

Water supply securing in Bouregreg Basin under a changing climate

Wafae EL HARRAKI^{1*}, Hajar Habib², Rafik Zitouni³, Ikram Benchbani² and Youness Laabdi²

¹The National Superior School of Mines of Rabat (ENSMR), Morocco

²General Directorate of Water (DGH), Ministry of Equipment and Water, Morocco

³River basin Agency of Bouregreg Chaouia (ABHBC), Benslimane, Morocco

Abstract. Climate change impacts on water resources are being felt in a pronounced way, especially in the Mediterranean region with a faster pace of warming and an increasing frequency and severity of droughts. This context necessitates adopting proactive adaptation strategies that would increase water systems resilience over time using simulation models. This study employs RIBASIM model to assess water security in Morocco's Bouregreg basin under climate change and growing demands. It also discusses options of adaptation and water supply security in the future. Results show that public water supply from the SMBA-Tiddas complex could decrease by 25-36% (222.7 - 190.5-vs. 297.7 MCM/y for the reference scenario) under 30-40% inflow reduction scenarios, with irrigation water supply falling 36% (12.8 vs 20 MCM/y). Through the further analysis, the Casablanca desalination project and Sebou-Bouregreg interbasin transfer emerge as crucial adaptation measures in terms of securing the future water demand of the basin (2050) and increase of its resilience. This analysis provides a framework for climate-resilient water planning in semi-arid regions.

1 Introduction

Water resources in the Mediterranean region are facing growing pressure not only due to population growth and economic activities, but also as a result of the unequivocal climate change effects on the hydrological regime [1-2]. Indeed, precipitation across the region has witnessed a clear disruption with a tendency to decrease during the last years, an increase in temperature and evapotranspiration as well as frequent extreme events (more severe and prolonged droughts and acute floods) with trends of changing climate at a rate 20% than the global average [3-4].

Morocco exemplifies these regional challenges, having endured six consecutive years of severe drought across the entire country, accompanied by unprecedented temperature levels that have severely impacted reservoir and groundwater levels, consequently affecting agricultural productivity. Indeed, according to the latest state of the climate of 2024 in

* Corresponding author: wafae.elharraki@enim.ac.ma

Morocco discussed in a report presented on 20 June 2025 in Rabat [5], 2024 was the hottest year in Morocco with an average temperature anomaly of $+1.49^{\circ}\text{C}$ compared to the 1991-2020 period. The country has experienced a significant rainfall deficit of -24.8%, throughout this ongoing drought trend for the sixth year. This alarming situation has pushed Moroccan decision-makers to incorporate climate change into the water planning process, from the regulatory framework, to the strategies preparation (the National water plan (PNE) and the Directory Plans of integrated management of water resources (PD Aire)).

This context could compromise socio-economic development, and lead to choosing costly solutions to deal with the challenging context of water resources. It could also conduct potentially in some regions to substantial economic consequences, in particular on the Gross Domestic Product (GDP) which may reach 10% of loss under a global warming of more than 3°C [6].

To tackle this situation, relying on studies for the long-term integrating the projected impacts of climate change is highly needed to elucidate tendencies of water supply and implement proactive water management strategies. One effective way to achieve this, is through climate change integration into the planning process which can be processed through calibration and validation of a hydrological model based on historical inflows, then the integration of bias-corrected projections of precipitation and temperature into the validated model to assess the future inflows and water balance components under chosen climate change scenarios [7, 8]. When hydrological modelling is not feasible due to the lack of data, another approach; called the runoff elasticity [9-10], has been developed for assessing the impact of climate change on water availability. [11] used this method to analyse runoff trends in Sebou, Loukkos and Laou basins for the future.

These methods have been applied in some studies to evaluate the expected change in future streamflow of the Bouregreg basin in Morocco, which is the subject of this study.

[12] conducted a study aiming at estimating hydrological changes under climate change scenarios working with the CNRM-CM5 climate model from the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP), and comparing the future period of 2040s (2030-2050) to the historical period (1982-2001).

According to the results of these estimates, which were used for hydrological modelling in GR2M, annual streamflow will decline by 44.63% in the future under the emission scenario RCP 4.5. The decline would be more pronounced under the pessimistic emission scenario RCP8.5 reaching 64.3%.

[13] investigated the impact of climate change on water resources and specifically on the environmental flow of Bouregreg basin using SWAT and the indicators of Hydrologic Alteration program (IHA). Climate projections (precipitation and temperature) used in this research belong to the Global climate CNRM-CM5 and the studied period is the 2090s (2085-2100) compared to the baseline (1990-2005), under RCP 4.5 and RCP 8.5. Results indicated that by the end of the century (2090), the overall water yield is expected to decrease by 7% under RCP 4.5 and by 45% under RCP 8.5.

The main goal of this study, is to evaluate the limit of available water resources in the Bouregreg basin dams complex (Sidi Mohamed Ben Abdellah (SMBA)-Tiddas) under two climate change scenarios of decreased streamflow chosen based on the literature. Simulations using the model RIBASIM would give an insight about future possible withdrawals from these two dams and discussions are made about desalination projects (Casablanca for instance) and the interbasin transfer Sebou-Bouregreg as possible adaptation strategies in order to secure future water supply.

2 Material and Methods

2.1 Study area

The study is located in the Bouregreg-Chaouia Hydraulic Basin, which contain important hydraulic infrastructures as the reservoirs SMBA (Sidi Mohamed Ben Abdellah) and Tiddas on Bouregreg watershed. Indeed, SMBA was built on the Bouregreg River in 1979, while Tiddas dam was implemented in 2022 and is roughly 5 kilometers west of the Tiddas village. This reservoir was built to improve the Bouregreg River's water management. The SMBA-Tiddas hydraulic complex is positioned as depicted in the following figure.

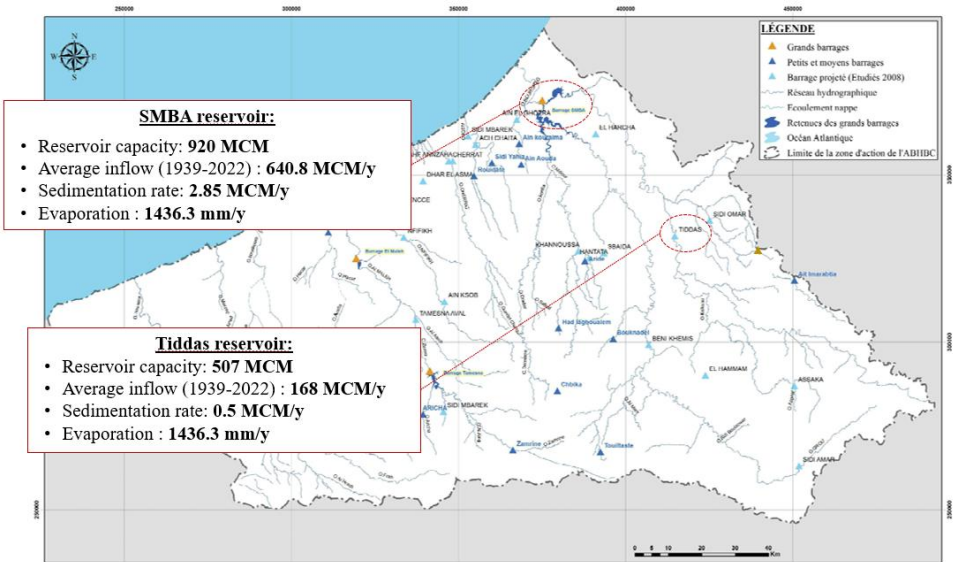


Fig. 1. Location of the water system SMBA-Tiddas into Bouregreg-Chaouia watershed (Source: ABHBC, 2025)

2.2 Simulation model: RIBASIM

This study was conducted using River Basin Simulations (RIBASIM) software developed by “Delft Hydraulics” in the Netherlands. RIBASIM was created to assist basin stakeholders in planning and evaluating various water allocation strategies at watershed level [14]. The model evaluates water supply compared to present and future water demands across time frames and scenarios using the following function to assess the stock variation in dam reservoir:

$$\Delta V = VE - VS - EN \times S \times 10^{-6} \tag{1}$$

- Where:
- ΔV: change in water stock (in MCM);
 - VE: volume of water entering the system (inflow) (in MCM);
 - VS: volume of water leaving the system or releases (outflow) (in MCM);
 - EN: net evaporation (in mm);
 - S: surface area of the dam reservoir (in Km²).

This model, has been used by Moroccan water planners and policymakers for many years to support strategic decisions regarding water allocations.

2.3 Data

2.3.1 Inflows

Inflows across the period (1939-2022) were afforded by the River basin agency of Bouregreg Chaouia (ABHBC).
The total average inflow over this period is 640.8 MCM/y. The following table shows the different time series taken into account in simulations.

Table 1. Inflows series modelled in the water system SMBA-Tiddas

Unit	Node of inflow	Average (1939-2022) in MCM/y
Bouregreg	Q1: Sidi Cherif	30.12
	Q2: SCherif Khannoussa	1.95
	Q3:SMBA Khannoussa	68
	Q4a:Sidi Amar	145.54
	Q4b: Khémis Sidi Amar	29
	Q5:Sidi Jaber Khémis	13.9
	Q6:SMBA Sidi Jaber	52
	Q7:Tiddas	168
	Q8a:Sidi Omar	26.88
	Q8b: AEzzaiar SidiOmar Tiddas	90.08
	Q9: SMBA Aezziar	15.38

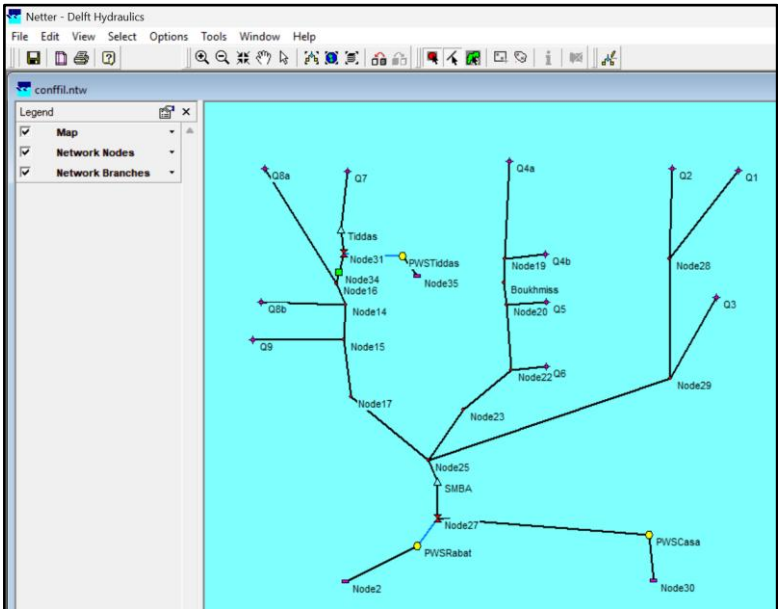


Fig. 2. Schematization of the water system SMBA-Tiddas under RIBASIM

2.3.2 Water demands

Simulations are made considering projected water demands of public water supply (PWS) and irrigation (IRR) at the horizon 2050, according to the latest studies made by the river basin agency of Bouregreg-Chaouia (ABHBC).

Table 2. Water demands modelled in the water system SMBA-Tiddas

Water demand by 2050 (MCM/y)		
PWS	Tiddas	5.5
	Rabat	217.2
	Casa	345.8
IRR	Perimeter Tiddas	31.9

2.3.3 Scenarios of climate change that would be assessed

Climate change scenarios chosen in this study derive from the analysis of previous studies related to Bouregreg watershed. Indeed, results of studies [12-13] using the CNRM-CM5 climate model revealed that expected inflows reductions are around 7%-44.6% and 64%-45% under moderate (RCP4.5) and severe (RCP8.5) emission scenarios respectively. In addition to these researches, the PDAIRE of Bouregreg (the directory plan of integrated water resources management) took into account a hypothesis of inflows reduction of 20% by 2050.

Taking into account these various expected levels of inflows reduction, in this study, two plausible scenarios of inflows reduction in the future compared to the baseline period (1980-2021) were adopted to analyse future water supply, which are:

- Scenario 1 of Climate change (SC1-CC): corresponds to a reduction of inflows up to 30%.
- Scenario 2 of Climate change (SC2-CC): corresponds to a reduction of inflows up to 40%.

3 Results and discussion

3.1.1 The hydraulic performance of the system

Simulations of the water system complex SMBA-Tiddas were carried out in two main phases. The first phase focused on the reference period using the long inflow series (1939-2022) to assess the overall system performance. The second phase considered only the shorter inflow series (1980-2022). This part of the study is essential to evaluate system performance both when including years with high inflows (before 1980) and when excluding them, thereby providing decision-makers with insights about the system’s optimistic performance as well as its behaviour under reduced average inflow conditions.

Table 3. Water supply from the system SMBA-Tiddas using a long and short time series of inflows (MCM/y)

Long period (1939-2022)			Short period (1980-2022)		
PWS	IRR (guaranteed in 80% of time steps)	Total	PWS	IRR (guaranteed in 80% of time steps)	Total
302.7	31.9	334.6	297.7	20	317.7

The simulations results (table 3) show a decrease in total water supply **from 334.6 MCM/y** in the long period to **317.7 MCM/y** in the short period (with an average inflow of 488.2 MCM/y), representing a reduction of about 5%.

It is important to highlight that results of simulations of Bouregreg basin for a period of simulation (1941-2015) presented in the study of PDAIRE Bouregreg [15] revealed that the volume of public water supply guaranteed at 100% from SMBA-Tiddas is: **301 MCM/y**. This volume is highly coherent with findings of the present study (table 3) which conducted to **302.7 MCM/y guaranteed at 100 %** (for a period of simulation (1939-2021)).

Through simulations of this study, it is remarked that the Public Water Supply (PWS) remains relatively stable decreasing slightly from 302.7 MCM/y to 297.7 MCM/y (around 1.7 % lower). However, the irrigation demand guaranteed in 80% of time steps (IRR) drops significantly from 31.9 MCM/y to 20 MCM/y, a reduction of about 37%.

These results indicate that under recent inflow conditions, the system's capacity to reliably meet irrigation demands reduced, while Public Water Supply remains relatively secured.

Overall, the analysis suggests that:

- The system is resilient in maintaining PWS under less favourable hydrological conditions.
- Irrigation reliability is more sensitive to reduced inflows, highlighting the need for adaptive water allocation or efficiency measures.
- The difference between the two periods reflects a likely shift toward drier hydrological conditions in recent decades.

3.1.2 Response of the hydraulic system to climate change

In this part, simulations are presented to assess the response of the water system by the horizon 2050 under the two climate change scenarios, in comparison with the reference scenario (period 1980-2022).

After extracting the potential water supply from the system respecting shortage criteria over the simulation period (ensuring 100% reliability for public water supply and analysing irrigation supply guaranteed at an 80% probability), the resulting water balance for the three scenarios are summarized in table 4 below.

These water balance calculations take into account the Casablanca desalination plant project, which is planned to be implemented in two phases:

- Phase I by 2026, providing 200 MCM/y for PWS,
- and Phase II by 2028, increasing the allocation for PWS to 250 MCM/y.

It should be noted that the effective volume considered from the Casablanca desalination plant in this study is 175.1 MCM/y. This adjustment reflects the extraction of the portion of supply that would be supplied from this desalination plant to zones already served by Sidi Said Maachou and Daourat dams (downstream Al Massira dam). This is consistent with the National Water Plan directive to preserve the water resources from these dams for local demands.

In addition to Casablanca desalination water plant, another key climate change adaptation measure considered in our analysis is Sebou-Bouregreg interbasin transfer. This project, launched at the end of 2023, has already played a major role during the ongoing drought by helping to secure water supply for the Rabat-Casablanca economic hub. The system has a design flow capacity of 15 m³/s, corresponding to an annual transfer volume of approximately 400 MCM/y considered in this study.

It is also worth noting that this phase is part of a larger project, in which the second phase will increase the flow capacity from Sebou to Bouregreg Basin to 45 m³/s. In the final phase,

the transfer will be extended to interconnect with the Oum Er Rbia Basin, which is currently experiencing declining surface water availability and rising water demand.

Table 4. Results of the water balance under the three scenarios: Without CC, under SC1 of CC, under SC2 of CC

	Without CC (Period 1980-2022)	Sc1 CC:-30% of inflow regarding the period (1980-2022)	Sc2 CC:-40% of inflow regarding the period (1980-2022)
Water demand 2050	Volume in MCM/y		
PWS Rabat	217.2	217.2	217.2
PWS Tiddas	5.5	5.5	5.5
PWS Grand Casa	345.8	345.8	345.8
Sous total (1)	568.5	568.5	568.5
Irrigation upstream	31.9	31.9	31.9
Water Offer 2050			
Bouregreg water offer for PWS (2)	297.7	222.7	190.5
Bouregreg water offer for IRR (guaranteed in 80% of time steps)	20	12.8	12.8
Desalination Casa (250 - Water Demand Settati/ Berrechid) (3)	175.1	175.1	175.1
Difference (2+3-1)	-95.7	-170.7	-202.9
Interconnexion Sebou (4)	400	400	400
Difference (2+3+4-1)	304.3	229.3	197.1

3.1.3 Discussion of results

Results, shown in the previous section, demonstrate the combined contribution of the Casablanca desalination plant and the Sebou-Bouregreg interbasin transfer, in terms of ensuring a reliable water supply for Rabat, the Grand Casablanca and Tiddas area. However, the remaining volume that could be mobilized for the Oum Er Rbia Basin is projected to decline from 304 MCM/y under the reference scenario (without climate change) to 229 MCM/y under the first climate change scenario (Sc1: - 30% inflow) and to 197 MCM/y under the second scenario (Sc2: - 40% inflow).

Overall, simulations indicate that PWS from the SMBA–Tiddas complex would decrease by approximately 25% under (Sc1) and 36% under (Sc2), while the irrigation supply guaranteed in 80% of time steps would decline by 36%. This highlights the relative resilience of urban PWS compared to irrigation, which is more sensitive to reduced inflows under climate change.

Moreover, the preparatory study of Bouregreg PDAIRE [15] considered 20% inflows reduction by 2050 compared to historical inflows and public water supply, which resulted in a drop of PWS volume to 264 MCM/y. This indicates the sensitivity of the system to climate variability, as was also shown by results of simulations of the present study, and supports the necessity to adopt adaptations measures to reinforce the resilience of this system.

Table 5. Water supply reduction from the water system SMBA-Tiddas under climate change (CC) scenarios

Summary of results			
	Scenario without CC	SC1 CC (-30%)	SC2 CC (-40%)
PWS (MCM/y)	297.7	222.7	190.5
IRR (MCM/y)	20	12.8	12.8
Reduction PWS with CC		-25%	-36%
Reduction IRR with CC		-36%	-36%

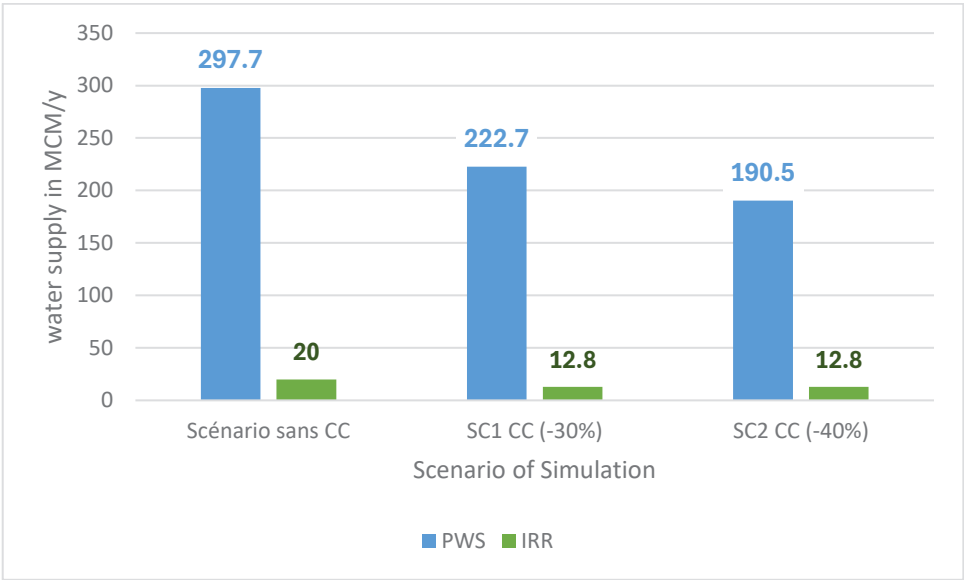


Fig. 3. Variation of water supply through the complex SMBA-Tiddas with climate change scenarios

The substantial reduction in irrigation water supply under both climate scenarios suggests that agricultural water management will require significant adaptation, potentially including crop selection changes, improved irrigation efficiency, and alternative water sources. The vulnerability of irrigation supplies compared to public water supply reflects the priority allocation strategies embedded in current water management approaches.

Based on these findings, several strategic recommendations emerge for improving water security in the Bouregreg basin. Priority should go to speeding up the implementation of planned desalination plants and interbasin transfer projects as major adaptation options. These projects are essential for maintaining water security under climate change scenarios. The interconnexion of Sebou-Bouregreg for instance, which costed around 6 billion MAD, was accomplished in a record time (10.5 months) and allowed to supply 12 million inhabitants in the corridor Rabat-Casablanca beginning from the end of 2023 since SMBA dam suffered from low storage during the last years due to low water scarcity.

In addition to Casablanca desalination plant, which is under execution through a Public-Private-Partnership (PPP), a desalination plant is planned in Rabat which would decrease the pressure on SMBA dam and reallocate its water resources for developing irrigation in

Bouregreg region. It is worth mentioning that Morocco's strategy in developing desalination plants relies on developing renewable energy with these plants so as to reduce the cost of each cubic meter produced. This conducted to an expected cost of 1 m³ from Casablanca plant around 4.5 MAD which is very competitive to the cost from previous desalination plants in Morocco (which was around 10 MAD/m³).

These adaptation measures are projects that require high level of technicity and a cycle of engineering studies, as well as provisions of the necessary equipment (such was the case for Sebou-Bouregreg interconnexion which required for example 5118 units of the pipeline and 6 electropump groups), which justifies the need for simulation water supply under future hydrological scenarios to guide decision-makers about the appropriate horizons to implement this kind of projects. This was the interest of several authors across different water systems [16, 17, 18].

Along with this, developing contingency plans for agricultural water demand management becomes important, including drought-resistant crop varieties and precise irrigation technologies to improve efficiency with limited water availability. Also, strengthening real-time monitoring systems will allow a flexible management response. And finally, systematic integration of climate considerations into all water infrastructure planning and policy development will ensure long-term resilience in the basin's water management.

The Bouregreg basin case study shows the challenges and opportunities of adaptation to climate change for water resources. While significant impacts are expected, proactive implementation of diversified supply strategies can maintain water security for critical urban and economic areas. The success of these strategies will depend on sustained political commitment, adequate financing, and adaptive management approaches that can respond to changing conditions.

4 Conclusion

This study analysed the reaction of the SMBA and Tiddas dams complex, in the Bouregreg basin under different climate change scenarios at the horizon 2050, using RIBASIM for reservoirs and water allocation simulations. The results reveal significant vulnerabilities in the region's water supply system and highlight the urgent need for adaptive management strategies.

The analysis demonstrates that climate impacts are already observed when comparing different historical periods. Using inflows from the short time series (1980-2022) and the long time series (1939-2022), simulations resulted in a 2% reduction in average water supply for drinking water demand and a substantial 37% decrease in guaranteed irrigation volumes (at 80% reliability). This finding underscores that recent climatic variations have already begun affecting the basin's water resources.

Under future climate change scenarios, the impacts intensify considerably. The SMBA-Tiddas complex would experience reductions in public water supply of 25% under the first climate scenario (30% inflow reduction) and 36% under the more severe scenario (40% inflow reduction). Irrigation supply guaranteed at 80% reliability would decrease by 36% under both scenarios, indicating particular vulnerability in the agricultural sector.

Despite these challenges, the water balance analysis incorporating planned adaptation measures shows promise for meeting future demands. The combination of the Casablanca desalination plant (contributing with 175 MCM/y for the water demand in the study area) and the Sebou-Bouregreg interbasin transfer (400 MCM/y) would successfully secure water supply for Rabat, Grand Casablanca, and the Tiddas area at 2050. However, the remaining volume available for potential transfer to the Oum Er Rbia basin would decrease from 304 MCM/y under current conditions to 229 MCM/y and 197 MCM/y under the two climate scenarios, respectively.

These results highlight the critical importance of diversifying water supply sources and implementing adaptation strategies proactively. The successful integration of desalination and interbasin transfer demonstrates that technological and infrastructure solutions can effectively mitigate climate change impacts, though at considerable financial investment.

References

1. Tuel, A, E.A.B. Eltahir. Why Is the Mediterranean a climate change hot spot? .Journal of Climate, **33** (14) , pp. 5829-5843, 10.1175/JCLI-D-19-0910.1 (2020)
2. IPCC, Climate change 2022: Impacts, adaptation and vulnerability Retrieved from <https://www.ipcc.ch/report/ar6/wg2/> (2022)
3. Lionello, P, Scarascia.L, The relation between climate change in the Mediterranean region and global warming. Regional Environmental Change, **18** (5) , pp. 1481-1493, 10.1007/s10113-018-1290-1 (2018)
4. MedECC, Climate and environmental change in the Mediterranean Basin - Current situation and risks for the future .W. Cramer, K. Marini, J. Guiot (Eds.), First Mediterranean Assessment Report https://www.medecc.org/wp-content/uploads/2021/04/Rapport_MedECC_ebook.pdf (2020)
5. Direction Générale de la Météorologie, Etat Climat Maroc 2024 (Minstry of the Equipment and Water, 2024)
6. P. Waidelich, F. Batibeniz, J. Rising, J.S. Kikstra, & S.I. Seneviratne, Climate damage projections beyond annual temperature. Nature Climate Change. **14**, 592–599. <https://doi.org/10.1038/s41558-024-01990-8> (2024).
7. C.J. Chawanda, A. Nkwasa, W. Thiery & A. van Griensven, Combined impacts of climate and land-use change on future water resources in Africa. Hydrology and Earth System Sciences **28** (1), 117–138. <https://doi.org/10.5194/hess-28-117-2024>, (2024)
8. 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. Model. Earth Syst. Environ. **10**, 349–369. <https://doi.org/10.1007/s40808-023-01775-6>. (2024):
9. A. Sankarasubramanian, R.M. Vogel, and J.F. Limbrunner, Cli mate elasticity of streamflow in the United States, Water Resour. Res., **37**, 1771–1781 (2001)
10. Q.Tang and D.P. Lettenmaier, 21st century runoff sensitivities of major global river basins, Geophys. Res. Lett., **39**, L06403, <https://doi.org/10.1029/2011GL050834> (2012)
11. N. El Moçayd, S. Kang, and E.A.B Eltahir, Climate change impacts on the Water Highway project in Morocco, Hydrol. Earth Syst. Sci., **24**, 1467–1483, <https://doi.org/10.5194/hess-24-1467-2020> (2020)
12. K. Mahdaoui, Tarik Chafiq, Lmahfoud Asmlal, Mohamed Tahiri, Assessing hydrological response to future climate change in the Bouregreg watershed, Morocco. Scientific African, Volume 23,e02046,ISSN 2468-2276, <https://doi.org/10.1016/j.sciaf.2023.e02046> (2024)
13. Y. Brouziyne, S. Belaqziz, L.Benaabidate, A. El Bilali, A. Elbeltagi, O.Tzoraki & A. Chehbouni, Modeling long term response of environmental flow attributes to future climate change in a North African watershed (Bouregreg watershed, Morocco). Ecohydrology and Hydrobiology. **Volume 22**, Issue 1, Pages 155-167 10.1016/j.ecohyd.2021.08.005 (2022)

14. Ribasim website: <https://www.deltares.nl/en/software-and-data/products/ribasim-river-basin-planning-and-management>)
15. ABHBC, Etude d'actualisation du plan directeur d'aménagement intégré des ressources en eau du bassin hydraulique du Bouregreg et de la Chaouia (2022)
16. Abbas, S. A., Xuan, Y., & Bailey, R. T., Assessing climate change impact on water resources in water demand scenarios using SWAT-MODFLOW-WEAP. *Hydrology*, 9(10), 164 (2022)
17. Omar, M. M., Evaluation of actions for better water supply and demand management in Fayoum, Egypt using RIBASIM. *Water Science*, 27(54), 78-90 (2013)
18. Farrokhzadeh, S., Hashemi Monfared, S. A., Azizyan, G., Sardar Shahraki, A., Ertsen, M. W., & Abraham, E., Sustainable water resources management in an arid area using a coupled optimization-simulation modeling. *Water*, 12(3), 885 (2020)