African Journal of Advanced Studies in Humanities and Social Sciences (AJASHSS)
المجلة الإفريقية للدراسات المتقدمة في العلوم الإنسانية والاجتماعية
Online-ISSN: 2957-5907
Volume 5, Issue 3, 2026
Page No: 683-693
Website: https://aaasjournals.com/index.php/ajashss/index

Arab Impact factor 2025: 0.83	SJIFactor 2024: 6.856	ISI 2025: 1.191

Assessing the impact of climate change on the severity and frequency of droughts in the western region of Saudi Arabia using the Standardized Precipitation Index (SPI) for the period (1959–2024)

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تقييم أثر التغير المناخي على شدة حالات الجفاف وتكرارها في المنطقة الغربية للسعودية باستخدام المؤشر المعياري للمطر (SPI) للفترة (1959–2024)

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Received: June 24, 2026	Accepted: September 02, 2026	Published: September 17, 2026

Abstract:
This study aims to demonstrate the impact of climate change on the change in monthly rainfall rates in the Makkah region, as any change in the rainfall pattern, whether an increase, decrease, or irregularity of rainfall, leads to clear repercussions on plants. This is based on the analysis of monthly rainfall rate data for a period of 66 years, which was divided into two time periods: the first extended from (1959-1991), and the second from (1992-2024), and extracting the monthly averages for the two periods. The results confirmed that there is a clear difference in rainfall rates between the two study periods in favor of the second period (1992-2024), as rainfall rates increased by a difference of 4.1 mm.
The data were then entered into the Drought Indices Calculator (DrinC) software to calculate the Standardized Precipitation Index (SPI) for estimating dry and wet years in the Makkah region, based on 12-month values over a 66-year period. The data were divided into two periods, each 33 years long, to understand the impact of climate change on rainfall patterns in the second period compared to the first, and how this affected the SPI levels. The results confirmed a clear impact of climate change on rainfall rates and amounts across all months. Rainfall increased in the second period compared to the first, by a difference of 4.1 mm. Monthly variations were observed, with months that previously recorded low rainfall, such as the summer months, experiencing higher amounts. Conversely, wet months saw a relative decrease in rainfall, leading to variations in drought levels across the two periods.
The results confirmed that near-average aridity was the most frequent condition during most months of the two study periods, and it was the dominant condition between the two periods. It occurred 86% of the time in the first period and decreased to 75% in the second, a difference of 11%. Average humidity was also more prevalent in the second period than in the first, by a difference of 1%. Very high humidity was also more frequent in the second period compared to the first, by a difference of 3%. Extremely high humidity also increased in the second period compared to the first, by a difference of 1%. These results indicate that the region tends towards wetter than dry conditions during the second period. A relative improvement in humidity was observed during the main rainy season, which is an indicator of continued vegetation growth due to improved humidity conditions in the region.

Keywords: Climate change, drought, Standardized Precipitation Index, SPI, Makkah, Saudi Arabi.

الملخص
تهدف هذه الدراسة لبيان أثر تغير المناخ في تغير معدلات هطول الامطار الشهرية في منطقة مكة المكرمة إذ يؤدي أي تغير في نمط الهطول سواء بالزيادة أو النقصان أو عدم انتظام الأمطار إلى انعكاسات واضحة على النباتات، وذلك بالاعتماد على تحليل بيانات المعدلات الشهرية للأمطار لفترة 66 عاماً، حيث قُسمت إلى فترتين زمنيتين: امتدت الأولى من (1959-1991)، والثانية من (1992-2024)، واستخراج المتوسطات الشهرية للفترتين، وقد أكدت النتائج ا أن هناك تبايناً واضحاً

في معدلات هطول الامطار بين فترتي الدراسة لصالح الفترة الثانية (1992 - 2024)، إذ ارتفعت معدلات هطول الامطار بفارق 4.1ملم.
ومن ثم ادخال البيانات إلى برنامج حاسبة مؤشرات الجفاف(*(The Drought Indices Calculator (DrinC)*) ، لحساب مؤشر المطر المعياري *((Standardised Precipitation Index (SPI)*) لتقدير السنوات الجافة والرطبة في منطقة مكة بالاعتماد على قيم 12 شهراً للفترة 66 عاماً. وقسمت البيانات الى فترتين، كل فترة طولها ثلاثة وثلاثون عاماً. لفهم أثر تغير المناخ على تغير معدلات هطول الامطار في الفترة الثانية مقارنة بالفترة الأولى وكيف أثر ذلك في تغير مستويات مؤشر *SPI*.
وأكدت النتائج على أن هناك أثر واضح للتغير المناخ على معدلات وكميات هطول الامطار على مستوى جميع الاشهر. حيث سجلت الامطار ارتفاعا في الفترة الثانية مقارنة بالفترة الأولى بفارق وقدره 4.1 ملم. وتباينت على المستوى الشهري فالأشهر التي كانت تسجل كميات أمطار منخفضة ارتفعت كمياتها كأشهر فصل الصيف. اما الأشهر الرطبة فقد انخفضت معدلاتها نسبيا، مما أدى الى التغير في مستويات الجفاف خلال الفترتين.
أكدت النتائج أن مستوى الجفاف إلى يقارب للمعدل هو الأكثر تكراراً خلال معظم الأشهر في فترتي الدراسة، إذ يعتبر هو السائد نسباً بين الفترتين، فقد تكرر بنسبة 86% في الفترة الأولى وانخفضت نسبته في الفترة الثانية 75% وبفارق وقدرة 11%، أما على مستوى متوسط الرطوبة فتعد الفترة الثانية أكثر رطوبة من الفترة الاولى وبفارق قدرة 1%. وحقق مستوى شديد الرطوبة أيضا ت تكرارًا اعلى في الفترة الثانية مقارنة بالفترة الأولى بفارق قدرة 3%. وبالنسبة لمستوى رطوبة شديدة جدا فهو ايضا شهد ارتفاعا في لفترة الثانية مقارنة بالفترة الاولى بفارق نسبته 1% مما تدل النتائج على ان المنطقة تميل إلى الرطوبة عن الجفاف خلال الفترة الثانية. وحدوث تحسّن نسبي في الرطوبة خلال موسم المطر الرئيس مما يعد مؤشرا لاستمرار نمو الغطاء النباتي نتيجة لتحسن ظروف الرطوبة في المنطقة.

الكلمات المفتاحية: تغير المناخ، لجفاف، المؤشر المعياري للمطر، *SPI*، مكة المكرمة، السعودية.

Introduction

Climate change is currently a reality and one of the most serious challenges facing humanity due to its direct and indirect repercussions on ecosystems, water resources, and agricultural activities, resulting in economic, environmental, and social impacts that hinder efforts to achieve sustainable development (IPCC, 2021, p. 6). Climate change is defined as a rise in temperature above its normal average as a result of human activities, leading to changes in other climatic elements for a long period of no less than thirty years. This inevitably leads to a greater frequency and intensity of extreme weather events, and consequently, to fluctuations in the seasons and changes in their characteristics (Asmahan Ali Othman, 2023, p. 94)**.**

Given the varying causes of drought depending on the nature of different regions worldwide, most scientists have begun to link the increasing severity of droughts to climate change. This is because, with the increase in greenhouse gas emissions into the atmosphere, air temperatures rise, leading to greater moisture loss from surface and groundwater. Higher temperatures also increase water evaporation from soil and plants, and can reduce rainfall frequency. When rain does fall in drought-affected areas, drier soils become less able to absorb water, which may explain the increased frequency of flash floods in arid regions (Yohannes Yihdego, 2019, p9).

With the increasing prevalence of drought globally, discussions surrounding its definition have become more diverse, and there is no universally accepted definition. However, a common definition of drought is a decrease in rainfall below the expected average over a specific period (Yohannes Yihdego, 2019, p1). While droughts occur naturally, climate change has generally accelerated hydrological processes, exacerbating their severity and impacting numerous consequences. Drought directly affects vital plant functions from germination to maturity and increases the risk of forest fires. Drought indices are used as alternative indicators to track and assess drought levels; therefore, it is crucial to establish accurate and effective drought indices to study drought characteristics within a changing and volatile climate (Sourav Mukherjee, 2018, p1)**.**

Drought indices are defined as a set of quantitative variables or criteria used to characterize and monitor drought conditions. These indicators include, for example, rainfall amounts, temperatures, river flows, groundwater and reservoir levels, as well as soil moisture and snow cover. These indicators are typically numerical values calculated to estimate drought severity, based on climatic or hydroclimatic inputs, with the aim of accurately characterizing the qualitative state of the drought. These indicators contribute to a quantitative assessment of drought severity, location, timing, and duration. Drought severity is defined as the degree of deviation from normal climatic values, and specific thresholds can be established to measure the onset and end of the phenomenon and to monitor its geographical extent. Location refers to the spatial area affected by drought conditions, while timing and duration are determined based on the time periods associated with the onset and end of the phenomenon (WMO, 2013, p. 4).

Significance of the Study:

The importance of this study lies in its highlighting of one of the most pressing environmental issues: drought, a prominent manifestation of climate change in the Makkah region of western Saudi Arabia. The study's significance is further highlighted by**:**

1 **-**Providing quantitative and objective indicators (SPIs) to aid in the management of water and agricultural resources within an environmentally sensitive area heavily reliant on seasonal rainfall**.**

2 **-**Contributing to the identification of drought trends in the region, thus protecting drought-threatened plants and promoting drought-resistant species**.**

3 **-**Supporting climate change planning and adaptation efforts by providing decision-makers and researchers with accurate scientific evidence on the frequency and intensity of droughts, thereby identifying plant species best adapted to extreme climatic conditions**.**

4 **-**Enriching the scientific literature with a regional study that contributes to understanding climate dynamics in Saudi Arabia and linking them to global climate change patterns**.**

Study objectives:

1 **-**Demonstrating the impact of climate change on rainfall patterns and, consequently, on drought levels between the two study periods. 2. Analyzing climate changes at the Makkah Meteorological Station during the period (1959–2024) by examining changes in their quantities**.**

3 **.**Applying the SPI index to classify drought and humidity events according to their intensity and determining their frequency during the two periods**.**

4 **.**Comparing the climatic periods (1959–1991 and 1992–2024) to reveal changes in the intensity and frequency of drought as an indicator of the impact of climate change**.**

5 **.**Highlighting the temporal and seasonal patterns of drought and linking them to the climatic characteristics of the region**.**

6 **.**Providing scientific and practical recommendations that can be applied in the fields of agricultural and pastoral planning, water management, and mitigating the risks of climate disasters

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Statement of the problem:

1 **.**Does climate change affect monthly rainfall patterns in the region? And has it affected the characteristics of the standard rainfall index by comparing its peak in the first period (1959-1991) with the second period**?(2024-1992)**

2 **.**What is the overall trend of drought in the region? Is there a variation in monthly and annual drought periods across the study periods**?**

3 **.**Has there been a change or fluctuation in the length of drought periods across the study periods**?**

Hypotheses

1 **.**Climate change has affected monthly rainfall patterns in the region, and consequently affected the characteristics of the standard rainfall index from the second period compared to its peak in the first period**.**

2 **.**The overall trend of drought in the region shows variations in its levels throughout the year, especially during the winter and spring months**.**

3 **.**The second period records lower annual drought values than the first period.

Study Area:

The spatial boundaries of the Makkah region are defined by its location in western Saudi Arabia, at latitude 23.21 degrees north and longitude 39.37 (Map 1). It is situated at an altitude of 951 meters above sea level (Ibrahim Darwish, 2017, p. 271).

Map (1) Location of Mecca/Saudi Arabia.

Source: Prepared by the researcher using GIS, based on the National Atlas (1978, p. 25).

Methodology of the Study:

This study employed a statistical analysis of average daily rainfall rates in the Makkah region using the (Climate Engine[1]) platform for the period 1959–2024. The data were then entered into the Drought Indices Calculator (DrinC) software (version 1.7) to calculate the Standardized Precipitation Index (SPI). This index was used to estimate dry and wet years in the Makkah region (D. TIGKAS, H. VANGELIS, 2013, p. 1333). The data was based on 12-month values over a 66-year period to create a long-term database that can be used to monitor hydrological impacts in subsequent studies. The data was then divided into two equal periods of 33 years each: 1958–1991 and 1992–2024. This division aimed to understand the impact of climate change on rainfall rates and its effect on the SPI.

(1) https://app.climateengine.org/climateEngine

First: Calculating the Standardized Precipitation Index (SPI):
The Standardized Precipitation Index (SPI) originated from research conducted by McKee et al. in 1992 at Colorado State University in the United States. The results of this research were first presented at the Eighth International Conference on Applied Climatology in January 1993, where their study focused on the relationship between drought in terms of its frequency, duration, and spatial extent. The index is based on the use of long-term rainfall records to measure deviations from the average in a standardized manner. In 2009, the World Meteorological Organization (WMO) recommended the adoption of the SPI as a primary tool for monitoring drought conditions, considering it the standard measure that countries should use to monitor and assess drought situations. In 2011, the WMO further recommended the widespread use of the index and provided practical guidance for countries seeking to establish drought early warning systems (WMO, 2013, p. 13).
The Standardized Precipitation Index (SPI) developed by McKee et al. is a versatile tool for monitoring and analyzing drought. The SPI is calculated based on long-term rainfall records for the site and time period under study. These records are fitted to a suitable probability distribution and then converted to a standard normal distribution, with the index average value being zero (McKee & Edwards, 1993). Positive SPI values indicate above-average rainfall, while negative values reflect below-average rainfall. Because the SPI is a standardized index, it allows for the representation of both wetter and drier climatic conditions in the same way (Table 1). Although it can be used to track rainfall periods, its most common use is in assessing the duration, intensity, and magnitude of drought events (D. TIGKAS, 2013, p. 1336).

Table (1) Classification of drought conditions according to the Standard Rainfall Index (SPI)

SPI values	Classification
≤2	Very high humidity
1.5 و 1.99	Extremely high humidity
1 و 1.49	Moderate humidity
- 0.99 و 0.99	Approximately average humidity
- 1.49 و - 1	Moderate dryness
- 1.99 و- 1.5	Severe dryness
≥ 2	Very severe dryness

Source: D. TIGKAS, H. VANGELIS, TSAKIRIS, Water Resources Management in an Interdisciplinary and Changing Context, Porto, Portugal, 26th-29th June 2013, p1333.

The Standardized Precipitation Index (SPI) can be calculated across multiple timescales, enabling diverse applications. Depending on the drought impact, SPI values for 3 months or less may be useful for monitoring baseline drought, values for 6 months or less can be used to monitor agricultural impacts, and values for 12 months or longer can be used to monitor hydrological impacts. It is also possible to calculate the SPI on grid precipitation datasets, providing users with a wider range of options compared to those working with station-based data alone. The Standardized Precipitation Index is designed to measure rainfall deficits across multiple timescales, reflecting the impacts of drought on water resources needed by various decision-makers. The relatively short 6-month timescale is suitable for studying the response of weather patterns and soil moisture (agriculture) to variations in rainfall. Meanwhile, the flow of streams, reservoirs, and groundwater responds to longer-term variations in rainfall over timescales ranging from 6 months to 24 months or longer. **The standard rainfall index is the most commonly used due to its ease of application and the reliability of its results** (WMO, 2013, pp. 13, 14, 42).
Rainfall in Makkah is characterized by its scarcity, variability, and suddenness (Mashael Al-Otaibi, 2024, p. 1731). Table (1) and Figure (2) show a clear variation in monthly rainfall rates. Specifically, there is a noticeable fluctuation between wet and dry months when comparing the rates during the second period to the first. The months differ in their rates of change across the two periods, although rainfall rates generally trend upwards. Rainfall amounts in the second period (91.7 mm) were higher than in the first period (87.6 mm), a difference of 4.1 mm.
On a monthly basis, rainfall rates vary in their trend. They tend to increase during the months of September, October, December, January, March, May, June, July, and August, and decrease significantly in the remaining months. The rainy season in the first two periods begins in October and ends in May, with peak rainfall occurring in November and December. The period from June to August is dry. In the subsequent period, rainfall is distributed throughout the year, with peaks occurring in August and September.

As confirmed by Table (2) and Figure (2), most months showed SPI values close to the average across all months during the two study periods. This indicates a relatively homogeneous temporal distribution of rainfall throughout the year, with no significant differences. The results for the autumn months (September, October, and November), which mark the true beginning of the rainy season, show that autumn rainfall rates generally increased in the second period (1991-2024). Therefore, we find that September and October had higher SPI values in the second period compared to the first. The drought index in November of the second period increased by 0.22 compared to the first period. The results also confirm the recurrence of moderate to very humid levels in September and November of the period 1992-2024. Furthermore, the recurrence of moderate droughts in November of the same period, in contrast to the more frequent humid conditions observed during the first period, is also noteworthy.
Considering the typically wet months, which are the winter months (December, January, and February): we find that SPI values rose to near-average levels during December and January in the second period, while they decreased significantly in February by 0.26, increasing the likelihood of drought occurring and recurring during that month in the future.
As for the spring months (March, April, and May), a change is evident between the two periods. Rainfall in March and May was higher in the second period than in the first, which contributed to a decrease in drought during those months. However, rainfall decreased in April by 0.8 mm, leading to an increase in drought by 0.14, indicating the possibility of recurring droughts during this month.
The summer months (June, July, and August) are characterized as being close to average during both periods and are generally dry, but rainfall was higher in the second period than in the first.

Table (2) shows the change in rainfall rates/mm, Standard Rainfall Index (SP) for the period (1959-2024).

month	Periods	Average/mm	The difference in change	((SPI)	The difference in change	Description
September	first	0.2	1.9	-0.45	1.21	Approximately average
	Second	2.0		0.76		Approximately average
October	first	4.1	0.7	0.22	0.07	Approximately average
	Second	4.8		0.15		Approximately average
November	first	26.6	-2.2	0.13	0.22	Approximately average
	Second	24.4		-0.09		Approximately average
December	first	23.8	1.6	0.06	0.04	Approximately average
	Second	25.5		0.02		Approximately average
January	first	8.6	0.0	0.04	-0.01	Approximately average
	Second	8.7		0.05		Approximately average
February	first	7.9	-2.9	0.44	0.26	Approximately average
	Second	5.0		0.18		Approximately average
March	first	6.4	1.9	0.40	0.01	Approximately average
	Second	8.4		0.38		Approximately average
April	first	3.2	0.8	0.46	0.14	Approximately average
	Second	2.4		0.32		Approximately average
May	first	5.3	2.2	0.30	0.14	Approximately average
	Second	7.6		0.44		Approximately average
June	first	0.1	0.7	0.45	0.29	Approximately average
	Second	0.8		0.75		Approximately average
July	first	0.1	0.1	0.41	0.04	Approximately average
	Second	0.2		0.45		Approximately average
August	first	0.3	1.6	0.46	0.31	Approximately average
	Second	1.9		0.77		Approximately average
Annual	first	87.6	4.1	0.24	0.11	Approximately average
	Second	91.7		0.35		Approximately average

Source: Researcher's work based on data from the National Meteorological Center in Tripoli using DrinC and SPSS.

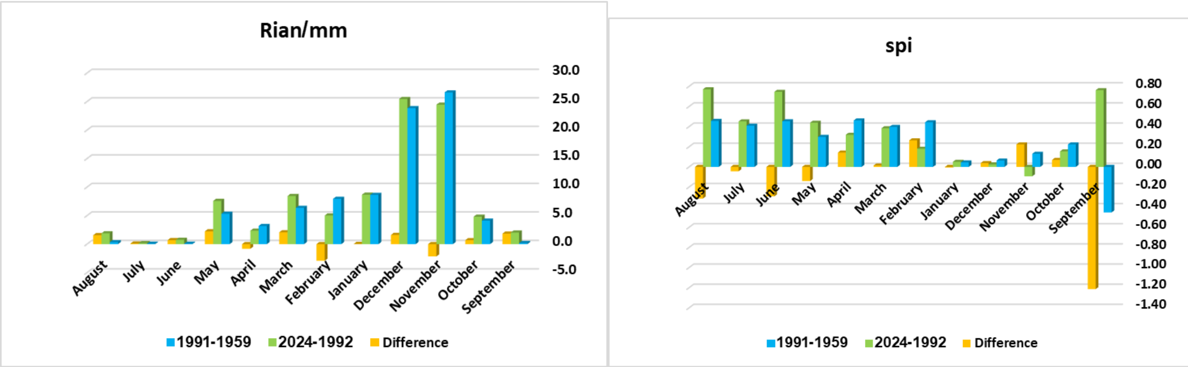

Figure (1) Change in rainfall rates, Standard Rainfall Index ((SP)) for the period (1959 - 2024).
Source: The researcher's work based on the data in Table (1).

Second: Frequency and Intensity of Drought and Wet Periods:

Table (3) presents the relative frequency (%) of the Standard Rainfall Index (SPI) values at both the monthly and annual levels for the Makkah region. This aims to illustrate the frequency of drought and wet periods throughout the year.

The results in Table (3) represent the frequency and intensity of drought and wet periods for the two study periods. At the annual level, we find that severe or extreme droughts were rare or completely absent, confirming that rainfall in the Makkah region tends to be moderate without recording extreme weather events. The average drought frequency was 1% in the first period and 6% in the second. The results also confirm that near-average drought levels were the most frequent during most months in both periods, as they were the predominant type. They occurred 86% in the first period and decreased to 75% in the second, a difference of 11%. Regarding average humidity, the second period was 1% wetter than the first. High humidity levels also saw a higher frequency in the second period compared to the first, by a difference of 3%. Extremely high humidity levels also increased in the second period compared to the first, by a difference of 1%, confirming that the region tends towards humidity rather than drought during the second period. This is accompanied by a relative improvement in humidity during the main rainy season.

The results of comparing the first and second periods indicate that the second period has a higher frequency of average drought periods during December and January, by a difference of 9% and 21% respectively, demonstrating a clear fluctuation in rainfall amounts during these months. February showed no significant improvement between the two periods. Meanwhile, high humidity levels increased in the second period compared to the first period for December by a difference of 9%, while remaining unchanged in January and February.

While the spring months remain relatively dry, there are slight indications of improved rainfall in the second period. Results confirm a rise in the average dryness level, ranging from 88% to 91% during March and April. This level then decreased in May from 91% to 88%. Regarding humidity, the results confirm high humidity levels in April and May. This suggests a relative improvement in rainfall towards the end of the rainy season, though it remains limited.

As for the summer months (June, July, and August) (the dry period), average dryness levels prevail, ranging between 82% and 97% in both periods. A clear change is observed, with a decrease in dryness rates during the second period compared to the first. The decrease was 24% in June, 10% in July, and 15% in August.

In autumn, the results show a relative improvement in humidity levels during the second period, specifically in September and October. The high humidity level rose to 18% in September (second period) after registering 0% in the first period, confirming a clear improvement in rainfall conditions during the second period. The region transitioned from near-total drought to more humid conditions. Rainfall fluctuated in November (second period), indicating a more severe drought compared to the first period.

Table (3) shows the relative frequency (%) of the standard monthly and annual rainfall index values for the Makkah region.

month	Periods	Very severe dryness	Severe dryness	Moderate dryness	Approximately average humidity	Moderate humidity	Extremely high humidity	Very high humidity
September	first	0	0	0	97	3	0	0
	Second	0	0	0	61	21	18	0
October	first	0	0	0	76	18	6	0
	Second	0	0	0	85	6	3	6
November	first	0	0	0	76	18	6	0
	Second	0	0	24	58	15	0	3
December	first	0	0	9	73	12	6	0
	Second	0	0	18	58	3	15	6
January	first	0	0	3	82	6	3	6
	Second	0	0	24	58	12	3	3
February	first	0	0	0	76	18	6	0
	Second	0	0	0	88	6	6	0
March	first	0	0	0	88	3	6	3
	Second	0	0	0	91	0	6	3
April	first	0	0	0	85	0	6	9
	Second	0	0	0	91	3	6	0
May	first	0	0	0	91	3	6	0
	Second	0	0	0	82	12	3	3
June	first	0	0	0	94	6	0	0
	Second	0	0	0	70	18	3	9
July	first	0	0	0	94	0	6	0
	Second	0	0	0	82	0	18	0
August	first	0	0	0	97	3	0	0
	Second	0	0	0	82	12	0	6
Annual	first	0	0	0	86	8	4	2
	Second	0	0	0	75	9	7	3

Source: The researcher's work based on the data in Table (1).

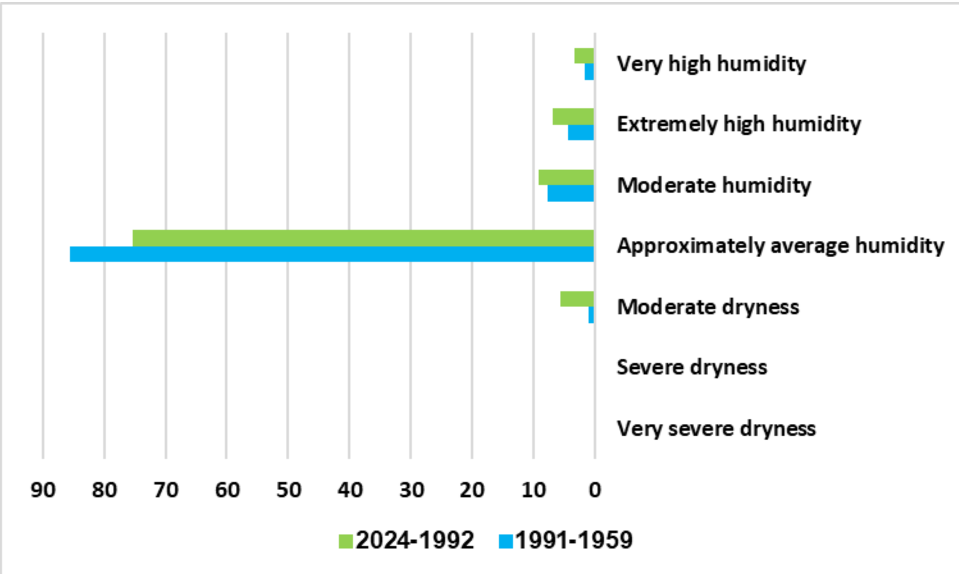

Figure (2) Relative frequency % of the classification of the standard index values for annual rainfall for the study area.

Source: The researcher's work based on the data in Table (2).

Findings:

1 .Drought directly affects plant growth because it limits the most essential element upon which plants depend for all their vital functions: water. The impact of drought on plants can be summarized as follows:

2 .The results indicated a trend in rainfall rates across the two periods, generally trending upwards. Rainfall amounts in the second period (91.7 mm) were higher than in the first period (87.6 mm), a difference of 4.1 mm.

3 .The results showed that the rainy season during the first period begins in October and ends in May. The peak rainfall occurs in November and December, while the period from June to August is dry. In the second period, rainfall is distributed throughout the year, with peak levels in August and September.

4 .The results showed that rainfall rates during the autumn months generally increased in the second period (1991-2024). Therefore, we find that the SPI values in September and October were higher in the second period compared to the first. The drought index in November was also higher in the second period compared to the first, by a difference of 0.22 mm. 5. The results confirm the recurrence of average to very humid levels in September and November during the period 1992–2024. There were also recurring periods of moderate drought in November of the same period, in contrast to the humidity levels observed during the first period.

6 .SPI values for the winter months rose to near-average levels during December and January in the second period, while they decreased significantly in February by 0.26.

7 .Spring months confirm the difference between the two periods. Rainfall in March and May was higher in the second period than in the first, which contributed to lower drought rates during those months. However, rainfall decreased in April by 0.8 mm, leading to an increase in drought rates by 0.14. This suggests a potential increase in the frequency of droughts during April in the future.

8 .All summer months were characterized as being near average during both periods and were generally dry, but rainfall rates were higher in the second period than in the first. 9- The study confirmed that the frequency of severe or extreme droughts was rare or nonexistent, indicating that rainfall in the Makkah region tends to be moderate without any extreme weather events. The frequency of moderate drought was 1% in the first period and 6% in the second.

10 -The results also confirm that near-average drought was the most frequent occurrence during most months in both periods, representing the most prevalent pattern. It occurred 86% in the first period and decreased to 75% in the second, a difference of 11%.

11 -Regarding average humidity, the second period was 1% more humid than the first. High humidity also saw a higher frequency in the second period compared to the first, by 3%. Extremely high humidity also increased in the second period compared to the first, by 1%, further confirming the findings that the region tends towards humidity rather than drought during the second period. This indicates a relative improvement in humidity during the main rainy season. 12- The quarterly results showed that spring remained relatively dry, but with slight indications of improved rainfall in the second period. The results confirmed high humidity levels in April and May, suggesting a relative improvement in rainfall towards the end of the rainy season, although it remained limited.

13 -As for the summer (dry period), near-average drought conditions prevailed, ranging between 82% and 97% in both periods. A clear change was observed, with a decrease in drought rates during the second period compared to the first. The decrease was 24% in June, 10% in July, and 15% in August.

14 -The autumn results confirmed a relative improvement in humidity levels during the second period, specifically in September and October. The high humidity level in September, the second period, rose to 18% after recording 0% in the first period. This indicates a clear improvement in rainfall conditions during the second period, as the region transitioned from near-total drought to wetter conditions.

Recommendations:

1 -Encourage researchers to focus on applying drought indicators using the Standard Rainfall Index (SPI) to assess drought in its various temporal and spatial dimensions, with the aim of providing a scientific basis for decision-makers in water resource and agricultural management.

2 -Develop early warning systems that rely on drought indicator results to monitor drought conditions periodically and link them to agricultural and water resource management programs at the local and regional levels.

3 -The study recommends implementing effective adaptation strategies to rationalize water use and encourage the cultivation of drought-resistant plant species.
4 -Integrate the study's findings into sustainable development plans to ensure the optimal use of natural resources in light of climate change.
5- Utilize the SPI in managing dams and reservoirs by predicting periods of scarcity or abundance to benefit from rainfall.

Compliance with ethical standards
Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

References:

1. IPCC (2021). Sixth Assessment Report (AR6) – Summary for Policymakers, P6. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf?utm_source=chatgpt.com

2. أسمهان علي المختار عثمان، تحليل ونمذجة درجات الحرارة في منطقة الزاوية للفترة 1961 – 2099 باستخدام التقنيات المكانية، أطروحة دكتوراه غير منشورة، مقدمة إلى مجلس كلية الآداب، قسم الجغرافيا، جامعة الزاوية، الزاوية، ليبيا، 2023، ص94.
/https://www.facebook.com/groups/1037255876355884/posts/7328533327228076

3. Yohannes Yihdego & Babak Vaheddoost3 &Radwan A. Al-Weshah, Drought indices and indicators revisited, Arabian Journal of Geosciences, 2019.P9. https://doi.org/10.1007/s12517-019-4237-z

4. Yohannes Yihdego & Babak Vaheddoost3 &Radwan A. Al-Weshah, Drought indices and indicators revisited, Arabian Journal of Geosciences, 2019.P1.
5. Sourav Mukhenee, Ashok Mishra, Kevin E. Trenberth, Climate Change and Drought: a Perspective on Drought Indices, Current Climate Change Reports, Springer International Publishing AG, part of Springer Nature 2018, P1. Springer DOI – Climate Change and Drought: a Perspective on Drought Indices https://doi.org/10.1007/s40641-018-0098-x

6. المنظمة العالمة للأرصاد الجوية (WMO) دليل المؤشرات والأرقام القياسية للجفاف مارس 2013 ص42.
7. إبراهيم درويش، آثار غطاءات الأرض واستخداماتها في تباين درجات الحرارة بمدينة مكة المكرمة والمشاعر المقدسة، مجلة العلوم الاجتماعية، مجلد45، العدد3، 2017، ص271.https://journals.ku.edu.kw/jss/index.php/jss/article/view/2303

8. مشاعل فهد مطلق العتيبي، المناخ الفسيولوجي في مدينتي مكة المكرمة وابها بالمملكة العربية السعودية (دراسة في المناخ التطبيقي)، مجلة الدراسات الإنسانية والأدبية، العدد 31 يونيو 2024، ص1731. https://journals.ekb.eg/article_443132.html

9. D. TIGKAS, H. VANGELIS, G. TSAKIRIS, Water Resources Management in anInterdisciplinary and Changing Context, Porto, Portugal, 26th-29th June 2013, P1327. https://www.researchgate.net/publication/349424413_Introduction_Water_Resource_Management_Within_the_Climate_Change_Context_in_Africa_Synthesis_Key_Findings_and_Future_Challenges

10. المنظمة العالمة للأرصاد الجوية (WMO) دليل المؤشرات والأرقام القياسية للجفاف مارس 2013 ص13.
11. Mckee, T.B., Doesken, N.J. and Kleist, J.1993. The relationship of drought frequency and duration times scales. American Meteorological Society. 8th Conference on Applied Climatology, 17-22 Janvier, Anaheim, 179-184 . https://www.droughtmanagement.info/literature/AMS_Relationship_Drought_Frequency_Duration_Time_Scales_1993.pdf?utm_source=chatgpt.com

12. D. TIGKAS, H. VANGELIS, G. TSAKIRIS, Water Resources Management in anInterdisciplinary and Changing Context, Porto, Portugal, 26th-29th June 2013, p1336 . https://drought-software.com/rf/DrinC_EWRA_Porto2013.pdf?utm_source=chatgpt.com

13. المنظمة العالمة للأرصاد الجوية (WMO) دليل المؤشرات والأرقام القياسية للجفاف مارس 2013 ص13 – 42.
https://www.droughtmanagement.info/find/guidelines-tools/handbook-drought-indicators-and-indices/?utm_source=chatgpt.com

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