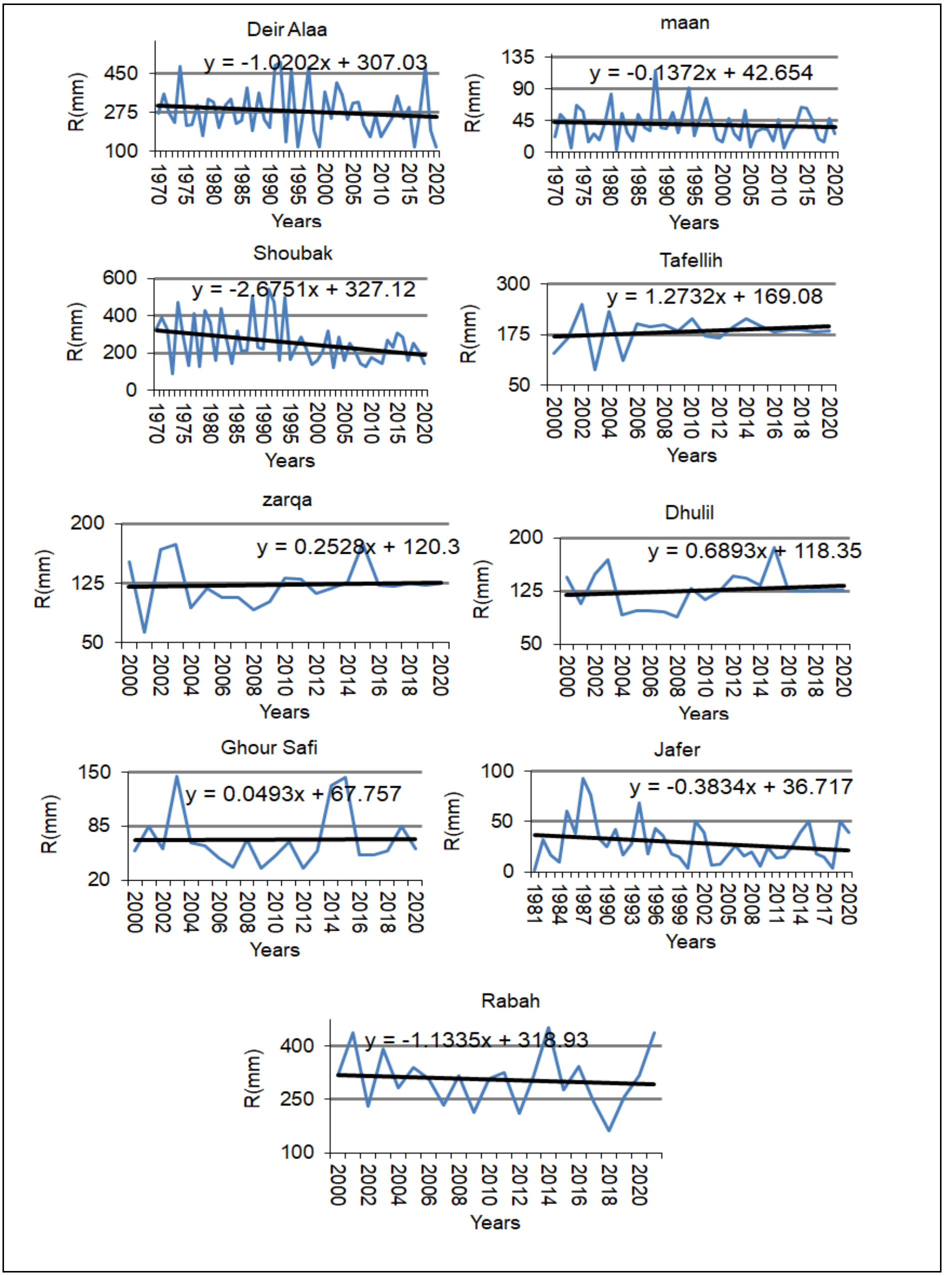
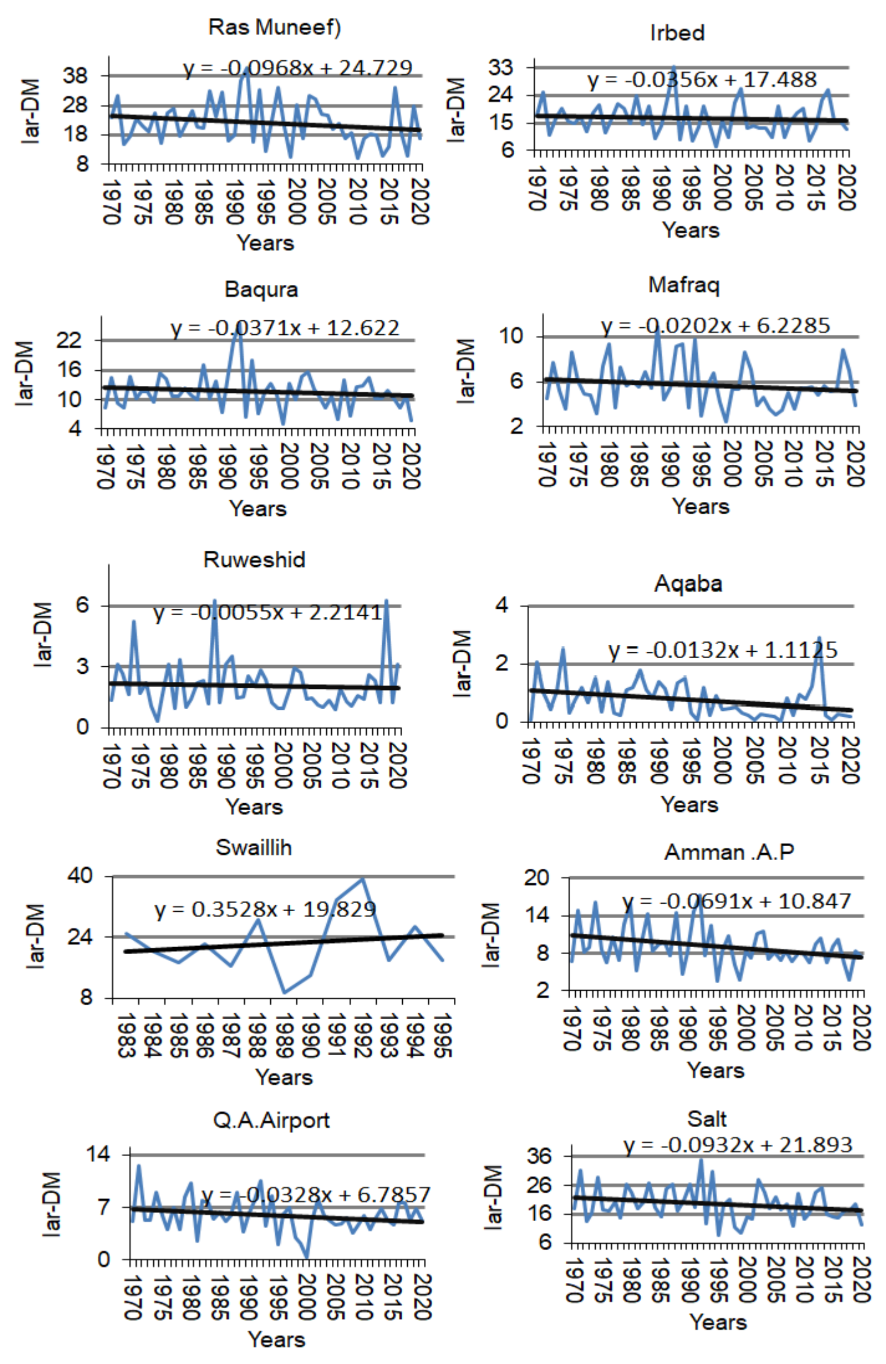


Figure 9 Changes in the General Trend of Rainfall Rates Related to Climatic Stations for Different Periods During 1970-2020

Source: Author by SPSS

The general trend of the annual Iar-DM values reflects the reality of spatiotemporal changes. The highest Iar-DM rate for the study period was during the second period 1983-1996, and the lowest was during the fourth period 2008-2020 in most of the stations in Jordan. In specific, the Iar-DM rates in Ras Munif, Baqoura, Sweileh, Deir Alla and Ma'an stations during the period 1983-1996 reached 25.4, 13.4, 22.3, 9 and 1.7, with an increase of 15%, 15.5%, 9.9%, 11.1% and 21.4%, respectively. As for the Iar-DM rates for these stations during the period 2008-2020, they amounted to 17.9, 10.7, 17.6, 7.2, and 1.2, with a reduction of 19%, 8%, 13.3%, 11.1%, and 14. 3%, respectively, compared to the general Iar-DM rates for these stations during the whole period 1970-2020. Figure 10.


Ras Muneef)
y = -0.0968x + 24.729
lar-DM
38
28
18
8
1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
Years
Irbed
y = -0.0356x + 17.488
lar-DM
33
24
15
6
1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
Years
Baqura
y = -0.0371x + 12.622
lar-DM
22
16
10
4
1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
Years
Mafraq
y = -0.0202x + 6.2285
lar-DM
10
6
2
1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
Years
Ruweshid
y = -0.0055x + 2.2141
lar-DM
6
3
0
1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
Years
Aqaba
y = -0.0132x + 1.1125
lar-DM
4
2
0
1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
Years
Swaillih
y = 0.3528x + 19.829
lar-DM
40
24
8
1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995
Years
Amman .A.P
y = -0.0691x + 10.847
lar-DM
20
14
8
2
1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
Years
Q.A.Airport
y = -0.0328x + 6.7857
lar-DM
14
7
0
1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
Years
Salt
y = -0.0932x + 21.893
lar-DM
36
26
16
6
1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
Years

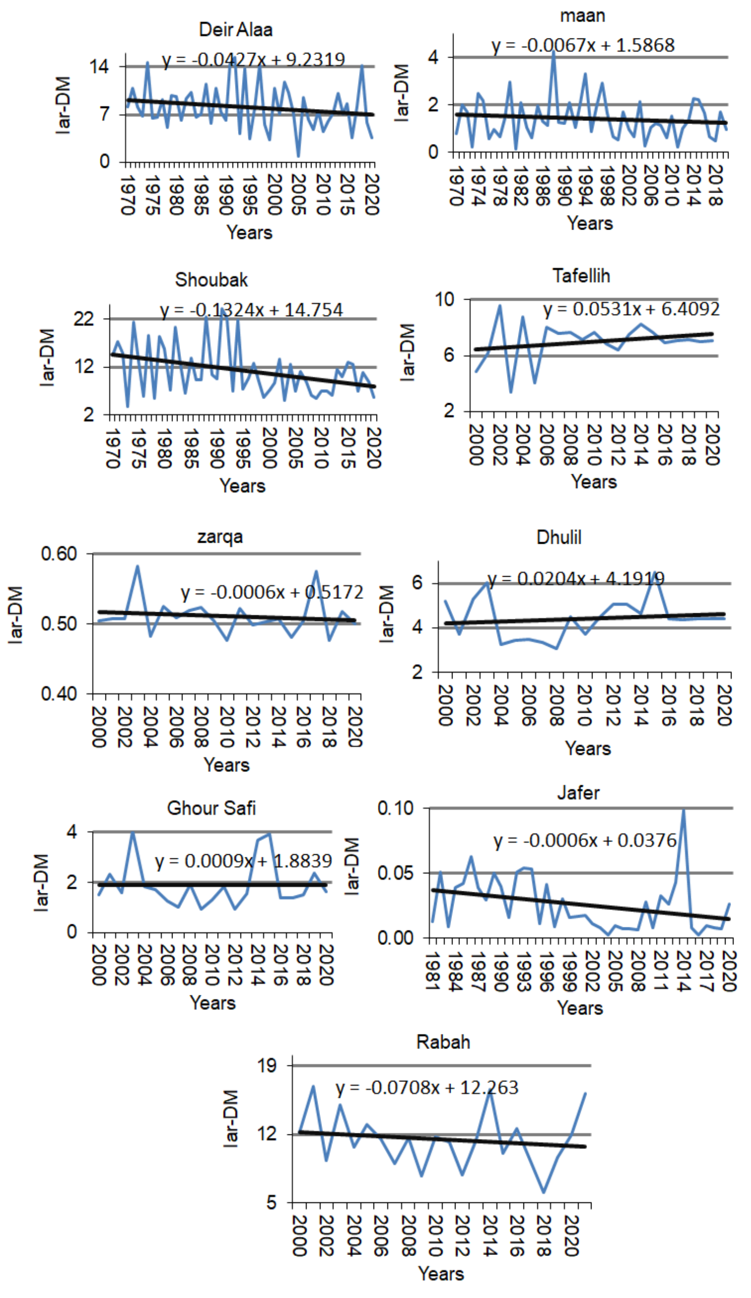
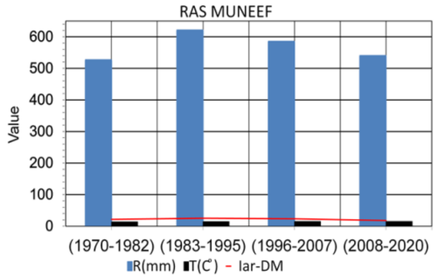


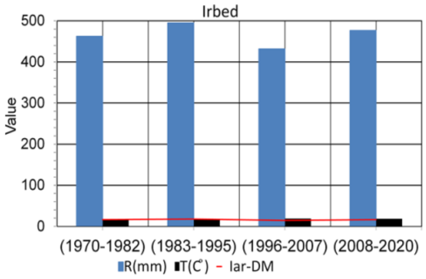
Figure 10 Changes in the general trend of Iar-DM rates related to climatic stations for different periods during 1970-2020 **Source:** Author by SPSS

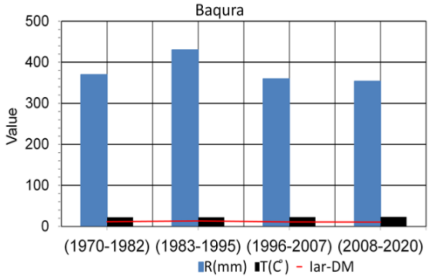
Effect of the general trend of temperature and rainfall on the general trend Iar-DM for the period 1970-2020

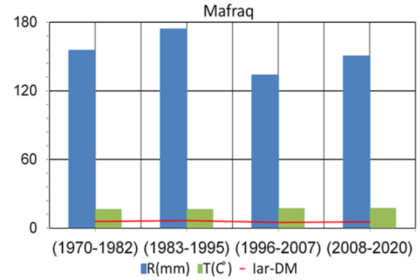
The analysis of the meteorological parameters shows a warming trend, decreasing precipitation, and a strong, statistically significant reduction in Iar-DM according to climatic indices. Notably, a more realistic description of the climate was achieved by applying the De Martonne index, which classifies the climate of Jordan as semi-arid. There is a strong and statistically significant reduction of precipitation in both temporal and spatial terms. The aforementioned indices indicated that possible turning points could be identified during the study period.

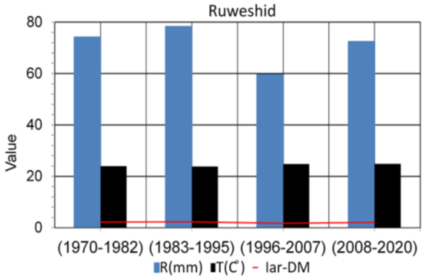
Thus, there is a symmetry between the increase in temperature rates, decrease in rainfall rates, and increase in Iar-DM rate during the different research periods. The time periods in which the average temperature increased, and the temperature decreased were characterized by an increase in the rate of Iar-DM. This means that there is a negative relationship between the average temperature and the rate of Iar-DM, and a positive relationship between the rate of rain and the rate of Iar-DM. On the one hand, the highest average rainfall in Jordan was in 1992, when it was 472.5 mm. As a result, this year was one of the wettest years during the study period and it also recorded the highest Iar-DM rate of about 18.1, and the lowest average temperature of about 17.43°C. On the other hand, the lowest average rainfall was in 1999, with 135.8 mm, and the lowest Iar-DM average was 4.81. As for the years in terms of highest temperature, it was 2010, when the average temperature was about 20.56 ° C. Figure 11. This result could represent a strong indication of the future climate of the area.

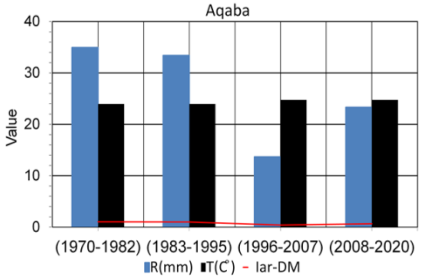

RAS MUNEEF
Value
0
100
200
300
400
500
600
(1970-1982) (1983-1995) (1996-2007) (2008-2020)
R(mm) T(C°) Iar-DM

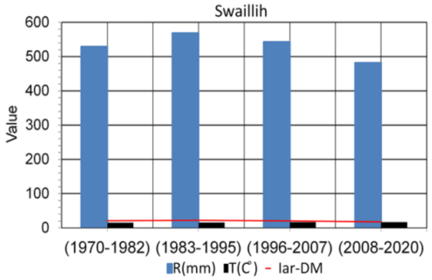

Irbed
Value
0
100
200
300
400
500
(1970-1982) (1983-1995) (1996-2007) (2008-2020)
R(mm) T(C°) Iar-DM

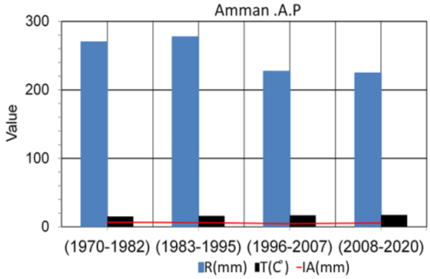

Baqura
Value
0
100
200
300
400
500
(1970-1982) (1983-1995) (1996-2007) (2008-2020)
R(mm) T(C°) Iar-DM

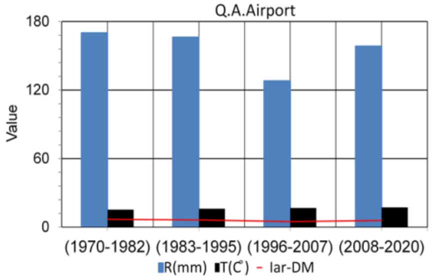

Mafraq
0
60
120
180
(1970-1982) (1983-1995) (1996-2007) (2008-2020)
R(mm) T(C°) Iar-DM

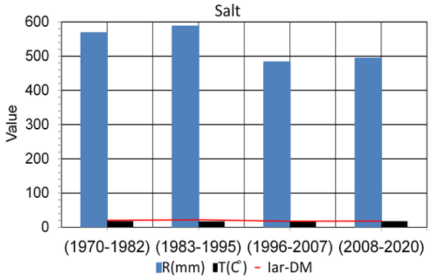

Ruweshid
Value
0
20
40
60
80
(1970-1982) (1983-1995) (1996-2007) (2008-2020)
R(mm) T(C°) Iar-DM


Aqaba
Value
0
10
20
30
40
(1970-1982) (1983-1995) (1996-2007) (2008-2020)
R(mm) T(C°) Iar-DM


Swaillih
Value
0
100
200
300
400
500
600
(1970-1982) (1983-1995) (1996-2007) (2008-2020)
R(mm) T(C°) Iar-DM


Amman .A.P
Value
0
100
200
300
(1970-1982) (1983-1995) (1996-2007) (2008-2020)
R(mm) T(C°) IA(mm)


Q.A.Airport
Value
0
60
120
180
(1970-1982) (1983-1995) (1996-2007) (2008-2020)
R(mm) T(C°) Iar-DM


Salt
Value
0
100
200
300
400
500
600
(1970-1982) (1983-1995) (1996-2007) (2008-2020)
R(mm) T(C°) Iar-DM

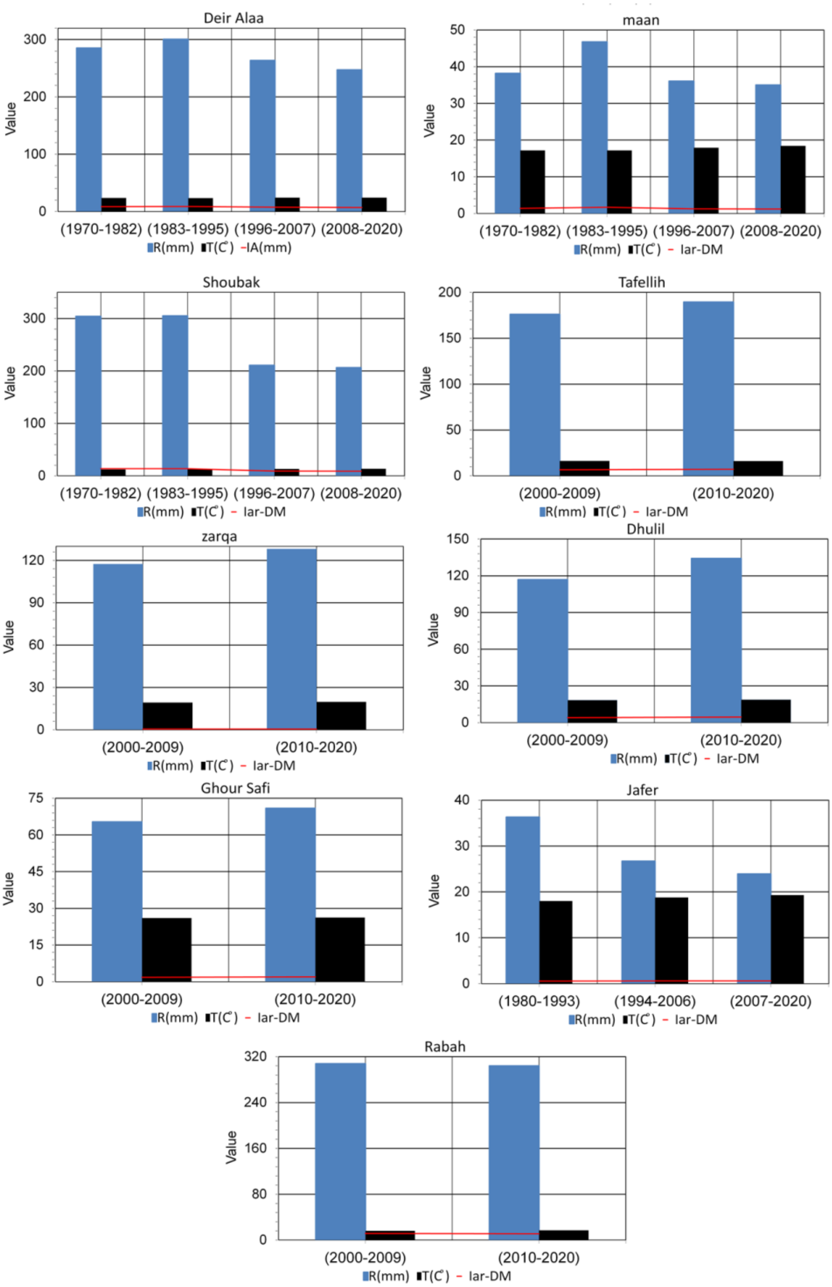


Figure 11 The effect of the general trend of temperature and rainfall on the general trend Iar-DM related to climate stations and during different periods during 1970-2020 **Source:** Author by SPSS

Climate change and Iar-DM in Jordan

Distribution and frequency of annual rates and their deviations from their general rates for temperature, rainfall and Iar-DM

The use of the aridity index is extended to obtain an estimate of the change in drought conditions, due to a change in climate, manifested in data related to changes in annual rainfall and temperature. A change in climate may cause either or both decreased rainfall and an increase in temperature. Annual temperature and rainfall data, used to estimate Iar-DM، and the interannual variations in rates of temperature and rainfall, may also be related to climatic regimes in a broad sense. In a more general sense, global climate change, will affect Iar-DM. Subsequently، the effect of both rain rate and temperature on Iar-DM is related to the recurrence of periods of humidity and drought.

The number of years in which the annual temperature rate exceeded the general average was 23 years for the period 1996-2020. Figure 12a. Meanwhile, the number of years in which the rainfall rate exceeded the general average during the four study periods (1970-1982, 1983-1995, 1996-2007 and 2008-2020) was eight years, six years, three years, and zero years, respectively. Figure 12b. What distinguishes the period 1983-1995 is that the amount of rainfall during the wet years for this period was very high, and this affected the height of Iar-DM as well. Figure 12c.

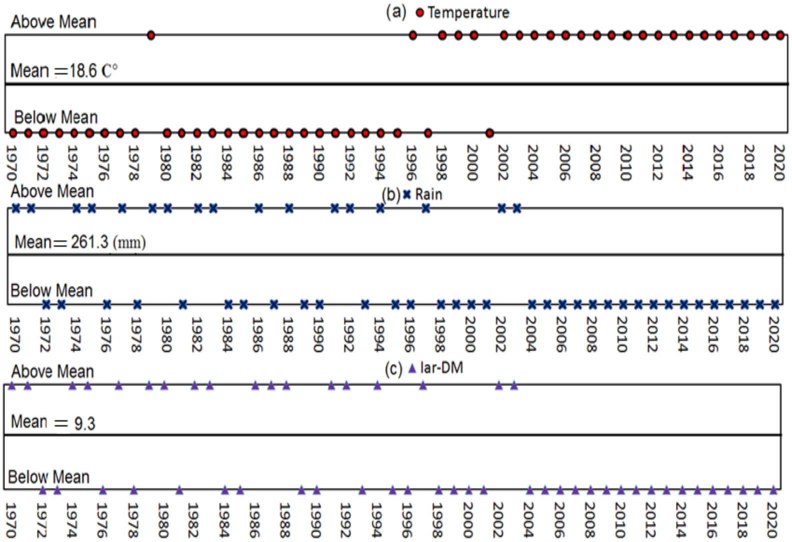


Figure 12 Distribution of the number of years according to annual rates compared to general rates a: temperature, b: rainfall, c: Iar-DM **Source:** Author by SPSS

The deviation of the rates for each period of time compared to its annual average indicates a general trend of decreasing annual rainfall, and a general trend of an increase in annual temperature rates, which will exacerbate drought years. The percentage of wet years, i.e. those in which the amount of rainfall exceeded the annual average for the period 1970-1982 was 62%, and the dry years in which the average temperature exceeded the annual average for the same period was 8%. As for the last period 2008-2020, the percentage of dry years in which rainfall was less than its annual rate was 100% in addition, the dry years in which the average temperature exceeded the annual average for the same period was also 100%. This actually exacerbated the occurence of drought and increased the economic and social stress of the countries affected by this. Table 4.

Table 4 Distribution of the frequency of numbers and the ratio of negative and positive deviations of the rates: temperature, rainfall, Iar-

DM during the period 1970-2020

variable	Time Period	Positive Deviation	The Ratio (%)	Negative Deviation	The Ratio (%)
T (C°)	1970-1982	1	8	12	92
	1983-1995	0	0	13	100
	1996-2007	10	77	2	15
	2007-2020	13	100	0	0
R (mm)	1970-1982	8	62	5	38
	1983-1995	6	46	7	54
	١٩٩٦-٢٠٠٧	3	23	9	69
	2007-2020	0	0	13	100
Iar-DM	1970-1982	8	62	5	38
	1983-1995	7	54	6	46
	1996-2007	3	23	9	69
	2007-2020	0	0	13	100

Source: Author by SPSS

Pearson correlation coefficient between rates: temperature, rainfall,and Iar-DM

Pearson's Correlation coefficients analysis between the annual rainfall rate for Jordan for the period 1970-2020 and the annual Iar-DM rate for the same period indicates an almost perfect positive correlation between them, showing an increase or decrease for most weather stations with a statistical significance at the level of 1%, with the exception of Al-Jafr and Zarqa stations, which indicate a positive but weak correlation. Also, the presence of a negative correlation between the annual mean of temperature with years on the one hand and with Iar-DM, on the other hand, is statistically significant at confidence levels of 1% and 5% for most stations for the same period. The most serious matter for climate change is the moderate to strong positive statistical significance at 1% between years and average annual temperature, and the negative interannual correlation and rainfall rates for most stations for the period 1970-2020. Finally, the correlation between the annual rainfall rate and the annual Iar-DM average on the one hand, and the annual average temperature, on the other, was negative for most of the stations in the study period. Table

5.**Table 5** Pearson's Correlation Coefficients Between Rates: Temperature, Rainfall, and Iar-DM During the Period 1970-2020

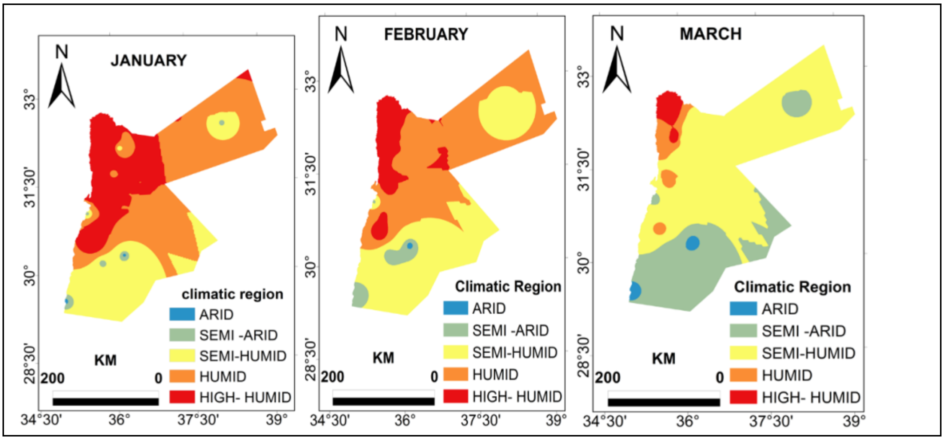
Station	R (mm) & Iar-DM	T (C°) & Iar-DM	R (mm) & T (C°)	Station	R (mm) & Iar-DM	T (C°) & Iar-DM	R (mm) & T (C°)
Ras Muneef	+0.944**	+0.03	+0.2	Deir Alaa	+0.931**	-٠.28*	-0.2
Irbed	+0.992**	-0.4	-0.2	maan	+0.998**	-0.1	-0.01
Baqura	+0.998**	-0.4	-٠.34*	Shoubak	+0.998**	-٠.46**	-٠.41**
Mafraq	+0.998**	-0.3	-0.3	Jafer	+0.33*	-0.3	-0.1
Ruweshid	+0.999**	-0.2	-0.2	Tafellih	+0.993**	-0.4	-0.3
Aqaba	+0.998**	-0.0١	+0.02	zarqa	+0.1	-0.4	-0.1
Swaillih	+0.980**	-0.4	-0.2	Dhulil	+0.997**	-0.1	-0.02
Amman .A.P	+0.996**	-0.4	-٠.3٥*	Ghour Safi	+0.999**	-0.3	-0.2
Q.A.Airport	+0.991**	-٠.40**	-٠.32*	Rabah	+0.992**	+0.01	+0.1
Salt	+0.993**	-0.2	-0.1	(Correlation is significant at the 0.01 level (2-tailed** .) (Correlation is significant at the 0.05 level (2-tailed* .)			

Source: Author by SPSS

Based on the foregoing, Jordan is clearly affected by the results of climate change, and most global climate models (GCMs) and various researches confirm the findings of this study. Indeed, most global climate models predict an increase in temperatures and a decrease in annual rainfall rates in the Middle Eastern region (Black et al. 2011: P51; IPCC 2007). Therefore, the results of changes in surface runoff reflect the results of precipitation systems, as most climate simulation models indicate an increase in the coefficient of variation for annual rainfall, which can be predicted by a decrease in the number of rainy days (Smiatek et al. 2014: P1520; Lelieveld et al. 2012: P667). The simulation results using (High-Resolution Regional Climate Model) also indicate by comparing rainfall for the periods (2040-2069) and (2070-2099) with the period (1961 - 1991) a 10% decrease in the eastern parts of the Mediterranean Sea and the Middle East, which will result in a decrease in runoff, environmental, economic, and social consequences, and a decrease in the per capita share of water, especially when this is coupled with the dynamic population increase in a country like Jordan (Chenowth et al. 2011: P1-6). Moreover, the results of The Hadley Model and The MPI Model application indicate an increase in temperature and a decrease in monthly runoff in the Zarqa River Basin, except for the month of April, in which it did not change, and May, when the runoff increased. Clearly, most of the indicators for these two models indicate that the surface runoff rate will decrease by approximately 12%, according to The Hadley Model, and by 40%, according to The MPI Model. The highest change in surface runoff appears when temperatures rise by (+4° C), as this will be accompanied by a change of (-20%) in the amount of rain. These results are consistent with other findings of other researchers in the Middle East related to the scenarios of an increase in temperature (+2°C - +4°C) and a decrease in rainfall by (10%) and the accompanying decrease in the rate of surface runoff by (40-60%). Yet in the case of a temperature increase of (+2°C - +4°C), and a (10%) increase in the rainfall rate, the surface runoff rate will decrease by (10-30%), the surface runoff rate will increase by approximately (20%) in case the temperature increased by (+2° C) the rainfall increased by (20%), (Abdulla and Al-Omari 2008: P43). Furthermore, Al-Sababhah (2013) concluded that proves the results of climate models related to climate change: he found that there was a (+3.2%) change in annual rainfall in the 1980s compared to the 1970s, accompanied by a change of (+3.60%) in the rate of surface runoff for the same period of comparison, while the decade of the nineties witnessed a change of (-2.6%) in the rate of rain and (-7%) in the rate of surface runoff compared to the decade of the eighties in the Jafr Basin in southern Jordan, which constitutes approximately 14% of the area of Jordan.

٣,٥ Classification of climatic regions in Jordan based on Iar-DM

Iar-DM is one of the important methods of climatic classification, and this process is mainly related to the change in monthly or yearly temperature and rainfall rates. Location and climatic characteristics MAKE Jordan a rather dry a with extreme, fluctuations; and monthly and annual variation in rainfall and temperature rates, and consequently, variation in the monthly and annual Iar-DM rates. Furthermore, the maps of climatic classifications based on the Iar-DM comparison show that the highest percentage of humid and highly-humid climate zones were in January, February, and March, at respectively 75%, 54%, and 23%, of Jordan’s area of 89,025 km². As for the arid climate zone, it dominated all months for the period from May to October. The arid and semi-arid climate zones; constituted 90% of Jordan’s area for the month of November and the humid and highly-humid ranges constituted 20%; the semi-humid areas made up 67%, and the arid and semi-arid zones about 57% of Jordan’s area during the month of December. Figure 13.



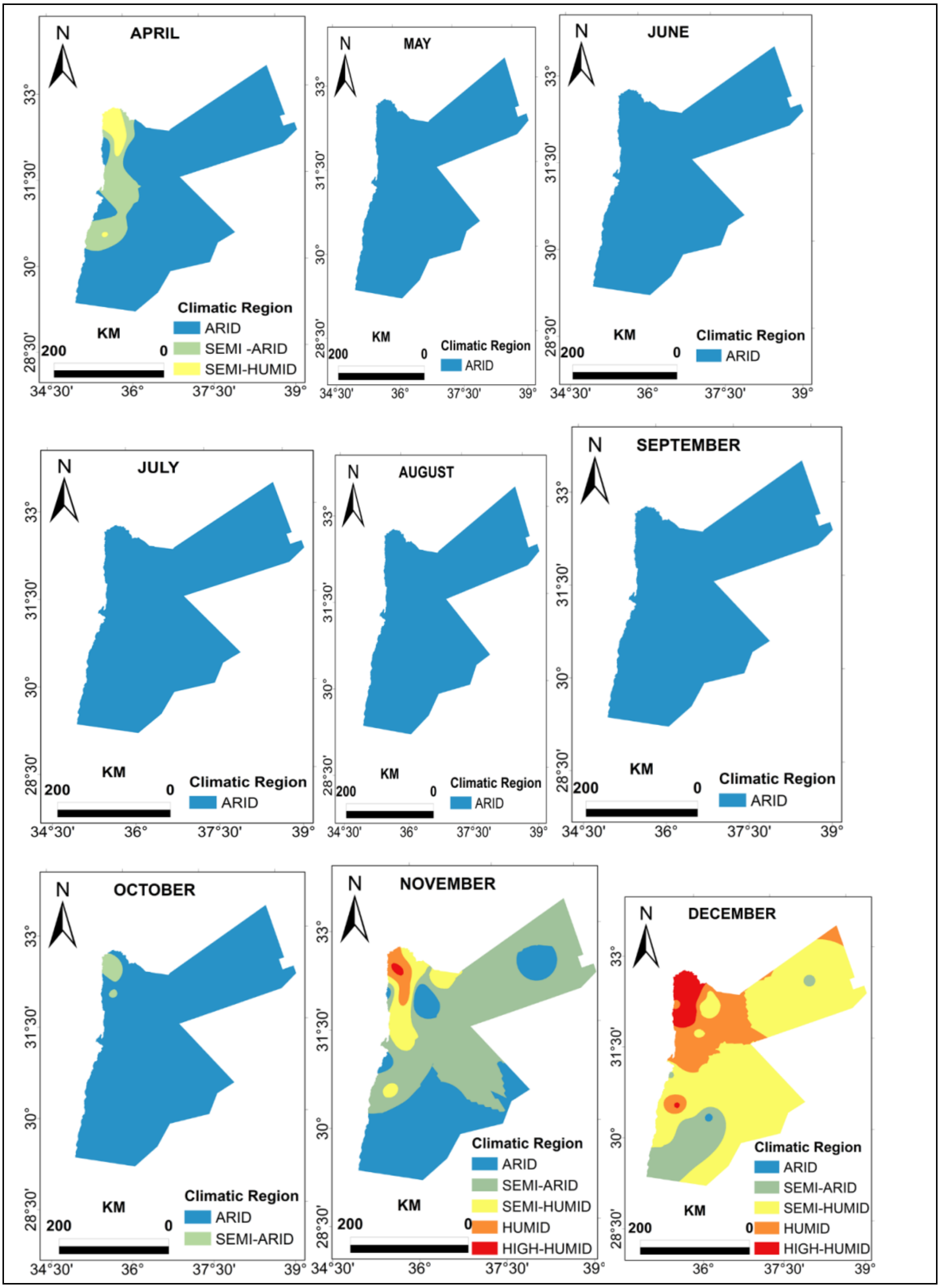


Figure 13 Monthly climatic classification of Jordan based on Iar-DM

Source: Author by Arc GIS10.7

Finally, it is important to classify the climate in Jordan, as it is closely related to the distribution of natural vegetation, agricultural and economic activities, livelihoods, population distribution, etc. Indeed, Jordan was classified into four climatic regions: arid, semi-arid, semi-humid, and humid. Figure 14.

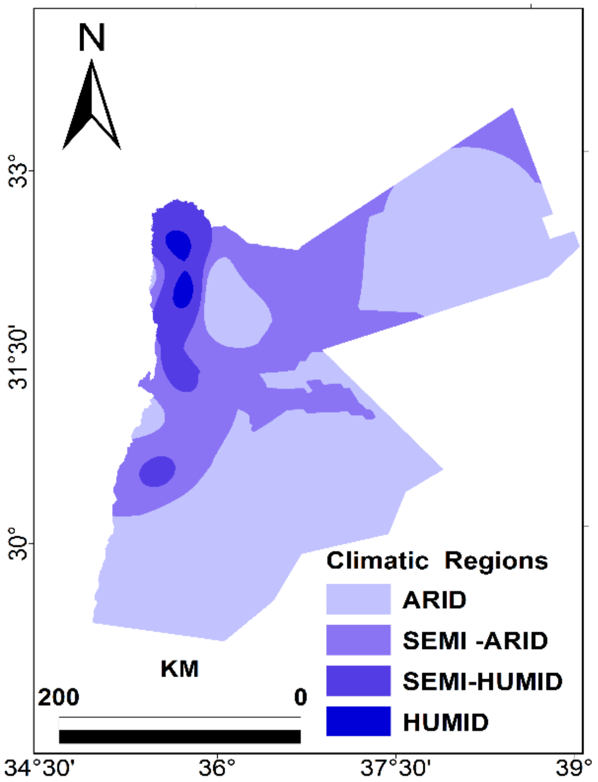


Figure 14 General Climatic Classification of
Jordan Based on Iar-DM **Source:** Author by Arc GIS10.7

In addition, the percentage of arid and semi-arid climatic regions areas was 92.8%, while the percentage of the humid and semi-humid climatic regions was 7.2% of the total area of Jordan. Table 6.

Table 6 Areas and percentages of climatic regions in Jordan Based on Iar-DM

Climatic Regions	Area(Km²)	The Ratio(%)
Humid	0.9	0.9
Semi-Humid	5.6	6.3
Semi -Arid	25.5	28.6
Arid	57.3	64.2
Total	89.3	100

Source: The author

As a result of the simultaneous drought conditions of the changes that will occur in the rates of temperature and rainfall in the arid and semi-arid regions of the world, these regions will suffer from an increasing shortage in the currently available water sources. The lack of rainfall will also affect soil productivity and development in the regions where severe and persistent drought conditions prevail (Al-Sababhah and Hazaymeh 2019). The expected result of climate change in the Middle East is a further decrease in rainfall, as Arab countries are considered among the countries in the world most affected by high temperature and declining rainfall rates, on top of their past suffering from drought and water scarcity (Issar 2006; Afed 2009). (Evans 2009: P417) indicated that model (2A) predicts an increase of about 1.4 K over-temperature by the middle of the 21st century, and it may reach 4 K at the end of the century in the Middle East. There will also be a significant change represented by the decrease in rainfall in large areas of the eastern Mediterranean, accompanied by a loss of more than 170,000 km² of exploitable rainy agricultural lands by the end of the century, and an increase in dry season length, which reduces the length of the use of pastures. Changes in the timing of maximum rainfall would also affect the growing season of the plant and significantly change the agricultural systems and types of agricultural crops. The final result is a continuous decrease in the value of Iar-DM and more dehydration.

conclusions and recommendations

By extracting the deviation of the rates for each time period from its annual average, we clearly notice that there is a general trend of decreasing annual rainfall and increasing annual temperature rates, and this explains the increasing number of dry years. The proportion of wet years in which the volume of rainfall exceeded the annual average for the first period 1970-1982 was 62%, and the drought years in which the average temperature exceeded the annual average for the same period was 8%. As for the last period, 2008-2020m the percentage of years in which the volume of rainfall was less than annual was 100%. Moreover, the percentage of dry years, in which the average temperature exceeded the annual average for the same period; was 100%, resulting in a huge increase in the number of years of drought. In addition, the analysis of Pearson's correlation coefficient between the rainfall rate during the period 1970-2020 and the Iar-DM rate for the same period indicates that there is an almost perfect positive correlation between them, with an increase or decrease for most stations, and it is statistically significant at the level of 1%, except for Al-Jafr and Zarqa stations data, exhibit a positive but weak relationship. Furthermore, a negative correlation between the mean annual temperature and years on the one hand, and Iar-DM, on the other, was statistically significant for most stations at confidence levels of 1% and 5% for the period 1970-2020. As a result, it was found that Jordan was affected by the results of climate change with a moderate to strong positive correlation and a statistical significance at the level of 1% between years and the annual average temperature. Moreover, there is a negative correlation between years and annual average rainfall for most stations for the same period. In addition, the correlation between annual average rainfall and annual average Iar-DM, and the annual average temperature was negative for most stations during the study period. It was also found that the percentage of the arid and semi-arid climatic zone was about 92.8%, while the percentage of humid and semi-humid climate zones was 7.2% of the total area of Jordan.

In conclusion, this study recommends conducting more studies related to climate change in Jordan and other countries of the Middle East. It is also suggested, that governments of most affected countries should take the necessary adaptive and precautionary measure to reduce the social and economic effects of climate change.

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