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Climate change and water resources: A comparative study in the MAGHREB

Changement climatique et ressources en eau : Une étude comparative au MAGHREB

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Abstract:

In the face of a global food crisis and climate change, ensuring access to water resources becomes a critical concern for human activities. The Maghreb region, including Morocco, Tunisia and Algeria, is particularly exposed to ecological vulnerabilities. The environmental degradation in this region has already led to adverse effects on the well-being of populations and hindered economic development. While demographic projections provide some clarity, the uncertainties surrounding climate change projections persist due to inadequate climatological data, both in terms of quantity and quality.

Nonetheless, numerous climate projections for Southern Europe indicate a worrisome trend of increasing temperatures and decreasing precipitation. The Maghreb countries, due to their geographical proximity, are expected to face significant repercussions. This challenge is further compounded by the presence of the hyper-arid Sahara, which exacerbates the impact of climate change. Consequently, the Maghreb states recognize the imminent climate evolution as a major concern.

The post-Covid-19 economic recovery, as well as the major disruptions to energy and food supply chains caused by the war in Ukraine, have made the Maghreb region more vulnerable. At the same time, the climate crisis is likely to further exacerbate the vulnerabilities of the Maghreb countries, underlining the urgent need to develop a strategy to mitigate the effects of climate change while preserving the region's biodiversity. A joint report by the IPCC and IPBES stresses that climate and biodiversity are two interconnected challenges that must be tackled jointly.

The aim of this essentially theoretical study is to present an overview of current projections of climate change in the Maghreb region and explore their potential consequences on water resources. It encompasses an analysis of the various aspects of climate change, while emphasizing the necessity of implementing adaptation strategies to mitigate the adverse impacts on water resources.

Keywords: Maghreb, Morocco, Tunisia, Algeria, water resource, climate change, adaptation strategies, ecological vulnerabilities.

JEL CLASSIFICATION : Q 25, Q 54

Paper type: Theoretical research

Résumé :

Face à la crise alimentaire mondiale et au changement climatique, garantir l'accès aux ressources en eau devient une préoccupation essentielle pour les activités humaines. La région du Maghreb, qui comprend le Maroc, la Tunisie et l'Algérie, est particulièrement exposée aux vulnérabilités écologiques. La dégradation de l'environnement dans cette région a déjà eu des effets néfastes sur le bien-être des populations et a entravé le développement économique. Si les projections démographiques apportent quelques éclaircissements, les incertitudes entourant les projections relatives au changement climatique persistent en raison de l'insuffisance des données climatologiques, tant en termes de quantité que de qualité.

Néanmoins, de nombreuses projections climatiques pour l'Europe du Sud indiquent une tendance inquiétante à l'augmentation des températures et à la diminution des précipitations. Les pays du Maghreb, en raison de leur proximité géographique, devraient être confrontés à des répercussions importantes. Ce défi est encore aggravé par la présence du Sahara hyperaride, qui exacerbe l'impact du changement climatique.

La relance économique post-Covid-19, ainsi que les perturbations majeures dans les chaînes d'approvisionnement énergétiques et alimentaires causées par la guerre en Ukraine, ont fragilisé la région du Maghreb. Parallèlement, la crise climatique risque d'aggraver davantage les vulnérabilités des pays du Maghreb, soulignant la nécessité urgente de développer une stratégie pour atténuer les effets des changements climatiques tout en préservant la biodiversité de la région. Un rapport conjoint du GIEC et de l'IPBES souligne que le climat et la biodiversité sont deux défis interconnectés qui doivent être abordés conjointement.

Cette étude essentiellement théorique vise à présenter une vue d'ensemble des projections actuelles de l'évolution du climat dans la région du Maghreb et à explorer leurs conséquences potentielles sur les ressources en eau. Elle comprend une analyse des différents aspects du changement climatique, tout en soulignant la nécessité de mettre en œuvre des stratégies d'adaptation pour atténuer les impacts négatifs sur les ressources en eau.

Mots clés : Maghreb, Maroc, Tunisie, Algérie, ressources en eau, changement climatique, stratégies d'adaptation, vulnérabilités écologiques

JEL Classification : Q 25, Q 54

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1. Introduction

In a Maghreb context marked by an exacerbated risk of water short-ages, water resource management and climate change has become a major concern of public policies in Africa in general and North Africa in particular in recent years. Indeed, the needs of economic growth and demographic expansion have placed the Maghreb region at the heart of this issue. This situation is further exacerbated by rainfall fluctuations, ongoing climate change and inadequate management of available water re-sources.

Adaptation to climate change has received considerably more attention in scientific and political debates, becoming a subject of growing interest for both producers and decision-makers (Pierre V.V., 2012). Adaptation is defined as all the measures and adjustments implemented by individuals, organisations or any living being in order to minimise the direct and indirect effects of climate change or to take advantage of it (Stéphane, 2011)

In agriculture, common adaptation methods include crop diversification, land and water management, changing planting calendars, crop rotation, plant variety variability, crop insurance and income diversification, migration, combined use of surface and groundwater, development of new water sources (such as deep drilling, buying and selling water on informal markets), sale of land and conversion to rain-fed agriculture (Smit B., 2002) (Bryan E., 2009) (Jones L., 2011) (Van Steenbergen F., 2015) (Alam, 2015) (Bosco J.K., 2016).

In arid zones, the scarcity of groundwater resources, exacerbated by the risks associated with climate change, affects all agricultural production systems to varying degrees (Iglesias A., 2015), raising adaptation issues (Grami D., 2015). Adaptation to this scarcity of natural resources is crucial, particularly in the light of climate change, and can take the form of private or public adaptation

The perception and adoption of adaptation strategies are two key components of adaptation in agriculture (Elum Z.A., 2017). They are generally interdependent. According to (Yegbemey R.N., 2014), producers' adaptation to factors such as climate change is only as consistent as their perception and understanding. Any misperception can lead to inappropriate adaptation behaviour. This means that farmers must first perceive a change in climatic conditions before implementing a set of strategies to cope with it

According to the World Bank (2018), Tunisia, Algeria, and Morocco will become global hotspots by the end of the 21st century. Increasing temperatures and reduced precipitation will escalate drought frequen-cy in the region (World Bank, 2017). Droogers et al. (2012) discerned that climate changes will account for 22% of water shortages by 2050.

Confronted with tensions arising from heightened water demand and competition among diverse uses, policymakers in Maghreb countries have had to explore alternative solutions beyond constructing more reservoirs and interregional transfers. Starting from the 1990s, the three area’s countries have introduced new public water management policies, known as the "water mix." This approach involves combining conventional and unconventional resource mobilization (such as sea-water desalination and wastewater purification), adopting water-saving irrigation techniques, and curbing losses in distribution networks.

Central to this approach is a demand management policy, supported by economic instruments like progressive pricing, the application of the "polluter-pays" principle, and the restriction of irrigation water quotas. Concurrently, these countries are establishing commercial strategies that promote the import of products with high virtual water content.

At the heart of this approach is a policy of demand management, supported by economic instruments such as progressive pricing, the application of the "polluter pays" principle and the limitation of irrigation water quotas. At the same time, these countries are implementing commercial strategies that encourage the import of products with a high virtual water content.

This essentially theoretical study is divided into two distinct parts. The first part provides an overview of projected climate change in the Maghreb region and analyses its potential impact on future water resources. The second part examines the adaptation strategies needed to mitigate the effects of these changes on regional water resources. These consequences and their scope are the subject of increasingly in-depth discussions at high-level multilateral meetings. The Maghreb countries may therefore seek to benefit from financial support and international scientific expertise in this field.

2. Unfavorable hydrogeographical context, Evolution of precipitation, and the impact of climate change in Maghreb (Morocco, Algeria, Tunisia).

The three North African countries of Morocco, Tunisia and Algeria form part of a region that lies between the Mediterranean Sea to the north, the Sahara to the south and the Atlantic Ocean to the west. It is located in a desert region that covers more than two-thirds of its surface area.
Precipitation, already characterized by significant temporal and spatial variations, is now undergoing substantial impacts due to ongoing climate change. Concurrently, population growth, rapid urbanization, and economic development have significantly increased water demands across all sectors. Consequently, these countries recurrently face a major water crisis (Gana, 2006). Over the past decades, the Maghreb region has witnessed a decline in water resources (Thivet, 2009). As such, the Maghreb countries are consistently affected by water stress. According to the World Resources Institute (WRI, 2022), the Maghreb countries will experience extremely high levels of water stress by 2040. Moreover, in terms of precipitation frequency, rising temperatures are resulting in significant alterations in precipitation patterns, leading to reduced rainfall amounts in the region. This crisis situation manifests in the scarcity and degradation of water resources, alongside an increasing competition among diverse water uses (agriculture, tourism, industry, and domestic use). Indeed, water resources are primarily allocated to agriculture, accounting for over 80%, 13% for drinking water supply, and the remainder for industry (Agoumi, 2003).
The economies of the countries in this area are heavily dependent on agriculture, particularly rain-fed agriculture (dependent on seasonal rainfall). The agricultural sector contributes around 15% of the Gross Domestic Product (GDP), with employment rates of 38% in Morocco, 16% in Tunisia, and 22% in Algeria (FAO, 2017). Moreover, agricultural lands cover half of the Maghreb's area. Non-irrigated agriculture in North Africa, which accounts for 50% of total agriculture, is highly reliant on winter precipitation, in particular on total accumulation of precipitation and the frequency of rainy days during this period (Garcia-Ruiz, 2011). However, constrained by limited water resources, this sector experiences significant fluctuations in terms of production and yields due to the variability of precipitation patterns, both intra-annually and interannually. Before considering some of the impacts of climate change on water resources in the Maghreb, it is essential to conduct a brief review of the literature, both theoretical and empirical, on the relationship between climate change and water resources in this region.

2.1 Literature review

At the beginning of the century, climatology focused mainly on the analysis of statistics relating to various parameters such as precipitation, temperature, wind speed, etc. These data were used in a wide range of applications, including understanding geographical and environmental features, building infrastructures and making optimised decisions. These data were used in a wide range of applications, including understanding geographical and environmental features, building infrastructure and making optimised decisions. Towards the middle of the century, attention also turned to studying the physical and chemical processes that explain these statistics. For example, major climatic disturbances originating in the equatorial Pacific Ocean were observed during this period. It wasn't until the 1970s that certain specialists began to examine the potential impact of increasing concentrations of greenhouse gases in the atmosphere. Meteorological simulators were then adapted to allow long-term climate simulations. The first simulations aimed at projecting the future climate in the event of a doubling in the concentration of greenhouse gases seemed to confirm the intuitive principle that increasing the thickness of a greenhouse will cause it to warm up. However, the climate system, unlike a simple greenhouse, is highly complex. Over the last 20 years, scientists have continued to develop these simulators by exploring the many complexities of the climate system, which has generated unavoidable uncertainties. Despite this, these tools, which are capable of simulating the planet's historical climate, remain essential for anticipating the characteristics and scale of future climate change.

In 1995, the Intergovernmental Panel on Climate Change (IPCC) formalised what many scientists already knew: man has a perceptible influence on the climate. On a global scale, the average temperature has risen by around 0.5 degrees Celsius since the beginning of the century. However, this global trend is not necessarily reflected at regional level due to temporary climate fluctuations generated by the atmosphere, which sometimes makes it difficult to detect trends, especially on a local scale. Long-term global warming remains a reality. It is important to take into account the natural variability of the climate, influenced by various factors such as solar flux, ocean currents and volcanic eruptions.

Before confirming global warming, the IPCC assessed the statistical significance of the trend detected and distinguished it from natural climate variability. Scientific research on climate change and its implications for North Africa is relatively prolific. It covers a wide range of subjects, from changes in the average climate to extreme climatic events, not forgetting the repercussions on water resources, agriculture, health, ecosystems, tourism and energy. Several summary reports are also available, including those by UNESCO (2010) on the Maghreb, the World Bank on North Africa and the Middle East (2014), IRES on Morocco (2011), and ESCWA (2017) for North Africa and the Middle East.

In this context, in order to condense current knowledge on climate change in the Maghreb, it appeared necessary to undertake a new synthetic analysis of the existing literature, integrating the most recent publications and applying impact models developed at global level to the Maghreb context. Without claiming to be exhaustive, this document summarises the observations of changes already recorded over the last few decades, the projections up to 2050 and the main anticipated impacts.

According to many experts, the potential effects of climate change on water resources are varied, encompassing impacts on water supply, rainfall distribution, and the frequency and intensity of extreme weather events such as droughts and floods, with indirect repercussions on virtually all environmental and economic sectors. Hydrological regimes are significantly influenced by two main factors : temperature and precipitation. For both of these variables, and in almost all North African countries, a marked warming trend has been observed over the last few decades, with a particular accentuation in summer and with regard to minimum temperatures (donat, 2013). This rise in temperatures has been accompanied by an increase in hot nights, hot days and heat waves, as well as a decrease in cold spells (Fathalli B, 2017) (Zeroual A, 2019).

With regard to average rainfall during the wet season, from October to March, a downward trend has been observed in recent decades, with the greatest decrease in the Mediterranean regions of Morocco and Algeria and in parts of Libya, while a slight increase in rainfall has been recorded in the Mediterranean region of Egypt (Nashwan MS, 2019) (Taibi S, 2017) For Tunisia, the trends are not uniform (Fathalli, 2019).

In parallel with the decrease in rainfall during the wet season, winter drying has been observed over large areas of western North Africa since at least the 1970s (Tramblay Y, 2018) (Zittis, 2018). However, some wet years since the 2000s can be attributed to increased climate variability (Nouaceur Z, 2016). Regarding heavy precipitation events, most regions of North Africa have shown no significant trends over the last decades (Nasri B, 2016), while a general increase in the frequency of droughts can be observed in all regions of North Africa .

2.2 Temperature Trends

Over the past three decades, a significant increase in annual temperatures has been observed in the Maghreb region (Vizy, 2017). During this period, data on annual and seasonal mean temperatures in North Africa reveal a widespread warming due to the inherent natural variability of this geographic area. Furthermore, it is noted that surface temperature averages experience a rise during the spring and summer seasons in the northern part (A. Barkhordarian, 2012).

In recent years, the Mediterranean region has experienced climate warming at a faster rate than the global average, with a particularly pronounced acceleration around the Maghreb during summers. This situation presents differential risks associated with temperature increases between the Scandinavian region of Europe and the Mediterranean region. For instance, during the summer of 2021, temperatures reached levels well above 45 °C in Morocco, nearing the absolute heat record of 50.3 °C recorded on July 13, 1961, in Smara, in the southern provinces of the Kingdom. In Tunisia, in mid-August 2021, the thermometer climbed to 48 degrees in Tunis, surpassing the previous heat record of 46.8°C set in 1982. During this period, Beja recorded a temperature of 48.9°C, making it the fourth hottest location worldwide. In Algeria, during the summer of 2021, temperatures reached up to 48°C in several provinces, including Tizi-Ouzou, Bejaïa, Annaba, and El-Tarf (Jaldi, 2022).

According to projections by the Intergovernmental Panel on Climate Change (IPCC) climate warming in the Maghreb could be more severe than previously anticipated. In a scenario where greenhouse gas emissions do not experience a drastic increase or a significant reduction, temperatures are projected to increase by 3.8°C by 2100 compared to the early 20th century, with summers experiencing an average increase of 5°C in the Maghreb. This increase would lead to more frequent, intense, and prolonged heatwaves. Furthermore, the effects of warming would be felt at higher altitudes, resulting in a reduced snow cover duration and snow thickness in the Atlas and Rif Mountains in Morocco since the 1960s. In the most extreme scenario of a temperature increase exceeding 4°C by 2100, all ski resorts in the coastal town of Ifrane would become nonviable without the use of artificial snow (IPCC, 2022).

2.3 Precipitation Largely Absorbed by Intense Evaporation

Over the past century, the average annual precipitation in the Maghreb has exhibited a decrease. Notably, over the last thirty years (1979-2008), northern regions have seen a clear reduction in winter and early spring precipitation quantities. However, an analysis of observed data reveals a significant increase in autumn precipitation in certain areas of northern Algeria and Morocco (Barkhordarian, 2013).

In general, it has been estimated that most of the time, the number of days without precipitation exceeded 330 days per year (i.e., less than 1 mm of rain per day) in the Maghreb between 1997 and 2008 (Cook, 2012). Despite the decline in precipitation over the past three decades, the Maghreb has also witnessed some exceptional precipitation events that have triggered severe natural disasters (Daoud, 2013).

In the Maghreb, the average annual precipitation is estimated to be around 357 km^3, equivalent to a water depth of 110 mm. This modest amount of precipitation can be attributed to the high level of aridity, which varies based on the different climatic zones present in the region.

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Approximately 88% of these precipitation volumes are absorbed by actual evapotranspiration, playing a significant role. These precipitations, primarily concentrated during the cold season (accounting for 80% of the total), exert their influence mainly along the coastal areas of Algeria and Tunisia, as well as the Moroccan Atlas Mountains.
In addition, multiannual drought periods represent a major challenge for the economies of the Maghreb countries. These droughts are becoming increasingly frequent and prolonged, as Stockton (1988) and Mutin (2011) point out. Surface water resources, which play a crucial role, are particularly dependent on rainfull fluctuations. In 2020, the average availability of surface water in this area was around 44 billion m3/year, of which more than 65% was in Morocco.

2.4 Increasingly High Utilization Indices

The annual renewable water reserve allocated per person in the Maghreb region stood at 464 m^3 in 2020. This value notably remains below the theoretical scarcity threshold set by the World Health Organization (WHO, 2015)), which is set at of 1,000 m^3 per person per year. This applies even to Morocco, which has the broadest access to surface water resources

Figure 1: Exploitable water resources (million m^3/capita/year)

Source: FAO – AQUASTAT 2015

Among the Maghreb countries. It is important to note that this allocation of water, although modest, can be misleading as it concerns renewable resources, not all of which are effectively usable. With population growth, this supply will fall to less than 290 m^3/capita/year by 2030. Algeria's already critical situation, at less than 290 m^3/capita/year, would worsen (in the absence of alternative non-conventional resources), as the supply would fall to around 180 m3/capita/year.

2.5 Are Water-Related Risks Well controlled and Mitigated ?

Despite the forecast increase in demand for water due to population and economic growth, alterations induced by climate change will play a predominant role in variations of water stress across the region. Climate change intensifies water stress through various mechanisms, including reduced precipitation and elevated temperatures (IPCC, 2022). This trend increases evapotranspiration rates and irrigation requirements for crops (Verner, 2012), alongside periods of intense heat (Lelieveld, 2016). These factors will reinforce the water stress for surface waters in multiple regions and intensify precipitation irregularities.
Fragile nations, both politically and environmentally, will face specific water stress due to climatic disturbances. Simultaneously, climate change contributes to rising sea levels, thus increasing the risks of flooding and salinization of deltas and coastal aquifers. This saline water rise also impairs freshwater aquifers and river systems, particularly impacting coastal areas that

overexploit groundwater as excessive extraction favors the intrusion of saltwater (Mabrouk, 2013). Vulnerable populations are likely to be most affected by increased flood and drought risks, phenomena of particular concern in the Middle East and North Africa, where the most vulnerable populations are exposed to climate shocks (Hallegatte, 2016).
Floods dominate observed natural disasters in this region, but the exacerbation and intensification of drought periods are becoming inevitable with climate evolution. Recent droughts far exceed the natural variability of the past millennia (Cook B. I., 2016), increasing concerns about their exacerbation due to climate change. Water scarcity poses difficult choices in the Middle East and North Africa region, where water, energy, and food intersect. The interactions between these complex sectors create challenging trade-offs that can have unforeseen consequences. Indeed, water is essential for food production, while energy is crucial for water production (desalination or pumping groundwater). The League of Arab States emphasizes in its Strategic Framework for Sustainable Development the importance of multisectoral approaches to address complex resource management issues (Gelil, 2014).

3. Adaptation Strategy

Before the impacts of climate change gained widespread media attention, the Maghreb nations had already set up some strategies to enhance water supply through hydraulic mobilization policies. This approach primarily relied on dams construction and well drilling. Over the past five decades, regulated water volumes, which were close to the extracted volumes, have significantly increased, surpassing 22.50 km3. However, in the face of growing water needs, these quantities have proved insufficient.
In this context, the official reports of Maghreb countries presented under the "United Nations Framework Convention on Climate Change" provide a valuable insight into the strategic vision guiding policymakers in the region, namely Algeria, Morocco, and Tunisia. By actively participating in international forums and establishing "National Committees on Climate Change," officials and experts in these three maghrebans countries strive to identify key elements for reorienting their water management policies towards an approach more focused on rationalizing water resources.
This approach aims to enhance water use efficiency by adopting measures such as regulated water pricing, promoting water-efficient irrigation techniques, and developing unconventional water supply sources. However, before listing a few strategies, it is essential to provide a vision of climate change mitigation.

3.1 Climate change mitigation strategies

There are two broad categories of water mitigation strategies: technology-based and nature-based. In order to meet many of the global water challenges and deliver additional benefits in all areas of sustainable development, nature-based solutions (NBS) are an essential way to go beyond business as usual. NBS use or reproduce natural processes to increase water availability: soil moisture retention or groundwater recharge, improve water quality (for example, natural or artificial wetlands) and therefore reduce the risks of water-related disasters and climate change. Ecosystems function as carbon sinks that absorb greenhouse gas emissions in SfN-based mitigation approaches. The preservation or restoration of wetlands, the reforestation of mangroves and the preservation of natural flood plains near rivers are just a few examples. Although peatlands, which are formed by peat soil and the wetland habitat that develops on its surface, account for only around 3% of the Earth's surface, they store at least twice as much carbon as all the Earth's forests. These interrelated hydrological and terrestrial and terrestrial ecosystems are an important resource for mitigating unexplored climate change mitigation resource.

Technological solutions to mitigate climate change generally require investment in reducing emissions from water infrastructure, such as drinking water supply, wastewater and storm water treatment, water pumping for agriculture and other uses. There are several strategies for reducing the risks associated with water and sanitation that need to be taken into account when planning and managing water abstraction, distribution and treatment operations in this context:
Increased energy efficiency: Energy savings of 10-30% can be achieved in water supply and wastewater treatment by installing energy-efficient pumps tailored to the specific characteristics of the network.
Renewable energy production and energy recovery: hereby reducing demand for fossil fuels
Production of electricity using turbines installed along water supply and wastewater treatment networks treatment networks

3.2 Widespread Water-Efficient Irrigation

With decreasing water availability, competition among various water uses becomes even more intense, especially as irrigation needs increase. These needs dominate in all countries; however, Algeria distinguishes itself by presenting a relatively moderate proportion (63%), in contrast to the rates observed in Morocco (86%) and Tunisia (80%). To alleviate pressure from agriculture on water reserves, irrigation methods known for their water consumption efficiency are gaining adoption.

3.3 Improving Irrigation Performance

Irrigated cultivated areas in the Maghreb region are estimated at around 12% (FAO, 2017) of the total agricultural area used. Official data presents approximations due to the unpredictable nature of precipitation and, consequently, water availability. Nearly 56% of irrigated lands in the Maghreb are concentrated in Morocco. In contrast, Algeria and Tunisia have two and three times fewer irrigated lands than Morocco, respectively.
In the Maghreb region, areas with abundant water and those intensively used are at a certain geographical distance. To address this situation, substantial water transfers are undertaken, but these transfers result in significant water resource loss. This phenomenon is also observed in usage areas; where between 50% and 60% (Jihad, 2012) of water is lost due to the lack of maintenance of supply channels and the use of gravity irrigation methods, especially in Morocco.
The Maghreb countries are confronted with the need to expand their agricultural lands through irrigation to ensure food security. By 2030, these areas could increase to 3.5 million hectares (FAO, 2017), representing an approximately 30% increase from the current situation. However, this expansion is uncertain in Morocco and Tunisia due to concerns about water supply, given that the majority of their water resources are already utilized. In Algeria, technical and financial challenges limit the capacity to increase regulated water supply despite efforts to manage water flows.
Maghreb countries are implementing projects to promote more efficient irrigation methods, aiming to cover around 80% of irrigated lands by 2030 (Jihad, 2012).These methods allow for increased agricultural production while limiting water consumption and soil erosion, with gains ranging from 40% to 60% compared to traditional irrigation.

3.4 Wastewater : a valuable resource

Currently estimated at around 2,330 hm3/year for the three countries, wastewater discharges present approximate data, partly due to the frequent inclusion of rainwater from roofs and streets. The Maghreb region housed about 200 sewage treatment plants (35% in Morocco, 50% in Algeria, and 15% in Tunisia), with a theoretical annual treatment capacity of 1,125 hm3. However, the amount of treated wastewater barely reaches 550 hm3/year. Treatment rates range

from 14% in Morocco to 39% in Tunisia for discharged waters. Treatment methods are generally secondary or even primary, suitable for uses like golf course irrigation or irrigating fruit trees, vineyards, and fodder crops. Nevertheless, these treatment levels prove insufficient when treated effluents are intended for irrigation of some vegetable crops or discharge into rivers. Tunisia stands out in terms of reclaimed water reuse, with a rate of 30 % (Jihad, 2012).
Significant amounts of untreated wastewater are discharged into the environment, leading to water quality deterioration. Sewage treatment plants, when present, are often ineffective due to insufficient maintenance. In Morocco, of about 70 existing plants, fewer than half operate regularly. Deteriorating water quality leads to environmental damage, estimated at about 2.7% of GDP for Tunisia, and around 4.4% and 4.9% of GDP for Morocco and Algeria, respectively. This plays a significant role in degrading water resources.

3.5 What Socio-economic Adaptation Ensures Equitable Access to Water Services ?

Until the 1990s, water tariffs in Maghreb countries were low, contributing to significant losses in aging networks, estimated at half of the produced resources in 1995. These losses resulted from inadequate pricing that favored patronage and lack of maintenance. Since the late 1990s, improvements have been observed in Morocco and Tunisia due to regular tariff revisions, widespread meter usage, and abandonment of flat-rate billing in certain cities. In Morocco, the potable water recovery rate exceeds 99%, and this economic approach has led to reduced water consumption, particularly among heavy users. Tariff increases have also encouraged alternative practices. In Algeria, despite meter generalization, network efficiency remains low due to payment issues. In all countries, an economic approach has been adopted for potable water and sanitation management, with progressive tariffs promoting access and waste prevention.

3.6 Seawater : An Inexhaustible Resource

In the Maghreb region, desalination of seawater and brackish groundwater was first adopted to address potable water needs in isolated desert areas. Currently, production stands at about 0.8 hm3/day, mainly from nearly twenty plants largely powered by conventional energy sources. In Morocco, the first seawater desalination facility was established in Tarfaya in 1976, followed by several other units, including the largest one in Laayoune, with a capacity of 66,000 m3/day. Morocco currently has 12 existing stations with capacity118, 700 m3/day and plans to increase this capacity to 396,200 m3/d with this 7 stations under construction by 2030 (nouacer, 2017) .
On the southern coast of Tunisia, desalination of brackish water has primarily been developed since the 1980s, with a current capacity of over 100,000 m3/day, projecting an increase of 5 to 6 times by 2030. However, the relatively high cost of seawater desalination limits its use to coastal desert areas. For other regions, desalination will become inevitable when conventional water resources are insufficient. This has already been the case for over a decade along the Algerian coastal strip, especially in cities and petrochemical complexes. Algeria, a regional leader in desalination, produces over 600,000 m3/day in a dozen large plants and plans to reach 2.6 hm3/day by 2030 (nouacer, 2017)

4. Conclusion

In conclusion, climate change has emerged as a major global concern, directly or indirectly affecting all countries. To address this new challenge, a comprehensive approach is imperative. Southern nations, such as those in the Maghreb region, are particularly susceptible to these impacts. Each country must formulate its own responsive strategy to mitigate the effects of climate change.
However, the responsibility of Northern countries remains pivotal. They hold a critical role in providing scientific, technical, and financial support within the framework of international cooperation for sustainable development. Global collaboration is essential to collectively meet

this challenge and safeguard the future of our planet. The Maghreb countries have already put in place strategic guidelines aimed at strengthening their research capacity on climate change and its effects. Although complex climate models are still difficult to assess on a fine and precise scale, they have the advantage of raising awareness of future risks among decision-makers in the Maghreb. However, few people are aware of these risks.
There are considerable uncertainties regarding the evolution of water availability, both in terms of quantity and quality. Rainfall forecasts are subject to considerable uncertainty, as hydrological systems are complex and subject to strong anthropogenic pressure, while knowledge of these systems, particularly as regards the instrumental monitoring of rivers, remains incomplete. These factors make it extremely difficult to model these systems and, consequently, to assess the impact of climate change on future water availability. However, in the context of climate change, water resources are showing a general downward trend, with an increase in water deficit observed particularly during the summer months. This trend will inevitably have repercussions on the various uses to which water is put, as well as on its distribution.
Effective adaptation to climate change will depend on the commitment and cooperation of the Maghreb countries in reducing greenhouse gas emissions, as well as on the adoption of "no-regrets" measures that will broaden the range of solutions to be developed in terms of water-saving irrigation techniques, wastewater reuse, seawater desalination, and so on. Delayed implementation of these measures risks compromising adaptation to climate change.

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