American Journal of Climate Change, 2024, 13, 682-696
https://www.scirp.org/journal/ajcc
ISSN Online: 2167-9509
ISSN Print: 2167-9495

The Contribution of the Spatial Distribution of Rainfall for the Understanding of the Hydrological Functioning of the Upper Oum Er-Rbia Basin (Upstream Machraa Edahk)—Morocco

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How to cite this paper: Lahlou, N., Kane, C., & Mohamed, E. G. (2024). The Contribution of the Spatial Distribution of Rainfall for the Understanding of the Hydrological Functioning of the Upper Oum Er-Rbia Basin (Upstream Machraa Edahk)—Morocco. *American Journal of Climate Change, 13,* 682-696.
https://doi.org/10.4236/ajcc.2024.134031

Received: June 29, 2024
Accepted: November 29, 2024
Published: December 2, 2024

Abstract

In recent years, climate change has emerged as one of the most pressing environmental issues globally. Morocco, like many other countries, has been significantly affected by these changes, particularly over the past decade. In this context, we aim to examine the spatial and temporal distribution of rainfall as a hydrological indicator to understand its impact on the hydrological dynamics of the upper Oum Er-Rbia basin. The Oum Er-Rbia basin is one of the largest watersheds in Morocco in terms of water resources, after the Sebou basin. Besides, the studied area covers an area of 6965 km2. The altitudes are between 2410 m and 415 m. Oum Er-Rbia river takes its source from the Middle Atlas at 2400 m altitude and crosses the Middle Atlas range, the Tadla plain. It shows diversity in relief with diverse structural forms. It is fed by several permanent and seasonal tributaries. The present study consists of analyzing the variations of rainfall events through a statistical analysis of rainfall data provided by the reference stations in the Upper Oum Erbia basin for a chronicle of (1934-2023), and spatializing the precipitation at different scales, annual and monthly, through the rainfall data, provided by 33 rainfall stations, with a chronicle of 30 years, inter-station period (1984-2013). From a methodological point of view, this study places us within a palette of concepts of spatialization that are said to be normative or traditional and are part of the set of methods existing in the field of spatialization. The main objective of this paper is to extract all the information that can inform us about the rainfall characteristics of this period, to determine the rainfall trends and to identify the spatial and temporal rainfall distributions. All this is in order to follow, understand and determine the nature of the impact of climate variability on the hydrological functioning in the upper basin of Oum Er-Rbia.

Keywords

Upper Basin of Oum Er-Rbia, Rainfall Distribution, Climate Variability, Hydrological Response, Atlas Mountainous (Morocco)

1. Introduction

Precipitation is the most important element of climate for both living beings and environments. So many reasons why most studies and analyses rely on precipitation much more than on other climate parameters (El Orfi et al., 2020). All surface or groundwater resources are conditioned by precipitation. The analysis of spatialization and rainfall variability is very important for forecasting and water resources management.

Morocco, is located in the extreme Northwest of the African continent, its relief is characterized by mountain ranges: the Rif in the North and the Atlas in a Southwest/Northeast axis (including the Middle Atlas, the High Atlas and the Anti-Atlas), which culminates at 4 165 m (Toubkal) (Missenard, 2006). The country has an essentially semi-arid to arid climate across most of its territory, (Lahlimi Alami, 2011), with two main seasons: a hot and dry summer and a cold and wet winter, Morocco is drained by 9 large sets of watersheds. These surface resources are very unevenly distributed: the basins of Loukkous, Sebou and Oum Er-Rbia, bring together 71.5% of national resources (Agoumi & Debbagh, 2006). On the other hand, underground resources are relatively better distributed over the territory (Lahlou & El Ghachi, 2017).

This study seeks to illuminate the critical role of rainfall in influencing hydrological processes and the replenishment of dams. A primary objective is to identify and analyze the factors that govern the patterns of water flow and circulation. This involves examining the spatial distribution of precipitation and evaluating the impact of rainfall inputs on hydrological systems (Ghadbane et al., 2024). Additionally, the study aims to quantify water flows to better understand their variability and significance in sustaining dam reservoirs. By exploring these aspects, the present study tries to provide valuable insights into how rainfall dynamics affect water resources management and contribute to more effective strategies for maintaining dam functionality and addressing water scarcity challenges (Ennaji et al., 2024).

2. Presentation of the Study Area

The Oum Er-Rbia basin (**Figure 1**), Morocco's second-largest water resource basin after the Sebou, spans an area of 6,965 km^2. The upper Oum Er-Rbia basin features elevations ranging from 415 m to 2,410 m. Originating in the Middle

Atlas at an altitude of 2,400 meters, the Oued Oum Er-Rbia flows through the Middle Atlas range and the Tadla plain, traversing diverse topographies along its course.

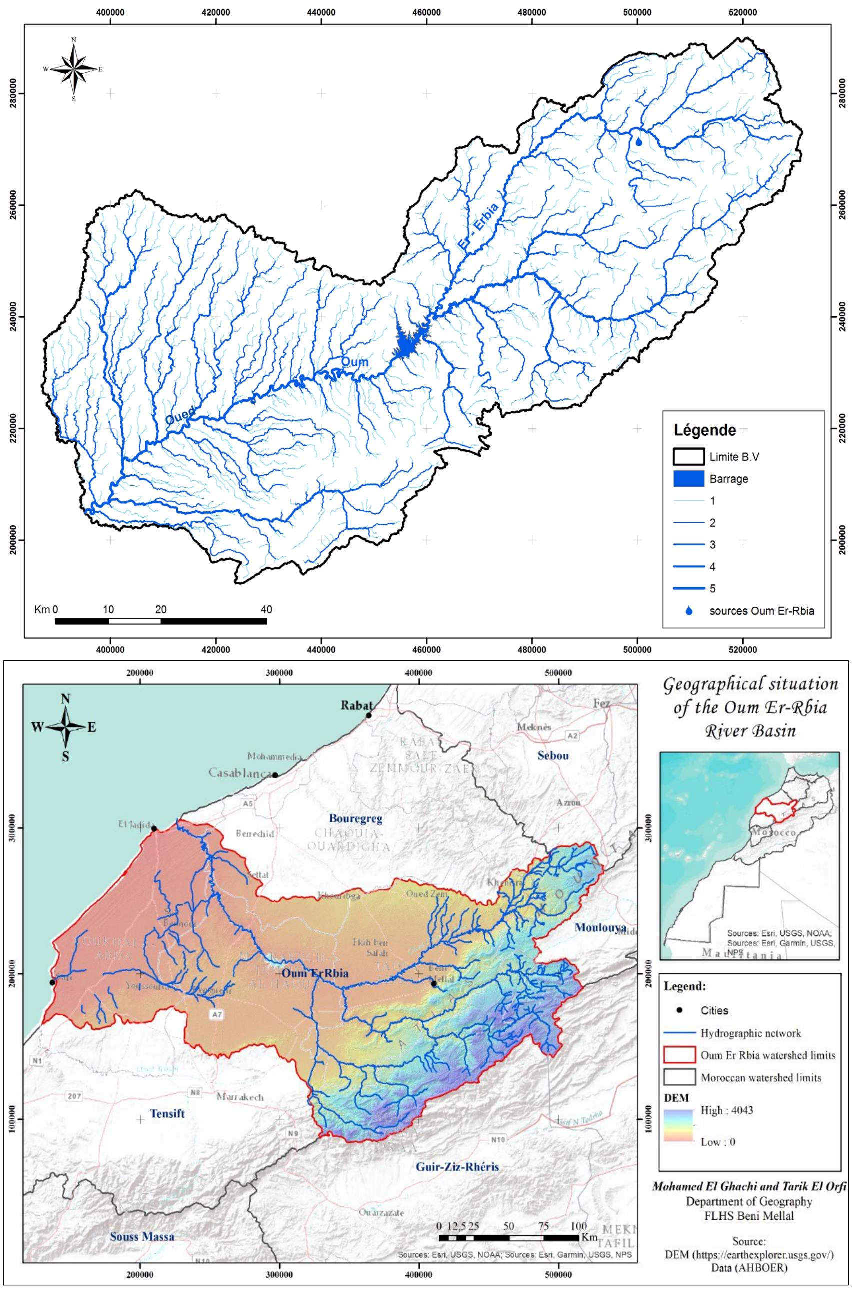


Figure 1. Geographical location of the study area

The region experiences a continental climate characterized by significant seasonal and daily temperature fluctuations. Winters are harsh, while summers are notably hot. Average annual rainfall varies between 400 and 700 mm, depending on the specific area. Additionally, storms are relatively frequent and can cause considerable damage. Since the 1980s, this climate has undergone noticeable changes, reflecting broader environmental shifts (El Ghachi & Morchid, 2015).

3. Data and Methods

3.1. Data

The rainfall data used in this research is obtained from the Hydraulic Agencies of Oum Er-Rbia, Sebou, Moulouya and Bouregreg basins. As a first step, the regional vector was calculated for the 33 stations scattered throughout the study area and its surroundings. The annual rainfall data from these stations show good homogeneity, with a correlation coefficient between 0.82 and 0.96. In the Oum Er-Rbia rainfall can be data from six stations (**Table 1**).

Table 1. The rain gauge stations are used in the upper basin of the Oum Er-Rbia basin.

Station	X	Y	Z	Correl/Vecteur
Tamchachat	512330	274340	1685	**0.82**
Tarat	476400	267500	1036	**0.94**
Taghzout	461400	235500	628	**0.96**
Taghzirt	423900	205600	565	**0.83**
Tadla	418980	219740	511	**0.86**
Machraa Edahk	394980	204800	406	**0.89**

3.2. Methods

Rainfall was spatialized using three simple spatial interpolation methods: inverse distance weighting, Kriging and Thiessen:

Thiessen method: The Thiessen method is the simplest method. It is defined as "an arithmetic method in which we assign to each rainfall a weight proportional to a presumed zone of influence, such that a point located in this zone is closer, in horizontal distance, to the corresponding rain gauge than to any other rainfall" (Roche, 1963). To apply this method, we will follow (Remenieras, 1986), which explains: "In the middle of each of the straight lines which link the stations, we raise the bisectors whose intersections determine polygons. In general, we calculate the area of the elementary polygon thus assigned to each station as a "percent" of the total surface of the basin, and this percentage serves as a weighting coefficient specific to each station.

Kriging method: The African researcher Daniel Gerhardus Krige is considered the first to formulate the method Kriging in 1951, and he worked on developing it after the Frenchman Georges Matheron in 1962. (Lahlou, 2021) Kriging is a set of interpolation methods for estimating the value of a property at a point in geographic space from neighboring observations, using the theory of regionalized variables. Kriging is most appropriate when you know there is a spatially correlated distance or directional bias in the data.

Inverse distance weighting method (IDW): A suitable method for conceptualizing spatial relationships between spatially continuous variables such as precipitation data. The method was implemented in the ArcGis software with all available rainfall stations. (Nejjari, 2002)

4. Results and Discussion

4.1. Dynamic of Rainfall Intensity (1934-2023)

The analysis of annual precipitation is designed to uncover temporal variations and extract valuable climatic insights from rainfall data. By examining precipitation patterns over time, from 1934 to 2023, we can identify fluctuations and trends that reflect broader climatic changes. This analysis reveals that annual precipitation amounts can vary significantly both year-to-year and across different geographic regions. Understanding these variations helps in assessing the spatial distribution of rainfall and its implications for regional climate patterns, water resources, and ecological impacts. This comprehensive approach allows us to gain a clearer picture of how precipitation influences and interacts with the environment over extended periods (**Figure 2**).

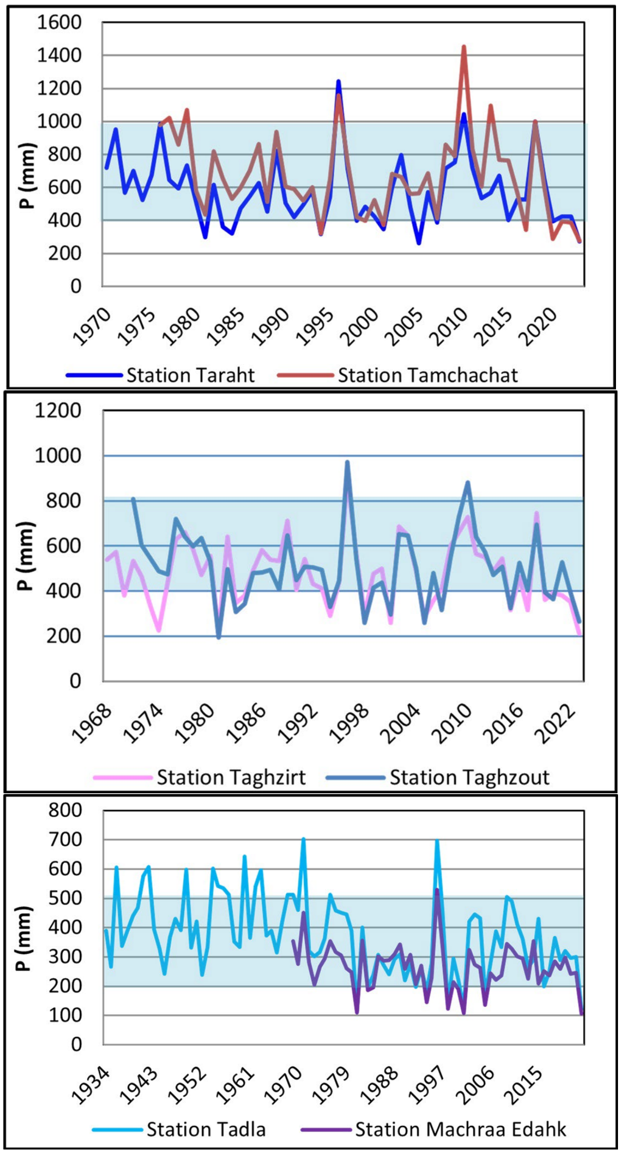
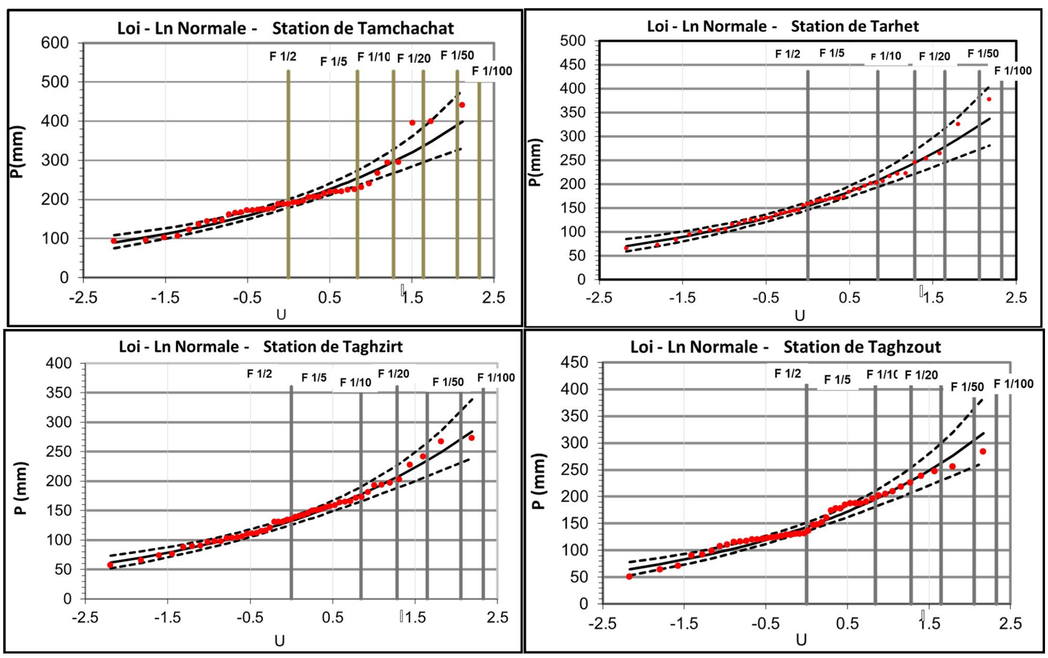


Figure 2. Annual rainfall at gauging station of Oum Er-Rbia basin. (1934-2023)

Annual precipitation exhibits significant variability, with a peak of 984 mm recorded in 2010 and a low of 225 mm in the drier year of 2005. This variability has led to a noticeable deviation from the annual average precipitation at the studied stations, highlighting an imbalance between the number of dry and wet years. This discrepancy underscores the need to understand the underlying factors influencing these fluctuations and their impact on local water resources and climate patterns.

4.2. Adjustment of Annual Precipitation of the Upper Oum Er-Rbia Basin (1934-2023)

To gain a clearer understanding of precipitation variability, we adjusted the annual precipitation series from six monitoring stations using the Ln-Normal distribution model, which is widely accepted for this purpose. This adjustment facilitates a more accurate representation of precipitation patterns, as illustrated in Figure 3. Several factors influence the distribution of rainfall in the Upper Oum Er-Rbia basin. Topography plays a significant role, with higher elevations in the Middle Atlas region receiving more rainfall due to orographic lift, where moist air is forced upward by mountainous terrain. Climatic patterns, including shifts in atmospheric pressure systems and wind patterns, also impact rainfall distribution (Chakir et al., 2024). For example, changes in the Azores High or Mediterranean cyclones can affect precipitation levels. Additionally, local weather systems such as thunderstorms and cyclones contribute to variability in rainfall. Climate change further complicates this picture by altering weather patterns, affecting the frequency, intensity, and distribution of precipitation events. Understanding these factors is essential for accurately interpreting adjusted precipitation data and for effective water resource management and environmental planning in the Upper Oum Er-Rbia basin.



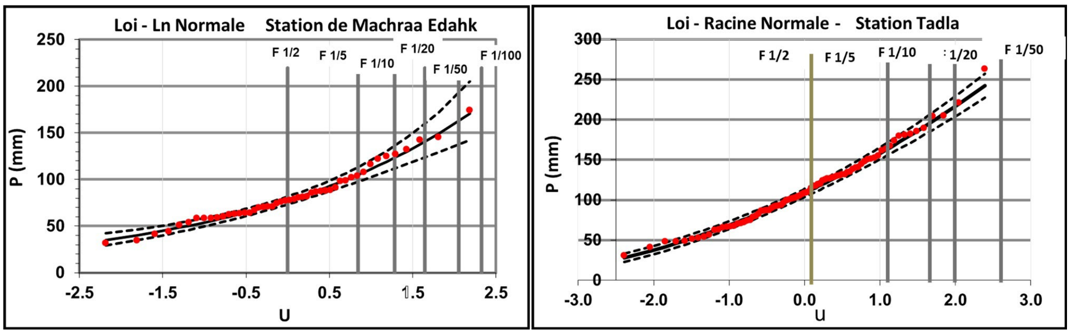


Figure 3. Adjustment of maximum annual precipitation at reference stations. (1934-2023)

The results of the statistical adjustments using the Log-Normal (**Figure 3**) distribution reveal that precipitation values are predominantly clustered around the central part of the curve, with a significant concentration between −0.5 and 1.5. Very wet years are found at the high end of the distribution, notably including 1996, 2010, and 2014, across all reference stations. Conversely, dry years are located at the lower end of the curve, with notable instances being 1973, 1981, 1994, 2005, and 2023. This distribution highlights the variability in annual precipitation and underscores the distinct patterns of extreme wet and dry years within the Upper Oum Er-Rbia basin.

Table 2. Maximum annual precipitation frequency for the period (1934-2023) /Ln-Normal.

Fréquence	1/2	1/5	1/10	1/20	1/50	1/100
Période de retour (ans)	**2**	**5**	**10**	**20**	**50**	**100**
Tamchachat	189	254	297	337	389	440
Tarhat	154	209	244	279	232	378
Taghzourt	143	195	230	262	284	-
Taghzirt	133	178	207	235	272	-
Tadla	109	150	174	195	220	263
Machraa Edahk	77	105	123	140	163	174

Table 2 summarizes the return periods of the highest annual rainfall recorded at the six study stations, arranged sequentially from the upper to the lower part of the basin. The table indicates that the highest recorded values, associated with a return period of 1/00, were observed at only four stations: Tamchachat, located in the upper basin; Kasbah Tadla; the Laughter Project; and Machraa Edahak, situated at the lower end of the basin. These extreme values were recorded just once during the study period at each respective station. While the highest values were observed infrequently, with a maximum of 189 mm at Tamchachat and a minimum of 77 mm at Machraa Edahak, these figures illustrate significant variability in precipitation. The recurrence of high values approximately every two years at all stations underscores their importance in contributing to the region's water resources. These rainfall extremes play a crucial role in determining the availability and distribution of water resources throughout the basin.

4.3. Monthly Flow Coefficient of Oum Er-Rbia Basin (1975-2016)

The upper Om Er-Rbia basin is influenced by cycles of high and low water, which are related to climatological inputs (Figure 4).

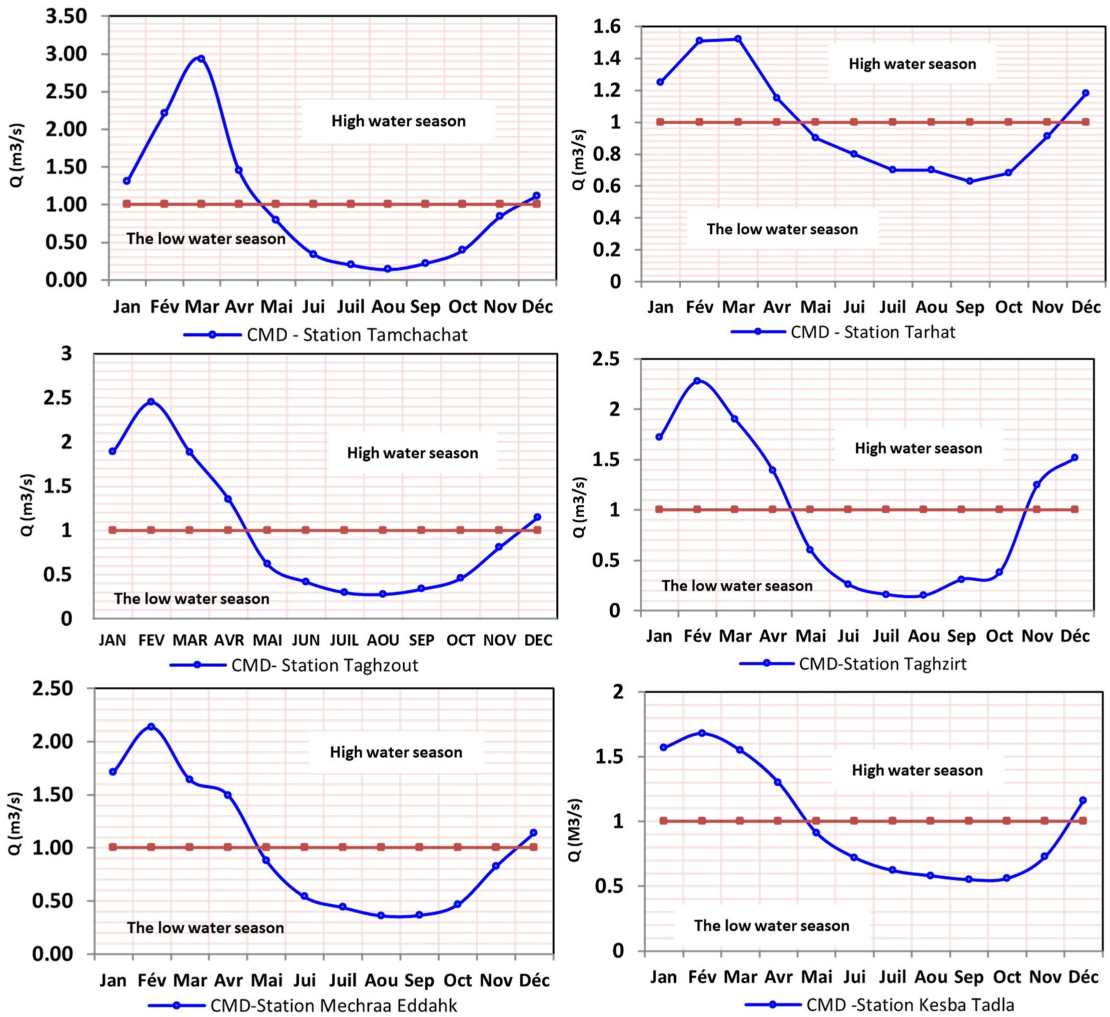


Figure 4. The hydrological regime of Oum Er-Rbia basin. (1975-2016)

Spatialisation of Annual Rainfall by Using Kriging, Inverse Distance (IDW) Methods

The two maps of average annual precipitation (Figures 5 and 6) for the period from 1984 to 2013 reveal that the most temperate regions are situated in the northeast and southeast, at altitudes above 1,000 meters. Additionally, these maps confirm that the rainfall regime generally decreases from the northeast to the southwest. Notable differences between the two maps are observed in areas where precipitation exceeds 500 mm, particularly in the mountainous regions. In contrast, the plains exhibit relatively uniform average precipitation levels. Overall, we therefore observe an increase in precipitation in conjunction with altitude. However, the relationship between precipitation and elevation is complex and depends on how the region is exposed to prevailing winds and synoptic conditions (Ghanem, 2002).

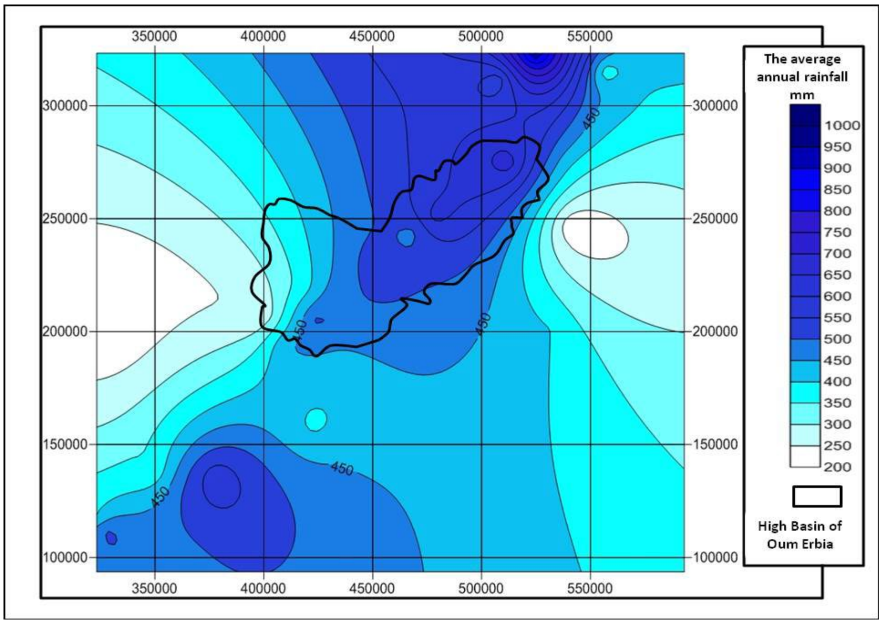


Figure 5. Map of average annual precipitation. (Kriging method)

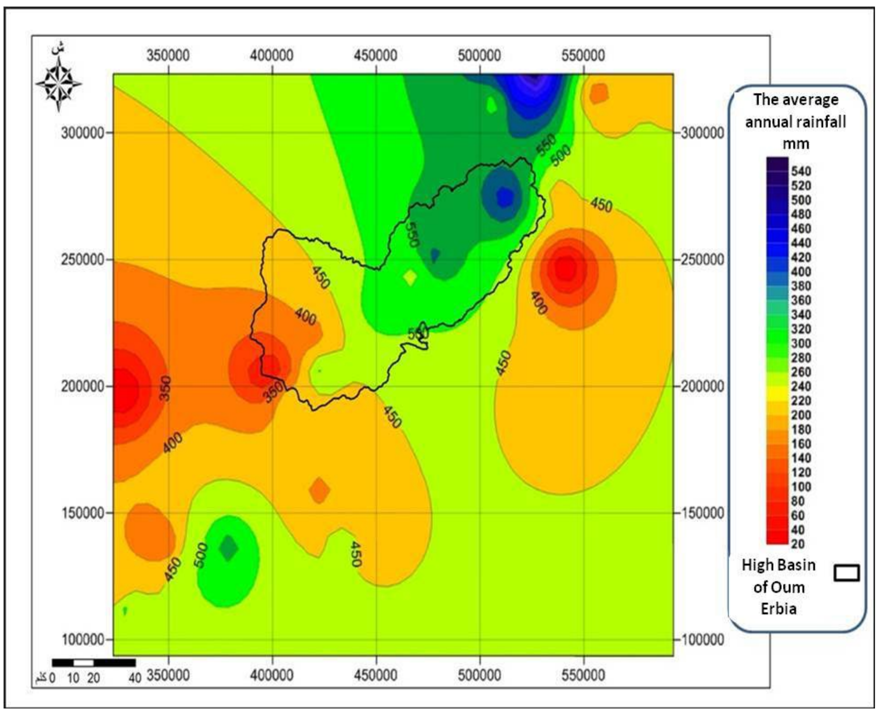
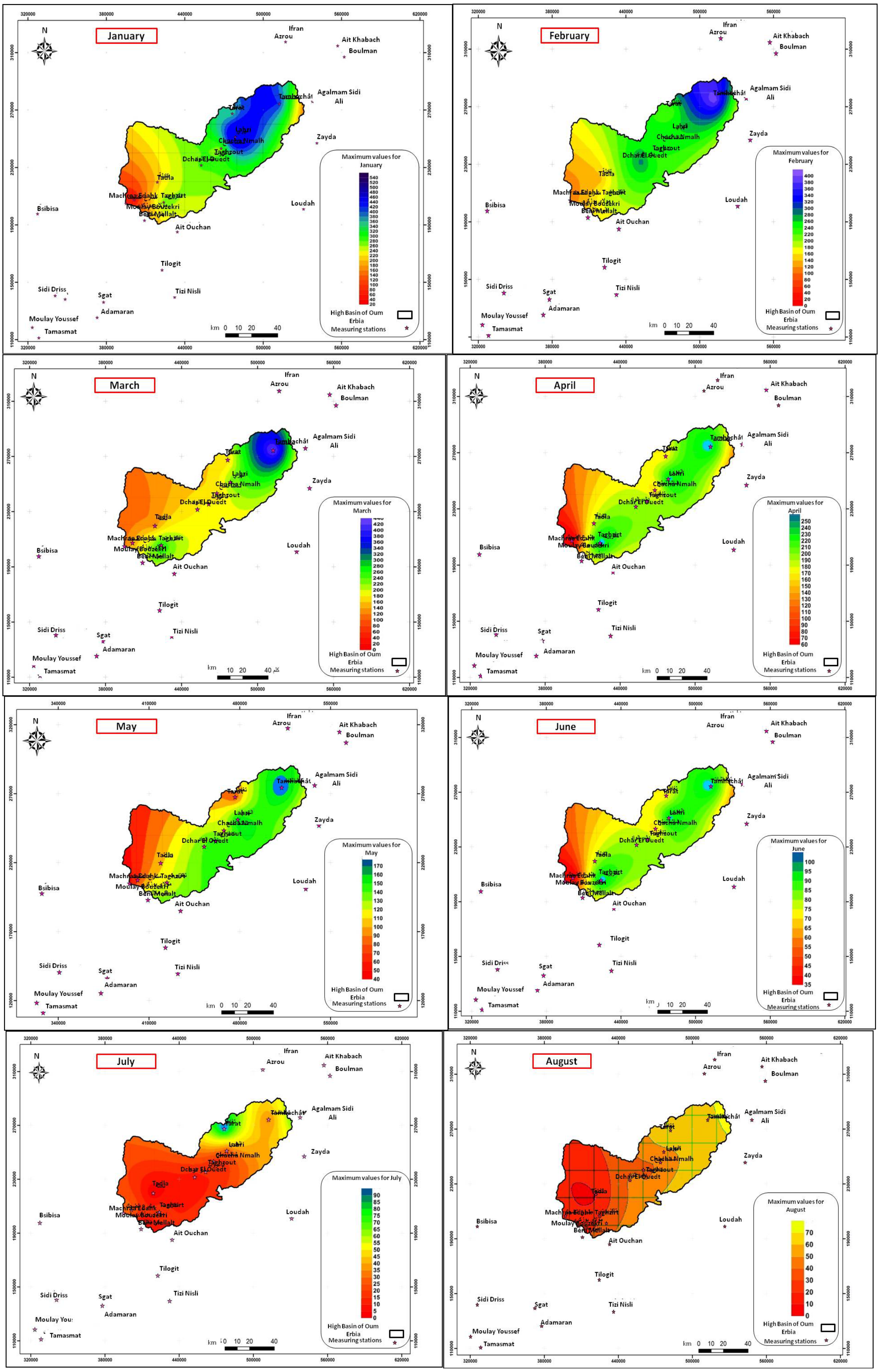


Figure 6. Map of average annual precipitation. (Inverse distance weighting method)

4.4. Spatial Distribution of the Highest Monthly Rainfall Values: Kriging Method

Using the highest monthly rainfall data from the study's selected stations, we were able to map the spatial distribution of rainfall on a monthly basis. This analysis was conducted separately for each month, utilizing the Surfer and ArcGIS programs to create detailed spatial representations of rainfall patterns.


January
February
March
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May
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Maximum values for January
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Maximum values for March
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Maximum values for May
Maximum values for June
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Maximum values for August
High Basin of Oum Erbia
Measuring stations
Ifran
Azrou
Ait Khabach
Boulman
Agalmam Sidi Ali
Zayda
Loudah
Bsibisa
Ait Ouchan
Tilogit
Tizi Nisli
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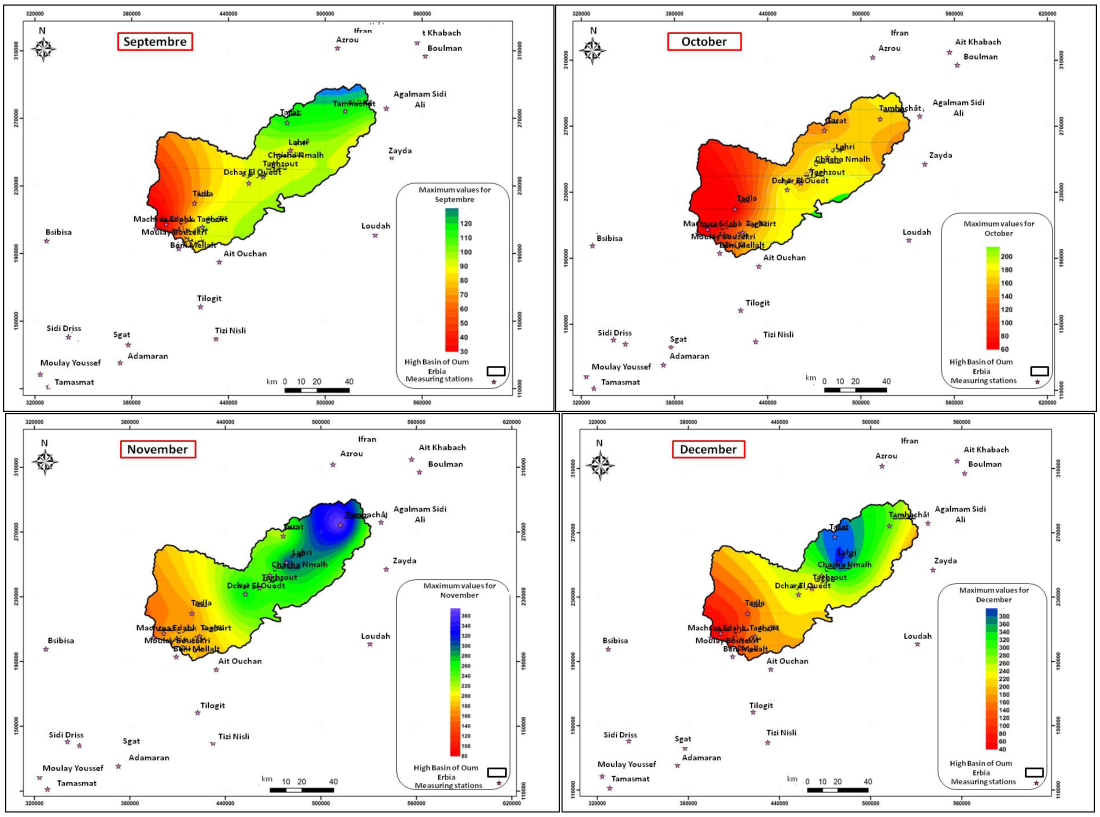

Figure 7. Spatial distribution of the highest monthly rainfall values.

The monthly distribution of maximum rainfall values for the statistical period from 1984 to 2016 (Figure 7) reveals significant variability in the spatial distribution of rainfall across the upper Oum Er-Rbia basin. Rainfall is highly concentrated in the upper basin, with a gradual decrease towards the center during the seven rainy months from November to May, reflecting the specific patterns of each month. In contrast, rainfall diminishes during the four months from June to September. July and August are the driest months, while September experiences relatively higher rainfall, particularly in the upper basin. This increased precipitation in September can be attributed to the activity of thunderstorms during that period.

4.5. Spatialization of Rainfall in the Oum Er-Rbia Basin: Thiessen Methods

By comparing the spatially distributed monthly precipitation data with measurements from the stations located within the basin, we can evaluate the accuracy and consistency of our spatial models. (Figure 8) provides a summary of this comparison, illustrating that there is a very small difference between the spatially interpolated precipitation values and those recorded directly at the stations. This close correspondence indicates that the spatial models effectively capture the precipitation patterns observed at the stations. The minimal discrepancies highlight the reliability of the spatial distribution in reflecting actual rainfall conditions across the basin, reinforcing the accuracy of our spatial analysis and its utility in understanding regional precipitation patterns.

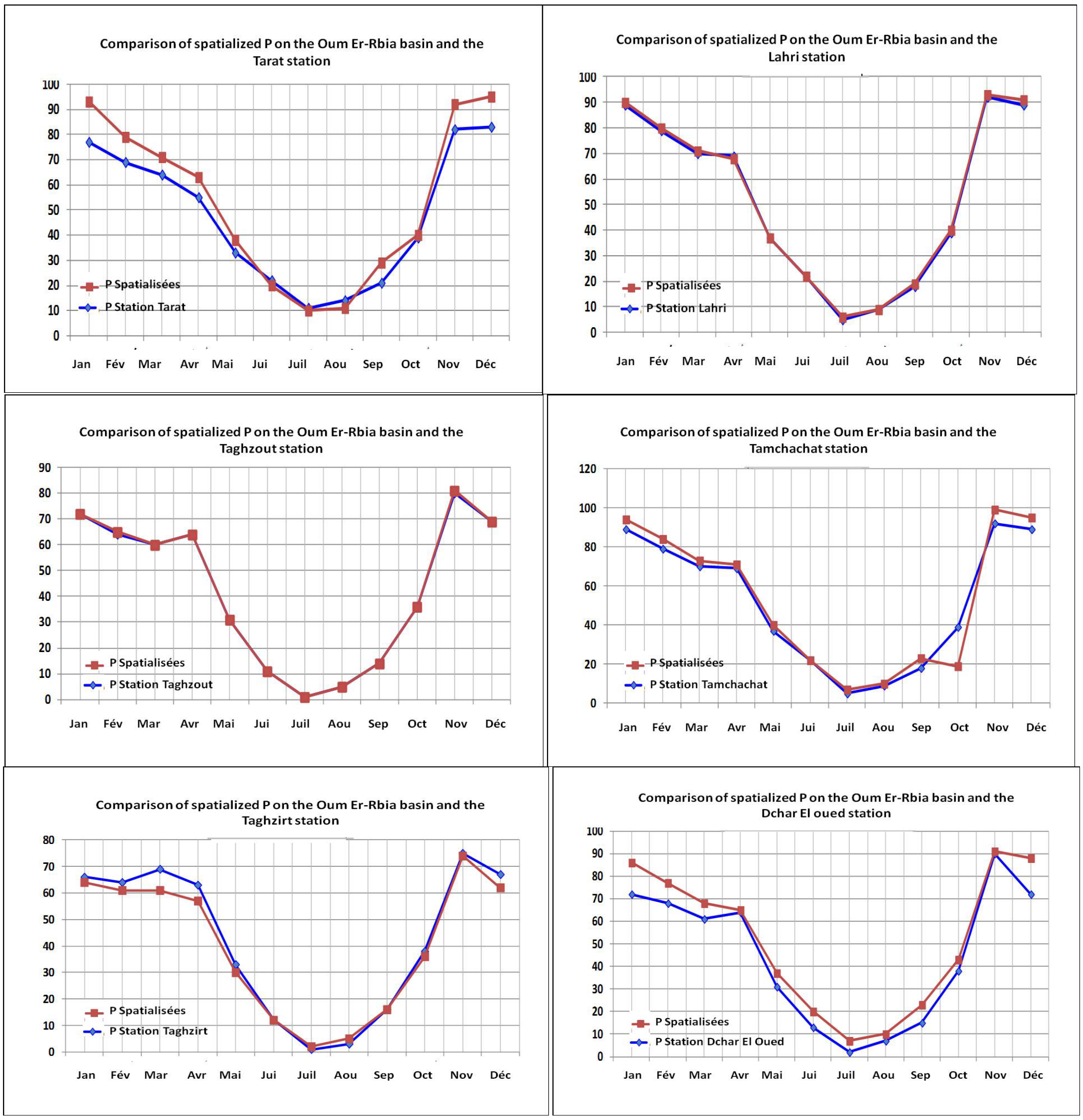

Figure 8. Comparison of spatial rainfall and rain gauging stations.

It has been clearly demonstrated through the spatial distribution of rainfall, based on the three most commonly used methods: Thiessen, Inverse distance and Kriging, and also based on rainfall rates for 33 different stations in their spatial distribution, that there is a large gradation in the distribution of rainfall between the high stations that record significant rainfall and the middle stations that record medium rainfall, while the lower stations record weak rainfall compared to the high stations. Thus, topography remains the main controller of this spatial distribution (Lahlou, 2021).

5. Conclusion

According to the results obtained, precipitation in the basin is characterized by spatio-temporal variability. Regarding spatial variability, the study area is located in a non-homogeneous climatic context. It benefits from average rainfall ranging from 263 mm to 1454 mm. The upstream part of the basin is more watered than the middle part, while the downstream part is the driest part. On a temporal scale, annual precipitation can vary quite significantly from year to year.

Through this study, the effects of climate variability on the upper Oum Er-Rbia basin in the context of climate change have caused human interference in the basin through the construction of a set of dams, which have played an important role in the management and mobilization of water resources, as well as a strategic role in reducing flooding and low water phenomena.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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