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Climate Variability and Water Resources in the Souss-Massa Region: A Study of Rainfall Patterns

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Abstract:

This study focuses on the climatic characteristics of the Souss-Massa watershed, specifically analyzing precipitation and temperature patterns. The findings reveal that the region experiences an arid to semi-arid climate with an oceanic influence near the coast. Variability in rainfall is observed across different seasons, with winter receiving the highest amount of precipitation, followed by autumn and spring. In contrast, summer is the driest season, contributing minimally to the total rainfall. Spatially, the coastal and upstream areas receive more rainfall compared to the downstream areas, with notable variations between the north and south of the watershed. The study emphasizes the importance of understanding the spatiotemporal distribution of rainfall for better water resource management in the region. Overall, the Souss-Massa watershed exhibits both temporal and spatial irregularities in temperature and precipitation, characterized by alternating wet and dry years.

Keywords: Souss-Massa, trend, rainfall, Climate Variability, Water Resources.

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التغايرية المناخية والموارد المائية بمنطقة سوس ـ ماسة: دراسة أنماط هطول الأمطار

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الملخص

تركز هذه الدراسة على الخصائص المناخية لحوض سوس ماسة، وتحليل أنماط الهطول والحرارة بشكل خاص. تكشف النتائج أن المنطقة تشهد مناخًا قاحلًا إلى شبه قاحل مع تأثير محيطي قرب الساحل. يُلاحظ التباين في هطول الأمطار عبر فصول السنة المختلفة، حيث يتلقى فصل الشتاء أعلى كمية من الهطول، تليه فصول الخريف والربيع. بالمقابل، يُعتبر الصيف الموسم الأكثر جفافًا، حيث يسهم بشكل ضئيل في إجمالي هطول الأمطار. من الناحية المكانية، تتلقى المناطق الساحلية والمناطق العلوية من الحوض مزيدًا من الهطول مقارنة بالمناطق السفلى، مع وجود تباينات ملحوظة بين الشمال والجنوب لحوض سوس ماسة. تؤكد الدراسة أهمية فهم التوزيع المكاني والزماني للهطول لتحسين إدارة موارد المياه في المنطقة.

بشكل عام، يظهر حوض سوس ماسة تباينًا زمانيًا ومكانيًا في درجات الحرارة وكميات الهطول، يتميز بالسنوات الرطبة والجافة المتناوبة.

الكلمات المفتاحية: سوس ماسة، اتجاه، هطول الأمطار، تغير المناخ، موارد المياه.

Introduction

Morocco, a country with a subtropical Mediterranean climate, is subject to the influences of atmospheric circulations from both temperate and intertropical latitudes. Its climate is characterized by increasingly frequent extreme events related to climate change. The subtropical influence is believed to cause drought in northern Morocco, while the North Atlantic influence is more associated with flooding (Sebbar, 2011).

Indeed, due to its geographical location in the Mediterranean basin, Morocco experiences significant interannual precipitation fluctuations. The study of this variability is of particular interest to scientific research and water resource managers. This variability directly affects the water balance and can disrupt the normal flow of rivers. The study area is an example where the impact of this climatic variability reduces the available water resources for a constantly growing population.

The objective of this contribution is to establish a general assessment in order to better anticipate the intensification of this change. On one hand, we aim to study the interannual variability of precipitation at three different nested temporal scales (year, season, month) in the Souss-Massa watershed. On the other hand, we have identified and analyzed the spatial and temporal variability of precipitation indices over the period 1968-2015.

1. Material and methods

1.1. Presentation of the Study Area

The Souss-Massa watershed (Figure 1) is located in the southwest of Morocco between 7.5°-9.9°W and 29.3°-31.1°N. It covers an area of approximately 24,867 km², which represents 3.49% of the total area of the Kingdom. From a hydrogeographical perspective, the Souss-Massa basin can be subdivided into three successive parts: an upstream part, from the highest point in the east, the Siroua Massif (3000m), to Aoulouz, where the river emerges from the mountains through gorges that mark the end of its mountainous course; a middle part between Aoulouz and Taroudant, where the valley forms a rectangle measuring 60 km by 20 km; and a downstream part to the estuary. In this section, the valley widens further westward, while the edge of the Anti- Atlas Mountain range extends southward.

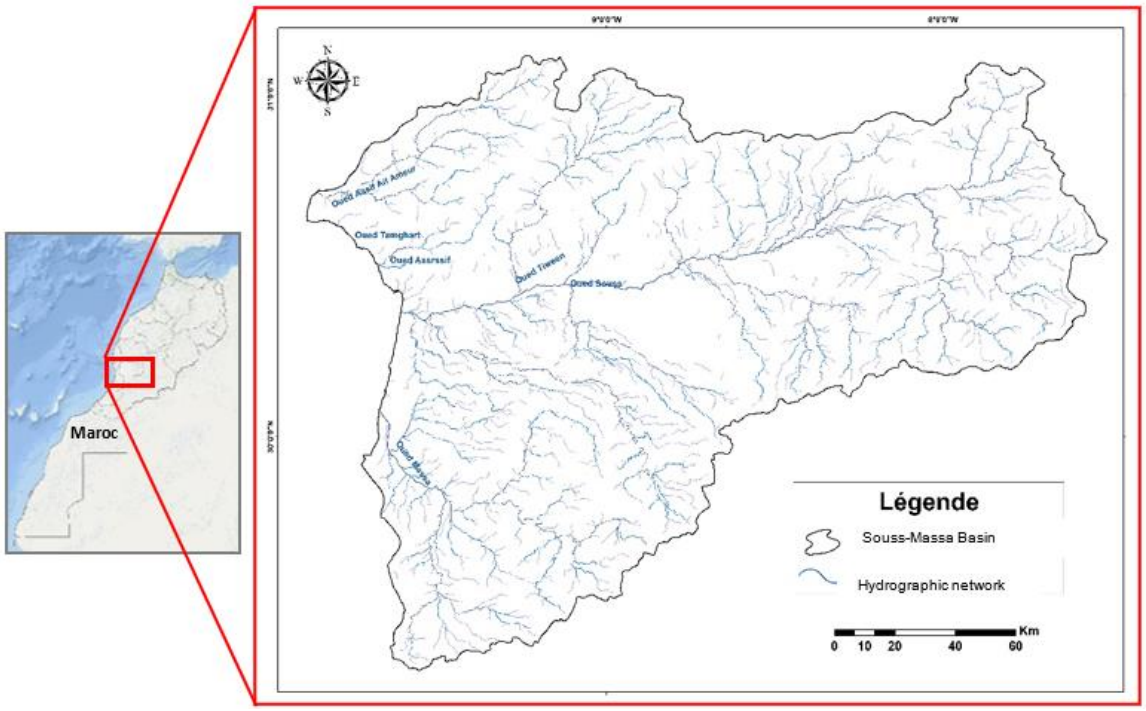

Figure 1: Geographical location of the Souss-Massa watershed.

1.2. Methods

Statistical approaches were applied to precipitation data series to monitor the current rainfall system in the study area. In this study, the "CUSUM" method was adopted to determine the internal heterogeneity of the series under investigation. Additionally, the statistical tests of Pettitt (1979), Lee Heghinian (1977), and U of Buishand (1984), as well as the segmentation procedure of Hubert, were used to detect potential changes in the rainfall regime and analyze discontinuities in the dataset. All these methods (Buishand's test, Pettitt's test, Lee and Heghinian's Bayesian method) are included in the Khronostat software developed by the Institute of Research for Development (Boyer, 1998). Statistical analysis of precipitation and temperature was conducted at annual, monthly, and seasonal scales.

1.3. Rainfall Data of the Study Area

For a comprehensive analysis of recent climate variability in the study area, it is necessary to have a general and accurate overview of the rainfall network and ensure the quality and reliability of the data from the selected stations in this study (Figure 2).

The entire set of rainfall data is made available to us by the Souss-Massa Hydraulic Basin Agency (ABHSM). The climate data used in this study cover a period of 46 years (1968-2015) and represent the three parts of the basin (upstream, middle, and downstream). The variability in data quality and recording duration necessitated the selection of stations based on three criteria: the duration of the data record (covering the longest possible time), the extent of data gaps (minimizing missing data), and their geographical position relative to the basin.

The table 1 presents the list of selected rainfall and temperature stations. It shows the main characteristics of the different stations, which have varying recording periods.

Table 1: Identification of selected rainfall stations.

Basins	Stations	Coordinates			Chronicles	Location
		Longitude	Latitude	Altitude (m)		
Souss-Massa	Aoulouz	-8,15	30,70	680	1968 à 2015	Upstream
	Taroudant	-8,90	30,50	209	1968 à 2015	Middle
	Agadir	-9,57	30,38	23	1914 à 2015	Downstream

Initially, an attempt was made to include as many stations as possible that were spatially well distributed across the study area and had long observation series. The selection of the studied stations was guided by three key factors:

- The proximity of the station to the study area: The climatic stations are distributed differently, and therefore, the station closest to the study area was deemed appropriate and representative.
- The length of the data record (covering the longest possible time).
- Data quality (minimizing missing data).

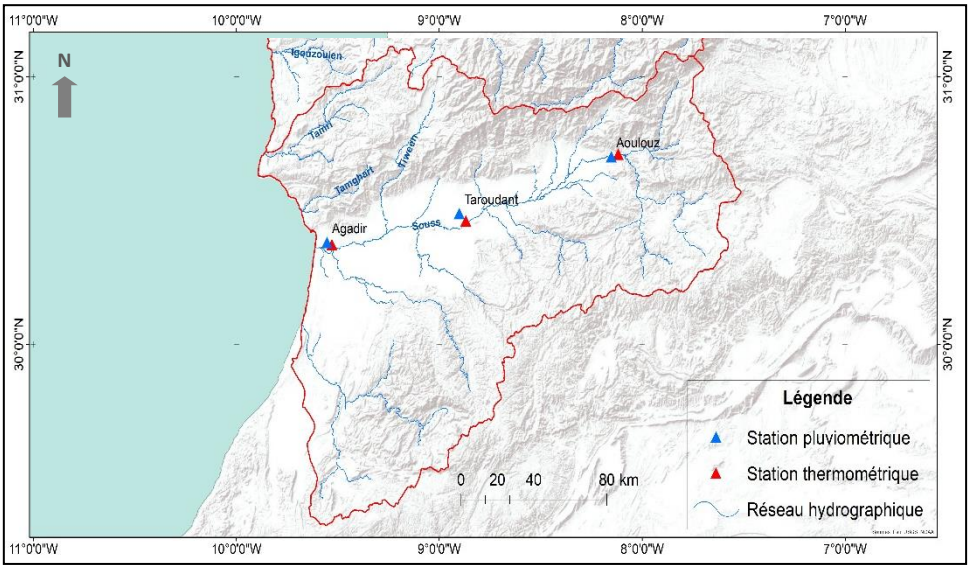

Figure 2**:** Location of rainfall and temperature stations in the two watershed areas.

2. Results and Discussion

2.1. Rainfall and Water Availability in the Souss-Massa Basin

2.1.1. Annual Rainfall Data The analysis of annual and interannual

Rainfall patterns shows a temporal evolution of precipitation with alternating wet and dry years throughout the series. It can be observed that the highest precipitation levels were recorded during the hydrological year 2010 downstream of the basin (Agadir station) with 613 mm, and 561 mm within the basin (Taroudant) during the same year (2010), while upstream (Aoulouz station) recorded 724 mm during the hydrological year 2013. On the other hand, the driest year of the study period had a minimum of 77 mm at the Agadir station, 59 mm at Taroudant, and 133 mm at the Aoulouz station.

From a statistical point of view, considering years below the average as dry years, it can be observed that out of the 48 years studied (1968-2015), 26 years were below the average (dry years) for the Agadir station, 26 years for the Taroudant station, and 28 years for the Aoulouz station (Figure 3).

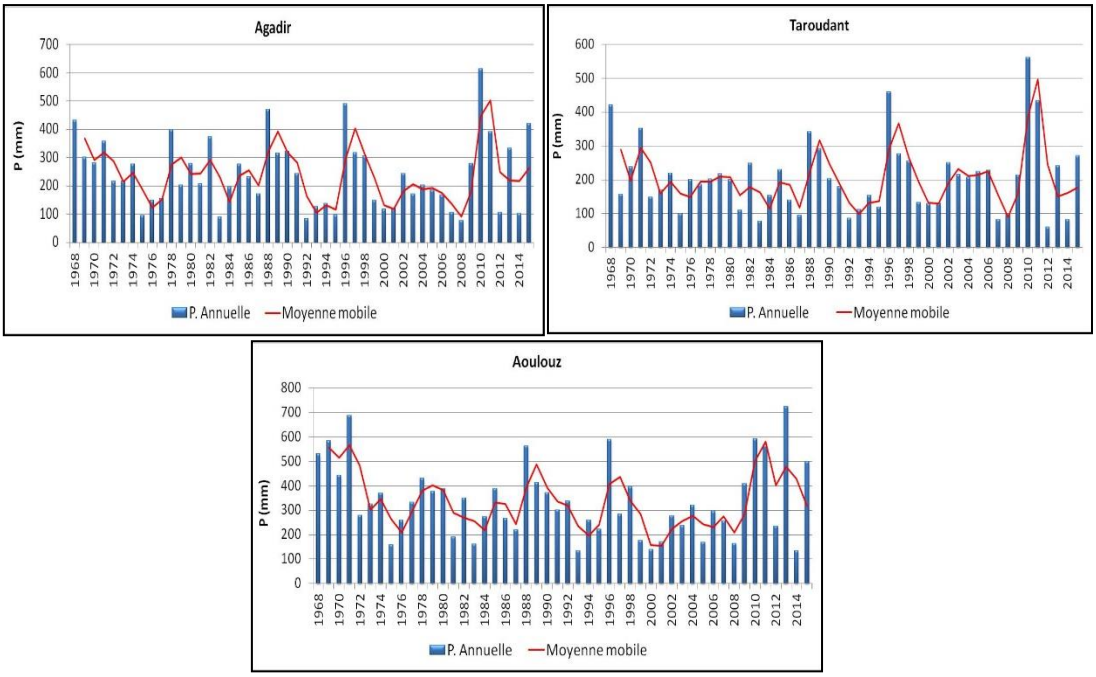

Figure 3: Variation of annual precipitation compared to the moving average at the Agadir, Taroudant, and Aoulouz stations (1968-2015).

The stations indicate that the upstream of the Souss-Massa basin receives abundant rainfall, with precipitation levels exceeding 700 mm (Aoulouz station). The interior of the basin, represented by the Taroudant station, records the lowest rainfall in the series, with an average of 206 mm (less rainfall). Downstream, the Agadir station has an average precipitation level of 242 mm (Table 2).

Table 2: Statistical characteristics of the three stations (1968-2015).

Station	Moyenne P (mm)	Max P (mm)	Min P (mm)
Agadir	242	613	77
Taroudant	206	561	59
Aoulouz	338	724	133

2.1.2. Monthly Rainfall Data The analysis of average monthly

Precipitation over the 48 years shows that the average monthly precipitation at the Agadir station is characterized by a maximum (47 mm) in December and a minimum (0.1 mm) in July. Similarly, the average monthly precipitation at the Taroudant station shows a maximum (36 mm) in December and a minimum (0.3 mm) in July. At the Aoulouz station, the average monthly precipitation shows a maximum (54 mm) in November and a minimum (1.2 mm) in July. Thus, the average monthly precipitation shows heterogeneity and significant variability in their distribution. Based on this analysis, two classes can be identified: the first class experiences higher precipitation, extending from October to April, with average monthly precipitation exceeding 16 mm, while

the second class experiences lower precipitation, extending from May to September, with an average below 16 mm (Figure 4).

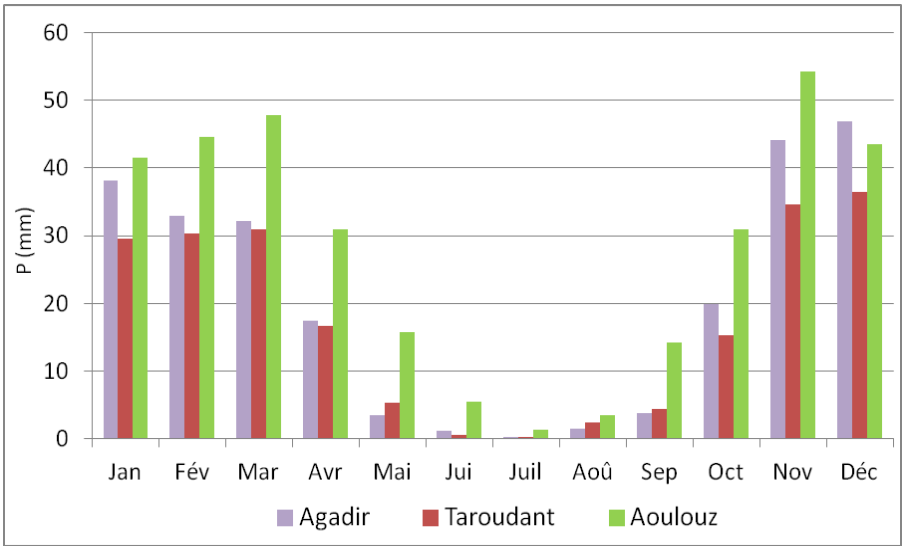

Figure 4: Average monthly precipitation at the Agadir, Taroudant, and Aoulouz stations (1968-2015).

The analysis of the monthly precipitation coefficient (CMP) at the three stations (Figure 5) shows the existence of two periods compared to the reference value of each station. At the Agadir station (reference value 0.083), the winter period receives the highest precipitation from November to March, while the period of low precipitation occurs during the summer months, from April to September. Similarly, at the Taroudant station (reference value 0.075), the winter period from November to March experiences the highest precipitation, while the summer period from April to September experiences low precipitation. At the Aoulouz station (reference value 0.096), the winter period from November to April experiences higher precipitation, while the summer period from May to September experiences low precipitation.

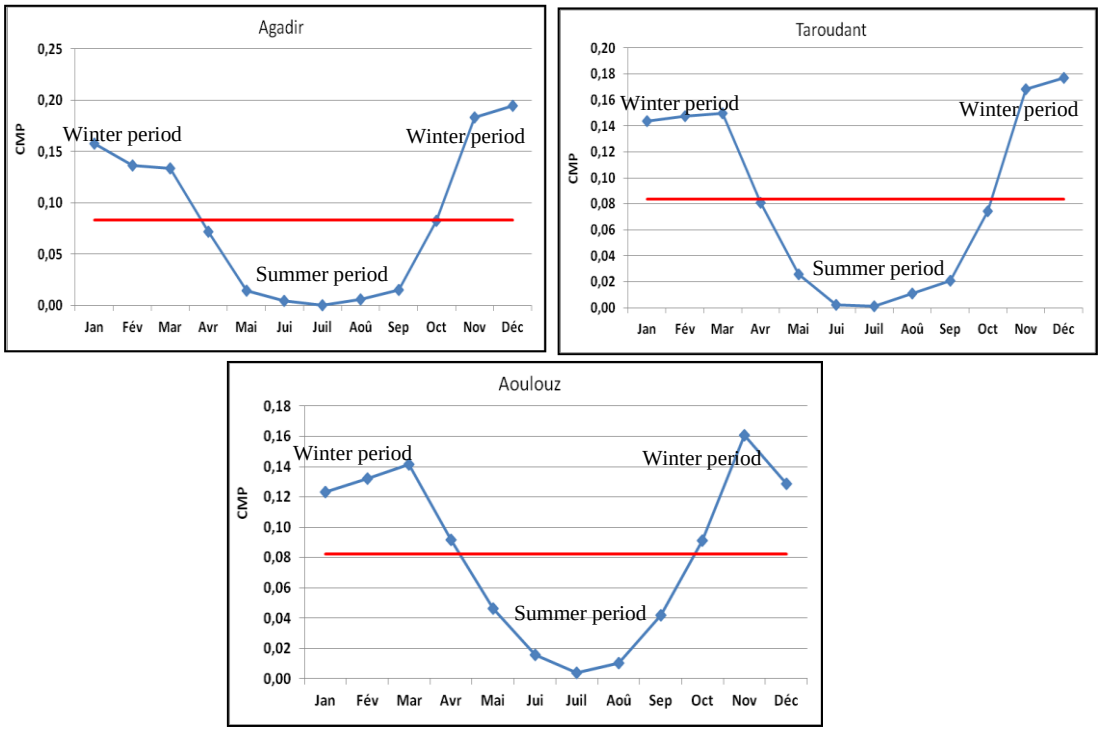

Figure 5: Monthly precipitation coefficient (CMP) at the Agadir, Taroudant, and Aoulouz stations (1968-2015).

2.1.3. Rainfall Data on a Seasonal Scale

All the pluviometric stations in the Souss-Massa watershed received the maximum amount of rainfall during winter. The analysis of precipitation variations for each season over the past 48 years shows a strong seasonal variation, with winter being the rainiest season in all three stations, while autumn and spring remain slightly less rainy (Figure 6).

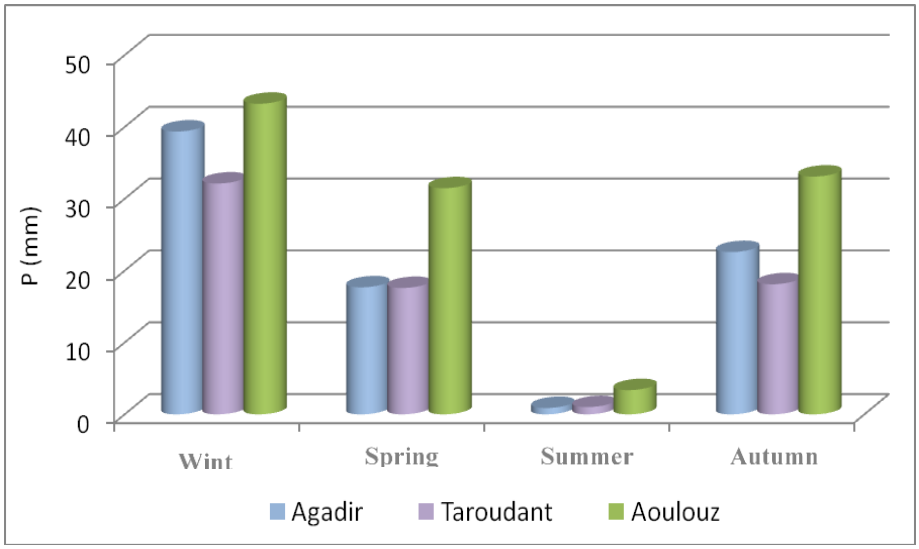

Figure 6: Seasonal average precipitation at the stations: Agadir, Taroudant, and Aoulouz (1968-2015).

The seasonal variation of precipitation in the Souss-Massa watershed is summarized in Table 3. It can be observed that the winter season receives the highest amount of precipitation for all three stations: Agadir (49%), Taroudant (47%), and Aoulouz (39%). The autumn season follows, while summer remains the driest season, contributing less than 3% to the total rainfall during the 1986-2015 period (Table 3).

Table 3: Seasonal rainfall and their contributions to the average annual rainfall at the stations of Agadir, Taroudant, and Aoulouz (1968-2015).

Stations	**Contribution (%)**	Winter	Spring	Summer	Autumn
Agadir	Mean seasonal precipitation (mm)	39	18	01	23
	Contribution (%)	49	22	01	28
Taroudant	Mean seasonal precipitation (mm)	32	18	01	18
	Contribution (%)	47	26	01	26
Aoulouz	Mean seasonal precipitation (mm)	43	31	03	33
	Contribution (%)	39	28	03	30

The number of available stations is insufficient, so the spatialization of annual rainfall does not yield satisfactory results. To obtain a better understanding of rainfall distribution at different time scales in the Souss-Massa basins, a map produced by the National Meteorological Department was consulted, which provides information on the average annual rainfall in Morocco calculated over the period 1971-2000 (Figure 7).

The spatial distribution of precipitation in Morocco confirms that the Atlantic coast and the upstream areas of the two watersheds generally receive more rainfall than the downstream areas. The southern part of Souss-Massa is less rainy. It can be observed that precipitation amounts exhibit significant spatial variation, with approximately 300 mm difference between the upstream and downstream areas for the Tensift basin and about 400 mm difference between the north and south of the Souss-Massa watershed (latitudes). This difference primarily depends on factors such as proximity to the sea, altitude, and latitudes.

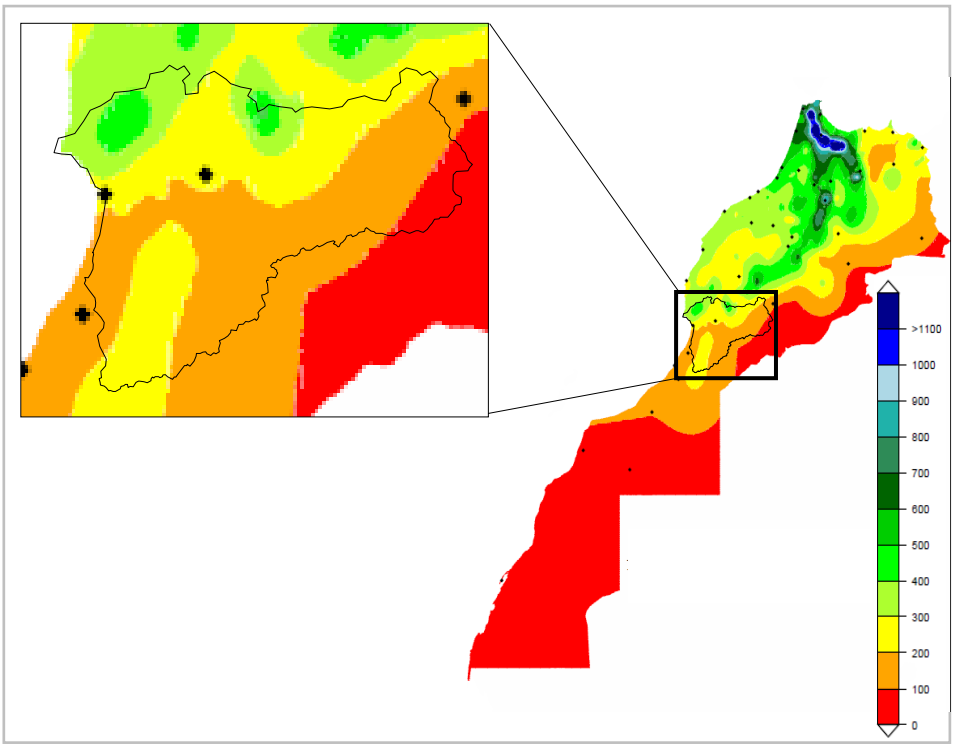

Figure 7: Average annual rainfall in Morocco calculated over the period 1971-2014 (Source: DMN).

Conclusion

This climatic study of the Souss-Massa watershed provides valuable insights into the region's climate patterns. The analysis reveals a diverse climate ranging from arid to semi-arid, with variations influenced by factors such as proximity to the ocean, altitude, and latitude. The study highlights the seasonal distribution of precipitation, with winter being the rainiest season and summer the driest. The spatial analysis indicates higher rainfall along the Atlantic coast and upstream areas compared to the downstream regions. The research underscores the importance of understanding the spatiotemporal variability of temperature and rainfall for effective water resource management. Overall, the Souss-Massa watershed exhibits temporal and spatial irregularities in precipitation and temperature, characterized by alternating wet and dry years. These findings contribute to a better understanding of the climate dynamics in the study area and can inform future planning and decision-making processes.

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