Institute for Water
and Energy Sciences
(incl. Climate Change)

PAN-AFRICAN UNIVERSITY
INSTITUTE FOR WATER AND ENERGY SCIENCES
(including CLIMATE CHANGE)

Master Dissertation

Submitted in partial fulfillment of the requirements for the Master degree in

WATER POLICY

Presented by

Chihab Eddine RAHMOUN

TITLE:

EVALUATION OF WATER RESOURCE MANAGEMENT SCENARIOS USING THE WEAP MODEL: CASE OF THE COASTAL ORAN BASIN

Defended on 17/04/2025 Before the Following Committee:

Chair	Boumediene MAAMAR	Dr.	Abou Bekr Belkaid University, Algeria
Supervisor	Slim ZEKRI	Prof.	Sultan Qaboos University, Oman
Co-supervisor	Cherifa ABDELBAKI	Prof.	Abou Bekr Belkaid University, Algeria
External Examiner	Suhair Abdelgayoum Mohamed SAAD	Dr.	Al Rawabi Dairy Company, UA Emirate
Internal Examiner	Mohammed Zakaria DEBBAL	Dr.	Abou Bekr Belkaid University, Algeria

DEDICATION

I dedicate this dissertation to my parents, Djamila and Nasr Eddine, whose unconditional love, invaluable sacrifices, precious advice and transmitted values have forged my path, as well as to my sister Asmaa, my brothers Hadj Boumedien and Sid Ahmed Yacine, my brother-in-law Omar and my niece Ihssane, whose comforting presence, inspiring example and pure joy have illuminated every step of this journey. I extend it to my uncles, aunts, cousins and friends who have supported me; to the person whose support and encouragement have made this project possible thank you for your presence and your strength, always there when I needed you most; and to the moving memory of my departed forebears, whose absence mingles with the pride I aspire to offer them through this modest tribute.

PAN AFRICA UNIVERSITY

STATEMENT OF THE AUTHOR

By my signature below, I declare that this thesis/dissertation is my work. I have followed all ethical principles of scholarship in the preparation, data collection, data analysis, and completion of this thesis or dissertation. I have given all scholarly matter recognition through accurate citations and references. I affirm that I have cited and referenced all sources used in this document. I have made every effort to avoid plagiarism.

I submit this document in partial fulfillment of the requirement for a degree from Pan African University. This document is available from the PAU Library to borrowers under the rules of the library. I declare that I have not submitted this document to any other institution for the award of an academic degree, diploma, or certificate.

Scholars may use brief quotations from this thesis or dissertation without special permission if they make an accurate and complete acknowledgment of the source. The dean of the academic unit may grant permission for extended quotations or reproduction of this document. In all other instances, however, the author must grant permission.

Name: **Chihab Eddine RAHMOUN** Signature:

Date: **02/04/2025**

PAU Institute: **The Pan African University Institute of Water and Energy Science (PAUWES)**

BIOGRAPHICAL SKETCH

Chihab Eddine RAHMOUN is a dedicated civil engineer and water policy specialist with a Master's degree in Water Policy from the Pan-African University Institute of Water and Energy Sciences (PAUWES) and a Master's in Civil Engineering from Abou Bekr Belkaid University. His expertise lies in water resources management, hydrological modeling, and sustainable development strategies, supported by technical proficiency in tools such as WEAP, HEC-HMS, QGIS, and Autodesk Civil 3D.

Currently serving as a Research Intern at Sultan Qaboos University (Oman), he contributes to water security strategies by simulating supply-demand scenarios for arid regions. Previously, at Algeria's Oranie Chott Chergui Hydrographic Basin Agency, he analyzed hydrological data to inform the Integrated Water Resources Management (IWRM) strategy. His professional journey includes three years as a Civil Engineer at ETB Cherifi, where he coordinated complex infrastructure projects and liaised with government stakeholders.

Fluent in Arabic, French, and English, he combines technical rigor with creativity, evidenced by his graphic design and voluntary engagements.

His work reflects a commitment to addressing global water challenges through innovation, interdisciplinary collaboration, and community-driven solutions.

Tel: +213 658 126 733 LinkedIn: @chihebrahmoun Facebook: @chiheb.rahmoun

ACKNOWLEDGEMENTS

بسم الله الرحمن الرحيم

الحمد لله رب العالمين، والصلاة والسلام على رسول الله وعلى آله وأصحابه أجمعين .

I begin by praising Allah (SWT) for His boundless mercy, guidance, and the strength to complete this work.

I extend my sincere gratitude to the African Union Commission (AUC) for awarding me a full scholarship to pursue my Master's in Water Policy at the Pan African University Institute of Water and Energy Sciences (PAUWES) and for funding this research. This opportunity has been instrumental in advancing my academic and professional expertise in water resource management.

I am deeply thankful to the National Agency for Integrated Water Resources Management (AGIRE) for their critical support and provision of essential data, which formed the foundation of this study. Special recognition goes to Mr. Badraoui Abderrahim, engineer at AGIRE, for his technical guidance and collaborative spirit, and to Madam Karima Azzouz from the Oranie Chott Chergui Hydrographic Basin Agency (ABH OCC).

My profound appreciation goes to Prof. Slim Zekri, my supervisor, and Prof. Chérifa Abdelbaki, my co-supervisor, for their invaluable mentorship, rigorous academic feedback, and unwavering support throughout this research. Their expertise in water policy and sustainable management profoundly shaped the quality and direction of this work. I also acknowledge the contributions of my thesis committee members for their constructive critiques and encouragement.

Finally, I acknowledge the countless individuals, mentors, researchers, and professionals whose indirect contributions have informed and inspired this work.

Chihab Eddine RAHMOUN
April 2025

Table of contents

1. INTRODUCTION 1

1.1. Background 1

1.2. Problem Statement 2

1.3. Aim and Objectives of the study 3

1.4. Research questions 3

2. LITERATURE REVIEW 4

2.1. Water Resource Management in Algeria 4

2.1.1. Introduction 4

2.1.2. Integrated Water Resources Management (IWRM) 5

a. IWRM Principles 6

b. Operational implementation 6

2.1.3. Algerian watersheds 7

a. Catchment areas 8

2.1.4. Algerian water potential 9

a. Conventional water resource potential 9

❖ Surface water resources 11

❖ Groundwater resources: 11

b. Non-conventional water resources 13

❖ Wastewater potential 13

❖ Seawater desalination 13

❖ Brackish waters 13

2.1.5. Governance of water resources in Algeria 13

a. Legislative and planning framework 13

b. Institutional structures 14

2.1.6. The water pricing system 14

a. Water and wastewater tariffs 14

b. Water pricing for industry 16

c. Water pricing for irrigation 17

d. Water production prices 17

2.2. Water Evaluation and Planning System (WEAP) 18

2.2.1. Background 18

2.2.2. Key features of WEAP 20

2.2.3. Program structure 20

a. Diagram 20
b. Data 21
c. Results 22
d. Block diagram 25
e. Notes 25
2.2.4. The WEAP approach 26
2.2.5. Applications of the WEAP Model in Water Resource Management 27
a. Climate Change and Water Availability 27
b. Socio-Economic Drivers of Water Scarcity 28
c. Infrastructure and Demand-Side Solutions 28
d. Transboundary and Multi-Sectoral Management 29
e. Methodological Innovations and Limitations 29
2.2.6. WEAP benefits 29
2.2.7. WEAP limitations and challenges 30
a. Dependence on quality data 30
b. Complexity of systemic interactions 30
c. Institutional and collaborative challenges 30
d. Financial and technical constraints 30
e. Climatic uncertainties and adaptability 30
f. Limited integration of machine learning 31
2.2.8. Future enhancements for WEAP 31

3. MATERIALS AND METHODS 32

3.1. Description of the Study Area 32

3.1.1. Location 32
a. Location Data 32
b. Geography 32
3.1.2. Morphological and morphometric characteristics of sub-catchments 33
3.1.3. Geomorphological characterization of the Oran Coastal Basin 35
a. Mountainous units 35
b. Inland plains and sedimentary basins 35
c. Coastal zone and adjacent plateaus 36
d. Forest cover and environmental issues 36
3.1.4. Climatology 37
a. Precipitation 37
b. Temperature 40
❖ Minimum Temperature 40
❖ Maximum Temperature 43

c. Decadal climate analysis (1993-2023) 45
3.1.5. Hydrography of the Oran Coastal Basin 46
a. Ghazaouet coastal sub-basin 46
b. Central Coastal Sub-basin 46
c. Eastern coastal sub-basin 46
3.1.6. Hydrogeology of the Oran Coastal Basin 47
a. Traras Mountains 47
b. Murdjadjo massif 47
c. Brédéah plain 47
d. Aïn Türck coastal plain 48
3.1.7. Socio-economic and demographic data 48
3.1.8. Data collection 50

3.2. Water resources in the basin 51
3.2.1. Introduction 51
3.2.2. Conventional water resources 51
a. Superficial water resources 51
❖ Dams 51
❖ Small dams 52
❖ Hill reservoirs 52
b. Groundwater resources 54
3.2.3. Unconventional water resources 55
a. Seawater desalination 56
b. Demineralization 57
c. Water treatment plant 58
d. Wastewater treatment plant 58

3.3. Situation of the hydraulic network and demand for water 60
3.3.1. Drinking water supply 60
3.3.2. Agriculture 61

4. RESULTS AND DISCUSSION 64

4.1. Introduction 64

4.2. Acquiring the WEAP 21 software license 64

4.3. Setting up the WEAP model 65
4.3.1. Creation of a new study area 65
4.3.2. Distribution of demand sites and water resources 67
a. Application sites (16 in total) 67

b. Infrastructure and resources 68
4.3.3. Cartographical presentation of the model 68
4.3.4. Demand sites 70
a. Domestic sites 73
b. Agriculture sites 76
c. Industry: 78
4.3.5. Resources distribution 79

4.4. Reference scenario 79

4.5. Infrastructure improvement and expansion scenario 87
4.5.1. Scenario comparison (2023-2053) 87
a. Reference scenario 87
b. Improvement scenario 87
4.5.2. Impact of scenario assumptions 87

4.6. Demographic and agricultural growth scenario 89

4.7. Minimum domestic consumption scenario 92

4.8. Scenario for improving agricultural activity 94

4.9. Progressive pricing scenario 94

4.10. Integrated best practice scenario 96

5. Conclusions, and Recommendations 98

5.1. Conclusion 98

5.2. Recommandations 100
5.2.1. Lever techniques 100
5.2.2. Institutionnel levers 100
5.2.3. Financial leverage 100
5.2.4. Climate adaptation measures 101
5.2.5. Social and equity considerations 101

LIST OF TABLES

Table 2.1-1. Water resource potential of Algerian river basins 8
Table 2.1-2. Drinking water tariff schedule applicable to the tariff zone (official journal 2005) 15
Table 2.1-3. Agricultural water prices 17
Table 2.1-4. Comparative costs of water sources and water infrastructure (in DA/m^3 and USD/m^3) 17
Table 2.2-1. WEAP Model Outputs (Droogers P Et Al, 2011) 23
Table 3.1-1. Morphological and morphometric characteristics of sub-catchments (ANRH). . 33
Table 3.1-2. Socio-economic and demographic data 48
Table 3.2-1 Surface water for drinking water supply (M^3/days) 51
Table 3.2-2. Dams supplying the Oran Coastal Basin 52
Table 3.2-3. Small dams feeding the Oran Coastal Basin 52
Table 3.2-4. Hill reservoirs supplying the Oran Coastal Basin 52
Table 3.2-5. Groundwater resources in the Oran coastal basin: Data by aquifer and wilaya... 54
Table 3.2-6. Volumes of water extracted (m^3/d) and number of extraction points (boreholes, wells, springs) by use (drinking water, industry, agriculture) 55
Table 3.2-7. Daily distribution of non-conventional water volumes (m^3/d) allocated to drinking water supply and agriculture. 55
Table 3.2-8. Seawater desalination plants 56
Table 3.2-9. Water demineralization plants 57
Table 3.2-10. Water treatment plant 58
Table 3.2-11. Wastewater treatment plant 58
Table 3.3-1. Water status and performance of drinking water networks in the Oran coastal basin 60
Table 3.3-2. Agricultural statute and irrigation need in the Oran coastal basin 61

LIST OF FIGURES

Figure 1. IWRM Principles (Source: Dublin Conference, 1992). 6
Figure 2. The five main hydraulics basins of Algeria 8
Figure 3. Basin map of Algeria (Bendjema et al, 2019) 9
Figure 4. Location of Algerian dams 10
Figure 5. Evolution of water resources per capita: Renewable, Conventional and Absolute scarcity threshold (2010-2030) 11
Figure 6. Map of Algerian Groundwater storage. (water.fanack.com 2019) 12
Figure 7. Seawater desalination plants in Algeria. 13
Figure 8. Flowchart depicting the methodology of WEAP Simulation 19
Figure 9. WEAP schema 21
Figure 10. WEAP Data 21
Figure 11. WEAP Result 22
Figure 12. WEAP diagram 25
Figure 13. WEAP note 26
Figure 14. Modeling in WEAP 27
Figure 15. Map of the study area (ABH-OCC) 33
Figure 16. Average monthly precipitation 1993-2003 (mm) 37
Figure 17. Average monthly precipitation 2004-2013 (mm) 37
Figure 18. Average monthly precipitation 2014-2023 (mm) 38
Figure 19. Average total annual precipitation 1993-2023 (mm) 38
Figure 20. Rainfall stations in the Oran coastal basin (Source ABH-OCC) 39
Figure 21. Hydrometric stations in the Oran coastal basin (Source ABH-OCC) 39
Figure 22. Minimum monthly mean temperature 1993-2003 (°C) 40
Figure 23. Minimum monthly mean temperature 2004-2013 (°C) 41
Figure 24. Minimum monthly mean temperature 2014-2023 (°C) 41
Figure 25. Annual mean minimum temperature 1993-2003 (°C) 42
Figure 26. Maximum monthly mean temperature 1993-2003 (°C) 43
Figure 27. Maximum monthly mean temperature 2004-2013 (°C) 43
Figure 28. Maximum monthly mean temperature 2014-2023 (°C) 44
Figure 29. Mean annual maximum temperature 1993-2003 (°C) 45
Figure 30. Acquisition and configuration of WEAP 21 (Water Evaluation and Planning System) academic license 65

Figure 31. Creating a new project in WEAP 66
Figure 32. Year and time steps settings 67
Figure 33. Conceptual diagram of the WEAP hydrological model for the Oran coastal basin 68
Figure 34. Map of the modelled water system of the Oran coastal basin using the WEAP interface 69
Figure 35. Demand sites of the basin. 70
Figure 36. Percentage distribution of population served by drinking water supply sites (2023) 71
Figure 37. Distribution of irrigated agricultural area in the Oran coastal basin (2023) 72
Figure 38. Distribution of industrial activities in the Oran coastal basin (2023) 73
Figure 39. Annual raw water demand for drinking water supply (2023) 74
Figure 40. Monthly raw water demand for drinking water supply (2023) 75
Figure 41. Annual Domestic water use rate. 75
Figure 42. Annual agricultural water demand (2023). 76
Figure 43. Monthly agricultural water demand (2023) 76
Figure 44. Annual water use rate in agricultural sites. 77
Figure 45. Annual industrial water demand (2023) 78
Figure 46. Monthly industrial water demand (2023) 78
Figure 47. Annual water use rate in industrial sites 79
Figure 48. Population trends in the reference scenario (2023-2053) 80
Figure 49. Evolution of agricultural land in the reference scenario (2023-2053) 81
Figure 50. Industrial production units in the reference scenario (2023-2053) 81
Figure 51. Total annual water demand in the Oran Coastal Basin for the three sectors (domestic, industrial, and agricultural) in the reference scenario (2023-2053) 82
Figure 52. Annual water demand from domestic sites in the reference scenario (2023-2053)83
Figure 53. Annual water demand from agriculture sites in the reference scenario (2023-2053) 83
Figure 54. Annual water demand from industry site in the reference scenario (2023-2053)... 84
Figure 55. Total annual water demand in the reference scenario (2023-2053) 85
Figure 56. Average monthly water demand in 2023-2053 85
Figure 57. Unmet demand in the basin - reference scenario (2023-2053) 86
Figure 58. Unmet demand for domestic demand sites in the two scenarios (Reference, Infrastructure improvement and expansion scenario) (2023-2053) 87
Figure 59. Demographic growth 89

Figure 60. Agriculture growth 90
Figure 61. Water demand for all demand sites in the two scenarios (Reference, Demographic and agricultural growth scenario) (2023-2053) 91
Figure 62. Unmet demand for all demand sites in the two scenarios (Reference, Demographic and agricultural growth scenario) (2023-2053) 92
Figure 63. Water demand for all demand sites in the two scenarios (Reference, Minimum domestic consumption scenario) (2023-2053) 92
Figure 64. Water demand for all demand sites in Minimum domestic consumption scenario in relation to reference (2023-2053) 93
Figure 65. Water demand for all demand sites in the two scenarios (Reference, improving agricultural activity) (2023-2053) 94
Figure 66. Water prices per m^3 95
Figure 67. Water demand for all demand sites in the two scenarios (Reference, Progressive pricing) (2023-2053) 95
Figure 68. Unmet demand for all demand sites in the two scenarios (reference, best-practice) (2023-2053) 96

LIST OF ABBREVIATIONS

ABH: Hydraulic Basin Agency

ADE: The Algerian Water Company

AGIRE: National Agency for Integrated Water Resources Management

ANBT: National Agency for Dams and Transfers

ANRH: The National Agency of Hydraulic Resources

BCM: Bilion Cubic Meter

DRE: Department of Water Resources

DSA: Department of Agricultural Services

FAO: The Food and Agriculture Organization

GDP: Gross Domestic Product

GIS: Geographic Information System

IWRM: Integrated Water Resource Management

MCM: Milion Cubic Meter

MRE: Ministry of Water Ressources

NASA: National Aeronautics and Space Administration

ONA: National Sanitation Office

ONID: National Office of Irrigation and Drainage

ONS: The National Institute of Statistics

PAUWES: Pan African University Institute of Water and Energy Sciences

SDG: Sustainable Development Goal

SEI: Stockholm Environment Institute

UN: The United Nations

WEAP: Water Evaluation And Planning System.

ABSTRACT

The Oran coastal basin, a semi-arid region in north-western Algeria, is under increasing water pressure due to climate change (rainfall is expected to fall by 10-20% by 2050) and exponential demand for water, particularly from agriculture (70% of abstractions). With a population of 3 million and a demographic growth rate of 1.8% per year, the region already has a structural deficit of 660 million m³ (2023), exacerbated by the over-exploitation of groundwater (-40% since 2000) and losses of 35% in irrigation networks. These challenges call for an urgent overhaul of water management to avert a humanitarian and ecological crisis.

Using the WEAP model, this study simulates the evolution of supply-demand imbalances over 30 years (2023-2053), integrating climatic, hydraulic (15 aquifers, 10 desalination plants) and socio-economic data. Of the seven scenarios tested, the most effective combines moderate population growth and sustainable agricultural practices, significantly reducing unmet demand. However, the projections reveal a critical increase in demand (1.89 billion m³ in 2053) and an annual deficit of 2.4 billion m³, exacerbated by the scarcity of rainfall and urban expansion. These results underline the ineffectiveness of supply-side solutions (dams, desalination) in the face of integrated management that prioritises demand.

For resilient and equitable management, the study proposes multi-dimensional measures: adoption of technologies (drip irrigation, IoT to reduce losses), progressive pricing with subsidies for vulnerable households, and strengthened governance via basin committees. Social equity is central, requiring priority access to water in rural areas and awareness-raising campaigns. Aligned with MDG 6, these recommendations provide an operational framework for decision-makers, although their implementation depends on up-to-date data and a lasting political commitment. This work illustrates the urgent need for a transition to adaptive management in arid regions, where water remains a matter of survival and justice.

Keywords: Integrated water resource management (IWRM), Oran coastal basin (Algeria), WEAP (Water Evaluation and Planning) modelling, Water stress.

RESUME

Le bassin côtier d'Oran, région semi-aride du nord-ouest algérien, subit une pression hydrique croissante liée au changement climatique (baisse de 10-20 % des précipitations d'ici 2050) et à une demande exponentielle en eau, notamment agricole (70 % des prélèvements). Avec 3 millions d'habitants et une croissance démographique de 1,8 %/an, la région accuse déjà un déficit structurel de 660 millions de m³ (2023), aggravé par la surexploitation des nappes phréatiques (-40 % depuis 2000) et des pertes de 35 % dans les réseaux d'irrigation. Ces défis appellent une refonte urgente de la gestion de l'eau pour éviter une crise humanitaire et écologique.

À l'aide du modèle WEAP, cette étude simule l'évolution des déséquilibres offre-demande sur 30 ans (2023–2053), intégrant des données climatiques, hydrauliques (15 aquifères, 10 usines de dessalement) et socio-économiques. Parmi sept scénarios testés, le plus efficace combine une croissance démographique modérée et des pratiques agricoles durables, réduisant significativement la demande non satisfaite. Les projections révèlent cependant une hausse critique de la demande (1,89 milliard de m³ en 2053) et un déficit annuel de 2,4 milliards de m³, exacerbé par la raréfaction des pluies et l'expansion urbaine. Ces résultats soulignent l'inefficacité des solutions d'offre (barrages, dessalement) face à une gestion intégrée priorisant la demande.

Pour une gestion résiliente et équitable, l'étude propose des mesures multidimensionnelles : adoption de technologies (irrigation au goutte-à-goutte, IoT pour réduire les pertes), tarification progressive avec subventions aux ménages vulnérables, et renforcement de la gouvernance via des comités de bassin. L'équité sociale est centrale, nécessitant un accès prioritaire à l'eau en zones rurales et des campagnes de sensibilisation. Alignées sur l'ODD 6, ces recommandations offrent un cadre opérationnel pour les décideurs, bien que leur mise en œuvre dépende de données actualisées et d'un engagement politique durable. Ce travail illustre ainsi l'urgence d'une transition vers une gestion adaptive dans les régions arides, où l'eau reste un enjeu de survie et de justice.

Mots-clés : Gestion intégrée des ressources en eau (GIRE), Bassin côtier oranais (Algérie), Modélisation WEAP (Water Evaluation and Planning), Stress hydrique.

1. INTRODUCTION

1.1. Background

"Water will not be the oil of the 21st century; it will be far more precious." This assertion, frequently reiterated in discussions concerning water security, assumes particular significance in arid regions such as the Oran Coastal Basin, where water resources are becoming increasingly scarce due to the combined effects of climate change and escalating demand. According to the United Nations, approximately 2.3 billion people currently inhabit areas experiencing severe water stress, a figure that could potentially double by the year 2050 if adequate policies are not implemented. The Algerian context, in particular, offers a salient example of the intricate challenges posed by sustainable water management, wherein the demands of socio-economic development are in direct conflict with ecological limitations.

The Oran Coastal Basin, situated in northwestern Algeria, is a critical water ecosystem supporting nearly 3 million residents and pivotal sectors such as irrigated agriculture (accounting for 70% of withdrawals) and the agri-food industry. However, this semi-arid region, characterized by an annual rainfall of less than 300 mm and high evapotranspiration, is experiencing mounting pressure on its water resources. Groundwater, a vital source of supply, has seen an alarming 40% decline in reserves since 2000 (National Hydraulic Resources Agency ANRH, 2020). This overexploitation, in conjunction with diminished natural recharge resulting from climate variability, portends significant challenges to the basin's long-term resilience.

The implications of this crisis extend beyond mere technical management, as they also reflect deep-rooted socio-economic tensions. Agriculture, the foundation of the local economy, consumes 1.2 billion m^3/year of water, often via inefficient irrigation systems (e.g., gravity-fed), generating estimated losses of 35%. Concurrently, the accelerated urbanization of Oran, the nation's second largest city, is exacerbating competition for drinking water. The interplay of these dynamics, compounded by a 2% annual population growth rate, positions the Oranese Coast as a nexus of a regional conundrum: the imperative to harmonize food security, urban expansion, and ecosystem preservation.

This work is thus part of an approach that is both scientific and operational. The aim is not simply to diagnose risks, but to propose concrete levers for action for local decision-makers. As Yates et al. (2005) emphasize, "the value of a water model lies in its ability to transform complex data into intelligible policies." The central inquiry of this research is to explore the transition between modeling and governance. In essence, the central question guiding this research is how WEAP can facilitate water management that is both sustainable and equitable in the context of increasing scarcity.

1.2. Problem Statement

The Oran Coastal Basin, situated in Algeria's arid and semi-arid northwestern region, is grappling with a multifaceted water crisis, marked by a growing disparity between limited water resources and a rapidly increasing demand. The region is subject to the capricious Mediterranean climate, characterized by annual rainfall varying between 200 and 450 millimeters. This climate is accompanied by recurrent droughts and high evaporation, a phenomenon that is further exacerbated by climate projections predicting a 10-20% decline in rainfall by the year 2050. The region's water resources, predominantly groundwater (accounting for 60% of supplies), are subject to overexploitation, evidenced by an annual decline of 2 meters in piezometric levels. Additionally, dams experience a loss of up to 25% of their capacity due to evaporation (Hamlat et al. 2012).

This pressure is exacerbated by sustained population growth (+1.8%/year) and rapid urbanization, amplifying domestic needs. The agricultural sector, constituting the primary consumer (70% of withdrawals), is characterized by the employment of inefficient irrigation methods, such as gravity-fed irrigation (yielding 40% of the total), and there are plans to augment its irrigated perimeters by 163,135 hectares by the year 2030. These dynamics are creating a structural water deficit, estimated at 84.42 million cubic meters (MCM) in 2006, and risk causing a collapse of underground and surface reserves if no corrective strategy is adopted (Hamlat et al. 2012).

Conventional approaches, such as the construction of dams or inter-basin transfers, are reaching their operational limits. Sites that are conducive to the construction of water reservoirs have been fully utilized, and desalination, although imperative (529.36 MCM produced in 2030 in the scenarios), remains financially burdensome (0.8 USD/m^3) and poses environmental risks, such as soil salinization. The absence of integrated policies capable of reconciling water security, social equity, and ecosystem preservation is further compounded by fragmented governance and a lack of coordination between sectoral players.

This issue underscores the pressing need to reevaluate water management strategies in arid regions, where current policy decisions will shape future water resilience in the face of both local and global challenges.

1.3. Aim and Objectives of the study

The objective of this study is to utilize the WEAP (Water Evaluation and Planning) model to assess water resource management scenarios in the Oran Coastal Basin. The study quantified the hydrological, economical, and environmental impacts over a 30-year period, extending from 2023 to 2053. The overarching objective is to identify resilient, adaptive strategies for mitigating water deficits, safeguarding ecosystems, and ensuring equitable access to water.

The research is structured around three specific objectives:

First, the study analyzed the limits of the current system. The second objective is to model supply-demand imbalances under the reference scenario, integrating climate and demographic projections.

The second objective is to evaluate contrasting scenarios: The reference scenario, the population and agricultural growth scenario, the minimum domestic consumption scenario, the agricultural improvement scenario, the infrastructure improvement and expansion scenario, the progressive pricing scenario, and the best practice scenario.

The third objective is to propose operational recommendations. Identify priority levers (technical, institutional, financial) for a transition to sustainable management.

1.4. Research questions

- What is the current supply-demand imbalances in the Oran coastal basin, and how will they evolve under the combined effect of population growth, agricultural pressures and climate change by 2053?
- To what extent can management scenarios reduce water deficits while preserving groundwater and surface resources?
- Which demand management policies (pricing, irrigation technologies) are most effective in balancing sectoral needs without compromising ecosystem sustainability?

2. LITERATURE REVIEW

2.1. Water Resource Management in Algeria

2.1.1. Introduction

Algeria, a North African country dominated by the Sahara, faces a chronic water shortage, aggravated by its geographical aridity, rapid population growth (projected at 45 million by 2020) and extreme climatic cycles alternating between drought and flooding (Zekri, 2020). Resolving the water crisis is an essential condition for the country's socio-economic development, requiring sustainable resource management, increased public awareness of water conservation, and a fight against water pollution and wastage.

Algeria has limited water resources, well below the scarcity threshold set by the World Bank (1,000 m^3/capita/year). Per capita water availability, already low, has fallen from 1,500 m^3/year in 1962 to a projected 430 m^3/year in 2025, under the combined effect of demographic pressure, climatic variability, and soil erosion in the northern plains, which reduces agricultural potential and groundwater recharge. Demand for drinking water is set to double over the next 25 years, accounting for almost 40% of mobilizable resources by 2025, with critical shortages in western regions.

The agricultural sector, the main consumer of water, suffers technical losses of up to 40% in irrigation networks (and up to 70% in urban areas). Institutional and infrastructural challenges persist:

- Inequitable access: On average, only 55 liters/capita/day are allocated to households, with discontinuous distribution in most towns.

- Health risks: More than 8 million rural dwellers depend on cisterns or precarious storage, exposed to water-borne diseases.

- Waste: 50% of water distributed is not billed (leaks, illicit connections).

- Pollution: wastewater is discharged untreated into watercourses, while wastewater treatment plants are falling into disuse due to lack of maintenance.

With a surface area of 2.38 million km^2 (80% of which is desert), Algeria concentrates its meagre surface water resources on the northern flank of the Atlas Mountains, where rainfall remains unpredictable. This geography forces the country to rely heavily on inter-regional transfers and unconventional solutions, such as desalination, to offset territorial imbalances.

Despite the efforts of the public authorities, matching water policies to actual needs remains a challenge, underlining the urgent need for integrated management, combining infrastructure modernization, transparent governance and technical innovation.

2.1.2. Integrated Water Resources Management (IWRM)

Integrated Water Resources Management (IWRM) is based on a systemic framework articulating three interdependent dimensions: environmental, socio-economic and institutional. Its aim is to optimize the sustainable use of water by reconciling sectoral imperatives (agriculture, industry, domestic needs), spatial dynamics (watershed management, including cross-border management) and temporal issues (adaptation to climate change). The polycentric governance of IWRM strengthens coordination between local, national, and international stakeholders via participatory mechanisms: basin committees, public consultations, and transparency tools. These mechanisms legitimize decisions and reduce disparities in power. In ethical terms, IWRM is based on two pillars: ecological sustainability (maintaining environmental flows) and social equity (universal access to resources). However, its implementation faces structural challenges: institutional complexity, fragmented hydrological data, and inadequate funding for cross-sectoral projects. To meet these challenges, technological innovation (IoT sensors, predictive models) and adaptive policies (plans that can be revised according to climatic hazards) are strategic levers. Holistic IWRM thus requires a hybridization of scientific knowledge and a long-term political commitment to reforming normative frameworks, positioning researchers as key players in the assessment of these complex dynamics.

a. IWRM Principles

The IWRM approach finds its roots in the Dublin-Rio Principles, four key principles that were adopted at the 1992 Dublin Conference on Water and endorsed at the Rio de Janeiro Summit on Sustainable Development (Figure 1).

Figure 1. IWRM Principles (Source: Dublin Conference, 1992).

b. Operational implementation

The IWRM paradigm encompasses a series of interconnected practices aimed at harmonizing water security, social equity, and ecological resilience.

The integration of temporal planning is a critical component of IWRM, involving the strategic allocation of resources and activities across different time horizons to ensure the effective and efficient use of water resources. The integration of short, medium, and long-term perspectives enables the anticipation of climatic and demographic challenges. In Algeria, the National Water Plan (PNE 2030) prioritizes securing drinking water supplies and adapting irrigation systems.

Robust information systems are also integral to the success of IWRM. The integration of hydrometeorological monitoring networks, predictive models (WEAP, SWAT), and remote sensing technologies (ANRH siltation monitoring) facilitates informed decision-making.

Erosion control strategies are also employed. The implementation of agroecological measures (e.g., reforestation, terraces) and hydraulic measures (e.g., anti-sediment sills) in basins is crucial for reducing siltation.

Proactive risk management is also essential. This includes the implementation of anti-flood infrastructure, such as retention basins, the establishment of early warning systems, and the strict regulation of urbanization in flood-prone areas.

The development of non-conventional resources is also imperative. The reuse of treated wastewater (with a potential of 1.2 billion m^3/year in Algeria) for the irrigation of non-food crops and the artificial recharge of water tables (e.g., the Mitidja water table) is a notable example.

Optimization of use: Mobilization of urban rainwater (e.g., through roof drainage, rain gardens) and improved efficiency (e.g., agricultural drip irrigation, smart metering).

Participatory governance: This will involve the involvement of local stakeholders and transparency mechanisms to legitimize pricing reforms and combat illicit abstraction.

The IWRM approach necessitates the systemic integration of technical, regulatory, and social solutions, supported by sustainable funding and clear performance indicators (water loss rates, quality of service). In Algeria, the coherent implementation of IWRM has the potential to transform water challenges into catalysts for sustainable development, harmonizing food security, public health, and ecosystem preservation.

2.1.3. Algerian watersheds

Located in an arid to semi-arid zone, Algeria has a hydrological regime marked by three major characteristics:

- Extreme irregularity of water inflows, with pronounced seasonal variations;

- Sudden, destructive floods, often associated with intense, localized rainfall;

- High levels of solid transport, encouraged by soil erosion and runoff.

These dynamics are reflected in the abrupt alternation between prolonged low flows (zero flows in dry periods) and flash floods, generating increased erosion upstream and recurrent flooding downstream.

In terms of hydrography, the Algerian territory is divided into five distinct regions, structured according to a logic of complementarity of water resources and balance between availability and local needs. This spatial division, illustrated by dedicated maps, aims to optimize integrated water management on the scale of coherent physical basins, where resource-need interactions are analyzed and planned systemically.

Figure 2. The five main hydraulics basins of Algeria

Table 2.1-1. Water resource potential of Algerian river basins

Basins	Oranie Chott Chergui	Chéliff Zahrez	Algérois Soumam Hodna	Constantinois Seybouse Mellègue	Sud	Total
Potential Resource (Hm^3/year)	1.025	1.840	4.380	4.500	700	12,45
Percentage (%)	8,7	15,7	37,3	38,3	0,56	100,0

a. Catchment areas

These basins are, in turn, divided into seventeen watersheds (see figure 3), organized into three distinct categories:

- Mediterranean tributary basins (codes 02, 03, 04, 09, 10, 11, 14, 15, 16): These include rivers flowing towards the Mediterranean Sea.
- Endoreic and high plains basins (codes 01, 05, 07, 08, 12, 17): These basins, which have no maritime outlet, drain closed areas (lakes, sebkhas) or inland plateaus.
- Saharan basins (codes 06, 13): Located in the Algerian Sahara, they are characterized by episodic runoff and mainly underground water resources (fossil aquifers).

This division reflects a geographical and hydrological logic, aimed at harmonizing resource management according to the climatic, topographical and socio-economic specificities of each zone.

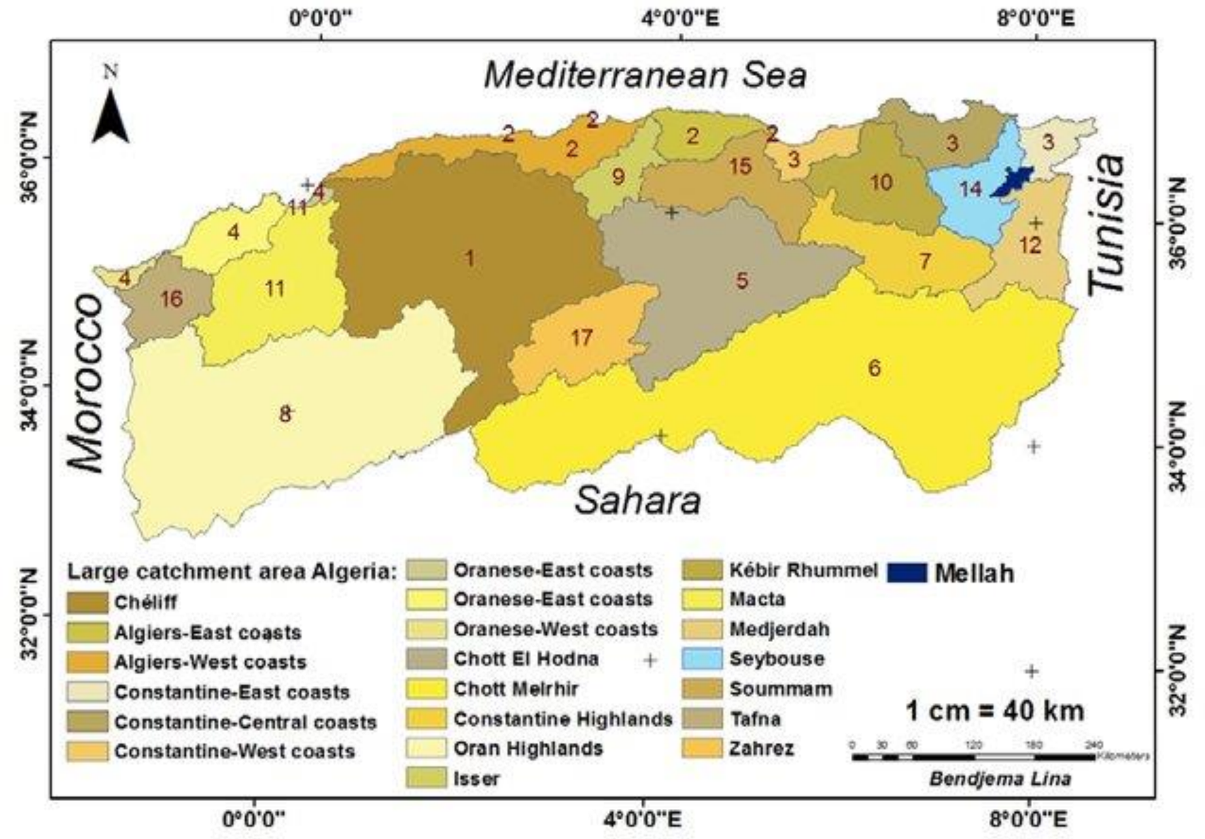


Figure 3. Basin map of Algeria (Bendjema et al, 2019)

2.1.4. Algerian water potential

a. Conventional water resource potential

Average annual rainfall in northern Algeria is estimated at between 95 and 100 billion m^3: over 80 billion m^3 evaporate, 3 billion m^3 infiltrate and 12.5 billion m^3 flow into rivers.

In northern Algeria, the main source of water is runoff, while surface water is stored in 59 large dams with a capacity of 5.7 billion m^3. The remaining 6.8 billion m^3 flows directly into the sea. This means that 54.4% of surface runoff is untapped.

With such a large number of dams (59 large dams and 62 small dams, for a total of 121 reservoirs), Algeria has ranked first in the Arab world since 2010, and 2nd in Africa, after South Africa.

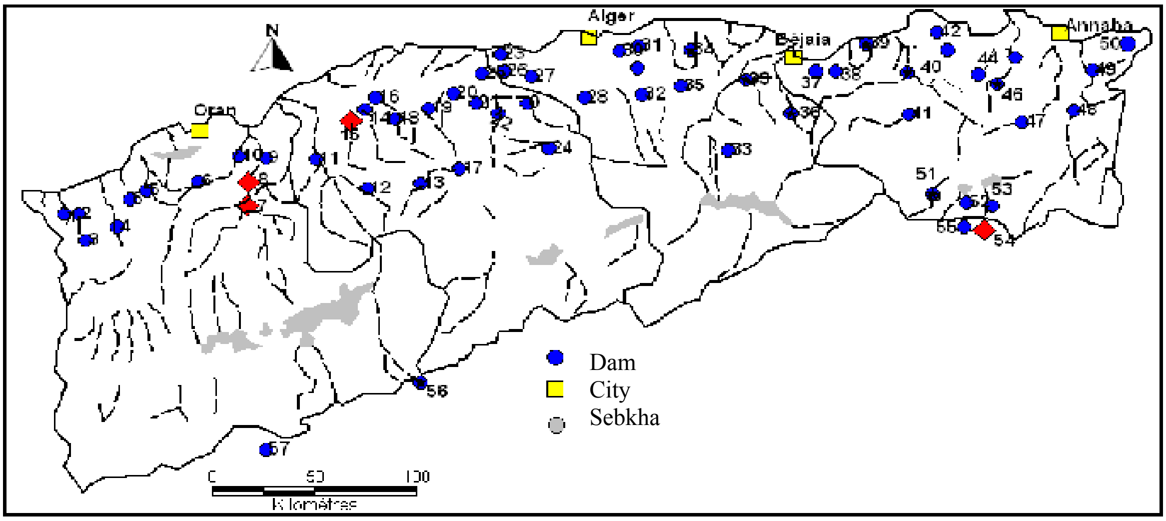


Figure 4. Location of Algerian dams

In an arid to semi-arid climate, Algeria's water resources are limited and unevenly distributed, with a global potential estimated at 21.1 billion m^3/year. Only 75% of this volume is renewable, distributed as follows:

Surface water: 12.5 billion m^3/year (60% renewable),

Renewable groundwater: 3.2 billion m^3/year (15% renewable).

Geographical distribution highlights major disparities:

Northern regions: 14.5 billion m^3/year, dominated by surface runoff (12 billion m^3) and renewable groundwater (2.5 billion m^3).

Saharan regions: 6.6 billion m^3/year, 93% from fossil groundwater (6.1 billion m^3), non-renewable on a human scale, and marginally from episodic runoff (0.5 billion m^3).

This dependence on fossil water in the Sahara and irregular surface runoff in the North exposes the country to the risk of long-term shortages, requiring strategic management to preserve these vulnerable resources.

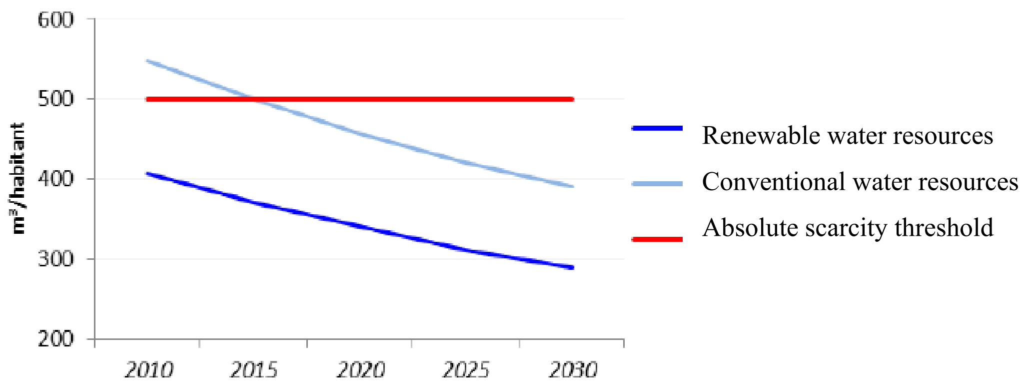


Figure 5. Evolution of water resources per capita: Renewable, Conventional and Absolute scarcity threshold (2010-2030)

❖ Surface water resources

Knowledge of surface water resources is based on:

- A rain gauge network comprising 1,122 stations

- A hydrometric network comprising 147 stations

- A climatological network comprising 200 stations

Numerous studies have shown that watercourses in northern Algeria are characterized by a simple hydrological regime (interannual alternation of high and low water), reflecting the preponderance of a single mode of supply.

In the Mediterranean climate of northern Algeria, rivers are fed by rainfall. Maximum flows are recorded during the winter and early spring, and minimum flows (low-water period) extend over four to five months during the summer and early autumn.

Surface water, which accounts for two-thirds of the country's potential, is also represented by the contribution of 34 wadis with a total flow of 12.5 billion m^3/year, and is characterized by irregularity, making it impossible to mobilize more than 5 to 6 billion m^3. In addition, their spatial distribution calls for major transfers to meet the needs of the least well-supplied regions.

❖ Groundwater resources:

The renewable groundwater resources available in the aquifers of northern France are estimated at almost 2.5 billion m^3. They are distributed across 177 aquifers, and their study is based on an inventory of:

- 9,000 springs

- 23,000 boreholes

- 60,000 wells

The various aquifers identified in Algeria can be divided into 3 main types: karstic aquifers, alluvial aquifers and sedimentary basins.

The northern Sahara harbors 02 major fossil aquifers (Complexes terminal (CT) nappe and Continental intercalary (CI) nappe), whose reserves are immense, but whose resources are non-renewable:

The exploitable potential of these Saharan aquifers in Algeria is estimated at 6.1 billion m^3/year (Etude SASS/OSS-Vol.4-June 2003).

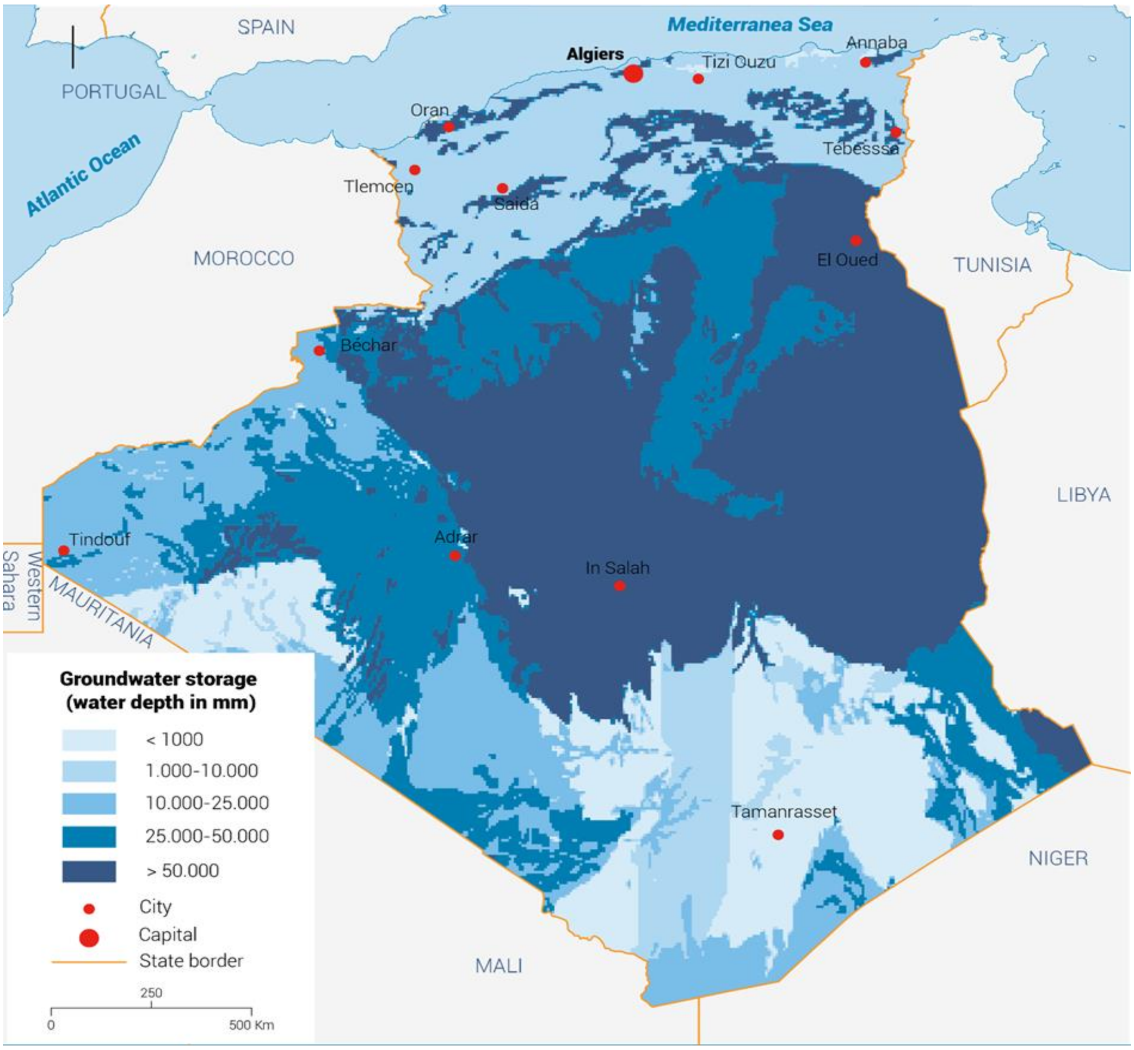


Figure 6. Map of Algerian Groundwater storage. (water.fanack.com 2019)

b. Non-conventional water resources

❖ Wastewater potential

With wastewater production currently estimated at 1.2 billion m^3 and a treatment capacity of 0.8 billion m^3, Algeria has embarked on an ambitious program to reuse treated wastewater.

❖ Seawater desalination

Algeria is currently building 13 large-scale seawater desalination plants, with a total production capacity of 2.3 hm^3/day. Currently (July 2016), 11 large plants with a capacity of 2.21 hm^3/day have been commissioned, corresponding to 806.6 hm^3/year. The strategic objective of this program will be to secure the drinking water supply for the populations of the major coastal cities in the North, and to reallocate water from dams in the Tellian Atlas for irrigation and transfer to the high plateaus.

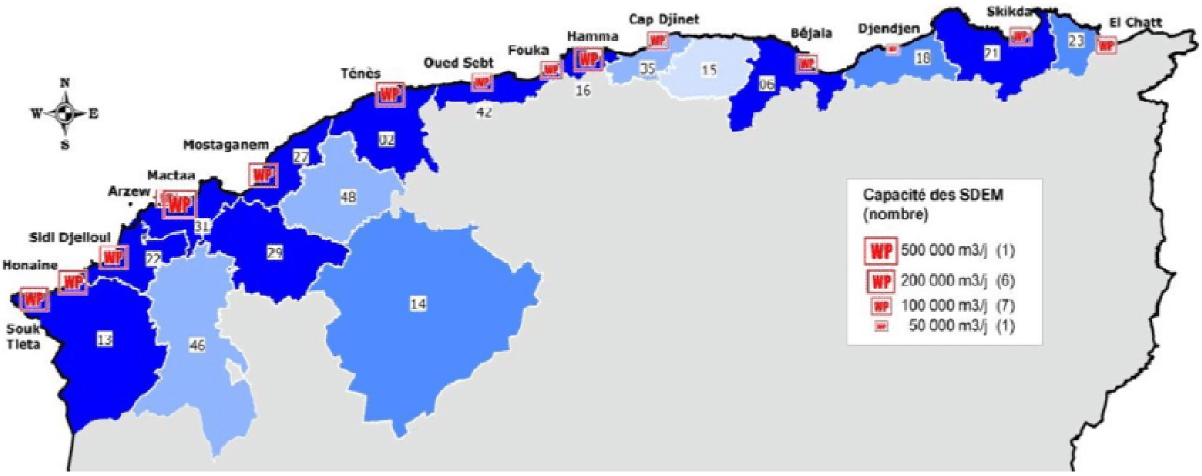


Figure 7. Seawater desalination plants in Algeria.

❖ Brackish waters

The non-renewable groundwater resources of the Saharan regions have relatively high salinity levels (3 to 6 g/l), exceeding the required drinking water standards.

2.1.5. Governance of water resources in Algeria

The governance of water resources in Algeria is based on a complex institutional and legislative framework, marked by recent reforms aimed at integrated and sustainable management.

a. Legislative and planning framework

Law n°05-12 of 2005 is the cornerstone of the legal system promoting integrated water resource management (IWRM). It governs

- Definition of the public hydraulic domain.

- Priority to drinking water supply.

- Planning through tools such as the National Water Plan (PNE) and Water Resource Development Master Plans (PDARE). The latter, drawn up at river basin level, aim to balance supply and demand by integrating climatic and socio-economic scenarios.

b. Institutional structures

The governance system operates at several levels:

- National level: The Ministry of Water Resources (MRE) steers sectoral policy, supported by technical directorates (DEAH, DAEP, DAPE) and specialized agencies:

❖ ANRH (resource monitoring).
❖ ADE (drinking water distribution).
❖ ONA, ONID (sanitation).
❖ AGIRE (IWRM coordination).

- Regional level: River Basin Agencies (ABH) manage data and local plans, while Basin Committees facilitate consultation between stakeholders.

- Local level: Wilaya Water Resources Departments (DREW) oversee project implementation and resource protection.

2.1.6. The water pricing system

Appropriate pricing is an effective way of ensuring rational use of water, on the one hand, by influencing users' consumption, and, on the other hand, by freeing up sufficient financial resources for the proper operation of services.

In terms of pricing for public water services, and the interests of fairness, tariffs have always been set by the State, with the constant aim of ensuring access for low-income groups.

This policy has led to a great waste of resources, a lack of maintenance of installations and a failure to meet needs, due to a lack of sufficient resources.

a. Water and wastewater tariffs

The rules governing the pricing system for public drinking water supply services are set out in Law 05-12 of August 4, 2005 on water, and Decree 05-13 of January 9, 2005, laying down the pricing rules for public drinking water supply and sanitation services, as well as the related tariffs.

Pricing is based on the principles of financial equilibrium, social solidarity, incentives to save water and protection of the quality of water resources. The tariffs applied must, by law, cover all or part of the financial costs of investment, operation, maintenance, and renewal of water management infrastructures.

Drinking water tariffs vary according to territorial tariff zone, user category, and volume of water drawn or supplied.

The basic tariffs, exclusive of tax, applicable in the five territorial tariff zones are shown in the table.

Table 2.1-2. Drinking water tariff schedule applicable to the tariff zone (official journal 2005)

Categories	Consumption band Drinking water	Unit price DA	Sanitation Unit price DA
Category 01: Individuals	T-1: 0 à 25 m^3 /trim	6,3	2,35
	T-2: 26 à 55 m^3 /trim	20,48	7,64
	T-3: 56 à 82 m^3 /trim	34,65	12,93
	T-4 : Sup à 82 m^3 /trim	40,95	15,28
Category 02: Administrations - Craftsmen and Service sector businesses	Single Tranche	34,65	12,93
Category 03: Industrial and Tourist Units	Single Tranche	40,95	15,28

Applying this scale of rates to the volume of water actually consumed, broken down by consumption category and band, gives an amount proportional to the volume consumed over a given period of time. This amount corresponds to the variable part of the tariff for the supply of drinking water. The fixed part of the tariff, known as the fixed subscription fee, which covers all or part of the costs of connection maintenance, water meter rental and maintenance, and commercial management, is set as follows:

- Households: 240 DA/quarter;

- Administrations, craftsmen and services: 450 DA/quarter;

- Industrial and tourist units: 4500 DA/quarter.

In addition to this drinking water supply charge, which is based on a binomial formula with a fixed (subscription) and a variable part, the price of the public drinking water service is calculated by integrating:

a) Value-added tax (VAT): 7%.

b) Management fee: This fee of 3 DA per cubic meter is charged for the concession to manage public production, transport and distribution facilities.

c) “Water conservation” and “Water quality protection” fees: 4% of the amount before tax for northern wilayas and 2% for southern wilayas.

For domestic users, the rate rose from 21.2 DA/m^3 to 32 DA/m^3. The average price paid by the user is around 64 DA/m^3 (including sanitation charges and charges for water conservation and protection). This selling price per m^3 of drinking water should be compared with the cost of production, estimated in 2005 at around 90 DA/m^3, which should currently be in the region of 125 to 150 DA/m^3 (taking seawater desalination into account).

The weight of the water bill in the household budget (extrapolated from a survey by the National Statistics Office) represents on average nearly 1% of household income. However, it is around 1.30% for the lowest income categories, which explains the stagnation in water rates.

For the country as a whole, according to ADE (Algerian Water Company), the cubic meter of water distributed was 65% subsidized in 2015. The CEO of ADE estimates that the average price per cubic meter is DA 45, which would enable him to cover all ADE's expenses.

b. Water pricing for industry

In addition to urban water supply, large-scale industry (LSI) obtains its water either from private boreholes, or in a mixed mode (private boreholes + urban water supply). Since 2005, the government has applied a water abstraction fee to encourage large-scale industry to use water resources wisely.

Currently, only large-scale users (water distribution companies, industries and tourist resorts) pay the fee, set at 25 DA/m^3 (and 80 DA/m^3 for water injected into oil wells or for other hydrocarbon-related uses).

c. Water pricing for irrigation

The pricing of publicly-managed irrigation water is set by regulation (Law 83-17 of July 16, 1983). It mainly concerns large-scale irrigation schemes and small and medium-scale irrigation areas, equipped by the State or on its behalf, whose management is conceded to irrigators' associations or cooperatives. The tariffs payable by the user are calculated according to a binomial formula based on the maximum flow rate subscribed (fixed part) and the volume actually consumed (variable part).

The latest pricing system introduced in 2005 (decree 05-14 of January 9, 2005) increases the price of water for agricultural use from 1.00/1.25 DA/m^3 to 2.00/2.50 DA/m^3, depending on the type of irrigation.

Table 2.1-3. Agricultural water prices

Irrigation Perimeters	Volumetric Rate (Da/m^3)	Fixed Rate (Da/liter/sec/Ha)
Sig	2,50	250
Habra	2,50	250
Mina	2,00	250
Bas Cheliff	2,00	250
Moyen Cheliff	2,00	250
Haut Cheliff	2,50	400
Mitidja Ouest	2,50	400
Hamiz	2,50	400
Guelma-Bouchegouf	2,50	400
Saf Saf	2,00	400
Bounamoussa	2,50	400

d. Water production prices

Table 2.1-4. Comparative costs of water sources and water infrastructure (in DA/m^3 and USD/m^3)

Sources	**Cost \$ / m^3**
Desalination water: 90 da/m^3	0.67
Drilling water: 22 da/m^3	0.22
Dam water: 11 da/m^3	0.16
Activated sludge purification water	0.34
Construction costs for rainwater retention basins	70-100

Financial management of the drinking water sector in Algeria is faced with a major cost recovery deficit, with only 42% of the volume produced currently billed to users. The remaining 58%, referred to as non-revenue water, is divided between technical losses (30%) due to dilapidated networks (leaks, corrosion) and commercial losses (70%) linked to illicit connections or fraud. These losses reflect structural shortcomings: ageing infrastructures (40% of pipes are over 30 years old), lack of modernization of leak detection systems, and poor control of illegal tapping, often motivated by unequal access or socio-economic difficulties. In financial terms, this waste represents an annual loss of revenue estimated at DA 45 billion (2020), compromising the profitability of public investments and the sustainability of services. Technically, it exacerbates the pressure on already limited resources, particularly in a context of growing water stress. An effective response requires an integrated approach combining urgent rehabilitation of networks (in particular via leak geolocation technologies), reinforced controls (digitization of connections, dissuasive penalties), and community awareness-raising to restore confidence in institutions. Without this, the goal of universal drinking water coverage, enshrined in the SDGs, will remain unattainable.

2.2. Water Evaluation and Planning System (WEAP)

The Water Evaluation and Planning (WEAP) model is a widely used microcomputer-based integrated water resources planning tool designed to simulate water supply, demand and allocation in different sectors, integrating hydrology with demand analysis (Sieber and Purkey 2015). Developed by the Stockholm Environment Institute (SEI), the US Army Corps of Engineers, USAID, Japan's Global Infrastructure Fund, and the World Bank (Sieber and Purkey 2015). WEAP provides a user-friendly, scenario-based framework for assessing current and future water resource conditions while considering climate change, population growth, land-use changes, and policy interventions, making it useful for short- and long-term planning (Yao et al. 2021) (Razisadath et al. 2023).

2.2.1. Background

Many regions face formidable freshwater management challenges. Allocation of limited water resources, environmental quality and sustained water use policies are issues of growing interest. Conventional distribution-oriented simulation models are not always adequate. Over the past decade, an integrated approach to water development has emerged that places water distribution projects in the context of demand issues, water quality and ecosystem preservation.

WEAP aims to incorporate these values into a practical tool for water resources planning. WEAP is distinguished by its integrated approach to water system simulation and policy orientation. WEAP places the demand side of the equation (water use modulations, equipment efficiencies, reuse, price and allocation) on an equal footing with the supply side (river flow, groundwater, reservoirs and water transfers). WEAP is a laboratory for examining alternative water development and management strategies.

WEAP is comprehensive, simple and easy to use, and aims to assist rather than substitute for skilled planners. As a database, WEAP provides a system for maintaining demand and distribution information. As a forecasting tool, WEAP simulates water demand, supply, flow, storage, pollution generation, treatment and distribution. As a policy analysis tool, WEAP evaluates a full range of water development and management options, and considers multiple competitive uses of water systems.

WEAP was developed at the Stockholm Environment Institute (SEI) by researchers Jack Seiber, Water Systems Modeler; Chris Swartz, Research Associate; and Annette Huber-Lee, SEI Water Resources Program Director (Rakotondrabe,2007). The model is semi-theoretical, continuous-time, semi-distributed and deterministic. As it is a semi-theoretical model, it needs to be calibrated and verified (Abrishamchi et al. 2007).

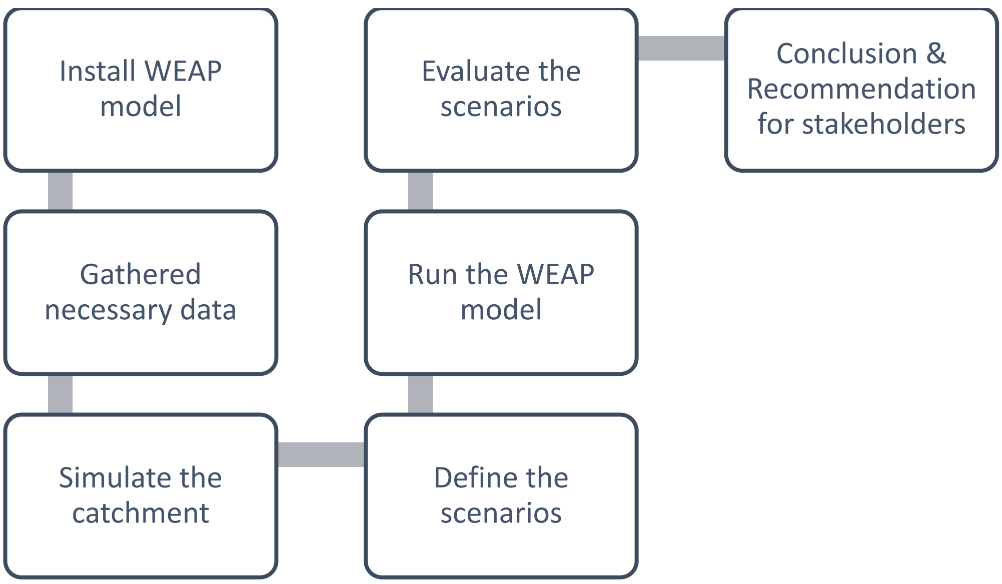


Figure 8. Flowchart depicting the methodology of WEAP Simulation

2.2.2. Key features of WEAP

WEAP operates on a node-link network representation, where water sources (e.g., rivers, reservoirs, groundwater) and demand sites (e.g., domestic, agricultural, industrial users) are modeled as interconnected elements. This structure enables users to analyze multiple water allocation scenarios, taking into account environmental, social and economic factors (Li et al. 2015 a, b).

The model integrates hydrological, operational and socio-economic parameters, making it a flexible tool for river basin management, urban water planning and climate impact assessments. WEAP can be linked with hydrological models, climate models, and optimization techniques to improve predictive accuracy and decision-making capabilities (Ortiz-Partida et al. 2023).

2.2.3. Program structure

WEAP consists of five main views: Schematic, Data, Results, Block Diagrams and Notes. These five views are presented below.

a. Diagram

This view contains Geographic Information System (GIS)-based tools for easy configuration of your system. Objects (such as demand nodes, deductions) can be created and placed in the system by selecting, dragging and pasting items from a menu. Image (raster) or vector files obtained by ArcView or other standard GIS tools can be added to the schematic as a background. You can quickly access data and results for any node by clicking on the object of interest.

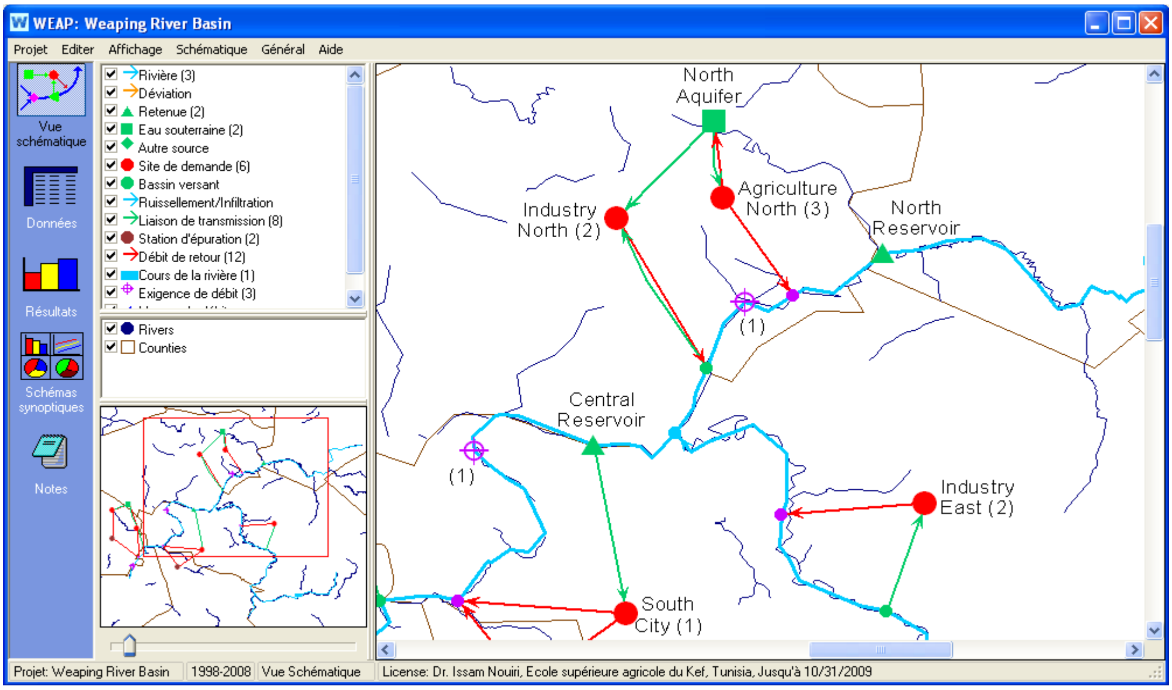


Figure 9. WEAP schema

b. Data

The data view lets you create variables and relationships, enter assumptions and projections using mathematical expressions and dynamic relationships with Excel.

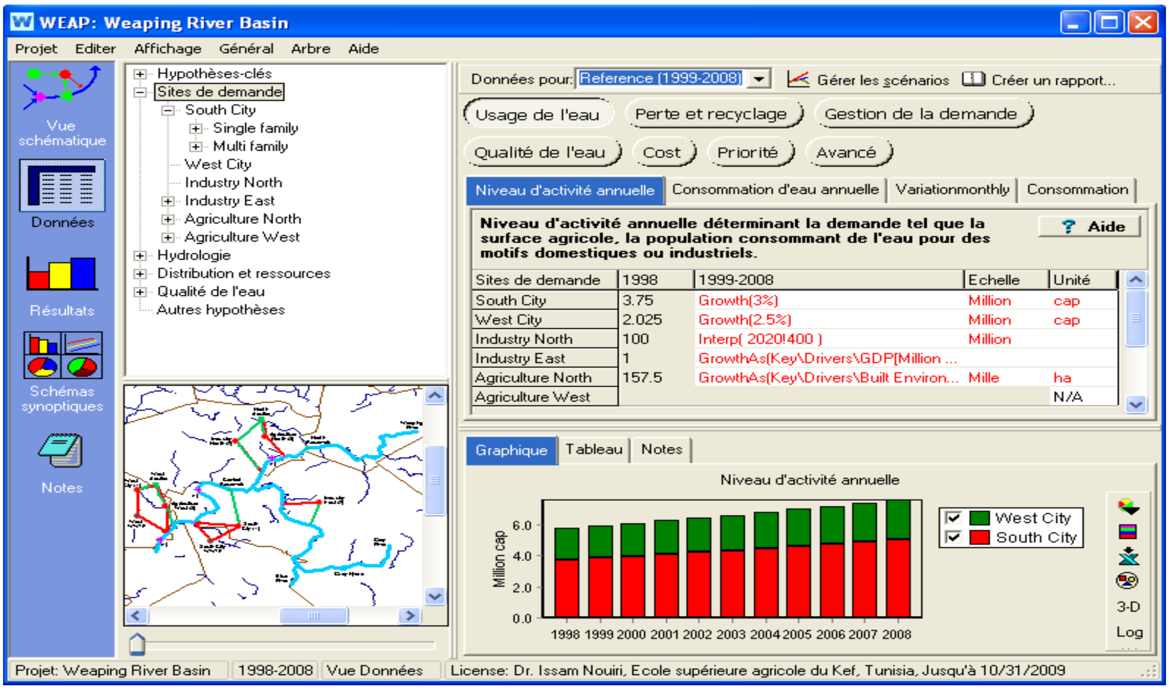


Figure 10. WEAP Data

c. Results

The results view provides a detailed and flexible display of model outputs in graphs and tables, and in the schematic.

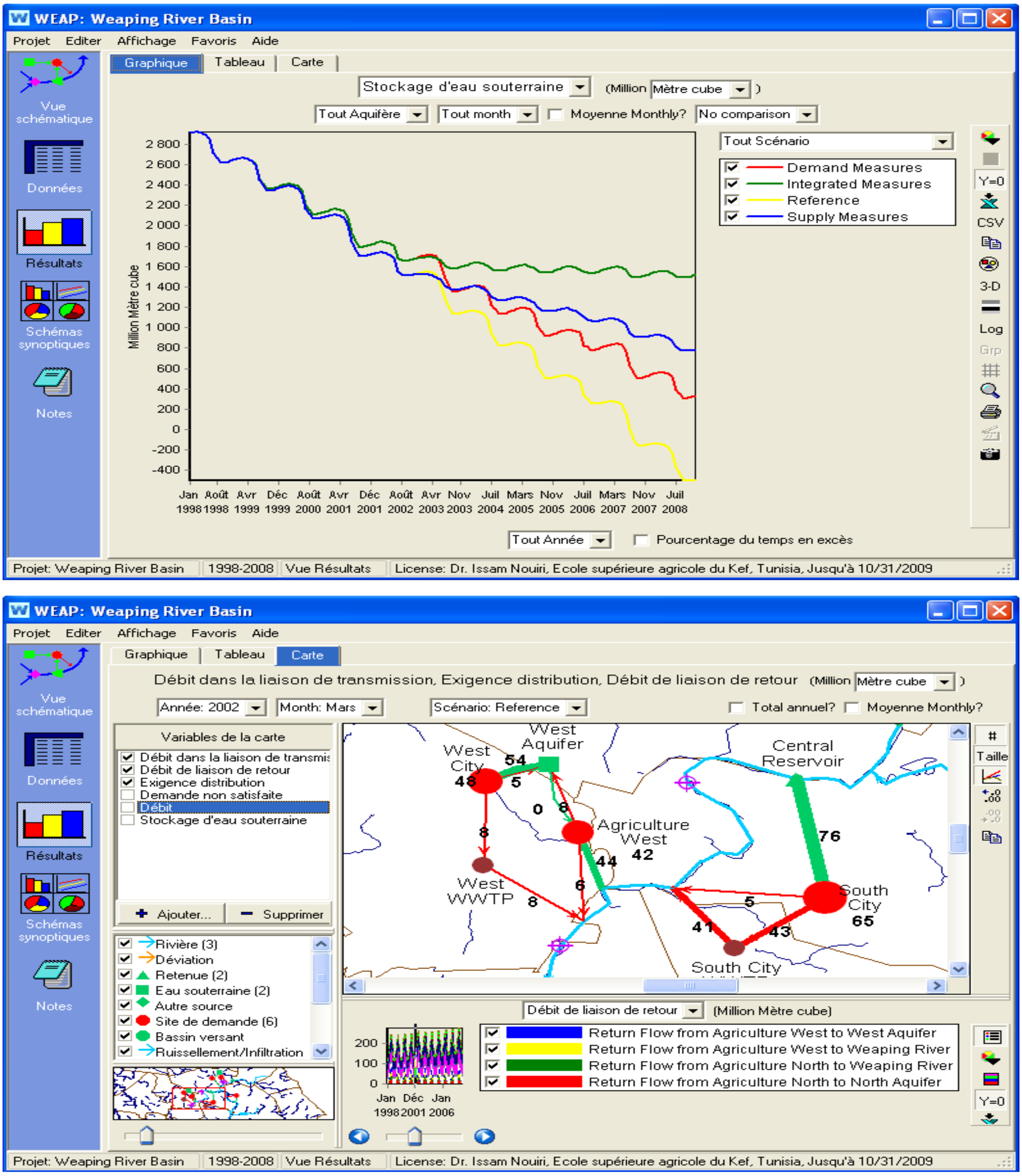


Figure 11. WEAP Result

Table 2.2-1. WEAP Model Outputs (Droogers P Et Al, 2011)

Application results	- Water demand - Supply requirement - Supply delivered - Unmet demand - Coverage - Inputs (demand and outputs) - Minimum flow - Minimum flow delivered - Unmet minimum flow requirement - Flow coverage
Supply results and resources	- Entering the pool - Basin exit - River ❖ Flow rate ❖ Gauged flow (absolute) ❖ Gauged flow (%) ❖ Stage ❖ Speed ❖ Reach (length) - Groundwater ❖ Storage ❖ Inlet and outlet ❖ Overflow ❖ Height above river ❖ River outlets - Reservoir ❖ Storage volume ❖ Storage volume ❖ Storage altitude ❖ Inflows and outflows

	❖ Hydropower - Transmission link ❖ Flow rate ❖ Inputs and outputs - Other power supplies ❖ Inputs and outputs - Return link ❖ Flow ❖ - Inputs and outputs
Capture results	- Results (FAO method) ❖ Runoff versus precipitation ❖ Observed precipitation ❖ Infiltration / flow runoff ❖ ET Potential ❖ ET Current (including irrigation) ❖ HE Deficit ❖ Total yield ❖ Total market value - Results (soil moisture method) ❖ Soil classes (input-output) ❖ Observed precipitation ❖ Snow accumulation ❖ Infiltration / runoff ❖ Effective monthly precipitation for HE (including snowmelt) ❖ Area ❖ Temperature ❖ Net solar radiation ❖ Monthly PET reference ❖ ET Potential ❖ Current ET (including irrigation) ❖ Relative soil humidity (%) ❖ River flow without irrigation

	❖ River flow with irrigation ❖ GW flow without irrigation ❖ GW flow with full irrigation ❖ Irrigation with return fraction of surface water flow ❖ - Irrigation with return fraction of groundwater flow
Water quality results	- Pollution generation - Pollution load - Pollution input to treatment plants - Inputs to and outputs from treatment plants - Surface water quality
Financial results	- Net cost ratio - Net present value - Average cost of Water ratio

d. Block diagram

You can highlight key indicators in your system for a quick overview.

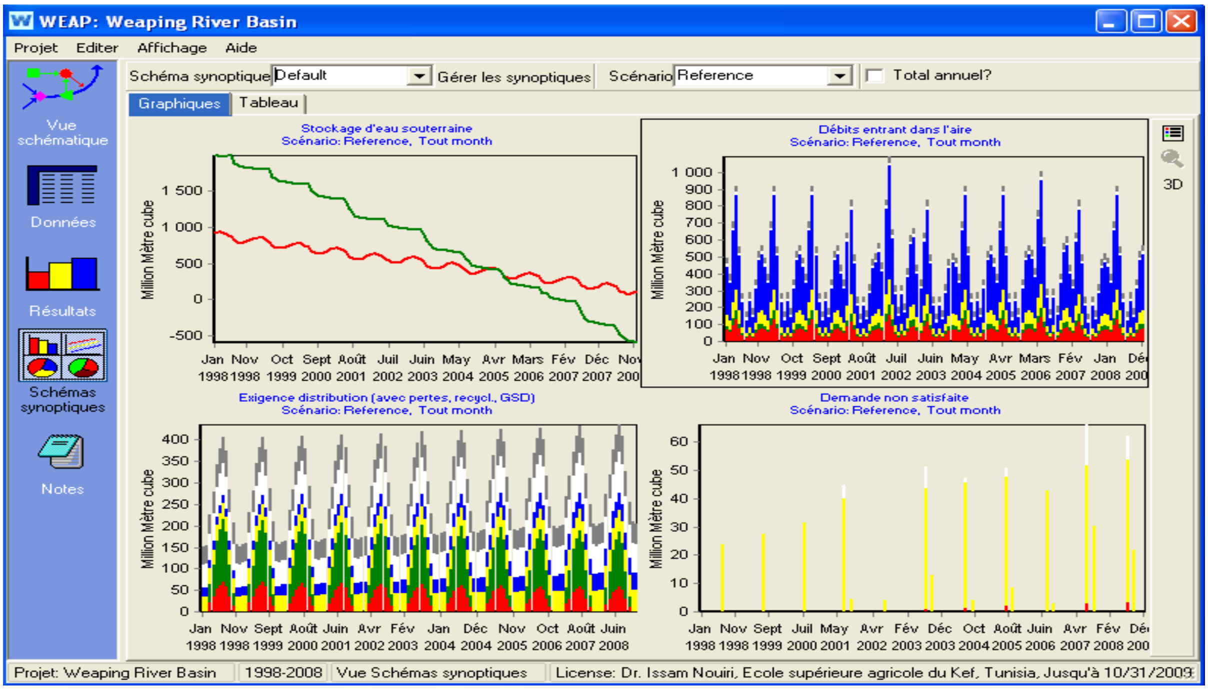


Figure 12. WEAP diagram

e. Notes

The Note view provides a place to document your data and assumptions.

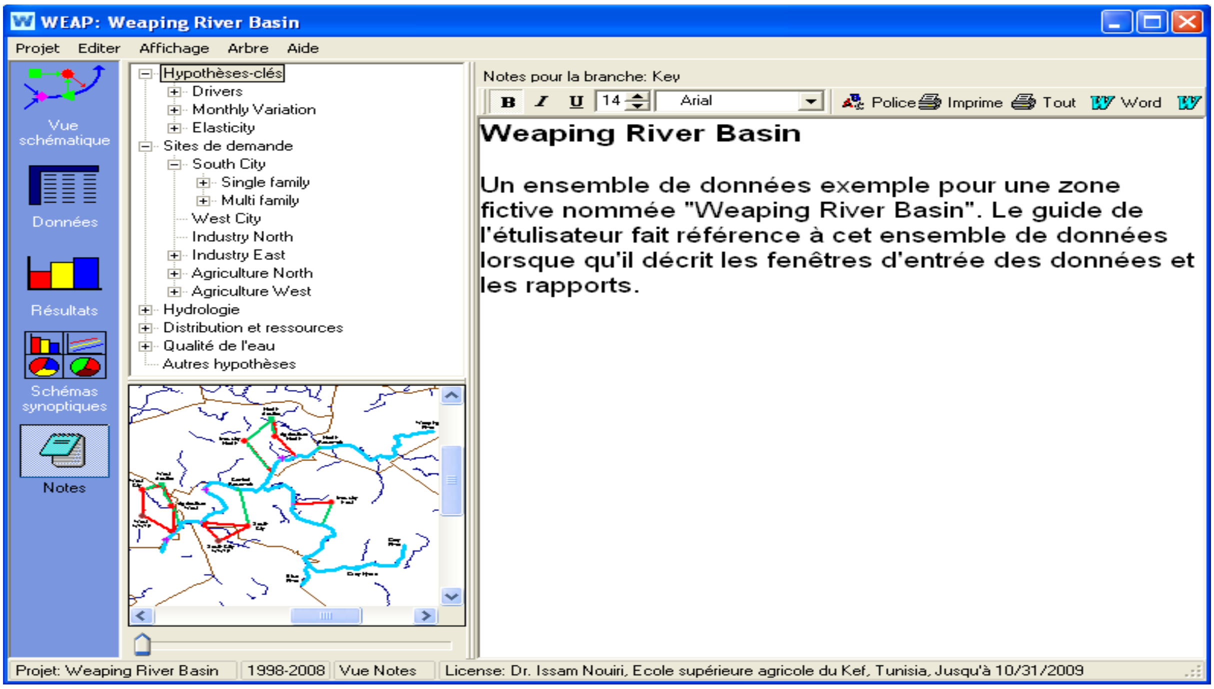


Figure 13. WEAP note

2.2.4. The WEAP approach

The WEAP approach operating with the basic principles of water balance, WEAP is applicable to municipal and agricultural systems, to single planning areas or for complex river systems with extended boundaries. In addition, WEAP can address a wide range of issues: sectoral demand analyses, water conservation, water rights and allocation priorities, groundwater and surface water simulation, reservoir management, hydropower generation, pollution monitoring, ecosystem requirements, vulnerability measures and project cost-benefit analyses.

The analyst represents the system in terms of its various sources of water supply (rivers, streams, groundwater, dams and desalination plants); withdrawals, transfers and wastewater treatment possibilities; ecosystem requirements; water demands and pollution generation. Data structure and level of detail can be easily customized to meet the requirements of a particular analysis, and to reflect the limitations imposed by restricted data.

WEAP applications typically involve several steps. Study definition, which identifies the simulation period, spatial boundaries, system components and problem configuration. The Current State, which can be seen as a calibration step in the development of an application, provides a snapshot of the current water demand, pollution load, resources and supplies for the system. Basic assumptions must be built into this Current State to represent policies, costs and factors affecting demand, pollution, supply and hydrology. Scenarios are built on the basis of the Current State. They explore the impact of alternative assumptions or policies on future water availability and use. Finally, Scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental objectives and sensitivity to uncertainty in the estimation of key variables.

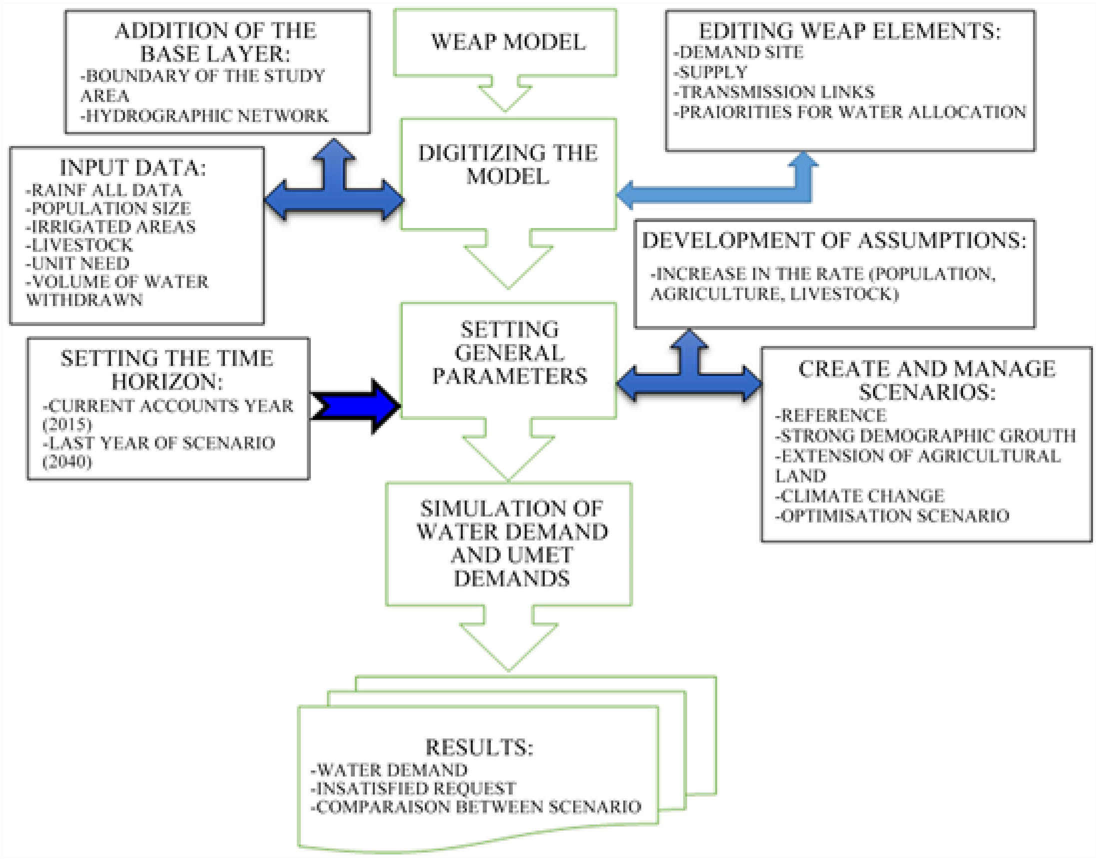


Figure 14. Modeling in WEAP

2.2.5. Applications of the WEAP Model in Water Resource Management

The Water Evaluation and Planning (WEAP) model has emerged as a critical tool for addressing water resource challenges across diverse geographical and socio-economic contexts.

a. Climate Change and Water Availability

WEAP's capacity to integrate climate projections has been pivotal in assessing future water security. For instance, in the Irawan Watershed (Philippines), Cacal et al. (2024) projected a 20–40% decline in surface water availability by 2050 under high-emission scenarios, underscoring the urgency of adaptive strategies such as rainwater harvesting and watershed conservation (Cacal, J.C. et al., 2024). Similarly, in the Zayandeh Rud Basin (Iran), Javadinejad et al. (2019) coupled WEAP with climate models to optimize water allocation, revealing that agricultural demand could only be met with 60% confidence under drought conditions, compared to 83% for domestic and industrial needs (Javadinejad, S. et al., 2019). These studies highlight WEAP's utility in translating climate uncertainties into actionable risk metrics.

In Western Algeria, Hamlat et al. (2013) used WEAP to evaluate the compounding effects of rising temperatures and declining rainfall on groundwater recharge. Their simulations predicted a 30% reduction in aquifer replenishment by 2030, necessitating stricter irrigation quotas and drought-resistant crop policies (Hamlat, A. et al., 2013). Such findings align with global trends, where WEAP serves as a bridge between climatological data and localized water governance.

b. Socio-Economic Drivers of Water Scarcity

WEAP's strength in modeling socio-economic dynamics is exemplified by studies linking population growth and resource exploitation to water stress. In the Indus River Basin (Pakistan), Hassan et al. (2019) forecasted a 35% surge in water demand by 2040, driven primarily by urbanization and agricultural expansion, urging policymakers to prioritize efficiency over new infrastructure projects (Hassan et al., 2019). Contrastingly, in the Gilgel Gibe Watershed (Ethiopia), Fanta et al. (2022) found that socio-economic factors such as farmland encroachment and population doubling by 2040 would exacerbate water scarcity more severely than climate change itself, advocating for demand-side management (Fanta et al., 2022).

The Sistan Region (Iran) study by Shahraki et al. (2019) integrated WEAP with the FAO's crop-water requirements, revealing that reducing irrigated areas by 15% and improving efficiency by 25% could mitigate shortages without compromising food security (Shahraki et al., 2019). These applications underscore WEAP's role in balancing competing demands while addressing equity concerns.

c. Infrastructure and Demand-Side Solutions

Several studies leverage WEAP to test infrastructural interventions and conservation policies. In the Veda River Basin (India), Carpenter and Choudhary (2022) demonstrated that constructing water storage structures and artificial recharge systems could reduce unmet demand by 25% under high-population-growth scenarios (Carpenter and Choudhary, 2022). Similarly, in Selangor (Malaysia), Mohd Firdaus Hum and Abdul Talib (2016) showed that demand-side measures such as leak reduction and public awareness campaigns could cut water deficits by 40% by 2040, even with a 3% annual population increase (Mohd Firdaus Hum and Abdul Talib, 2016).

In Algeria's Seybouse Basin, Mansouri et al. (2017) combined WEAP with multi-criteria analysis to evaluate hybrid strategies, including wastewater reuse and inter-basin transfers, to address projected 2030 shortages (Mansouri et al., 2017). These studies illustrate WEAP's adaptability in designing context-specific solutions, from decentralized infrastructure to behavioral interventions.

d. Transboundary and Multi-Sectoral Management

WEAP's spatial resolution enables its application in transboundary and multi-sectoral contexts. For Lake Tana (Ethiopia), Alemayehu et al. (2010) simulated trade-offs between hydropower generation and ecological flows, revealing that expanding irrigation could lower lake levels by 1.5 meters, threatening fisheries and wetlands (Alemayehu et al., 2010). In the Subarnarekha Basin (India), Kumar et al. (2021) identified "unmet demands" during dry years, emphasizing the need for interstate cooperation to allocate water across industrial, agricultural, and domestic sectors (Kumar et al., 2021).

e. Methodological Innovations and Limitations

While WEAP's flexibility is widely acknowledged, studies also note challenges. Data scarcity, particularly in regions like the Subarnarekha Basin, often limits calibration accuracy [1]. Additionally, few studies (e.g., Seybouse Basin [4]) address equity implications, such as disproportionate impacts on smallholder farmers. Nevertheless, innovations like coupling WEAP with hydrological models (Zayandeh Rud [10]) or participatory approaches (Gilgel Gibe [5]) enhance its robustness. (Kumar, R. et al., 2021 ; Mansouri, S. et al., 2017 ; Fanta, S.S. et al., 2022 ; Javadinejad, S. et al., 2019).

2.2.6. WEAP benefits

Water Evaluation and Planning (WEAP) offers remarkable flexibility, adapting to various scales (local communities, transboundary basins) and integrating climatic, hydrological and socio-economic data to simulate supply or sustainable management scenarios (Rajosoa et al., 2021; Yates et al., 2021). It promotes sustainable development by balancing human, economic and ecological needs, notably via the Water-Energy-Food Nexus, and by anticipating the impacts of climate change (Ghimire et al., 2022; Ramírez et al., 2022). Its user-friendly interface makes it accessible to non-experts, encouraging collaboration between stakeholders (Samaké et al., 2023; Fard & Sarjoughian, 2024). WEAP also enables sensitivity analyses to assess uncertainties (e.g., climate variability) and adjust strategies (Yates et al., 2021). Inexpensive and compatible with local data, it is particularly well suited to developing countries (Ossa-Moreno, n.d.; Rajosoa et al., 2021). Finally, it facilitates informed decision-making through clear visualizations and comparative scenarios, supporting equitable and resilient policies.

These assets make it a key tool for integrated, sustainable water management in the face of climate and demographic challenges.

2.2.7. WEAP limitations and challenges

There is growing interest in the use of the WEAP model, both within the scientific community and among water resource management practitioners. However, despite its undeniable advantages, WEAP faces several limitations and challenges that may influence the effectiveness of its application.

a. Dependence on quality data

WEAP requires accurate and complete hydrological data to generate reliable simulations. In many regions, the absence or obsolescence of historical data (flows, withdrawals, etc.) compromises the reliability of models, particularly in developing countries where collection systems are fragile (Johannsen et al., 2016; Dali, 2021). Collecting up-to-date data remains a major logistical and financial challenge.

b. Complexity of systemic interactions

Modeling interactions between climatic, socio-economic and environmental variables (urbanization, agriculture, climate) requires complex data management. Integrating multiple temporal and spatial scales can lead to interoperability errors or oversimplifications, limiting the accuracy of scenarios (Mohammadpour et al., 2023; Dias et al., 2023).

c. Institutional and collaborative challenges

The success of WEAP depends on interdisciplinary collaboration between public, private and community players. Conflicts of interest, lack of institutional coordination or gaps in water governance hamper its application, especially in cross-border or politically sensitive contexts (Muok & Onyango, 2020).

d. Financial and technical constraints

Implementing WEAP requires significant financial resources for user training, data acquisition or custom model development. These costs limit its adoption in regions with limited budgets, despite its relative affordability compared to other tools (Höllermann et al., 2010).

e. Climatic uncertainties and adaptability

Although WEAP incorporates climate scenarios, long-term uncertainties (e.g., precipitation trends, extreme events) can distort its projections. Models must be constantly recalibrated to reflect the latest climate forecasts, which requires in-depth technical expertise (Furlong et al., 2015; Ochola et al., 2004).

f. Limited integration of machine learning

While WEAP can handle scenario-based simulations, it lacks advanced AI-based predictive analytics, which could improve decision-making in highly dynamic water systems (Rashid and Kausik 2024).

Despite its usefulness, WEAP remains dependent on robust data, effective institutional collaboration and adequate resources. To overcome these limitations, investments in data collection, training of local stakeholders and hybrid approaches (combining WEAP with other tools) are essential. Better integration of local knowledge and emerging technologies (AI, remote sensing) could also enhance its relevance in a variety of contexts.

2.2.8. Future enhancements for WEAP

Given the rapid evolution of management needs in the face of climatic, demographic and economic challenges, numerous avenues for future improvement have emerged in the literature.

- The reinforcement of hydrological modules, notably through better simulation of surface and groundwater interactions (Mansouri et al., 2017; Höllermann et al., 2010).

- The integration of water quality modules and the extension of the approach to the interrelations of the water-energy-food nexus (Slaymane & Soliman, 2022; Salem et al., 2023; Dias et al., 2023; Abdelkader et al., 2023).

- The adoption of new information technologies (remote sensing, IoT) and artificial intelligence methods to improve resolution and calibration (Ojwang et al., 201; Awad & Zaid-Alkelani, 2019).

- The development of advanced sensitivity analysis and stochastic optimization mechanisms to enhance the adaptability and resilience of management scenarios (Hall & Murphy, 2010; Yan et al., 2016; González-Cebollada & Grassa, 2022; Waage & Kaatz, 2011).

- Increasing interoperability between WEAP and other modeling platforms to support an integrated approach to critical infrastructures (Dau et al., 2021; Kularathna et al., 2017).

These lines of development aim to transform WEAP into a more comprehensive tool, capable of responding to the complex challenges of sustainable water resource management in a context of rapid change and multiple uncertainties.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

a. Location Data

The Oran Coastal Basin is part of the Oranais Chott El Chorgui basin, located north of the Tafna and Macta basins on the Mediterranean coast. The geographical coordinates of the basin are specified as -02°12'46.7703" and 00°18'00.8352" east longitude and, 34°54'28.5722" and 36°01'54.2246" north latitude. The maximum altitude within the catchment varies from 1061 m (Tessala Mountains) to 1021 m (Traras Mountains), while the minimum altitude is 15 m (at the coastal fringe). The catchment area covers an area of 5.845 km^2 i.e., 7.65% of the total surface area of the hydrographic region, and has a population of over 2.788.229 spreads over six wilayas (ABH-OCC, 2023).

The Oran Coastal Basin, identified by national code 04, comprises six sub-basins with distinct characteristics: Ghazaouet Coastal (0401 - 899 km^2), Aïn Temouchent Coastal (0402 - 1,229 km^2), The Andalous Coastal (0403 - 405 km^2), Sebkha of Oran (0404 - 2,180 km2), Sebkha of Arzew (0405 - 773 km^2) and Mostaganem Coastal (0406 - 359 km^2), reflecting a marked geographical and hydrological diversity.

b. Geography

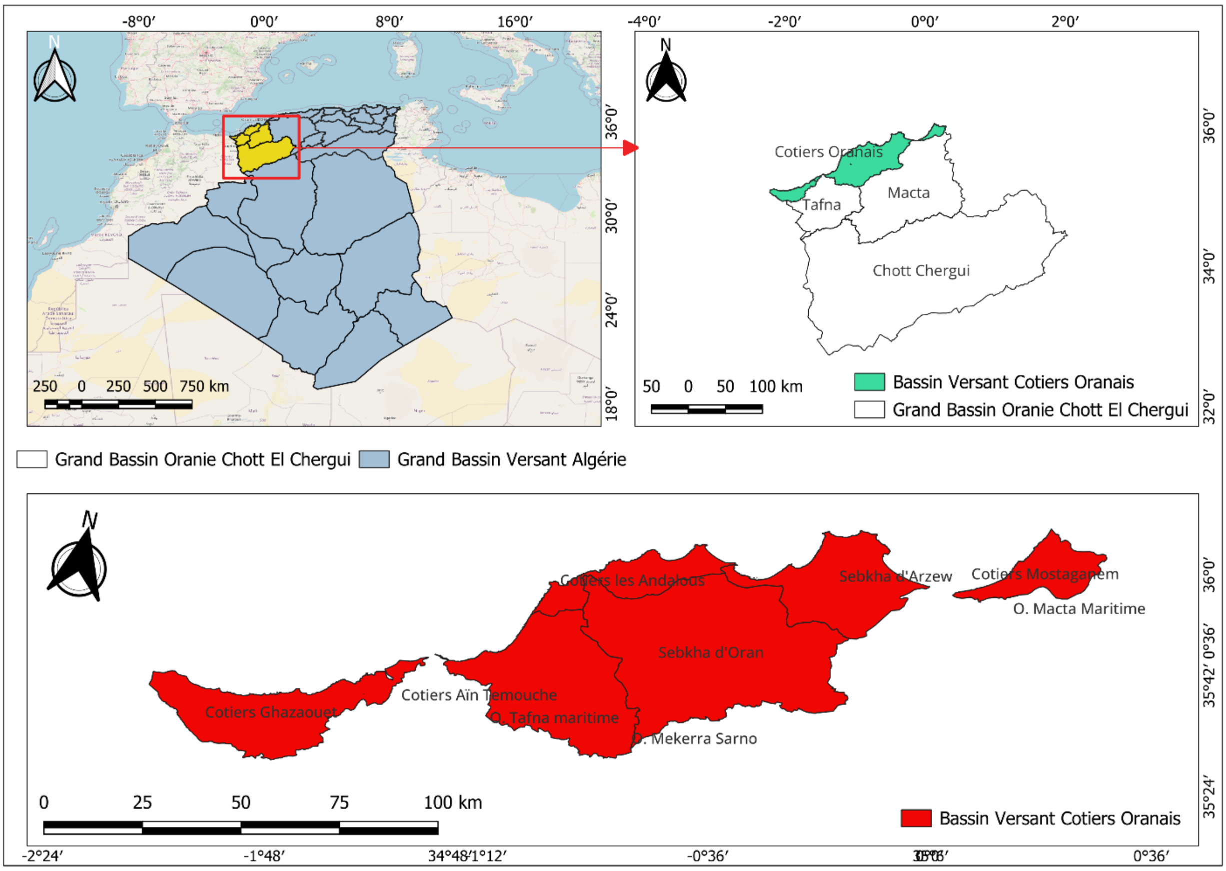
The Oran coastal basin is characterized by a tripartite geographical organization, marked by distinct morpho-structural units:

- To the north, the mountainous area is dominated by the Traras massif (wilaya of Tlemcen) and the Murdjadjo massif (wilaya of Oran), which form high, rugged reliefs structuring the northern edge of the basin.

- In the center, an intermediate zone combines alluvial plains, such as the Mleta plain (wilaya of Oran), with tabular plateaus such as Mostaganem, as well as the hilly formations of the Hamoul hillsides (wilaya of Oran), reflecting a geomorphological transition between the northern reliefs and the southern spaces.

- In the south, the landscape evolves towards more accentuated relief, marked by the Tessala mountains, where a sharp topographic rise marks a clear break with the central terrain.

This spatial configuration underlines the diversity of the landscapes, which are structured around three distinct groups: mountains, plain-plateaus and steep southern reliefs, reflecting the geological and hydrological dynamics specific to the region.



Oran Coastal Basin

Figure 15. Map of the study area (ABH-OCC)

3.1.2. Morphological and morphometric characteristics of sub-catchments

Table 3.1-1. Morphological and morphometric characteristics of sub-catchments (ANRH).

Sub-basin	Shape parameter			Relief parameter			Hydrographic Parameter
	S (Km^2)	P (Km)	Kc	IG	IM	Average altitude (M)	Dd (Km^{-1})

- S: Surface area
- P: Perimeter

Coastal Oranais Occidental	892	190	1,80	5,66	8,98	490	0,17
Coastal Oranais Central	4587	355	1,48	3,07	6,31	380	0,15
Coastal Oranese Oriental	359	110	1,63			364	

- Kc: Gravel compaction index
- IG: Overall slope index
- IM: Average slope index Dd: Drainage density

Morphometric analysis of the sub-basins of the Oran Coastal Basin reveals marked structural heterogeneity, reflecting distinct geomorphological and hydrological dynamics. The Central sub-basin stands out for its dominant surface area (4,587 km^2), representing almost 80% of the total surface area analyzed, compared with 892 km^2 for the Occidental and 359 km^2 for the Oriental. This spatial disparity is accompanied by significant morphological variations: compactness coefficients (Kc > 1) indicate globally elongated shapes, characteristic of coastal basins, with a more pronounced stretching for the Central (Kc = 1.48), suggesting a longitudinal extension influenced by tectonic or topographic constraints.

Relief parameters highlight a decreasing altitudinal gradient from northwest to southeast, with the Occidental showing a high mean altitude (490 m) and steep slope indices (GI = 5.66; IM = 8.98), typical of mountainous reliefs conducive to intense runoff. The Central, on the other hand, with its moderate average altitude (380 m) and lower relief indices (GI = 3.07; IM = 6.31), evokes a landscape of plains and plateaus, favoring regular water runoff but potentially prone to waterlogging. The Oriental, although compact (Kc = 1.63), has gaps in relief and drainage density data, limiting its interpretation.

Drainage density (Dd), higher in the Occidental (0.17 km^{-1}) than in the Central (0.15 km^{-1}), corroborates the hypothesis of a more branched hydrographic network in hilly areas, while the low density of the Central could reflect permeable substrates or differential erosion. These morphometric contrasts imply differentiated hydrological issues: increased flooding and erosion risks in the Occidental, versus flow management and aquifer recharge challenges in the Central. The lack of complete data for the Oriental underlines the need for further studies for an integrated understanding of the basin.

In summary, this morpho-structural tripartition underlines the importance of adaptive approaches to water resource management, integrating the topographic, hydrographic and lithological specificities of each sub-basin.

3.1.3. Geomorphological characterization of the Oran Coastal Basin

The Oran Coastal Basin is structured into distinct geomorphological units, shaped by tectonic, erosive and sedimentary processes. These landforms have a direct influence on hydrological dynamics and water resource management.

a. Mountainous units

- Massif des Traras: Located to the north of the wilaya of Tlemcen, this coastal range extends over 1,250 km^2, from the mouth of the Tafna wadi to the Algerian-Moroccan border. Its rugged relief, marked by slopes >25% over 75% of its surface area, is subject to intense erosion, generating high levels of sediment transport to downstream rivers. Morphology varies from a steep eastern sector to a more undulating western sector, influencing rainfall distribution and infiltration.
- Tessala Massif: Culminating at 1,061 m (Djebel Bouhaneche), this mountainous complex (average altitude: 800 m) forms a southern topographical barrier. Its high relief favors orographic precipitation, crucial for the supply of groundwater and wadis downstream.

b. Inland plains and sedimentary basins

- Brédéah Plain: Sandwiched between the Murdjadjo massif (north), the Meleta plain (west), the Hassis plateau (east) and the Sebkha of Oran (south), this area acts as a natural retention basin for surface water and sediments.
- Boutlélis-Messerghin plain: Located in the foothills of the Murdjadjo, it feeds the underlying karstic aquifers. The predominant infiltration in these limestone formations limits surface runoff, reducing the risk of flooding but complicating controlled groundwater recharge.
- Meleta Plain: An east-west trough (sub-basin 0404), it accumulates terrigenous and eolian sediments eroded from the Tessala mountains. Its Neogene to Holocene substrate, 3,000 m thick in places (ANRH, 2009), constitutes a major sediment reservoir, with implications for groundwater quality.
- - Aïn Témouchent -El Amria plain: A plateau at an average altitude of 300 m, it marks a transition between mountainous relief and low-lying areas, playing a key role in the redistribution of runoff towards the Sebkha of Oran.

c. Coastal zone and adjacent plateaus

- Beni Saf coastal massif: rising to 409 m (Djebel Skhouna), this coastal relief modulates freshwater inflows into the Mediterranean, while limiting saline intrusion into aquifers.
- Ouled Boudjemaa Plateau: Sloping towards the Sebkha of Oran (average altitude: 350 m), it favors gravity drainage of surface water, essential for the wetland's water balance.
- Aïn Türck coastal plain: An interface between the Mediterranean and the Murdjadjo, this plain is vulnerable to soil and groundwater salinization, requiring integrated resource management.
- Mostaganem Plateau: With a surface area of 500 km^2, it hydrologically connects the Beni Chougrane mountains (south) to the Chéliff plain (east), influencing inter-basin water transfers.

d. Forest cover and environmental issues

Forests, covering 874 km^2 along the coast, stabilize soils and reduce water and wind erosion. Their plant cover improves infiltration, recharging aquifers while limiting the silting-up of wadis. This ecosystem function is critical in mitigating the impact of flash floods, which are frequent in adjacent mountainous areas.

The landforms-plains-coast emphasize a geomorphological dynamic marked by the interaction of tectonic, erosive and sedimentary processes. Topographical contrasts directly influence hydrological regimes, soil distribution and natural resource management strategies.

3.1.4. Climatology

a. Precipitation

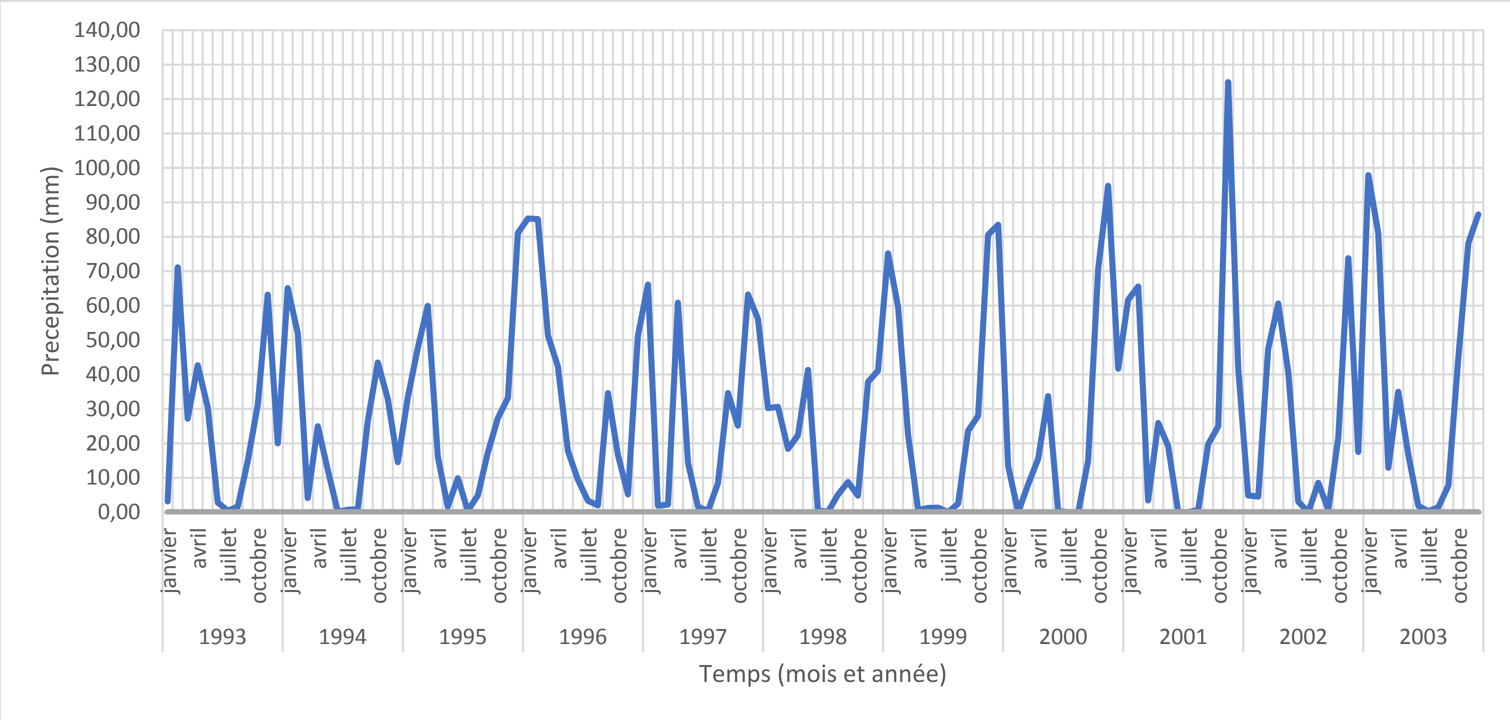


Figure 16. Average monthly precipitation 1993-2003 (mm)

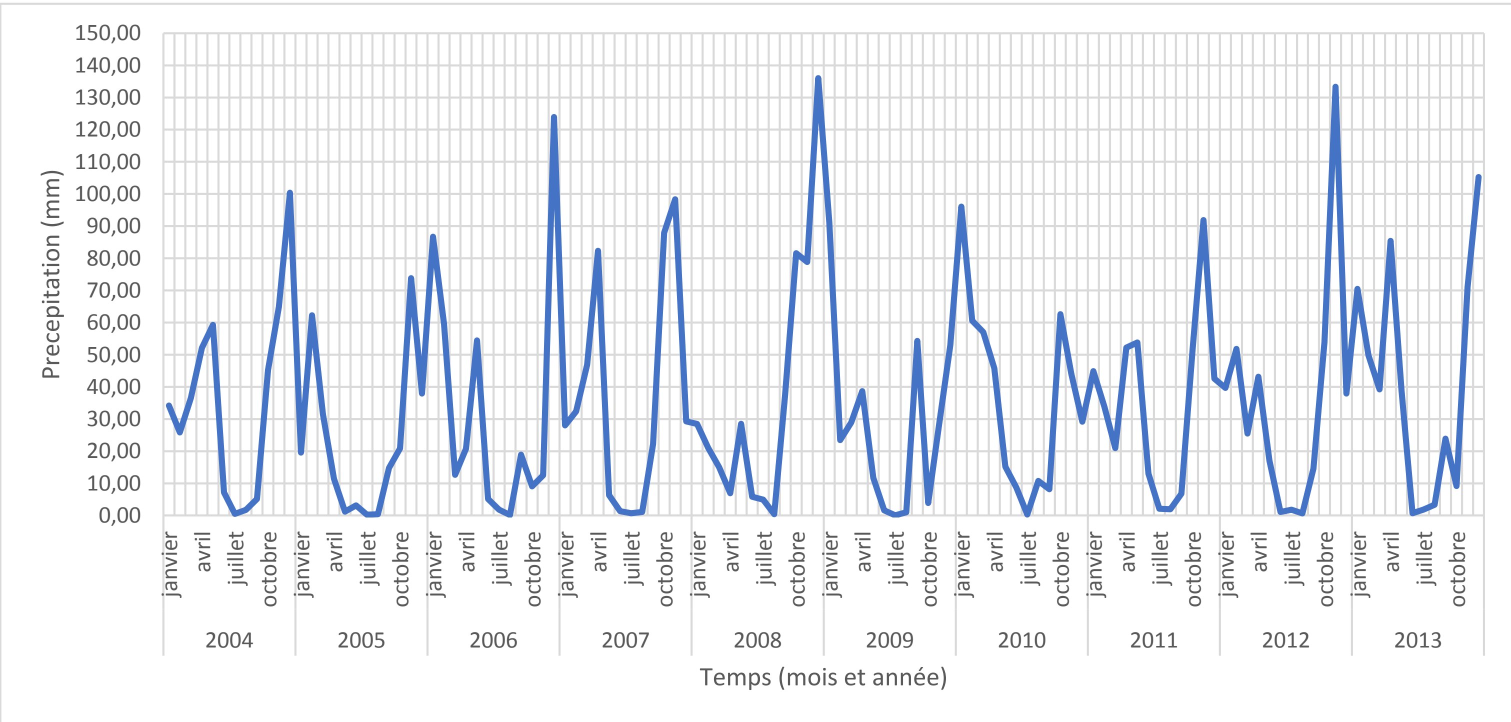


Figure 17. Average monthly precipitation 2004-2013 (mm)

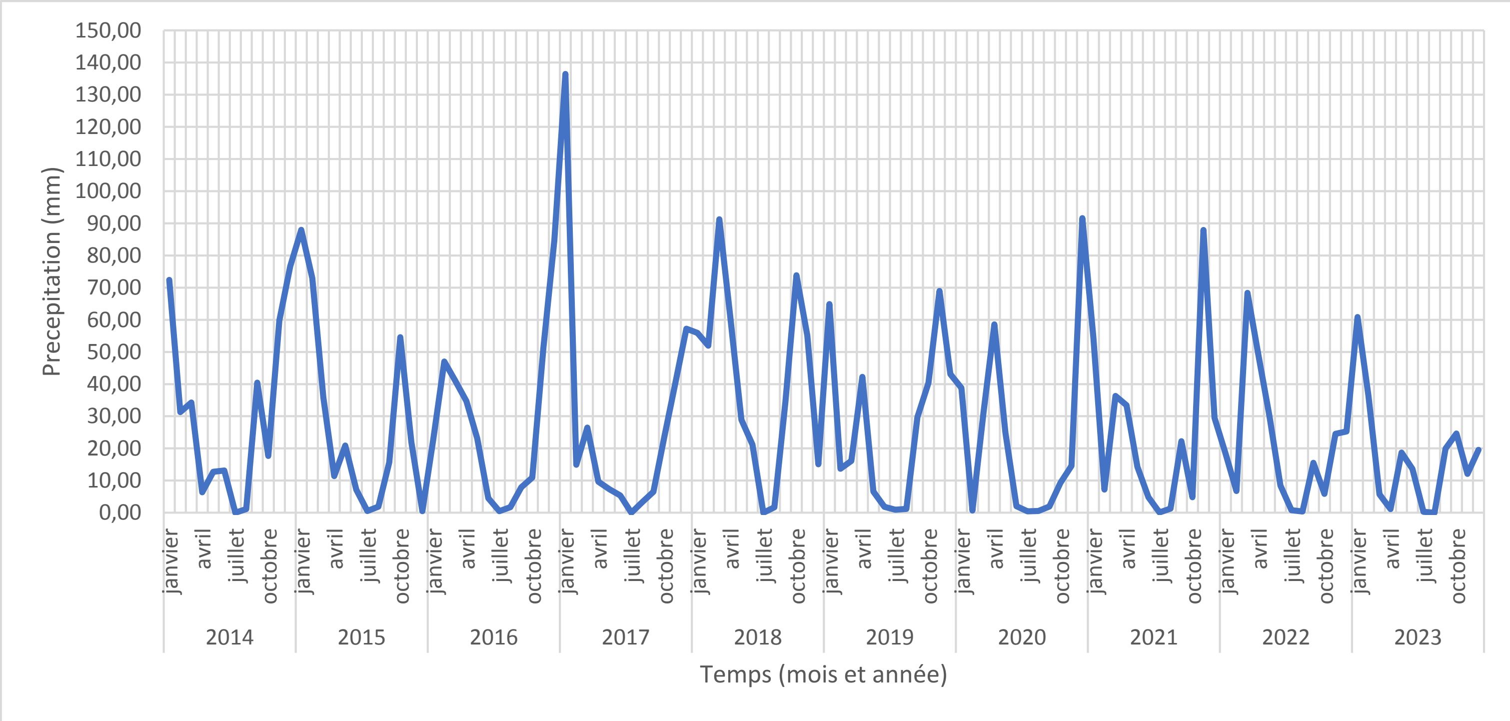


Figure 18. Average monthly precipitation 2014-2023 (mm)

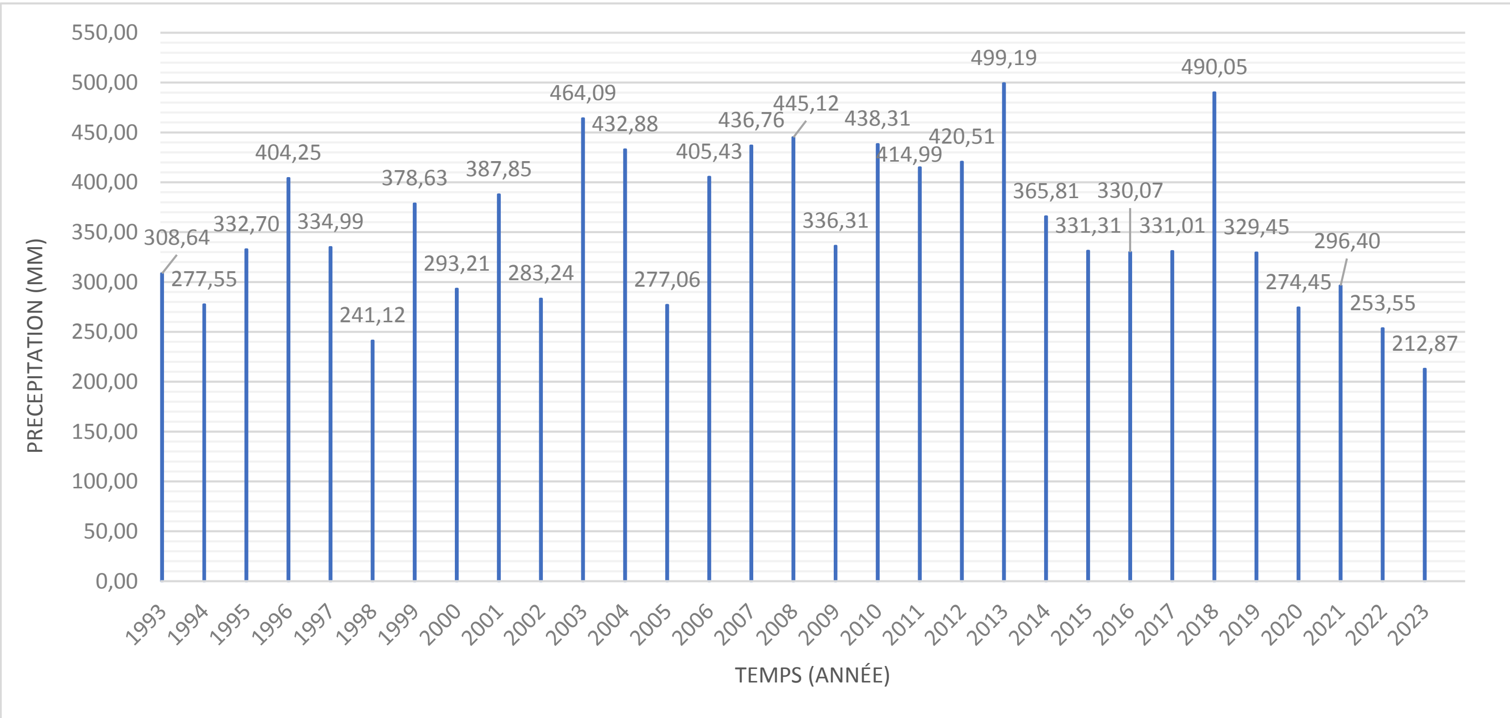


Figure 19. Average total annual precipitation 1993-2023 (mm)

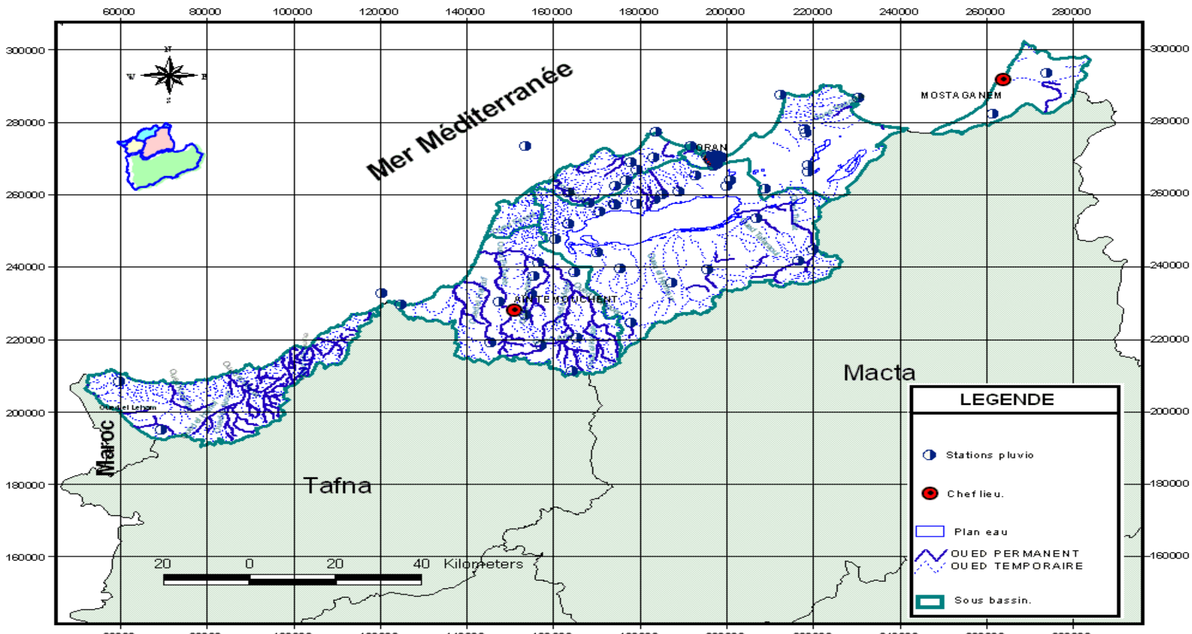


Figure 20. Rainfall stations in the Oran coastal basin (Source ABH-OCC)

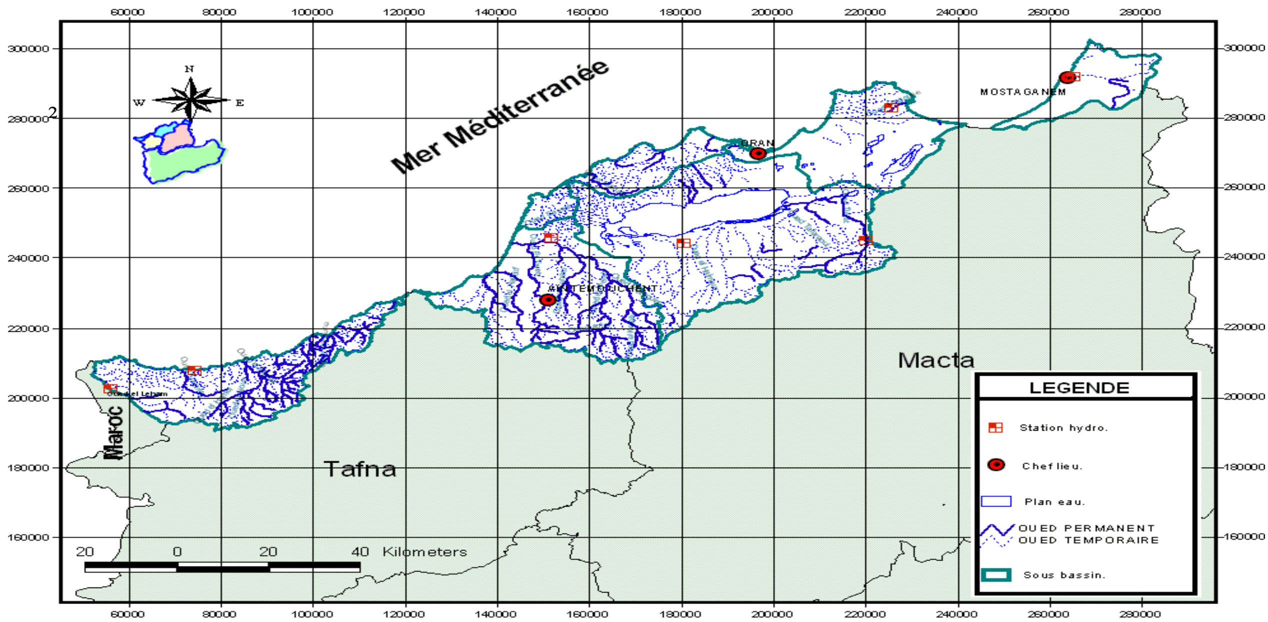


Figure 21. Hydrometric stations in the Oran coastal basin (Source ABH-OCC)

b. Temperature

❖ **Minimum Temperature**

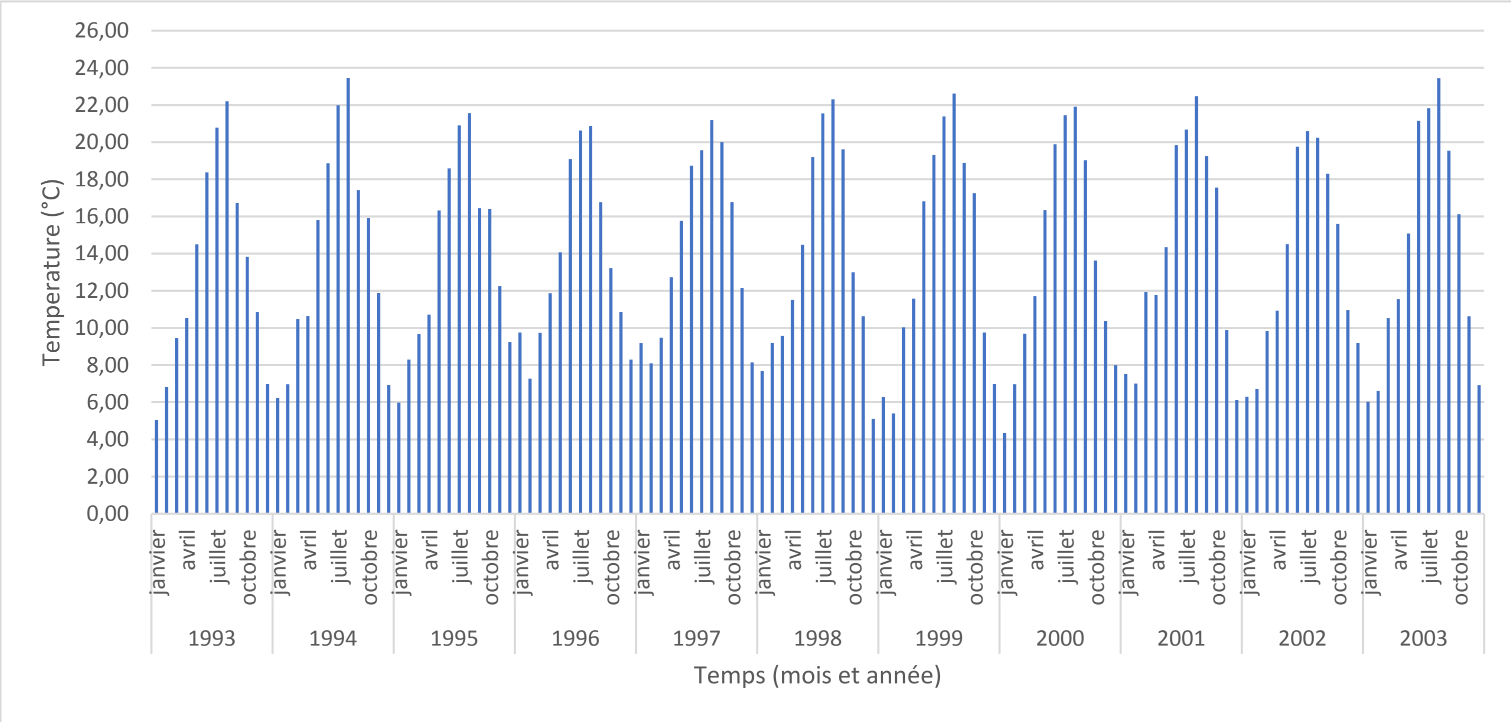


Figure 22. Minimum monthly mean temperature 1993-2003 (°C)

Figure 23. Minimum monthly mean temperature 2004-2013 (°C)

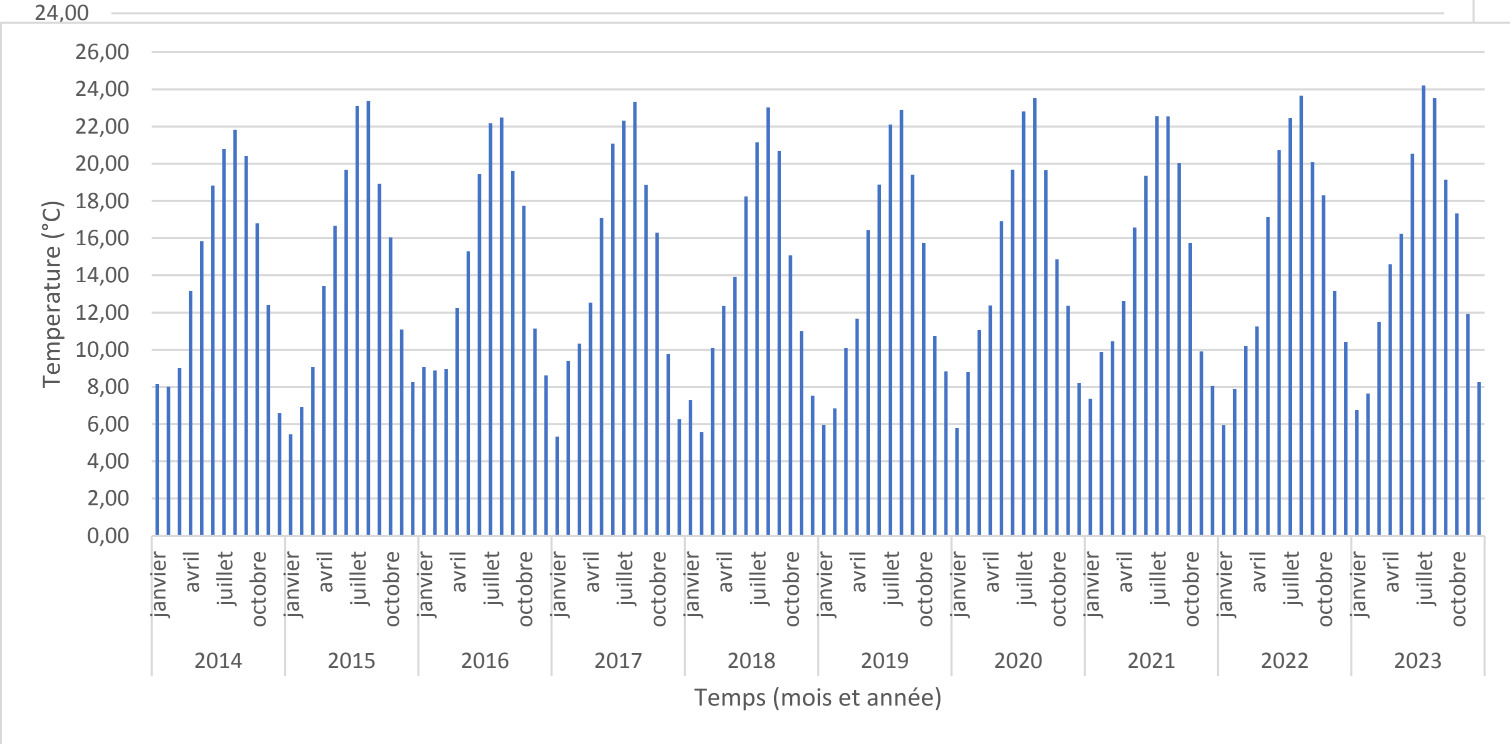


Figure 24. Minimum monthly mean temperature 2014-2023 (°C)

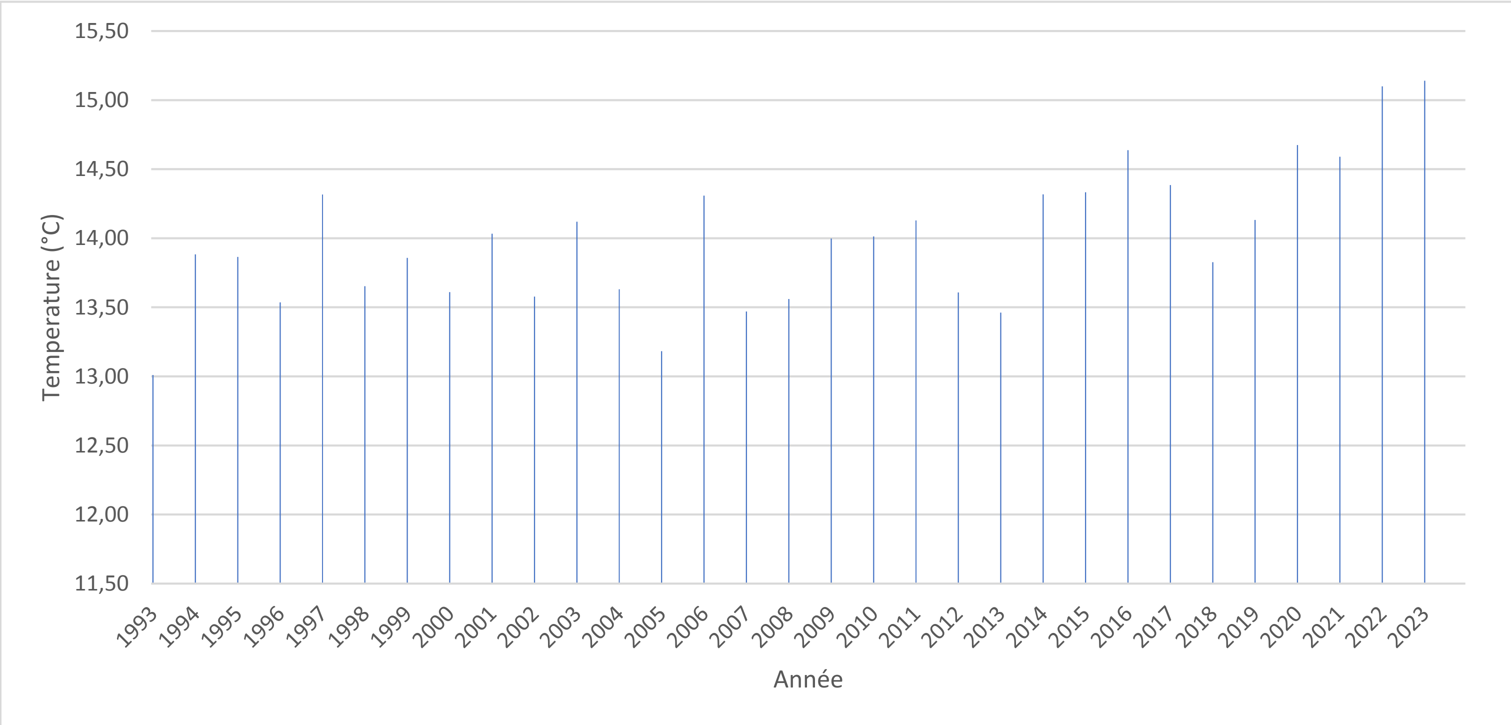


Figure 25. Annual mean minimum temperature 1993-2003 (°C)

❖ **Maximum Temperature**

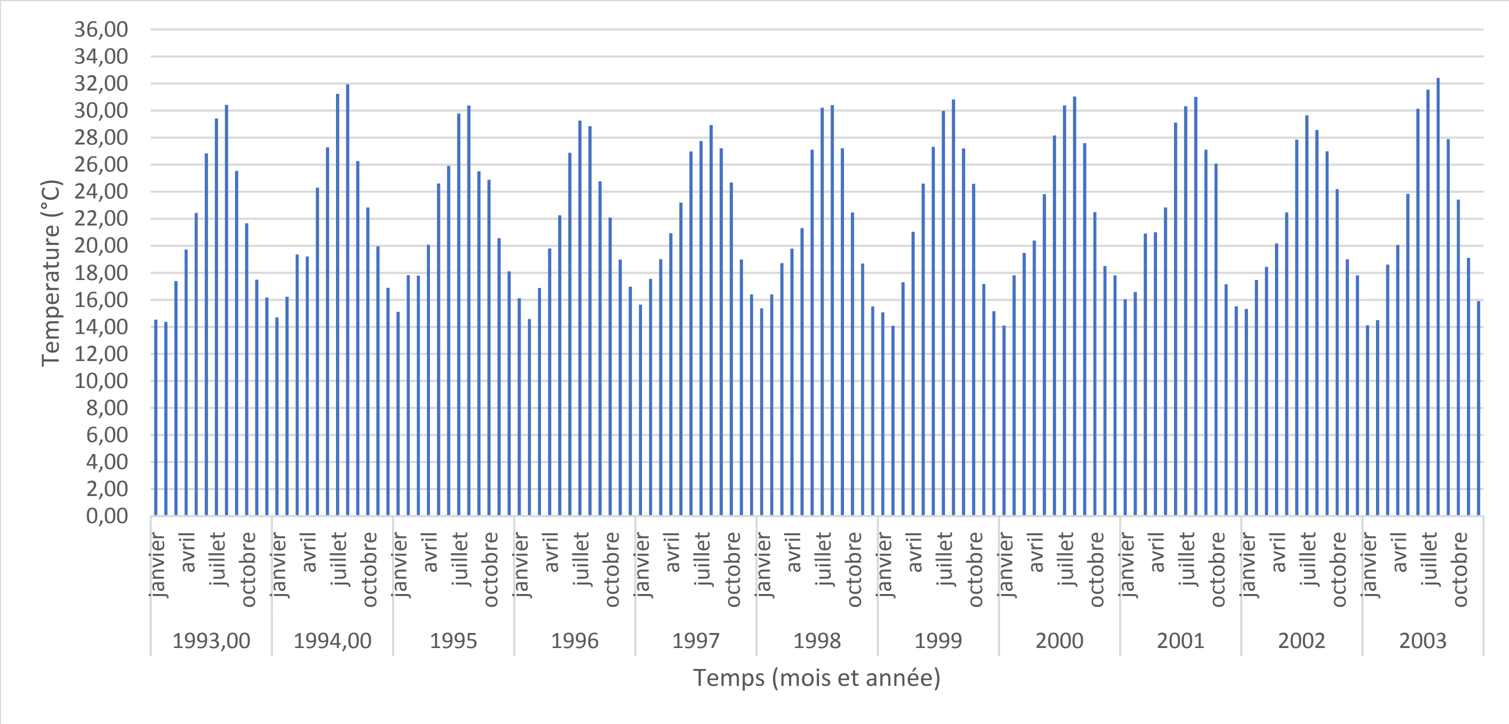


Figure 26. Maximum monthly mean temperature 1993-2003 (°C)

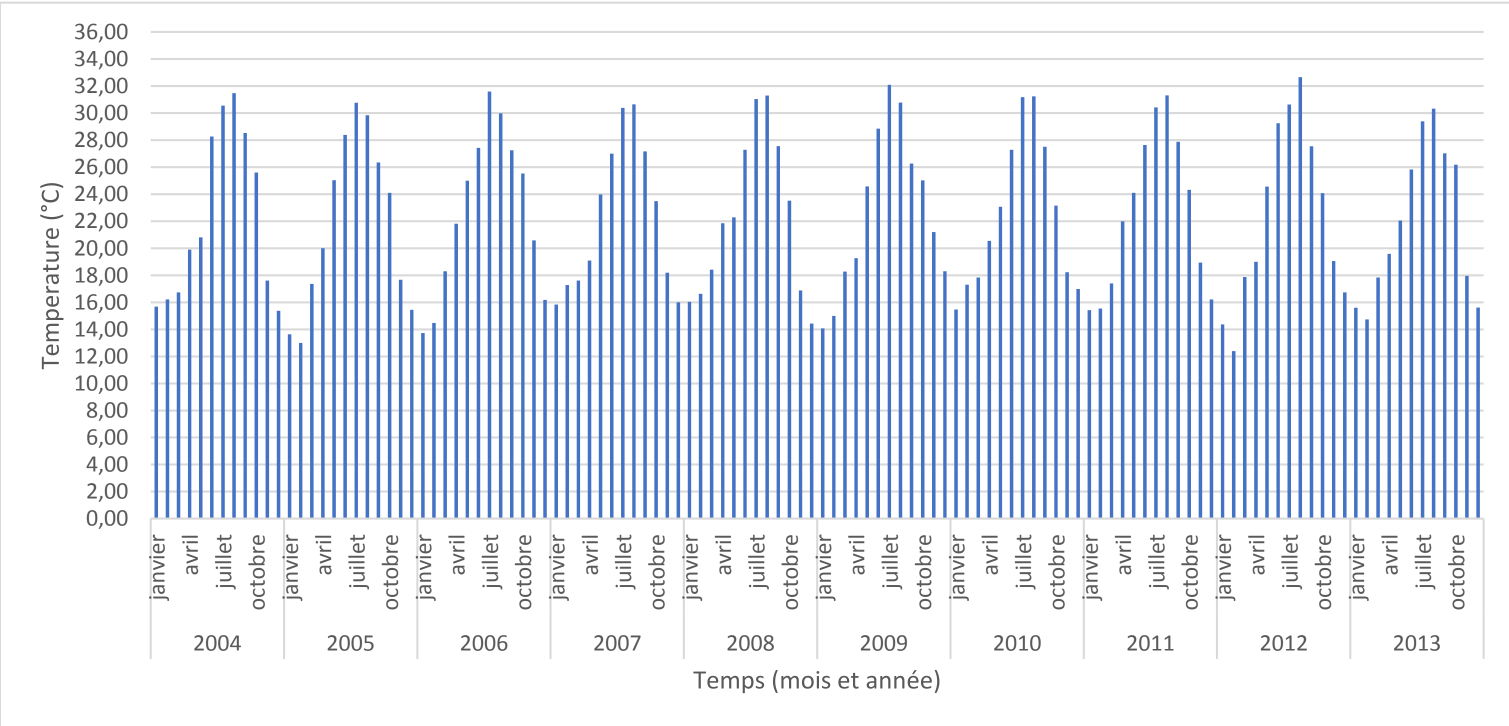


Figure 27. Maximum monthly mean temperature 2004-2013 (°C)

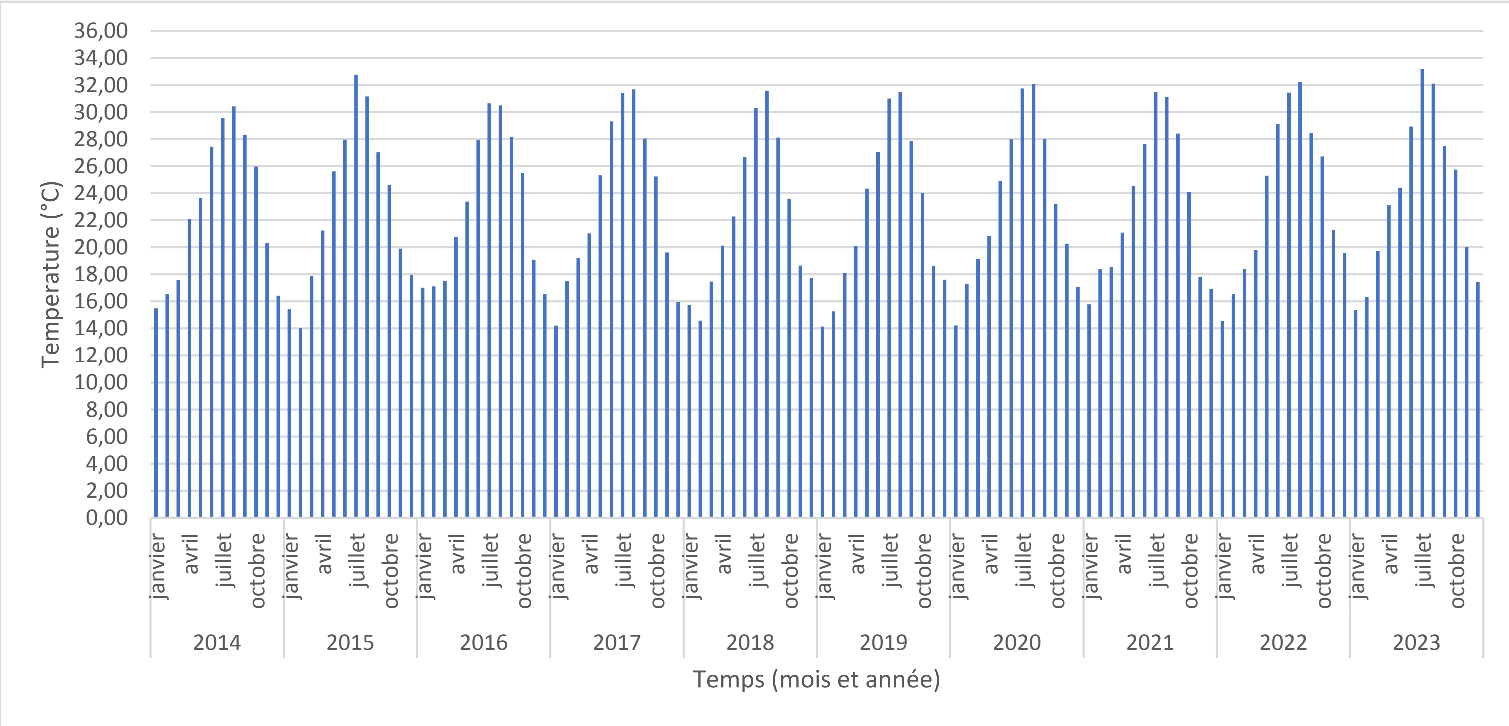


Figure 28. Maximum monthly mean temperature 2014-2023 (°C)

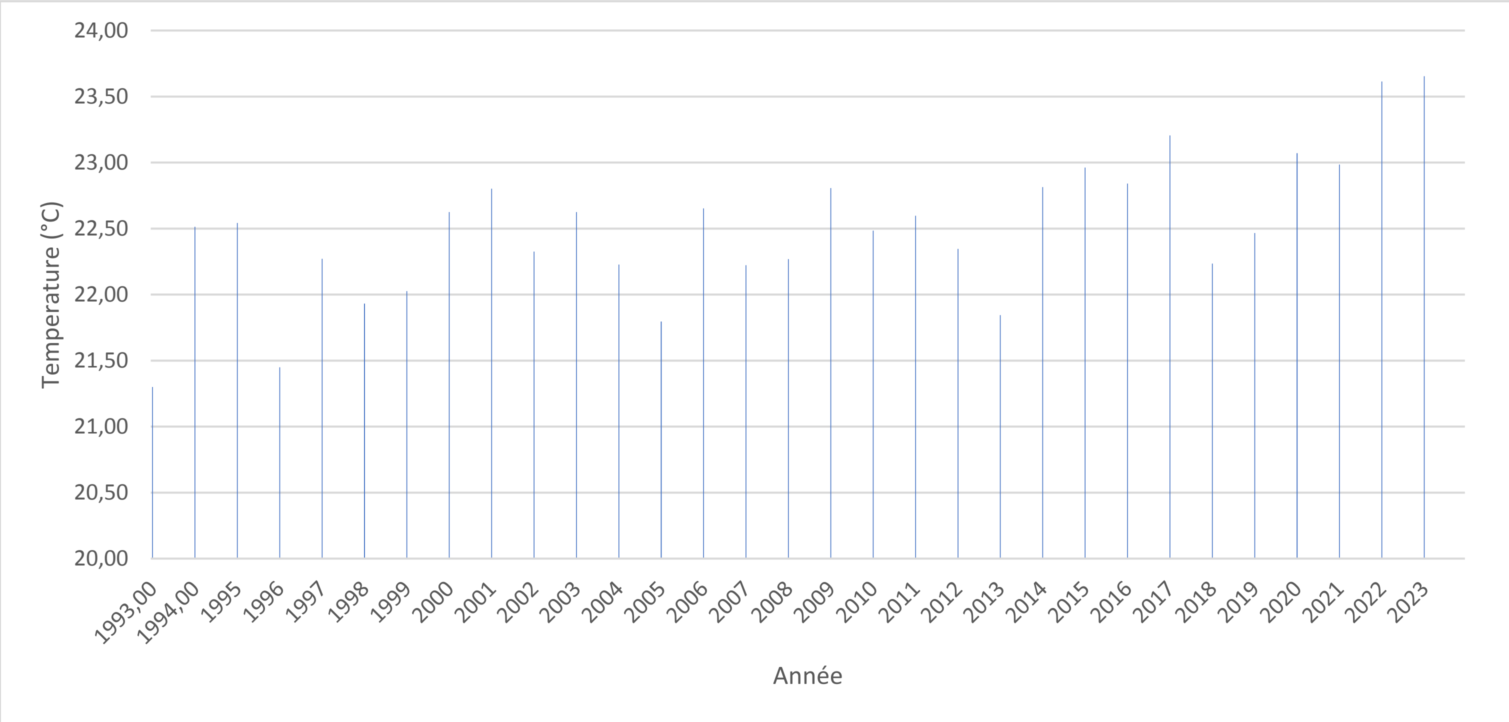


Figure 29. Mean annual maximum temperature 1993-2003 (°C)

c. Decadal climate analysis (1993-2023)

The period 1993-2000 was characterized by marked climatic instability, with average annual precipitation of 327 mm and high inter-annual variability. Winters, often wet (e.g., 65.11 mm in January 1994), contrast with dry summers, including the extreme case of July 1999 (0.00 mm). Summer temperatures remain moderate (maximums around 28-29 °C), but a slight warming appears at the end of the decade (30.41 °C in August 1998). Winter minima, which can be harsh (2.66 °C in January 1996), reflect a stable annual temperature range.

The decade 2001-2010 saw an acceleration in thermal anomalies, with a drop in average precipitation (-4%, to 315 mm) and systematically arid summers (e.g., July 2003 at 0.29 mm). Summer highs climbed sharply (+2 °C vs. 1990), peaking at 32.42 °C in August 2003 during a historic heatwave. Winters are becoming milder (average 7-8 °C), and the annual thermal amplitude is increasing, signaling a disruption in seasonal patterns.

Between 2011 and 2023, the climate evolves towards an amplification of extremes. Average rainfall rises to 343 mm, masking a polarization between very wet years (499.19 mm in 2013) and dry years (274.45 mm in 2020). Summers become hyper-arid (e.g.: 0.40 mm in August 2022), while summer highs regularly exceed 33 °C (e.g.: 33.19 °C in August 2023). Winters are generally milder (8-9 °C on average), alternating between cold spells (3.48 °C in February 2012) and unusually mild weather (9.07 °C in January 2016).

In 30 years, summer maximum temperatures have risen by +1.5 to 2 °C, with an acceleration after 2010, while summer rainfall has dropped by -15%, despite stable annual totals. This tropicalization of the climate - hotter, drier summers, mild but unstable winters - is accompanied by an upsurge in extreme events (droughts, floods, heatwaves), in line with IPCC projections. These dynamics call for the reinforcement of adaptation strategies, particularly in the face of summer aridification and the intensification of thermal risks.

3.1.5. Hydrography of the Oran Coastal Basin

The Oran Coastal Basin is structured into three sub-watersheds with distinct dynamics, shaped by interactions between topography, climate and human activities.

a. Ghazaouet coastal sub-basin

Representing 12% of the total surface area, the Ghazaouet coastal sub-basin stretches across the foothills of the Traras mountains (1,021 m). Its hydrographic network, dominated by the Marsa wadi and its tributaries (Tlatat wadi, Zlamet wadi), drains rainwater towards the Mediterranean via a torrential regime. Winter floods, generated by intense rainfall (>50 mm/day), transport large sediment loads to the river mouths, contributing to the silting-up of coastal areas. This phenomenon, coupled with historical deforestation of the slopes, accelerates coastal erosion, threatening agricultural and urban infrastructures.

b. Central Coastal Sub-basin

Covering 80% of the basin, the central coastal sub-basin combines endoreic (closed depressions) and exoreic (drainage to the sea) systems. The evaporitic depressions of the Sebkha of Oran and the Saline of Arzew capture 47 Hm^3/year of surface runoff, mainly from the El Maleh wadi and its tributaries (Mategeur Wadi, Es Senane Wadi). These areas, characterized by high evaporation rates (>1,500 mm/year), are subject to increased salinization of soil and groundwater, exacerbated by unregulated agricultural abstraction. At the same time, the exoreic wadis (Tafna Wadi, El Hallouf Wadi) have intermittent regimes, with severe summer low flows and flash floods in winter, limiting their use for irrigation.

c. Eastern coastal sub-basin

With only 8% of the total surface area, the eastern coastal sub-basin is distinguished by its wetland ecosystems, notably the Macta marshes, fed by the Wadi Tine. This watercourse, which rises in the clay soils of Sirat, has seen its flow reduced by urban expansion and agricultural pumping. The Ain Sefra wadi, with its intermittent regime, illustrates the vulnerability of water resources to climate variability: its flows, dependent on autumn rains, decrease drastically during prolonged droughts (e.g., 2016-2018). These pressures threaten local biodiversity, including several migratory avian species dependent on wetlands.

The hydrographic heterogeneity of the basin calls for an integrated approach, combining fine hydrological modeling (e.g., SWAT to simulate flows) and participatory governance. Such a strategy, aligned with sustainable development objectives, is essential to reconcile water security, ecological preservation and climate resilience.

3.1.6. Hydrogeology of the Oran Coastal Basin

The Oran Coastal Basin has a hydrogeological diversity structured by varied geological formations, influencing the availability and quality of groundwater resources.

a. Traras Mountains

Jurassic limestones (Lias) are the main aquifers in this mountainous area, characterized by a complex geology combining volcanic and sedimentary rocks. These mostly perched aquifers are drained by natural springs such as Ain El Kébira (historical flow rate: 30 l/s) and Ain Skhouna (16 l/s). Current exploitation relies on a few boreholes (e.g., Maaziz: 14 l/s; Beni Ouarsous: 20 l/s), but total potential remains poorly known due to heterogeneous fracturing and a lack of hydrodynamic data. For sustainable management, detailed mapping of perched aquifers is essential, combining geophysical surveys and 3D modeling, in order to optimize exploitation without depleting reserves.

b. Murdjadjo massif

This highly tectonized and fractured limestone massif is home to an extensive karstic aquifer stretching from Ras El Ain to Boutlelis. The main outlets are the Brédéah, Misserghin and Ras El Ain springs, fed by effective rainfall recharge. The low-salinity water (dry residue: 0.5-1 g/l) reflects rapid circulation in the karstic networks, limiting salt accumulation. However, vulnerability to diffuse pollution (nitrates, pesticides) requires protection of recharge zones, through agricultural restrictions and strict control of upstream industrial activities.

c. Brédéah plain

Made up of red alluvium with pebbles, this plain bordering the Sebkha of Oran is home to a shallow water table (level at 2 m). However, the lack of effective drainage and the proximity of the Sebkha have led to progressive salinization of the water, with dry residue levels rising from 1 g/l in the west to 7 g/l in the east. This deterioration is accentuated by intense evaporation

(>1,500 mm/year) and capillary rise during dry periods. To mitigate this phenomenon, the installation of surface drains and soil rinsing systems is essential, coupled with the regulation of water withdrawals to limit salt rises.

d. Aïn Türck coastal plain

The sands, sandstones and lumachels here form a major coastal aquifer, in direct contact with the Mediterranean. The aquifer, fed by local rainfall, undergoes a pronounced saline intrusion near Andalouses, where salinity rises sharply (dry residue >3 g/l). A second water table, located in the scree slopes, persists despite the steep gradient, thanks to the low transmissivity of the surrounding terrain, which limits drainage losses. To preserve water quality, strict control of coastal abstraction is necessary, along with the creation of hydraulic barriers (freshwater injection) to push back the salt front.

Understanding the hydrogeological dynamics of the Oran Coastal Basin is crucial to reconciling resource exploitation and preservation in the face of climatic and anthropogenic pressures. An integrated approach, combining continuous monitoring (piezometers, salinity monitoring), mitigation techniques (drainage, barriers) and adaptive governance (quotas, zoning), is essential to guarantee long-term water resilience. These measures, aligned with the Sustainable Development Goals (SDG 6), must be based on transdisciplinary collaboration between hydrologists, decision-makers and local communities.

3.1.7. Socio-economic and demographic data

Table 3.1-2. Socio-economic and demographic data

Code	Wilaya	Municipality	Surface area (km2)	Population (inhabitants)	Population growth (%)
13	Tlemcen	GHAZAOUET, NEDROMA, SOUAHLIA, BAB EL ASSA, EL FEHOUL, HONAINE, BENI OUARSOUS, DAR YAGHMORACEN, MERSA BEN M'HIDI, AIN KEBIRA, SOUK THLATA, M'CIRDA FOUAGA, TIANET, DJEBALA, SOUANI, BENI KHALED (SOUK EL KHEMIS)	899	145 813	0.39

22	Sidi Belabass	AIN EL BERD, AIN THRID, TESSALA, SEHALA THAOURA, SIDI DAHO DEZAIRS, MAKEDRA	264.5	25 562	1.17
27	Mostaganem	MOSTAGANEM, AIN TEDELES, MEZEGHRANE, HASSI MAMECHE, AIN NOUICY, AIN BOUDINAR, SOUR, KHEIR EDDINE, SAYADA, MANSOURA, MASRA, STIDIA, AIN SIDI CHRIF, FORNAKA	359	294 166	2.06
29	Mascara	ZAHANA, EL ALAIMIA, RAS AIN AMIROUCHE, OGGAZ, EL GAADA	199.2	19 794	1.30
31	Oran	GDYEL, AIN BIYA, BETHIOUA, HASSI BENOKBA, BIR EL DJIR, AIN TURK, ORAN, BOUSFER, BEN FREHA, MERS EL KEBIR, HASSI BOUNIF, MISSERGHIN, SIDI CHAHMI, ES SENIA, EL KERMA, TLELAT WADI, ARZEW, HASSI MEFSOUKH, MARSA EL HADJADJ, EL ANCAR, BOUFATIS, AIN EL KARMA, BOUTLETIS, EL BRAYA, TAFRAOUI, SIDI BENYEBKA	2037.4	1 904 354	3.05
46	Ain Temouchent	HAMMAM BOUHADJAR, HASSI EL GHELLA, AIN LARBAA, EL MALAH, CHAABET EL HAM, SIDI	2085.9	398 540	1.11

		BEN ADDA, BENI SAF, AIN-TEMOUCHENT, AIN TOLBA, AIN KIHEL, EL AMRIA, EL MSAID, TAMZOURA, OULED BOUDJEMAA, SEBAH WADI, TERGA, OULED KIHAL, SIDI BOUMEDIENE, CHENTOUF, SIDI SAFI, HASSASNA, OULHASSA GHERABA, AGHLEL, EMIR ABDELKADER, BARKACH WADI, SIDI OURIACH, AOUBELIL, BOUZEDJAR			
Total	**6 wilayas**	**95 Municipalities**	**5 845**	**2 788 229**	**1.68 %**

3.1.8. Data collection

The data used in this study come from a variety of institutional sources: for the drinking water supply, agricultural and industrial sectors, they are collected from the National Agency for Integrated Water Resources Management (AGIRE), and the Hydrographic Basin Agency (ABH OCC). Climatic data (rainfall and temperature) are provided by the National Hydraulic Resources Agency (ANRH) and supplemented by satellite data from the Terra Climate database, enabling a detailed analysis of meteorological trends and water stress.

Demographic data are provided by the National Statistics Office (ONS), and include spatial population distribution, growth rates and projections, essential for assessing pressure on resources.

3.2. Water resources in the basin

3.2.1. Introduction

The resources currently mobilized in the Oran Coastal Basin have different origins (surface water-groundwater, local resources-external resources) and are drawn from several points. They are used to supply drinking water to households and communities, industry and agricultural irrigation. This mobilization is achieved by means of several infrastructures, some of which are located outside the Wilaya to mobilize surface water (external transfers). Boreholes concentrated in certain communes, in addition to springs and wells, enable groundwater to be tapped. Given the pressure of water demand that accompanies the Wilaya's development, the latter also resorts to seawater desalination and wastewater reuse, but in proportions that are still limited.

This chapter presents the water resources of the Oran Coastal Basin, starting with an examination of the basin's conventional resources (mainly water from dams located outside the Wilaya), followed by a look at non-conventional resources, in particular the seawater desalination and wastewater treatment projects currently underway. Finally, the situation of underground resources will be presented, with a general description of the Wilaya's major hydrogeological units.

3.2.2. Conventional water resources

a. Superficial water resources

Table 3.2-1 Surface water for drinking water supply (M^3/days)

Wilaya	Surface water for drinking water supply (M^3/days)			
	BENI BAHDEL DAM	**DZIOUA**	**MAO**	**Total region**
Tlemcen	7 500			7 500
Mostaganem			16 779	16 779
Oran		20 371	75 267	95 638
Ain Temouchent		5 136		5 136
Total	**7 500**	**25 507**	**92 046**	**125 053**

- **Dams**

Table 3.2-2. Dams supplying the Oran Coastal Basin

Dam	Wilaya	Municipality	Nominal capacity (m^3)	Production (m^3/d)
Beni Bahdel	13 - Tlemcen	1342 - Beni Bahdel	110 000	37 202
Dzioua crater	46 - Ain Temouchent	4624 - Sidi Safi	25 507	25 507
MAO complex Chelif and Kerrada dams	27 - Mostaganem		100 000	92 046
		Total		**154 626**

❖ **Small dams**

Table 3.2-3. Small dams feeding the Oran Coastal Basin

Dam	Wilaya	Municipality	Initial capacity (Hm^3)
Graidia	Oran	Tafraoui	0,036
Ain Tassa	Oran		0,045
Guessaiba	Oran		0,06
Sidi Haddouche	Ain Temouchent	Aghlal	0,52
Hachama	Ain Temouchent	Aghlal	0,47
Mechimeche	Ain Temouchent	Aghlal	0,33
Ain Guemal	Ain Temouchent	Aghlal	0,45
Sekkane	Ain Temouchent	Ain Tolba	0,54
Hallouf Wadi	Ain Temouchent	Ouled Kihal	1,43
Bendjelloul	Ain Temouchent	Sidi Ouriache	0,96
		Total	**4.48**

❖ **Hill reservoirs**

Table 3.2-4. Hill reservoirs supplying the Oran Coastal Basin

Structure code	Dams	Wilaya	Municipality	Initial capacity (Hm^3)	Regulated volume (Hm^3)	Drinking water supply (%)	Irrigation (%)
RC0444	Beggoug Wadi	31 - Oran	3125 - Ain Kerma	0.13	0.13	0	100
RC0428	Mekhaissia	46 - Ain Temouchent	4612 - Sidi Ben Adda	2.96	2.54	0	100
RC0439	Bouguedra Wadi	46 - Ain Temouchent	4614 - El Malah	0.4	0.24	0	100
RC0433	Michimiche wadi	46 - Ain Temouchent	4607 - Aghlal	0.3	0.3	0	100
RC0458	Kalla	46 - Ain Temouchent	4621 - Hassasna	0.3	0.27	0	100
RC0436	Sekkane Wadi	46 - Ain Temouchent	4618 - Ain Tolba	0.55	0.51	0	100
RC0440	Sahb Sidi Ali Benaissa	13 - Tlemcen	1339 - Mersa Ben Mhidi	0.13	0.13	0	100
RC0441	Sidi Haddouche	46 - Ain Temouchent	4603 - Ain Kihal	0.52	0.24	0	100
RC0424	Guessiba Wadi	31 - Oran	3122 - Sidi Ben Yabka	0.11	0.11	0	100
			Total	**5,4**	**4,47**		

b. Groundwater resources

Table 3.2-5. Groundwater resources in the Oran coastal basin: Data by aquifer and wilaya

Groundwater								
Aquifers	Potential (Hm^3/year)	Wilayas	Drinking water supply		Agriculture		Industrial	
			Number	Operating flow (liter/sec)	Number	Operating flow (liter/sec)	Number	Volume (m^3/d)
SEBAA CHIOUKH I ISSER WADI REGION	1.52	Ain Temouchent	2,0	0,0	16,0	9,5	0	0
		Tlemcen	0,0	0,0	4,0	6,4	0	0
GHAZOUANAH WADI VALLEY	1.23	Tlemcen	3,0	15,5	100,0	162,7	0	0
KISS WADI VALLEY	1.05	Tlemcen	10,0	10,0	19,0	29,2	32	312
TRARAS MOUNTAINS	6.87	Tlemcen	22,0	20,0	344,0	529,3	0	0
MOSTAGANEM PLATEAU	15.56	Mostaganem	21,0	48,0	2084,0	5196,6	49	1177
MURDJADJO'S SOUTHERN FLANK	7.88	Oran	16,0	152,1	281,0	415,7	0	0
M'SILA FOREST	0.98	Oran	5,0	18,1	68,0	89,1	0	0
ARZEW MOUNTAINS	0.15	Oran	5,0	54,9	18,0	19,9	249	4829
COASTAL PLAIN OF ORAN	0.27	Oran	1,0	2,0	12,0	10,8	0	0
HASSIS PLATEAU	3.87	Oran	17,0	34,0	732,0	3817,4	83	1610
ORAN PLAIN	6.81	Oran	3,0	35,4	317,0	345,5	0	0
MULETA PLAIN	7.59	Oran	16,0	53,6	0,0	0,0	0	0
		Mascara	5,0	30,3	4,0	2,0	19	145
		Ain Temouchent	0,0	0,0	211,0	269,3	0	0
AIN TEMOUCHENT PLATEAU	4.25	Ain Temouchent	7,0	2,0	334,0	495,0	0	0
SIDI SAFI PLATEAU	1.78	Ain Temouchent	6,0	0,0	65,0	81,2	64	405
OULED TAOUI - OULED BOUJEMAA REGION	2.62	Ain Temouchent	9,0	0,0	230,0	471,2	0	0
Total	**62.43**		**148,00**	**475,83**	**4 839,00**	**11 950,73**	**498**	**8478**

Table 3.2-6. Volumes of water extracted (m^3/d) and number of extraction points (boreholes, wells, springs) by use (drinking water, industry, agriculture)

Wilaya	Volume / Quantity	Drinking water supply				Industry	Agriculture				Total
		Boreholes	Well	Source	S/Total	Boreholes	Forages	Well	Source	S/Total	
Tlemcen	Volume (m^3/d)	9 992	1 365	402	11 759	312	22 497	7 897	795	31 189	**43 260**
	Number	33	16	3	52	32	396	278	28	702	**786**
Sidi Belabass	Volume (m^3/d)	1 762	-	527	2 289	3	2 329	5 170	114	7 613	**9 904**
	Number	3	-	2	5	1	41	182	4	227	**233**
Mostaganem	Volume (m^3/d)	8 467	-	-	8 467	1 177	127 484	589 186	3 068	719 738	**729 382**
	Number	18	-	-	18	49	2 244	20 742	108	23 094	**23 161**
Mascara	Volume (m^3/d)	8 035	-	518	8 553	145	-	-	-	-	**8 698**
	Number	20	-	1	21	19	-	-	-	-	**40**
Oran	Volume (m^3/d)	8 710	1 058	446	10 214	6 438	19 316	127 484	284	147 084	**163 736**
	Number	13	6	7	26	332	340	4 488	10	4 838	**5 196**
Ain Temouchent	Volume (m^3/d)	36 634	2 505	4 259	43 398	404	66 242	49 539	4 374	120 156	**163 958**
	Number	28	14	16	58	64	1 166	1 744	154	3 064	**3 186**
Total	**Volume (m^3/d)**	**73 600**	**4 928**	**6 152**	**84 680**	**8 479**	**237 868**	**779 276**	**8 636**	**1 025 780**	**1 118 938**

3.2.3. Unconventional water resources

Table 3.2-7. Daily distribution of non-conventional water volumes (m^3/d) allocated to drinking water supply and agriculture.

		Tlemcen	Sidi Belabass	Mostaganem	Mascara	Oran	Ain Temouchent	Total
Drinking water supply (m^3/d)	**HONAINE SDS**	32 953						**32 953**
	SOUK THELATA SDS	21 196						**21 196**
	CHATT EL HILAL SDS					80 000	72 093	**152 093**
	BREDEAH					28 000		**28 000**
	BOUSFER SDS					3 000		**3 000**
	THE DUNES SDS					3 689		**3 689**
	MACTAA SDS				8 157	240 000		**248 157**
	KAHRAMA SDS					44 809		**44 809**
	MOSTAGANEM SDS			113 575				**113 575**

	LOAD BREAKER 3 - BUFFER TANK 2		2 666					**2 666**
Agriculture (m^3/d)	**Chabat Elham wastewater treatment plant**						411	**411**
	Kahrama wastewater treatment plant					21 370		**21 370**
	Ain Turk wastewater treatment plant					5 342		**5 342**
	Total	**54 149**	**2 666**	**113 575**	**8 157**	**426 210**	**72 504**	**677 261**

SDS: Seawater Desalination Station

a. Seawater desalination

Table 3.2-8. Seawater desalination plants

Name	Wilaya	Municipality	Commissioning year	Capacity (m^3/d)	Manager
Abdellah Wadi	13 - Tlemcen	1307 - Ghazaouet	2004	5 000	ADE - Algerian Water Company
Honaine station	13 - Tlemcen	1344 - Honaine	2012	200 000	MBH - Myah Bahr Honaine
Souk Tlata.	13 - Tlemcen	1333 - Souk Thlata	2011	200 000	AA - Almiyah Attilemçania
Mostaganem (Cheliff beach)	27 - Mostaganem	2701 - Mostaganem	2011	200 000	STMM - Shariket Tahliyat Miyah Mostaganem
Bousfert 1	31 - Oran	3116 - Bousfer	2005	2 500	SEOR - Oran Water and Sanitation Company
Kahrama (Arzew	31 - Oran	3106 - Arzew	2005	90 000	KAHRAMA - Kahraba Wa Ma

industrial zone)					
CAP BLANC	31 - Oran	3125 - Ain Kerma	2025	300 000	AEC - Algerian Energy Company
The Dunes 1 (Ain Turk)	31 - Oran	3109 - Ain Turk	2006	2 500	SEOR - Oran Water and Sanitation Company
Bousfer 2	31 - Oran	3116 - Bousfer	2005	1 000	SEOR - Oran Water and Sanitation Company
Bousfer 4	31 - Oran	3116 - Bousfer	2005	1 000	SEOR - Oran Water and Sanitation Company
Bousfer 3	31 - Oran	3116 - Bousfer	2005	1 000	SEOR - Oran Water and Sanitation Company
The Dunes 2 (Ain Turk)	31 - Oran	3109 - Ain Turk	2006	2 500	SEOR - Oran Water and Sanitation Company
Mactaa	31 - Oran	3108 - Marsat El Hadjadj	2015	500 000	TMM - Tahlyat Myah Magtaa
Beni Saf (Chatt El Hillal)	46 - Ain Temouchent	4612 - Sidi Ben Adda	2009	200 000	BWC - Beni Saf Water Company
Bouzedjar	46 - Ain Temouchent	4605 - Bouzedjar	2006	5 000	ADE - Algerian Water Company
			Total	**1 710 500**	

b. Demineralization

Table 3.2-9. Water demineralization plants

Code	Name	Commissioning year	Wilaya	Municipality	Capacity	Population served
DM0401	Bredeah	2004	31 - Oran	3124 - Boutlelis	27 000,00	115 000
DM0402	Bendafel	2010	13 - Tlemcen	1329 - Souahlia	864,00	300
				Total	**27 864,00**	**115 300**

c. Water treatment plant

Table 3.2-10. Water treatment plant

Manager	Commissioning year	Wilaya	Municipality	Installed capacity (m^3/d)	Current capacity (m^3/d)
SEOR - Oran Water and Sanitation Company	1991	46 - Ain Temouchent	4618 - Ain Tolba	260 000	14 138
SEOR - Oran Water and Sanitation Company	1990	46 - Ain Temouchent	4625 - Oulhaca Gherraba	260 000	14 138
			Total	**520 000**	**28 276**

d. Wastewater treatment plant

Table 3.2-11. Wastewater treatment plant

Name	Commissioning year	Process	Receiving environment	Impact	Capacity (inhabitant equivalent)	Nominal flow (m^3/d)
Ain El Turk	2011	Activated sludge	Sea	Coastline protection	250 000	30 000,00
Ain Larbaa	2006	Natural lagooning	Sebkha	Protecting the environment	14 500	1 740,00
Ain	2012	Aerated	Wadi	Coastline	25 000	2

Nouissy		lagooning		protection		800,00
Ain Temouchent	2014	Active sludge	Wadi	Wadi protection	72 800	10 920,00
Ain Tolba	2012	Sequencing batch reactor	Wadi	Wadi protection	16 000	1 920,00
Bouzedjar	2013	Activated sludge	Sea	Coastline protection	19 000	2 280,00
El Amria	2008	Natural lagooning	Sebkha	Environmental protection	33 000	3 960,00
El Kerma	2008	Activated sludge	Sebkha	Environmental protection	1 500 000	270 000,00
El Malah	2008	Natural lagooning	Wadi	Wadi protection	22 000	2 640,00
Emir Abdelkader	2005	Natural lagooning	Wadi	Wadi protection	4 000	480,00
Fornaka	2011	Natural lagooning	Wadi	Coastline protection	18 000	2 100,00
Ghriss	2005	Aerated lagooning	Wadi	Dam protection	48 000	5 800,00
Hassi El Ghalla	2008	Natural lagooning	Wadi	Wadi protection	18 500	2 220,00
Mesra	2013	Aerated lagooning	Wadi	Coastline protection	18 000	2 600,00
Hassasna	2015	Activated sludge	Wadi	Wadi protection	12 275	27 540,00
El Mersa monobloc	2024	Monobloc	Sea	Coastline protection	1 500	240,00
Mostagane	2017	Activated	Sea	Coastline	350 000	56

m		sludge		protection		000,00
Oggaz	2009	Natural lagooning	Wadi	Groundwater protection	7 200	864,00
Sidi Safi	2008	Natural lagooning	Wadi	Wadi protection	10 000	1 200,00
Ain El Kihel wastewater treatment plant	2020	Activated sludge	Wadi	Wadi protection	23 250	2 790,00
Zahana	2012	Lagunage naturel	Wadi	Wadi protection	20 000	2 400,00
				Total	**2 483 025**	**430 494**

3.3. Situation of the hydraulic network and demand for water

3.3.1. Drinking water supply

Table 3.3-1. Water status and performance of drinking water networks in the Oran coastal basin

Wilayas	Tlemcen	Sidi Belabass	Mostaganem	Mascara	Oran	Ain Temouchent	Total / average
Drinking water demand (m^3/d)	21 871	3 834	44 122	2 969	285 646	59 778	**418 221**
Total drinking water production (m^3/d)	87 379	4 533	137 966	17 074	505 350	84 866	**837 168**
Allocation (liter/days/capita)	615	136	195	268	284	194	**282**
Rate of loss in water supply networks (%)	30%	30%	30%	30%	44%	30%	**32%**

Drinking water production with losses (m^3/d)		61 165	3 173	96 576	11 952	282 996	59 406	**515 269**
Water deficit (m^3/d)		39 294	- 661	52 455	8 983	- 2 650	- 372	**97 048**
Storage capacity	**Total storage capacity (m^3)**	83 420	21 430	275 405	26 145	797 350	158 920	**227 112**
	Storage autonomy (days)	1,16	4,58	1,52	2,09	1,63	2,13	**2,19**
Distribution situation	**Daily**	20%	0%	50%	52%	3%	17%	**24%**
	1 day/2	31%	100%	35%	8%	51%	59%	**47%**
	1 day/3 and more	49%	0%	15%	40%	46%	24%	**29%**
Length of water supply network (km)	**Supply**	351,06	74,39	510,85	141,56	998,00	906,75	**2 982,61**
	Distribution	5 164,90	80,57	1 339,22	289,26	3 245,98	1 786,48	**11 906,41**
	Total	5 515,96	154,96	1 850,07	430,82	4 243,98	2 693,23	**14 889,02**
Connection rate (%)		94%	99%	100%	98%	100%	99%	**98%**

3.3.2. Agriculture

Table 3.3-2. Agricultural statute and irrigation need in the Oran coastal basin

Wilayas		Tlemcen	Sidi Belabass	Mostaganem	Mascara	Oran	Ain Temouchent	Total
Total agricultural area (ha)		83898	42880	58520	49055	96099	203585	**534037**
Useful agricultural area (ha)		57550	37287	51182	32628	90000	180995	**449642**
Irrigated area (ha)		7194	1714	25328	3154	12244	17950	**67584**
Water demand (m^3/ha/D)		118258	28175	416351	51847	201271	295068	**1110970**
Irrigation type	**Gravity Irrigation (ha)**	2204	19	4480	1042	6172	2275	**16192**
	Sprinkler Irrigation (ha)	3081	1302	8073	1865	2062	8175	**24558**
	Drip Feed Irrigation (ha)	1909	393	12775	248	4010	7500	**26835**
Cultivation type	**Market Gardening Cultivation (ha)**	4257	142	19192	174	3169	9355	**36289**
	Arboriculture Cultivation (ha)	2004	329	5535	2980	6122	3926	**20896**
	Industrial, Vineyards, Fodder and	9	48	0	0	2171	739	**2967**

	other Cultivation (ha)							
	Cereal Cultivation (ha)	924	1195	601	0	782	3930	**7432**
Water supply	**Boreholes (ha)**	4063	0	3330	0	1762	10379	**19534**
	Wells (ha)	1572	0	21993	0	8626	5201	**37392**
	Hill reservoirs and small dams (ha)	0	0	0	0	30	275	**305**
	Sources (ha)	124	0	4	0	201	219	**548**
	Run-of-river pumping (ha)	1435	0	1	0	0	1851	**3287**
	Wastewater treatment plant (ha)	0	0	0	0	1625	25	**1650**

4. RESULTS AND DISCUSSION

4.1. Introduction

This chapter presents the main results of water resource modelling in the Oran coastal basin using WEAP 21 software, followed by a critical analysis of their scope and limitations. Structured along two axes, it first sets out the water imbalances identified under different scenarios (status quo, efficiency measures, diversification of sources), and then discusses their appropriateness to the region's demographic and socio-economic challenges.

The Current Accounts is the dataset from which the scenarios are built. Scenarios explore possible changes to the system on future years after the Current Accounts year. A default scenario, the “reference” or “business-as-usual” carries forward the Current Accounts data into the entire project period specified and serves as a point of comparison for the other scenarios in which changes are made to the system data (SEI 2007). The current situation (2023) is extended to the future (2024–2053). No major changes are imposed in this scenario. Besides the reference scenario (BAU), six other scenarios are analyzed which are:

- Improving and expanding infrastructure
- Demographic and agricultural growth
- Minimum domestic consumption
- Improvement of agricultural activity
- Progressive pricing
- Integrated best practice

4.2. Acquiring the WEAP 21 software license

Access to robust and recognized modelling tools is a key step in guaranteeing the scientific rigor of hydrological studies. As part of this research, obtaining a license for the WEAP 21 software (Water Evaluation and Planning System, version 21) was a fundamental prerequisite for analyzing the complex dynamics of water resources in the Oran coastal basin.

Although the standard version can be downloaded free of charge from the official website (http://www.weap21.org), activating it requires a valid license, together with a unique identifier and registration code. For this study, a free academic license was granted, in accordance with the access protocols reserved for scientific research. Details of this license, documented in (Fig.), include:

- Username: Chihab Eddine Rahmoun, Université Abou Bekr Belkaid Tlemcen, Algeria;

- Registration code: 987-741-702-594-656;

- Validity: Active until 14 July 2025, with deactivation of data storage after this date.

Figure 30. Acquisition and configuration of WEAP 21 (Water Evaluation and Planning System) academic license

4.3. Setting up the WEAP model

The configuration of the WEAP (Water Evaluation and Planning) model for the Oran coastal basin was structured in four key stages: (1) spatial and temporal delimitation of the water system, (2) integration of input data, (3) definition of demand and supply scenarios, and (4) calibration and validation of the model. The aim of this approach is to faithfully reproduce the interactions between water resources, sectoral uses and climatic constraints.

4.3.1. Creation of a new study area

A new project is created in WEAP's Schematic interface by selecting the study region on the world map, followed by the precise delimitation of the catchment area, in accordance with the methodology illustrated in Fig.

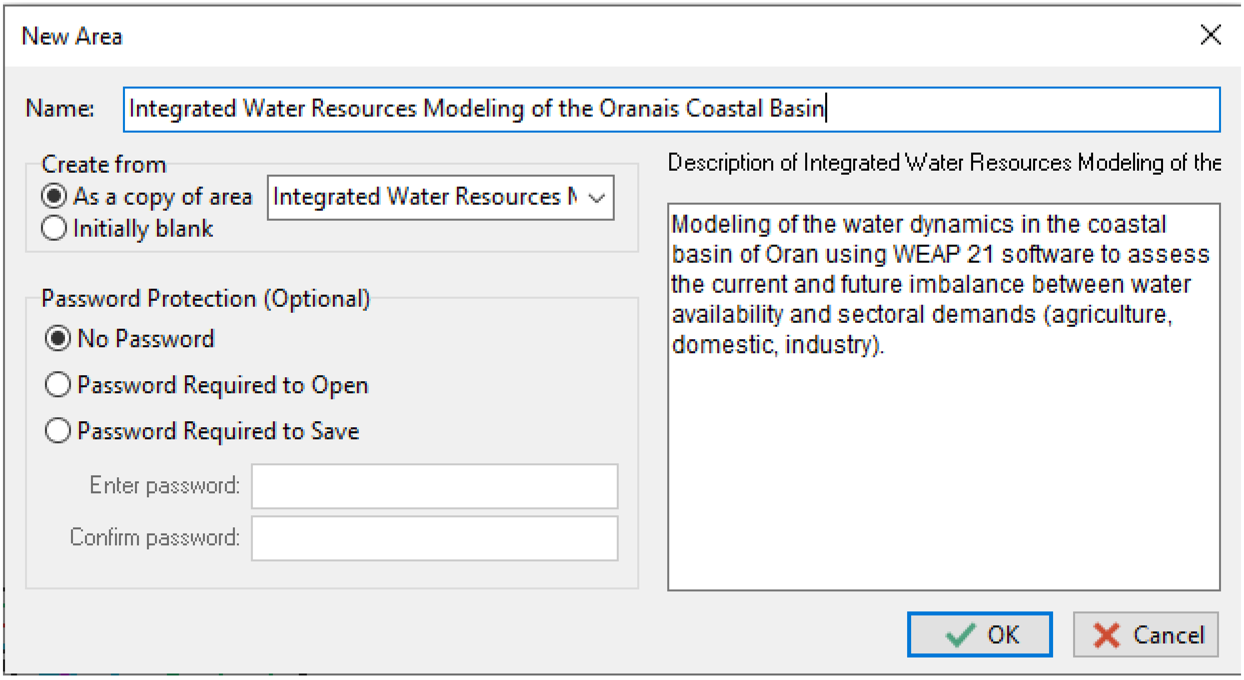


Figure 31. Creating a new project in WEAP

The temporal configuration of the WEAP model for the Oran coastal basin was defined with 2023 as the reference year, chosen for the availability of recent hydrological and socio-economic data, and covers a 30-year period (2023-2053), ideal for assessing long-term impacts. Monthly time steps are used to capture seasonal variations. As illustrated in the schematic model in Figure.

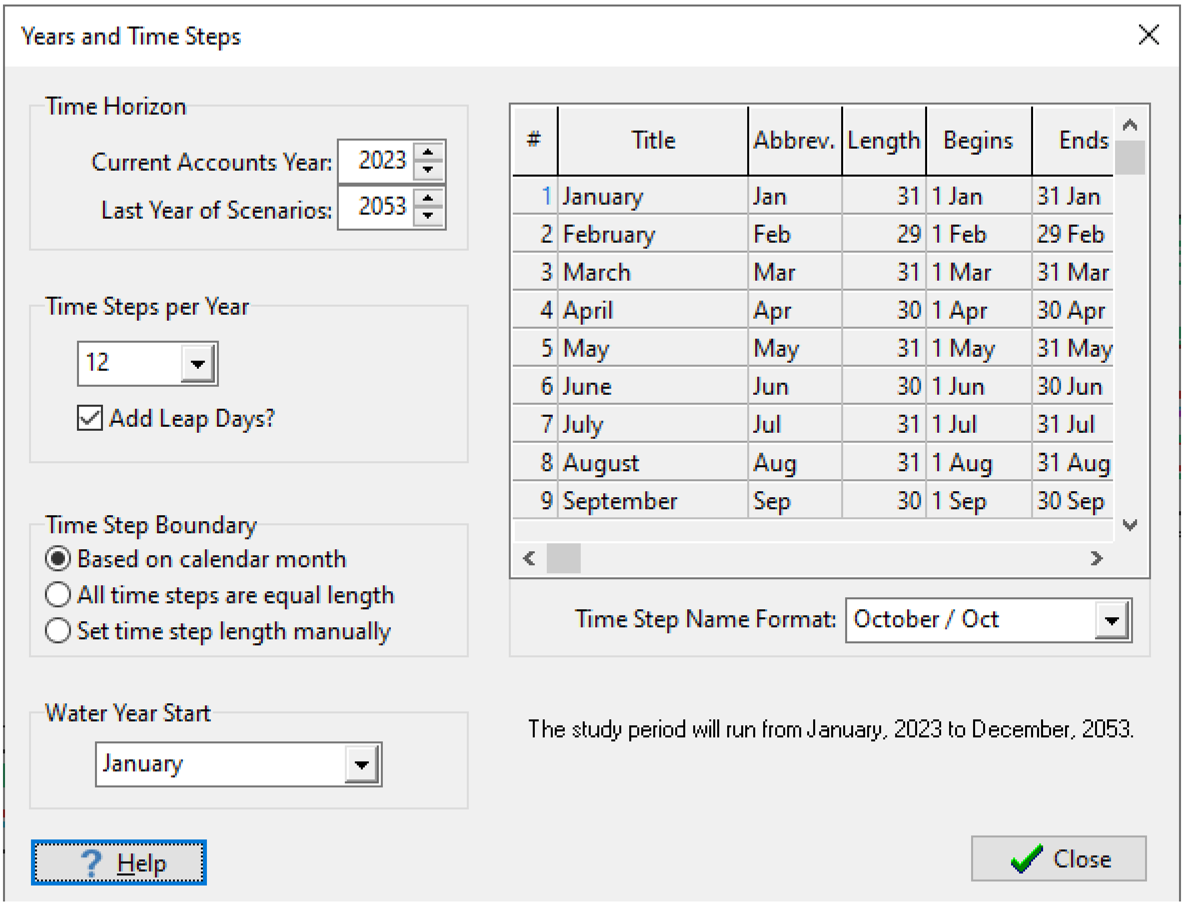


Figure 32. Year and time steps settings

4.3.2. Distribution of demand sites and water resources

The spatial configuration of demand sites and water resources in the Oran coastal basin is structured as follows:

a. Application sites (16 in total)

- Domestic (6 sites**):** Tlemcen. DWS, Sidi Belabass. DWS, Mostaganem. DWS, Mascara. DWS, Oran. DWS, Ain Temouchent. DWS ;
- Agricultural (5 sites) : Tlemcen. Agr, Mostaganem. Agr, Mascara. Agr, Oran. Agr, Ain Temouchent. **Agr ;**
- Industrial (5 sites): Tlemcen Industrial, Mostaganem Industrial, Mascara Industrial, Oran Industrial, Ain Temouchent Industrial.

b. Infrastructure and resources

- Water networks: 59 transmission links to connect demand sites to supply sources;
- Return flows: 20 return flows modeling the partial reinjection of treated wastewater or drainage water;
- Water resources: Groundwater (15 aquifers), 10 desalination plants (including 1 in progressive activation), 1 dam and 2 transfers, 3 water treatment plants.

This configuration reflects the complex interactions between sectoral withdrawals, natural availability (surface and groundwater), and infrastructure management, essential for simulating water stress dynamics in the basin.

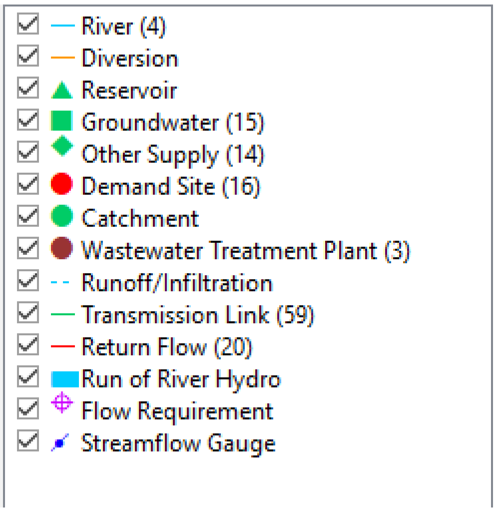


Figure 33. Conceptual diagram of the WEAP hydrological model for the Oran coastal basin

4.3.3. Cartographical presentation of the model

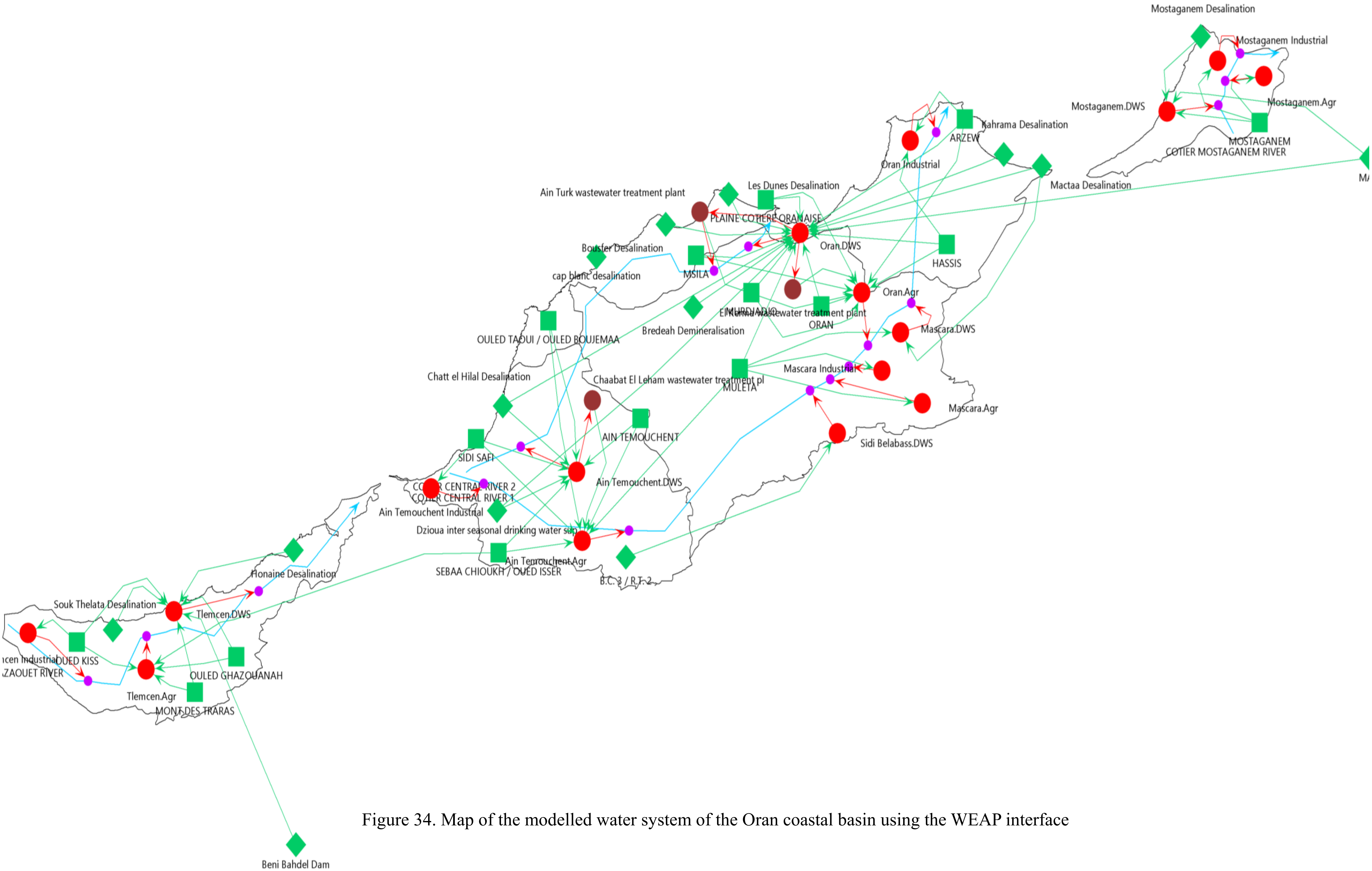


Figure 34. Map of the modelled water system of the Oran coastal basin using the WEAP interface

4.3.4. Demand sites

The Table presents annual demand projections (2023-2053) for different sectors (domestic, agricultural, industrial) in the Oran coastal basin. The data are based on distinct methods for estimating growth: using the Growth From function for the domestic and industrial sectors, based on a variable annual growth rate applied to the 2023 population or production, which is calculated on the basis of the 2008 census, and for the agricultural sector using the Interp function, which linearly interpolates land area between 2023 and 2053, based on the total use of useful agricultural land by 2053.

Annual level of activity driving demand, such as agricultural area, population using water for domestic purposes, or industrial output.

Demand Site	2023	2024-2053	Scale	Unit
Tlemcen.DWS	145813	GrowthFrom(0,39%; 2023; 145813)		cap
Ain Temouchent.DWS	398540	GrowthFrom(1,11%; 2023; 398540)		cap
Sidi Belabass.DWS	25562	GrowthFrom(1,17%; 2023; 25562)		cap
Oran.DWS	1904354	GrowthFrom(3,05%; 2023; 1904354)		cap
Mascara.DWS	19794	GrowthFrom(1,3%; 2023; 19794)		cap
Mostaganem.DWS	294166	GrowthFrom(2,06%; 2023; 294166)		cap
Tlemcen.Agr	7194	Interp(2023;7194; 2053;57550)		ha
Ain Temouchent.Agr	17950	Interp(2023;17950; 2053;180995)		ha
Mascara.Agr	3154	Interp(2023;3154; 2053;32628)		ha
Oran.Agr	12244	Interp(2023;12244; 205;90000)		ha
Mostaganem.Agr	25328	Interp(2023;25328; 2053;51182)		ha
Tlemcen Industrial	32	GrowthFrom(3%; 2023; 32)		Prod.
Ain Temouchent Industrial	64	GrowthFrom(4%; 2023; 64)		Prod.
Mascara Industrial	19	GrowthFrom(3%; 2023; 19)		Prod.
Oran Industrial	332	GrowthFrom(5%; 2023; 332)		Prod.
Mostaganem Industrial	49	GrowthFrom(4%; 2023; 49)		Prod.

Figure 35. Demand sites of the basin.

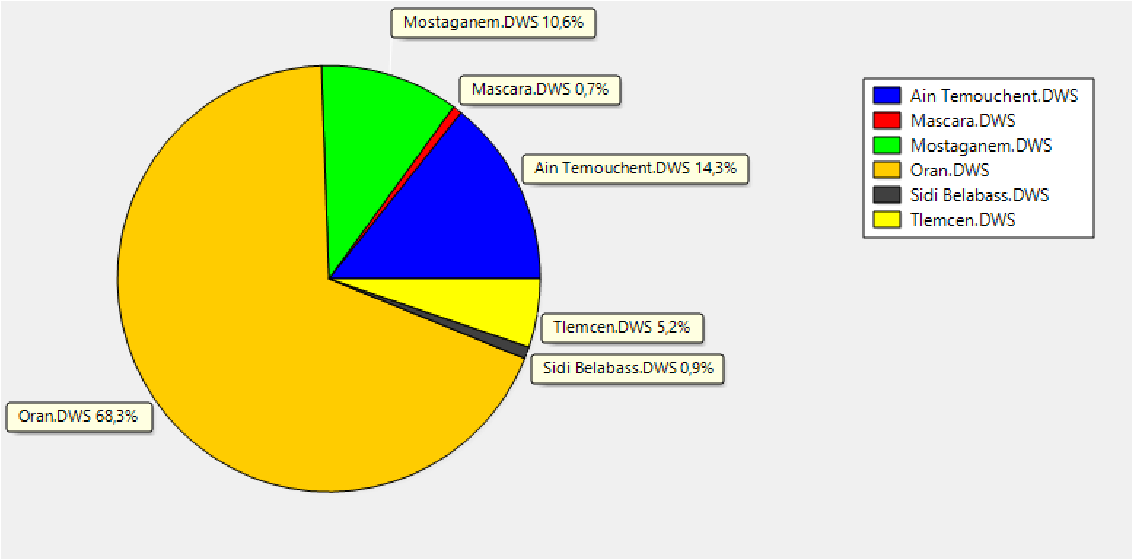


Figure 36. Percentage distribution of population served by drinking water supply sites (2023)

The demographic distribution associated with drinking water supply in the Oran coastal basin reveals an extreme concentration in Oran (68.3% of the population), reflecting an urban-centric development model that amplifies territorial imbalances, while outlying areas (e.g. Mascara: 0.7%) and Sidi Belabass (0.9%) suffer systemic marginalization, linked to historical, geographical and socio-economic factors, aggravated by expansionist agricultural projections (e.g. +908% area growth in Ain Temouchent. Agr by 2053). This configuration generates critical socio-environmental tensions: increased pressure on hydraulic infrastructures in Oran, vulnerability of rural regions dependent on agriculture, and risks of usage conflicts in a context of growing water scarcity. To mitigate these imbalances, adaptive governance is required, combining decentralization of investment, predictive models integrating climate hazards, and sectoral regulation mechanisms, in order to reconcile water security, territorial equity and long-term ecological resilience.

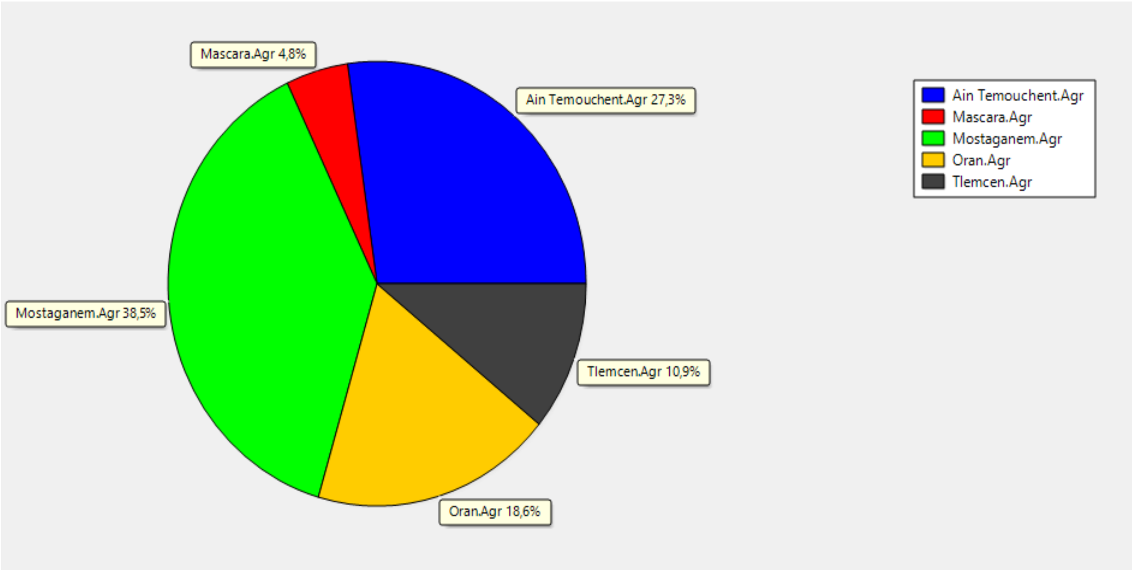


Figure 37. Distribution of irrigated agricultural area in the Oran coastal basin (2023)

The distribution of agricultural activities in the Oran coastal basin in 2023 reveals a major concentration in Mostaganem (38.5%), followed by Ain Temouchent (27.3%) and Oran (18.6%), reflecting a geographical specialization influenced by agro-ecological factors (e.g., water availability, soil quality) or sectoral policies. This dominance contrasts with the modest drinking water allocations for Mostaganem, highlighting a risk of imbalance between agricultural needs and water resources. Regions such as Mascara (4.8%) and Tlemcen (10.9%) remain marginalized, despite their diversification potential, accentuating territorial disparities.

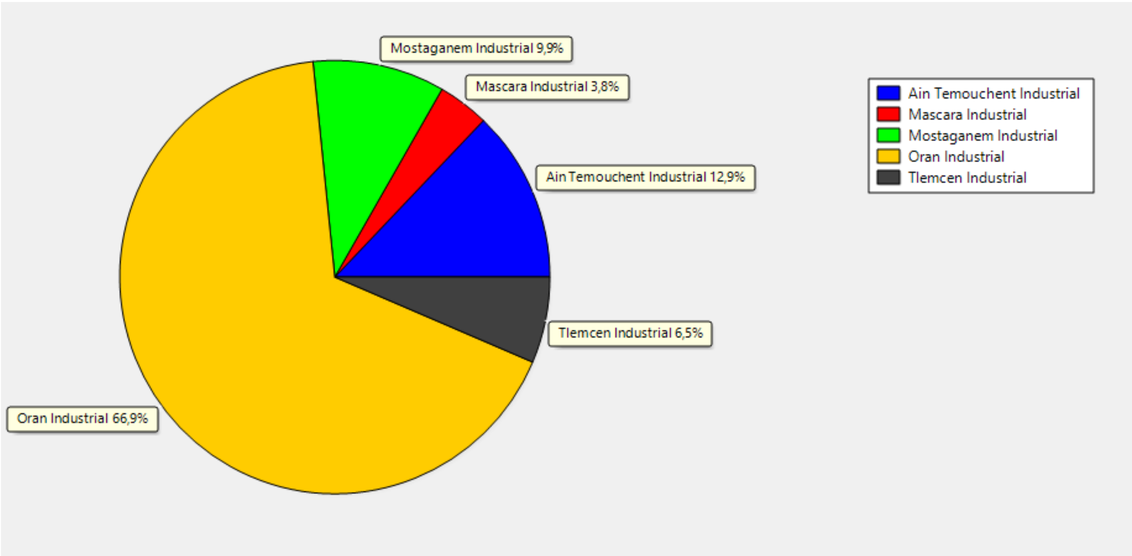


Figure 38. Distribution of industrial activities in the Oran coastal basin (2023)

Industrial sector distribution in the Oran coastal basin in 2023 is strongly polarized around Oran (66.9%), confirming its role as a central economic hub, while other sites such as Ain Temouchent (12.9%), Mostaganem (9.9%) and Tlemcen (6.5%) occupy secondary positions, and Mascara (3.8%) remains marginal. This concentration reflects the dynamics of industrial agglomeration, driven by developed infrastructures and privileged access to markets. However, this dominance raises systemic risks: increased pressure on energy and water resources (already critical in Oran, with 68.3% of the population and 18.6% of agricultural activities), excessive economic dependence on a single site, and marginalization of outlying regions despite their diversification potential.

a. Domestic sites

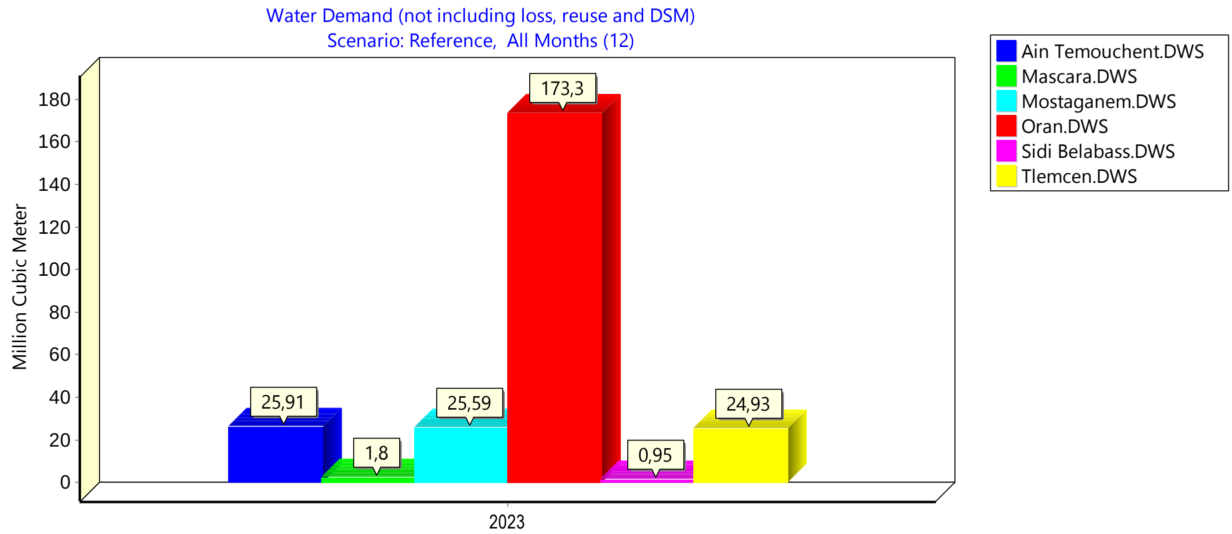


Figure 39. Annual raw water demand for drinking water supply (2023)

The figure reveals an extreme concentration in Oran (173.3 million m^3; 68.6% of the total), reflecting its demographic (1.9 million inhabitants) and industrial weight. Other sites, such as Ain Temouchent (25.9 million m^3; 10.3%), Mostaganem (25.6 million m^3; 10.1%) and Tlemcen (24.9 million m^3; 9.9%), illustrate secondary contributions, while rural areas (Sidi Belabass: 0.95 million m^3; 0.4%) and (Mascara: 1.8 million m^3; 0.7%) remain marginalized. This distribution raises critical risks: overexploitation of groundwater in Oran, increased vulnerability in the face of population growth projected at +3.05%/year, and socio-economic imbalances between urban and rural areas. To mitigate these challenges, strategies such as optimizing water infrastructures, promoting water-efficient technologies and inclusive governance are required, in order to reconcile water security, territorial equity and resilience in the face of climatic and demographic challenges.

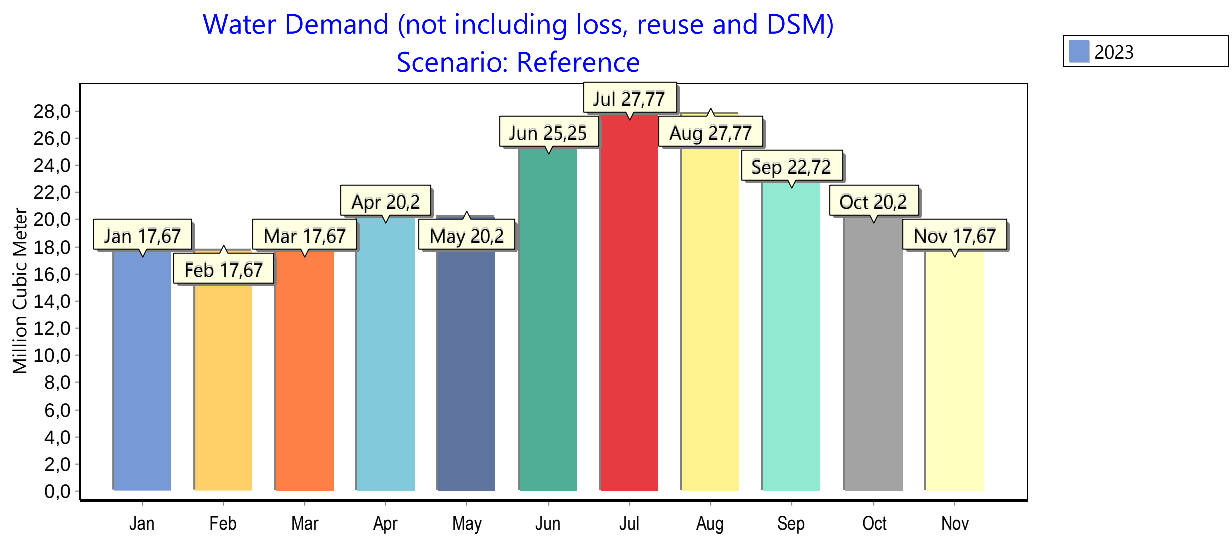


Figure 40. Monthly raw water demand for drinking water supply (2023)

Monthly raw water demand for drinking water supply in the Oran coastal basin in 2023 follows a pronounced seasonal variability, with a summer peak in July and August (27.7 million m^3/month), corresponding to an increase of 57% compared to the winter months (17.7 million m^3/month from January to March). This increase reflects intensified domestic needs (tourism, over-consumption) and climatic pressures (summer drought). The intermediate values (20.2 to 25.2 million m^3/month) observed in April-June and September-October suggest transitions linked to residual agricultural activities or seasonal adjustments. The annual sum (252.5 million m^3) confirms the dominance of Oran (68.6% of the total), where high consumption (91 m^3/pers/year) combined with sustained population growth (+3.05%/year) exacerbates the risks of overexploitation of resources.

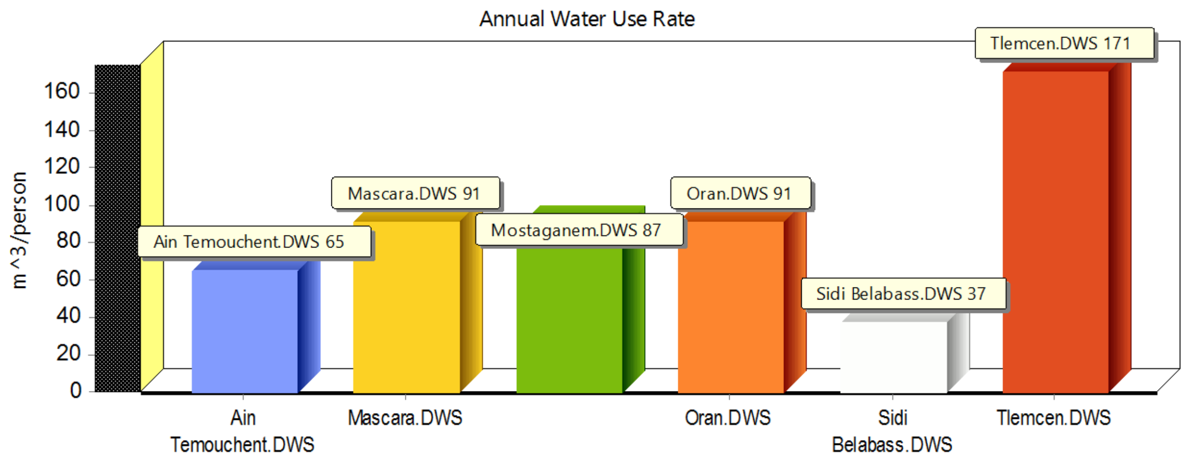


Figure 41. Annual Domestic water use rate.

Data on annual domestic water consumption in the Oran coastal basin reveal critical disparities: Tlemcen shows an exceptional rate of 171 m^3/pers/year (≈468 L/day/pers), well above WHO standards (50-100 L/day/pers), suggesting massive network leaks or a methodology that fails to take into account resource allocations to other basins, while Sidi Belabass (37 m^3/pers/year; ≈101 L/day/pers) reflects restricted access or rationing. Other towns (Oran, Mascara: 91 m^3/pers/year; Mostaganem: 87 m^3/pers/year) also exceed sustainable thresholds, highlighting inefficient resource management. These discrepancies illustrate structural inequalities (access, infrastructure) and uncontrolled technical losses, requiring urgent network audits, targeted modernization (e.g., AI leak detection) and equity policies to bring consumption into line with sustainability objectives (SDG 6) in a context of growing water stress.

b. Agriculture sites

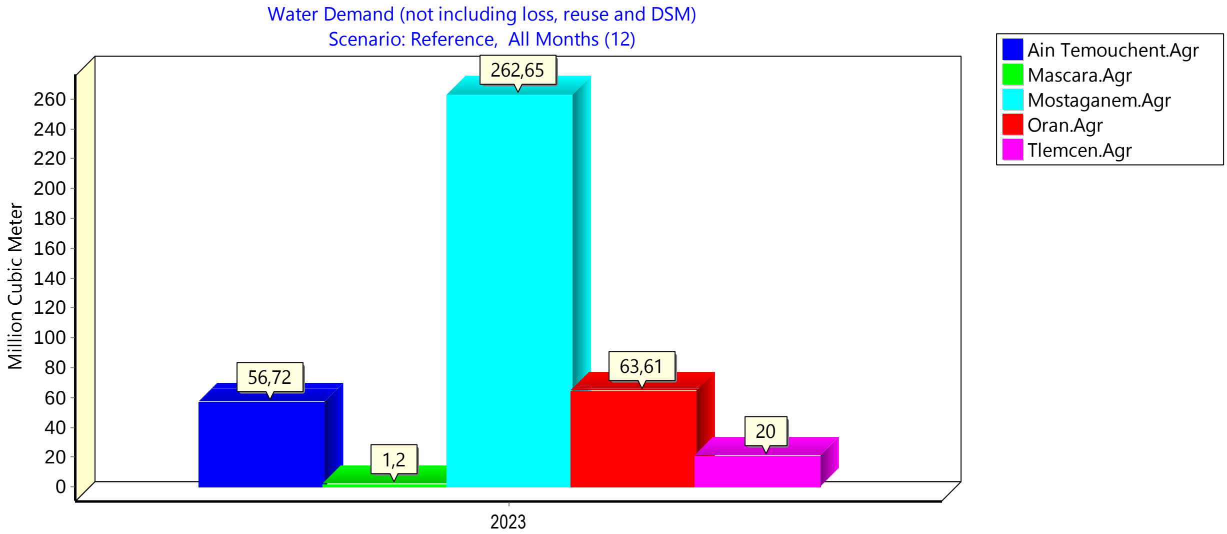


Figure 42. Annual agricultural water demand (2023).

Total agricultural water demand in the Oran coastal basin amounts to 404.2 million m^3 in 2023, with an extreme concentration in Mostaganem (262.7 million m^3; 65% of total), probably reflecting extensive cultivated areas or water-intensive crops (e.g., market gardening, citrus fruits). Other sites, such as Ain Temouchent (56.7 million m^3; 14%) and Oran (63.6 million m^3; 16%), contribute secondarily, while Mascara (1.2 million m^3; 0.3%) and Tlemcen (20.0 million m^3; 5%) remain marginal.

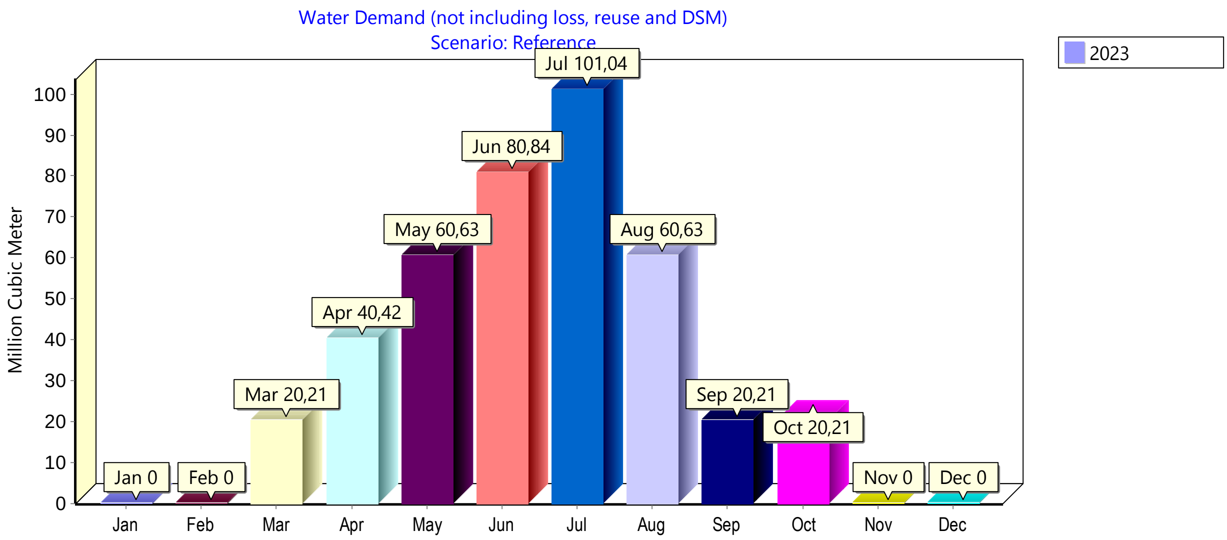


Figure 43. Monthly agricultural water demand (2023)

Agricultural water demand in the Oran coastal basin in 2023 shows marked seasonality, with zero withdrawals in January, February, November and December, indicating dependence on winter precipitation or fallow periods, followed by exponential growth from March onwards (20.2 million m^3) to reach a summer peak in July (101.0 million m^3), then a gradual decline until October (20.2 million m^3). This dynamic reflects intensive crop cycles (e.g., cereals, vegetables), requiring massive irrigation during critical growth phases. The annual total (404.2 million m^3), 75% of which is concentrated between April and August, poses risks of overexploitation of groundwater and inter-sectoral tensions (agriculture vs. domestic needs). For sustainable management, agronomic optimization (resilient crops, precision irrigation) and strategic storage infrastructures are essential to mitigate seasonal water stress and secure water resources.

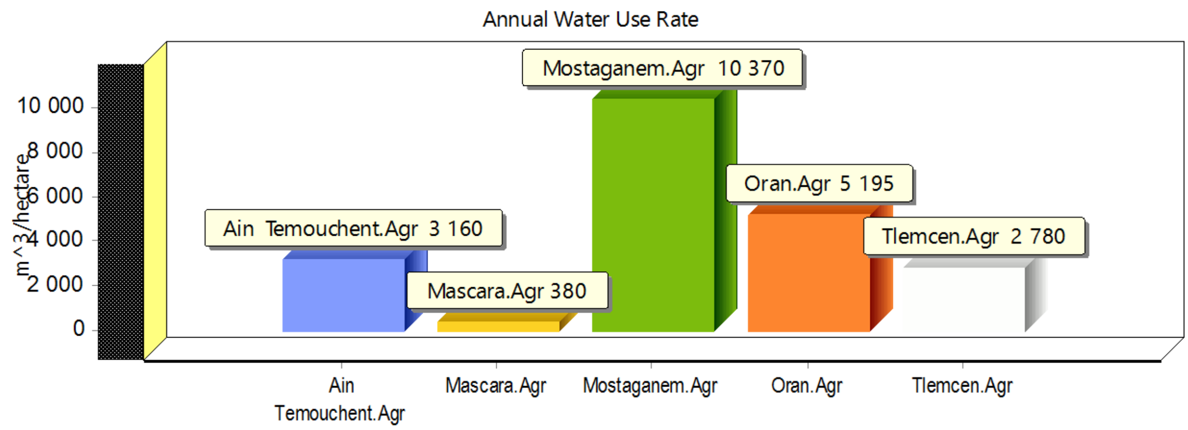


Figure 44. Annual water use rate in agricultural sites.

Data from the Oran coastal basin reveal a marked heterogeneity in agricultural water use (2023), where Mostaganem (10,370 m^3/ha) stands out for an exceptional rate, potentially linked to water transfers to other regions, explaining an aggregate demand higher than local needs. Conversely, Mascara (380 m^3/ha), whose abnormally low rate could be explained by dependence on external sources (groundwater or inter-basin transfers), masks a complex water reality. Oran (5,195 m^3/ha) and Ain Temouchent (3,160 m^3/ha), integrated into the basin, reflect local practices balanced according to national standards (6,000 m^3/ha), while Tlemcen (2,780 m^3/ha) combines moderate irrigation and rainfall contributions. These disparities, exacerbated by unaccounted inter-regional flows, distort sustainability indicators and raise the risk of overexploitation (e.g., Mostaganem water table).

c. Industry:

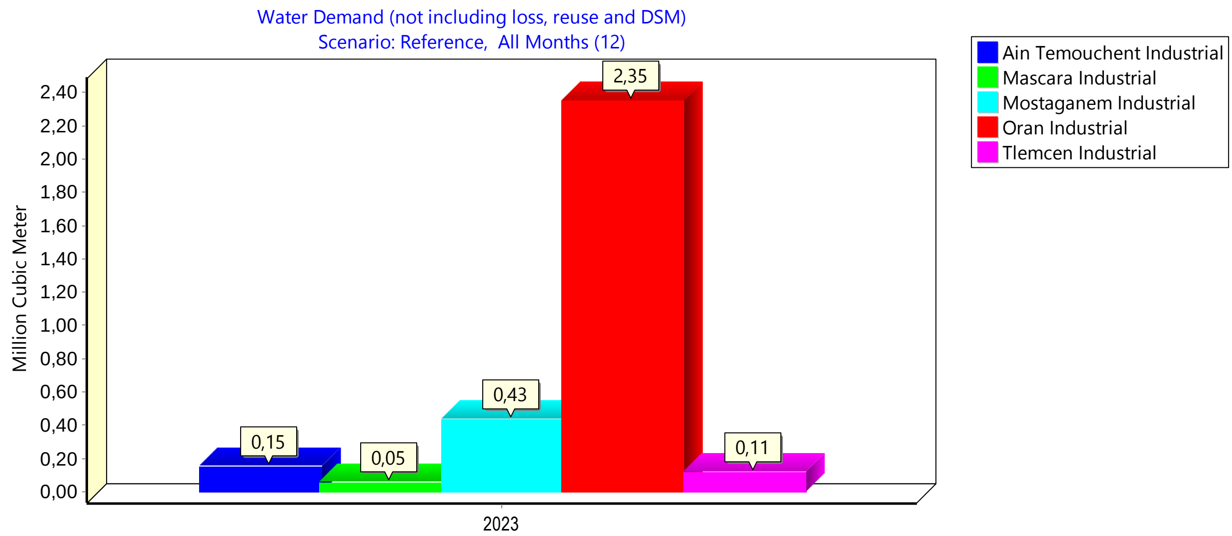


Figure 45. Annual industrial water demand (2023)

Industrial water demand data for 2023 in the Oran coastal basin amount to 3,093,757 m^3, and reveal an extreme concentration in Oran (2.35 million m^3; 76% of the total), reflecting its status as a dominant economic hub, due to heavy industries (e.g., petrochemicals, food processing) and a high density of factories. Other sites, such as Mostaganem (0.43 million m^3; 14%) and Ain Temouchent (0.15 million m^3; 5%), contribute marginally, while Tlemcen (0.11 million m^3; 4%) and Mascara (0.05 million m^3; 2%) remain insignificant.

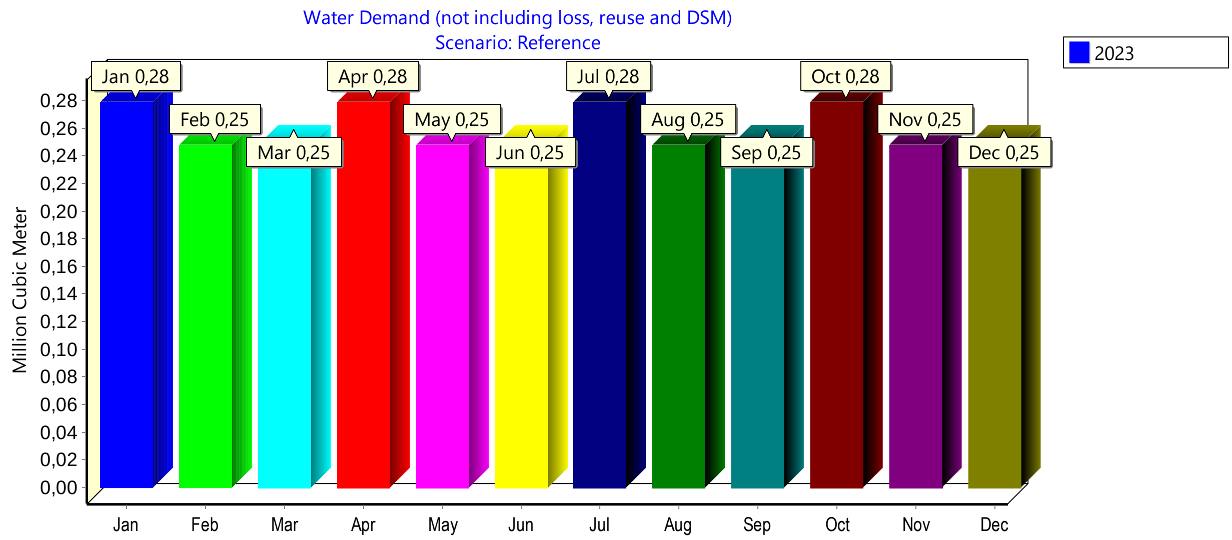


Figure 46. Monthly industrial water demand (2023)

Monthly data reveal stable but periodic industrial demand, alternating between 278,438 m^3 (January, April, July, October, December) and 247,501 m^3 (other months), for an annual total of 3,093,757 m^3. This quarterly alternation (peaks every 3 months) could correspond to production cycles, scheduled maintenance or seasonal variations in activity.

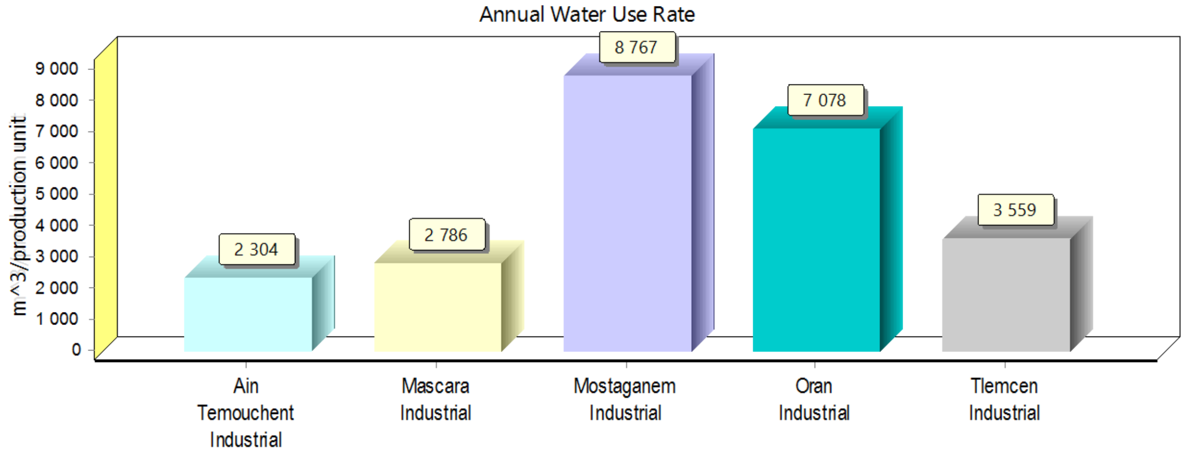


Figure 47. Annual water use rate in industrial sites

Mostaganem stands out with an exceptionally high rate (8,767 m^3/unit), suggesting intensive industrial processes and tourist complexes, while Oran (7,078 m^3/unit) confirms its status as a dominant but energy-hungry industrial hub. In contrast, Ain Temouchent (2,304 m^3/unit) is remarkably efficient, reflecting less energy-intensive activities. Mascara (2,786 m^3/unit) and Tlemcen (3,559 m^3/unit) occupy an intermediate position.

4.3.5. Resources distribution

The average capacities of the key water resources in the region are as follows: Groundwater, with a capacity of 5.5 million m^3 per year, plays a significant role in sustaining water availability. Additionally, the dam, with an average capacity and flow of 0.381 million m^3 per second, serves as a vital component of the water supply infrastructure, ensuring a steady flow of water to meet various demands. These capacities are pivotal in managing and distributing water resources efficiently to support domestic, agricultural, and industrial needs within the Basin.

4.4. Reference scenario

The reference scenario, or Business-as-Usual (BAU), simulates the evolution of the water system in the Oranese coastal basin by extending current trends, without introducing any new policies or infrastructures. The main objective is to establish an objective basis for comparison in order to assess the effectiveness of alternative scenarios.

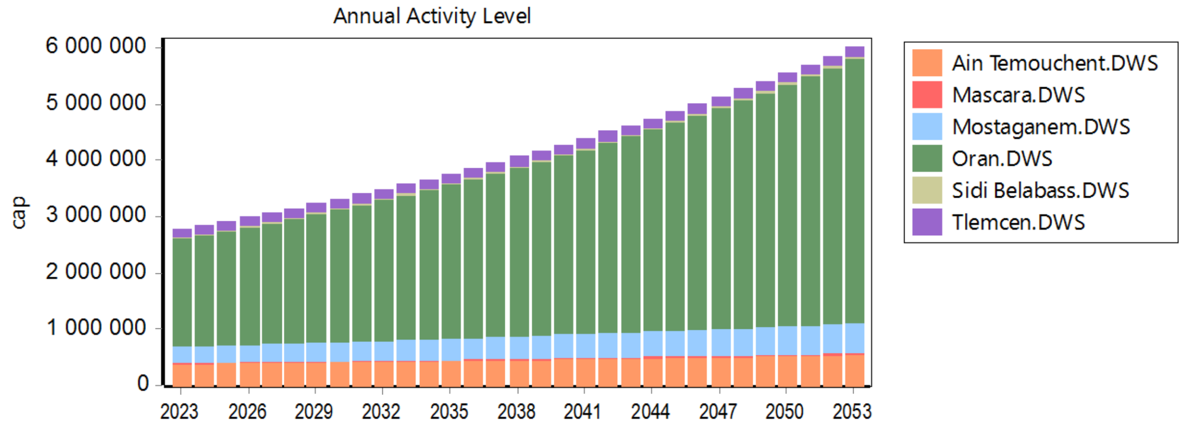


Figure 48. Population trends in the reference scenario (2023-2053)

The data reveal a marked increase in total demand, from 2.79 million inhabitants served in 2023 to 6.02 million in 2053, i.e., a doubling in 30 years. This increase, mainly driven by Oran (68% to 78% of total demand), is explained by accelerated urbanization and economic development, requiring massive investment in infrastructure (desalination, networks). Mostaganem and Ain Temouchent follow a moderate upward trend (CAGR of ~2.2% and ~1.1%), reflecting demographic expansion, while Tlemcen shows relative stagnation (CAGR of ~0.4%). Smaller regions (Mascara, Sidi Belabass) are experiencing linear growth (~1.6-1.8%). Regional disparities underline the urgency of targeted policies: priority to Oran to avoid shortages, promotion of water-saving technologies, and diversification of sources (recycled water, rain).

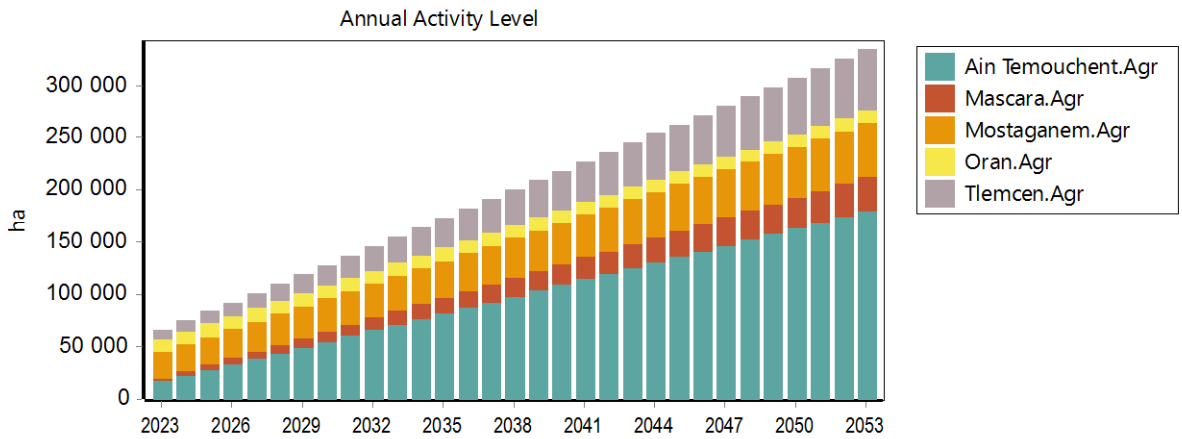


Figure 49. Evolution of agricultural land in the reference scenario (2023-2053)

The data forecast an unprecedented expansion in agricultural land, from 65,870 ha in 2023 to 334,599 ha in 2053, representing growth of 408% in 30 years (average annual rate of ~5.6%). This increase is mainly driven by Ain Temouchent (+1,795%, ~8.2%), Mascara (+935%, ~8.3%) and Tlemcen (+700%, ~7.5%), suggesting a massive conversion of land, potentially linked to ambitious agricultural policies or irrigation projects. Mostaganem posted moderate growth (+102%, ~2.3%), while Oran stagnated (12,244 ha fixed), probably due to urbanization limiting access to arable land. This agricultural explosion raises major challenges: conflicts with demand for drinking water (which is rising sharply in these regions), risks of soil degradation and loss of biodiversity. Oran's stagnation, despite its demographic boom, raises questions about its future dependence on food supplies. To ensure sustainability, measures are needed to optimize irrigation, regulate land conversion and ensure synergy between urbanization and agricultural logistics.

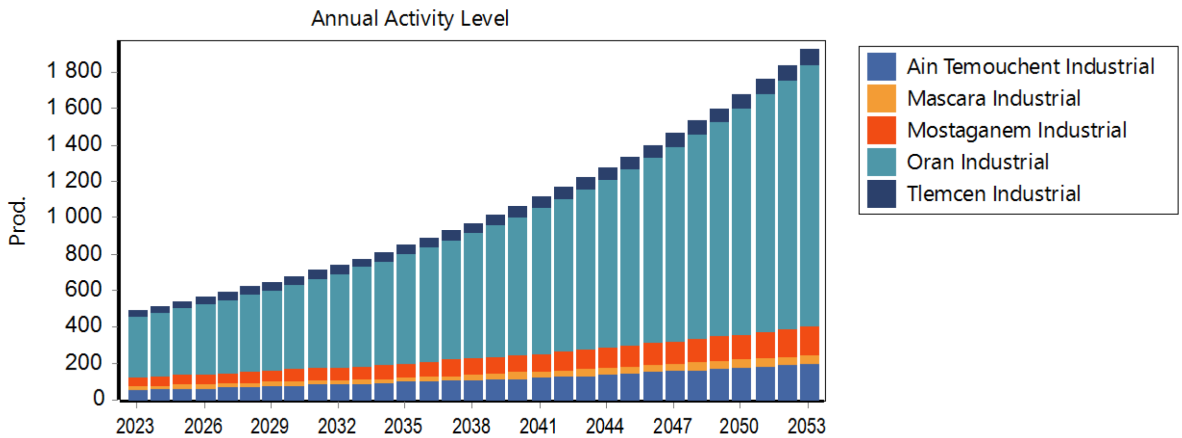


Figure 50. Industrial production units in the reference scenario (2023-2053)

The data reveal sustained industrial growth, with total activity rising from 496 units in 2023 to 1,925 units in 2053, an increase of 288% in 30 years (average annual rate of ~4.7%). This dynamic is largely driven by Oran, which accounts for 75% of total production in 2053 (versus 67% in 2023), rising from 332 to 1,435 units (annual growth rate of ~4.5%). This hegemony probably reflects its status as a central economic hub, with investments in strategic sectors (energy, logistics, technology). Mostaganem (+224%) and Ain Temouchent (+224%) show similar growth, suggesting industrial diversification or synergies with the expanding agricultural sector. Conversely, Mascara (+143%) and Tlemcen (+143%) recorded more modest growth, linked to structural constraints or less dynamic specialization.

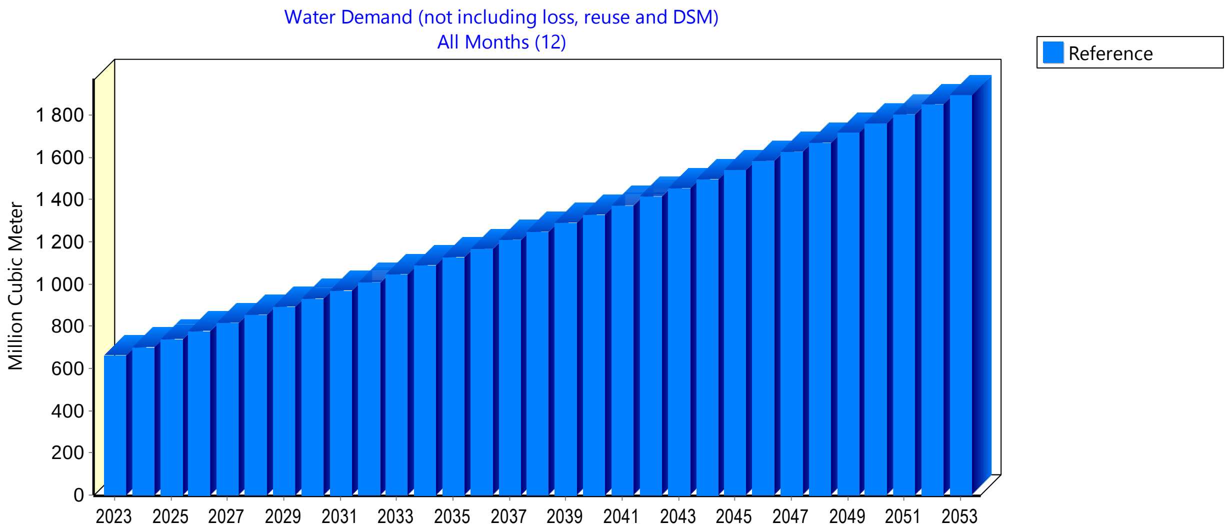


Figure 51. Total annual water demand in the Oran Coastal Basin for the three sectors (domestic, industrial, and agricultural) in the reference scenario (2023-2053)

The scenario forecasts a continuous increase in water demand, from 660 million m^3 in 2023 to 1.89 billion m^3 in 2053, representing average annual growth of 4.4% and a cumulative total of 38.9 billion m^3 over 30 years. This increase, well in excess of population (+1.8%) and sector (+1%) growth rates, is due to three key factors: (1) explosive agricultural expansion (+408% cultivated land, generating 60-70% of demand), (2) industrial expansion (+288% activity, particularly in Oran), and (3) the doubling of the urban population supplied with drinking water. By 2040, demand exceeds 1.33 billion m^3, signaling critical pressure on resources, with major risks: groundwater depletion (annual withdrawals >1.8 billion m^3 in 2050), conflicts of use between sectors and regions, and increased vulnerability to droughts. These projections, though theoretical, reveal an unsustainable trajectory without radical measures: diversification of sources (desalination, wastewater reuse), adoption of efficient technologies (drip irrigation, modernized urban networks), and proactive governance (quotas, progressive pricing).

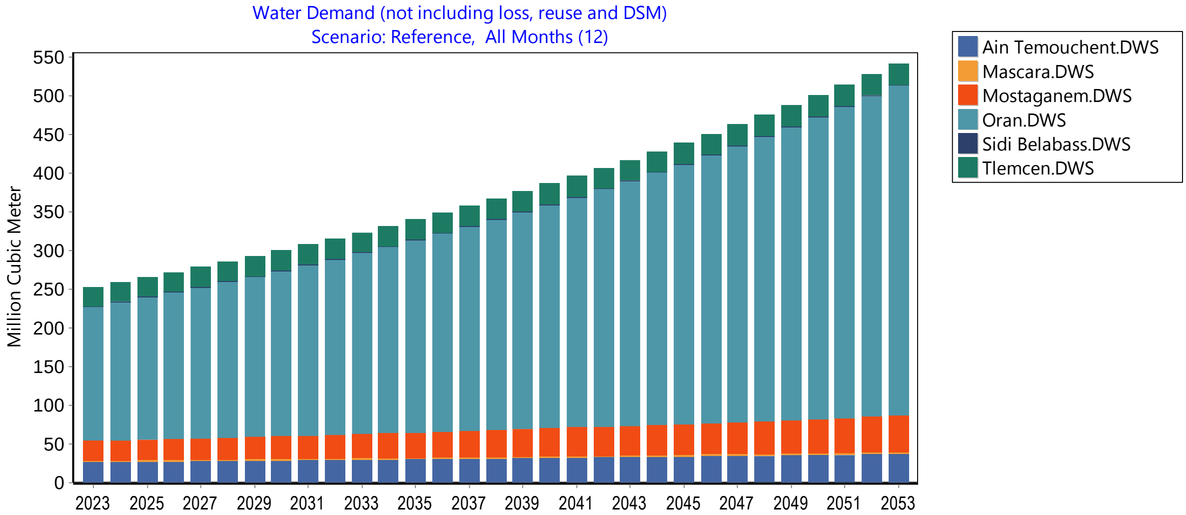


Figure 52. Annual water demand from domestic sites in the reference scenario (2023-2053)

Demand for drinking water is growing across the board, rising from 252.5 million m^3 in 2023 to 542 million m^3 in 2053 (+115%), at an average annual rate of 2.6%. This increase, mainly driven by Oran (69% of total demand in 2023, 79% in 2053), reveals an extreme concentration. Mostaganem (+84%) and Ain Temouchent (+39%) follow a sustained dynamic, while Tlemcen (+12%) and Sidi Belabass (+42%) show moderate growth. Mascara (+47%) reflects rural and agricultural development.

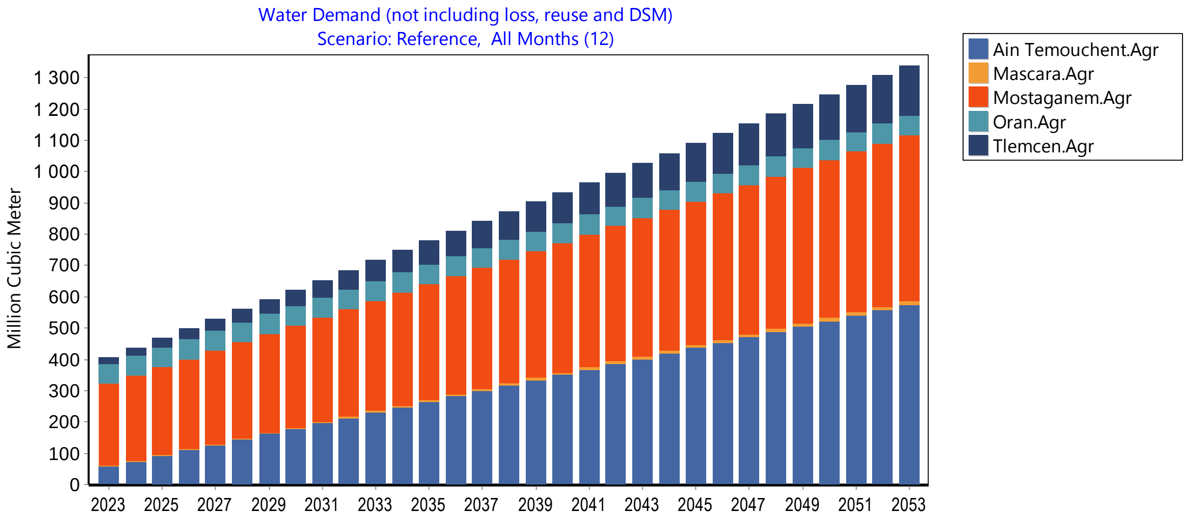


Figure 53. Annual water demand from agriculture sites in the reference scenario (2023-2053)

Demand for agricultural water is growing explosively, rising from 404 million m^3 in 2023 to 1.34 billion m^3 in 2053, an increase of 231% (average annual rate of ~5.6%). This increase, largely driven by Ain Temouchent (+908%) and Tlemcen (+700%), reflects an aggressive expansion of cultivated land, while Mostaganem (+102%) and Mascara (+935%) follow a steady trajectory. Oran, on the other hand, maintains a stable demand (63.6 million m^3/year), due to urban constraints or limiting policies.

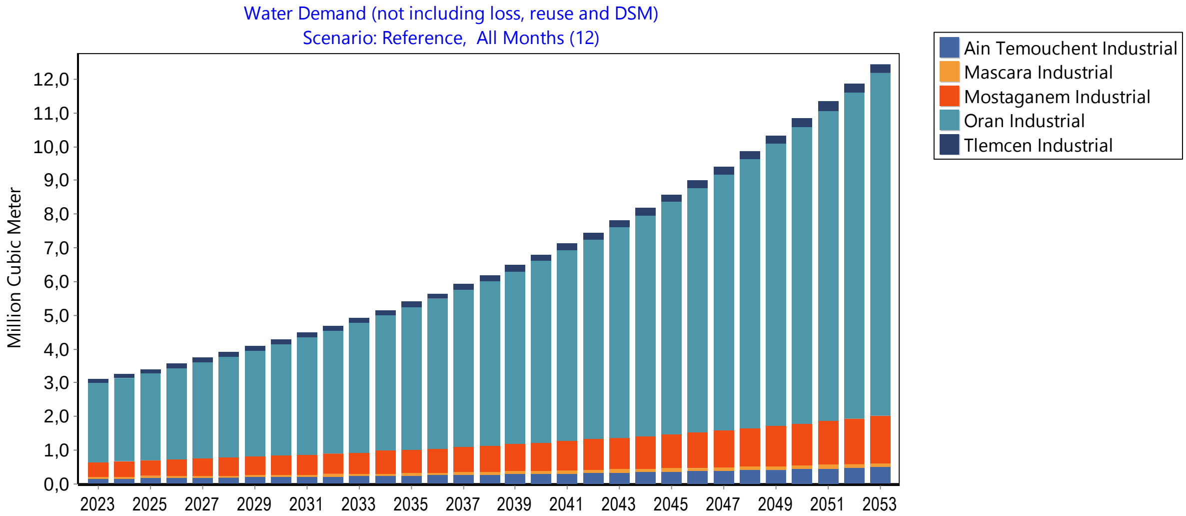


Figure 54. Annual water demand from industry site in the reference scenario (2023-2053)

Demand for industrial water is growing exponentially, rising from 3.09 million m^3 in 2023 to 12.43 million m^3 in 2053, a fourfold increase in 30 years (average annual rate of ~5.1%). This increase is dominated by Oran, which accounts for 76% of total demand in 2023 (2.35 million m^3) and 82% in 2053 (10.16 million m^3), consolidating its status as a central industrial hub. Other regions show contrasting dynamics: Mostaganem triples its demand (+224%, from 0.43 to 1.39 million m^3), reflecting economic diversification. Ain Temouchent (+225%) and Tlemcen (+143%) show sustained growth, linked to emerging industrial projects. Mascara (+143%) showed modest growth, probably limited by less water-intensive infrastructures or specializations.

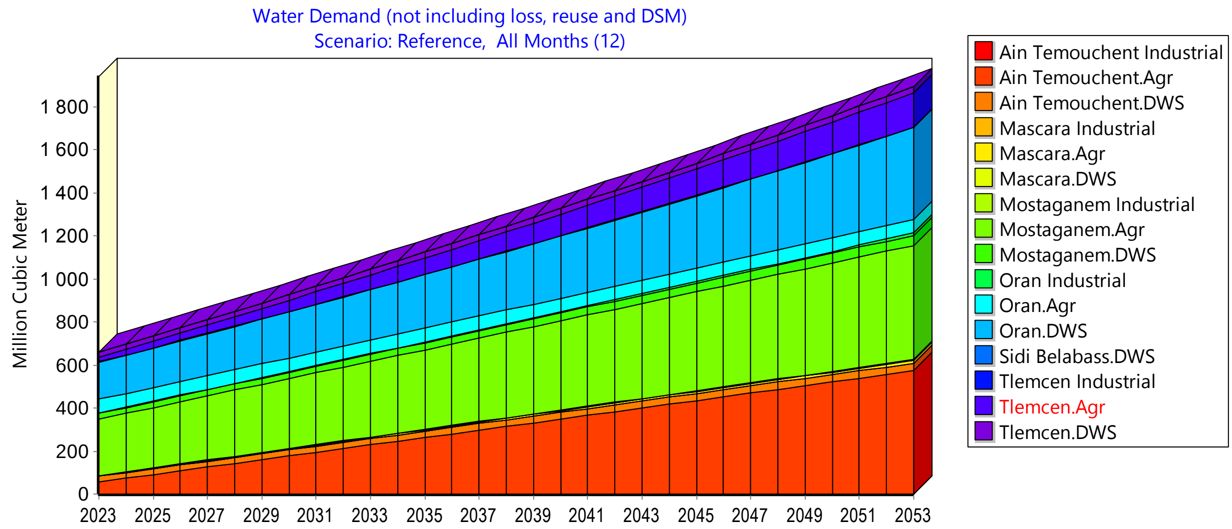


Figure 55. Total annual water demand in the reference scenario (2023-2053)

By 2023, agriculture will dominate with 61.3% of total demand (404.2 million m^3), followed by domestic use (38.3%, 252.5 million m^3) and industry (0.5%, 3.1 million m^3). By 2053, agriculture's share will have risen to 70.7% (1.34 billion m^3), while domestic use, although doubling in volume (542.1 million m^3), will see its share fall to 28.6%, due to the disproportionate growth of agriculture. Industry, despite a 4-fold increase in consumption (12.4 million m^3), remains marginal (0.7%).

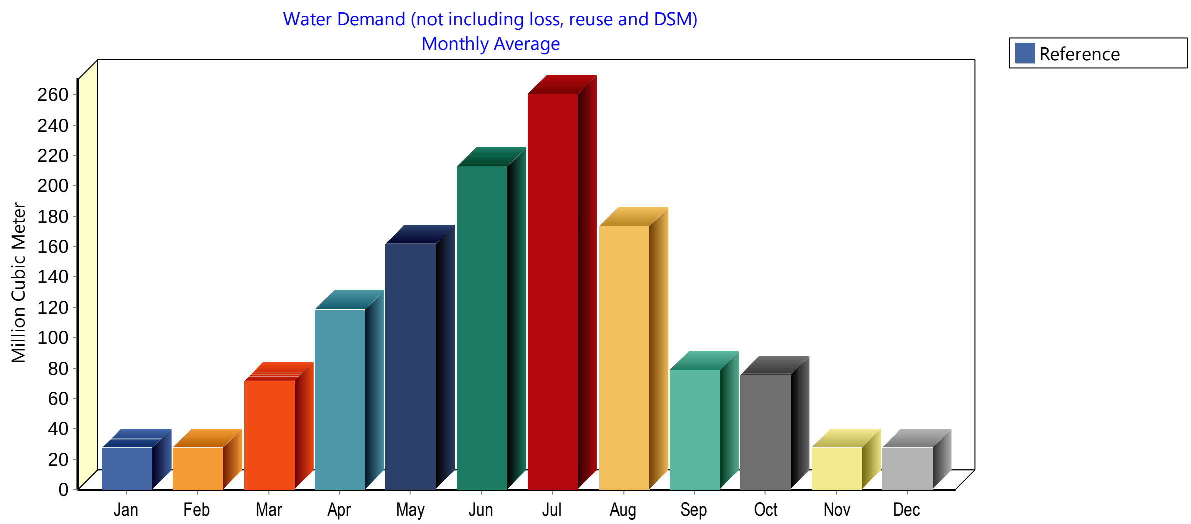


Figure 56. Average monthly water demand in 2023-2053

Water demand shows extreme seasonal variability, with a critical summer peak and winter troughs, for an annual total of 1.256 billion m^3. The months of May to August account for 61% of annual demand (767 million m^3), peaking in July (260 million m^3, or 20.7% of the total), mainly due to intensive agricultural irrigation and increased domestic needs (tourism, hot climate). Conversely, the winter months (January, February, November, December) record the lowest withdrawals (21.5 million m^3/month), due to crop dormancy and reduced economic activity.

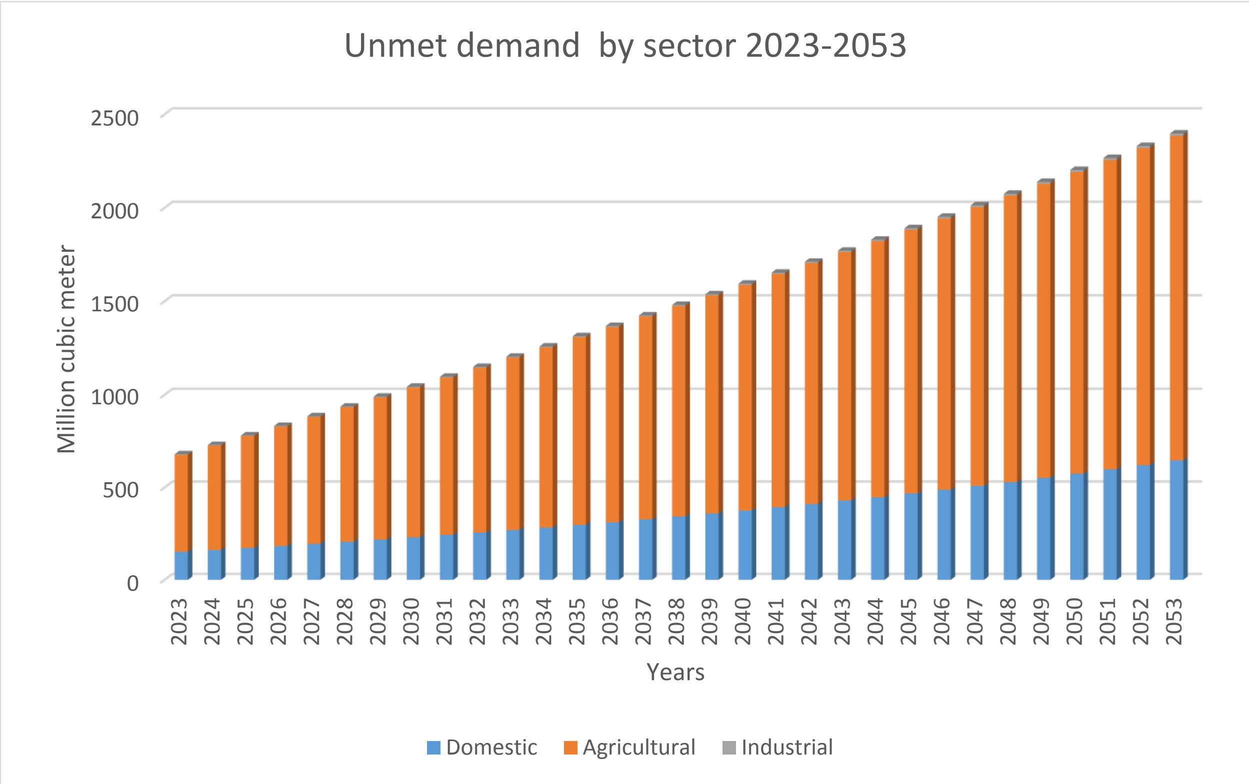


Figure 57. Unmet demand in the basin - reference scenario (2023-2053)

Unmet water demand almost triples between 2023 (680 million m^3) and 2053 (2,397 million m^3), with average annual growth of 4.1%, revealing unsustainable pressure on resources. Agriculture dominates this demand, rising from 525 million m^3 (77.2% of the total) in 2023 to 1,739 million m^3 (72.5%) in 2053, due to uncontrolled expansion of irrigated land and inefficient irrigation techniques. Domestic use follows an alarming trajectory, jumping from 152 million m^3 (22.3%) to 646 million m^3 (27%), driven by rapid urbanization and dilapidated networks, threatening equitable access to drinking water, particularly in metropolises like Oran. Industry, although marginal (0.5%), is seeing its demand quadruple (from 3.1 to 12.4 million m^3), concentrated in Oran, exposing this economic hub to localized risks.

4.5. Infrastructure improvement and expansion scenario

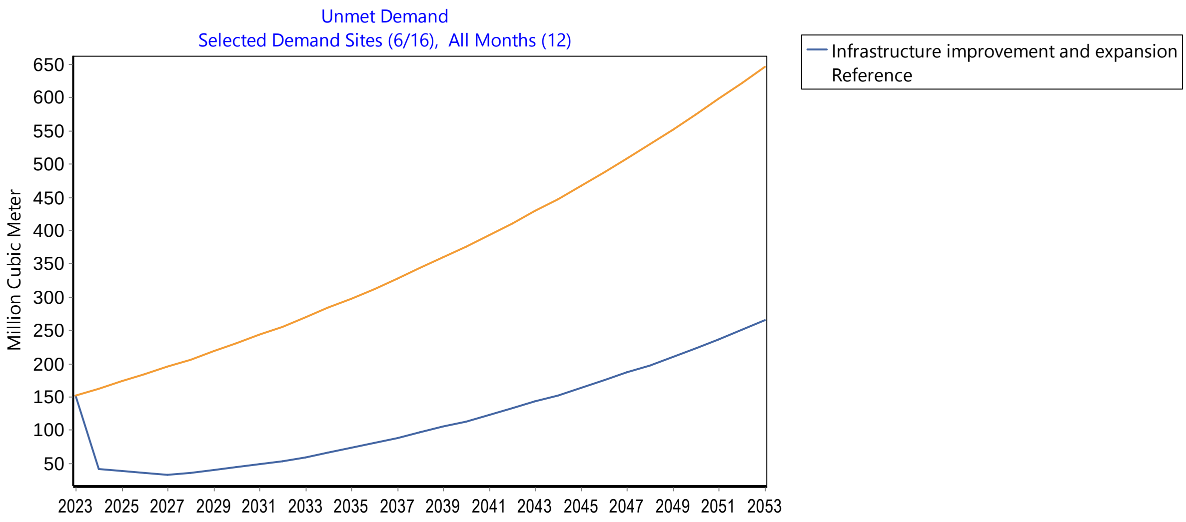


Figure 58. Unmet demand for domestic demand sites in the two scenarios (Reference, Infrastructure improvement and expansion scenario) (2023-2053)

4.5.1. Scenario comparison (2023-2053)

a. Reference scenario

Unmet demand is rising steadily, from 152.0 million m^3 (2023) to 646.2 million m^3 (2053), with a cumulative total of 11.24 billion m^3.

b. Improvement scenario

Unmet demand decreases from 2024, from 152.0 million m^3 (2023) to 41.5 million m^3 (2024), then gradually increases (but remains well below the reference scenario), reaching 265.1 million m^3 (2053). The cumulative total is 3.64 billion m^3, a 68% reduction on the reference scenario.

4.5.2. Impact of scenario assumptions

The proposed measures explain this reduction:

- Improved desalination plants (80% capacity): Increases drinking water supply, reducing dependence on traditional sources.
- Interconnection of dams and storage at Dzioua: Enables strategic redistribution of raw water, optimizing existing resources.
- Substitution of desalinated water for surface water: Reduces energy costs and preserves groundwater.
- Reduction of losses (AEP: 30% → 15%; Irrigation: 23% → 10%): The deployment of the SEOR technology system (digitization of networks) in all wilayas explains the drastic drop from 2024.

Against a backdrop of growing water stress, reducing losses in drinking water networks, estimated at 40%, is an economically and ecologically optimal solution to the construction of energy-hungry new infrastructures. With a network of 15,000 km serving 2.788 million inhabitants in the basin, an investment of $126.7 million (equivalent to 9,990 DA/connected inhabitant, source: PDARE) would make it possible to recover 40% of lost water, i.e., 120 million m^3 per year, sufficient to supply an additional 2,000,000 residents. In comparison, new infrastructures (dams, desalination plants) require initial costs 5 to 10 times higher ($500 million to $1 billion), dependence on foreign capital and high energy consumption (3-10 kWh/m^3 versus 0.1-0.5 kWh/m^3 for rehabilitation). This approach prioritizes the efficiency of the existing system, avoiding land artificialization and pollutant discharges, while stimulating the local economy by employing regional workers and companies. Integrating IoT technologies to map leaks and smart meters to limit fraud, it aligns water resilience, energy sobriety and Sustainable Development Goals (SDGs 6 and 7), offering a rapid return on investment and strategic autonomy in the face of climatic and geopolitical challenges.

The under-performance of desalination plants, despite substantial investment, stems from systemic dysfunctions including opaque management, paralyzing bureaucracy and corrupt practices between public players and international companies. The latter, protected by unbalanced agreements, bill in full for their services, with no obligation to deliver results, leading to chronic under-utilization of infrastructure (40-70% of capacity vs. 80-90% as envisaged). This situation exacerbates water shortages, increases public debt and undermines public confidence. To remedy the situation, a multidimensional institutional reform is required:

- Transparency and accountability: Independent audits by neutral bodies, open data publication of contracts and performance, and legal protection for whistle-blowers.
- Contract renegotiation: Introduction of conditional clauses linking payments to production targets and penalizing underperformance, while favoring partnerships with local players.
- Citizen and technological control: Involvement of local oversight committees, deployment of IoT sensors to monitor production in real time, and use of blockchain to trace financial flows.
- Optimization before expansion: Maximize existing assets through predictive maintenance and the integration of renewable energies, before considering new construction.

These measures, combined with a green energy transition, would reduce operating costs by 30 to 40%, freeing up resources for other priorities (education, health). Such an approach, anchored in the principles of inclusive governance and sustainability, would transform desalination plants into pillars of resilient water security, while restoring the legitimacy of public institutions.

4.6. Demographic and agricultural growth scenario

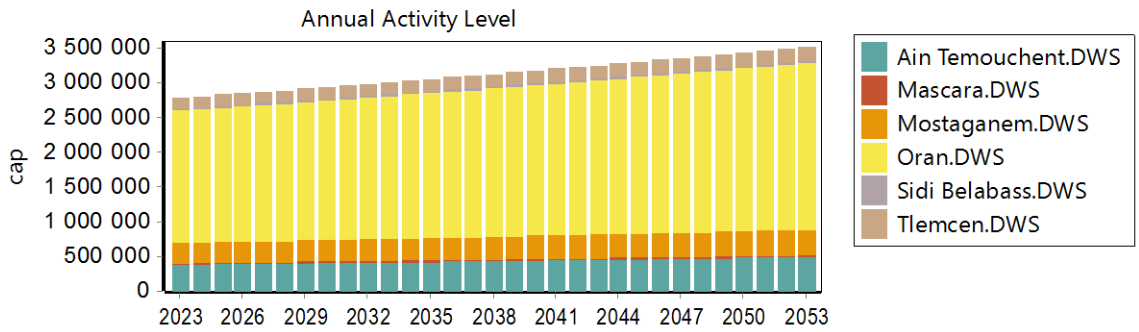


Figure 59. Demographic growth

The population served by domestic sites will rise from 2,788,229 in 2023 to 3,520,133 in 2053, an increase of 26.3% over 30 years. The moderate demographic growth observed in the region (~0.78% annual, source: world meters) can be explained by a multifactorial socio-demographic transition, marked by interconnected socio-economic and cultural dynamics. Firstly, the global economic crisis has led to a slowdown in local investment, exacerbating unemployment and inflation, delaying the average age of marriage and reducing birth rates. Secondly, the decline in fertility stems from the growing empowerment of women, 34% of whom are now part of the working population (compared with 18% in 2000), giving priority to professional careers and access to modern contraception (used by 60% of women of childbearing age). Thirdly, the evolution of family structures towards nuclear models (2-3 children) is taking place against a backdrop of accelerated urbanization and high education costs, reinforced by pro-family planning public policies. Finally, the abundance of individual life choices, influenced by globalization, values social mobility and financial stability to the detriment of early parenthood.

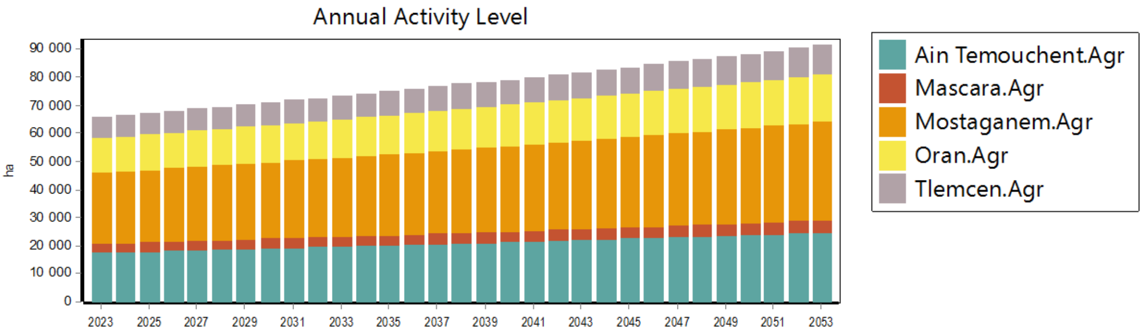


Figure 60. Agriculture growth

The total agricultural area will rise from 65,870 ha in 2023 to 91,458 ha in 2053, an increase of 38.8% over 30 years (average annual growth rate: ~1.1%). This expansion reflects increased pressure to meet food demand, linked to population growth (+26.3% over the same period) and the intensification of farming practices.

The modest growth of the agricultural sector is explained by a complex socio-economic context, where state incentives (land reclamation, land grants, public funding) come up against structural obstacles. On the one hand, the reluctance of young people to enter agriculture persists despite these programs, due to the perceived precariousness of the sector: unemployment benefits offer immediate security, while working conditions (exposure to temperatures in excess of 40 °C, physical hardship) and unstable incomes discourage people from setting up. On the other hand, limitations on public and private investment are holding back modernization: despite financing tools, bureaucracy, climatic risks and a lack of technical support are deterring banks and farmers alike. Finally, the land granted is often marginal (poor soils, far from water networks), and struggles to generate attractive yields. To reverse this trend, a multidimensional reform is needed: simplifying access to credit, raising the profile of the farming profession in the media, integrating adaptive technologies (climate-controlled greenhouses, solar irrigation), and improving living conditions in rural areas (housing, health). Without these measures, the basin's agricultural potential will remain under-exploited, despite its key role in regional food and water security.

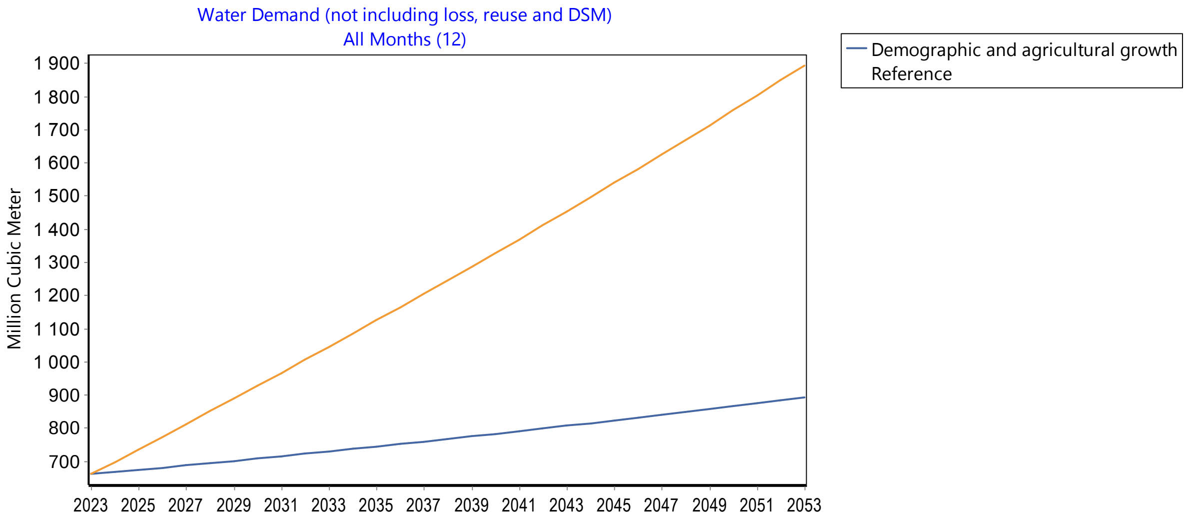


Figure 61. Water demand for all demand sites in the two scenarios (Reference, Demographic and agricultural growth scenario) (2023-2053)

The data reveal a major divergence between the two scenarios. The "Demographic and agricultural growth" scenario shows moderate annual demand, rising from 659.7 million m^3 (2023) to 892.4 million m^3 (2053), with average annual growth of 0.7% and a cumulative total of 23.86 billion m^3 over 30 years. Conversely, the "Reference" scenario, with no regulatory measures, shows exponential growth (3.3%/year), reaching 1,893.2 million m^3 in 2053, for a cumulative total of 38.93 billion m^3 (+63% compared to the first scenario).

The difference between the two scenarios lies in the updating of data and assumptions. The Reference scenario, based on obsolete statistics (ONS 2008), overestimates water demand by ignoring recent dynamics. Conversely, the "Demographic and agricultural" scenario incorporates updated data, reflecting a controlled demographic transition (+0.7%/year vs. +3.3%), reducing cumulative demand from 38.9 to 23.8 billion m^3 (-39%). This realistic approach avoids overexploitation of the water tables and the exorbitant costs of the Reference scenario, while aligning objectives with the SDGs. In conclusion, the periodic revision of planning models, integrating current socio-environmental data, is crucial for sustainable water management in the face of climate and demographic challenges.

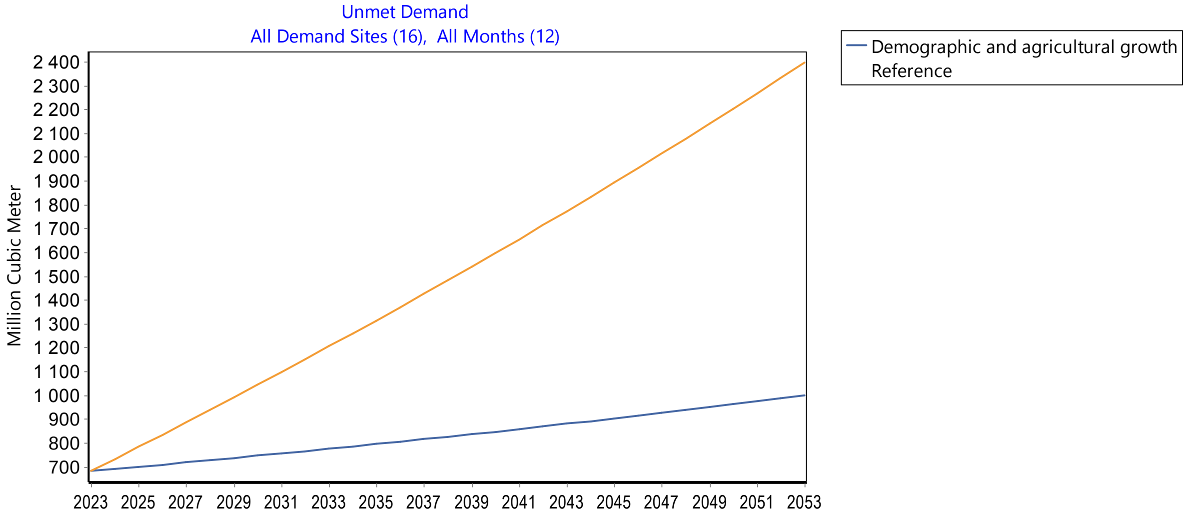


Figure 62. Unmet demand for all demand sites in the two scenarios (Reference, Demographic and agricultural growth scenario) (2023-2053)

4.7. Minimum domestic consumption scenario

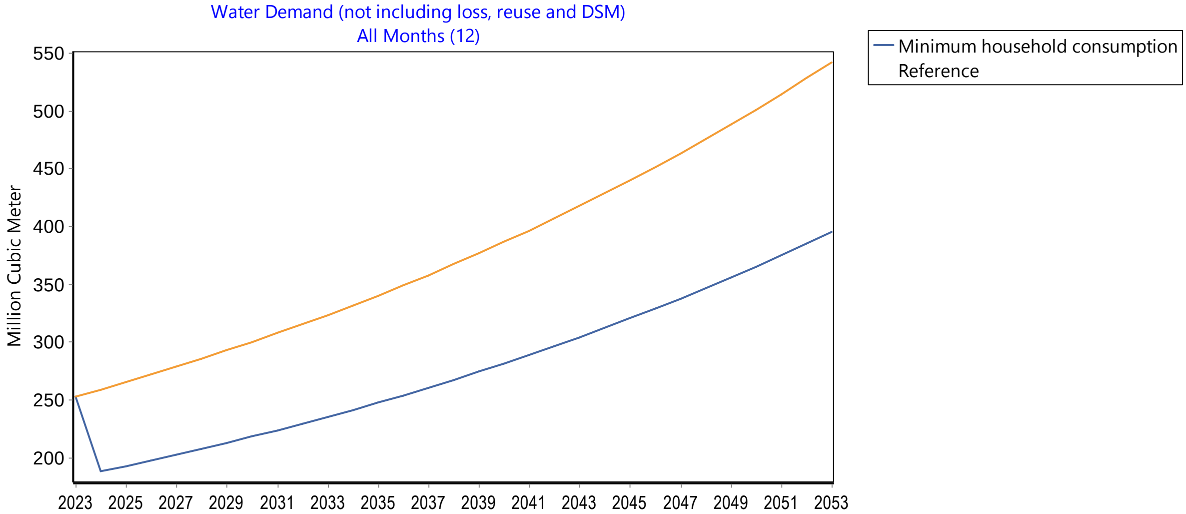


Figure 63. Water demand for all demand sites in the two scenarios (Reference, Minimum domestic consumption scenario) (2023-2053)

This scenario imposes a quota of 180 liters/day per inhabitant for drinking water, without taking into account technical losses (leaks, wastage). The aim is to reduce domestic water demand by strictly limiting consumption. The quota scenario would reduce cumulative demand by 26% compared with the Reference scenario (11.71 → 8.59 billion m^3).

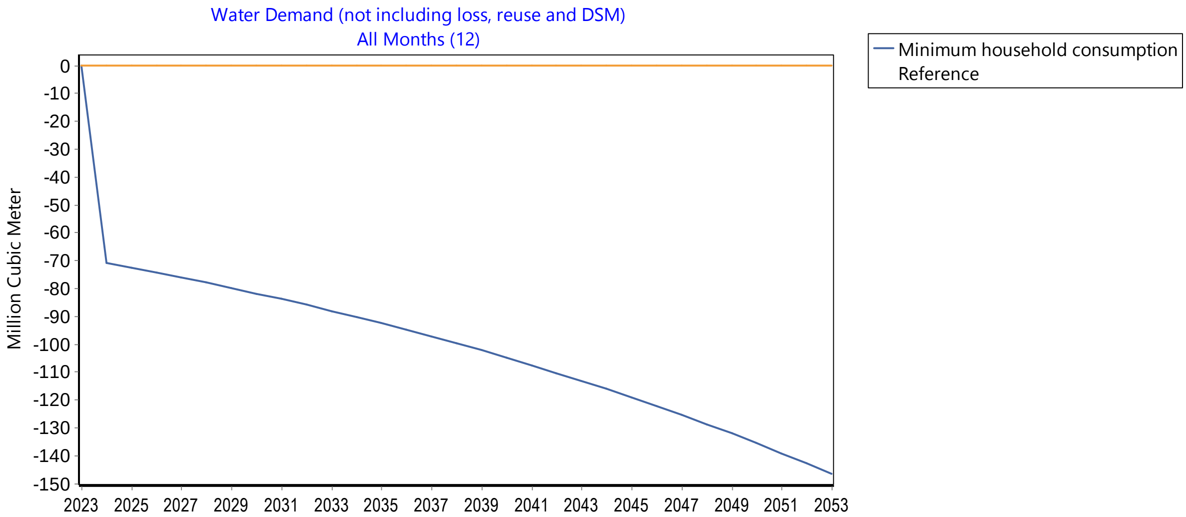


Figure 64. Water demand for all demand sites in Minimum domestic consumption scenario in relation to reference (2023-2053)

Minimum consumption generates cumulative savings of 3.114 billion m^3 over 30 years (2023-2053), or 8% of total demand in the reference scenario (38.93 billion m^3), with a gradual reduction from -70.9 million m^3 (2024) to -146.8 million m^3 (2053) (compound annual growth rate: +2.3%/year). Imposing a gross quota of 180 L/day/capita (including 30% losses) achieves a net consumption of 126 L/day, while emphasizing that reducing losses to 15% would lower the quota to 148 L/day, freeing up an additional 32 L/day/capita. These measures have a significant impact on resources:

- Avoided withdrawals: Equivalent to 3.5 years of total domestic consumption in the basin (base 2023), i.e., strategic preservation of reserves to cope with future droughts.
- Reduced pressure on water tables: Delays projected depletion by 5 to 10 years, according to current projections, mitigating the risks of salinization and drying up of coastal aquifers.

This approach, combining sobriety and technical optimization, illustrates how proactive management can reconcile human needs and ecological sustainability in a context of growing water stress.

4.8. Scenario for improving agricultural activity

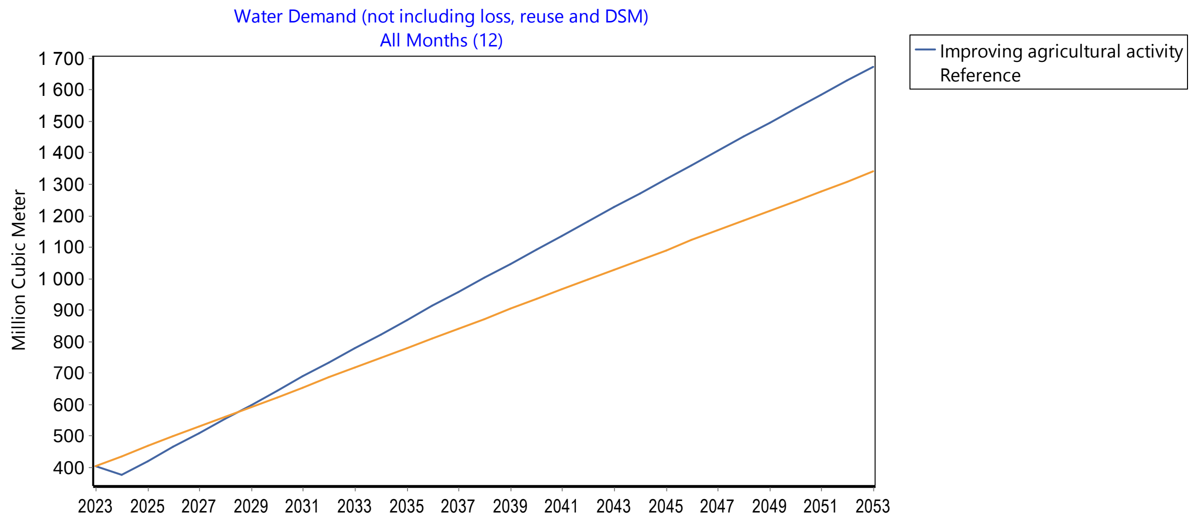
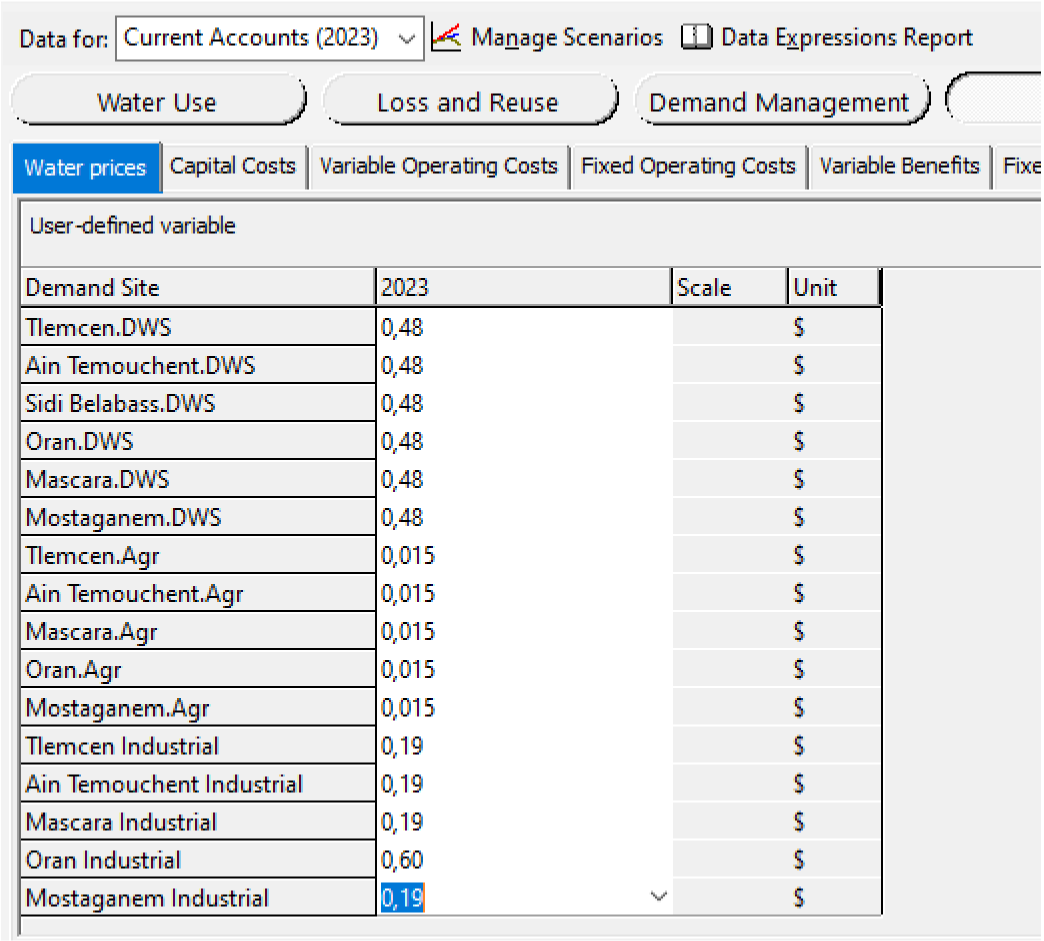


Figure 65. Water demand for all demand sites in the two scenarios (Reference, improving agricultural activity) (2023-2053)

Setting an annual water allocation of 5,000 m^3/ha in the scenario of improved agricultural practices leads to an initial 7% reduction in agricultural water demand as early as 2024 (374 vs. 435 million m^3), reflecting the optimization of water efficiency through the adoption of precision irrigation techniques (drip irrigation). However, this trend reverses in the medium term: by 2028, demand exceeds that of the reference scenario (+1% in 2028; +25% in 2053), with a cumulative 30-year deficit 15% higher (31.1 vs. 27.0 billion m^3). Total demand in 2053 is estimated at 1,673 million m^3, higher than in the reference scenario (1,339 million m^3), due to the increase in irrigated area from 65,870 ha in 2023 to 334,599 ha in 2053. This paradoxical dynamic can be explained by a rebound effect (Jevons paradox): efficiency gains encourage the expansion of irrigated areas (+408% by 2053), cancelling out initial savings. The WEAP model incorporates unregulated agricultural growth, exacerbating pressure on resources. In the absence of complementary mechanisms (land capping, promotion of resilient crops), a fixed allocation exacerbates water stress in the long term. These results underline the need for integrated strategies, combining water quotas, land regulation and agro-ecological transition, to reconcile food security and ecosystem sustainability in arid regions.

4.9. Progressive pricing scenario

Water pricing plays a key role, as illustrated in the table provided, detailing water prices for different sectors and localities. Prices for agriculture are similar, at \$0.015 per m^3, compared with \$0.19 to \$0.60 (Oran: hydrocarbons) for industry and \$0.48 for drinking water supply.



Data for: Current Accounts (2023) | Manage Scenarios | Data Expressions Report

Water Use | Loss and Reuse | Demand Management

Water prices | Capital Costs | Variable Operating Costs | Fixed Operating Costs | Variable Benefits | Fixe

User-defined variable

Demand Site	2023	Scale	Unit
Tlemcen.DWS	0,48		$
Ain Temouchent.DWS	0,48		$
Sidi Belabass.DWS	0,48		$
Oran.DWS	0,48		$
Mascara.DWS	0,48		$
Mostaganem.DWS	0,48		$
Tlemcen.Agr	0,015		$
Ain Temouchent.Agr	0,015		$
Mascara.Agr	0,015		$
Oran.Agr	0,015		$
Mostaganem.Agr	0,015		$
Tlemcen Industrial	0,19		$
Ain Temouchent Industrial	0,19		$
Mascara Industrial	0,19		$
Oran Industrial	0,60		$
Mostaganem Industrial	0,19		$

Figure 66. Water prices per m^3

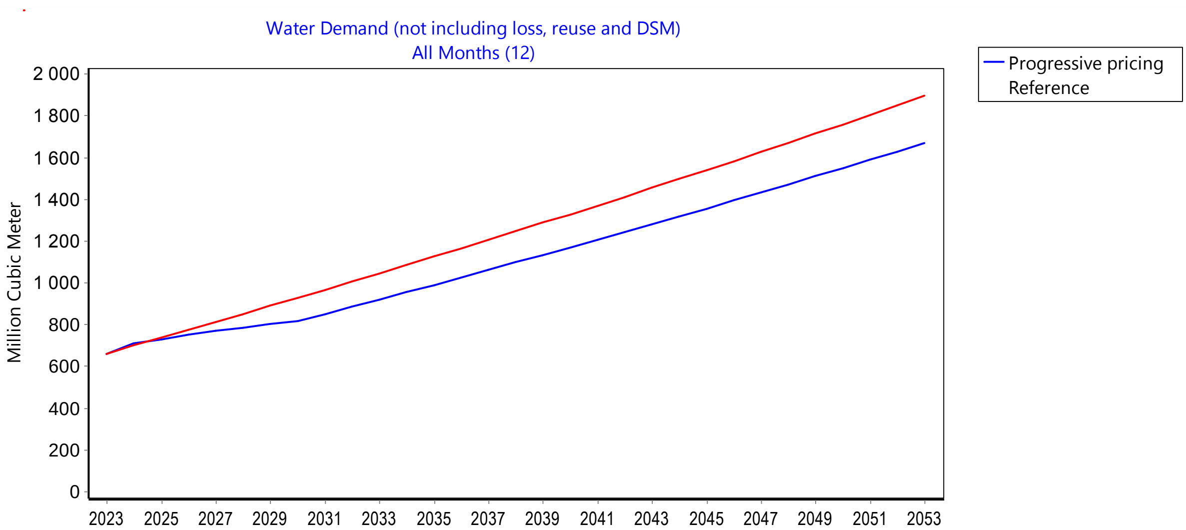


Figure 67. Water demand for all demand sites in the two scenarios (Reference, Progressive pricing) (2023-2053)

The "Progressive Pricing" scenario, combining an increase in water prices until the true price of water is reached ($1.13 for drinking water, $0.20 for agriculture and between $0.80 and $1.20

for industry) and a 10% population growth linked to illicit connections in shantytowns, reduces total water demand by 10.85% (4.2 billion m^3) over 30 years compared to the “Reference” scenario, aligned with the 10-20% reduction assumption. Although an initial rise in demand in 2024 (+7.2% vs. +5.7% for the reference) reflects the impact of illicit connections (70% of commercial losses), progressive pricing then limits annual demand growth to 2.55% (vs. 2.87%), peaking in 2053 at 1.67 billion m^3 vs. 1.89 billion for the reference. This long-term efficiency, although at the lower end of projections, underlines the deterrent role of high prices for large consumers, while revealing structural challenges: behavioral inertia in the face of pricing, uncontrolled demographic pressure, and the need for complementary policies (leakage control, water reuse). So, despite a significant reduction, achieving sustainability objectives in a context of chronic scarcity (40% drop in water tables since 2000) requires an integrated approach, combining strengthened governance, energy-saving technologies and social equity for vulnerable households.

4.10. Integrated best practice scenario

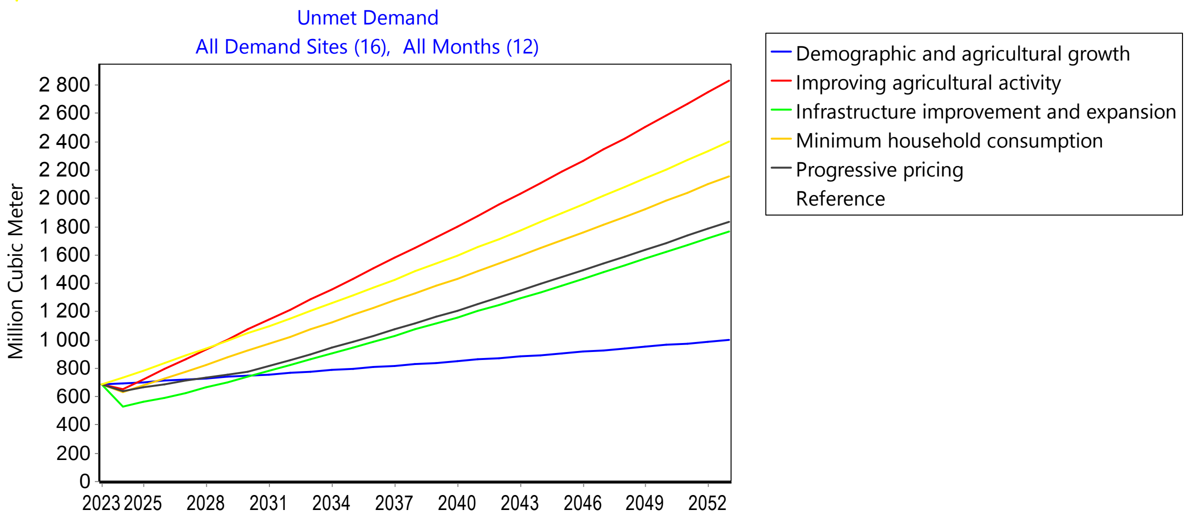


Figure 68. Unmet demand for all demand sites in the two scenarios (reference, best-practice) (2023-2053)

This study evaluates six scenarios for managing unmet water demand. The results reveal significant differences between the strategies, both in terms of annual demand and cumulative trends. The “Demographic and agricultural growth” scenario emerges as the most efficient, with a total unmet demand of 25.7 billion m^3 (2023-2053) and a compound annual growth rate (CAGR) of 1.37%, compared with 51.9 billion m^3 and 4.92% for the “Improving agricultural activity” scenario, the least efficient. This discrepancy is explained by the probably integrated management of the former, combining moderate population growth and optimized agricultural practices, while the latter, despite its name, reflects agricultural intensification unsupported by infrastructure or water-saving policies, exacerbating pressure on resources. The "Infrastructure improvement and expansion" scenario (33.9 billion m^3; CAGR 3.45%) and the "Progressive pricing" scenario (35.7 billion m^3; 3.58%) show an intermediate efficiency, but higher than the reference scenario (46.5 billion m^3; 4.50%). The former illustrates the impact of investments in water networks to reduce losses and increase supply, while the latter highlights the dissuasive role of progressive pricing (penalizing large consumers) in moderating demand. On the other hand, the "Minimum household consumption" scenario (41.7 billion m^3; 4.20%), while reducing domestic consumption, remains less effective, suggesting that measures targeting households alone neglect other key sectors such as agriculture and industry. These results highlight two critical dynamics: - The effectiveness of multi-factorial approaches: the success of the "Demographic and agricultural growth" scenario implies coordination between demographic management, sustainable agricultural practices and water governance, in contrast to the failure of the "Improving agricultural activity" scenario, which focuses on a single sector without global regulation. - The need to combine pricing and infrastructure: While progressive pricing reduces demand, its effect remains limited without modernized infrastructure to capture, distribute and recycle water efficiently. In conclusion, reducing unmet demand in the Oran basin requires a holistic strategy, integrating controlled growth, technological innovation and economic incentive mechanisms, while strengthening governance to limit illicit connections and wastage. The best scenarios offer a roadmap for balancing socio-economic development and water sustainability in a context of growing water stress.

5. Conclusions, and Recommendations

5.1. Conclusion

This prospective study, based on integrated water resource modeling using the WEAP system, analyzed the water trajectories of the Oran coastal basin in a context of accelerating climatic, demographic and socio-economic change. By combining hydrological data, climate projections (IPCC RCP 4.5 and 8.5 scenarios) and socio-structural parameters (population growth, agricultural expansion), it reveals a dynamic of growing tension between limited availability and sectoral needs, characteristic of arid Mediterranean regions.

The results highlight a linear increase in water demand, from 660 million m^3 in 2023 to 1.89 billion m^3 in 2053, under the combined effect of three key factors:

- Agricultural expansion, responsible for 70.7% of total demand in 2053, resulting from an extension of irrigated areas (+408%) and crop intensification, despite stagnant water efficiency.
- Demographic pressure (+1.8%/year), amplifying domestic needs, particularly in urban centers such as Oran, where human concentration generates 79% of drinking water demand.
- Industrial growth, albeit marginal (0.7%), reflecting an economy polarized around water-hungry sectors (agri-food, energy).

Climate projections, with falling rainfall (-20%), rising temperatures (+3 °C) and more frequent droughts, are exacerbating these imbalances. The annual water deficit, estimated at 2.4 billion m^3 in 2053, exposes a systemic vulnerability, particularly marked during summer periods (61% of demand between May and August). This seasonal pattern increases the risk of overexploitation of water tables, already in decline (-40% since 2000), and compromises the natural recharge of aquifers.

The WEAP model was used to simulate a number of scenarios, including: Business-as-Usual, Population and Agricultural Growth, Minimum Domestic Consumption, Improved Agricultural Activities, Improved and Expanded Infrastructure, Progressive Pricing, and Integrated Best Practices.

These scenarios are used to assess the impact of different policies on water demand, groundwater reserves and intersectoral conflicts. The analysis reveals that, without new policies, unmet demand could triple by 2053, with agricultural consumption dominating (70%), exacerbated by climate change and population growth.

The results show that the "Population and agricultural growth" scenario is the most effective, significantly reducing unmet demand through integrated management combining moderate population growth and optimized agricultural practices. In comparison, the reference scenario is unsustainable, projecting a dramatic increase in demand due to agricultural expansion, industrial growth and urbanization without new policies, leading to groundwater depletion and intersectoral conflicts.

Other scenarios, such as "Infrastructure Improvement and Expansion" and "Progressive Pricing", show intermediate effectiveness by focusing on losses and moderating demand through technological improvements and economic incentives. However, the "Minimum domestic consumption" scenario is less effective, as it neglects the agricultural and industrial sectors, which dominate consumption.

The study highlights the need for a multifaceted strategy, integrating:

- Controlled demographic and agricultural growth,
- Technological innovations, such as efficient irrigation and digitization of networks,
- Economic mechanisms, such as progressive pricing,
- Strengthened governance to reduce illicit water use and wastage.

This approach aims to balance socio-economic development with water sustainability, in the face of the pressures of climate change and population growth.

The study warns of the limitations of supply-side solutions, such as building new dams or desalination, due to their high costs, environmental risks and operational inefficiencies. It argues in favor of demand-side management, which seems more promising for reducing water deficits in the long term. Adaptation to climate change, via resilient agricultural practices and regular model updates, is essential to anticipate future risks, notably a projected 10-20% drop in abstractions by 2050.

Social equity is also a central issue, with disparities in access to water between Oran and rural areas, requiring targeted investment. Participatory governance and collaboration with parties are crucial to legitimize and ensure the success of policies, while monitoring the social impacts of reforms, such as tariff adjustments, to protect vulnerable populations.

This research contributes to a holistic understanding of water challenges in arid regions, where water scarcity is a critical vulnerability factor. The study concludes that an integrated approach, combining technical, institutional, financial, climatic and social levers, is essential to guarantee long-term water security in the Oran coastal basin. This balance between socio-economic development and environmental sustainability must be aligned with global objectives, such as SDG 6 (clean water and sanitation), in order to reconcile human needs with ecosystem preservation.

To meet these complex challenges, continuous monitoring of resources, enhanced collaboration between stakeholders and adaptive public policies are essential. These measures, anchored in inclusive and proactive governance, will enable us to anticipate crises, optimize resource allocation and strengthen resilience in the face of climatic and demographic uncertainties. Thus, the success of sustainable water management depends on a collective commitment, where technical innovation and social equity combine to build a viable water future.

5.2. Recommandations

The recommendations are structured into five categories, as follows:

5.2.1. Lever techniques

Reduce water losses (currently 32%) to 15% in 5 years via IoT systems, smart metering and network rehabilitation. Promote drip irrigation to reduce demand to 5,000 m^3/ha/year. Improve the efficiency of desalination plants (80% operational capacity) with renewable energies.

5.2.2. Institutionnel levers

Strengthen coordination via basin committees and a centralized data-sharing platform. Implement quotas and strict monitoring for groundwater abstraction. Promote participatory governance with local communities, NGOs and the private sector.

5.2.3. Financial leverage

Introduce progressive pricing (e.g., USD 1.13/m^3 for domestic use, USD 0.20/m^3 for agriculture) with subsidies for low-income households or subsidies for water-optimizing equipment (low-flow showerheads, aerators/faucet aerators, dual-flush or low-volume toilets, water-saving washing machines and dishwashers, smart water meters, smart valves, and drip irrigation systems). Allocate public funds to infrastructure modernization (USD 126.7 million estimated) rather than costly new projects (USD 500 million to USD 1 billion for new desalination plants). Exploring public-private partnerships and international financing for projects such as wastewater reuse.

5.2.4. Climate adaptation measures

Develop drought-resistant crops and seasonal storage systems, in the face of a projected 10-20% drop in water withdrawals by 2050. Set up early warning systems and flood management infrastructures. Regularly update WEAP models with new climate data and socio-economic trends.

5.2.5. Social and equity considerations

Ensure equitable access to water by investing in underserved regions (current connection rate 98%). Launch awareness campaigns to promote water conservation. Monitor the social impacts of tariff reforms and offer alternatives for populations dependent on water-consuming activities.

These recommendations offer a roadmap for decision-makers, drawing on insights from the WEAP model to ensure adaptive, equitable and resilient water management.

REFERENCES

Agence Nationale des Ressources Hydrauliques. (2020). Rapport sur l'état des ressources en eau en Algérie.

Besbes, M., Chahed, J., & Hamdane, A. (2018). Gestion participative de l'eau en Tunisie. Éditeur.

Intergovernmental Panel on Climate Change. (2021). Climate change 2021: The physical science basis. Groupe de travail I du GIEC. https://doi.org/10.1017/9781009157896

Stockholm Environment Institute. (2016). WEAP user guide. SEI.

Yates, D., Sieber, J., Purkey, D., & Huber-Lee, A. (2005). WEAP21—A Demand-, Priority-, and Preference-Driven Water Planning Model: Part 1: Model Characteristics. Water International, 30(4), 487–500. https://doi.org/10.1080/02508060508691893

Nations Unies. (2015). Objectif de développement durable 6 : Eau propre et assainissement. https://www.un.org/sustainabledevelopment/fr/water-and-sanitation/

Groupe de Développement Agricole. (2018). Rapport annuel sur la gestion des aquifères en Tunisie. Ministère de l'Agriculture Tunisien.

Hamlat, A., Errih, M., & Guidoum, A. (2013). Simulation of water resources management scenarios in western Algeria watersheds using WEAP model. Arabian Journal of Geosciences, 6, 2225–2236. https://doi.org/10.1007/s12517-012-0539-0

Zekri, S. (Ed.). (2020). Water Policies in MENA Countries. Springer International Publishing. https://doi.org/10.1007/978-3-030-29274-4

Kumar, R. et al. (2021). Evaluating Water Supply Risk in the Middle Reaches of Subarnarekha River Basin Using WEAP. Indian Journal of Environmental Protection.

Alemayehu, T. et al. (2010). Water Resource Implications of Development in Lake Tana Catchment. Ecohydrology and Hydrobiology.

Carpenter, A. & Choudhary, M.K. (2022). Water Demand Analysis in Veda River Basin Using WEAP. Trends in Sciences.

Mansouri, S. et al. (2017). Inter-Region Water Planning in Seybouse Basin. Journal of Water and Land Development.

Fanta, S.S. et al. (2022). Water Supply-Demand Assessment in Gilgel Gibe. Sustainable Water Resources Management.

Cacal, J.C. et al. (2024). Climate Impacts on Irawan Watershed. Earth (Switzerland).

Hamlat, A. et al. (2013). Water Management in Western Algeria. Arabian Journal of Geosciences.

Hassan, D. et al. (2019). Future Water Demand in Indus Basin. Sustainable Water Resources Management.

Shahraki, A.S. et al. (2019). Integrated Water Management in Sistan. Water Resources.

Javadinejad, S. et al. (2019). Multi-Index Analysis in Zayandeh Rud Basin. Water Conservation Science and Engineering.

Mohd Firdaus Hum, N.N. & Abdul Talib, S. (2016). Water Management in Selangor. Jurnal Teknologi.

Droogers P., Terink W., Hunink J., Kauffman S., et Godert V. L., 2011 : « Options de gestion de l'eau verte dans le bassin du Sebou, Maroc – Analyse avantages-coûts utilisant le modèle WEAP », Green Water Credits Report M2a / FutureWater Report 102.

SEI (Stockholm Environment Institute), Tutoriel de WEAP. Guide utilisateur du système d'évaluation et de planification des ressources en eau (WEAP); 2008.

Sieber, Purkey D (2015) WEAP. Environment 343. http://www.weap21.org/ Accessed 10 Dec 2024

Razisadath PV, Rinishakartheeshwari M, Elango L (2023) WEAP model-based evaluation of future scenarios and strategies for sustainable water management in the Chennai Basin, India. Aqua Water Infrastruct Ecosys Soci 72(11):2062–2080. https://doi.org/ 10.2166/aqua.2023.144

Yao AB, Mangoua OMJ, Georges ES, Kane A, Goula BTA (2021) Using the “Water Evaluation and Planning” (WEAP) model to simulate water demand in Lobo Watershed (Central-Western Cote d’Ivoire). J Water Resour Prot 13(03):216–235. https://doi. org/10.4236/jwarp.2021.133013

Li X, Zhao Y, Shi C, Sha J, Wang ZL, Wang Y (2015a) Application of Water Evaluation and Planning (WEAP) model for water resources management strategy estimation in coastal Binhai New Area, China. Ocean Coast Manag 106:97–109. https://doi.org/10. 1016/j.ocecoaman.2015.01.016

Li Z, Deng X, Wu F, Hasan SS (2015b) Scenario analysis for water resources in response to land use change in the middle and upper reaches of the Heihe River Basin. Sustainability 7(3):3086–3108. https://doi.org/10.3390/su7033086

Ortiz-Partida JP, Fernandez-Bou AS, Maskey M, Rodríguez-Flores JM, Medellín-Azuara J, Sandoval-Solis S, Ermolieva T, Kanavas Z, Sahu RK, Wada Y, Kahil T (2023) Hydro-economic modeling of water resources management challenges: current applications and future directions. Water Econ Policy 9(1). https://doi.org/10. 1142/S2382624X23400039

Rashid AB, Kausik MAK (2024) AI revolutionizing industries worldwide: A comprehensive overview of its diverse applications. Hybrid Adv 7(August):100277. https://doi.org/10.1016/j.hybadv. 2024.100277

Fard, M. and Sarjoughian, H. (2024). A knowledge interchange broker composition modeling framework for simulating water, energy, and water-energy nexus systems. Simulation, 100(7), 657-682. https://doi.org/10.1177/00375497241233783

Ghimire, U., Piman, T., Shrestha, M., Aryal, A., & Krittasudthacheewa, C. (2022). Assessment of climate change impacts on the water, food, and energy sectors in sittaung river basin, myanmar. Water, 14(21), 3434. https://doi.org/10.3390/w14213434

Rajosoa, A., Abdelbaki, C., & Mourad, K. (2021). Water assessment in transboundary river basins: the case of the medjerda river basin. Sustainable Water Resources Management, 7(6). https://doi.org/10.1007/s40899-021-00566-0

Ramírez, C., Almulla, Y., Joyce, B., Huber□Lee, A., & Nerini, F. (2022). An assessment of strategies for sustainability priority challenges in jordan using a water–energy–food nexus approach. Discover Sustainability, 3(1). https://doi.org/10.1007/s43621-022-00091-w

Samaké, O., Traoré, K., Bengaly, A., Yens, A., Traoré, B., & Cisse, F. (2023). Effets de différentes modalités de trempage de semences sur le rendement du maïs dans l'agriculture de décrue à yélimané en zone sahélienne du mali. International Journal of Biological and Chemical Sciences, 16(6), 2549-2559. https://doi.org/10.4314/ijbcs.v16i6.7

Yates, D., Mehta, V., Huber□Lee, A., McCluskey, A., & Purkey, D. (2021). Exploring the water-energy nexus in california via an integrative modeling approach. Journal of Water Resources Planning and Management, 147(12). https://doi.org/10.1061/(asce)wr.1943-5452.0001431

Ossa-Moreno, J. Integrated hydrological and economic modelling of a mining region.. https://doi.org/10.14264/uql.2019.714

Dali, N. (2021). Planning and management of water resources in the context of economic devlopment and climate change in algerian highlandsby the weap model, case of the gareat el tarf basin (northwestern algeria). Civil and Environmental Engineering Reports, 31(1), 200-215. https://doi.org/10.2478/ceer-2021-0015

Dias, I., Lázaro, L., & Barros, V. (2023). Water–energy–food security nexus—estimating future water demand scenarios based on nexus thinking: the watershed as a territory. Sustainability, 15(9), 7050. https://doi.org/10.3390/su15097050

Furlong, C., Guthrie, L., Silva, S., & Considine, R. (2015). Informing infrastructure planning processes for iuwm projects., 395-406. https://doi.org/10.2495/sd150341

Höllermann, B., Giertz, S., & Diekkrüger, B. (2010). Benin 2025—balancing future water availability and demand using the weap 'water evaluation and planning' system. Water Resources Management, 24(13), 3591-3613. https://doi.org/10.1007/s11269-010-9622-z

Johannsen, I., Hengst, J., Goll, A., Höllermann, B., & Diekkrüger, B. (2016). Future of water supply and demand in the middle drâa valley, morocco, under climate and land use change. Water, 8(8), 313. https://doi.org/10.3390/w8080313

Mohammadpour, M., Zeinalzadeh, K., Rezaverdinejad, V., & Hessari, B. (2023). Assessing the impacts of large□scale substitution of pressurized irrigation on basin hydrology through a water accounting framework. Irrigation and Drainage, 72(2), 465-477. https://doi.org/10.1002/ird.2790

Muok, B. and Onyango, O. (2020). Impacts of conflicting, institutional mandates on water security: pathways for water sector development in turkana county, kenya. Science Technology & Public Policy, 4(2), 44. https://doi.org/10.11648/j.stpp.20200402.11

Ochola, W., Kerkides, P., Argyrokastritis, I., & Kollias, V. (2004). Water resources hazard management system: spatial extension for the assessment of sustainable water use practices in kenya. Irrigation and Drainage, 53(3), 225-236. https://doi.org/10.1002/ird.120

Abdelkader, A., Elshorbagy, A., Elshamy, M., & Wheater, H. (2023). Future pathways of water, energy, and food in the eastern nile basin.. https://doi.org/10.22541/essoar.169264778.88321360/v1

Awad, M. and Zaid-Alkelani, M. (2019). Prediction of water demand using artificial neural networks models and statistical model. International Journal of Intelligent Systems and Applications, 11(9), 40-55. https://doi.org/10.5815/ijisa.2019.09.05

Dau, Q., Momblanch, A., & Adeloye, A. (2021). Adaptation by himalayan water resource system under a sustainable socioeconomic pathway in a high-emission context. Journal of Hydrologic Engineering, 26(3). https://doi.org/10.1061/(asce)he.1943-5584.0002064

Dias, I., Lázaro, L., & Barros, V. (2023). Water–energy–food security nexus—estimating future water demand scenarios based on nexus thinking: the watershed as a territory. Sustainability, 15(9), 7050. https://doi.org/10.3390/su15097050

González□Cebollada, C. and Grassa, N. (2022). Sensitivity analysis in water resources models to improve projects resilience. https://doi.org/10.21203/rs.3.rs-1846289/v1

Hall, J. and Murphy, C. (2010). Vulnerability analysis of future public water supply under changing climate conditions: a study of the moy catchment, western ireland. Water Resources Management, 24(13), 3527-3545. https://doi.org/10.1007/s11269-010-9618-8

Höllermann, B., Giertz, S., & Diekkrüger, B. (2010). Benin 2025—balancing future water availability and demand using the weap 'water evaluation and planning' system. Water Resources Management, 24(13), 3591-3613. https://doi.org/10.1007/s11269-010-9622-z

Kularathna, M., Ashbolt, S., Jahanbani, H., Daamen, C., Mckerrow, M., & Rhodes, B. (2017). Transition from water resource system modelling towards integrated water modelling: melbourne water's challenges and experiences. https://doi.org/10.36334/modsim.2017.l6.kularathna

Mansouri, S., Ouerdachi, L., & Remaoun, M. (2017). Inter-region planning and analysis of water resources by using weap model seybouse (annaba) and coastal east of constantine (el-taref). Journal of Water and Land Development, 33(1), 115-122. https://doi.org/10.1515/jwld-2017-0026

Ojwang, R., Dietrich, J., Anebagilu, P., Beyer, M., & Rottensteiner, F. (2017). Rooftop rainwater harvesting for mombasa: scenario development with image classification and water resources simulation. Water, 9(5), 359. https://doi.org/10.3390/w9050359

Salem, S., Salem, A., Karmaoui, A., & Khebiza, M. (2023). Vulnerability of water resources to drought risk in southeastern morocco: case study of ziz basin. Water, 15(23), 4085. https://doi.org/10.3390/w15234085

Schultz, G. (2000). Potential of modern data types for future water resources management. Water International, 25(1), 96-109. https://doi.org/10.1080/02508060008686801

Slaymane, R. and Soliman, M. (2022). Integrated water balance and water quality management under future climate change and population growth: a case study of upper litani basin, lebanon. Climatic Change, 172(3-4). https://doi.org/10.1007/s10584-022-03385-0

Waage, M. and Kaatz, L. (2011). Nonstationary water planning: an overview of several promising planning methods1. Jawra Journal of the American Water Resources Association, 47(3), 535-540. https://doi.org/10.1111/j.1752-1688.2011.00547.x

Yan, D., Werners, S., Huang, H., & Ludwig, F. (2016). Identifying and assessing robust water allocation plans for deltas under climate change. Water Resources Management, 30(14), 5421-5435. https://doi.org/10.1007/s11269-016-1498-0

Lina, Bendjema & Baba-Hamed, Kamila & Bouanani, Abderrazak. (2019). Characterization of the climatic drought indices application to the Mellah catchment, North-East of Algeria. Journal of Water and Land Development. 43. 28-40. 10.2478/jwld-2019-0060.

APPENDIX

```
WEAP Data Expressions Report

Area: Integrated Water Resources Modeling of the Oranais Coastal Basin
Scenario: Infrastructure improvement and expansion
Date: 15/04/2025


Key Assumptions
Demand Sites
  Tlemcen.DWS                      Loss and Reuse      Loss Rate (%)
15
  Ain Temouchent.DWS               Loss and Reuse      Loss Rate (%)
15
  Sidi Belabass.DWS                Loss and Reuse      Loss Rate (%)
15
  Oran.DWS                         Loss and Reuse      Loss Rate (%)
20
  Mascara.DWS                      Loss and Reuse      Loss Rate (%)
15
  Mostaganem.DWS                   Loss and Reuse      Loss Rate (%)
15
  Tlemcen.Agr                      Loss and Reuse      Loss Rate (%)
10
  Ain Temouchent.Agr               Loss and Reuse      Loss Rate (%)
10
  Mascara.Agr                      Loss and Reuse      Loss Rate (%)
10
  Oran.Agr                         Loss and Reuse      Loss Rate (%)
10
  Mostaganem.Agr                   Loss and Reuse      Loss Rate (%)
10
  Tlemcen Industrial
  Ain Temouchent Industrial
  Mascara Industrial
  Oran Industrial
  Mostaganem Industrial
Hydrology
  Water Year Method
  Read from File
Supply and Resources
  River
    COTIER GHAZAOUET RIVER
      Reaches
        Below COTIER GHAZAOUET RIVER Headflow
        Below Tlemcen Industrial Return
        Below Tlemcen.Agr Return
        Below Tlemcen.DWS Return
    COTIER CENTRAL RIVER 1
      Reaches
        Below COTIER CENTRAL RIVER 1 Headflow
        Below Ain Temouchent Industrial Return
        Below Ain Temouchent.Agr Return
        Below Sidi Belabass.DWS Return
        Below Mascara.Agr Return
        Below Mascara Industrial Return
        Below Oran.Agr Return
        Below Mascara.DWS Return
        Below Oran Industrial Return
    COTIER CENTRAL RIVER 2
      Reaches
        Below COTIER CENTRAL RIVER 2 Headflow
        Below Ain Temouchent.DWS Return
        Below Ain Turk wastewater treatment plant Return
        Below Oran.DWS Return
    COTIER MOSTAGANEM RIVER
      Reaches
        Below COTIER MOSTAGANEM RIVER Headflow
        Below Mostaganem.DWS Return
        Below Mostaganem.Agr Return
        Below Mostaganem Industrial Return
  Groundwater
    Vallée de OUED KISS
    Vallée de OULED GHAZOUANAH
```

```
    MONT DES TRARAS
    REGION DE SEBAA CHIOUKH OUED ISSER
    PLATEAU DE SIDI SAFI
    PLATEAU DE AIN TEMOUCHENT
    REGION DE OULED TAOUI OULED BOUJEMAA
    PLAINE DE LA MULETA
    FLANC SUD DU MURDJADJO
    FORET DE MSILA
    PLAINE COTIERE ORANAISE
    PLATEAU DE ORAN
    PLATEAU DES HASSIS
    MONT DE ARZEW
    PLATEAU DE MOSTAGANEM
  Other Supply
    Honaine Desalination
    Souk Thelata Desalination
    Chatt el Hilal Desalination
    Mactaa Desalination
    Mostaganem Desalination
    Bousfer Desalination
    Les Dunes Desalination
    Kahrama Desalination
    Brédéah Demineralisation
    BRISE CHARGE 3  RESERVOIR TAMPON 2
    Beni Bahdel Dam
    Dzioua inter seasonal drinking water supply
    Mostaganem Arzew Oran transfer system MAO
    cap blanc desalination
  Transmission Links
    to Tlemcen.DWS
      from Honaine Desalination        Linking Rules       Maximum Flow   Volume (m^3/day)
Interp( 2027;45000;  2053;50000 )
      from Souk Thelata Desalination   Linking Rules       Maximum Flow   Volume (m^3/day)
Interp( 2027;28000;  2053;40000 )
      from Vallée de OULED GHAZOUANAH   Linking Rules       Maximum Flow   Volume (m^3/day)
1339
      from MONT DES TRARAS
      from Vallée de OUED KISS
      from Beni Bahdel Dam
    to Ain Temouchent.DWS
      from Chatt el Hilal Desalination   Linking Rules       Maximum Flow   Volume (m^3/day)
Smooth( 2027;80000;  2053;92000 )
      from REGION DE SEBAA CHIOUKH OUED ISSER
      from PLATEAU DE AIN TEMOUCHENT
      from PLATEAU DE SIDI SAFI
      from REGION DE OULED TAOUI OULED BOUJEMAA
      from Dzioua inter seasonal drinking water supply   Linking Rules       Maximum Flow
Volume (m^3/day)         Interp( 2027;10000 )
    to Sidi Belabass.DWS
      from BRISE CHARGE 3  RESERVOIR TAMPON 2
    to Oran.DWS
      from Chatt el Hilal Desalination   Linking Rules       Maximum Flow   Volume (m^3/day)
Interp( 2027;90000;  2040;95000;  2053;100000 )
      from Brédéah Demineralisation
      from Bousfer Desalination        Linking Rules       Maximum Flow   Volume (m^3/day)
Interp( 2053;5000 )
      from Les Dunes Desalination      Linking Rules       Maximum Flow   Volume (m^3/day)
Interp( 2053;4500 )
      from Mactaa Desalination         Linking Rules       Maximum Flow   Volume (m^3/day)
Interp( 2027;350000;  2053;450000 )
      from Kahrama Desalination        Linking Rules       Maximum Flow   Volume (m^3/day)
Interp( 2053;80000 )
      from FLANC SUD DU MURDJADJO
      from FORET DE MSILA
      from PLAINE COTIERE ORANAISE
      from MONT DE ARZEW
      from PLATEAU DE ORAN
      from PLATEAU DES HASSIS
      from PLAINE DE LA MULETA
      from Dzioua inter seasonal drinking water supply   Linking Rules       Maximum Flow
Volume (m^3/day)         Interp( 2027;30000 )
      from Mostaganem Arzew Oran transfer system MAO
    to Mascara.DWS
      from Mactaa Desalination         Linking Rules       Maximum Flow   Volume (m^3/day)
Interp( 2027;15000 )
      from PLAINE DE LA MULETA
    to Mostaganem.DWS
```

```
      from Mostaganem Desalination     Linking Rules       Maximum Flow   Volume (m^3/day)
Interp( 2027;180000 )
      from PLATEAU DE MOSTAGANEM
      from Mostaganem Arzew Oran transfer system MAO
    to Tlemcen.Agr
      from REGION DE SEBAA CHIOUKH OUED ISSER
      from Vallée de OULED GHAZOUANAH
      from MONT DES TRARAS
      from Vallée de OUED KISS
    to Ain Temouchent.Agr
      from REGION DE SEBAA CHIOUKH OUED ISSER
      from PLAINE DE LA MULETA
      from PLATEAU DE AIN TEMOUCHENT
      from PLATEAU DE SIDI SAFI
      from REGION DE OULED TAOUI OULED BOUJEMAA
      from Chaabat El Leham wastewater treatment plant
    to Mascara.Agr
      from PLAINE DE LA MULETA
    to Oran.Agr
      from FLANC SUD DU MURDJADJO
      from FORET DE MSILA
      from MONT DE ARZEW
      from PLAINE COTIERE ORANAISE
      from PLATEAU DES HASSIS
      from PLATEAU DE ORAN
      from El Kerma wastewater treatment plant
      from Ain Turk wastewater treatment plant
    to Mostaganem.Agr
      from PLATEAU DE MOSTAGANEM
    to Tlemcen Industrial
      from Vallée de OUED KISS
    to Ain Temouchent Industrial
      from PLATEAU DE SIDI SAFI
    to Mascara Industrial
      from PLAINE DE LA MULETA
    to Oran Industrial
      from MONT DE ARZEW
      from PLATEAU DES HASSIS
    to Mostaganem Industrial
      from PLATEAU DE MOSTAGANEM
  Return Flows
    from Tlemcen.DWS
      to Tlemcen.DWS Return
    from Ain Temouchent.DWS
      to Chaabat El Leham wastewater treatment plant
      to Ain Temouchent.DWS Return
    from Sidi Belabass.DWS
      to Sidi Belabass.DWS Return
    from Oran.DWS
      to Ain Turk wastewater treatment plant
      to El Kerma wastewater treatment plant
      to Oran.DWS Return
    from Mascara.DWS
      to Mascara.DWS Return
    from Mostaganem.DWS
      to Mostaganem.DWS Return
    from Tlemcen.Agr
      to Tlemcen.Agr Return
    from Ain Temouchent.Agr
      to Ain Temouchent.Agr Return
    from Mascara.Agr
      to Mascara.Agr Return
    from Oran.Agr
      to Oran.Agr Return
    from Mostaganem.Agr
      to Mostaganem.Agr Return
    from Ain Turk wastewater treatment plant
      to Ain Turk wastewater treatment plant Return
    from Tlemcen Industrial
      to Tlemcen Industrial Return
    from Ain Temouchent Industrial
      to Ain Temouchent Industrial Return
    from Mascara Industrial
      to Mascara Industrial Return
    from Oran Industrial
      to Oran Industrial Return
    from Mostaganem Industrial
```

```
      to Mostaganem Industrial Return
Water Quality
  Wastewater Treatment
    El Kerma wastewater treatment plant
    Ain Turk wastewater treatment plant
    Chaabat El Leham wastewater treatment plant
Other Assumptions
```