ESJ Natural/Life/Medical Sciences Peer-reviewed

Temporal Variability of Rainfall and Trend Analysis of Melloulou Watershed in Morocco

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Doi:10.19044/esj.2024.v20n6p139

Submitted: 20 October 2023
Accepted: 13 February 2024
Published: 29 February 2024

Cite As:
Yassine B. & Youssef B.B. (2024). *Temporal Variability of Rainfall and Trend Analysis of Melloulou Watershed in Morocco*. European Scientific Journal, ESJ, 20 (6), 139. https://doi.org/10.19044/esj.2024.v20n6p139

Abstract

This paper focuses on analyzing the temporal variability of rainfall and rainfall trends using a statistical analysis of rainfall data in the Melloulou watershed for a half-century chronicle (1970-2020). The objective of this study is to extract all the rainfall characteristics and the rainfall variability during this period to determine the rainfall trends. The working method is based on a statistical approach to detect the climatic characteristics of the Melloulou basin. The study of the standardized precipitation index (SPI) and the rainfall deficit index (RDI) showed the alternation of very long dry periods with wet periods. The Mann-Kendall test under the RStudio also showed a decreasing rainfall trend.

Keywords: Climate variability, trend, SPI, RDI, Melloulou Basin

Introduction

Climate variability is a global climate phenomenon that affects many countries in the world according to the work of the Intergovernmental Panel on Climate Change. The increase in the frequency of the occurrence of weather extremes has been identified as a major global environmental concern. The significant societal, ecological, and economic consequences of climate extremes, such as dry spells, are everywhere in the world (Kaur, 2022).

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

Since the early 1980s, the southern shore of the Mediterranean has experienced a series of dry years (Zamrane, 2016). However, Morocco is currently experiencing the longest dry period in its modern history, which is characterized by a decrease in precipitation and a clear upward trend in temperatures (Driouech et al., 2010). During the last decades, the extension of dry episodes has become structural in the Mediterranean, including Morocco (Sebbar et al., 2013). The climate of the latter is predominantly semi-arid hot, dry summers, occasional droughts, and mild, relatively wet winters (Critchfield, 1983).

The Melloulou watershed is part of this Mediterranean area, which is located in the northern Middle Atlas and in the southwestern part of the Guercif plain. It occupies an area of 2589 km ². The climate of this area is marked by seasonal thermal contrasts and very clear irregularities in rainfall. As a result, it experiences frequent periods of drought that have directly impacted the forest and soil formations. Also, precipitation is a fundamental component of the climate, and changes in its patterns can have large implications to human health, ecosystems, plants, and animals in general and in particular (Chakraborty, 2022).

In this variable and rainy climatic context, the present study is focused on using a complete and homogeneous meteorological series to analyze the rainfall trend on an annual, seasonal, and monthly scale in the Melloulou watershed. For this purpose, a statistical approach was adopted to promote a chronological analysis of this climatic phenomenon.

Consequently, a correct climatic analysis requires the use of a complete and homogeneous weather series (Fratianni *et al., 2010*). This analysis allows us to identify the rainfall trend at the scale of the Melloulou watershed.

1. Materials and Methods

1.1 Location of the Study Area

Our study area is drained by the Oued Melloulou, which represents one of the main tributaries of the left bank of the Moulouya whose confluence with the latter is located near the city of Guercif. The watershed of Oued Melloulou is located in the Eastern Middle Atlas, and it covers an area of 2589 km². Oued Melloulou covers a distance of about 100 km from its source, located on Lake Tameda, to its confluence with the Moulouya in Guercif (Mabrouki et al., 2017). The Melloulou watershed extends, in a triangular shape, from SW to NE bounded by latitudes 33°32'N, 34°13'N and longitudes 3°22'W, 4°15'W, and opens onto the northern part of eastern Morocco. It is bounded to the north and northwest by the Inaouène watershed (tributary of Oued Sebou), to the west by the basin of the upper Sebou, and to the southeast by the basin of the middle Moulouya. It is characterized by a highly variable topography ranging

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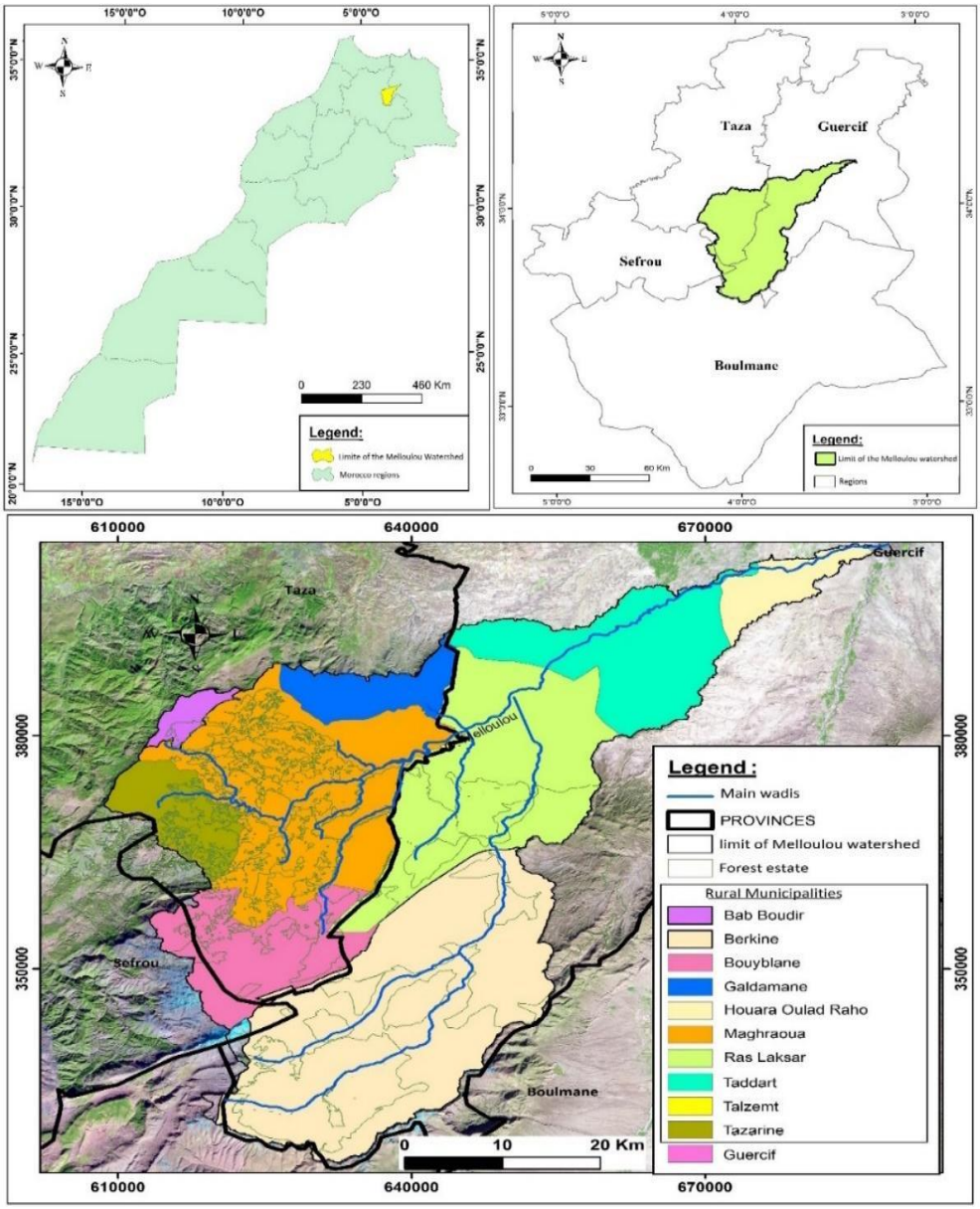
from the plains of the Northeast (plain of Guercif) to the high peaks of the northern Middle Atlas. Administratively, the Oued Melloulou watershed is shared by the territorial division between the provinces of Guercif (157595.41 ha), Taza (94281.50 ha), Sefrou (6548.46 ha) and Boulemane (659.05 ha) with the total area of 60.82%, 36.39%, 2.52% and 0.25% of the basin respectively (DPEF GUERCIF).

Figure 1. The geographical location of the Melloulou watershed



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1.2 Data

The study of climate and its variability is based on the annual rainfall series recorded at three stations located in the Melloulou basin (Table 1). The data was gotten from the Moulouya Water Basin Agency (ABHM) and the Provincial Directorate of Water and Forests in Guercif (DPEF). They are of variable quality. Among the stations located in the study area, three stations were selected whose coordinates and characteristics are shown in Table 1 below:

Table 1. The coordinates of the stations retained in the Melloulou watershed

Stations and Coordinates	Duration of Observations	Longitude	Latitude	Altitude (m)
Belfarah	1970- 2020	657000	391200	600
Berkine	1970- 2020	647900	354900	1000
Guercif	1970- 2020	689000	404400	332

1.3 Methodology

The study of the temporal variability of rainfall and the measurement of its trend requires the acquisition of a long series of reliable rainfall data. The reference period is from 1970 to 2020. To define the statistical characteristics of the chronicle studied (1970 - 2020) of the stations of Berkine, Belfarah and Guercif, a series of statistical tests have been applied to identify the different variations of rainfall and to extract information on the climatic characteristics that the study area has experienced. Our choice of stations was based on two criteria: complete observation series and a relatively homogeneous spatial distribution of stations. To carry out this study on the rainfall recorded at the three stations at the annual, seasonal and monthly scales, we applied the following approach:

- Firstly, we made a purely statistical study of rainfall to determine the characteristics of the variation in rainfall amounts and to analyze the frequencies of annual rainfall.
- Secondly, we calculated the Standardized Precipitation Index, which is called in English 'Standardized Precipitation Index' (SPI) created by McKee to determine wet and dry periods. However, this standardized rainfall index (SPI) reflects either the rainfall surplus or deficit for the year under consideration in comparison with the average rainfall of the study period (Abdou et al., 2008). It is expressed by the following formula:

$$SPI = \frac{(Xi - Xm)}{Si}$$

Where:
Xi is the cumulative rainfall for a year i;
Xm is the average rainfall observed for a given series;

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Si is the standard deviation of annual rainfall for a given series.

➢ Thirdly, the use of rainfall deficit index (RDI) allows us to identify and calculate the percentage of the number of deficit years. The positive value indicates a wet year, while the negative value indicates a dry year. It is expressed by the following formula:

$$RDI\ (\%) = ((Pi-Pm)/Pm)*100$$

Where:
RDI: Rainfall Deficit Index (in percent);
Pi: Annual precipitation (in mm);
Pm: Average precipitation (in mm).

➢ The final phase of this approach was reserved for the analysis and verification of rainfall trends, by applying the Mann-Kendall test using the RSTUDIO software. This test is commonly used to detect monotonic trends in a series of environmental, climatic, and hydrological data (Pohlert, 2018). The Mann-Kendall test is defined as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sig}\left(X_j - X_i\right),$$

$$\operatorname{sgn}\left(X_j - X_i\right) = \begin{cases} +1 & \text{if } \left(X_j - X_i\right) > 0 \\ 0 & \text{if } \left(X_j - X_i\right) = 0 \\ -1 & \text{if } \left(X_j - X_i\right) < 0, \end{cases}$$

Consequently, a positive value of S indicates that there is an increasing trend and vice versa (Yadav, 2014). The S statistic is approximately a normal distribution when n>0. The mean of S is zero and the variance can be calculated as follows:

$$\operatorname{Var}(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i \left(t_i - 1\right)\left(2t_i + 5\right) \right]$$

Where ‘n’ is the number of data in the series under study, ‘m’ is the number of related groups, and ‘ti’ is the number of data in the group of order ‘I’ (Sintayehu et al., 2021).

The presence of a significant trend is assessed by applying the following formula:

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$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\mathrm{VAR}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{S+1}{\sqrt{\mathrm{VAR}(S)}} & \text{if } S < 0. \end{cases}$$

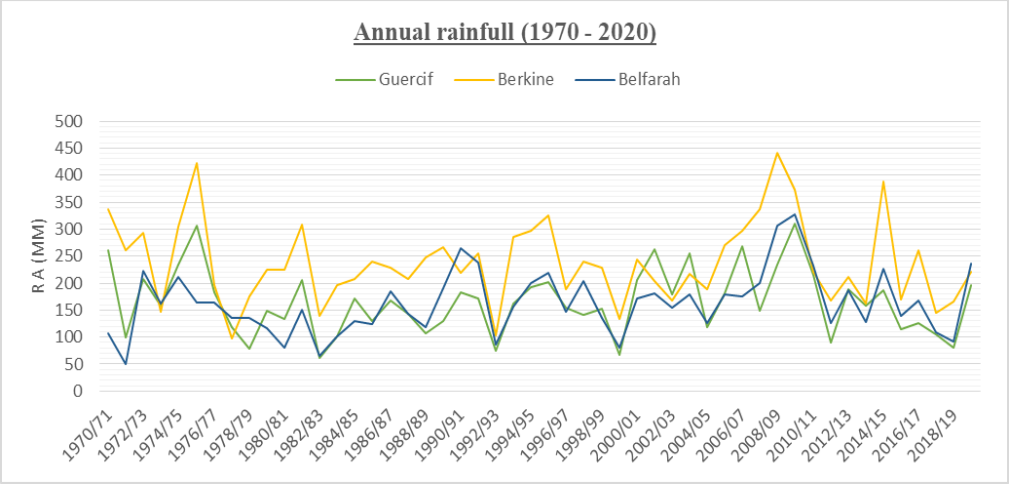
Zero values of Z indicate no trend, positive values of Z indicate increasing trends, and negative values of Z indicate decreasing trends.

2. Results

2.1 Analysis of Annual Rainfall

The annual rainfall in the Melloulou watershed is low in terms of quantities. They are between 50.20 mm recorded in 1971 in Belfarah and 442 mm recorded in 2009 in Berkine (Figure 2). They have experienced a variability of about 300 mm.

Figure 2. Annual Rainfall in the Melloulou Watershed



2.2 Frequency Analysis of Precipitation

The frequency analysis is a statistical method that allows us to designate different climatic states (dry, wet ...) during the studied chronicle. The frequency analysis of the annual rainfall, which amounts for the period 1970-2020, allows us to determine the distribution of these amounts during the indicated chronicle (Figure 3).

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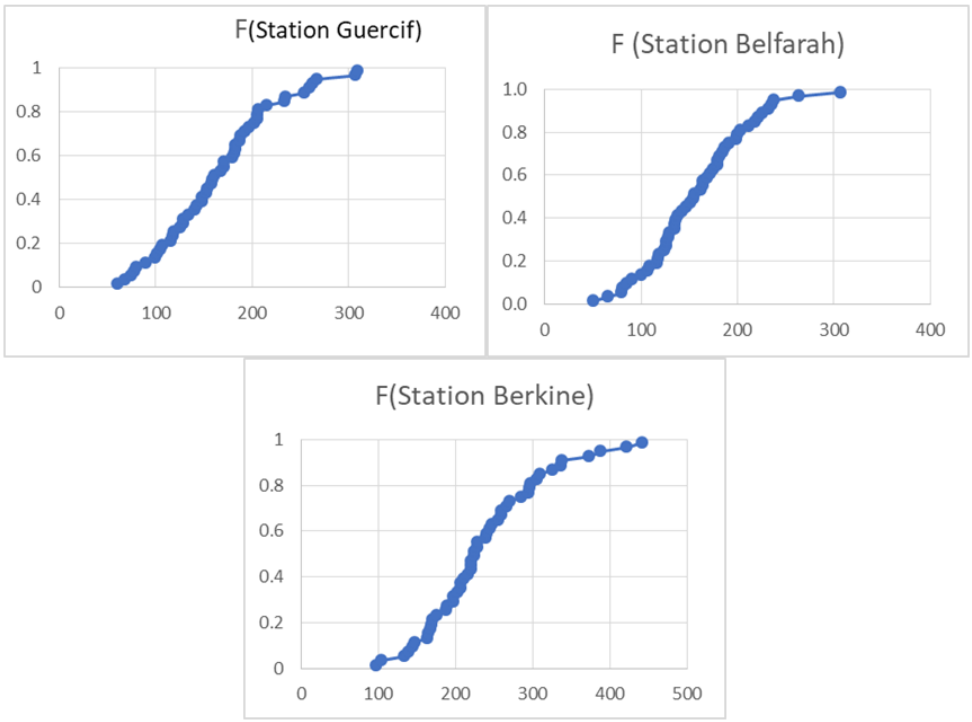

Figure 3. Frequency Analysis of Precipitation

The analysis of rainfall amounts allows us to divide the years into four classes:

✔ Years with a frequency of less than 0.25 are considered dry years
✔ Years with a limited frequency between 0.25-0.75 are moderate years
✔ Frequency years between 0.75-0.90 represent wet years
✔ Years with frequency greater than 0.90 are obviously very wet years

From the results obtained (Table 2), we can see that there is a great homogeneity between the measuring stations and a perfect equality of dry, moderate, wet, and very wet periods in the Melloulou basin. Therefore, this means that these three stations are subject to the same climatic factors.

Classes	Frequency	Station Guercif (Number of Years)	Station Belfarah (Number of Years)	Station Berkine (Number of Years)
Dry year	F<0.25	13	13	13
Moderate year	0.25<F<0.75	25	25	25
Wet year	0.75<F<0.90	7	7	7
Very wet year	F>0.90	5	5	5

Table 2. Frequency Analysis of Annual Precipitation (1970-2020)

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2.3 Analysis of Monthly Rainfall

The purpose of the study of the monthly rainfall regime is to understand the distribution of rainfall during the year in the Melloulou watershed.

We based our study on the 50-year averages observed in the stations of Guercif, Belfarah, and Berkine. From Figure 4, we can say that the average monthly precipitation decreases from upstream to downstream. The wet period begins in September in the station of Berkine and in October in the station of Guercif and Belfarah, and it lasted until May. The months of February, March, and April recorded the maximum values with monthly averages of about 71 mm, 68 mm and 87 mm, respectively. Also, the minimum monthly averages were recorded in July: 1.5 mm in Guercif and Belfarah and 7.29 mm in Berkine. The summer months receive significant rainfall, which corresponds to stormy rains during the summer period.

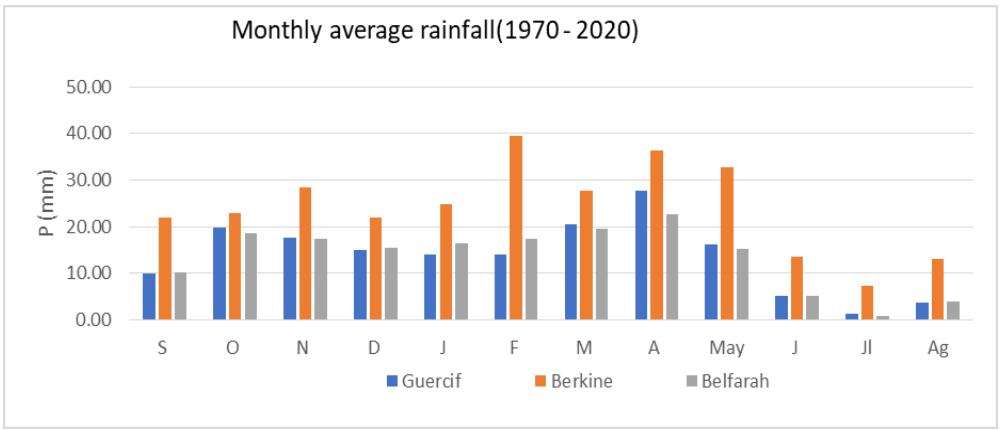

Figure 4. Average Monthly Rainfall

2.4 Seasonal Rainfall

Seasonally, rainfall is concentrated in spring (March, April and May) with an average of 64.48 mm in Guercif, 97.07 mm in Berkine, and 57.63 mm in Belfarah during the period from 1970 to 2020. Winter and autumn are more or less wet, with a slight difference in seasonal averages. Also, summer is relatively dry (Figure 5).

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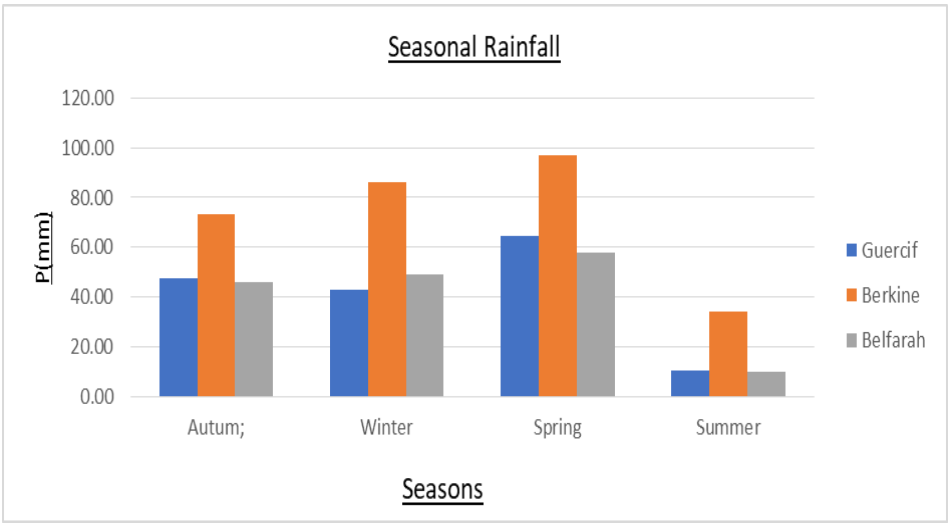
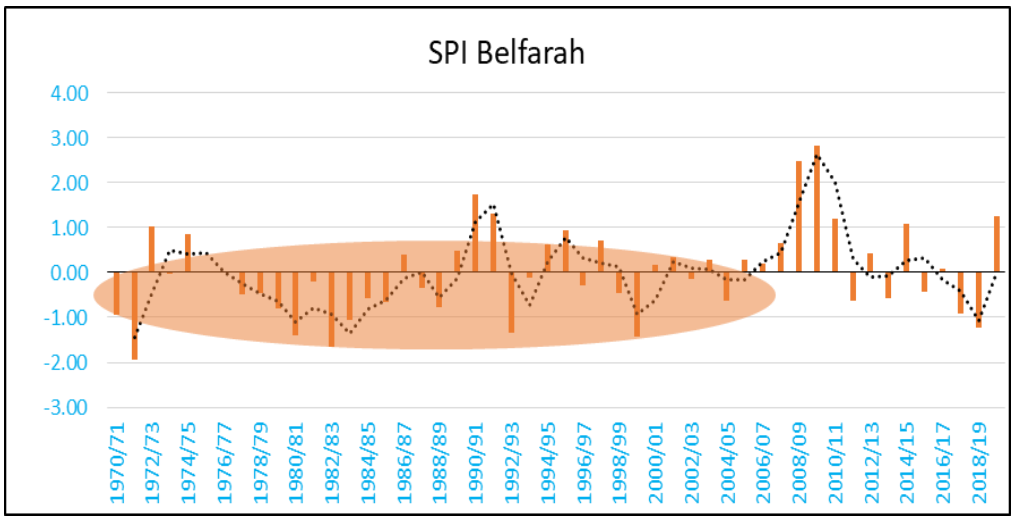


Figure 5. Average seasonal rainfall from 1970 to 2020

2.5 Standardized Precipitation Index (SPI)

The advantage of the SPI index is its adaptation to different periods of time, and it allows for early detection of drought situations (Bouly et al., 2020). The statistical analysis and the calculation of the SPI were carried out on the cumulative rainfall of the agricultural year. This index defines the severity of the drought. Negative annual values indicate drought compared to the reference period, while positive values indicate wet conditions. The results obtained from the calculation of the standardized rainfall index in the Melloulou watershed are shown below:



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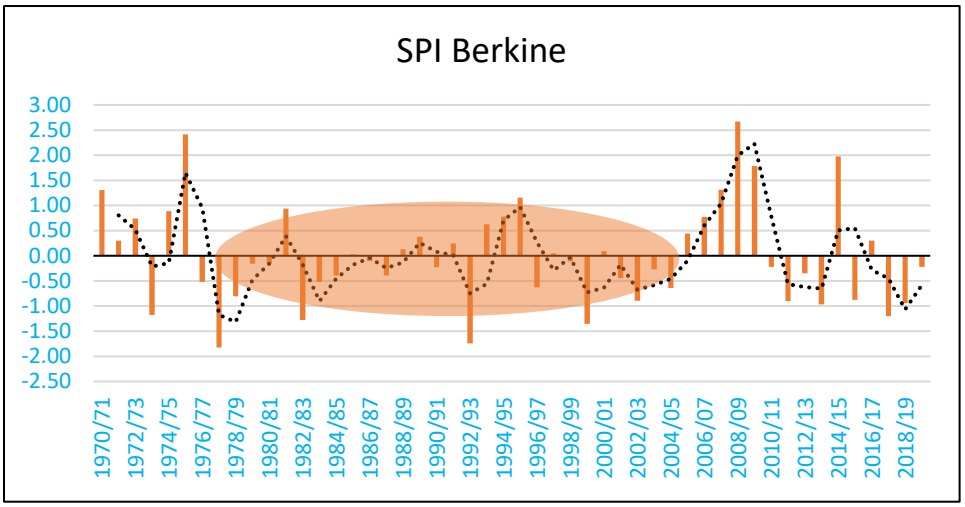

Figure 6. SPI results in the watershed Melloulou

According to the results of graph No. 6, we observe a general downward trend in rainfall from the year 1970 to the year 2007 in the station of Belfarah, from the year 1976 to 2007 in the station of Berkine, and from the year 1976 to 2001 in the station of Guercif.

From Figure 6 and Table 3, we can conclude that the moderate and ordinary period are the most frequented in the watershed of Melloulou, with a rate of 71%. Thus, the wet period experience a decrease in the number with a rate of about 15%, while the dry period is almost the same order with a rate of 14%. The application of the method of moving averages for the trend of the SPI reveals oscillations of the SPI whose magnitude and duration are very variable.

Table 3. The Frequency of the Periods in the BV of Melloulou

	Station		
Period	**Berkine**	**Belfarah**	**Guercif**
Extreme humidity	2	2	2
High humidity	5	6	6
Moderate humidity	15	17	16
Ordinary drought	22	18	18
Severe drought	6	7	8
Very severe drought	0	0	0

2.6 Rainfall Deficit Index

The rainfall deficit index was used to estimate the variation in rainfall in relation to the average. The average of the highest rainfall deficit of the 1970-2020 series studied was recorded at the station of Belfarah with an estimated value of -69.13%. Thereafter, this was followed with the station of

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Guercif with a deficit of -63.11% and the station of Berkine which recorded a deficit of -59.07%. The station of Belfarah has experienced the longest duration of rainfall deficit from 1977/1978 to 1985/1986 with a maximum rate of -59.48%. The rainfall deficit of the station of Berkine was recorded within a period of five years only with a maximum rate of -59.07%. At the station of Guercif, this time, the rainfall deficit is spread over four years only. Furthermore, the rainfall abundance for the series 1970-2020 was observed in the station of Belfarah with a rate that exceeds 100% for the year 2009/2010. At the second level, the station of Guercif shows a rate of 87.34%. Finally, the station of Berkine with rainfall abundance has a value of about 86.36%.

2.7. Trend Analysis

The Mann Kendall Test for the series, extending from 1970 to 2020, shows that the Guercif and Berkine station records a downward trend, while the station of Belfarah records a negative trend. The results obtained via the Mann-Kendall test are presented in the table below:

Table 4. Results of the Mann-Kendall Test

Station	Period	Average (mm)	Mann Kendall Test	
			S value	Z value
Guercif	1970-2020	165	0.0	-0,56
Belfarah	1970-2020	163	1.1	1.77
Berkine	1970-2020	237	-0.42	-0,61

3. Discussion

Annual precipitation in the Middle Atlas Mountains region is characterized by high variability (Sebbar et al., 2020). The study of this climatic variability and trend are based on the history of rainfall. In Melloulou watershed, rainfall is highly variable in space and time (Obda Kh et al., 2009). The climatic conditions of the Melloulou watershed are characterized by rainfall concentrated on the spring season. Fluctuations in rainfall amounts are severe. Some years are very deficient in rainfall, while others are surplus. This fluctuation is linked to the elevation and exposure of the slopes (Taous et al., 2009).

The use of certain indices has shown a trend of decreasing rainfall during the period 1970-2020. The impacts of this decrease in rainfall have been materialized by the decrease in the flow of water sources, as well as the flow of wadis. Additionally, the cereal production recorded a drop during the last years and the regression of the forest surfaces is at the level of quantity and quality. This downward trend in rainfall can be linked to the decrease in the frequency of disturbances in the north and west.

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The frequency analysis of rainfall and the standardized rainfall index (SPI) and the rainfall deficit index (RDI) revealed that the Melloulou watershed has experienced rainfall deficits in different years in the three stations (Guercif, Belfarah, and Bekine). While the decline in rainfall has intensified in various regions, particularly in the Tamgilt area, leading to a reduction in water sources and grain production, an increase in rainfall has been observed in other areas, even in different years.

The results derived from the indices applied to the Melloulou basin show that it alternates between dry and wet periods lasting from 4 to 5 years. In addition, the evolution of SPI and PDI values of the different stations show that the climatic domain of the Melloulou basin is a domain of nuance.

According to the Mann-Kendall test, a negative trend in precipitation will result in a decrease in the number of rainy days and an increase in the duration of dry periods.

Conclusion

In conclusion, this study aims to provide a summary of climate variability and its trend over the last five decades (1970 – 2020). The indices were calculated based on monthly, seasonal, and annual rainfall data.

The climatic study of the Melloulou watershed, through indices (SPI and RDI) and the Mann-Kendall test, has allowed us to show the differences in duration between the years characterized by a water deficit and those characterized by a water excess.

The Melloulou basin thus experiences alternating wet and dry phases. The Mann-Kendall test confirms an upward trend in the station of Belfarah and downward in both stations (Berkine and Guercif). The latter is evidenced by a reduction in the amount of rainfall, and a slowdown of natural resources and human activities.

Conflict of Interest: The authors reported no conflict of interest.

Data Availability: All of the data are included in the content of the paper.

Funding Statement: The authors did not obtain any funding for this research.

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