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Rainfall Repercussions: Assessing Climate Change Influence on Iraq Precipitation Patterns

Abdul Haleem A. Al-Muhyi*, Faez Younis Aleedani, Munaf Qasim Albattat, Jamila Mohammed Badr

Marine physics Department, Marine Science center, University of Basrah, Iraq

*Corresponding Author: abdulhaleem.hussien@uobasrah.edu.iq

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Keywords: Rainfall variability, drier years, deforestation, heterogeneity, temporal.

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Abstract:

The unequal spatial and temporal distribution of precipitation, exacerbated by climate change, has received significant attention. Rainfall is pivotal for crop growth and environmental health, crucial in the water cycle, and essential to replenishing surface water sources vital for drinking water supplies. Consequently, understanding this phenomenon is critical for future planning. Evaluating spatial and temporal variations in rainfall is essential for the effective management of water resources. This study employs a statistical analysis of rainfall data from 16 rain gauge stations to identify annual rainfall trends, Linear Regression Equations, Coefficients of Determination (R^2), Precipitation Concentration Index (PCI), and Rainfall Variability Index (RVI). The findings of the study come to show as the PCI has indicated strongly irregular rainfall concentration in Iraq. RVI identifies 2017 and 1983 as notably dry years, while 2018 stands out as a particularly wet year within the 40-year period from 1980 to 2019. RVI also highlights that normal rainfall years predominate, with very dry years ranging from 2 to 13, dry years from 3 to 11, wet years from 1 to 7, and very wet years from 6 to 10 within the study period.

Keywords: Rainfall variability, drier years, deforestation, heterogeneity, temporal.

تقييم أثر تغير المناخ على توزيع الأمطار في العراق

عبد الحليم علي المحيي*، فايز يونس خليل العيداني، مناف قاسم البطاط، جميلة محمد بدر

جامعة البصرة، مركز علوم البحار، قسم الفيزياء البحرية

abdulhaleem.hussien@uobasrah.edu.iq, faez.khalil@uobasrah.edu.iq, munaf.jaber@uobasrah.edu.iq, alfoutimalmhdoya@gmail.com

الخلاصة:

لقد حظي التوزيع المكاني والزماني غير المتكافئ لهطول الأمطار والذي تفاقم بسبب تغير المناخ باهتمام كبير. يعد هطول الأمطار أمرًا محوريًا لنمو المحاصيل والصحة البيئية، وهو أمر بالغ الأهمية في دورة المياه، وضروري لتجديد مصادر المياه السطحية الحيوية لإمدادات مياه الشرب. وبالتالي، فإن فهم هذه الظاهرة أمر بالغ الأهمية للتخطيط المستقبلي. يعد تقييم الاختلافات المكانية والزمانية في هطول الأمطار أمرًا ضروريًا للإدارة الفعالة للموارد المائية، تستخدم هذه الدراسة التحليل الإحصائي لبيانات هطول الأمطار من ١٦ محطة قياس المطر لتحديد اتجاهات هطول الأمطار السنوية، ومعادلات الانحدار الخطي، ومعاملات التحديد (R^2)، ومؤشر تركيز هطول الأمطار (*PCI*)، ومؤشر تقلب هطول الأمطار (*RVI*).

تكشف النتائج عن اتجاه الانحدار سلبي في هطول الأمطار السنوي. ويشير *PCI* إلى عدم انتظام تركز الأمطار بشكل كبير في العراق. ويحدد *RVI* عامي ٢٠١٧ و١٩٨٣ على أنهما سنوات جافة بشكل ملحوظ، في حين يبرز عام ٢٠١٨ باعتباره عامًا ممطرًا بشكل خاص خلال فترة ٤٠ عامًا (١٩٨٠-٢٠١٩). يسلط *RVI* الضوء أيضًا على أن سنوات هطول الأمطار العادية هي السائدة، حيث تتراوح سنوات الجفاف الشديد من ٢ إلى ١٣، وسنوات الجفاف من ٣ إلى ١١، وسنوات الرطب من ١ إلى ٧، والسنوات الرطبة جدًا من ٦ إلى ١٠ خلال فترة الدراسة.

الكلمات المفتاحية: تقلب هطول الأمطار، سنوات الجفاف، إزالة الغابات، عدم التجانس، الزمانية.

1. Introduction:

Climate change is caused by a variety of human activities such as burning fossil fuels, deforestation, and agricultural practices. These activities have led to an increase of carbon dioxide and other greenhouse gases in the atmosphere, trapping more heat and causing an increase in global temperatures. This has led to a number of changes in the earth’s climate, such as more frequent and intense storms, floods, droughts, and heat waves. It can also lead to significant changes in weather patterns .The unequal spatial and temporal distribution of precipitation, which is exacerbated by climate change, has received a lot of attention recently **[1]**. This is because climate change will alter all aspect of the hydrological cycle ranging from evaporation through precipitation, run-off and discharge **[2]**.

Rain is considered one of the most critical components of weather and climate. Changes in precipitation, including its decrease, can lead to climatic draught, which in turn causes hydrological and agricultural droughts. These impacts affect the nation's environmental system, economic growth, and food security. Moreover, extreme rainfall events, such as floods, highlight the importance of understanding rainfall variability and intensity [3].

Rain also plays a significant role in the hydrologic cycle, Both science and socioeconomics place great emphasis on its fluctuation through time and geography. Although the annual total rainfall may not change, a change in seasonal rainfall significantly impacts runoff, evapotranspiration, and infiltration, which affects ecosystem management, stream flow, and flood forecast [4].

Research into this phenomenon is a top priority when making plans for the future. Evaluation of spatial and temporal variations in rainfall is crucial for the effective management of water resources. The present study aims to examine the rainfall distribution characteristics of the Iraq area, by utilizing time series data from 1980 to 2019. The study will analyze trends in annual rainfall, which may show either decreasing or increasing patterns. The study will analyze trends in annual rainfall, which may show either decreasing or increasing patterns. Additionally, the research will use the rainfall concentration index to estimate the monthly heterogeneity of rainfall, and the rainfall variability index, which is typically computed as the standardized precipitation departure.

The findings of this study could help inform decision-making and water resource management plans in Iraq. For instance, they could provide insights into the spatial and temporal variations in rainfall, enabling adjustments to water management plans. Furthermore, the findings could enhance preparations for and management of floods, as well as inform drought management strategies.

2. Location and Extent of Studied Area:

The Republic of Iraq is located in Southwest Asia, northeast of the Arab homeland. It is bordered by Turkey to the north, Iran to the east, Syria, Jordan, and Saudi Arabia to the west, and the Arab Gulf, Kuwait, and Saudi Arabia to the south. Iraq is divided into 18 governorates, situated between latitudes 29° 5′ and 37° 22′ north, and longitudes 38° 45′ and 48° 45′ east, covering an area of 435,052 square kilometers. Iraq's climate is located within the northern temperate region, but it is characterized as subtropical continental. Its rainfall pattern is similar to that of the Mediterranean, with most rain falling in winter, autumn, and spring, and little to none in summer. Data from the country's 16 weather stations were used to create a GIS database, as shown in **Figure 1**.

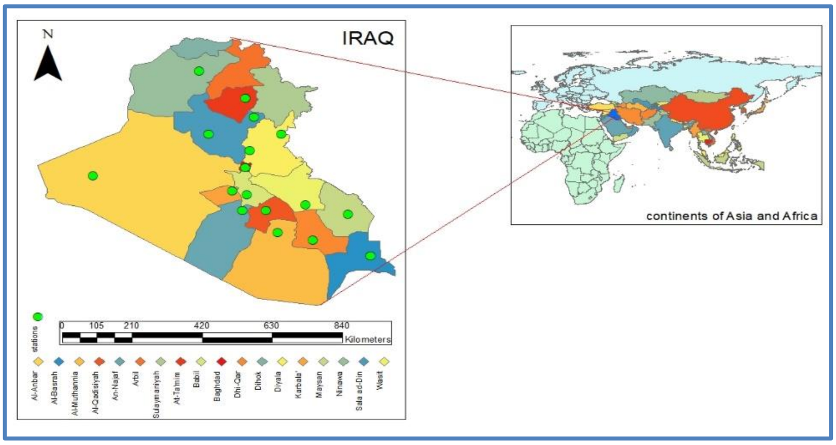

Figure 1: The Study area

3. Data and Methodology:

The Iraqi Meteorological Organization and Seismology Department provided monthly rainfall data for the period 1980-2019 from 16 rain gauge sites. Missing data in climate time series can be addressed using the Inverse Distance Weighting (IDW) strategy, as described in references [5] and [6].

$$P_k = \frac{\sum_{k=1}^{n} \frac{R_k}{d_k^2}}{\sum_{k=1}^{n} \frac{1}{d_k^2}}$$

Where, P_k = missing rainfall value, R_k = rainfall value at k surrounding rainfall stations, n = number of observations of surrounding stations, and d_k = Distance from missing rainfall station to k^{th} surrounding rainfall stations. The technique of examining historical rainfall data to identify long-term trends in precipitation is known as rainfall trend analysis. Statistical methods such as regression analysis and the coefficient of determination (R2) are used to determine the significance of rainfall trends. The monthly rainfall heterogeneity was analyzed using the rainfall concentration index, originally proposed by [7] and modified by [8].

$$PCI = 100 * \frac{\sum_{k=1}^{12} P_k^2}{\sum_{k=1}^{12} P_k} \text{ --------------(1)}$$

Where P_i is the amount of rainfall in the i^{th} month. The index was calculated for each rain gauge and for each year over the study period. The annual PCI values describe in the Table 1.

Table 1: classification of (PCI) [9,10]

Rang of precipitation concentration index (PCI) Value			
PCI < 10	PCI >11 and < 15	PCI >16 and < 20	PCI >20
Uniform rainfall concentration	Moderate rainfall concentration	Irregular rainfall concentration	Strongly irregular rainfall concentration

The available rainfall time series can be divided into different climatic regimes such as "very dry climatic year," "normal climatic year," "wet climatic year," "very wet climatic year," etc. using the rainfall variability index **Eq. (2)**.

$$V_i = \frac{(R_i - m)}{\sigma} \quad -------(2)$$

Where, V_i is rainfall variability index for year i, R_i is the annual rainfall for year i, and m and σ are the yearly precipitation series' mean and standard deviation for the given duration of study station respectively**[6]**. The rang of rainfall variability index describe in **Table 2.**

Table 2: Rang of rainfall variability index

$V_i > 1$	$V_i \geq 0.5$ and ≤ 1	$V_i \leq 0.5$ and ≥ -0.5	$V_i \geq -0.5$ and ≤ -1	$V_i > -1$
very wet year	*wet year*	*normal year*	*dry year*	*very dry year*

3. Results and discussion:

Using Excel software, a statistical analysis of rainfall was conducted for each of the sixteen stations to identify any trends or persistence in the data. A linear regression test was performed, revealing a rising tendency in all stations toward shortfall and sparse rainfall. The values of R2 ranged from 0.00004 to 0.0946, except for four stations (Baghdad, Samawa, Hilla, and Missan), which showed a weak coefficient of determination and a positive trend (see **Table 3**). The table also presents the linear regression equations for each station.

Table 3: Rainfall Trend

stations	location		Regression equation	R^2 coefficient of determination	Trend sign
	Latitude	Longitude			
Mosul	36.32°	43.15°	y = -1.7782x +398.43	0.0247	Negative
Kirkuk	35.47°	44.40°	y = -2.7581x + 401.51	0.0706	Negative
Tuz	34.88°	44.65°	y = -1.3032x + 300.71	0.0248	Negative
Khanaqin	34.35°	45.38°	y = -1.799x + 334.72	0.0498	Negative
Tikrit	34.34°	43.42°	y = -1.6888x + 218.96	0.0816	Negative
Alkhalls	33.83°	44.53°	y = -0.6662x + 189.81	0.0181	Negative
Baghdad	33.30°	44.40°	y = 0.7979x + 103.92	0.0278	Positive
Rutba	33.03°	40.28°	y = -0.9179x + 130.82	0.0409	Negative
Hilla	32.45°	44.45°	y = 0.4636x + 96.698	0.0172	Positive
Al- hai	32.13°	46.03°	y = -0.03x + 135.29	0.00004	Negative
Najaf	31.95°	44.32°	y = -0.6501x + 108.79	0.0291	Negative
Diwaniya	31.95°	4.95°	y = -0.2284x + 108.69	0.0037	Negative
Samawa	31.27°	45.27°	y = 0.4431x + 89.533	0.0115	Positive
Nasiriya	31.02°	46.23°	y = -0.3453x + 130.48	0.0051	Negative
Missan	31.83°	47.17°	y = 1.008x + 154.13	0.0221	Positive
Basra	30.52°	47.78°	y = -1.5156x + 160.62	0.0946	Negative

The average annual total rainfall for all of Iraq from 1980 to 2019 is represented by contour lines in **Figure 2**. The highest amount of rainfall, 308 mm, was recorded in the north, while the lowest, 95 mm, was in the southwest. The average rainfall amount, 120 mm, was observed in the west.

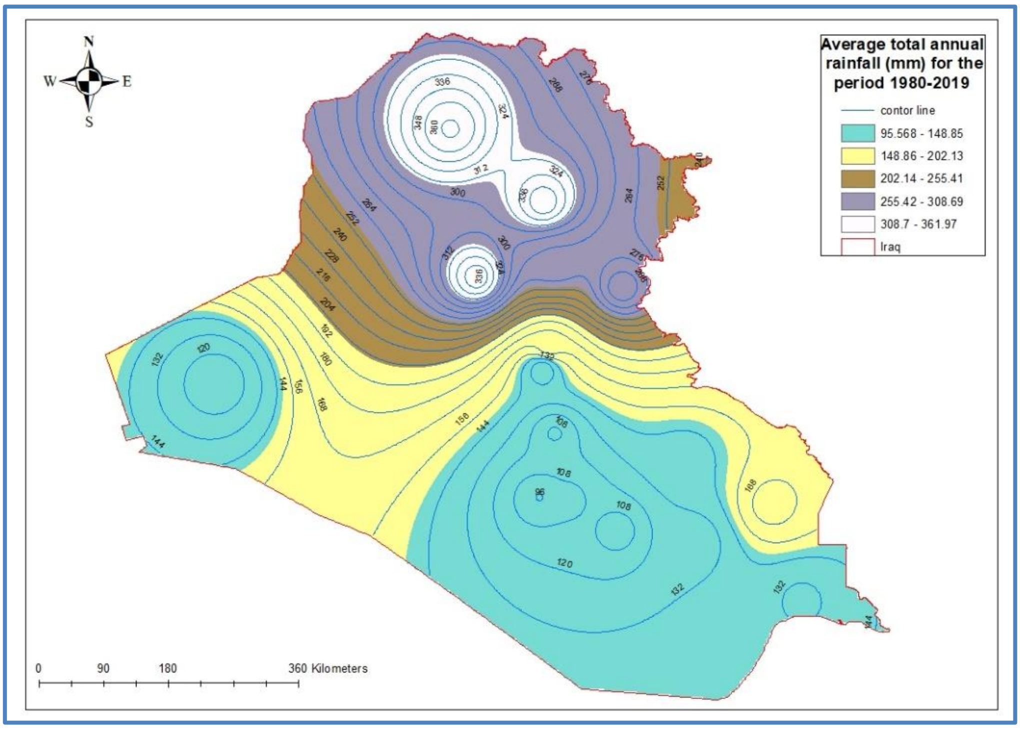

Figure 2: Average total annual rainfall (mm) for the period 1980-2019

Oliver's definition of the Precipitation Concentration Index (PCI) describes it as a potent measure of the temporal distribution of precipitation (7). **Eq. (1)** is used to calculate the yearly PCI for all stations (see **Table 4**). The number of years for each PCI class is determined based on the PCI value, as shown in **Table 5**. It is observed that no years have a PCI value less than 10. Kirkuk and Baghdad fall into the PCI class >11 and <15, with one and two years of moderate rainfall concentration, respectively. All stations have the number of years in the class PCI >16 and <20, indicating irregular rainfall concentration. The largest number of years is located in the PCI class larger than 20, indicating strongly irregular rainfall concentration.

From **Figure 2**, we observe that the average annual PCI values in Iraq range from 22.4 to 31.4. The highest PCI values are concentrated in the southern region, specifically in the governorates of Samawa and Nasiriya, while the lowest values are in the northern region, particularly in the governorates of Mosul and Kirkuk. This indicates that the majority of rainy years in Iraq between 1980 and 2019 are characterized by strong irregularity.

Table 4: PCI level of precipitation concentration measured on an annual scale for a specific year

Year	Mosul	Kirkuk	Tuz	Khanaqin	Tikrit	Alkhalls	Baghdad	Rutba	Hilla	Alhai	Najaf	Diwaniya	Samawa	Nasiriya	Missan	Basra
1980	20.3	17.0	18.4	19.7	18.7	18.4	21.2	22.0	39.6	52.0	45.1	45.5	57.3	47.2	46.6	40.8
1981	16.3	16.9	17.1	18.8	18.1	17.0	21.5	20.4	20.2	35.9	27.8	25.2	42.4	31.2	34.6	27.2
1982	17.2	15.8	15.1	16.8	16.6	16.0	14.5	15.6	23.6	29.4	17.7	22.5	23.9	29.0	34.3	24.0
1983	16.0	15.6	15.8	20.9	18.0	18.6	19.0	17.9	18.4	22.8	28.1	25.6	36.7	26.5	28.0	29.1
1984	25.4	30.1	29.4	31.0	37.2	30.3	25.7	19.1	20.4	32.8	31.2	24.2	29.9	38.8	30.4	33.2
1985	18.0	19.7	18.9	21.6	24.8	24.7	26.2	19.5	18.0	23.9	27.8	18.7	64.0	31.9	31.6	38.1
1986	18.2	23.2	20.0	18.9	20.7	21.4	22.3	16.1	28.4	19.5	26.2	22.1	29.1	23.5	19.1	18.8
1987	23.9	26.1	27.8	25.3	22.4	21.7	26.3	46.8	31.7	24.0	33.8	21.5	20.6	27.1	25.3	27.0
1988	21.5	19.5	19.4	18.5	24.7	18.6	20.7	18.8	22.7	19.9	22.2	20.2	22.4	26.1	20.7	21.7
1989	28.0	25.7	21.6	25.9	35.4	21.6	28.7	27.8	28.4	24.8	41.7	28.1	35.6	25.8	24.2	24.0
1990	20.5	26.8	24.2	28.7	33.2	18.0	23.0	45.1	32.1	33.6	45.4	35.4	38.1	29.9	18.3	23.0
1991	32.4	14.5	19.0	22.1	19.0	30.8	16.2	34.1	25.6	29.4	19.2	20.0	23.3	18.5	15.2	22.0
1992	17.7	18.6	17.5	20.0	19.4	19.9	20.3	18.9	30.0	24.8	24.3	38.9	23.4	23.1	28.4	22.2
1993	17.6	13.5	23.7	15.9	17.9	28.1	38.6	16.4	25.1	27.7	34.6	27.7	21.3	20.6	20.2	24.7
1994	15.9	17.1	19.2	19.7	21.5	18.9	19.1	35.8	27.7	28.5	25.6	35.8	25.3	25.1	29.9	20.4
1995	22.0	24.7	21.1	20.3	25.7	20.9	32.9	52.3	39.7	21.4	24.5	30.3	25.3	19.1	21.9	26.6
1996	22.7	23.8	22.1	26.4	29.5	22.6	25.2	20.1	26.2	28.0	29.7	23.9	27.1	28.0	25.7	23.6
1997	16.9	15.9	20.1	19.2	21.3	26.1	26.5	27.2	32.8	29.3	24.6	21.0	21.8	20.6	24.6	22.3
1998	22.7	26.7	33.9	35.3	48.8	38.1	26.0	23.2	31.4	51.4	35.3	34.4	49.9	42.0	34.1	47.8
1999	19.0	30.1	30.9	36.1	28.8	33.6	37.2	27.5	28.8	25.4	26.3	22.8	37.4	27.8	31.0	22.5
2000	19.0	25.1	21.6	35.7	23.5	35.5	30.6	23.6	30.5	29.5	30.2	26.2	22.9	43.3	38.6	39.3
2001	18.9	19.7	23.5	20.7	17.6	17.8	20.0	32.4	19.3	22.4	23.1	22.7	19.5	48.6	31.9	33.4
2002	22.1	24.5	22.9	18.2	16.6	22.0	24.3	19.6	26.7	28.6	21.2	37.9	25.1	50.8	26.5	20.0
2003	18.9	18.7	18.2	20.3	23.7	18.6	17.8	16.8	38.1	26.1	23.7	33.3	18.1	33.4	19.7	22.2
2004	20.7	24.2	23.9	25.8	30.1	19.5	21.2	16.4	35.7	31.8	30.8	34.9	19.2	25.3	30.2	22.9
2005	21.8	23.8	26.4	25.4	29.1	27.4	36.8	21.0	29.5	26.7	24.1	27.9	21.9	32.8	34.5	37.5
2006	19.9	25.7	22.2	22.6	27.1	27.2	23.9	19.9	17.0	19.3	18.4	19.1	32.1	20.8	23.0	26.0
2007	23.5	24.7	26.7	27.7	31.0	31.7	22.8	16.7	38.8	27.6	30.4	25.6	26.0	50.1	24.1	25.3
2008	19.3	23.1	26.4	21.3	23.1	27.4	28.1	19.5	33.1	20.6	20.7	20.5	36.3	35.7	36.3	44.4
2009	24.2	18.6	18.2	17.4	17.5	22.5	16.4	22.4	20.0	27.3	21.0	23.9	19.4	28.4	36.7	28.3
2010	17.6	18.6	18.9	18.5	18.0	20.1	24.8	25.5	19.9	22.9	21.3	22.9	25.2	34.3	36.3	23.7
2011	25.7	22.3	24.4	21.6	23.5	23.3	22.8	37.5	35.2	26.8	27.0	26.5	31.6	18.7	31.1	23.7
2012	19.0	19.9	22.9	36.2	26.2	20.8	35.8	27.3	44.2	32.8	31.8	40.9	28.0	32.2	44.7	29.3
2013	20.1	22.0	29.9	33.8	23.2	31.6	40.7	27.6	62.6	25.5	48.6	35.2	50.5	56.5	39.4	34.2
2014	19.1	17.5	17.7	17.2	20.7	16.7	21.3	16.5	26.2	19.1	25.5	27.9	23.0	29.2	23.1	46.1
2015	18.4	16.8	18.4	23.7	19.4	33.7	27.0	20.3	21.7	26.6	24.7	33.5	26.1	25.7	18.6	25.6
2016	17.7	21.2	18.6	17.7	24.1	23.6	23.5	21.3	29.3	25.6	26.1	23.7	39.0	27.4	19.7	19.8
2017	25.7	29.4	35.2	29.7	39.6	46.8	39.5	35.9	25.6	57.9	25.3	45.2	48.1	44.1	36.2	56.0
2018	18.9	22.4	21.3	23.9	20.5	23.9	23.5	21.8	22.3	30.7	18.7	21.2	33.8	38.8	28.1	23.1
2019	21.9	19.1	20.1	18.2	23.4	18.7	22.5	15.4	26.1	20.0	22.3	17.5	22.6	18.6	27.2	19.8

Table 5: Number of years for each class of Precipitation Concentration Index (PCI)

Number of years				
Stations	PCI≤10	PCI >10 and ≤15	PCI >15 and ≤ 20	PCI>20
Mosul	0	0	0	40
Kirkuk	0	2	3	35
Tuz	0	0	20	20
Khanaqin	0	0	15	25
Tikrit	0	0	12	28
Alkhalls	0	0	14	26
Baghdad	0	1	6	33
Rutba	0	0	19	21
Hilla	0	0	6	34
Al- hai	0	0	5	35
Najaf	0	0	4	36
Diwaniya	0	0	5	35
Samawa	0	0	4	36
Nasiriya	0	0	4	36
Missan	0	0	7	33
Basra	0	0	4	36

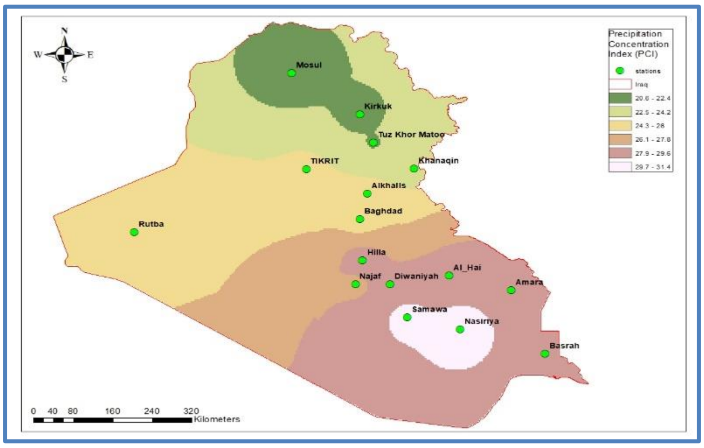

Figure 3: Annually Average of Precipitation Concentration Index (PCI)

The Rainfall Variability Index (RVI) **Eq. (2)** is used to classify the climatic systems of the 40-year data series for Iraq. Based on the RVI values, the periods are classified as shown in the table in the data and methodology section. The rainfall variability index plots for each station are presented in **Figures 4, 5, and 6**. In these plots, values above the positive red dashed line represent very wet years, values between the solid red line and the dashed red line represent wet years, values between the solid red line and the solid green line represent normal years, and negative values between the solid green line and the dashed green line represent dry years. Negative values below -1 indicate very dry years.

It has been observed that the years 2017 and 1983 were the driest years, while the year 2018 was the wettest during the 40-year period. **Table 5** shows the number of years for each classification and for each station. It is clear from the table that the number of normal years is prevalent during the study period, ranging from 10 to 21 years. The number of very dry years ranged from 2 to 13 years, dry years from 3 to 11 years, wet years from 1 to 7 years, and very wet years from 6 to 10 years. The variability in rainfall patterns for the entire Iraq, as determined by applying RVI, is shown in **Figure 7**. It can be seen that normal rainfall occurred 36.1% of the time, dry years occurred 19.5% of the time, very wet years occurred 15.8% of the time, very dry years occurred 14.4% of the time, and wet periods were experienced 9% of the time.

Table 6: Number of years for each class of Rainfall Variability Index (RVI)

stations	Number of years				
	$V_i > +1$	V_i betwee +0.5 to +1	V_i is within ±0.5	V_i between -0.5 to -1	$V_i < -1$
Mosul	8	2	16	8	6
Kirkuk	7	3	17	8	5
Tuz	10	1	12	11	6
Khanaqin	9	6	10	9	6
Tikrit	7	3	17	8	5
Alkhalls	6	7	14	7	6
Baghdad	6	4	18	6	6
Rutba	5	3	19	11	2
Hilla	6	5	14	9	6
Al-hai	4	7	14	9	6
Najaf	9	2	12	10	7
Diwaniya	4	4	21	3	8
Samawa	6	3	16	11	4
Nasiriya	7	5	15	5	13
Missan	7	1	16	10	6
Basra	5	11	9	10	5

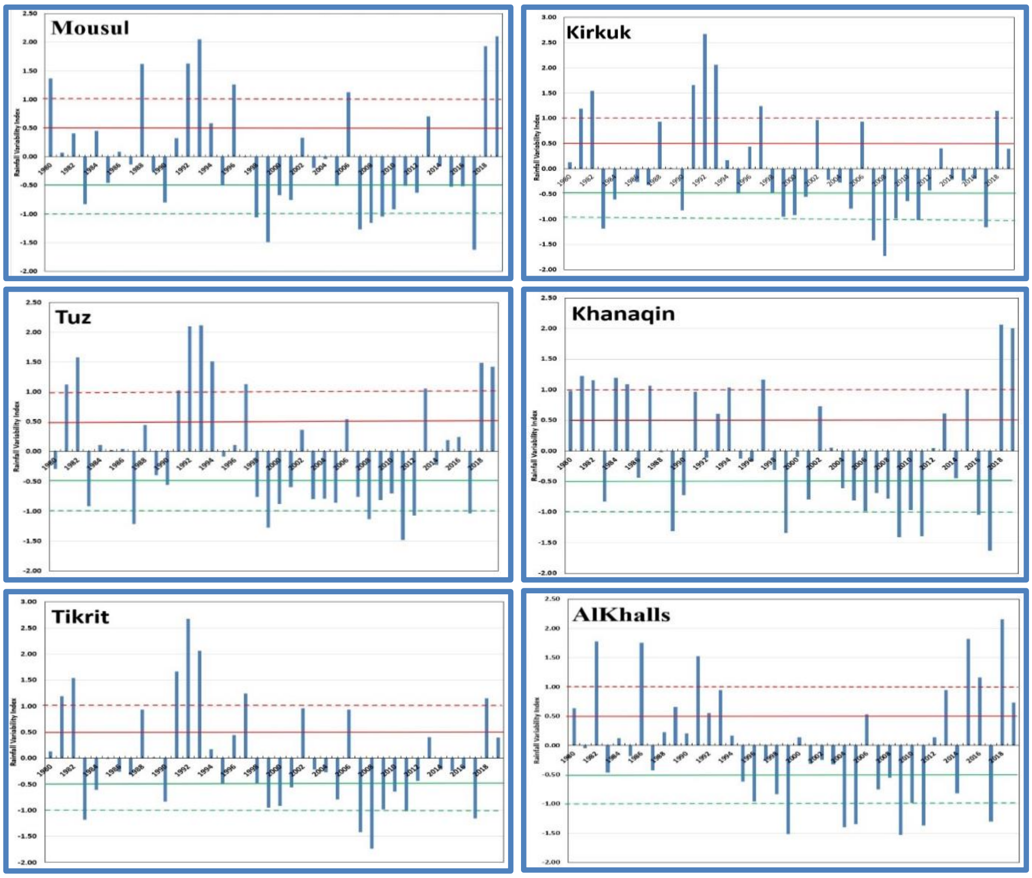

Figure 4:Rainfall variability index plots for stations of (Mosul, Kirkuk,Tuz, Khanaqin,Tikrit, Alkhalls).

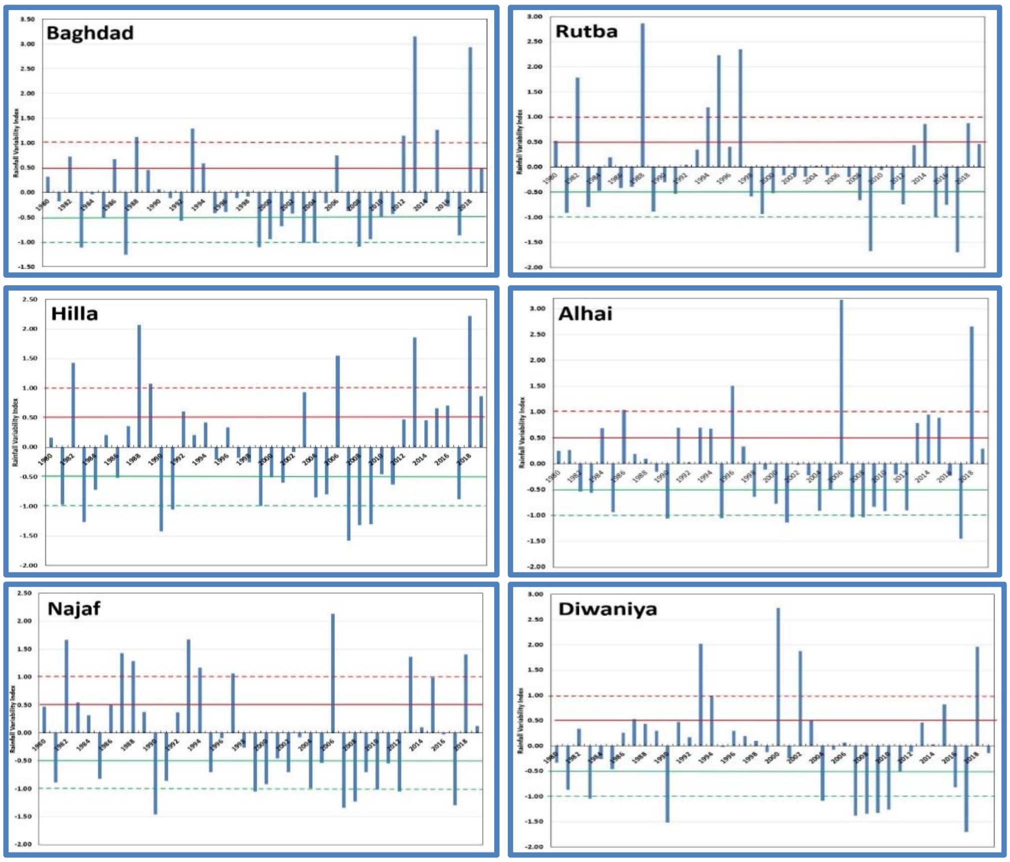

Figure 5: Rainfall variability index plots for stations of (Baghdad, Rutba, Hilla, Al-hai , Najaf, Diwaniya).

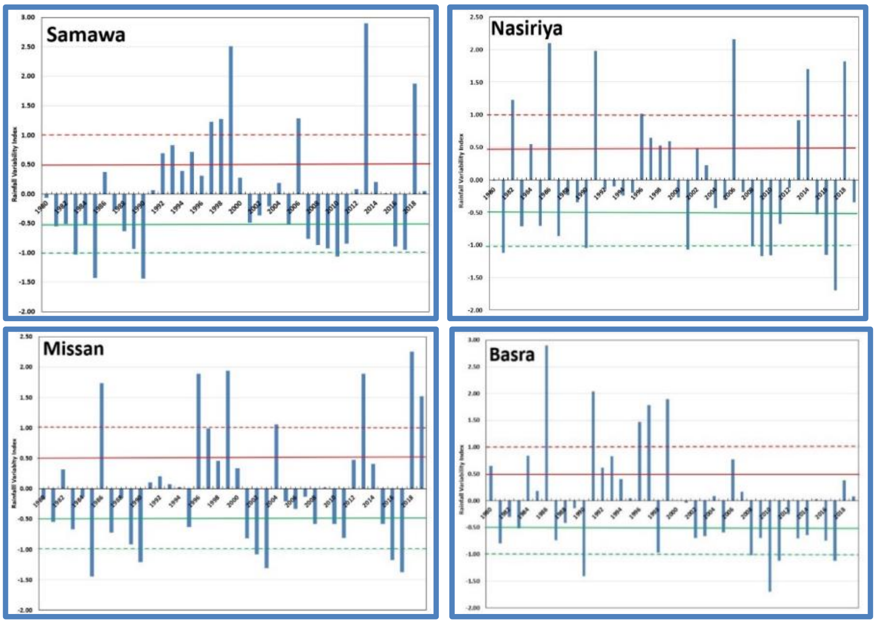

Figure 6: Rainfall variability index plots for stations of (Samawa, Nasiriya, Missan and Basrah)

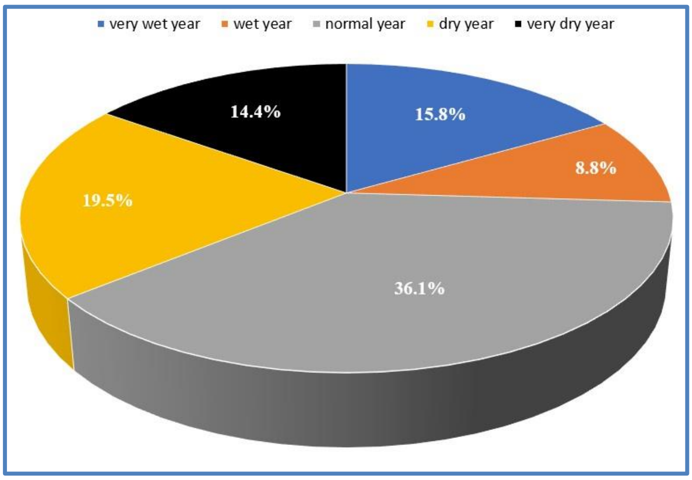

Figure 7: IRAQ's rainfall variability index distribution over time (1980-2019)

4. Conclusion:

Climate change is a global phenomenon that affects many aspects of Earth's climate, including rainfall distribution in Iraq. While the effects of climate change on rainfall in Iraq are not yet fully understood, there is evidence to suggest that the amount and intensity of rainfall are changing. Despite the impact of climatic changes on rainfall in Iraq, as evidenced by the negative linear regression trend of annual average rainfall for the period 1980-2019, the geographical distribution of rainfall remains variable from one place to another, depending on the factors causing precipitation. It is found that the annual average rainfall in northern regions is high, while in central and western regions, it is moderate, and in southern regions, it is low. The concentration indicator suggests strongly irregular rainfall concentration, while the RVI indicator shows that rainfall in Iraq fluctuates between normal, dry, and very dry years, with very few wet years confined to the northern region. This variation in rainfall distribution is due to several factors, including the astronomical location of Iraq cities.

Terrain plays a significant role in heavy rainfall situations, with topographic features impacting rainfall fluctuation. Rainfall depth increases with elevation (known as the orographic effect), while depressions in the Mediterranean Sea, the Red Sea, and the Arabian Gulf cause light to medium intensity rain.

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