International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 3, 2025
https://www.theaspd.com/ijes.php

Assessment Of Risks And Vulnerabilities Related To Climate Change On Water Resource Availability And Forms Of Adaptation In The Wilaya Of Constantine, (Algeria)

Sandra Boussetti
Institute of Urban Technology Management, University of L'Arbi Ben M'hidi Oum El Bouaghi (Algeria), boussetti.sandra@yahoo.fr,ORCID: https://orcid.org/0009-0001-1467-7675
Received: 23/03/2025 Accepted: 25/04/2025 Published: 12/05/2025

Abstract
Faced with the worsening impacts of climate change, the wilaya of Constantine, located in a semi-arid zone, presents a marked vulnerability in terms of water resource management. This study uses simulations from the RCA4 regional climate model to assess the effects of climate change on local water availability. It adopts an integrated territorial approach, combining climate data, socio-economic dynamics and institutional frameworks. The results reveal an increase in temperatures (>1 °C), a reduction in precipitation (509 mm/year) and an intensification of evaporation over a period of 51 years. Analysis of the SPI and RDI indices highlights an increase in moderate to severe droughts, particularly in 1983 (SPI ≈ -2.1), 2005 (-2.0) and 2021 (-1.7), reflecting strong interannual variability since the 2000s. These findings call for an urgent reconfiguration of water planning in order to strengthen territorial resilience in a Mediterranean context subject to increasing climatic pressures.
Keywords: *Climate change, Vulnerability, Risk, Standard Precipitation Index, Wilaya of Constantine.*

INTRODUCTION

The recent findings of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) unequivocally confirm the existence of global warming (IPCC, 2007). Although natural climate fluctuations are recognized, scientific research has clearly established that the increase in human-induced greenhouse gas concentrations is a determining factor in current global climate disruptions (IPCC, 2007). While uncertainties remain regarding the exact extent of these disruptions, numerous studies highlight their significant impacts on water resource management, both in terms of availability and demand (El- Meddahi , 2016; Moumni et al., 2018).

The African continent is particularly exposed to the impacts of climate change, due to its high structural vulnerability (Adenle et al., 2017). This fragility is exacerbated by the heavy reliance on agriculture for livelihoods and food security, its weight in the national economy, as well as limited adaptation capacities (Busby et al., 2014 ; Calzadilla et al., 2013). Furthermore, pressure on water resources is intensifying due to population growth and changing uses, a situation that climate change is likely to further aggravate (Ayanlade et al., 2018 ; Faramarzi et al., 2013 ; Goulden et al., 2009). These conditions make it imperative to implement adaptation and mitigation strategies tailored to local specificities (Epule et al., 2017).Among the regions particularly affected, semi-arid areas, such as northeastern Algeria, are already experiencing the tangible effects of climate change. This global phenomenon profoundly influences natural and socioeconomic systems, in particular by intensifying pressure on water resources, considered one of the most vulnerable sectors. Reduced rainfall, rising temperatures and the increased frequency of droughts threaten the already precarious balance between water supply and demand. According to the FAO, Algeria is one of the countries characterized by structural water stress, with an average availability of less than 500 m³ per capita per year (Naïmi -Aït- Aoudia & Berezowska - Azzag , 2016), which increases its exposure to climatic hazards (CNES, 2000, p. 14). Projections for the decade 2020–2030 predict a decrease in precipitation of around 5 to 13%, combined with an increase in temperatures of between 1.5°C and 4.5°C (Mohamed N. & Khelil MA, 2015, p. 56). At the same time, water demand could double due to the combined effect of population growth and rapid urbanization that the country has experienced since the beginning of the 21st century. For more than thirty years, Algeria has suffered from a persistent meteorological drought (Zeroual et al ., 2017), leading to a significant decrease in surface flows, estimated between 37% and more than 70% depending on the region (Meddi & Hubert, 2003), which hinders efforts to develop hydraulic infrastructure.In this context, the wilaya of Constantine, located in the northeast of the country, is experiencing increasing pressure on its water resources. This research proposes an integrated approach to analyzing territorial vulnerability to climate change, taking into account environmental, economic, social, and institutional dimensions. The objective is to construct a chain of impacts to better understand the risks related to water resources in this territory. Part of a reflection on territorial adaptation to climate change in Mediterranean environments, this study emphasizes the need to rethink water management policies to ensure greater sustainability of urban resources.Methodologically, this study is based on a combination of quantitative and qualitative data, collected in particular through interviews with institutional actors and local users. This dual approach aims to establish a precise and in-depth diagnosis of the current situation. In order to achieve the research objectives, an analytical approach was adopted. This consists, on the one hand, of examining the potential impacts of climate change on the availability of water resources, and on the other hand, of evaluating the actions implemented to preserve this resource and strengthen the sustainability of its management.

MATERIALS AND METHODS

2.1 Conceptual framework: vulnerability, exposure and climate risk

The development of any climate change adaptation strategy requires, upstream, a rigorous assessment of the resilience of a system, understood as its capacity to anticipate, absorb and restructure its functions in response to climate disturbances. This assessment is crucial to mitigate impacts, seize emerging opportunities and adjust responses to effects, whether predictable or not (El- Meddahi , 2016) .

The IPCC, in its fourth report (AR4), defines vulnerability as the level of susceptibility of a system to the adverse effects of climate variations, including extreme events. This vulnerability depends on the exposure to hazards, the intrinsic sensitivity of the system and its adaptive capacity, i.e. its ability to adjust its structures or mechanisms to reduce impacts or take advantage of new conditions (IPCC, 2007). Operationally, it can be reduced either by reducing sensitivity or by strengthening adaptive capacities (GIZ, 2017). The fifth report (AR5) introduces an integrated approach to climate risk, based on the interrelationship between hazard, exposure and vulnerability. Risk therefore does not result solely from a hazard, but from an interaction between the characteristics of the hazard, the exposed elements and the weaknesses of the analyzed system. This conceptual framework, inherited from disaster risk analysis, allows for a systemic reading of potential climate impacts (IPCC, 2014). Thus, adaptation is seen as a process of gradual adjustment based on the articulation between the key dimensions of vulnerability. The methodological approach adopted in this study aims to model these interactions in order to support public decision-making in the face of future climate challenges.

Modeling impact dynamics: articulation of interacting components and factors

The conceptual approach to climate risk analysis is based on the articulation of three major components, the interaction of which makes it possible to characterize the level of risk to which a system is exposed (Figure 1):

Climate hazard component and its anticipated effects

The "climate hazard" component is manifested by extreme weather conditions, such as decreased precipitation, increased temperatures, and intense rainfall (Moumni et al., 2019). These phenomena lead to direct physical impacts (drought, flooding, erosion, soil degradation) as well as intermediate effects influencing hydrological processes, such as runoff or groundwater recharge (Epule , 2017). They compromise water availability for various uses and disrupt wetlands. This component includes the climate signal (direct manifestations of climate change) as well as cascading indirect impacts on natural and human systems, such as decreased agricultural productivity, ecosystem degradation, and increased water stress (Ghenim et al., 2011)."Vulnerability" component: vulnerability is defined by two fundamental dimensions

Vulnerability consists of two main dimensions: **sensitivity,** which expresses the system's dependence on climatic hazards, aggravated by pressure on water resources, declining agricultural yields and degradation of water infrastructure; and **adaptive capacity,** which depends on available resources, governance, water management policies, as well as awareness among stakeholders (Sadik El Yadari et al,. 2023; Krim et al,.2023). The combination of these factors increases risks to food security, water quality and public health.

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 3, 2025
https://www.theaspd.com/ijes.php

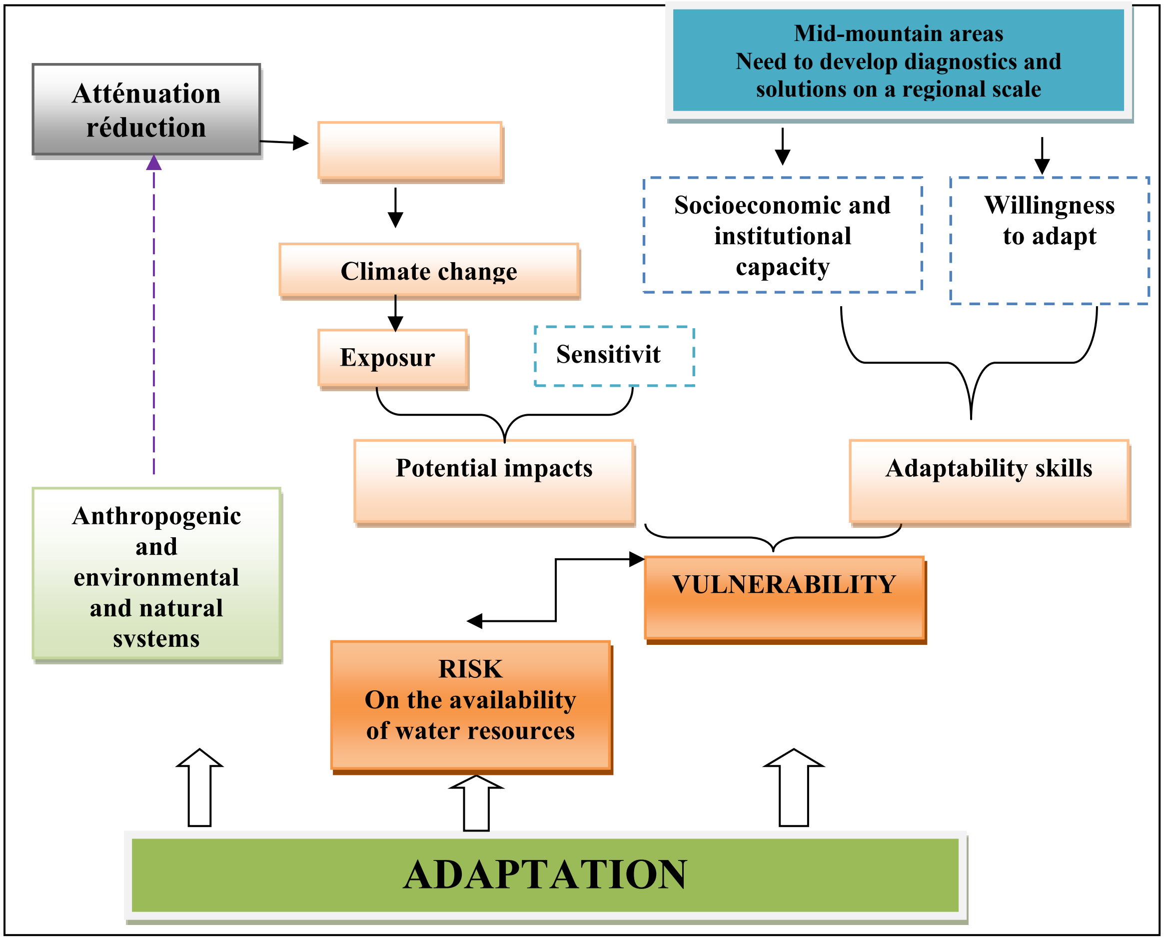

Figure 1. Structuring of the chain of impacts of risk analysis and vulnerability to climate change applied to the availability of water resources in the wilaya of Constantine according to the 5th assessment report of the IPCC (source: IPCC, GTII, AR5, 2014, p.3).

Exhibition Component spatial assessment of vulnerability factors to climate risks

Risk exposure is defined by a set of territorial factors, such as land use, population density, water uses, as well as agricultural and economic activities. It also takes into account the vulnerability of ecosystems and the state of the region's hydraulic infrastructure (Moumni , 2019). More specifically, the "exposure" component refers to the presence and concentration of human, economic and environmental issues in areas likely to be affected by a climate hazard. This exposure is manifested through variables such as population density, land use, the location of essential infrastructure, as well as spatial dynamics and changes in land use (Krim et al., 2023).

2.1.2 Implementation of risk and vulnerability analysis in the study area

Among the recognized methodological approaches for assessing climate vulnerability and risk, the one proposed by GIZ (2017) is based on a structured eight-step process. This framework successively includes: the preparatory phase of the analysis, the development of impact chains, the selection of relevant indicators, the collection and processing of data, the standardization of indicators, the weighting and aggregation of data, the integration of the different components of risk, and finally, the presentation and interpretation of the results of the assessment. In this study, we focus on the first two stages of this methodology applied specifically to the water resources sector. These are, on the one hand, the preparation phase of the vulnerability and risk analysis, and on the other hand, the development of climate impact chains (Krim et al,. 2023). In addition, a first part of the third phase will be addressed, through the identification of key indicators to characterize the vulnerability of the system studied (Sadik El Yadari et al .

1.1.3 Structuring and purpose of the analysis of climate risk and vulnerability
Risk and vulnerability analysis is an essential methodological tool for assessing the nature, probability and intensity of risks associated with climate hazards, as well as the vulnerability factors specific to the territory studied. It allows the generation of contextual knowledge on the impacts of climate change, particularly in the area of water resources, and facilitates the development of appropriate responses (Epule et al ,. 2017 ; krim et al,.2023) . This process aims to strengthen the capacity of local actors – institutions, decision-makers, water managers and stakeholders – to design adaptation strategies based on a detailed understanding of local risk dynamics (Epule et al., 2017).. It therefore serves as a fundamental lever in decision-making support, territorial planning and the development of climate-sensitive public policies
By identifying key climate threats and targeting systemic vulnerabilities, ARV analysis helps steer the water sector towards a sustainable development trajectory, promoting anticipation, resilience and proactive risk management at the local level.

Contextual issues related to risk and vulnerability analysis
As part of planning the adaptation of the water resources sector to the effects of climate change, risk and vulnerability analysis is a crucial step in establishing development priorities. It aims to reduce vulnerability and, in some cases, exposure to climate hazards in order to mitigate risks. For the study area, this analysis focuses on problems that have persisted for several decades, adopting a comprehensive approach that assesses the current performance of the system while strengthening its resilience (Krim et al ,. 2023 ; Sadik El Yadari ,.2023). Resilience is defined here as the capacity of the system to resist the impacts of climate change, but also to adapt and take advantage of these transformations, transforming them into opportunities. This process includes the integration of climate issues into local governance and the development of adaptation strategies specifically oriented towards water stress management.

b. Identification and quantification of potential impacts of climate change
The wilaya of Constantine is formed by a set of low mountains with a low altitude crest (rock of Constantine). These medium mountains appear as a series of more or less parallel limestone ranges, separated by intra-mountain depressions often occupied by a valley (Rhumel valley , Oued Boumerzoug), the rest of the relief is made up of the plateau of Ain El Bey, the hilly hills of the region of El Khroub , the plains of Didouche Mourad, Hamma Bouziane and Ain Smara. To the east of Constantine stands the large sandstone massif (Numidian nappe) of Djebel Ouahch occupying almost the entire eastern part of the Group (Boussetti et al ,. 2019). To the west of the Group stands Djebel Chettabah . The structural opposition that characterizes the GUC is reflected in a relatively simple substratum in the South, corresponding to the domain of high plains from which isolated massifs emerge, and to the more complex Tellian domain in the North (stack of tectonic sheets). The main watercourses that cross Constantine and its urban area are the Rhumel and Boumerzoug wadis , the confluence of which is located at the southern entrance to the old urban fabric of the Constantine conurbation. On the hydrogeological level, the limestone reservoir rocks, the Quaternary formations and the sandstone formations have a more or less high retention capacity. The limestone massifs give rise to karsts resurgences (AGIRE, 2024).

2.2 Environmental and socio-economic context in the Wilaya of Constantine
Situated between the semi-arid High Plains to the south and the sub-humid Tell to the north, the wilaya of Constantine covers an area of 2,297 km². It is bordered by the wilaya of Skikda to the north, the wilaya of Oum-El-Bouaghi to the south, the wilaya of Mila to the west and the wilaya of Guelma to the east. It is made up of six daïra and twelve communes (Figure 2). It is mainly part of the Rhumel wadi and its sub-wadi, the Boumerzoug wadi . In the center of the Constantine conurbation, at the entrance to the "Rock" overlooking the Rhumel gorges , is the confluence of these two large rivers, (PDAUC , 2019; AGIRE, 2024).

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 3, 2025
https://www.theaspd.com/ijes.php

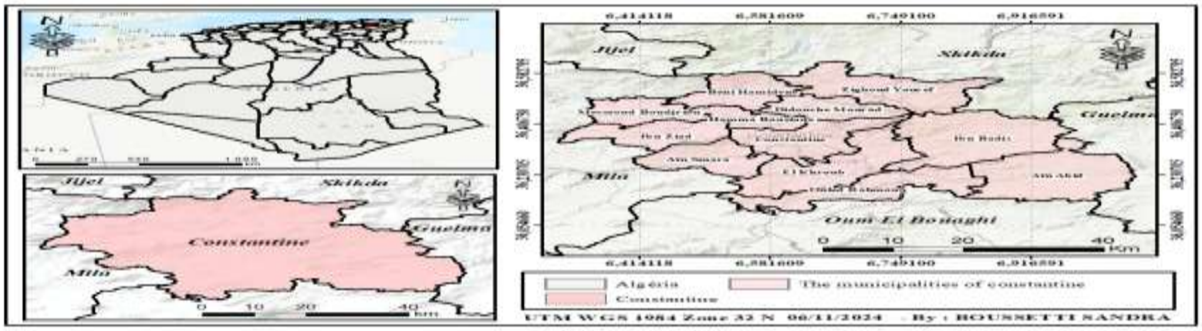

Figure 2: Geographic location the wilaya of Constantine (Source: Boussetti . GIS.2024)

2.2.1 Demographic evolution and spatial distribution of the population in the Wilaya of Constantine

The demographic dynamics of the wilaya of Constantine over the last decades has been characterized by sustained growth, although marked by irregular evolution. According to data from the General Population and Housing Census (RGPH) conducted by the National Office of Statistics (ONS), the population increased from 663,372 inhabitants in 1987 to 888,500 in 1998 , and then to 938,472 in 2008. This evolution corresponds to a relative increase of 22.1% between 1987 and 1998, and of 19.2% between 1998 and 2008, representing a cumulative growth of 41.3% over the period 1987–2008 (ONS, 2008).

Table 1: Demographic evolution in the wilaya of Constantine

Commune	Locality	Population (inhabitants)			1987-1998	1998-2008	Population estimate in 2024
		1987	1998	2008	TAGMA (%)	TAGMA (%)	
Wilaya of Constantine	Capitals	**526366**	**615327**	**616442**	-	-	-
	Agglomerations Secondary (*)						-
	Scattered areas						-
	Municipalities	**663372**	**808500**	**938472**	**1.82**	**1.39**	1,190,907

Source: ONS, 2008; URBACO, 2024

The average annual growth rate, however, has shown a downward trend, falling from 1.82% (1987–1998) to 1.39% (1998–2008). Nevertheless, a resumption of growth is observed for the period 2008–2024, with an estimated rate of 1.7%, bringing the projected population to approximately 1,190,907 inhabitants in 2024. In terms of spatial distribution, the wilaya had a population of 938,475 inhabitants in 2008 spread over a total area of 2,297.2 km², with an average density of 408.53 inhabitants/km². This density varies greatly depending on the municipality. The city of Constantine, as the capital of the wilaya and main urban center, has the highest density, exceeding 2,450 inhabitants/km² (ONS, 2019; URBACO, 2024).

The peripheral municipalities of Hamma Bouziane, El Khroub , Didouche Mourad and Ain Smara also have high densities, ranging from 300 to 1,123 inhabitants/km². In contrast, low densities, below 137 inhabitants/km², are recorded in predominantly rural municipalities such as Zighout. Youcef , Ibn Ziad , Ain Abid, Messaoud Boujeriou , Beni Hamidane and Ibn Badis . The latter are characterized by vast areas and a relatively dispersed population.

Climatic characteristics of the Wilaya of Constantine

The wilaya of Constantine, located in the northeast of Algeria, is subject to a climate Mediterranean with a semi-arid tendency, with hot and dry summers and relatively mild and moderately rainy winters (509.51 mm) (ONMC, 2024). However, in the context of global climate change, the local climate regime has undergone significant alterations between 1971 and 2024. Recent observations indicate an increase in average annual temperatures, estimated at between +1.5 and +2°C, particularly marked during the summer season. This trend is accompanied by an increase in the frequency, intensity, and duration of heat waves, generating increased thermal stress for agricultural systems, water resources, and populations. At the same time, the region is experiencing a gradual decline in average annual precipitation, combined with increasing variability in its seasonal distribution, compromising the regularity of water supplies and increasing the risks of drought, erosion and ecosystem degradation.

RESULTS AND DISCUSSION

3.1 Dynamics and interannual fluctuations of the rainfall regime in Constantine from 1971 to 2024

This climate study is based on the automated processing of several data matrices relating to climate data over 53-year periods (1971-2024). The calculation of other climate indicators uses climate data (precipitation and temperature) from weather stations located in the territory of Constantine. In this work, data were collected from the National Metrological Office Ain El Bey of Constantine (ONM, 2024) and from metrological stations that are or have been operational for a long time.

Table 2: Geographic coordinates of the stations included in the GUC

Station code	Stations	X	Y	Z	Period
10.04.10	Ain el Bey Constantine	850.35	344.72	590	1971-2024

Source: ONM Constantine 2024

Climate data recorded in recent decades show a gradual decrease in annual precipitation in the Constantine region. This decline is often accompanied by irregularity from one year to the next, with longer periods of drought followed by episodes of intense but brief rainfall, which favor runoff rather than infiltration. The annual rainfall height for the period considered varies from 902.28 mm in 1984 to 271.98 mm in 2021. While the interannual rainfall module is equal to 509.51 mm (ONMC, 2024).

The analysis of Figure 3 above shows significant negative deviations, indicating a climate drought situation, varying between -230.57 mm and -1.75 mm. The number of years with below-average rainfall reaches 33 years, or 60% of the 53-year period from 1971 to 2024. On the other hand, rainy years represent only 40%, with surpluses varying between +17.16 mm and +353.59 mm. This deficit was particularly accentuated during the years 1986, which alone account for 60% of the deficit years in this period, which has a negative impact on rainfall levels and, consequently, on the availability of water resources in the plain. Winter is the wettest season, this season contributes with 1/3 of the annual total, that is to say with 217.91 mm or 39.77% of the annual average. On the other hand, the dry season and summer reach nearly 33.03 mm, 6.03% of the annual average for the Constantine station.

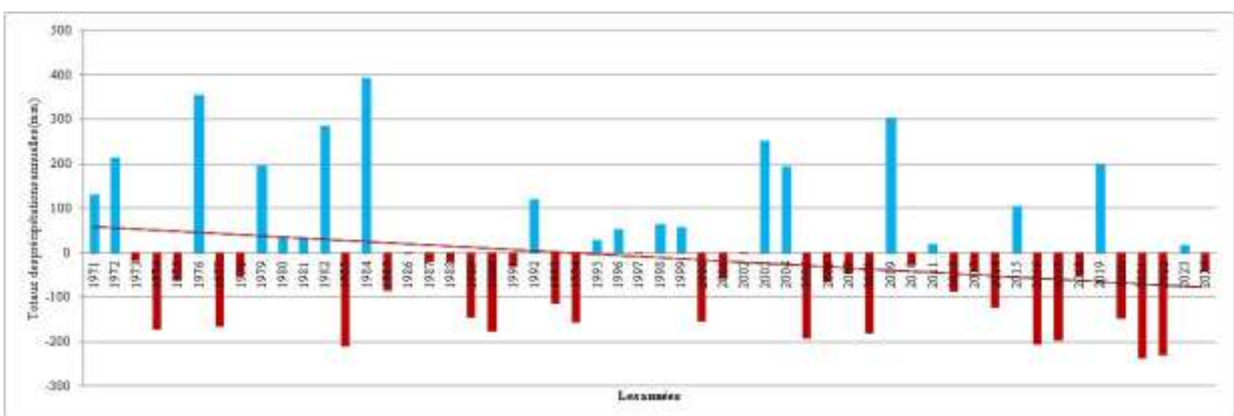

Figure 3: Precipitation Deviation Index at Ain El Bey station in Constantine Period: 1971- 2024.

3.2 Distribution and dynamics of daily precipitation and rain sequences

Analysis of available daily data shows that the number of rainy days is also marked by spatial and temporal irregularity. Analysis of the linear trend in the values of the Nmjcp Index (Consecutive Rainy Days) shows a slight decrease from 1971 to 2024 at the Constantine station (Figure 4).

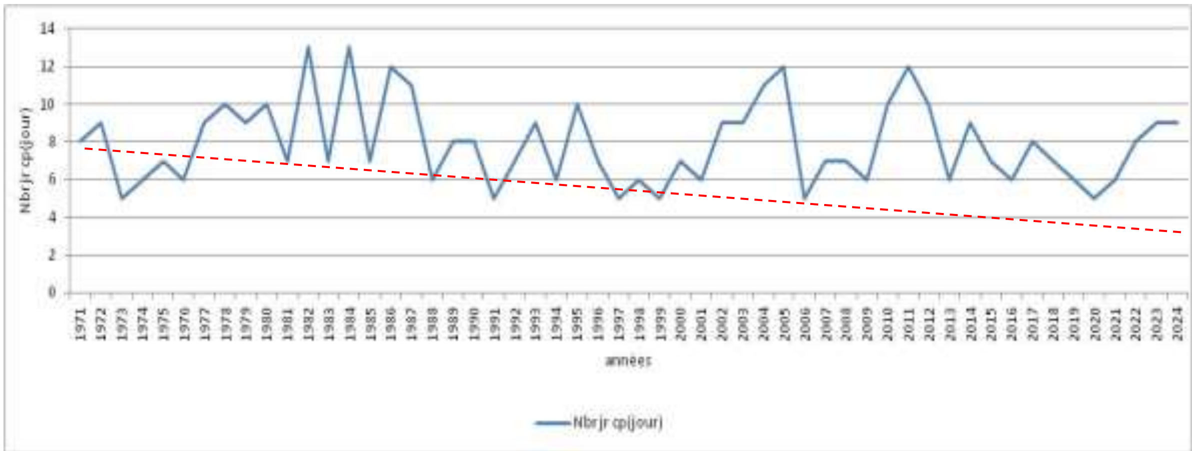

Figure .4: Nmjcp Index (Consecutive Rainy Days) at the Constantine station. Period from: 1971-2024.

Nmjcs Index (Consecutive Dry Days) shows a slight decline from 1971 to 2024 at the Constantine station. This heterogeneity complicates the standardization of water distribution across the wilaya. The alternation between short but intense episodes and long dry periods increases the risk of flooding and limits infiltration capacity (Figure 5). This behavior becomes problematic in a context of climate change where rational resource management becomes crucial.

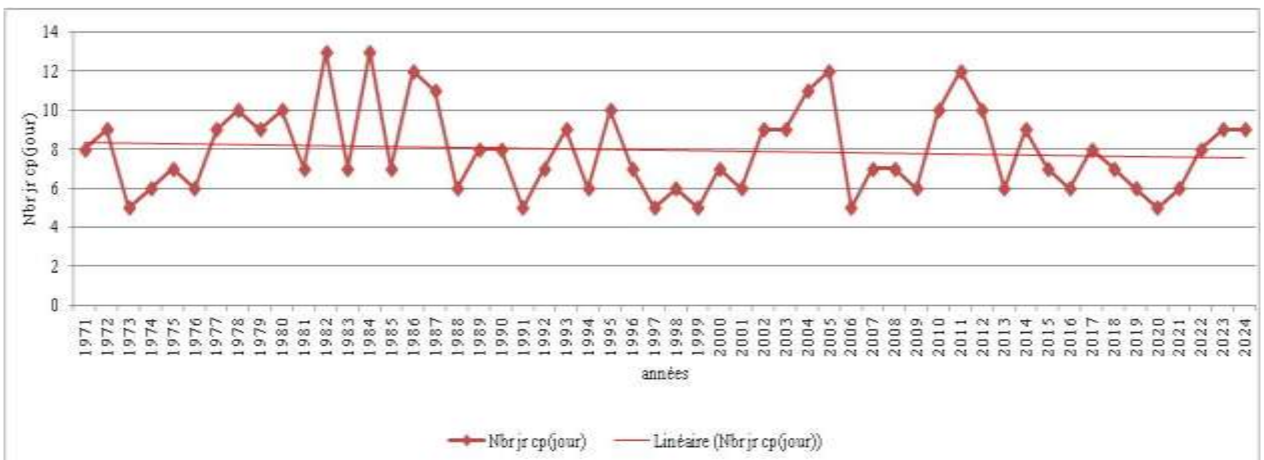

Figure 5. Annual evolution and linear trend of the values of the Nmj Index cs (Consecutive dry days): at the Constantine station. Period: 1971-2024

3.3 Spatio-Temporal assessment of drought through SPI and RDI Indices

The SPI (Standardized Precipitation Index) is used for monitoring meteorological drought at different time scales. It allows measuring the variability of precipitation over defined periods; ideally the longest possible in order to better capture climate trends (Ghenim , 2011; Zeroual et al, 2017). Its calculation is based on fitting rainfall data series to a probability distribution, as proposed by McKee et al. (1993).

Table 3. Drought categories (SPI) on annual and seasonal scales for the wilaya of Constantine between 1973-2024.

SPI	≥ 2	1.5-1.99	1- 1.49	(-) 0.99-0.99	(-) 1- (-) 1.49	(-) 1.50-(-) 1.99	≤ (-) 2
Drought status	Extremely humid	Very humid	Moderately humid	Near normal	Moderately dry	Very dry	Extremely-
Constantine	2	1	7	33	11	1	0

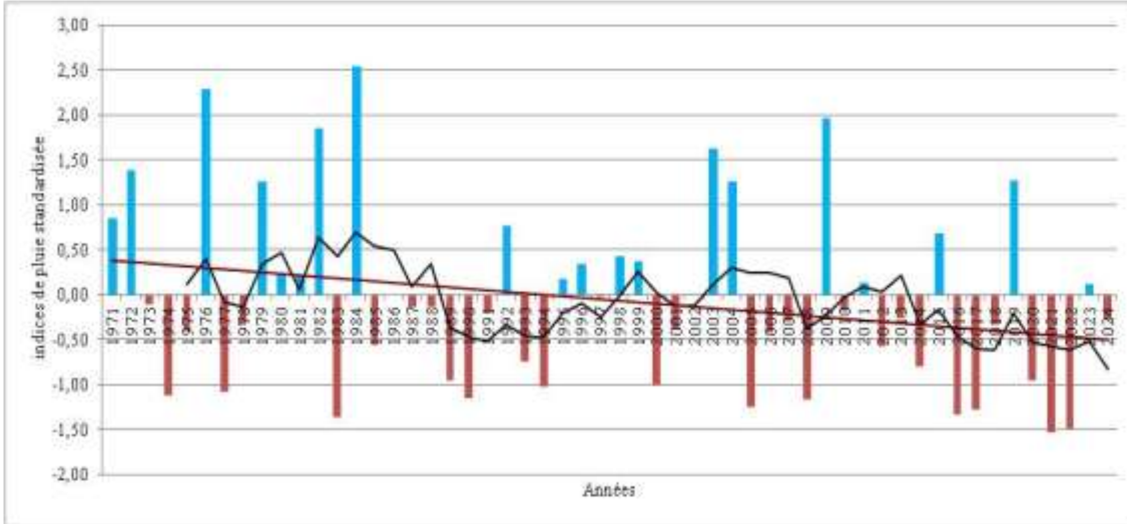

Figure 6. Analysis of the evolution of drought by the standardized rainfall index (SPI) in the wilaya of Constantine. Period: 1971 – 2024

Figure 6 and Table 3 illustrate the analysis of the interannual variability of precipitation in the wilaya of Constantine, based on the Standardized Precipitation Index (SPI), highlights a significant oscillation of values between approximately -2.2 and +1.9. This variability reflects the contrasting and irregular nature of the local Mediterranean climate. The years 1983 and 2005 were characterized by episodes of severe drought, with respective SPIs of approximately -2.1 and -2.0, while the years 1984 and 1976 correspond to exceptionally wet periods, with SPIs close to +1.9 and +1.8. The precise identification of drought episodes, defined by an SPI below -1.5, confirms the recurrence of such conditions over the period studied, with in particular the years 1974 (-1.8) and 2021 (-1.7) highlighting the frequency and severity of these rainfall deficits. These episodes can lead to major water stress, directly impacting agriculture, water resource management and local biodiversity. Furthermore, wet periods, illustrated by SPIs above +1.5 such as those of 1984 (+1.9), 1976 (+1.8) and 2009 (+1.6), contribute to the renewal of groundwater and soil recharge, although they can also increase the risk of localized flooding. Finally, a temporal trend suggests an increase in the frequency of severe droughts from the 1990s, particularly marked between 2000 and 2024, where the following years 1983 (SPI ≈ -2.1), 2005 (SPI ≈ -2.0) and 2021 (SPI ≈ -1.7) display very negative severe SPIs. This evolution seems to be part of the broader context of climate change affecting the Mediterranean basin, where an increase in extreme climatic events is observed. However, the statistical confirmation of this trend requires the implementation of additional analyses, including formal trend tests.

In addition, the evolution of the Index Deficit Ratio (IDR) over more than five decades in the wilaya of Constantine reveals a marked and significant climatic variability. Despite the occurrence of exceptionally rainy years, such as in 1984 when the IDR reached a maximum of +0.87 with 902.98 mm of precipitation, the frequency of these events tends to decrease over time (Figure 7). At the same time, years characterized by a rainfall deficit, illustrated by a minimum IDR of -0.44 in 2021 with only 271.98 mm, are becoming more numerous and sometimes more severe. This trend reflects a progressive climatic drying, consistent with climate projections for Algeria, which anticipate an overall decrease in precipitation coupled with a rise in temperatures. Statistical analysis indicates strong interannual variability, with 29 dry years (IDR < 0) and 25 wet years (IDR > 0) during the period studied. On a decadal level, the 1970s-1980s are characterized by a clear alternation between dry periods and very wet years, notably in 1976 and 1984, while the period 2000-2020 is marked by an apparent increase in the frequency and severity of dry years, as in the years 2016, 2021 and 2022 (very low RDI ~0.26-0.27). These observations highlight the importance of integrating climate variability into water resource management strategies and local adaptation to the effects of climate change.

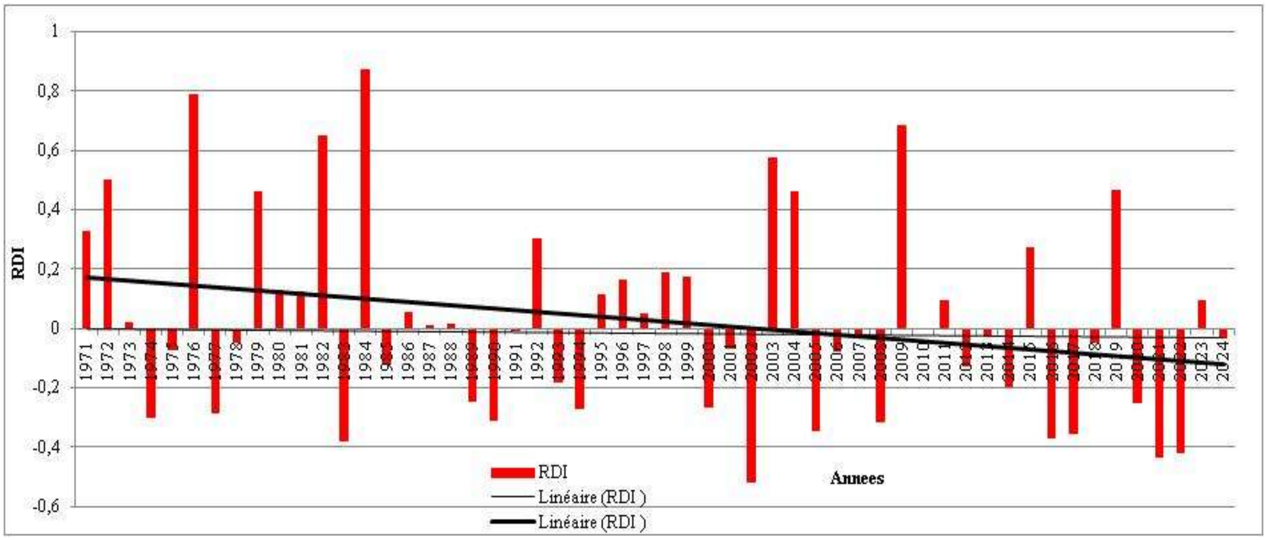

Figure 7. Analysis of the rainfall deficit (RDI) in the wilaya of Constantine Period: 1971 - 2024

3.4. Regional global warming: evidence of a clear trend

The average annual temperature in Constantine during (1973-2024) is 15.48°C, with an average temperature of 26.55°C during the month of July, marked the hottest month of the year. January is the coldest month of the year, with an average temperature of 6.94°C (Figure 8).

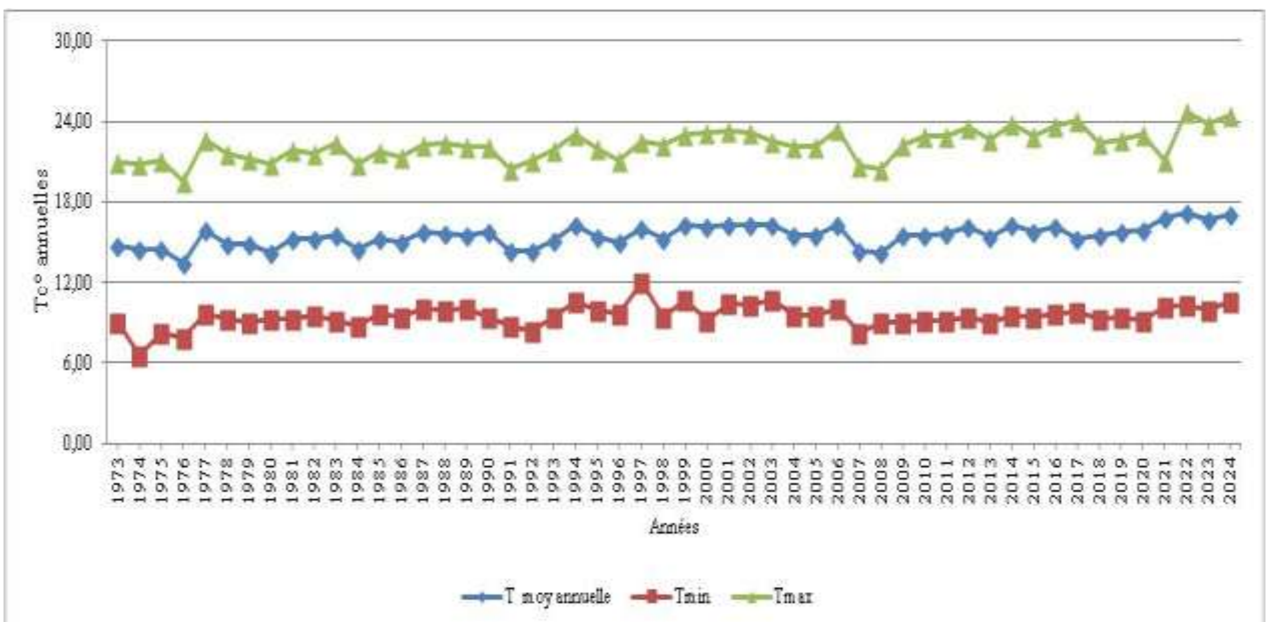

Figure 8. Evolution of annual temperatures (Tmoy, Tmin, Tmax) in the wilaya of Constantine. Period: 1973-2024.

The minimum interannual temperatures are 14°C in Constantine (due to the cold winters in the region), the maximum interannual temperatures are 17°C in Constantine.

A general warming trend is observed in Constantine for all months of the year, with the exception of December and January. From 1985 and 1981, the months of September, October and November recorded a temperature increase of approximately 1.3°C, 1.9°C and 1.4°C respectively (Figure 9). In spring, temperatures in March, April and May also show a warming trend, with increases of 1°C, 1.4°C and 1.5°C respectively, mainly from the early 1980s.

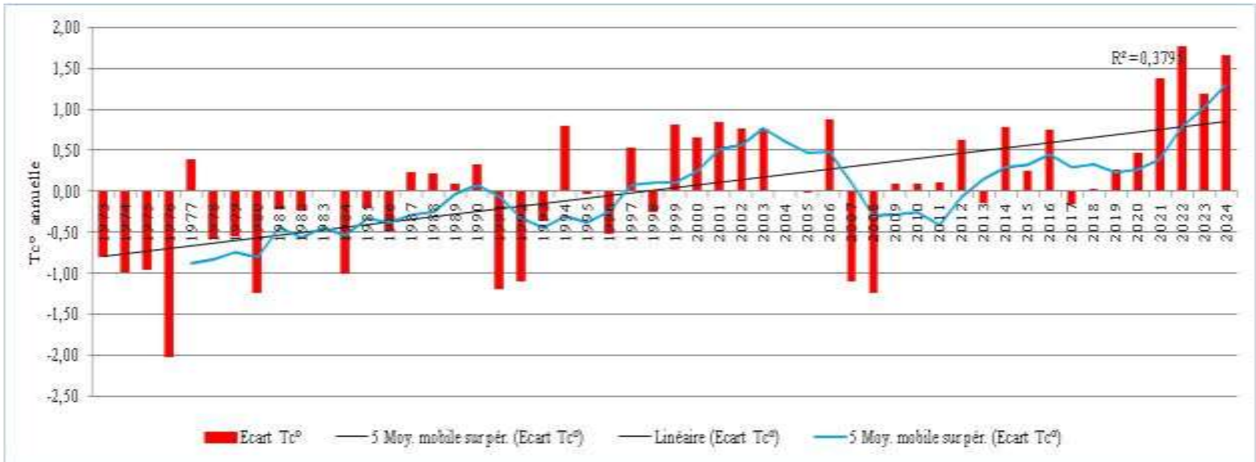

Figure 9. Annual temperature difference in the wilaya of Constantine. Period: 1973-2024.

In the summer period, the months of June and August show a similar rise of 1.7°C from the same period, while the month of July shows a more marked increase, reaching 2°C from 1981. It is worth noting that the months of April, May and June show warming trends consistent with those observed over the whole year. The warm season indicates a warming that ranges from 1.5°C to 2.6°C, it is the months of April, May, June, July and August that are marked by this significant increase between the mid-1980s and the mid-1990s.

The monthly evolution of humidity calculated in the Ain Bey station over a period of forty-one years (1973-2024), shows that humidity is often higher than 50% except in summer with a minimum value of around 48.17% in July. The maximum value in January is 79.25%, which indicates that the atmosphere is in a state more or less close to condensation.

3.5 Evaluation of the "Exposure" Component

3.5.1 Vulnerability of water resources to climate change: between surpluses and deficits (2024)

The wilaya of Constantine consists of 12 municipalities and has an estimated population of 1,190,907 inhabitants in 2024 (URBACO, 2024). The projected population growth is approximately 10,000 inhabitants every five years, bringing the population to 1,780,169 inhabitants by 2050. The average daily production of drinking water in the wilaya amounts to 319,707 m³/day, of which 15,420 m³ is intended for industrial uses. This volume has seen a significant increase, from 85 million m³ in 2009 to 119 million m³ in 2024. Water supply is mainly based on surface resources, which represent 71% of the total, notably from the Béni Haroun dam. Groundwater completes this contribution with a share of 29%. The wilaya's drinking water supply network (AEP) extends over 681 km of supply pipes and 3,505 km of distribution network. The total storage capacity is estimated at 463,310 m³, distributed between 62 reservoirs and 5 water towers, providing a useful volume of 148,300 m³. This infrastructure plays an essential role in regulating and securing the distribution of drinking water throughout the wilaya.In 2024, the daily drinking water needs in the wilaya of Constantine are estimated at 238,181.4 m³. This demand is expected to increase to 438,465.5 m³/day by 2050, in line with a projected population of 1,780,169 inhabitants. By this time, the need for hydraulic equipment will amount to 65,769.8 m³/day, while water losses will exceed 100,847 m³/day (Figure 10). This significant increase is mainly due to the annual population growth rate, as well as socio-economic dynamics and rapid urbanization of the region. Some municipalities have a surplus, notably: Constantine of 112,114 m³/day for 560,570 inhabitants (+25,291 m³); El Khroub of 44,766.8 m³/day for 223,834 inhabitants (+63,025.2 m³); Ain Smara, Hamma Bouziane, Didouche Mourad: surpluses varying from 4,400 to 13,800 m³/day. These municipalities benefit from a regular supply via the Béni Haroun dam. Conversely, others are recording deficits: Ouled Rahmoun : -2,498 m³/day; Ain Abid: -14,308.2 m³/day; Ibn Badis : -7,646.4 m³/day; Zighoud Youcef , Ibn Ziad , Messoud Boudjraou , Ben H'miden : deficits between -1,164 and -2,829 m³/day. These imbalances highlight the need for appropriate territorial planning and targeted investments to ensure an equitable distribution of the resource. These gaps illustrate a disparity in the distribution of drinking water resources, requiring targeted territorial planning and infrastructure investments to correct existing.

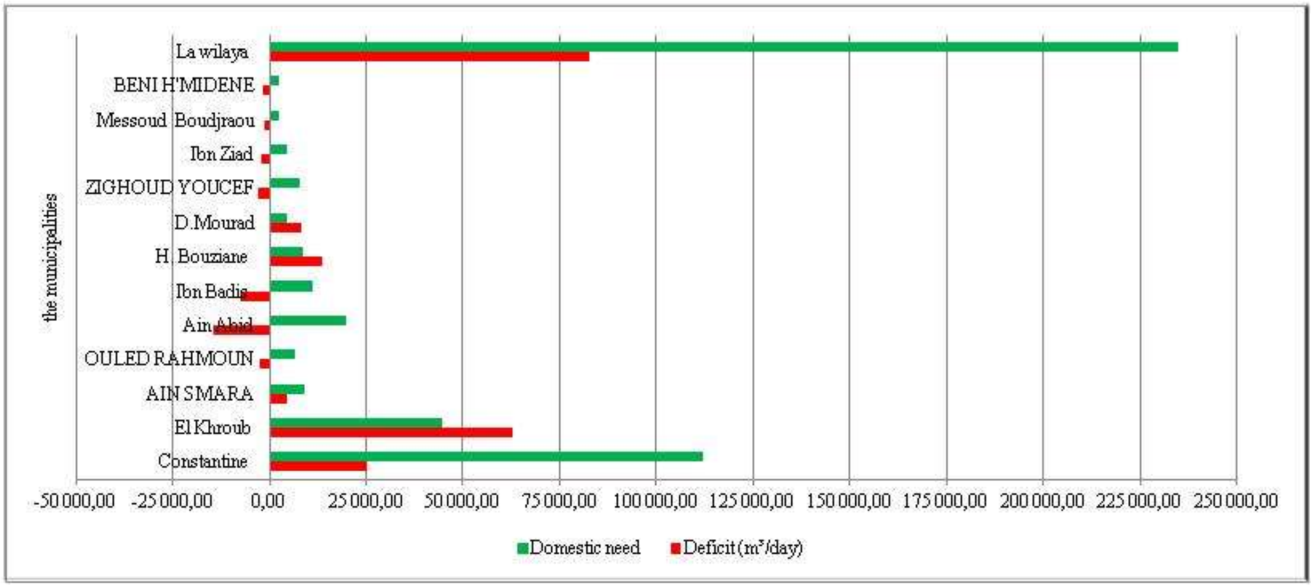

Figure 10. Estimation of water needs and deficit in the wilaya of Constantine in 2024

3.5.2 The impact of climate change on agriculture

The climate changes observed in the wilaya of Constantine are resulting in an increase in evapotranspiration, higher temperatures, and increasingly irregular precipitation. These climate disturbances have the direct effect of a decrease in agricultural yields, a reduction in arable land, and significant economic repercussions for the region. Furthermore, land use in this wilaya has experienced highly variable dynamics, influenced by several factors, among which climate plays a decisive role. Indeed, a marked rainfall deficit has been recorded over the last two decades, with an average decrease in annual precipitation of more than 200 mm. Currently, the usable agricultural area (UAA) of the wilaya is estimated at 175,939 hectares, of which 126,747 hectares are actually exploitable, spread across the twelve municipalities (PDAUC, 2016). The land use typology in the study area includes irrigated land representing approximately 3,333.77 hectares (2.85%), rangelands covering 50,935 hectares (27.98%) as well as forest areas occupying 28,074 hectares.

3.6. Assessment of the vulnerability of systems to climatic hazards

The main objective of vulnerability reduction is to modify the factors that amplify it while ensuring the sustainability of vulnerable elements. This approach is based on sustainable management and protection of both vulnerability factors and exposed elements. Vulnerability concerns the specific characteristics of exposed elements as well as the system in which they are inserted, which can either increase or mitigate the potential consequences of water stress on a given region. It is broken down into two major dimensions: sensitivity and the capacity to cope and adapt (Krim et al ., 2023).

3.6.1 Assessment of regional sensitivity factors: an approach based on six indicators.

Sustainable accessibility to water resources for domestic, agricultural and industrial uses ;
The performance and resilience of agricultural production in the face of environmental pressures ;
The physicochemical quality of water and the incidence of waterborne pathologies ;
Management and protection of wetlands of high ecological value ;
The conservation of forest ecosystems and sensitive natural environments.
Construction and rehabilitation of dams (e.g., the Beni Haroun Dam, interconnected to Constantine).
Development of interconnection networks to secure drinking water supplies.
Reduction of losses in distribution networks through modernization programs.

In many regions, sensitivity is increasing due to the growing demand for water resources. Local conditions complicate access to water, whether for domestic, agricultural or industrial use, which significantly limits the potential for local development. As a result, there has been a marked decline in irrigated areas, leading to a significant drop in agricultural production and threatening regional food security. This situation is aggravated by the deterioration of water quality, increasing salinity and increased erosion, particularly as a result of climate change, which has a lasting impact on land use patterns.

3.6.2 Capacity for institutional and social resilience and adaptation to environmental disturbances.

A region's ability to cope with water stress and adapt relies on several essential levers, among which nine key elements can be distinguished:

✓ Strengthening good governance in water management and the implementation of integrated water resources management (IWRM);

✓ Reducing water demand and promoting water saving;

Integration of water from desalination;

Reuse of treated waste water;

Artificial recharge of groundwater;

Optimal exploitation of existing hydraulic infrastructures;

Environmental preservation of watersheds, particularly through reforestation and protection of wetlands;

Mobilizing new financial resources through mechanisms such as water pricing and the polluter pays principle;

Strengthening observation networks and the water information system.

CONCLUSION AND RECOMMENDATIONS

The wilaya of Constantine, like many semi-arid regions of northeastern Algeria, is facing structural water stress aggravated by the effects of climate change. Analysis of climate variability over the period 1971–2024, using the Standardized indicator Precipitation Index (SPI), highlights a marked alternation between episodes of heavy precipitation and severe drought. Exceptionally wet years such as 1984 (SPI ≈ +1.9) or 1976 (SPI ≈ +1.8) contrast with critical drought years such as 1983 (SPI ≈ -2.1), 2005 (SPI ≈ -2.0) or 2021 (SPI ≈ -1.7). Since the 1990s, there has been a clear trend towards an increase in the frequency and intensity of dry episodes, confirming the amplification of water risk under the effect of climate change.These developments have direct impacts on land management and urban planning. The irregularity and seasonal concentration of precipitation, coupled with rising temperatures and increased summer evaporation, are permanently compromising the availability of water resources. This situation is all the more critical in a context of population growth, rapid urbanization, and increasing anthropogenic pressure on peri-urban areas and fragile natural environments, particularly steppe ecosystems.As an urban planning engineer, it seems essential to reassess urbanization and territorial development models in light of this growing water vulnerability. Despite some technical progress (water transfer from the Béni Haroun dam, hydraulic interconnections, wastewater reuse projects), the region continues to suffer significant structural losses in distribution networks (estimated at more than 51%) and a projected increase in demand for drinking water, reaching 438,000 m^3/day by 2050.

Faced with these challenges, the institutional response can no longer rely on reactive or sectoral approaches. It is urgent to move towards integrated, territorialized, and resilient water governance, based on several levers:

the integration of climate and hydrological data into urban planning tools;

modernization of drought monitoring, alert and management systems;

and the effective implementation of existing national strategic frameworks, such as the National Climate Plan (NCP), the National Plan to Combat Desertification (PNLCD), and the proposal for a National Drought Plan (PNS).

The latter should aim to organize in advance the quantitative management of the resource in times of water stress, by reconciling domestic, agricultural and ecological uses. It could be structured around three fundamental components:

1. The provision of common decision-making tools for institutional stakeholders;

2. The deployment of rapid intervention mechanisms to guarantee the continuity of the public drinking water service, and the definition of dynamic updating procedures, based on climate changes observed by indicators such as the SPI.

In conclusion, only a systemic, interdisciplinary approach adapted to territorial specificities will make it possible to strengthen the resilience of the wilaya of Constantine in the face of climatic challenges, to ensure the sustainability of its water resources and to orient urban planning towards more sustainable and adaptive models.

REFERENCES

AGIRE - ABH-CSM. (2024). Analysis of national and regional planning study reports, identification of assessment gaps by wilaya (e.g., Constantine wilaya). National Agency for Integrated Water Resources Management. https://agire.dz/abh-csm/

European Environment Agency (EEA). (2024). Pollution, overexploitation and climate change threaten the sustainability of water resources in Europe. https://www.eea.europa.eu/en/highlights/pollution-overexploitation-and.

Ayanlade , A., Radeny , M., & Akin - Onigbinde , AI (2018). Climate variability/change and attitude to adaptation technologies: A pilot study among selected rural farmers' communities in Nigeria. GeoJournal , 83 (2), 319–331. https://doi.org/10.1007/s10708-017-9771-1.

World Bank. (2016). Report: Climate Change and Water Scarcity: Threat to Hit Economic Growth by Up to 6 Percent in Some Regions. https://www.worldbank.org/news/press-release/2016/05/03/climate-driven-water-scarcity-could-hit-economic-growth-by-up-to-6-percent-in-some-regions-says-world-bank

Boussetti , S., & Mebarki , Z. (2019). Drinking water supply in the Urban Group of Constantine. Sciences and Technology Review, Series D, 49, 1–17. https://revue.umc.edu.dz/d/article/view/3079

Busby, J.W., Cook, K.H., Vizy , E.K., Smith, T.G., & Bekalo , M. (2014). Identifying hot spots of security vulnerability associated with climate change in Africa. Climatic Change, 124(4), 717–731. https://doi.org/10.1007/s10584-014-1142-z.

Calzadilla , A., Zhu, T., Rehdanz , K., Tol , RSJ, & Ringler , C. (2013). Economywide impacts of climate change on agriculture in Sub-Saharan Africa. Ecological Economics, 93, 150–165. https://doi.org/10.1016/j.ecolecon.2013.06.003.

Christos, A.K., Stavros, A., Demetrios , E.T., & George, A. (2011). Application of the Standardized Precipitation Index (SPI) in Greece. Water, 3(3), 787–805. https://doi.org/10.3390/w3030787.

El- Meddahi , Y. (2016). Climate change and its impacts on water resources, case of the Cheliff basin. [Doctoral thesis, Hasiba Ben Bouali-Chleff University]. http://dspace.univ-chlef.dz/handle/123456789/307.

Epule , TE, Ford, JD, Lwasa , S., & Lepage, L. (2017). Climate change adaptation in the Sahel. Environmental Science & Policy, 75, 121–137. https://doi.org/10.1016/j.envsci.2017.05.018.

Faye, C., Ndiaya , E., & Mbaye , I. (2017). A comparative assessment of meteorological drought sequences by indices, time scales and climatic domains in Senegal. Journal of Water and Environmental Sciences, 1 (1), 11–28.

GIZ. (2017). Supplementary guide on vulnerability: the concept of risk. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). https://fr.readkong.com/page/guide-complementaire-sur-la-vulnerabilite-leconcept-de-9640253

Ghenim , AN, & Megnounif , A. (2011). Characterization of drought by SPI and SSFI indices (Northwest Algeria). Journal of Sciences and Technologies, 18, 59–77. https://www.asjp.cerist.dz/en/article/37458.

IPCC. (2007). Climate Change 2007: Impacts, adaptation and vulnerability. Contribution of Working GroupII to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://www.ipcc.ch/report/ar4/wg2/

IPCC. (2014). Climate change 2014: Synthesis Report (SYR) of the IPCC Fifth Assessment Report (AR5). https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full_fr.pdf .

Krim , H., & Hassani, MI (2023). Risk/vulnerability analysis to climate change impacting the availability of water resources, wilaya of Relizane (Bas-Cheliff, Algeria). *Techniques Sciences Méthodes* , 10(10), 47–58. https://doi.org/10.36904/tsm/202310047

17.Kioutsioukis , I., Melas , D., & Zerefos , C. (2010) . Statistical assessment of changes in climate extremes over Greece (1955–2002). International Journal of Climatology, 30(12), 1723–1737 . http://dx.doi.org/10.1002/joc.2030.

Naïmi -Aït- Aoudia , M., & Berezowska - Azzag , E. (2016). Water resources carrying capacity assessment: The case of Algeria's capital city. *Habitat International, 58*, 51–58. https://doi.org/10.1016/j.habitatint.2016.09.006.

Moumni , H., Sebari , K., & Hammani , A. (2019). Integrated water resources management and adaptation to climate change. Moroccan Journal of Agronomic and Veterinary Sciences, 7(3). https://www.agrimaroc.org/index.php/Actes_IAVH2/article/view/765/884

Meddi , M., Taibi , S., & Mahé, G. (2010). Influence of climate indices on precipitation variability in Northwestern Algeria. *National Higher School of Hydraulics, Blida, Algeria. http://dx.doi.org/10.1684/sec.2009.0169 .

Meddi , M., & Hubert, P. (2003). Impact of the modification of the rainfall regime on the water resources of Northwestern Algeria. In E. Servat , W. Najem , C. Leduc, & A. Shakeel (Eds.), *Hydrology of the Mediterranean and Semi-arid Regions. (pp. 229–235). IAHS Press .

Mohamed, N., & Khelil , MA (2015). Climate change and water resources in Algeria: Vulnerability, impact and adaptation strategy. * Algerian Journal of Arid Environment , 5(1), 56–62. https://doi.org/10.12816/002220 .

National Meteorological Office of Constantine (ONMC), 2024. This public body is responsible for collecting meteorological data, producing forecasts and disseminating weather alerts throughout Algeria. https://www.meteo.dz/

National Office of Statistics (ONS). (2008). Urban Framework. Technical Directorate in Charge of Regional Statistics, Agriculture and Cartography. https://www.ons.dz/

Sadik El Yadari , & Abdelhamid Janati Idrissi . (2023). Climate change and effects of hydroclimatic drought on water resources and some forms of adaptation: case of the Inaouène watershed , Morocco. Journal of Multidisciplinary Studies in Economic and Social Sciences (REMSES). https://doi.org/10.48375/IMIST.PRSM/remses-v8i2.32357 .

Taïbi , FZH, Anza, H., & Zeroual , S. (2021). Study of the impact of climate change on the availability of water resources based on simulations of the regional climate model RCA4: case of the Ain basin Dalia (Algeria). Algerian Journal of Environmental Science and Technology, 7, 1860–1869. https://www.aljest.net/index.php/aljest/article/view/287 .

URBACO. (2024). The Constantine Urban Planning Studies and Development Center (URBACO) is an Algerian public company specializing in studies and land use planning. https://www.urbaco-dz.com/contact.html

Zeroual , A., Assani , A.K., & Meddi , M. (2017). Combined analysis of temperature and rainfall variability as they relate to climate indices in

Northern Algeria over the 1972–2013 periods. Hydrology Research , 48 (2). https://doi.org/10.2166/nh.2016.244

WEBSITES

- Algerian Water (ADE): www.ade.dz
- National Agency for Water Resources: http://www.anrh.dz/
- River basin agencies (ABH):
- FAO (2012): http://unstats.un.org/unsd/ENVIRONMENT/qindicators.htm
- http://www.populationdata.net/index2.php?option=palmares&rid=4&nom=grandes-villes consulted on 07/06/2012 .
- http://stats.oecd.org/viewhtml.aspx?QueryId=30107&vh=0000&vf=0&l&il=blank&lang=fr 06/28/2012
- Ministry of Water Resources: http://www.mre.gov.dz/ National Office of Statistics: http://www.ons.dz/ .
- https://www.eea.europa.eu/fr/themes/water .