Evolution of Bioclimatic Stages under climate change in the Ouergha Catchment (Northern Morocco)

Mohamed Boutallaka[1,*], *Mohamed* El Mazi[2], *Maryame* El Yazidi[3], *Khalid* El Hairchi[4], and *Mohammed* Benabdelhadi[3]

[1]Department of Geography, FLSH, Sidi Mohamed Ben Abdellah University of Fez, Morocco
[2]Department of Geography, Moulay Ismail University of Meknes, Morocco
[3] Laboratory of functional ecology and environmental engineering, FST, Sidi Mohamed Ben Abdellah University of Fez, Morocco
[4] Territory Team: Dynamics, Planning and Sustainable Development (TEA2D), FPK of Khouribga, Sultan Moulay Slimane University in Beni Mellal, Morocco

Abstract. Climate change is one of the greatest environmental challenges facing humanity in the 21st century. This change is having a negative impact on the world, and in particular on the Southern part of the Mediterranean. Climate projections predict a reduction in precipitation, with mountainous regions being the hardest hit. The intensity of the effects of climate variability will particularly affect humid and sub-humid areas, such as the Ouergha watershed in Northern Morocco. The aim of this study is to analyse the evolution of annual precipitation between 1960 and 2020, and to assess its impact on the spatio-temporal evolution of bioclimatic stages and to make future projections of bioclimatic stages according to two scenarios (RCP4.5 and RCP8.5). The results of the study indicate a significant drop in water supply, estimated at around 30% over the studied period. A sharp drop in precipitation marked the months of the wet seasons. The effects of this decline on local ecosystems are manifold. The semi-arid and sub-humid bioclimatic stages have replaced the humid and hyper-humid stages, whereas the RCP scenarios show that the rate of change reaches 34.4%. This led to an amplification of the water crisis during the dry seasons.
Keywords: Climatic variability, bioclimatic stage, precipitation, evolution, Ouergha catchment, Morocco.

1. Introduction

Climate is the main factor influencing the natural environment and human activities, rather than simply regulating space [1]. Climate change is bound to have an impact on all aspects and components of the environment [2]. The report published by the Intergovernmental Panel on Climate Change (IPCC, 2008; IPCC, 2014), and the COP27 Conference in 2022, confirmed that climate events and changes recorded over the recent period have significantly affected many physical and biological systems.

Morocco is among the North African and Mediterranean countries that are most vulnerable to the impact of climate change [3]. This is due to its position in the arid and semi-arid tropical latitudes, where the atmospheric circulation is generally stable and descending [4-5]. Several studies of the Moroccan climate revealed that the changes affecting the country are trending towards drought increased and warming temperatures. A significant increase in temperature has been observed in recent times, with values ranging from 0.10°C to 0.63°C depending on the region [6-7]. On the other hand, rainfall has decreased significantly since the 1970s. The analysis of statistical series on the interannual distribution of rainfall and temperature, both in Morocco and in neighbouring countries, has also revealed a trend towards warmer and drier conditions [2, 8, 12]. Future scenarios indicate that drought will increase significantly in the coming years [7]. In addition, modern climate change models and other climate elements, such as the IPCC A2 scenario climate model (MND, 2009), predict an increase in average temperatures, which could vary from 2°C to 6°C depending on the region of the country, until the 21st century [13], [14]. This will lead to a reduction in water resources and an increase in other phenomena, such as desertification and forest fires. This situation affects the agricultural production of Autumn crops and water resource [12], [15].

In order to minimize the increased impacts of climate change, international, national and local institutions have implemented a number of interventions to reduce the impact of CC, particularly in the face of frequent drought years and extreme climatic phenomena. The aim of this study is to spatialize the spatio-temporal distribution of bioclimatic stages in the Oued Ouergha catchment in northern Morocco, using GIS and climate data for the period between 1960 and 2020. It also aims to simulate the effects of climate change on the future distribution of bioclimatic stages under different scenarios.

* Corresponding author: boutallaka1988@gmail.com

2. Study Area

This study concerns the Oued Ouergha watershed, which topographically belongs to the Rif Mountains range, and more specifically to the central Rif. It is also part of the large Sebou Basin, and is located in its northern part (**Fig. 1**). It covers a very large area of 6150 km^2, extending north to the high peaks of the Rif Mountains range (Dahdouh, Tidghine, Tizirane) [16]. Administratively, the basin partially covers the provinces of Taounate, Chefchaouen, Sidi Kacem, Taza, Al Hoceima and Ouazzane.

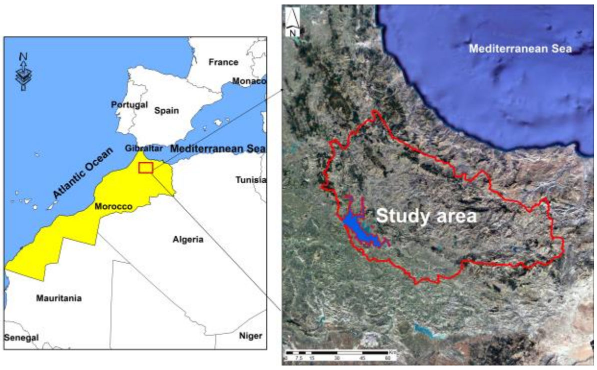

Fig. 1. *Study area*

3. Methodology

Rainfall and temperature data collected from the Sebou Basin Agency as well as physiographic factors (altitudes, exposures, topographic situations) were used to spatialize the bioclimates of the region on a map. This spatialization of precipitation and bioclimatic regions was carried out using IDW tools in ArcGis software.

The study of climatic variability and its impact on the distribution of bioclimatic stages is based on a geo-climatic approach**.** This involves statistical description of rainfall data from 25 measuring stations between 1960 and 2020. To ensure the validity and homogeneity of the obtained data, we carried out a critical study based on the statistical methods used in climate studies [17]. The precipitation data obtained are homogeneous, R^2 above 0.90, reflecting tolerable results. The climatic quotient proposed by Emberger (1933) has been used to spatialize bioclimatic regions. This quotient is based on annual precipitation and the extreme temperatures that have the greatest influence on vegetation (M and m).

To forecast future projections of bioclimatic stages, we have integrated two "Representative Concentration Pathway" scenarios; the first is an optimistic scenario (RCP4.5), and the second is a pessimistic scenario (RCP8.5). The version 4.2 of the Statistical Downscaling Model (SDSM) was used to analyze the uncertainty of precipitation forecasts for weather stations in the Ouergha watershed. The SDSM combines the features of a stochastic weather generator and methods based on multiple regression. It exploits empirical statistical techniques to establish links between large-scale historical circulation patterns, atmospheric moisture variables (predictors), and locally observed precipitation (predictors) [18-19]. The uncertainty analysis was carried out based on the application of Global climatic model (GCMs)and climate scenarios (RCP4.5 and RCP8.5) for the periods 2050 and 2100. The precipitation reduction steps can be broken down as follows: (i) Variable selection, a crucial step in establishing a credible regression model, involving the choice of the most appropriate NCEP predictors; (ii): Calibration, a conditional process establishing a monthly regression function between the selected predictors and 20 years of observed data, (iii): Validation, a procedure aiming to justify the validity of the reduction for future use, and (iv): Scenario generation, involving the creation of future precipitation scenarios from 2020 to 2100 [20].

4. Results and Discussion

4.1. Climatic characteristics of the area

The Ouergha basin belongs to the Mediterranean climate, which is characterized by cold, wet winters and hot, dry summers. The precipitation distribution is marked by a very high spatial-temporal variability; it varies from less than 600 mm in sheltered valleys to more than 1400 mm in mountain peaks exposed to Atlantic and Mediterranean perturbations. The Orographic factors (aspect and altitude) effects on precipitation are obvious and have an important and complex role. The western to north-western exposed slopes are wet and receive high levels of precipitation, while south and southeast aspects and sheltered valleys are drier. The rainfall gradient is about 50 mm/100 m. Precipitation decreases considerably from west to east due to continental effects and orographic barriers**.**

Over the period from 1960 to 2019, precipitation has shown a downward trend, particularly in mountainous areas. The deficit is estimated to -306 mm at the Bab Ouender station in the upper part of the basin, -80 mm at the Mjaara station in the lower part, and around -490 mm at the Jbel Ouedka station representing the high crests. Since the 1980s, this region has been affected by a successive drought, which have sometimes lasted more than four consecutive years, of which the 1986-1994 period was the longest drought, followed by 1999-2002, then 2004-2008, and finally 2012-2015 (**Fig. 2; Fig. 3**). Meanwhile, a significant drop was observed in the succession of wet years, no longer exceeding 3 consecutive years.

This downward trend in precipitation indicates that the climate in the Ouergha watershed has become drier than in the 1960s. The succession of drought is due to its latitudinal situation in the subtropical zone, which places it under the influence of atmospheric stability mechanisms and more particularly the movements of the jet stream in the upper atmosphere and the position of the Asor anticyclone at ground level, particular during the wet season. In addition, it is influenced by the North Atlantic Oscillation (NAO), which controls the arrival of climatic disturbances and is effectively responsible for the heterogeneity of precipitation in Morocco [21]. On the other hand, climate change has exacerbated drought in Morocco [12].

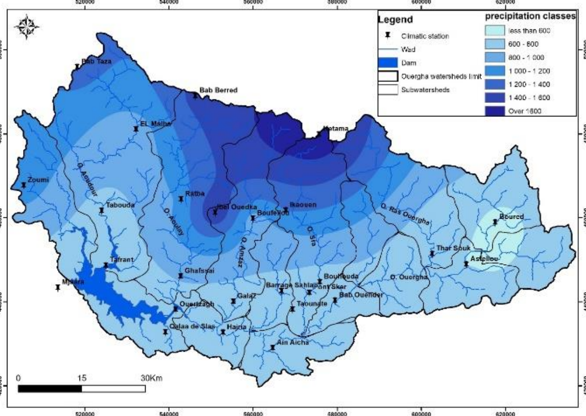

***Fig. 2**. The distribution of mean annual precipitation in the Ouergha catchment (1960-2020)*

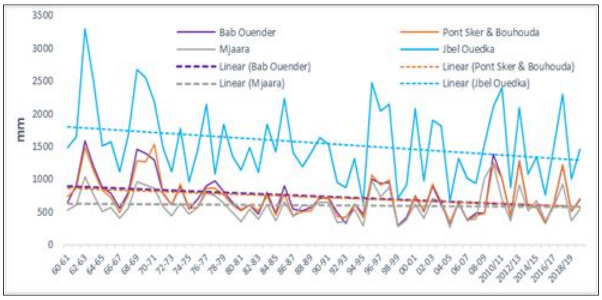

***Fig. 3**. Temporal rainfall distribution and general trends in the Ouergha catchment (1960-2020)*

4.2. Dynamics of bioclimatic stages

The IDW tool in ArcGIS software was used to spatialize the bioclimatic stages of the study area over the period from 1960 to 2020 (Fig. 5). Over this period, bioclimatic stages show a gradient ranging from semi-arid to hyper-humid located exclusively on ridges exposed to westerly winds. The most prevalent bioclimatic stages are the humid stage at medium altitude (31.5% of the basin surface), followed by the semi-arid stage at low altitude (400 m). The humid bioclimate (19%) is limited to mountainous areas above 1600 m altitude.

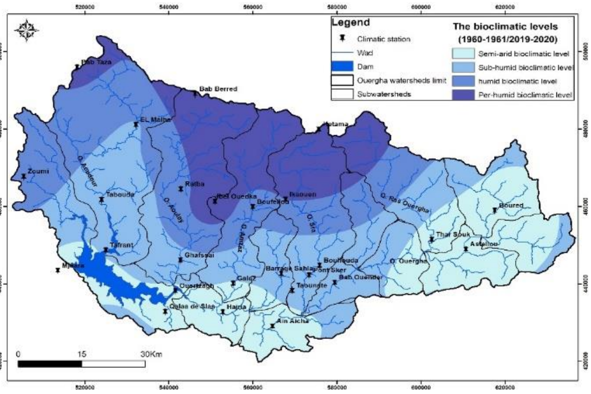

***Fig. 4**. Bioclimatic stages in the Ouergha catchment over the period (1960-2020)*

The comparison of bioclimate distribution between the 1960s and 2010-2020 (Fig. 4 and Fig. 6) shows a spatio-temporal trend in bioclimates regions marked by an increase in arid stages to the detriment of humid and hyper-humid bioclimates. The per-humid bioclimate decreased by 19%, and the humid bioclimate by 30%, while the sub-humid bioclimate increased by 33%. The semi-arid bioclimate has appeared on the margins of the study area. This situation was affected by the severe droughts in the 1980s and 1990s of the last century, which remain even more frequent today. These results are consistent with several studies confirming a reduction in humid and per-humid bioclimate and an expansion of arid and semi-arid bioclimate [12-22]. In the same context, [7] assessed future extreme events linked to climate change in CORDEX-MENA using the ALADIN-Climate regional climate model, whose results predicted contrasted changes in precipitation and a succession of prolonged droughts.

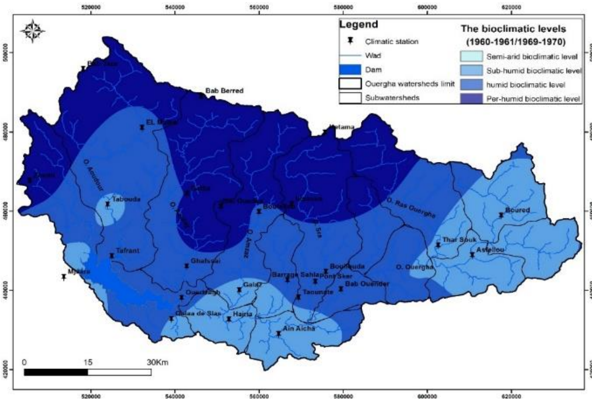

***Fig. 5**. Bioclimatic stages distribution in the Ouergha catchment: period 1960-1970*

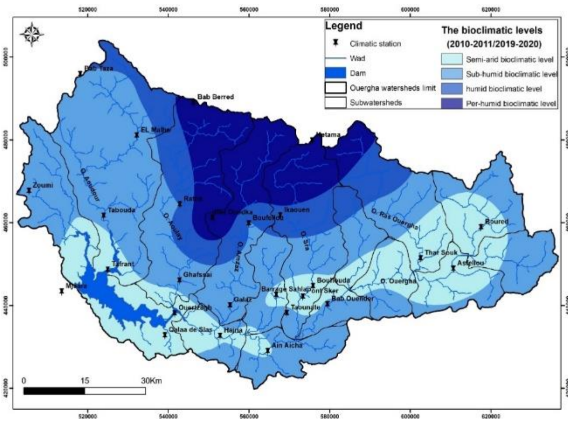

***Fig. 6.** Bioclimatic stages distribution in the Ouergha catchment: period 2010-2020*

4.3. Future climate projections in the bioclimatic stages

The evolution of bioclimatic stages in the context of climate change was simulated based on two scenarios (RCP4.5) and (RCP8.5) for the horizons 2050 and 2100, using the period (1960-2020) as a reference. The results are illustrated in Figure 7 and their statistics are given by Fig. 7and Table 1. For 2050, the greatest decreases in precipitation are expected in the wet and per-humid stages in the RCP4.5 and RCP8.5 scenarios, respectively. The lowest decreases are expected in the semi-arid and sub-humid stages. Similarly, in the second period (2050-2100), precipitation is expected to decrease in the humid and per-humid bioclimates, with higher values compared to the previous period.

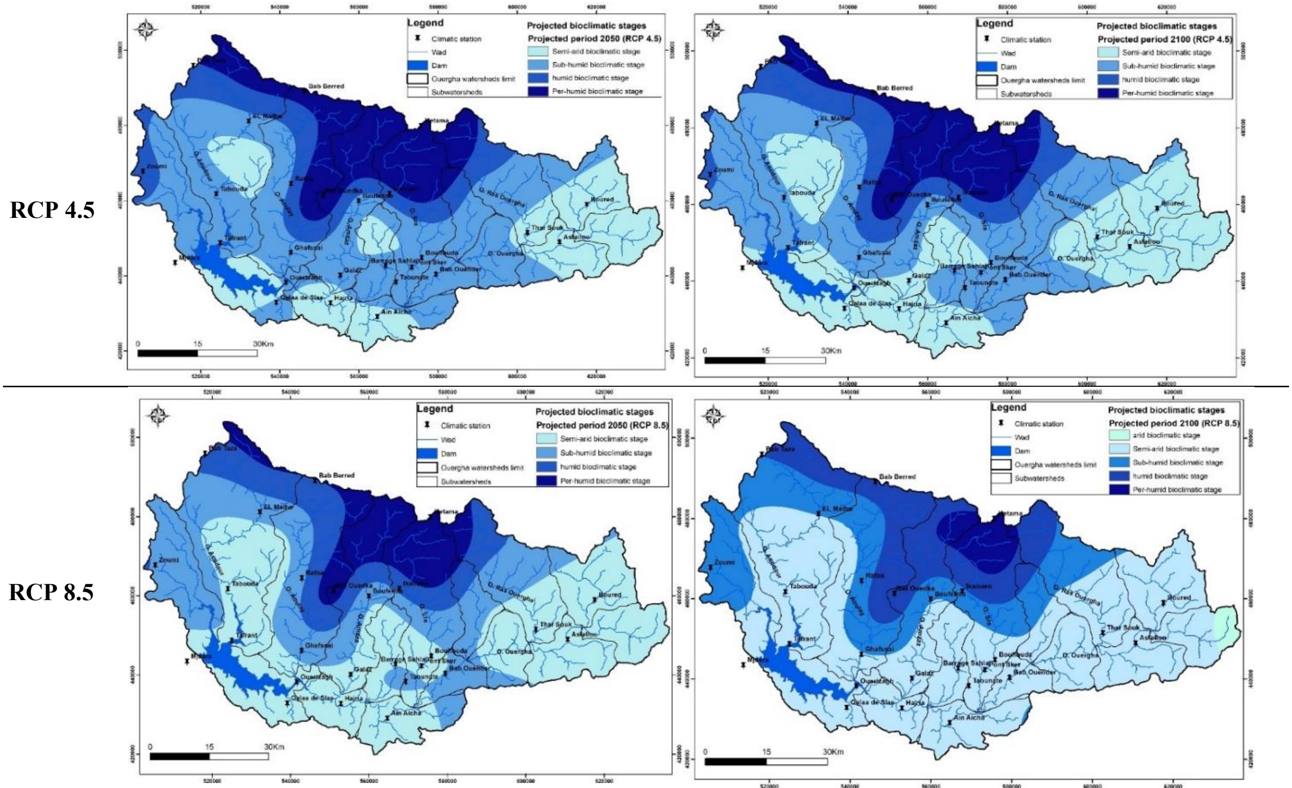

Fig. 7. *Projected bioclimatic stages in the Ouergha catchment*

Table 1*. Projected changes in bioclimatic regions of Ouergha catchment*

Bioclimatic regions	Precipitation change (mm)				Bioclimatic stages change (%)			
	2020-2050		2050-2100		2020-2050		2050-2100	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Per-humid	160	300	242	484	-1.8	-7.8	-4.6	-15.6
Humid	82	165	124	248	-11.1	-11.2	-11.5	-8.8
Sub-humid	68	119	102	205	13.7	-2	5.4	11
Semi-arid	54	109	82	164	0.8	21	10.7	34.4
Arid	-	-	-	-	-	-	-	1

The spatial extension of bioclimatic regions will be affected compared with the current situation. A decrease of -4.6% and -15.6% for the RCP4.5 and RCP8.5 scenarios, respectively, is forecasted for the per-humid region on the horizon of 2050. For the humid bioclimate, decreases of 11.5% and 8.8% are forecasted for the RCP4.5 and RCP8.5 scenarios respectively. In contrast, the sub-humid bioclimate is projected to increase by 13.7% for scenario RCP4.5 and decrease by 2% for scenario RCP8.5. In addition, the semi-arid bioclimate is set to increase significantly for the pessimistic scenario.

By the end of the century (2050-2100), a major drying out is expected, with the emergence of dry bioclimates and the extinction of wet bioclimates. The greatest decreases are projected in the per-humid bioclimate, with 4.6% and 15.6% according to the RCP4.5 and RCP8.5 scenarios, respectively. In addition, the humid bioclimate will be reduced by -8.8% and -11.5% for RCP4.5 and RCP8 respectively. An average change of 5.4 and 11 for both scenarios will be projected for the Sub-humid bioclimate. On the other hand, the semi-arid bioclimate is predicted to be the most extensive, recording an evolution of 10.7% for RCP4.5 and 34.4% for RCP8.5.

These results are similar to those found by several authors in Morocco and the Mediterranean region with similar climatic conditions, who have revealed that the drop in precipitation predicted by the different climate scenarios reflects a new distribution of bioclimatic, biogeographic and agro-ecological regions [2, 7, 12,17]. The impact of reduced rainfall and the expansion of semi-arid and sub-humid bioclimatic stages is having varying effects on the environmental landscape. This decline has been accompanied by a growing demand in water resources to irrigate crops. The expansion of industrial cultivation and the development of fields and agriculture through the introduction of hybrid seeds has increased the water demand, particularly during summer seasons (July and August). As far as vegetation is concerned, the extension of arid and sub-humid bioclimatic stages can lead to a redistribution of ecological conditions for plant species located in humid and per-humid bioclimatic stages, for example, the Atlas cedar specie and deciduous forests (*Quercus pyrenaica, Quercus Zéen, Quercus canariensis*, etc.). They can also cause large-scale fires. Several studies have reported that forests in semi-arid and sub-humid bioclimatic zones are the most vulnerable to forest fires [23]. Therefore, the decrease in rainfall in bioclimate humid and per-humid encourages the development of dense undergrowth, which becomes a major fuel source in the summer, which plays an important role in the spread of flames from the lower strata to the tree strata [24]. Thus, the extension of arid and sub-humid bioclimates at the detriment of humid bioclimates can exacerbate the phenomenon of desertification [25].

Conclusion

This study focused on the spatialization of Emberger bioclimatic stages and the estimation of their future evolution under climate change according to the two scenarios foregrounded above. The results are presented and spatialized on maps. Precipitation has shown a downward trend over the period 1960-2020, with mountainous areas, home to great ecological diversity, continuing to be the hardest hit by this decline. Droughts are becoming more frequent, sometimes lasting more than four consecutive years. A significant change is observed in bioclimatic stages, characterized by a spatial extension of semi-arid and sub-humid bioclimates at the detriment of humid and per-humid bioclimates. Predictions for both scenarios anticipate that regions dominated by humid climates will experience decreases of -4.6% and -15.6% for the RCP4.5 and RCP8.5 scenarios respectively by 2050, and -4.6% and -15.6% for the RCP4.5 and RCP8.5 scenarios respectively by 2100. In contrast, the sub-humid bioclimate is expected to increase by 13.7% for scenario 4.5 and decrease by 2% for scenario RCP8.5. Climate change will therefore have a negative impact on the national territory, particularly on water resources and the biodiversity that characterizes the country. This transformation indicates that the climate of the Ouergha watershed in particular, and that of Morocco in general, will become hotter and drier, which will have a direct impact on vulnerable environments, increasing the degradation of the environment. Consequently, this situation will have an impact on other economic, social and sustainable development stages. To reduce these accelerated impacts in the face of growing demand for territorial resources, international, national and local institutions concerned with the climate are obliged to draw up a set of procedures to reduce the exacerbation of risks linked to climate change and global warming.

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