Spatio-Temporal Variation of Precipitation The Case of the M'dez Watershed (Middle Atlas, Morocco)

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Abstract:

The objective this study is to analyze the spatio-temporal variability of precipitation amounts, in order to provide an objective assessment of its impacts on water resources. The analysis of precipitation variability was carried out in the M'dez watershed, which is distinguished by a diverse morphological mosaic. The rainfall parameters analyzed, for the period 1970-2024, include monthly, seasonal and annual average. Meteorological data were obtained from rainfall stations managed by the Sebou Basin Hydraulic Agency. In addition, precipitation anomalies were calculated and the standardized precipitation index (SPI) was calculated. For the study area, there was a high variability in precipitation amounts, both in terms of recorded values and the inconsistency of the years in which they occurred.

Keywords: Spatial variability, precipitation, water resources, M'dez basin, Morocco.

التباين المكاني والزماني لهطول الأمطار
دراسة حالة حوض واد مداز في الأطلس الأوسط، المغرب

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الملخص:

تهدف هذه الدراسة إلى تحليل التباين المكاني والزماني لكميات هطول الأمطار، بما يتيح تقييمًا موضوعيًا لتأثيراتها على الموارد المائية. أُجري تحليل تباين هطول الأمطار في حوض واد مداز، الذي يتميز بتنوع في المورفولوجيا. وشملت مؤشرات هطول الأمطار التي تم تحليلها للفترة 1970–2024 متوسط الكميات الشهرية والموسمية والسنوية. تم الحصول على بيانات الإرصاد من محطات هطول الأمطار التابعة لوكالة الحوض المائي لحوض سبو. كما تم حساب شذوذ هطول الأمطار ومؤشر هطول الأمطار القياسي (SPI). أظهرت النتائج أن منطقة الدراسة تتميز بتباين كبير في كميات هطول الأمطار، سواء من حيث القيم المسجلة أو من حيث اختلاف السنوات.

الكلمات المفتاحية: التباين المكاني، هطول الأمطار، الموارد المائية، حوض واد مداز، المغرب.

Introduction:

The M'dez watershed is characterized by a well-defined and highly diversified geomorphology, including basins, plains, stepped plateaus, and high mountain ranges exceeding 3000 m in elevation, notably Jbel Bou Iblane (3172 m). Located in northern Morocco, the watershed is influenced by a Mediterranean climate, characterized by mild and relatively humid winters and hot, dry summers. It should be noted that the Mediterranean Basin is strongly affected by the descending branch of the Hadley circulation during summer, while winter precipitation is primarily associated with the Atlantic westerly flow systems. This study aims to analyze the variability of precipitation in the M'dez watershed (Fig. 1).

The basin is distinguished by its relatively large perimeter, approximately 378 km. From a climatic perspective, it exhibits a temperate continental climate, with abundant precipitation across the Middle Atlas region, including during the summer season when convective storms are frequent. This relatively high level of humidity is mainly attributed to the orographic effect resulting from the interaction between the relief and the dominant westerly winds (Lepoutre & Martin, 1967).

I: Study Area

Geographically, the M'dez watershed, covering a total area of approximately 3,350 km², forms part of the greater Sebou Basin, located in northern Morocco and entirely within the Middle Atlas Mountains. The watershed extends between 33°05′ N latitude and 5°05′ W longitude (Fig. 1). The M'dez watershed is predominantly exposed to moist westerly airflows and is characterized by elevations exceeding 2000 m. The geological formations encountered range in age from the Mesozoic to the Cenozoic eras. Hydrologically, the watershed is mainly supplied by runoff originating from the Middle Atlas, within predominantly Liassic limestone sedimentary formations. The thickness of these limestone layers can reach up to 300 m. Infiltrated water re-emerges as springs, contributes to groundwater recharge, feeds artesian aquifers, or laterally supplies valley alluvial deposits.

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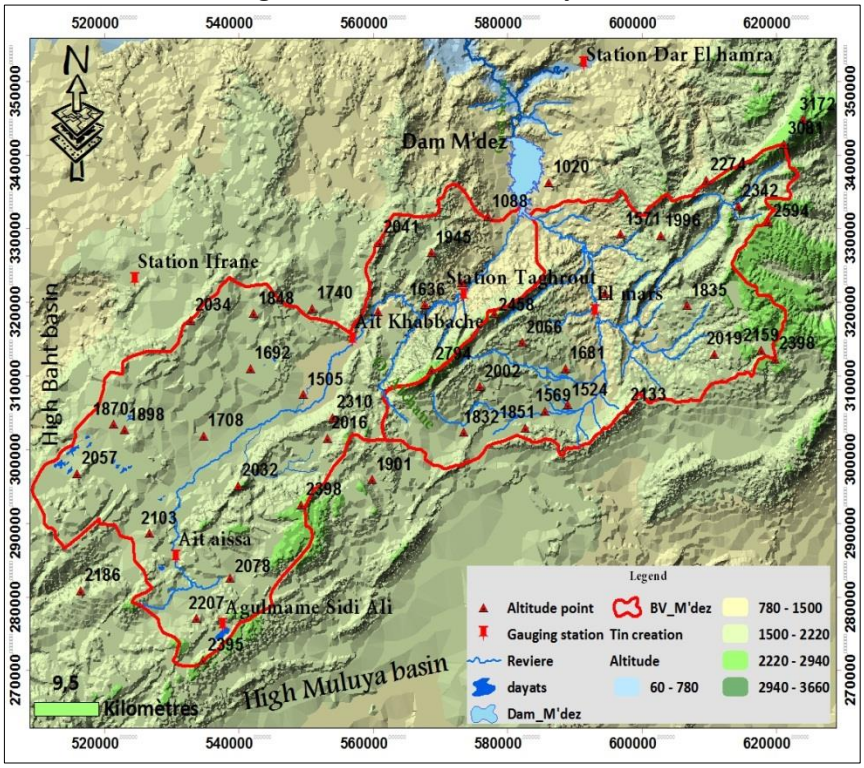
These physiographic and geological characteristics strongly influence the spatial distribution of rainfall, thereby exerting significant pressure on natural resources. Consequently, the study area is generally characterized by pronounced relief features which, due to their heterogeneous spatial distribution, exert varied influences on local and regional climatic conditions.

Figure 1 : Location of the study area

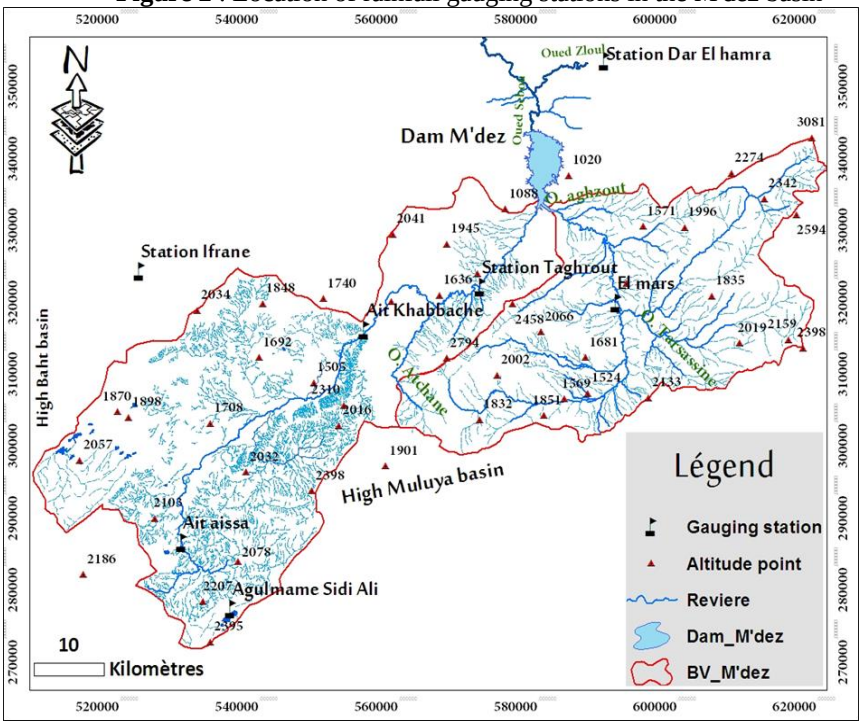


Reference: Topographic map of Azrou and Boulmane, scale 1/50,000 ; The researcher's work on the ArcGis software. The M'dez watershed is made up of an extremely diversified geomorphological mosaic, which merits detailed scientific study.

II: Methodology and Data

The analysis of precipitation variability (monthly, seasonal, annual) will be carried out for the rain gauge stations for the period 1970-2024. These stations are representative of the study area, both by their geographical location and by the difference in altitude between them (fig.2).

Figure 2 : Location of rainfall gauging stations in the M'dez basin



Reference : Topographic map of Azrou and Boulmane, scale 1/50,000 ; The researcher's work on the ArcGis software.

Several Several indices and methods have been developed to characterize and identify precipitation regimes across different time scales, including annual, seasonal, and monthly scales. To assess the vulnerability of water resources, this study adopts the Standardized Precipitation Index (SPI), as this approach facilitates the comparison of precipitation conditions across different periods and climatic contexts. The simplicity and effectiveness of the SPI stem from its ability to integrate several key factors essential for a robust characterization of rainfall variability.

Among these factors, the most important include the spatial variability of precipitation, the density and quality of the measurement network, the selected reference period, and the size and geographical location of the study area. Moreover, several studies have demonstrated the robustness of the SPI, while also emphasizing the precautions required for its correct interpretation (Parker, 1993).

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2.1: Standardized Precipitation Index (SPI)

The The Standardized Precipitation Index (SPI), originally proposed by McKee et al. (1993), is a widely used climatic index for the assessment of precipitation variability and drought conditions. Owing to its simplicity, flexibility, and effectiveness, the SPI has been extensively applied in studies focusing on drought monitoring and characterization.

The calculation of the SPI is based on long-term precipitation records and can be performed over multiple time scales, allowing for the identification of both short- and long-term drought conditions as well as the assessment of their severity. Compared to many other drought indices, the SPI is less complex and easier to interpret. Moreover, it enables the distinction between wet and dry periods, providing a standardized framework for comparing precipitation conditions across different regions and time periods.

Mathematically, the SPI is expressed as follows:

$$SPI = \frac{(Pi - Pm^{average})}{\sigma}$$

Pi : Precipitation of year i (average annual accumulation) ;
Pm : Average precipitation ;
σ : Standard deviation or standard deviation of the series of cumulative values at the station.

Thus, a year will be considered normal if its index is between -0.1 and +0.1. It will be considered wet if its index is greater than 0.1 and dry below -0.1. This interval remains open to criticism since it is relatively small so that normal years are very few in number. But it allows us to clearly distinguish between dry years and wet years. A classification of drought is carried out according to the values of the SPI.

Table 1. Dryness and humidity categories based on (SPI) values.

Classification (SPI)	
SPI>2	Extremely humid
1,5<SPI<1,99	Very humid
1,0<SPI<1,49	Moderately humid
-0,99<SPI<0,99	Close to normal
-1.49<SPI<-1,0	Moderately dry
-1,99<SPI<-1,5	Very dry
SPI<-2	Extremely dry

McKee, TB ; Doesken, NJ ; Kleist, J. La relation entre la fréquence et la durée de la sécheresse et les échelles de temps. Dans les actes de la 8e conférence sur la climatologie appliquée, Anaheim, CA, États-Unis, 17-22 janvier 1993 ; Volume 17, pp. 179-183.

II.1.2: Data Used

All the rainfall data is made available to us by the Sebou Hydraulic Basin Agency (ABHS). The climatic data for the area we are going to exploit covers a period of 54 years (1970-2024). These are monthly rainfall accumulations, to process and calculate annual and seasonal averages, then calculated the index (SPI) to characterize rainfall variability.

Table 2. Characteristics of Meteorological Stations in the Study Area

Stations				Period
	longitude	latitude	Altitude (m)	
Ait Khabbache	5.02° W	32.97° N	1478	1970-2024
El marse	4.72° W	33.01° N	1210	1970-2024
Pont M'dez	4.85° W	33.19° N	725	1970-2024
Aguelmame sidi Ali	5.15° W	32.64° N	2078	1970-2024

The objective is to identify the variability of interannual precipitation, and to analyze the spatio-temporal variability of precipitation indices over the period (1970-2024). Their trends and especially to identify the phases of drought.

III. Results and Discussion

III.1: Rainfall and water availability in the M'dez watershed

III.1.1: Spatial variation

Knowledge of the geographical distribution of rainfall is essential in hydro-pluviometric studies. It represents a crucial step for identifying areas with abundant precipitation as well as regions prone to drought. Furthermore, it provides the foundation for

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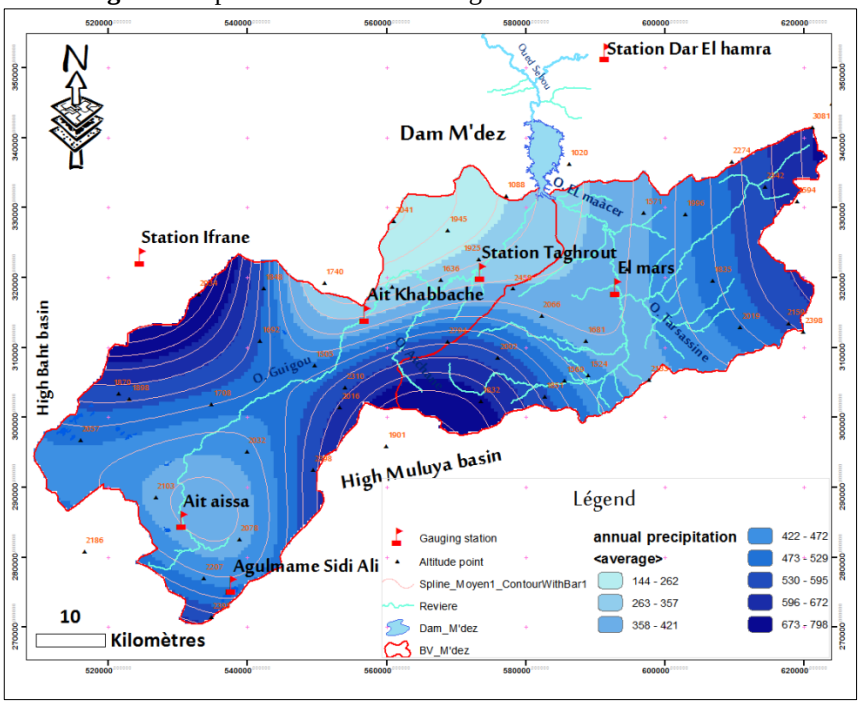
estimating the total amount of precipitation, a key component in calculating the hydrological balance of the M'dez watershed.
The application of different spatial interpolation methods generally produces similar results. In this study, the Thiessen polygon method was selected to estimate the average rainfall across the basin, primarily because it can be readily implemented using ArcGIS software. The resulting map, generated using the Thiessen method, illustrates the distribution of average rainfall throughout the entire M'dez watershed (Fig. 3). This work is valuable for producing and analyzing a map of annual mean rainfall, where both the rainfall values and the isohyetal lines exhibit a high degree of realism.

Figure 3 : Spatial variation of average annual rainfall 1970-2024



Reference : Topographic map of Azrou and Boulmane, scale 1/50,000 ; The researcher's work on the ArcGis software/ databases : Sebou River Basin Hydraulic Agency.

The reference period studied, from 1970 to 2024, indicates that rainfall distribution across the M'dez watershed varies considerably, depending on the type of precipitation, whether liquid or solid. According to the rainfall map presented above, the

southwestern and northeastern edges of the basin receive significantly higher rainfall compared to the valleys and wadis within the basin, such as Guigou and El Maasar (Guigou, El Maasar). This spatial variability is primarily attributed to the surrounding mountain peaks, which act as orographic barriers, intercepting cloud systems originating from the Atlantic Ocean. As a result, precipitation amounts exceed 1000 mm at higher elevations, including Mount Hebri (Ifrane station), Mount Tichoukt (Boulmane station), and particularly in the mountains of the eastern sector, such as Mount Bou Iblane.)

III.1.2: Rainfall analysis on an annual scale

The analysis of annual and interannual rainfall patterns reveals a temporal variability characterized by an alternation of wet and dry years throughout the study period. The highest precipitation was recorded in the southeastern part of the watershed at El Mars station during the 2009 hydrological year, with 828.10 mm; in the western sector at Aguelmame Sidi Ali station, 789.10 mm also in 2009; within the basin at Ait Khabbache station, 635.9 mm in 2010; and downstream at M'dez station, 483.70 mm in 2010. Conversely, the driest year of the study period occurred in 1976, with minimum precipitation values of 188.6 mm at Ait Khabbache station, 81 mm at M'dez station, 115.8 mm at El Mars station, and 211.6 mm at Aguelmame Sidi Ali station.

From a statistical perspective, considering years with below-average precipitation as dry years, it is observed that out of the 54 years analyzed (1970–2024), Ait Khabbache and El Mars stations experienced 25 dry years each, M'dez station experienced 27 dry years, and Aguelmame Sidi Ali station experienced 31 dry years (Fig. 1).

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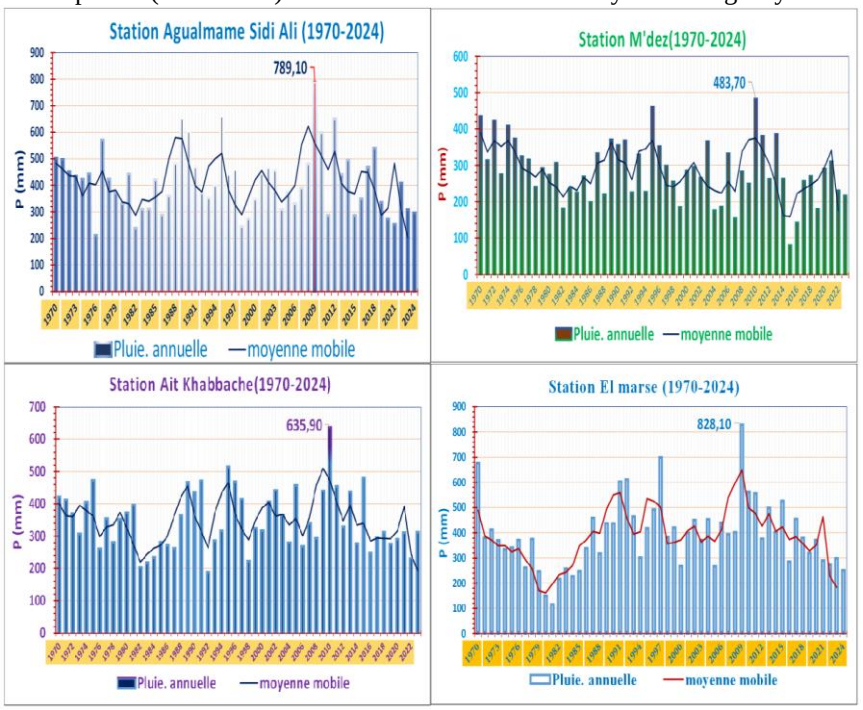
Figure 4. The evolution of precipitation compared to the moving average in the period (1970-2024).Source : Sebou River Basin Hydraulic Agency



The data show that the basin is water-rich, particularly in the south eastern part, where rainfall exceeded 800mm (Mars Station). In the northern part, the lowest rainfall in the range was recorded, averaging 288mm (less irrigated, Tab n°3).

Table 3 : Statistical characteristics of the four stations (1970-2024)

station	Average P (mm)	Pmaximum (mm)	Pminimum (mm)
Aguelmame Sidi Ali	425,63	789,10	221,60
Ait Khabbache	351,91	635,90	188,60
El marse	452,40	828,10	65,81
Pont M'dez	287,96	483,70	81,00

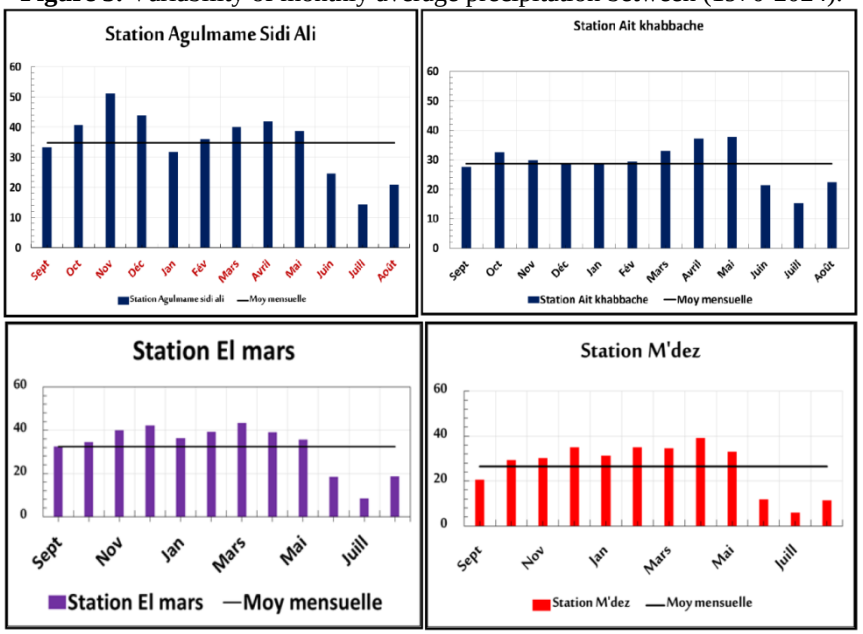
Databases : Sebou River Basin Hydraulic Agency

III.1.3: Rainfall analysis on a monthly scale

The analysis of average monthly precipitation over the 54-year period indicates that at Aguelmame Sidi Ali station, the highest average rainfall occurs in November (51.18 mm), while the lowest is recorded in July (14.31 mm). The average monthly precipitation exhibits considerable heterogeneity and variability, particularly in its spatial distribution from the upstream to the downstream

sections of the watershed. Furthermore, the analysis of average monthly precipitation at M'dez and Ait Khabbache stations shows that the recorded values are very similar. This similarity can be attributed to the exposure of both stations to the same air masses, with topography not posing a significant barrier to the humid currents (Fig. 2).

Figure 5. Variability of monthly average precipitation between (1970-2024).



source : Sebou River Basin Hydraulic Agency

An examination of the monthly average precipitation indicates that Aguelmame Sidi Ali station (34.79 mm) and El Mars station (32.34 mm) exhibit similar average values. A comparable pattern is observed at Ait Khabbache station, with a monthly average of 28.64 mm, while M'dez station records a slightly lower average of 26.43 mm. The monthly precipitation coefficient (MPC) calculated for the four stations reveals the existence of two distinct periods when compared to the reference value of each station (Fig. 3).

i. Aguelmame Sidi Ali Station (Reference value: 0.0833)

- **Winter period:** The wettest period, starting in October and lasting until May.
- **Low rainfall period:** Occurs during summer, from June to September.

ii. M'dez Station (Reference value: 0.0833)

- **Winter period:** From October to May.

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- **Low rainfall period:** From May to September.

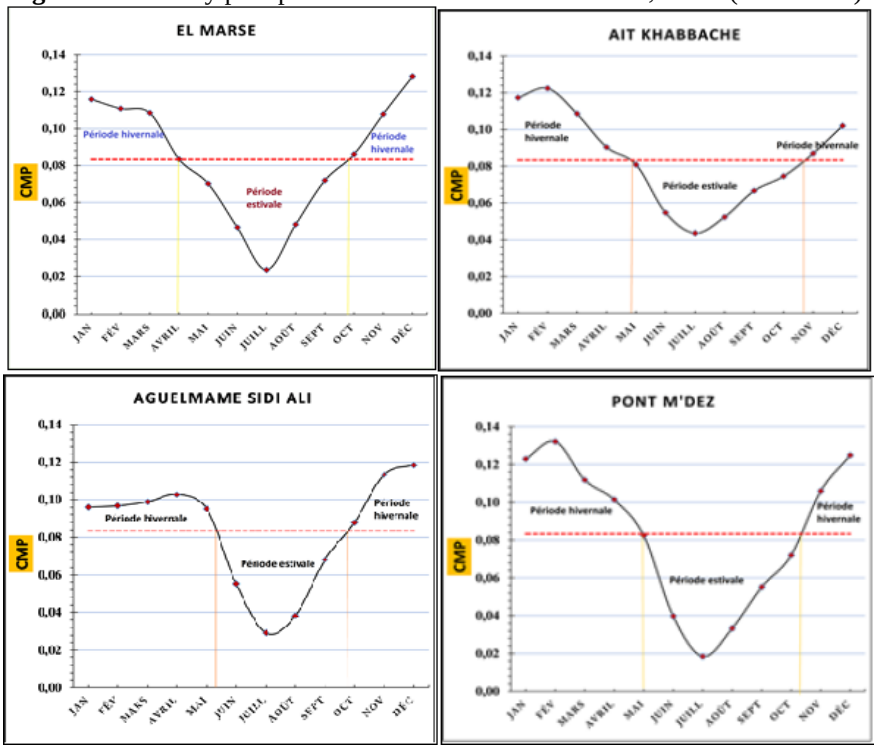
iii. Ait Khabbache Station (Reference value: 0.0833)

- **Winter period:** From October to May.
- **Low rainfall period:** From May to September.

iv. El Mars Station (Reference value: 0.0833)

- **Winter period:** From November to May.
- **Low rainfall period:** From May to October.

Figure 6 : Monthly precipitation coefficient of four stations, series (1970-2024).

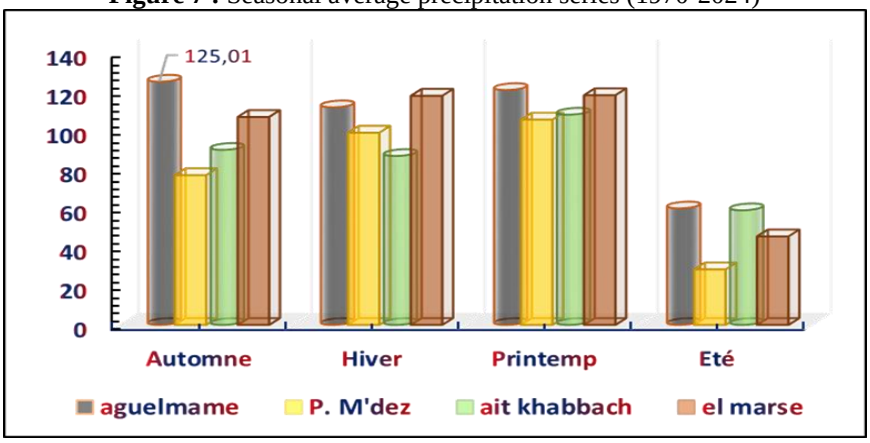


Source : Sebou River Basin Hydraulic Agency

III.1.4: Rainfall analysis on a seasonal scale

All rainfall stations in the M'dez watershed recorded the highest precipitation during spring. An analysis of seasonal rainfall variations over the past 54 years reveals pronounced seasonal differences, with the wettest seasons being spring and winter at all four stations, while autumn and summer exhibit relatively lower precipitation (Fig. 7).

Figure 7 : Seasonal average precipitation series (1970-2024)

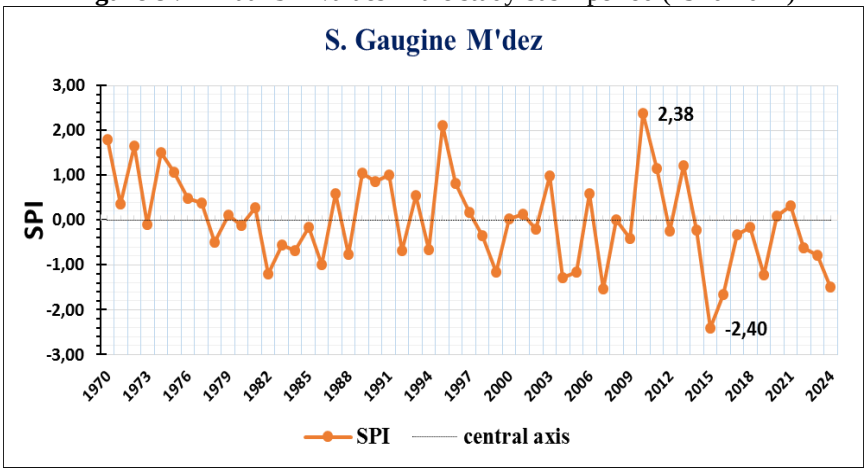


Source : Sebou River Basin Hydraulic Agency

III.2: The SPI index calculated on the annual scale in the Bv M'dez

The calculation of annual SPI values for each station within the M'dez watershed (Fig. 8), combined with the application of a moving average, reveals an alternation of dry and wet phases across all four stations during the period 1970–2024. The SPI diagram for Ait Khabbache station shows patterns similar to those observed at M'dez station, with minor differences in the annual values. Analysis of the SPI series indicates that prior to 1974, no prolonged dry sequences were observed at most of the stations..

Figure 8 : Annual SPI values in the study basin period (1970-2024)



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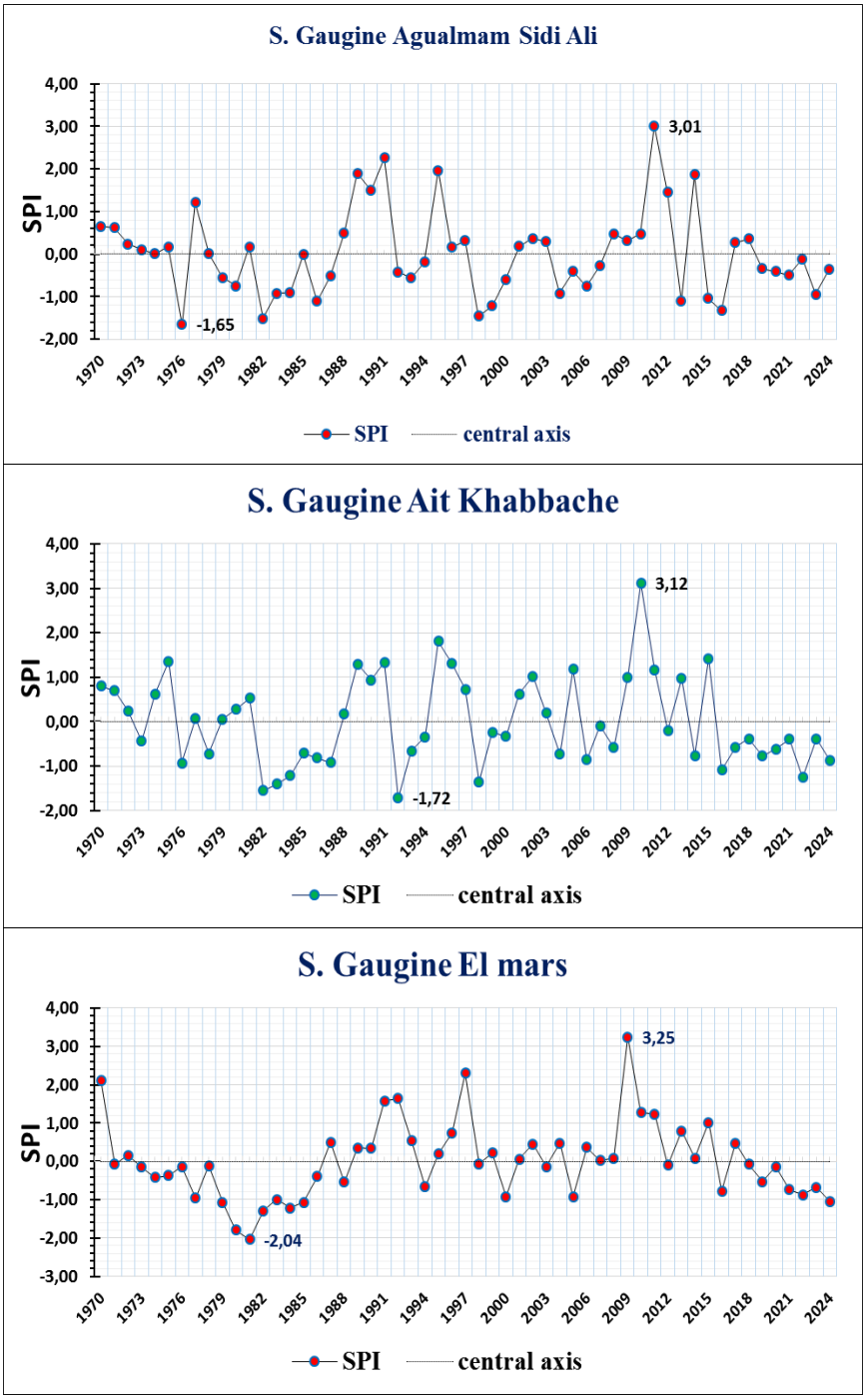

Source : Sebou River Basin Hydraulic Agency.

This analysis reveals three distinct phases:

- **1970–1979:** This period is characterized by a dominance of wet years, with positive SPI values. The highest value, +2.11, was recorded at El Mars station. Dry years during this phase were generally mild, with the exception of a severe dry year in 1977 at Aguelmame Sidi Ali station (SPI = -1.65).
- **1980–2007:** During this period, a prolonged sequence of dry years was observed at most stations, interspersed with a few wet years. The positive SPI values during these wet years were relatively low and did not significantly affect subsequent years.
- **2008–2021:** This period began with successive wet years until 2011, with a maximum SPI of approximately +3.25 at El Mars station in 2010. Subsequently, years alternated between wet and dry conditions until 2017. After 2017, droughts became generally severe, with the most extreme recorded in 2018 at M'dez station (SPI = -2.40).

From these results, the following conclusions can be drawn:

- During the 1980s and through the late 1990s, rainfall decreased significantly.
- After 1990, periods of drought were followed by three consecutive years of average rainfall until 2007, except at El Mars station, which experienced continuous rainfall throughout that period.
- After 2008, rainfall increased, accompanied by a negative phase in the global rainy season, with the most severe drought occurring in 2015.

IV. CONCLUSION

The results indicate significant climatic variability across the M'dez watershed, primarily attributed to the region's topography and prevailing Mediterranean climate influenced by continental air currents. This variability manifests as alternating wet and dry years, with dry years predominating.

SPI analysis demonstrates that the basin has experienced alternating periods of surplus and deficit precipitation throughout the study period. These periods are characterized by their intensity, highlighting the importance of identifying and predicting future

droughts, as such events could have profound impacts on society and the economy.

Hydrological droughts are expected to become more frequent in the future, emphasizing the need for decision-makers to develop a strategic plan aimed at protecting the region and preserving its water resources, both surface and groundwater.

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