BIO Web of Conferences **115**, 03003 (2024) https://doi.org/10.1051/bioconf/202411503003
RENA23

Comparative Study of Observed and Projected Future Climate Evolution in Two Watersheds (Souss-Massa and Ouergha, Morocco) Using the Statistical Downscaling Model (SDSM)

Maryame El-yazidi [1,*], *Mohammed* Benabdelhadi [1], *Marouane* Laaraj[1], *Mohamed* Boutallaka [2], *Malika* El-Hamdouny [1], *Fatima* Daide[1] *Hassan* Tabyaoui[3] & *Abderrahim* Lahrach[1]

[1] Laboratory of Functional Ecology and Environment Engineering, University of Sidi Mohamed Ben Abdellah, Fez, Morocco
[2] Natural Environments, Development and Socio-Spatial Dynamics, FLSH SAIS, Fez, USMBA, Morocco
[3] Resources and Environment Laboratory, Polydisciplinary Faculty of Taza, Sidi Mohamed Ben Abdellah University, Fez, Morocco

Abstract. The hydrological cycle and local climate of a region are directly impacted by climate change. Rapid fluctuations in climate alter weather patterns, resulting in the occurrence of extreme weather phenomena. This study examines two basins situated in distinct regions of Morocco, each influenced by specific climatic conditions. The primary aim of this study is to examine the climatic changes occurring within the two watersheds. Initially, it involves a comparative analysis of annual precipitation and temperatures from 1982 to 2022. Subsequently, the study projects precipitation and temperatures for the period spanning from 2024 to 2100. This analysis relies on data collected from 13 stations, 8 in the Souss-Massa and 5 in the Ouergha regions, using the Statistical Downscaling Model (SDSM) version 4.2.9. The investigation employs the fourth generation coupled global climate model CanESM2. Precipitation data and historical temperature models are used to forecast future temperatures and precipitation, based on Representative Concentration Pathway (RCP) scenarios 4.5 and 8.5. The projected scenarios indicate a decrease in observed precipitation for the years 2040, 2060, and 2080, while temperatures are predicted to rise in both watersheds across all future scenarios.

1 Introduction

In recent years, global attention has increasingly focused on the phenomenon of climate change. Scientific evidence, as highlighted by the Intergovernmental Panel on Climate Change (IPCC, 2014) and Pachauri [1], underscores the alarming trend of planetary warming, primarily driven by human activities. The escalating emissions of greenhouse gases, widespread deforestation, and the discharge of pollutants from industrial and transportation sources have collectively contributed to substantial alterations in Earth's climate.

The impact of climate change is especially evident in Morocco, with notable environmental transformations occurring in hydrographic basins like Souss-Massa and Ouergha. These alterations have triggered natural disasters such as floods, landslides, and coastal erosion, affecting water resources and agriculture. Morocco's susceptibility to climate change has driven the adoption of multiple policies and strategies focused on environmental protection and the promotion of sustainable development. As a result, the country positions itself as a leader in the fight against climate change in Africa [2].

In this context, understanding the dynamics of climate change and its implications for specific regions is of paramount importance for devising effective adaptation and mitigation strategies. This study aims to investigate and compare the observed and projected future climate evolution in the Souss-Massa and Ouergha watersheds using the Statistical Downscaling Model (SDSM). By examining the trends in precipitation and temperature over a specified period, this research seeks to provide valuable insights into the ongoing climatic changes in these critical Moroccan regions.

2 Materials and Methods

2.1 Study area

2.1.1 Souss-Massa Watershed

The Souss-Massa watershed (Fig. 1), situated in central-western Morocco, covering a total area of 27,000 km². It comprises 21% plains (5,700 km²) and 79% mountains (21,300 km²).

The geographical boundaries are defined by the Anti-Atlas to the South, the High Atlas to the North, the Siroua massif to the East, and the Atlantic Ocean to the West. Elevations within the watershed vary from sea level (0 m) along the Atlantic Ocean to 4,167 m at the

Corresponding author: maryame.elyazidi@usmba.ac.ma

summit of Toubkal in the High Atlas Mountains. Notably, the watershed encompasses two main plains: the Souss plain and the Chtouka-Massa plain, with elevations ranging from 0 to 700 m.

From an administrative standpoint, the Souss-Massa region comprises the prefectures of Agadir-Ida-Outanane, Inezgane-Ait-Melloul, Taroudant, and Tiznit. Its climate ranges from semi-arid to sub-desert, with a mild coastal climate in the West and a hot semi-continental climate in the East [3]. Cold winds from the Atlantic Ocean (Canary Current) and hot winds from the southern Sahara significantly influence the region [4].
Annual precipitation displays notable fluctuations. In wet years, rainfall levels can surge to three times the average, whereas during dry years, it may be as much as 15 times lower [5-6].

The fluctuation in precipitation is notably significant both over time and across different regions, with a marked decline from mountainous areas to the plains. Between 1998 and 2015, average annual precipitation levels ranged from about 250 to 300 mm in the plains, whereas mountainous regions received approximately 500 to 600 mm. [7]. The majority of precipitation from 1980-2013 occurs between November and March, while the dry season extends from May to October [8]. Annual temperature variations range from 14°C in the northern High Atlas region to 20°C in the southern Anti-Atlas region for the period 1980-2010. The annual evaporation rates range from 1,400 mm in mountainous areas and near the Atlantic coast to 2,000 mm in the plains of Souss, Massa, and Tiznit. The lowest evaporation rates occur in January, while the highest are recorded in July, averaging 35 mm (240 mm) in mountainous regions and 100 mm (270 mm) in the plains. [9].

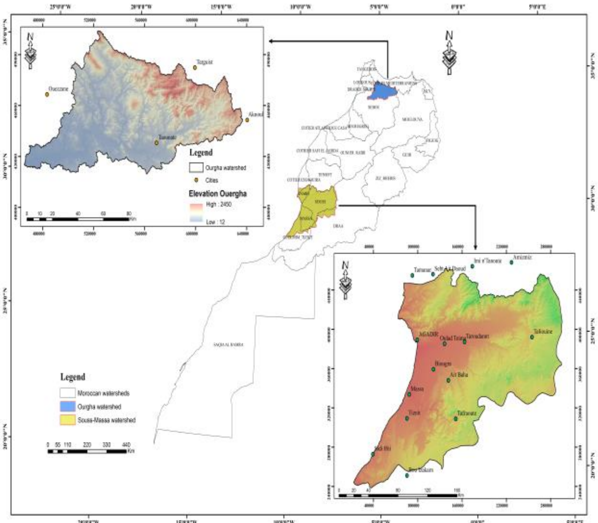

Fig.1. Geographic location of the Souss-Massa and Ouergha watersheds.

2.1.2 Ouergha Watershed

This watershed (Fig.1) constitutes a sub-basin of the Sebou, located in the Central Rif, occupying an area of 6,150 km² in Northern Morocco. It primarily covers the mountainous region of the Rif. To the North, its boundaries are marked by the Rif ridge, passing through Ketama, Bab Berred, and Bab Taza, approximately 30 km from the Mediterranean Sea. To the South, it is delimited by the watersheds of the pre-Rif tributaries of the Sebou, and to the East by the tributaries of the Moulouya and the eastern Sebou.

According to a study by Maqboul et al [10], during the period 2002-2023, the climate in the watershed is Mediterranean type, exhibiting a range from humid to semi-arid conditions. This climate is characterized by marked seasonal contrasts and very pronounced fluctuations in precipitation, with an annual average ranging between 497 mm/year and 1383 mm/year. According to a study conducted for the period 1990-2013, Ouergha watershed experiences two well-defined seasons: summer, characterized by drought, and winter, marked by precipitation. The rainy season extends from late October to the end of May, while the dry season spans from June to September [11].

2.2 Methodology

The climatic data used in this study include observed chronological series of precipitation accumulations as well as maximum, minimum, and average annual temperatures from the two watersheds for the period 1982-2022. These data were collected from 13 meteorological stations, including Amsul, Taroudant Pont, Immerguen, Aguenza, Pont Aoulouz, Ouijane, Amaghouz, and Imi Mikki for the Souss Massa watershed, as well as Bab Ouender, Mjaara, Ain Aicha, Galaz, and Jbel Ouedka for the Ouergha watershed. Future changes in precipitation and temperatures for the period 2024-2100 were calculated using the Statistical DownScaling Model (SDSM) [12].

The adopted approach allows using various statistical methods commonly applied in studies on climate variability. The objective is to analyse, evaluate, and compare current and future climatic data (precipitation and temperatures) from the two watersheds. To achieve this, we relied on the SDSM model to downscale future climate change scenarios.

The Statistical DownScaling Model (SDSM) serves as a valuable tool for evaluating and simulating parameters associated with climate change at regional and local levels. It uses a robust statistical downscaling technique to generate multiple meteorological scenarios tailored to specific sites, considering both current and future regional climate influences. By incorporating various factors, SDSM applies a reliable statistical downscaling method to produce accurate projections. The initial public release of this software occurred in 2001, and since then, more than 170 documented studies have been conducted worldwide.

The resulting data aims to facilitate a comparative analysis of climate between the two watersheds based on precipitation and temperature patterns. It also aims to elucidate future climate projections and trends using suitable predictive models, while assessing the dynamics of climate drought and aridity observed in other basins across Morocco.

3 Results and Discussions

The application of the Statistical DownScaling Model (SDSM) following its procedures, including the generation of meteorological data, model calibration, data analysis, and scenario development, enabled the generation of a set of synthetic daily meteorological data series. This was achieved using atmospheric predictor variables provided by a global climate model (GCM), with normalization of these variables relative to the reference period.

3.1 Climate Data from 1982 to 2022

3.1.1 Precipitation

The evolution of annual precipitation in the Souss-Massa (A) and Ouergha (B) watersheds (Fig. 2) shows an alternation of wet and dry years during the studied period in both watersheds with a downward trend pronounced for Souss-Massa. The Ouergha watershed experiences higher precipitation than the Souss-Massa, reaching 2000 mm at Jbel Oudka, while Souss-Massa does not exceed 500mm.

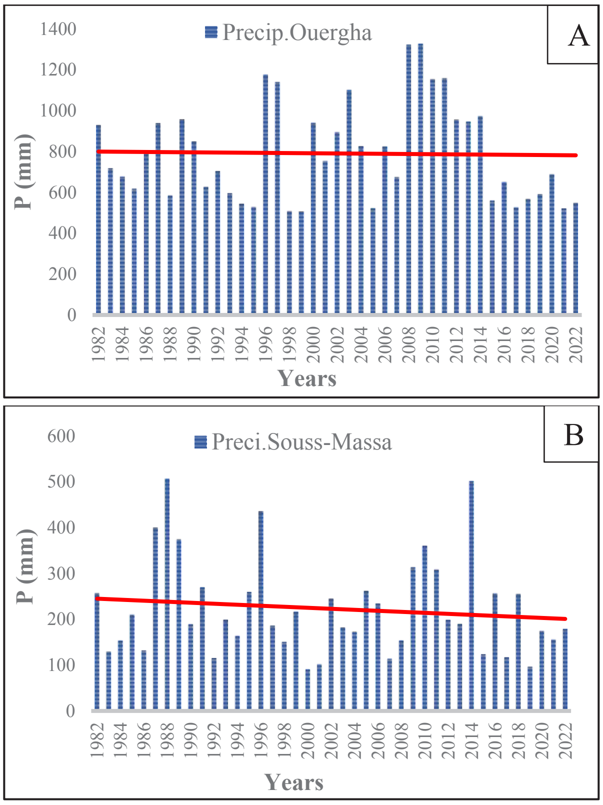

Fig. 2. Evolution annual Precipitation from 1982 to 2022 in the Two Watersheds: Ouergha (A) and Souss-Massa (B).

3.1.2 Temperature

The evolution of maximum, minimum, and average temperatures in the two watersheds, Souss-Massa (A) and Ouergha (B), during the period 1982-2022 (Fig. 3), indicates that all temperatures remain relatively stable throughout the study period. The maximum temperature ranges between 20 and 25 °C, while the minimum temperature is between 10° and 14 °C. The average temperature varies between 13°C and 15°C.

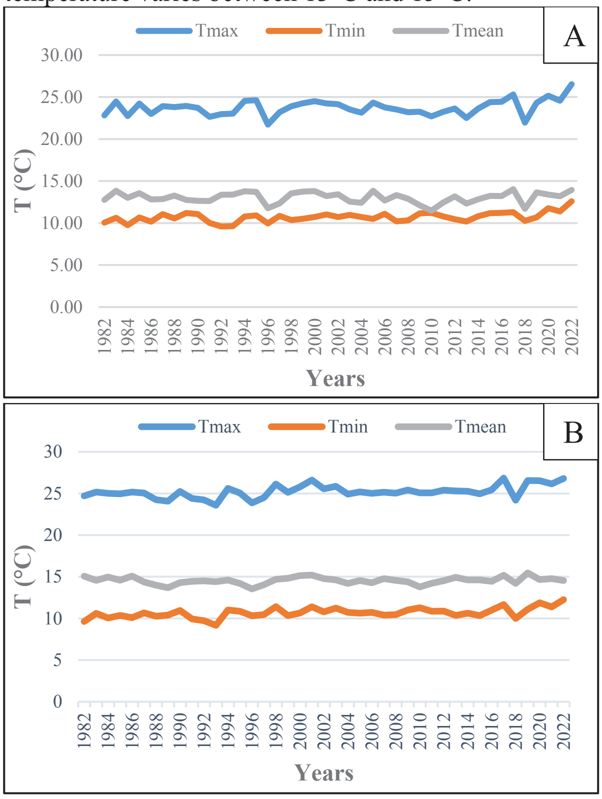

Fig. 3. Evolution of Maximum, Minimum, and Average Annual Temperatures Across Ouergha (A) and Souss-Massa (B) Watersheds from 1982 to 2022.

3.2 Future Climate Projection

To understand the evolution of precipitation and temperatures in the studied regions, it is essential to delve into the CMIP5 models from the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2014). These models provide valuable insights into the anticipated changes in extreme precipitation and how they are likely to manifest in the coming decades. Two Representative Concentration Pathways (RCPs) have been selected: RCP4.5 as a realistic emission scenario and RCP8.5 as a pessimistic [13].

The RCP 4.5 is characterized by intermediate emissions and is part of a low stabilization scenario, where radiative forcing is projected to reach 4.5 W/m^2 by the end of the 21st century. On the other hand, the RCP 8.5 represents a high emissions scenario, forecasting a radiative forcing of 8.5 W/m^2 by 2100 compared to pre-industrial levels, due to the increased greenhouse gas emissions [14].

3.2.1 Precipitation

The evolution of annual precipitation, according to the two projected scenarios (Fig.4) for the period from 2024 to 2100, demonstrates an alternation between wet and dry years, with a predominance of dry years during this period. There is also a downward trend observed for both scenarios and both watersheds, particularly pronounced for Souss-Massa, where precipitation would not exceed 300 mm.

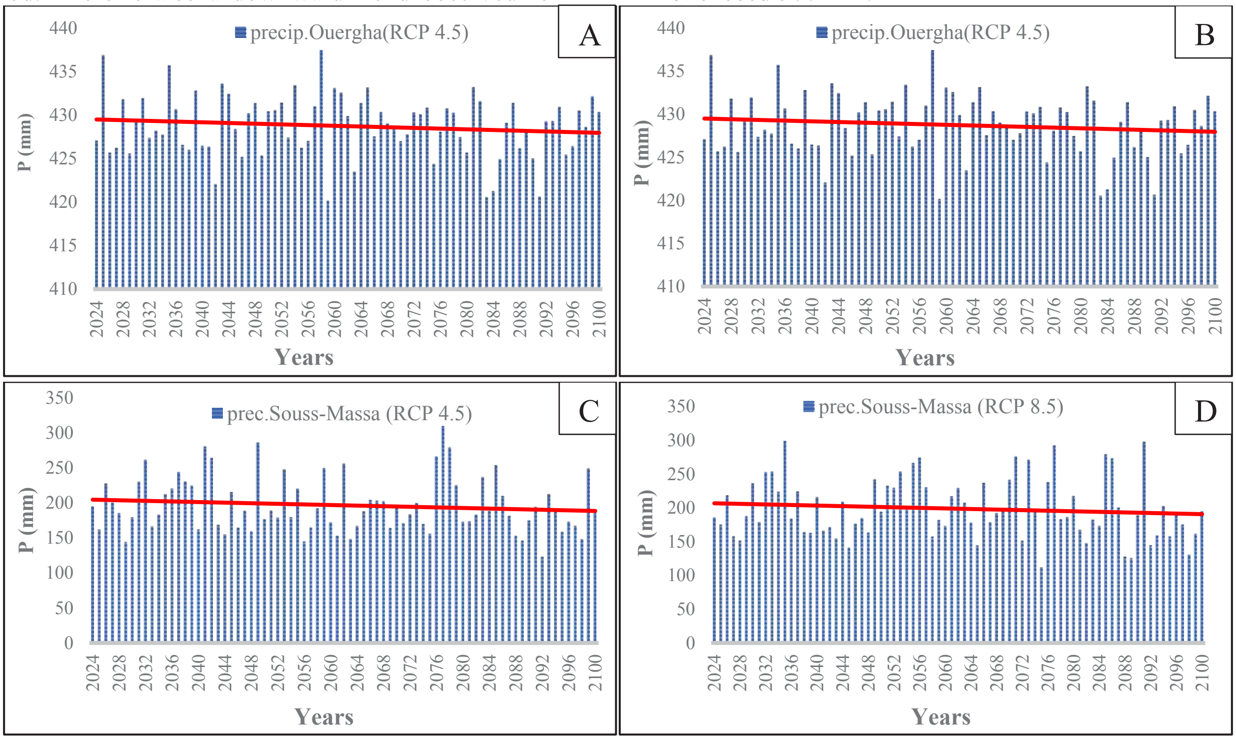

Fig.4. Evolution of annual precipitation according to scenarios (RCP 4.5) and (RCP 8.5) during the period 2024/2100 at the level of the two watersheds: Ouergha (A, B) and Souss-Massa (C, D).

3.2.2 Temperature

Future projections of maximum, minimum, and average annual temperatures for the two watersheds, Ouergha (A, B) and Souss-Massa (C, D), all indicate a rising trend, whether for the RCP4.5 emission scenario or the RCP8.5 scenario.

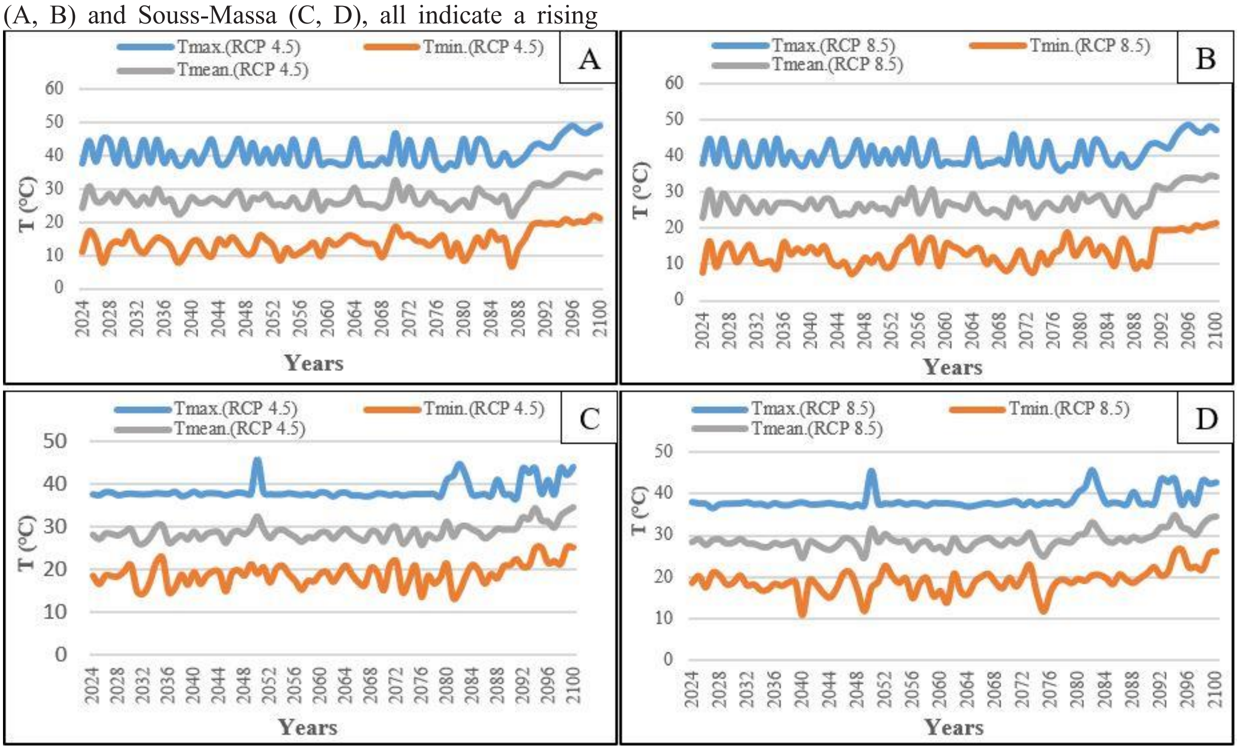

Fig.5. Evolution of annual temperatures according to scenarios (RCP 4.5) and (RCP 8.5) during the period 2024/2100 at the level of the two watersheds: Ouergha (A, B) and Souss-Massa (C, D).

For Ouergha, the increase in maximum and minimum temperatures will be significant throughout the study period under both scenarios, with a more pronounced increase from 2090 to 2100. Average annual temperatures follow a similar upward trend, reaching around 35.8°C according to RCP 4.5 scenario projections and 37°C according to RCP 8.5 scenario projections, with an accentuation of the trend after 2090 (Fig.5).

Table1. Evolution of annual temperature in the Ouergha watershed

	1982-2022	2024-2100 RCP (4.5)	2024-2100 RCP (8.5)
Tmax	+0,93°C	+3,76°C	+3,82°C
Tmin	+0,58°C	+3,49°C	+3,74°C
T-Mean	+0,64°C	+3,04°C	+3,06°C

Regarding Souss-Massa watershed, both scenarios predict a slight increase in maximum and minimum temperatures by 2050 and 2080. However, starting from the year 2092-2100, the temperature will undergo a very remarkable increase (Fig.5C, D), with annual average temperatures reaching approximately 35.5°C according to the RCP 4.5 scenario and around 36.4°C according to the RCP 8.5 scenario.

The overall results reveal a variation in precipitation and temperatures in the two watersheds between the period from 1982 to 2022, along with projections of maximum, minimum, and average annual precipitation and temperatures from 2024 to 2100 based on the scenarios used.

Table 2. Evolution of annual temperatures in the Souss-Massa watershed

	1982-2022	2024-2100 RCP (4.5)	2024-2100 RCP (8.5)
Tmax	+0,78°C	+2,07°C	+2,09°C
Tmin	+0,61°C	+2,70°C	+2,88°C
T-Mean	+0,41°C	+1,90°C	+2,02°C

Precipitation data for the period 1982-2022 shows an accentuation of variability, with a slight downward trend in both watersheds (Fig. 2 and 4). The cumulative precipitation is 1300 mm in the Ouergha watershed and 600 mm in the Souss-Massa watershed (Fig. 2). This disparity in precipitation between the two basins is generally influenced by several factors such as proximity to the ocean, altitude, and latitude.

For the period from 2044 to 2100, future projections under the RCP4.5 and RCP8.5 scenarios indicate a decrease in precipitation, with a more pronounced reduction. The projected cumulative precipitation will be 438 mm according to RCP4.5 and 440 mm according to RCP8.5 in the Ouergha watershed. For the Souss-Massa watershed, the corresponding figures will become 310 mm according to RCP4.5 and 300 mm according to RCP8.5 (Fig. 4).

In the Ouergha watershed, annual temperatures fluctuate with a rising trend, both during historical periods (1982-2022) and future periods (2024-2100) (Fig. 3 and 5). According to the RCP4.5 model, these fluctuations will increase by +3.76°C for Tmax, +3.49°C for Tmin, and +3.04°C for T-Mean. For the RCP8.5 model, these increases will be +3.82°C for Tmax, +3.74°C for Tmin, and +3.06°C for T-Mean (Table 1). As for the Souss-Massa results, differences will increase by +2.07°C for Tmax, +2.70°C for Tmin, and +1.90°C for T-Mean according to the RCP4.5 scenario. According to the RCP8.5 scenario, they will increase by +2.09°C for Tmax, +2.88°C for Tmin, and +2.02°C for T-Mean (Table 2).

Currently, the major challenge of climate change is well established. According to several studies, a decrease in precipitation is projected in Morocco by the end of the 21st century [15], leading to an anticipated reduction in water resources in the country, estimated between 10 and 15%. Furthermore, even without considering changes in precipitation patterns, a 1°C temperature increase could result in a 10% decrease in runoff in the Ouergha watershed [16].

The predictions suggest a decrease in precipitation and an increase in average temperature for the future period (2022-2050) compared to the reference period (1985-2013) [17]. These findings are consistent with another research studies [18], which highlights significant expected changes in climatic variables, including a reduction in precipitation in the Ouergha watershed. Estimates suggest decreases ranging from 13% to 15% for the period (2041-2080). Future climate projections indicate similar trends for the Souss-Massa region [19-20-21].

4 Conclusion

This study analyzed potential changes in the distribution of precipitation as well as in the maximum, minimum, and average annual temperatures in the Ouergha and Souss-Massa watersheds. The analysis was based on a comprehensive statistical evaluation of historical data on daily precipitation and temperatures covering the period from 1982 to 2022, using the averages of 13 meteorological stations (8 stations in Souss-Massa and 5 stations in Ouergha). The results reveal a downward trend in precipitation and an upward trend in temperatures observed in both watersheds.

To compare data from the historical period of 1982-2022 with those projected for the period 2024-2100, the statistical downscaling method (SDSM) was applied to future climate conditions with the RCP 4.5 and RCP 8.5

scenarios. Despite the geographical and climatic differences between the two watersheds, the results of both scenarios indicate a probability of decreased precipitation for both, which is consistent with the majority of studies on climate change. Additionally, maximum, minimum, and average temperatures are expected to follow upward trends. The most optimistic scenario forecasts a significant decrease in precipitation and an increase in temperatures towards the end of the century.

This climate change scenarios underscores the urgency of developing new policies and strategies aimed to more adequate water resources management and sustainable towards environmental and socio-economic issues.

References

1. IPCC, R. K. Pachauri, L. A. Meyer (Eds.) *Climate Change 2014: Synthesis Report.* Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: Core Writing Team (2014).
2. V. Ongoma, F. Driouech, Y. Brouziyne, T.Chfadi, TE. Epule, M. Tanarhte, A. Chehbouni. *Morocco's climate change impacts, adaptation and mitigation—a stocktake.* REC.**24,** 14 (2024). https://doi.org/10.1007/s10113-023-02176-2
3. T. Tagma, Y. Hsissou, L. Bouchaou, L. Bouragba, S. Boutaleb. *Groundwater nitrate pollution in Souss-Massa basin (south-west Morocco).* AJEST. ***3(10),*** 301-309 (2009). http://www.academicjournals.org/AJEST
4. T. Manssouri, H. Sahbi, I. Manssouri . *Elaboration of stochastic mathematical models for the prediction of parameters indicative of groundwater quality Case of Souss Massa-Morocco*. . IJCER. **4(5)**, 31–40. ISSN (e): 2250 – 3005 (2014). https://www.ijceronline.com
5. Hirich, R. Choukr-Allah, A. Nrhira, M. Malki, L. Bouchaou. *Contribution of seawater desalination to cope with water scarcity in Souss-Massa region in southern Morocco.* HEC. **53**, 213–226 (2017). https://doi.org/10.1007/698_2016_78.
6. R. Choukr-Allah, A. Nghira, A. Hirich, L. Bouchaou. *Water resources master plan for sustainable development of the Souss-Massa River Basin.* HEC. **53**,1–26 (2017). https://doi.org/10.1007/698_2016_67.
7. M. Hssaisoune, S. Boutaleb, M. Benssaou, B. Bouaakkaz, L. Bouchaou. *Physical geography, geology, and water resource availability of the Souss-Massa River Basin*. HEC.**53**, 27–56 (2017). https://doi.org/10.1007/698_2016_68
8. L. Mansir, B. Bouchaou, Y. Chebli, R. Ait Brahim, A. Choukr-Allah. *specific indicator approach for the assessment of water resource vulnerability in arid areas: the case of the Souss-Massa Region (Morocco)*, HSJ. **66(7)**, 1151–1168 (2021). https://doi.org/10.1080/02626667.2021.1924379.
9. Y. Ait Brahim, M. Seif-Ennasr, M. Malki, B. N'da, R. Choukrallah, Z.E.A. El Morjani, A. Sifeddine, H. Abahous, L. Bouchaou. *Assessment of climate and land use changes: Impacts on groundwater resources in the Souss-Massa River basin*. HEC.**53**, 121–142 (2017). https://doi.org/10.1007/698_2016_71.
10. R. Maqboul, M. Aoujdad, M. Fadli, M. Fekhaoui. JEZS. *Population dynamics of Physa acuta (Mollusca: Pulmonata) in the lakes of Rif mountains (Northern Morocco, Ouergha watershed).* **2(6)**, 240–245 (2014). www.entomoljournal.com.
11. L. Erraioui, S. Taia, K. Taj-Eddine, J. Chao, B. El Mansouri. *Hydrological Modelling in the Ouergha Watershed by Soil and Water Analysis Tool.* JEE. **24(4)**, 343–356 (2023). https://doi.org/10.12911/22998993/161043.
12. R.L. Wilby, C.W. Dawson, E.M. Barrow. *SDSM—a decision support tool for the assessment of regional climate change impacts*. EMS. **17(2)**, 145–157 (2002). https://sdsm.org.uk/SDSMManual.pdf.
13. M. Musie, S. Sen, P. Srivastava. *Application of CORDEX-AFRICA and NEX-GDDP datasets for hydrologic projections under climate change in Lake Ziway sub- basin, Ethiopia*. JHRS. **31**, 100721 (2020). https://doi.org/10.1016/j.ejrh.2020.100721.
14. T.F. Stocker, D. Qin, G.K. Plattner, L.V. Alexander, S.K. Allen, N.L. Bindoff, F.M. Bréon, J.A. Church, U. Cubasch, S. Emori. *Technical summary. In Climate change 2013: the physical science basis.* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 33–115). Cambridge University Press (2013).
15. Intergovernmental Panel on Climate Change (IPCC) Climate Change 2007: The Scientific Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by S. Solomon et al., Cambridge Univ. Press, New York (2007).
16. H. Rueff, C. Ariza. *Climate change, migration and economic development nexus in North Africa. An overview.* Consultant. CCEN. Thematic Input Paper 1. 1–14 (2016). https://doi.org/10.13140/RG.2.1.2952.1521.
17. L. Erraioui, N. Mafhoum, S. Taia, J. Chao, B.El. Mansouri, Haida, S. *Assessment of the relative impacts of climate changes and anthropogenic forcing on Ouergha watershed hydrology (North-East of Morocco).* E3S Web Conf. **336,** 00027 (2022). https://doi.org/10.1051/e3sconf/202233600027.
18. K. Mounir, H. Sellami, I. La Jeunesse, A. Elkhanchoufi. *Assessment of future climate and hydrological changes in semi-arid catchment using the SWAT model and bias-corrected EURO-*

CORDEX ensemble: a case of the Ouergha catchment, North of Morocco. MESE.**10**, 349–369 (2024). https://doi.org/10.1007/s40808-023-01775-6.

19. S. Marieme, H. El. Abdelaziz, C. Redouane, Z. Rashyd, N. Abdessadek. WRAA. *Assessment of Global Change Impacts on Groundwater Resources in Souss-Massa Basin*. book series: Springer Water. 115–140 (2017). https://doi.org/10.1007/978-3-319-51856-5_8
20. K.K. Kusi, A. Khattabi, N. Mhammdi. AJG. *Evaluating the impacts of land use and climate changes on water ecosystem services in the Souss watershed, Morocco.* **16**, 126 (2023). https://doi.org/10.1007/s12517-023-11206-6
21. O. Attar, Y. Brouziyne, L. Bouchaou, A. Chehbouni. Water. *A Critical Review of Studies on Water Resources in the Souss-Massa Basin, Morocco. Envisioning a Water Research Agenda for Local Sustainable Development.* **14(9)**, 1355 (2022). https://doi.org/10.3390/w14091355.