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REVIEW

Water Stress and Regional Governance in Morocco: Pathways to Agricultural Resilience through Advanced Regionalization

Redouane Kaiss [1*], Zakaria Benjouid [1], Mourad Faiz [2], Hanane Ech-Chahed [3], Azzedine Rakhimi [4], Said Saghir Zarouali [1], Ahmed Maimoun [1], Amine Hmid [5], Mariem Cherkaoui [5]

[1] Research Laboratory in Economics, Management, and Business Administration, Faculty of Economics and Management, Hassan I University, Settat 26002, Morocco

[2] Laboratory of Applied Studies and Research in Economics and Management, Cadi Ayyad University Marrakech, Marrakech 40000, Morocco

[3] Laboratory for Research in Theoretical and Applied Economics, Hassan I University, Settat 26002, Morocco

[4] Multidisciplinary Research Laboratory in Economics and Management, Faculty of Economics and Management, Sultan Moulay Slimane University, Beni-Mellal 23000, Morocco

[5] Interdisciplinary Laboratory, Business Engineering, Soft Skills, Management, and Law, Faculty of Legal, Economic, and Social Sciences of Ain Sebâa, Hassan II University, Casablanca 21100, Morocco

ABSTRACT

Water scarcity is a growing and multidimensional threat to sustainable development in arid and semi-arid regions, with Morocco representing a critical case. Intensified by climate change, recurrent droughts, and unsustainable resource use, the country faces declining water availability, particularly affecting rain-fed agriculture and rural livelihoods. This paper presents an interdisciplinary analysis of the intersection between water stress, agricultural productivity, regional inequalities, and governance structures. Special focus is placed on the potential of advanced regionalization—a decentralization reform introduced after the 2011 Constitution—to improve water management and agricultural resilience through localized, participatory governance. The study examines the

*CORRESPONDING AUTHOR:
Redouane Kaiss, Research Laboratory in Economics, Management, and Business Administration, Faculty of Economics and Management, Hassan I University, Settat 26002, Morocco; Email: redouane.kaiss.doc@uhp.ac.ma

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impacts of water scarcity on cereal production, food imports, and trade deficits, while highlighting institutional challenges, including fragmented governance, legal ambiguities, and poor policy coordination. Despite national frameworks, such as the National Water Strategy and IWRM plans, implementation remains weak at the regional level. Building on a territorial and systemic perspective, the paper argues for a paradigm shift in water governance that integrates regional specificities into national strategies. It advocates for empowering regional actors, adopting climate-resilient technologies, and using economic incentives to promote sustainable practices. Public-private partnerships, unconventional water sources, and interregional cooperation mechanisms are identified as key tools for building resilience and reducing regional disparities. Ultimately, the study argues that achieving water security and agricultural sustainability in Morocco requires inclusive, decentralized, and adaptive governance grounded in territorial equity and collaborative action across all levels of decision-making.

Keywords: Water Scarcity; Advanced Regionalization; Agricultural Sustainability; Territorial Development; Water Governance

1. Introduction

Water scarcity has become a serious and pressing global concern for several reasons, with numerous implications that include impacts on food security, economic development, social equality, and environmental sustainability [1]. The World Bank estimates that over 2 billion people worldwide lack access to safe drinking water, while 4.2 billion people globally lack adequate sanitation, further demonstrating the urgency of the global water crisis [2]. These issues are particularly apparent in arid and semi-arid regions, which are naturally limited by climate and hydrology [3]. Morocco is particularly vulnerable as the country is becoming more pressured by the convergence of uncertainties in water availability caused by, (1) climate change in the form of fluctuations in annual rainfall, increases in temperature, and increased evapotranspiration, (2) demographic forces, (3) accelerated urbanization, (4) unplanned land-use regulations, and (5) unproductive water consumption, particularly in agriculture [4–8].

Morocco's water challenges are not just environmental; they have significant socioeconomic impacts [9]. The agricultural sector contributes just under 14% of the total GDP of the national economy. It is responsible for around 34% of the total, mostly in rural areas, with agriculture reliant on water as an input [10]. Agricultural operations throughout Morocco are primarily rain-fed; the penetration of modern irrigation technologies and water-efficient infrastructure is minimal. Increasingly, drought conditions have disrupted cropping cycles, ultimately affecting yields and farmers' incomes, as well as reliance on food imports, particularly over the last two decades [11]. These factors have made water stress and scarcity more than seasonal issues; instead they have become an ongoing structural bottleneck to sustainable agricultural transformation, rural development, and prosperity [12].

Additionally, the institutional framework for water management remains hindered by inadequate collaboration among water service providers, a lack of regulatory enforcement, and the incomplete or non-integration of the climate change adaptation agenda into water strategies [13, 14]. Although national strategies are comprehensive, they have fallen in implementation, especially at the regional and local levels. These failures further contributed to discussions regarding governance reform, particularly in the context of advanced regionalization [15].

Introduced under Morocco's 2011 Constitution, advanced regionalization provides an unprecedented opportunity to rethink water governance from a regional and participatory perspective. As a framework for devolving decision-making powers and re-equalizing resources between regions, the advanced regionalization framework embraces the potential to connect national policy with local specificities. This paper aims to provide a fundamental understanding of the relationship between water stress and development in Morocco, with a particular focus on how advanced regionalization can be

leveraged to improve agricultural resilience, economic diversification, and territorial equity.

The study combines observations, policies, and a multidisciplinary approach to explore various aspects related to water availability, agricultural production, institutional governance, and regional planning, thereby unraveling complex relationship between decision-making and water. This paper also outlines a number of recommendations for rethinking Morocco's water governance system in a way that is adaptive, equitable, and resilient in an era of increasing climatic uncertainty and development pressure.

In this context, this paper seeks to address the following central research question: How can Morocco's advanced regionalization framework serve as a lever to enhance water governance and strengthen agricultural resilience in the face of growing water scarcity?

The analysis is guided by the hypothesis that decentralizing water management—when combined with adaptive technologies and inclusive governance—can mitigate regional disparities and contribute to sustainable territorial development. By adopting a systemic and territorial lens, the study explores the links between hydrological stress, agricultural production, governance fragmentation, and socioeconomic inequality.

The article explores the challenges associated with water scarcity in Morocco and possible responses. It begins with an in-depth analysis of the current water shortage situation, highlighting its impact on agriculture and food trade. It then focuses on the institutional and regional disparities that hinder equitable and efficient water management. With this in mind, the study examines how advanced regionalization can be leveraged to develop more resilient water and agricultural policies that are tailored to local specificities. This is followed by a discussion of the technological, economic, and governance tools that can be mobilized, including the utilization of unconventional water resources, smart irrigation systems, and public-private partnerships. The article then offers targeted policy recommendations before concluding with a summary of the main lessons learned and their implications for sustainable development in Morocco.

2. Methodology

This study adopts a qualitative, interdisciplinary approach grounded in policy analysis and literature synthesis. The objective is to examine the systemic interconnections between water scarcity, agricultural performance, territorial disparities, and governance frameworks in Morocco, with a particular emphasis on the role of advanced regionalization as introduced by the 2011 constitutional reform.

2.1. Policy and Institutional Review

The analysis is based on a critical examination of Morocco's key water and agricultural policy instruments, including the National Water Strategy, Integrated Water Resources Management (IWRM) plans, Plan Maroc Vert, and recent regional development frameworks. Legal texts such as Law 10-95 and Law 36-15 were reviewed to identify institutional roles, governance gaps, and implementation challenges.

2.2. Literature Synthesis

A comprehensive review of recent scientific literature, reports by international organizations (e.g., World Bank, FAO, UNDP), and national statistical data was conducted to contextualize trends in water availability, agricultural productivity, and socioeconomic vulnerability. Peer-reviewed sources published between 2019 and 2025 were prioritized, with a focus on studies related to water governance, decentralization, climate adaptation, and rural development in North Africa and Mediterranean contexts.

2.3. Descriptive Data Analysis and Interpretation

The study uses publicly available data to illustrate key trends in water resource distribution, cereal production, and trade balances. Figures and maps included in the paper are drawn from national statistical offices, basin agencies, and prior academic studies. All data sources are cited accordingly in the figure captions and text.

This qualitative design aims to foster an integrative and critical perspective, rather than generating new empirical data. It enables a diagnostic assessment of the current situation and the formulation of strategic recommendations grounded in both theory and practical policy.

3. Water Scarcity and Its Impact on Agricultural Production

An analysis of sectoral water use in Morocco highlights a significant imbalance in the distribution of water resources (**Figure 1**). Agriculture, by far the largest consumer of water, uses approximately 89.3% (88.5%); urban drinking water use accounts for only 7%, while rural drinking water use is about 2%. The industry, at 1.4%, and tourism, at 0.2%, use a negligible fraction of water. The implications of this massive agricultural water sector use suggest that water is essential to food production in Morocco. At the same time, this heavy reliance on water for agricultural production makes Moroccan food security and the livelihoods of rural populations, to some degree, vulnerable to changes in water availability (i.e., climate change, drought, or overexploitation of groundwater). The distribution of water usage today highlights the need for structural changes in water management. Drip irrigation systems, less water-intensive crops, and the implementation of integrated water resource management (IWRM) are among key strategies to maintain agricultural production sustainability. Furthermore, Morocco's limited water share for industry and tourism indicates weak economic diversification, not only about the effects of water use, but it may also weaken resilience to future associated water challenges. Thus, the figure demonstrates the importance of improving water use in agriculture as a means of adapting to water scarcity and maintaining agricultural productivity in Morocco.

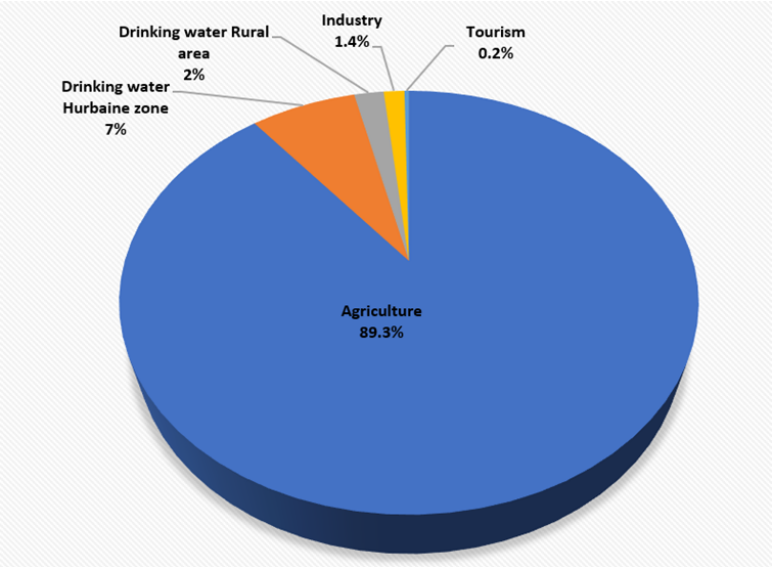

Figure 1. Sectoral water consumption in Morocco (%).

The trend of Morocco's renewable inland freshwater resources per capita per year is concerning because the freshwater available per capita per year has decreased from 1961 to 2023 (**Figure 2**), suggesting that the long-term trend of growing water scarcity is not only unsettling but may also continue to develop. In the early 1960s, per capita freshwater availability was over 2,500 cubic meters per year, a level of availability which was well above the water stress threshold of 1,700 m^3/year. However, throughout the decades, this value has dropped continuously from above the threshold, falling below the water stress threshold in the early 1980s and below the water scarcity threshold of 1,000 m^3/year in the late 1990s. Most disturbingly, since the 2010s, Morocco has entered a zone where water shortage conditions are considered extreme, with yearly per capita available freshwater below 500 m^3/year, indicating absolute water scarcity. This drastic reduction is the results of various factors, including

population growth, recurring droughts, climate change, and unsustainable water use, particularly in agriculture. The graphic demonstrates the increasing rates of water scarcity and highlights the serious concern about whether the country can meet its water needs in the coming years. The graphic identifies when we pass internationally accepted threshold values for scarcity (marked in the graphic as green (1700 m^3), red (1000 m^3), and a lower critical point for rare). This highlights the urgent need for national water policies, investment in non-conventional water sources (e.g., desalination or wastewater reuse), and educational campaigns to promote rational water consumption.

In return, the distribution of water resources in Morocco is characterized by significant spatial and temporal variability. Surface water in Morocco is poorly distributed. Approximately 70% of Morocco's surface water production is concentrated in only 15% of the country's territory, primarily in the northern part. Average annual renewable water resources per capita fell from 2,560 m^3 in 1960 to less than 620 m^3 in 2020, putting Morocco well below the water poverty line.

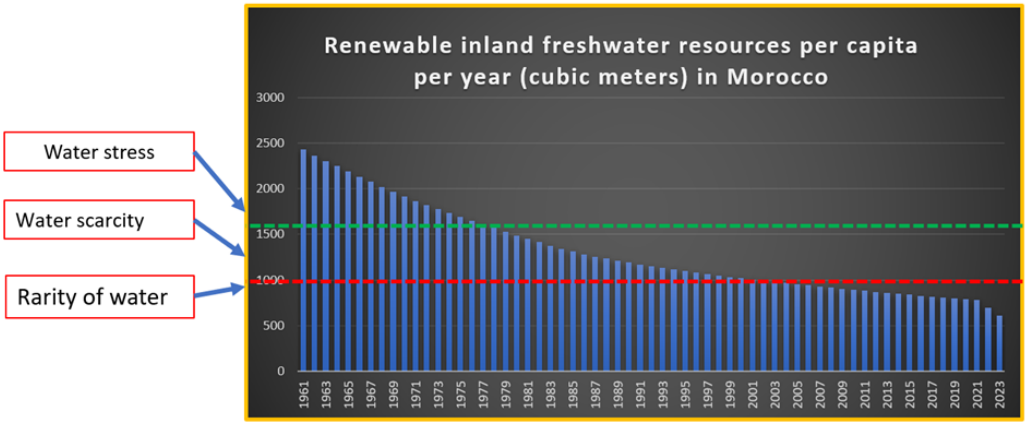

Figure 2. Renewable inland freshwater resources per capita per year (cubic meters) in Morocco.

3.1. Characteristics of Water Resources in Morocco

Figure 3 illustrates an overview of Morocco's water resources in major hydrological basins, showing both surface water (**Figure 3a**) and groundwater (**Figure 3b**) resources. The Sebou basin is the most wealthy in both types of water resources, with 5,600 million m^3/year of surface water and 1,110 million m^3/year of groundwater, representing a critical hydrological asset for the country. The basins of Loukos and Oum Er Rbia followed behind in surface water (3,434 million m^3/year and 3,315 million m^3/year, respectively). However, they had relatively low groundwater stocks, with Loukos' available groundwater being only 110 million m^3/year, suggesting that the Loukos basin relies on rever flow rather than underground aquifers. In contrast, systems like Moulouya, Tensift, and Sous-Massa have a healthier mix between surface water and groundwater, which serves as a cushion against water supply depletion during droughts. It appears that S. El Hamra et Oued Eddahab, in contrast, is precarious, with 274 million m^3/year of surface water and a worrisomely low 22 million m^3/year of groundwater, representing intense and critical water scarcity.

This spatial nature of water resources demonstrates a need for regionally based water management approaches. These allocations also highlighted unequal hydrological endowments between basins, with some having abundant supplies and others experiencing chronic scarcity. This demonstrates the necessity for inter-basin water transfers, efficient irrigation practices, or investment in groundwater recharge to protect water delivery strategies in the face of increased climate variability due to a changing climate.

To better visualize these disparities, **Figure 3** presents a map of Morocco's main hydrological basins, highlighting the contrast in water availability between the northern (Sebou, Loukkos) and southern (Drâa, Tensift, Oued Eddahab) regions. These differences contribute to unequal development opportunities and water insecurity across territories.

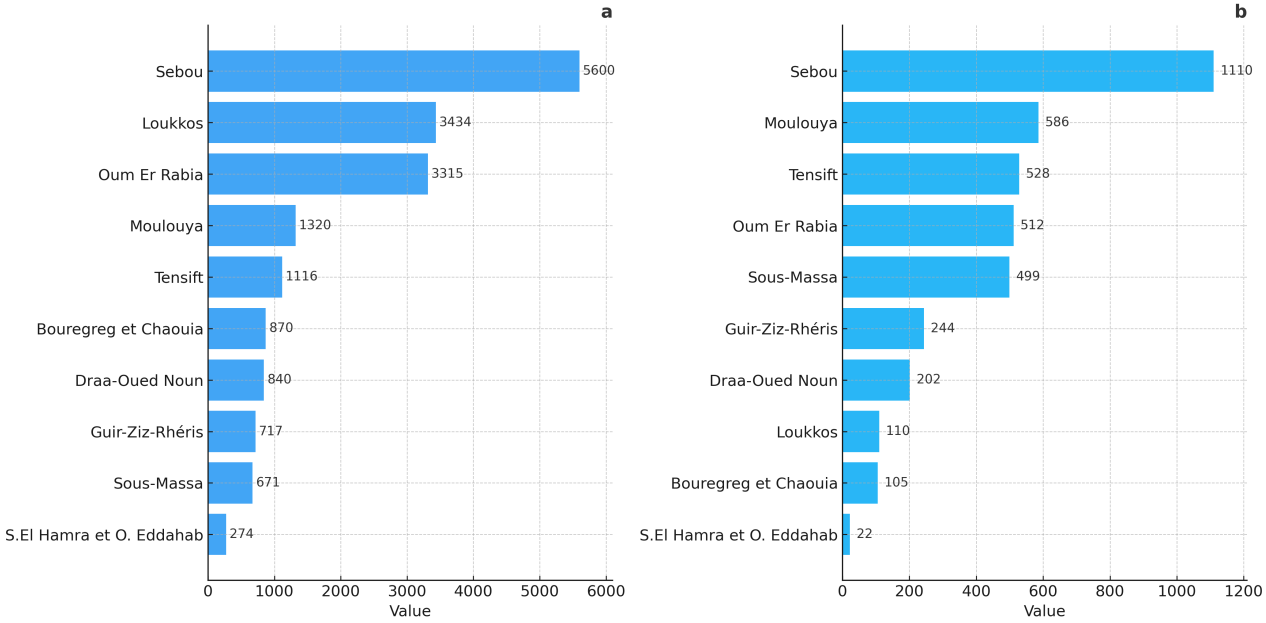

Figure 3. a: Surface water resources (Mm^3/year); **b**: Groundwater resources (Mm^3/year).

Institutional challenges further exacerbate these disparities. For instance, Regional Hydraulic Basin Agencies often lack financial autonomy and technical capacity to implement context-specific measures. In the Drâa-Tafilalet region, for example, delays in irrigation infrastructure upgrades are linked to overlapping mandates between regional councils and central agencies. Moreover, budgeting for water infrastructure remains highly centralized, limiting the ability of regions to respond proactively to localized water stress. Administrative bottlenecks and unclear responsibilities between basin agencies and regional governments hinder effective coordination, especially in water allocation during droughts.

3.2. Impact on Cereal Production

The Moroccan agricultural sector is particularly vulnerable to fluctuations in rainfall . Cereal production, which occupies more than 60% of cultivated land, shows high interannual variability. Drought years lead to significant yield reductions and increase dependency on imports (**Figure 4**). Between 2019 and 2022, Morocco's cereal imports increased by 58%, highlighting the direct relationship between water availability and the country's food trade balance (**Figure 5**).

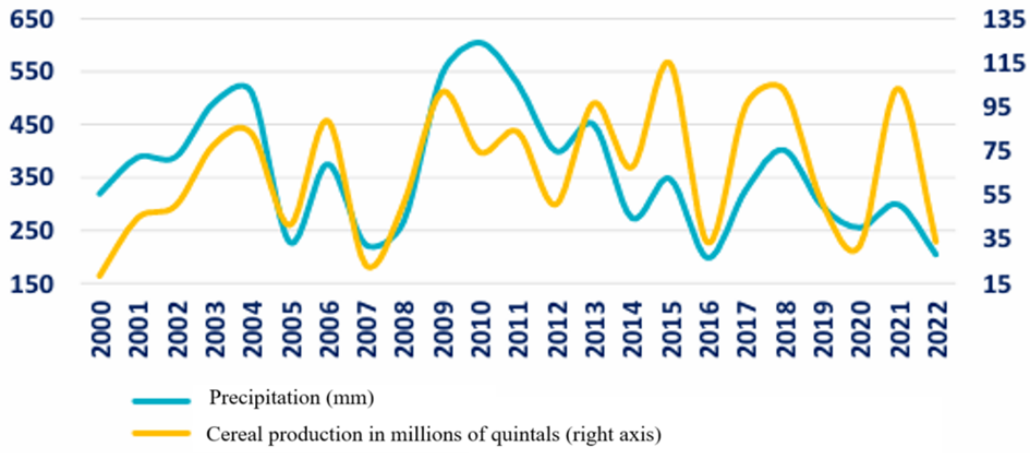

Figure 4. Precipitation and cereal yields.

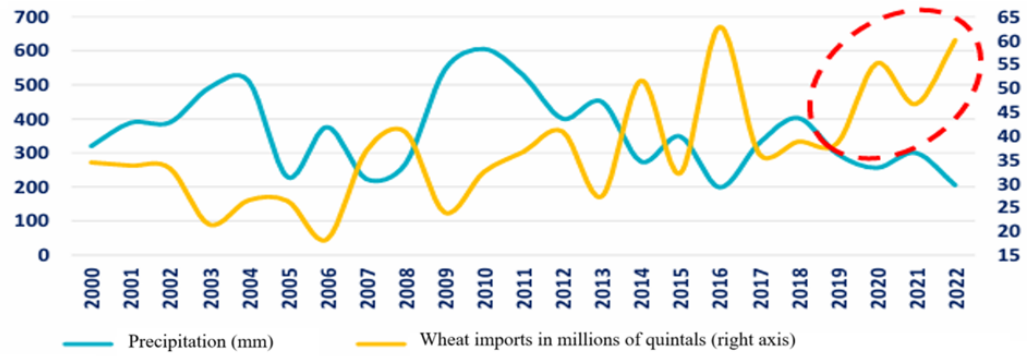

Figure 5. Precipitation and cereal imports.

3.3. Agricultural Trade and Economic Implications

Morocco considers agriculture a vital part of its economy, particularly in terms of employment, food security, and livelihoods [16]. However, the sector's considerable reliance on rainfall and freshwater makes it very vulnerable to the ever-increasing frequency of droughts and water scarcity. These climatic pressures negatively affect domestic food production, trade flows, and macroeconomic stability. In drought years, domestic production levels of important cereals, such as wheat, maize, and barley, can fall drastically in line with the decreased amount of irrigation water and soil moisture availability. This drop in production requires a significant increase in cereal imports to meet national consumption needs, which further deteriorates the agricultural trade balance. For instance, when drought levels are high, wheat imports can quadruple or triple, placing considerable strain on foreign currency reserves and international market volatility for commodities [17].

A period of agri-food trade deficit transforms into a structural vulnerability. In Morocco, on top of this transformation, the country faces extreme exposure to global market shocks, ranging from geopolitical conflicts to disruptions in global supply chains, which have led to inflationary trends in food prices [18]. The burden of this trade deficit falls more heavily on low-income families, particularly in rural communities where food expenditures account for a larger portion of the household's budget. In addition to food imports, water stress will also impact agri-food exports, particularly for high-value crops (such as citrus, olives, and early vegetables) that are crucial for generating foreign income and maintaining jobs in rural areas of Morocco. If there is a reduction in available water, producers will be left with the option of reducing the area of land under cultivation or switching to less water-intensive crops. Either option will result in reduced export revenues and lower rates of rural employment. In areas reliant on export-oriented agriculture, reductions in rents and jobs can lead to destabilized local economies. This concerns rural development because it takes years of investment and capacity building to generate economic and social progress in rural areas [19].

Additionally, water scarcity has consequences for agro-industrial processing and the broader value chain, resulting in increased production costs, reduced raw material availability, and complicated logistics [20]. This inhibits Morocco's aspiration to become a competitive force in both regional and international agri-food markets. In terms of policies, the growth in unpredictability of available water suggests a need to integrate climate resilience into agricultural trade strategies, e.g, under trade agreements developing partnerships with more than one trade partner, facilitating trade in climate smart agricultural products, supporting domestic food production capacity using water efficiency technologies (e.g., drip irrigation, treated wastewater reuse, desalination suitable for agriculture) and considering buffer stocks and strategic reserves of key staples for countering climate- induced trade shocks.

4. Institutional Framework and Regional Governance

4.1. Legal and Institutional Instruments

Morocco has established a plethora of laws aimed at managing water resources, including Law 10-95 and

Law 36-15, which form the basis for integrated water resource management. Several important institutions have also been established, including the High Council for Water and Climate (CSEC), basin agencies, and regional environmental councils. While these institutions exist, water governance remains fragmented and inefficient, primarily due to overlapping responsibilities, limited funding, and inadequate coordination.

4.2. Regional Disparities and Challenges

Morocco's hydrological landscape is characterized by severe regional variability in both water availability and water infrastructure, which plays a salient role in determining the spatial distribution of economic opportunities, agricultural production, and rural development pathways. These regional disparities shape access to water, but they are not only geographical and environmental; they are also inseparable from socio-economic inequalities that govern normative development patterns and amplify the vulnerabilities of already marginalized areas. Geographically, northern Morocco is home to renewable water resources that are in a much more plentiful supply and has more developed hydraulic infrastructure (i.e., both permanent and episodic) than other regions. The northern areas of the country also supply the majority of irrigated agricultural zones. They are the site of much of Morocco's agro-industrial activity, which has received considerable public and private investment. The result is that areas of northern Morocco have considerably more agricultural diversification, export potential, and employment generation than in other regions of the country, which provides a degree of regional economic dynamism.

Conversely, the southern and inland regions such as Drâa-Oued Noun, Souss-Massa, and Sakia El Hamra-Oued Eddahab, are experiencing chronic water scarcity due to their climate, limited surface water, and overexploited aquifers. These regions are also grappling with poorly developed infrastructure, including inadequate storage and water distribution capacity, limited access to modern technologies for irrigating their parcels, and restricted connection to national markets. This structural deficit of water will limit agricultural development, inhibit economic diversification, and worsen food and water security of local populations. These imbalances contribute to the development gap between regions, increasing the territorial inequality. In many provinces with severe water stress, young people migrate to cities or other regions in search of better opportunities, which contributes to rural depopulation and the degradation of traditional livelihood forms. This increase in migration not only heightens tension on urban social infrastructure and labor markets but may also pose an inherent risk to social stability in rural areas, where unemployment and resource scarcity can create frustrations that can develop into unrest.

The existing regional inequalities also entail policy implications. Water governance is centralized, with limited room for local contexst to be integrated into national plans. The use of Basin Agencies and regional water councils has not changed; once established, actors at the local level often lack the capacity or resources to effectively manage water according to their specific challenges, resulting in an unequal distribution of resources compared to existing regional needs. Bringing equality into the picture, however, requires an equal approach to water allocation and rural development through policies that emphasize investment in water infrastructure in regions with inequitable access. These policies should include extending the use of non-conventional water sources (e.g., desalination, treated wastewater), promoting water-saving irrigation systems (such as drip systems), and improving institutional coordination among actors at the national and regional scales. In addition, policies could include improving local participation in water governance and capacity building of local actors.

5. Advanced Regionalization as a Driver of Resilient Agriculture

5.1. Concept and Implementation

The Constitution of 2011 has established advanced regionalization, which, as a new governance perspective, represents a fundamental departure from a top-down, centralized development model to a decentralized and participatory governance of one's territory. The reform established new administrative and financial powers for regional councils, allowing these councils to develop and

implement strategies for regional development according to their unique socio-economic, environmental, and climatic realities. Advanced regionalization thus facilitates decentralization of governance by encouraging the emergence of regional initiatives in areas such as agriculture, water, land use planning, and environmental sustainability. In the face of increased climate variability and chronic water stress, the model of advanced regionalization provides regions with the flexibility to develop adaptive agricultural models and water strategies that are more adapted to local or regional realities. Furthermore, by engaging in local or regional planning processes, advanced regionalization will likely foster a greater sense of ownership and accountability among regional communities, facilitate accountability relationships among institutions, and intelligently mobilize local resources. Thus, the regional level can concurrently be a place to implement national strategies as well as a laboratory for innovation, experimentation, and co-governance.

A practical example of advanced regionalization in action is the Souss-Massa region, where the regional council partnered with the Ministry of Agriculture and private operators to co-manage water-saving irrigation infrastructure for citrus and early vegetable production. This initiative enabled the development of localized drought management plans and farmer training programs tailored to specific agro-ecological conditions.

Comparative experiences from Spain and Tunisia are also relevant. Spain's "Hydrological Confederations" enable decentralized basin-level governance under national oversight, while Tunisia's regional development plans have piloted groundwater co-management with farmer associations. These cases highlight both the potential and the limits of decentralization. Risks such as insufficient local capacity, lack of coordination across levels of governance, and elite capture have been reported and must be anticipated in Morocco's implementation strategy.

5.2. Opportunities for Water Governance

In the world of advanced regionalization, regional councils could revolutionize water governance by being in a unique position, distinct from national institutions, in working with rural communities, farmers, and water user groups that are often overlooked. Regional councils could take the reins in developing drought preparedness plans, regulating pumping from aquifers, and ensuring water is distributed to meet both agricultural and domestic needs. Regional councils could also lead the way for localized water-saving practices by collaborating with farmers to adopt irrigation best practices, such as drip irrigation, and helping them transition to crops that use less water. Improved small-scale irrigation infrastructure, such as rainwater harvesting, retention basins, and reservoirs managed by a community, can add another layer of resilience to local communities against seasonal water shortages. Regional institutions can also mediate competing interests (agriculture, tourism, urban planning) while ensuring participatory and conflict-sensitive water allocation decisions. A multi-level approach is necessary for integrated water resource management and sustainability over time.

5.3. Interregional Solidarity

Given the significant differences in water allocation among regions in Morocco, interregional solidarity is not only an operational necessity, but also a unique opportunity. The northern basins (Sebou, Loukkos) have huge surface and groundwater resources; however, the southern and inland regions (Tensift, Souss-Massa, Drâa) are often water deficient. National efforts have developed water interconnection systems (what we call an "autoroutes de l'eau" that could permit the transfer of water from surplus to deficit regions. These types of projects are technically possible, but they present challenges in terms of governance, management, cost sharing, and ecological impacts. The successful implementation of inter-basin transfers must prioritize transparent coordination mechanisms that ensure equitable participation from all regions involved. Solidarity cannot be limited to only aqueducts and transfers; it must also include: information and knowledge exchange, regional technical support systems, water planning, and joint coordination. In the spirit of cooperation, regional cooperation would take the form of interregional water compacts, which allow regions to mutually support each other while ensuring that ecological limits and regional autonomy are re-

spected. This would foster regional solidarity and cohesion while underlining the notion of water as a common good, essential for the national interest, as it is a shared and strategic resource.

6. Technological and Economic Responses

In Morocco, the adoption of efficient irrigation systems remains uneven. As of 2022, approximately 22% of irrigated land used drip irrigation, primarily in high-value export zones such as Souss-Massa and Tadla. Smallholder farmers, particularly those in inland and mountainous areas, face cost barriers and lack access to technical support for transitioning to modern systems.

The Agadir desalination plant serves as a flagship PPP project. While operational success has been reported, challenges include delayed cost recovery due to energy prices and disputes over water tariffs between stakeholders. Moreover, regulatory mechanisms to ensure transparency and environmental safeguards remain underdeveloped. To maximize PPP efficiency, governance frameworks must enforce equitable access, stakeholder accountability, and environmental monitoring.

6.1. Non-Conventional Water Resources

Conventional water refers to water resources obtained from natural hydrological processes, such as withdrawal from rivers, streams, lakes, reservoirs (including rainwater), and aquifers (including groundwater). Non-conventional water (**Figure 6**) includes other water sources, such as seawater, rainwater harvesting, agricultural drainage, thermoelectric cooling water, hydraulic fracturing water, or wastewater from industries, households, and domestic or commercial sources (including discharge from hot springs). These non-conventional water resources are plentiful, generating significant opportunities to address growing water demand given the rapid urbanization. Some countries that face extreme water scarcity have already started reusing treated wastewater for agricultural irrigation, including Egypt[21], Jordan[22], Tunisia[23], Turkey[24], and Saudi Arabia[25]. Despite these programs, irrigation primarily relies on conventional water sources. Within the Arab countries, conventional water sources provided 70.1% from surface water, 29.5% from groundwater, and non-conventional water resources used less than 0.3% of irrigation water[26].

Figure 6. Classification of unconventional waters[27].

Worldwide renewable water resources are estimated to be around 42,800 billion m^3 per year[28], but the problem lies in their effective collection and utilization. On the other hand, non-conventional water sources, such as seawater, domestic wastewater, and industrial effluent, are extremely variable, in both quality and quantity and usually require treatment before use, unless one wants to harm crops with unknown water qualities or potentially endanger public health[29]. Several technologies are available, including biological sand filtration, to mitigate these concerns[30]. Case studies on the management of non-conventional water use in agriculture have been conducted in countries, such as Spain, China, South Africa, and Egypt; however, the literature on the actual effectiveness of these technologies concerning agriculture and crops is limited. In this article, we review the regulatory, technological, and management aspects that facilitate the safe reuse of non-conventional water sources, contributing to the achievement of the Sustainable Development Goals. We will provide a general overview of the sources, treatment technologies, and future research needs[27].

Faced with increasing stress on its traditional wa-

ter supply sources, Morocco is moving ahead to improve water security through multiple avenues, aiming to reduce its reliance on traditional water sources. This includes building desalination plants, wastewater reuse, and groundwater aquifer recharge. The most high-profile project in this regard is the Agadir desalination plant, which is one of the largest desalination plants in Africa. The Agadir project is a significant piece of infrastructure designed to help diversify Morocco's water supply, meeting the drinking water needs of residents and the irrigation needs of the agricultural region, thereby contributing to the country's food security. The plant's capacity to desalinate seawater will help alleviate some of the stress on freshwater supplies that are already being stressed due to climate change, population growth, and the rising urban and rural population's desire for water. In addition to desalination, Morocco plans to reuse treated wastewater for agricultural irrigation to optimize the limited water available. The country has also begun exploring methods to recharge groundwater, aiming to replenish aquifers that have been depleted by excessive pumping. All of these efforts are part of a larger plan to achieve sustainable water management, reduce dependency on traditional water sources, and mitigate the impacts of water scarcity. This effort supports Morocco in achieving the United Nations' Sustainable Development Goals (SDGs) related to water conservation and responsible water management.

6.2. Efficient Irrigation Systems

Localized irrigation technologies, including drip irrigation and precision irrigation, have been encouraged to increase water use efficiency in agriculture [31]. They can minimize water loss by up to 50% compared to traditional surface irrigation supply systems, ensuring assured water availability [32]. Due to increased pressure on water resources, efficient irrigation plays a crucial role in achieving food security and environmental sustainability, as the agricultural sector accounts for approximately 70% of the world's freshwater supply, with considerable regional variation. In Morocco, this proportion can exceed 80% in areas of irrigated agriculture.

Government programs, including the National Program for Water Economy in Irrigation (PNEEI), aimed to help farmers transition from traditional to modern irrigation systems. The PNEEI has disbursed over 20 billion dirhams (roughly 2 billion euros) between 2008 and 2020 in support of the modernization of irrigation on 550,000 hectares of land. This investment has led to an increased uptake of more efficient irrigation systems, allowing farmers to better manage water resource availability while increasing productivity output. For example, with the uptake of drip irrigation, agricultural production output rose from 50 to over 100% under more assured water availability, where the greatest gains were recorded for more water-sensitive crops, including cereals, vegetables, and fruit.

Smart irrigation systems, using technologies such as the IoT, can also help conserve water [33]. Some studies suggest that smart irrigation systems can save between 30% and 40% of water and increase agricultural productivity [34]. This type of technology can play a crucial role in countries facing water shortages, which aligning with Sustainable Development Goal (SDG) 6: Water and Sanitation. In Morocco, irrigation plays a crucial role in agricultural production, and the development of IoT-based solutions could significantly impact conservation and yield [35].

The efficiency of modern irrigation systems can also have a positive economic impact. In Spain, the use of smart irrigation sensors has led to 25% reduction in water usage on certain orchards, resulting in increased profits. Investments in this technology can be recovered in 4 to 5 years through optimized use of water and increased productivity [36].

6.3. Public-Private Partnerships

Public-Private Partnerships (PPPs) are widely recognized as a strategic option for securing funding, reliable technology, and greater efficiency in the development of water infrastructure and service delivery [37]. In Morocco, where public investment cannot keep up with all the sustainable water management needs, PPPs can be an attractive option for making up the investment gap while promoting innovation and the delivery of better services.

Private partners can play a crucial role in the design, financing, construction, and operation of vital in-

frastructure, such as desalination, wastewater treatment, and irrigation systems. The Agadir desalination project, another example of a PPP with national agencies and private operators involved, has been delivering both potable drinking water to urban populations as well as irrigation water to agricultural co-operatives. Integrated projects like this provide examples of how public-private synergies can promote resource optimization and multifunctionality in distributed or regional water systems.

PPPs are also important facilitators of technological innovation in water management, such as the development of smart irrigation systems focused on the use of real-time weather data, soil moisture sensors, and automation. While these systems are developed through the collaboration of various partners, such as government-driven programs, agritech startups, and equipment manufacturers, they are typically facilitated through a PPP model. Likewise, remote sensing technologies and data analytics platforms are being integrated into water monitoring and planning systems, enabling predictive modeling and informed decision-making with an evidence-based foundation. Innovations like this enhance water efficiency, enabling systems to provide early warnings and adapt to climate change.

Nevertheless, to fully realize the benefits that PPPs bring, certain conditions of governance must be present. Contracts should include strong performance indicators, transparent procurement, and be transparent about risk sharing and accountability to protect the public interest. Furthermore, the regulation overseeing the PPP should prevent monopolization, ensure equitable tariffs, and conserve the environment. It is also important that PPPs are inclusive, such that smallholder farmers, rural communities, and local entrepreneurs could be included in co-designing, collaborating, and realizing the benefits of water projects.

Furthermore, capacity building is required to improve the public sector's ability to negotiate, manage, and monitor public-private partnership contracts, particularly within the context of advanced regionalization at both regional and municipal levels. Access to public funding combined with private capital and development funding can also support the scaling up and sustainability of these partnerships. Indeed, Public-Private Partnerships provide an exciting pathway to transform Morocco's water sector. Well-regulated and strategically aligned with national and regional development objectives, public-private partnerships can accelerate the transition to resilient, efficient, and inclusive water systems, facilitating agricultural modernization, food security, and territorial equity.

7. Policy Implications and Recommendations

To effectively address the growing challenges of water scarcity and its implications for agricultural sustainability and territorial equity, Morocco must adopt a multidimensional and integrated policy strategy (**Table 1**). The recommendations below are organized into four thematic areas, each targeting specific stakeholder groups and aligned with realistic implementation timelines.

7.1. Institutional and Legal Reforms

Target stakeholders include the Ministry of Equipment and Water as well as regional councils, with implementation foreseen in the medium term. It is recommended that the High Council for Water and Climate be reactivated to provide strategic oversight, strengthen inter-agency coordination, and align national and regional water policies. Furthermore, it is essential to clarify and rationalize the institutional mandates of basin agencies, regional councils, and ministerial departments in order to reduce overlap and fragmentation of responsibilities. Law 36-15 should be updated and made operational through clear regional and provincial guidelines that emphasize resilience and adaptive water governance. Additionally, promoting the adoption of regional water charters will help establish flexible, participatory governance frameworks that align with national objectives.

7.2. Investment and Infrastructure

The Ministry of Finance, public-private investors, and development banks are the primary stakeholders, with a timeframe ranging from short to medium term. Public investment in water infrastructure should be pri-

oritized in regions most affected by water stress, particularly southern and inland provinces. Support for efficient irrigation technologies, such as drip irrigation and localized water management systems, needs to be expanded. Simultaneously, infrastructure for non-conventional water sources, including wastewater reuse and desalination plants, should be scaled up using cost-sharing models. Developing agro-industrial clusters that integrate circular water systems will also help reduce pressure on freshwater resources.

7.3. Capacity Building and Local Governance

Regional councils, universities, NGOs, and basin agencies are the key stakeholders for these ongoing initiatives. Training programs should be launched for local officials, farmers, and water user associations on climate-resilient agricultural practices and water governance. Technical assistance must be provided to regional and local institutions to help design, implement, and monitor water strategies tailored to local needs. Moreover, establishing multi-stakeholder platforms will facilitate coordination among water users, technical experts, and policymakers at the territorial level.

7.4. Public Awareness and Education

This long-term effort involves stakeholders, such as the Ministry of Education, civil society organizations, and media outlets. Water sustainability education should be integrated into school curricula and vocational training programs. National media campaigns and community-based awareness initiatives should be organized to promote responsible water consumption and raise awareness of the risks of overexploitation. Finally, civic engagement in regional water planning should be encouraged by involving NGOs and local user groups in basin councils and development forums.

Table 1. Strategic Policy Recommendations.

Axis	Target Stakeholders	Timeframe	Key Actions
Institutional Reform	Ministry of Water, Regional Councils	Medium-term	Activate High Council, clarify mandates, regional water charters
Investment & Infrastructure	Public-Private Sector, Ministry of Finance	Short-to-Medium	Drip irrigation, desalination, wastewater reuse, agro-industrial clusters
Capacity Building	Regional Councils, NGOs, Universities	Ongoing	Training, local technical support, stakeholder coordination
Awareness & Education	Schools, Media, Civil Society	Long-term	Water education, media campaigns, civic participation in governance

8. Conclusion

The increasing water stress in Morocco is not only an environmental concern but a strategic economic challenge. Its repercussions on agricultural productivity, food security, and regional development call for an integrated and decentralized approach. Advanced regionalization offers a valuable framework for adapting water governance to local conditions, promoting innovation, and enhancing territorial equity. To ensure a sustainable agricultural future, Morocco must prioritize water in its development agenda, strengthen institutions, and foster a culture of shared responsibility and resilience.

Author Contributions

Conceptualization, R.K. and Z.B.; methodology, R.K. and M.F.; software, A.H.; validation, R.K., Z.B. and M.F.; formal analysis, M.F.; investigation, Z.B. and A.R.; resources, S.S.Z. and A.M.; data curation, Z.B. and A.R.; writing—original draft preparation, R.K., Z.B. and M.F.; writing—review and editing, H.E.M., A.H. and M.C.; visualization, A.R. and M.C.; supervision, R.K.; project administration, R.K.; funding acquisition, R.K. and H.E.M. All authors have read and agreed to the published version of the manuscript.

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The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Conflicts of Interest

The authors declare no conflict of interest.

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