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Modeling Trends in Rainfall Rates at Shahat Meteorological Station (1961 - 2050) Using Statistical Techniques

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الملخص:

يهدف البحث إلى التعرف على تقنية نموذج التصغير الاحصائي (Statistical Downscaling Model (SDSM))، ومعرفة الطرق التي تستخدم في توقع مناخ المستقبل. حيث سيتم الاعتماد على معدل هطول الأمطار لمحطة إرصاد شحات للفترة من (1961- 2020)، والتنبؤ بمعدلها نحو الزيادة أو النقصان مستقبلا (2021 – 2050) باستخدام SDSM وذلك بالاعتماد على سيناريوهات التغير المناخي (A2a) (B2a)؛ وهي سيناريوهات معتمدة لدى الفريق المعني بالتغير المناخي IPCC في تقرير عرف بـSRES في سنة 2000 لوضع توقعات للمناخ والبيئة بالاعتماد على غازات الاحتباس الحراري. إضافة إلى الاعتماد على أساليب التحليل الإحصائي المستخدمة في الدراسات المناخية بواسطةSPSS للكشف عن اختبار التباين في متوسطات معدلات هطول الأمطار السنوية والفصلية للفترات الثلاث، وهي: (1961-1990)، (1991-2020)، (2021 -2050)، ومن خلال استخدام تحليل اختبار ((One-way ANOVA، أظهرت النتائج اتجاهات للتغير في معدلات هطول الأمطار السنوية نحو الانخفاض مقارنة بالفترة الأولى، وتباينت فصليا وعند مستوى دلالة إحصائية أقل من 0.05. كما أكدت منحنيات الفروق المتجمعة على الاتجاه نحو الانخفاض في معدل هطول الامطار في محطة الدراسة خلال الفترات الثلاث باستثناء الفترة الخريفية من 2023-2039، وفصل الصيف حث يشهدان امطار اعلى من المعدل مقارنة بأول فترتين.

الكلمات الدالة: التصغير الاحصائي/ التغير المناخي/ معدلات هطول الامطار/ النموذج المناخي/ سيناريوهات المناخ/ SDSM.

Abstract:

This research paper aims to identify the Statistical Downscaling Model (SDSM) technique and the methods used to predict future climate. It relies on rainfall data from the Shahat meteorological station for the period from 1961 to 2020, and predict its increase or decrease in the future (2021-2050) using SDSM based on climate change scenarios (A2a) and (B2a), which are scenarios adopted by the IPCC climate change team in the SRES report in 2000 to make climate and environmental forecasts based on greenhouse gases. In addition, it will rely on statistical analysis methods used in climate studies by SPSS to detect variations in the means of annual and seasonal rainfall rates for the three periods: (1961-1990), (1991-2020), (2021-2050), using one-way ANOVA analysis. The results showed trends of decreasing annual rainfall rates compared to the first period, with seasonal variations and statistical significance level below 0.05. The cumulative difference curves also confirmed a trend of decreasing rainfall rates at the study station during the three periods, except for the autumn period from 2023-2039 and the summer season, which experienced higher than average rainfall compared to the first two periods.

Keywords: Statistical downscaling / Climate change / Rainfall rates / Climate model / Climate Scenarios / SDSM.

Introduction:

Modeling is known as a part of simulation of reality. Simulation processes have been developed primarily to obtain answers related to experiments that are difficult or impossible to perform. An example of this lies in the difficulty of finding accurate solutions when considering certain problems and scientific issues for which we want to find a solution. The model is defined as a formal framework for representing the basic characteristics of a complex system with a few key relationships. This model takes various forms such as shapes, mathematical equations, or computer programs (Attaei, 2012, p. 305, 307).

The global climate change has become inevitable today and cannot be avoided, and it will lead to changes in the Earth's climate characteristics and herald more impactful natural disasters. This necessitates changing our lifestyle, production, and consumption patterns, especially since controlling the magnitude of these changes is still within our reach.

Climate modeling is based on global climate models referred to as General Circulation Models (GCM). These models are also symbolic of digital models that combine physical interactions on the Earth's surface, in the ocean, atmosphere, and ice cover, to simulate the response of the global climate system to increased concentrations of greenhouse gases. They are used to make future projections of climate elements such as rainfall (Ricard, 2017, p. 41).

Global climate models use regional climate models (RCM) as inputs in analyzing and determining the strength of relationships between different climate elements. The models cannot directly provide information for smaller scales than their resolution capabilities, thus, a process called downscaling or size reduction has emerged. This method is used to reconstruct rainfall fields from low-resolution models to high-resolution fields by adapting the properties of large-scale models to be applied on smaller regions. The method, however, can be either dynamic, statistical, or a combination of both. The dynamic method requires nesting high-resolution specialized models within a less detailed global model (WMO, 2011, p. 6-11).

The significance of this study lies in applying these models to forecast future rainfall in the Shahat Meteorological Station until 2050. That is to understand the impact of climate change on its seasonal and annual rates, in order to present the results to policymakers in the agricultural and economic sectors in the Libyan state, so that they can take necessary actions and measures.

Significance of the study:

1. Due to the researchers' lack of interest in studying future prediction of climatic elements in general, and rainfall in particular, at the local level, this study has focused on this aspect to provide a scientific study that can be utilized.
2. Shahat Meteorological Station is characterized by the availability of continuous long-term climate data, especially for rainfall, making it an ideal model for the scientific application of the Statistical Downscaling Model (SDSM).
3. The use of modern statistical methods in climate studies and enriching libraries with such modern studies.
4. Assessment of the amount of change in rainfall rates at the Shahat Meteorological Station during the 21st century according to the proposed scenarios.

Objectives of the study:

This paper seeks to achieve the following objectives:

1. Applying the statistical downscaling model (SDSM) to derive a dataset for local rainfall at the meteorological station in Shahat.
2. Identifying the future trends and behavior of rainfall in Shahat (monthly, quarterly, and annually) based on simulations of important global models for climate forecasting and its scenarios during the period 2021-2050.
3. Presenting the study's findings to the relevant authorities to develop mechanisms and solutions for anticipated problems based on future annual and seasonal rainfall trends.

Statement of the problem:

1- Is there any change in the rates of seasonal and annual rainfall during my study period compared to the baseline period?
2- What is the overall trend of annual and seasonal rainfall rates at Shahat Meteorological Station during the two periods (1991-2020) and (2020-2050) compared to the baseline period (1961-1990)?
3- What is the amount of variation and change in the rate of seasonal and annual rainfall at the station for the period from 1961 to 2050?
4- To what extent has the change in rainfall rates affected the difference between dry and wet periods in the past?

Hypotheses of the study:

1) The seasonal and annual rainfall rates vary between increase and decrease compared to the baseline period (1961-1990).
2) There is a general trend towards a decrease in rainfall rates at the meteorological station compared to the baseline period, with a statistical significance level lower than 0.05.
3) The seasonal and annual rates of rainfall vary at the Shahat station during the study periods (1961-2050), with a significance level of 0.05.
4) The wet and dry periods in Shahat in the future (2021-2050) vary compared to past periods.

Delimitations of the study:

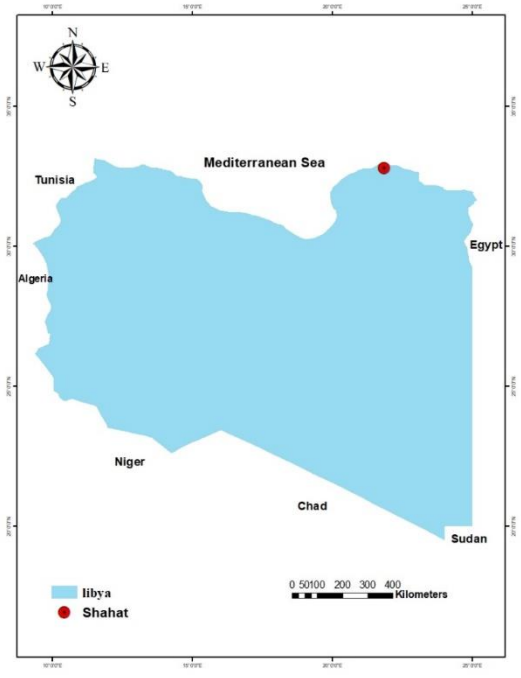
The Meteorological Station of Shahat is located in northeast Libya, at latitude of 32.8034486 degrees north and longitude of 21.8628205 east (Map 1). It is situated at an elevation of 621 meters and is a synoptic station with the international number 62056 (Al-Mellian et al., 2021, p. 35).

Methodology:

This study relied on the statistical analytical method for the daily averages of rainfall rates for Shahat station, issued by the Libyan National Meteorological Center, for the period (1990-1961). This was used in future simulation or modeling processes for the period 2021-2050, using the Statistical Downscaling Model (SDSM) technique, which is a tool used to support decision-making in future prediction of climate elements such as temperature, wind, and rainfall, based on greenhouse gas emission scenarios. This is to understand climate change over time during

the twenty-first century, represented by the HadCM3 model issued by the Hadley Center, affiliated with the United Kingdom Meteorological Office. Its performance aspects are operated in regional climate simulation based on the Global Climate Model (GCM), which is an approved tool and model by the International Panel on Climate Change (IPCC) (T. C. JOHNSM et al., 2006 p.13-27). The statistical package software (SPSS) is also used to perform statistical analyses to confirm trends and variations.

Map (1) Shahat Meteorological Station



Source: The researchers used GIS based on (The National Atlas, 1978, p25)

The first topic: **<u>Seasonal and annual variations in rainfall rates at Shahat meteorological station during the period (1961-2050).</u>**

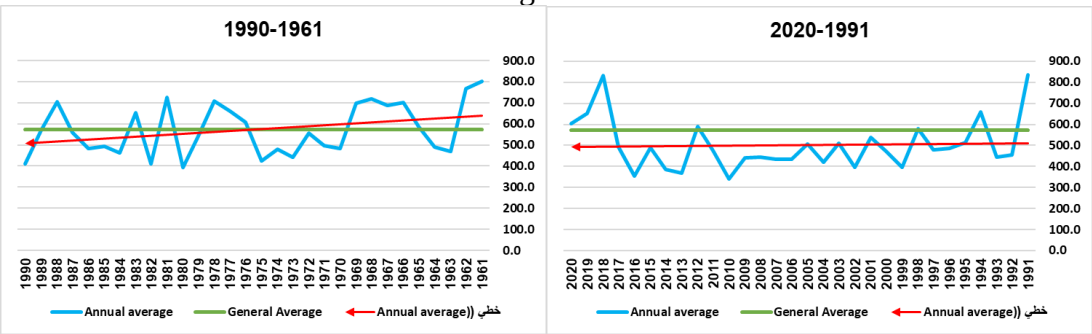
The results of simple linear regression showed a clear downward trend in the annual rainfall rates at the Shahat meteorological station, as well as variability in the seasonal rates in the second and third periods compared to the first period. The results of the linear regression analysis - Table (1) and Figure (1) - indicated the presence of negative values for the variable (b) in the annual rates of the second and third periods (future periods) compared to the baseline period (1961-1990), without statistical significance. The regression coefficient b was (-4.471, -0.615, -0.265) respectively.

We can further infer from Table (1) and Figure (1) that the general trend of the seasonal rainfall rates at the Shahat meteorological station in autumn, winter, and spring is clearly decreasing during the three periods, as indicated by the negative values of b. However, in summer, the results showed positive values for the variable (b) in the summer rates of the third period (future period) compared to the first two periods.

Table (1): The overall trend of seasonal and annual rainfall rates at the Shahat meteorological station for the period (1961-2050).

Seasons	Period	Mean	Std. Deviation	(R)	(R^2)	(B)	(sing)
Autumn	1961 - 1990	133.4	47.738	0.227	0.052	-1.232	0.203
	1991 - 2020	101.5	49.273	0.187	0.035	-1.045	0.323
	2021 -2050 A2a	123.3	51.568	0.444	0.197	-2.603	0.014
Winter	1961 - 1990	331.8	126.174	0.274	0.075	-3.830	0.143
	1991 - 2020	323.6	110.054	0.122	0.015	1.526-	0.520
	2021 – 2050 A2a	143.7	82.497	0.151	0.023	1.414-	0.426
Spring	1961 - 1990	102.9	59.201	0.119	0.014	0.798-	0.532
	1991 - 2020	74.7	45.536	0.243	0.059	-1.256	0.195
	2021 -2050 A2a	90.9	19.152	0.452	0.204	0.983-	0.012
Summer	1961 - 1990	4.3	7.256	0.131	0.017	-0.108	0.492
	1991 - 2020	1.3	3.176	0.443	0.196	-0.160	0.410
	2021 -2050 A2a	15.9	5.454	0.095	0.009	0.059	0.616
Annual	1961 - 1990	572.4	120.737	0.326	0.106	-4.471	0.003
	1991 - 2020	500.9	121.002	0.045	0.002	-0.615	0.032
	2021 -2050 A2a	373.9	83.402	0.028	0.001	-0.265	0.002

Source: The researchers relied on data from the National Meteorological Center in Tripoli using SDSM & SPSS.



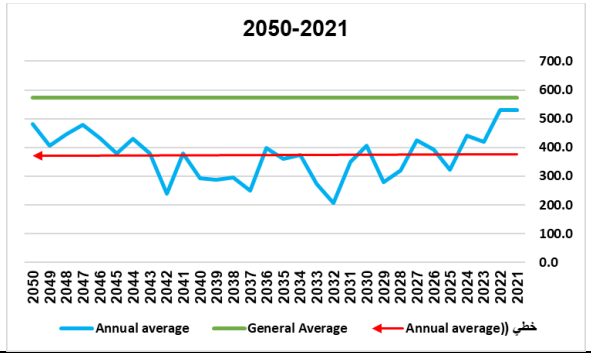
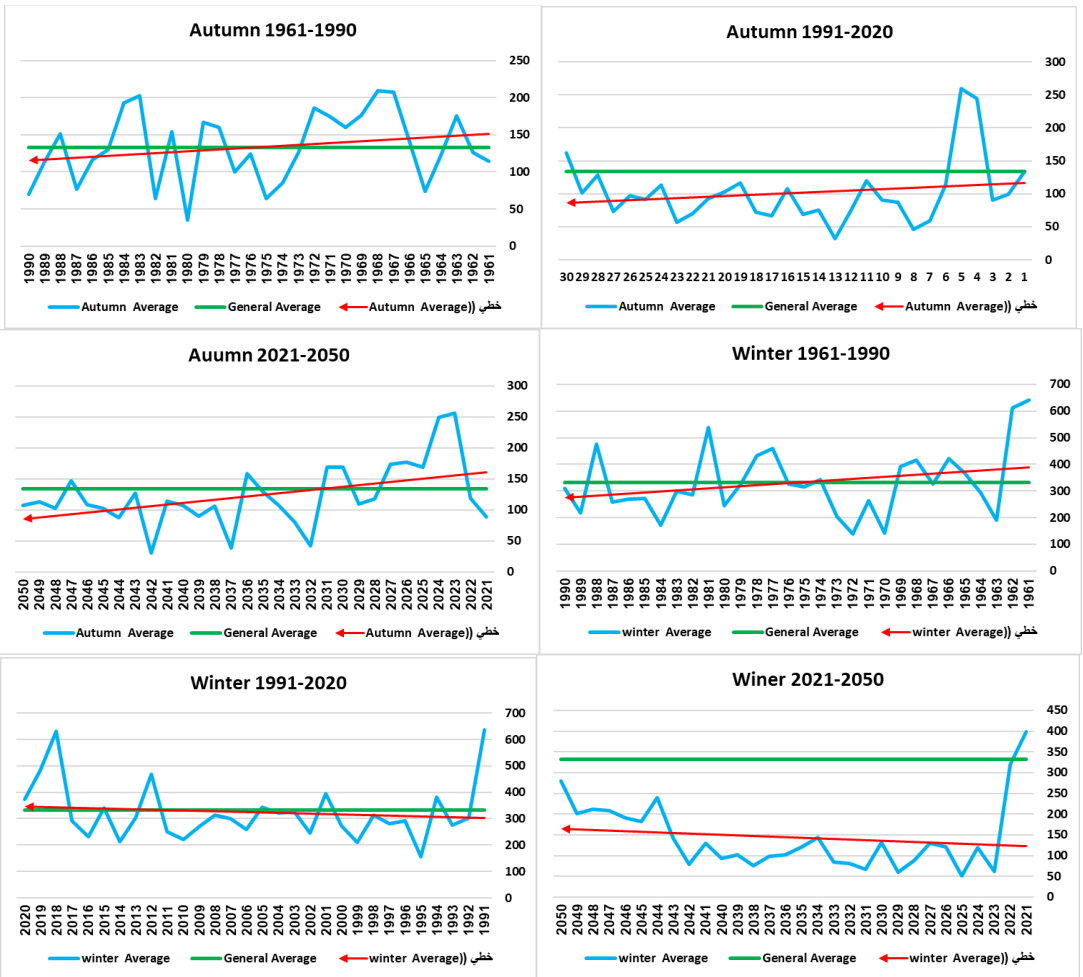


Figure (1). The overall trend of the annual mean maximum temperature at Shahat station for the period 1961-2050.
Source: The researchers worked by relying on Table (1) using Microsoft Excel 2010



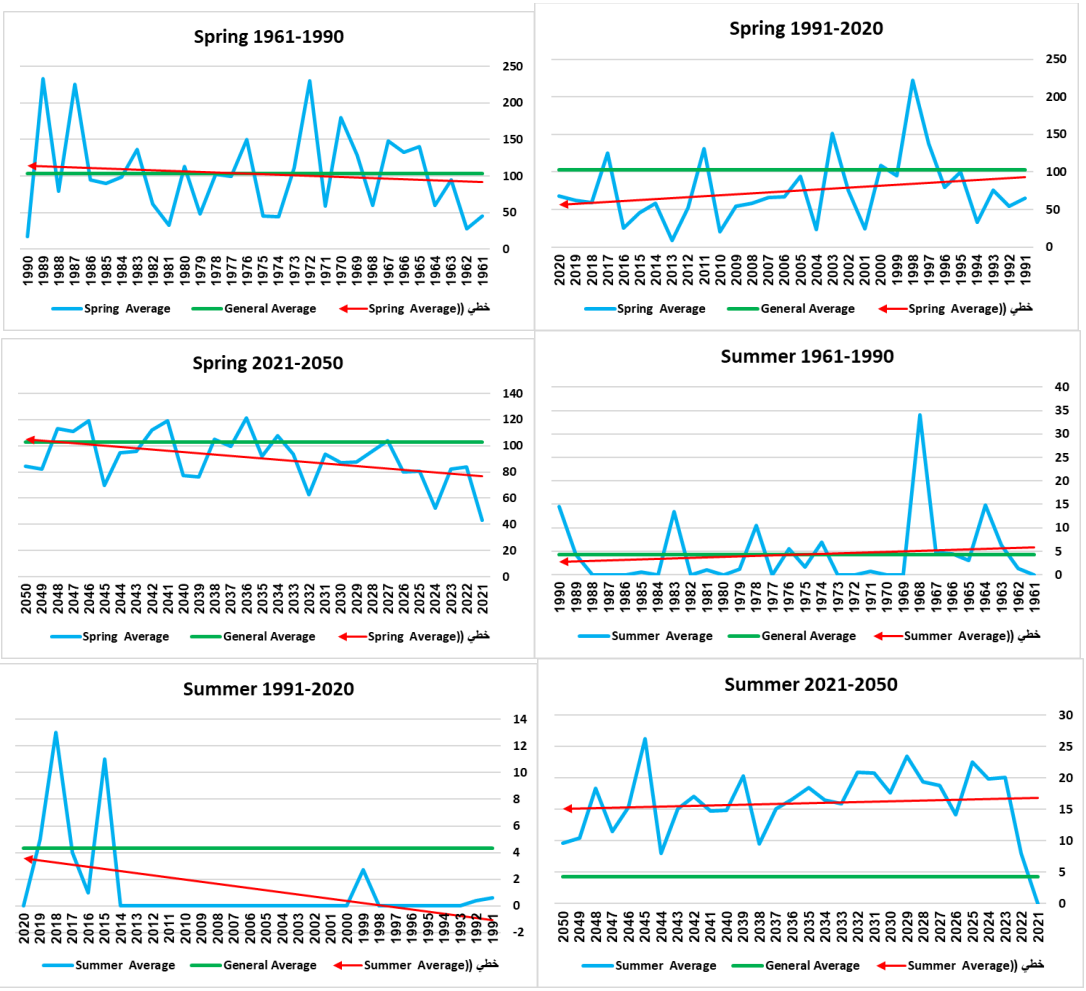


Figure (2). The general trend of seasonal rainfall at the Shahat station for the period 1961-2050.

Source: The researchers worked by relying on Table (1) using Microsoft Excel 2010

The second topic: <u>Analysis of Variance (One-way ANOVA) on the average rainfall rates at the meteorological station in Shahat during the period (1961-2050)</u>

The test of one-way analysis of variance is one of the laboratory tests used to compare means. It is a test used to determine whether there are differences between means or not, in order to identify what makes one mean different from other means (Ibrahim, 2004, p. 350).

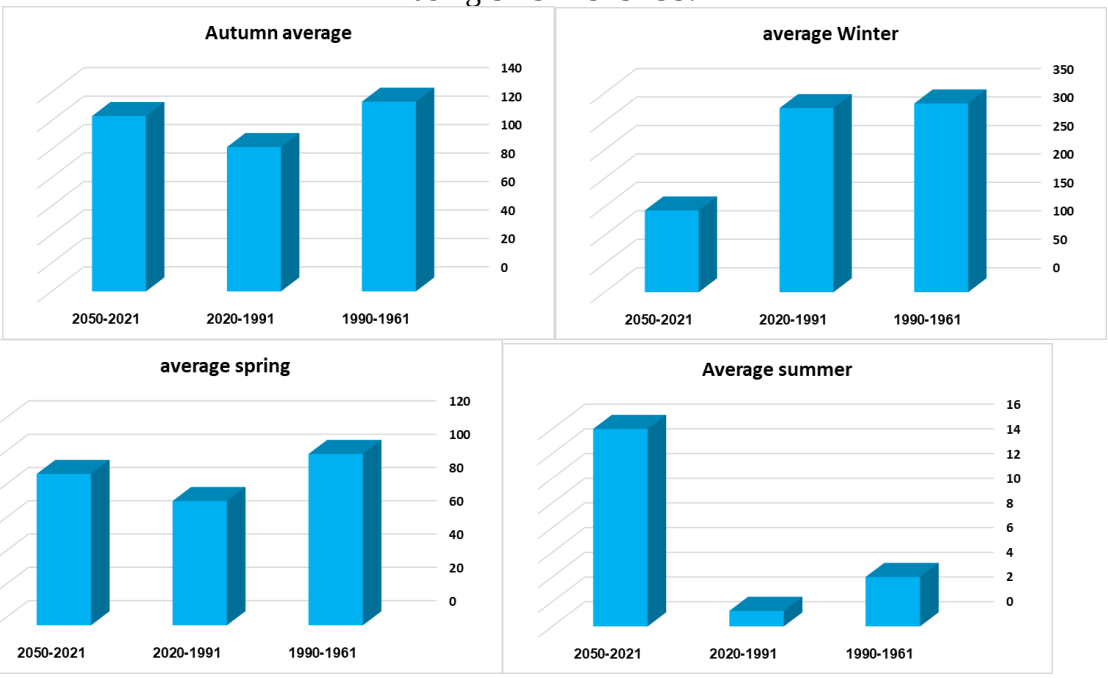
Through tables (2) and (3), the results of annual and seasonal variations confirmed the existence of variations in rainfall rates between the three periods in favor of the first period (1961-1990). The rainfall rate decreased by a difference of 71.5 mm in the second period, and in the future period, the difference reaches 198.5 mm compared to the baseline period, with a statistical significance level of less than 0.05.

The results of seasonal variations further confirmed that rainfall rates are decreasing in the future period during all seasons except for summer, where rainfall will increase by a difference of 11.6 mm, with a statistical significance level.

The table (2). One-way variance test for the quarterly and annual rainfall averages at the Shahat meteorological station for the period (1961-2050).

Seasons	Period	Mean	Difference in average	Std. Deviation	(sing)
Autumn	1961 - 1990	133.4	-	47.738	0.044
	1991 - 2020	101.5	31.9	49.273	
	2021 -2050 A2a	123.3	10.1	51.568	
Winter	1961 - 1990	331.8	-	126.174	0.000
	1991 - 2020	323.6	8.2	110.054	
	2021 -2050 A2a	143.7	188.1	82.497	
Spring	1961 - 1990	102.9	-	59.201	0.053
	1991 - 2020	74.7	46.2	45.436	
	2021 -2050 A2a	90.9	30	19.156	
Summer	1961 - 1990	4.3	-	7.256	0.000
	1991 - 2020	1.3	3	3.176	
	2021 -2050 A2a	15.9	11.6	5.454	
Annual	1961 - 1990	572.4	-	120.737	0.000
	1991 - 2020	500.9	71.5	121.002	
	2021 -2050 A2a	373.9	198.5	83.402	

Source: The researchers relied on data from the National Meteorological Center in Tripoli using SDSM & SPSS.



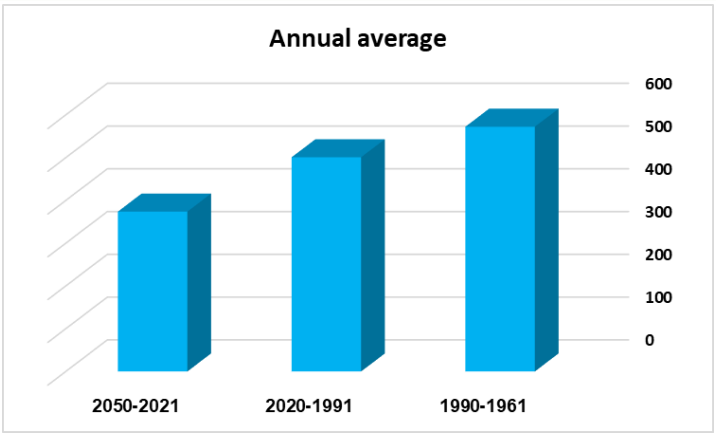


Figure (3). One-way analysis of variance for rainfall averages test for the period (1961-2050)

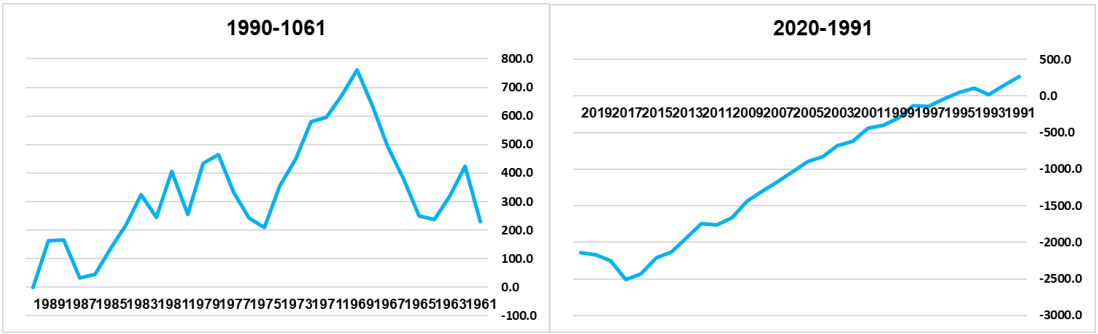
Source: The researchers relied on table (2) using SDSM & EXCEL.

The third topic: Cumulated Sums:

The cumulated or cumulative differences are a statistical method that is not affected by the average or size of the data, and it is the sum of the standard deviation for each year with the subsequent year. It is used to confirm the trend changes that occurred in the time series of annual and seasonal maximum temperatures at the Zwarah meteorological (Saleem, 2019, p.167).

Figure (4) confirms that rainfall rates generally tend to decrease during the three periods, and the curves show more clearly the years in which rainfall rates are higher or lower than the average during the three periods.

For the annual average rainfall in the Shahat station for the first period, there is a downward trend at the end of the period, but it confirms that the period from 1969-1973 was a rainy period. As for the second period 1991-2020, we find that it witnessed an increase in the beginning of the period from 1991-1999, while the curve of the future period shows that rainfall rates will be higher than the average in the beginning of the future period from 2021-2023, and then the curve indicates a decrease towards the end of the period.



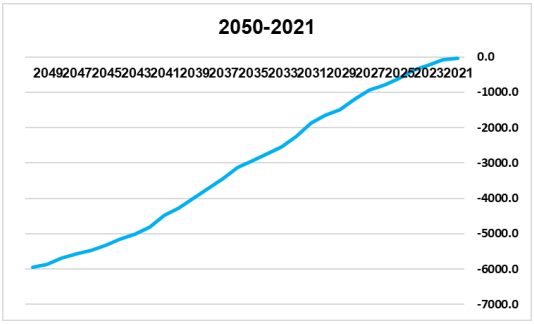
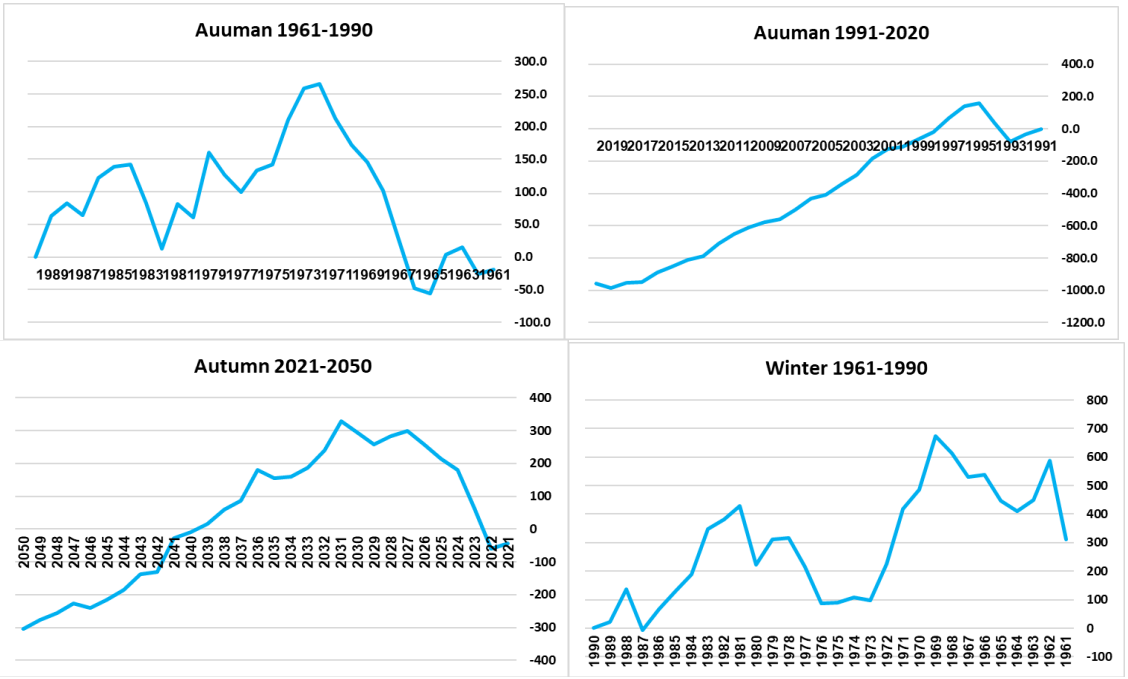


Figure (4). The cumulative annual differences curves of rainfall rates for the period (1961-2050).

Source: The researchers relied on data from the National Meteorological Center in Tripoli using SDSM & EXCEL.

As for the seasonal level, the results of the cumulative difference curves indicate in figure (5) in the autumn season an overall increase in its rates in the first period, while the second period witnessed an increase in its rates from 1994-1999, while we find higher autumn rates than the initial rate from autumn 2023 until autumn 2039, then it returns to a decreasing trend again.

As for the winter and spring seasons, the curves indicate a decrease in rainfall rates in the future period from 2021-2050 compared to the first and second periods. As for the summer season, we notice that it witnessed fluctuations in the first period, then a decrease from the average in the second period, and in the third period it indicates a general increase in its rates.



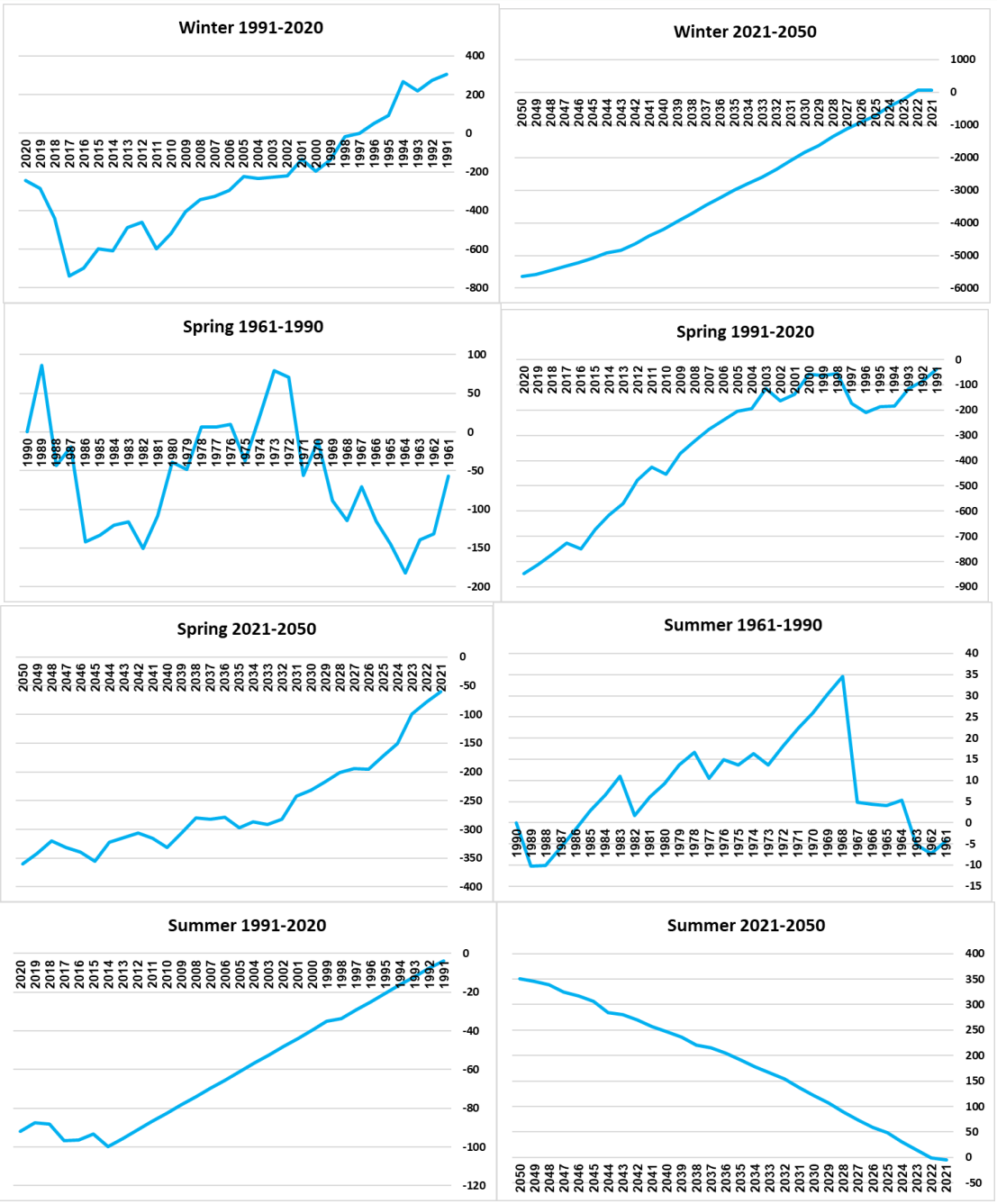


Figure (5) Cumulative difference curves of seasonal rainfall for theperiod (1961-2050).

Source: The researchers relied on data from the National Meteorological Center in Tripoli using SDSM & EXCEL.

Findings: -

1. The rainfall rates at the Shahat meteorological station show a general downward trend in the second and third periods compared to the baseline period, with a statistical significance level of less than 0.05.

2. The results of the annual and seasonal variations confirm the existence of variations in rainfall rates among the three periods in favor of the first period (1961-1990). The rainfall rate decreased by 71.5 mm in the second period, and in the future period, the difference reaches 198.5 mm compared to the baseline period, with a statistical significance level of less than 0.05. However, the variation test in the summer season confirms that the rainfall rate increases by 11.6 mm, with statistical significance.
3. The cumulated differences indicate that the rainfall rates for the future period generally tend to decrease, while the autumn rates for the period from 2023-2039 increase. This aligns with the data from the National Meteorological Center regarding autumn rainfall in 2023. In September 2023, during Storm Daniel, Shahat recorded rainfall rates higher than the average, with 161 mm in a single day from 8 am on September 10th, 2023, to 8 am on September 11th, 2023. This is higher than the baseline average of 133.4 mm.

Recommendations: -

1) The clear decrease in rainfall rates, especially in the winter and spring seasons, warns of several risks resulting from climate change in the coming years, and Libya is one of the most vulnerable countries to these risks, especially in relation to agricultural activity.
2) Decision-makers must take necessary and urgent measures to address these risks, such as floods and destructive flash floods, the recurrence of heatwaves and drought coinciding with the scarcity of groundwater in all regions, as well as the expansion of desertification and the loss of soil fertility and properties, which will have a significant impact on agricultural and urban lands. Therefore, raising awareness about these risks and rationalizing water use is essential to reduce drought and desertification.
3) The increase in autumn rainfall rates during the period from 2024 to 2039 warns of the recurrence of Mediterranean storms in the eastern region, such as the storm Daniel that occurred in the autumn of 2023 and resulted in loss of life and property.
4) It is important to emphasize the focus on monitoring operations and improving them by providing advanced measuring equipment and devices, developing capacities, and enhancing the efficiency of those working on them, to obtain accurate and reliable climate data that support scientific research projects and formulate scientific recommendations, through which future decisions are made in favor of the country.
5) The Government should give great importance to supporting scientific research projects on the future prediction of climate change, which aim to provide a unique approach to the risks involved.

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