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Water, agriculture, and climate: a study of Moroccan agricultural water management policy

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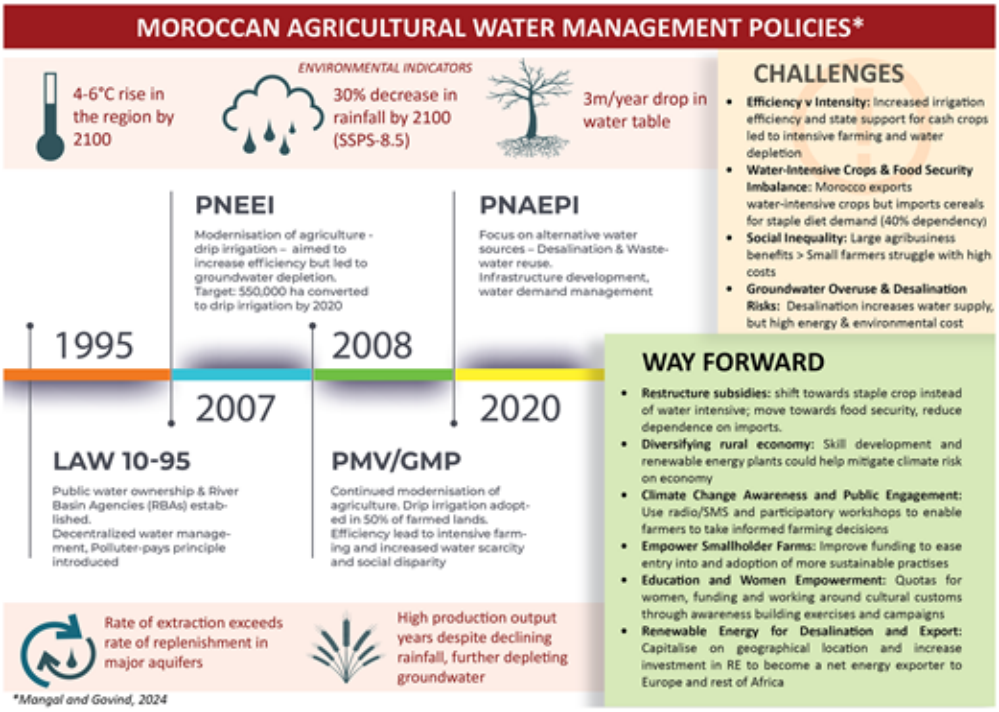
ABSTRACT



Morocco is grappling with the severe effects of climate change, causing droughts and decreasing annual precipitation. Agriculture, a significant sector of the economy and livelihood for a significant portion of the population, is facing the brunt of this, necessitating the adoption of water-efficient technologies. This paper examines agricultural water management practices in Morocco and the state policies, such as Law 10-95, the Green Morocco Plan, and the National Program for Drinking Water Supply and Irrigation. The Green Morocco Plan successfully promoted water-efficient techniques like drip irrigation, but inadvertently increased water intensity, exacerbating the scarcity. The paper

suggests a reorientation of Morocco's agricultural strategy towards self-sufficiency in traditional crops and a sustainable approach to water resource management. It also calls for the involvement of the greater community, education, and women's integration in the agricultural workforce to build a more resilient population. The analysis concludes with recommendations for policy adjustments that balance economic growth with environmental sustainability, suggesting a shift towards renewable energy and alternative water sources like desalination, albeit with caution due to associated environmental and economic costs.

HIGHLIGHTS

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- Identification of policy gaps in agricultural water management under climate change.
- Shows how efficiency programmes (PNEEI, PMV) reduced plot-level losses but increased basin-scale water stress.
- Recommends demand-side reforms, gender-inclusive Water User Associations, and renewable-powered desalination to balance the water-food-energy nexus.

Keywords: Agricultural water management policy, Climate change, Desalination, Groundwater depletion, Irrigation, Morocco

INTRODUCTION

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Agriculture is a cornerstone of Morocco's economy, contributing around 15% to the GDP and employing nearly 40% of the workforce (Ghanem 2015). Achieving food security is critical for national stability, as evidenced during the COVID-19 pandemic, which underscored the importance of having a robust domestic economy when global supply chains were disrupted. The importance of having a strong and resilient agricultural sector is thus necessary, especially for resilience in times of crises and unprecedented events.

Morocco faces multifaceted challenges in attaining food security due to severe water scarcity caused by climate change. The statistical data show that there is a significant decline in the annual precipitation over Morocco (Govind 2022). Ben Salem *et al*. (2023) propose that under the climate scenario of SSP5-8.5, there would be a 30% reduction in rainfall by 2100. The mean surface temperature is increasing, as shown in Figure 1.

Fig. 1

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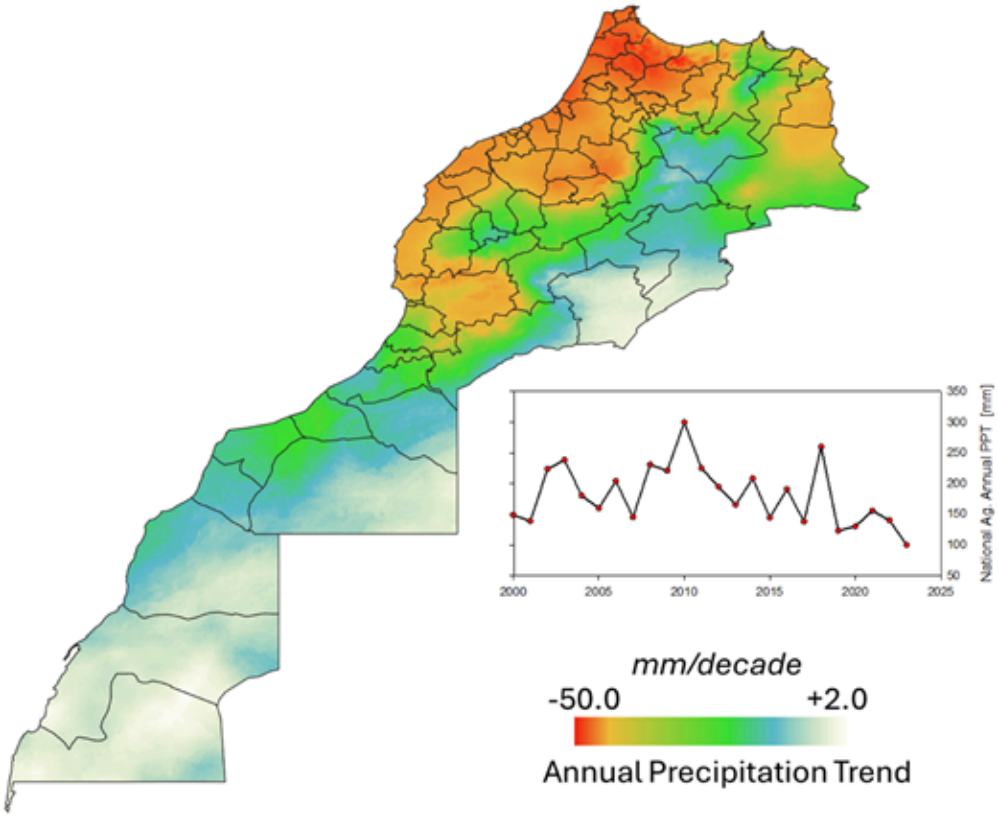

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Hotspots of CC in Morocco. TERRACLIMATE data (Abatzoglou *et al*. 2018) were used to explore hotspots of climate change. The slopes of the linear regression of the annual precipitation from 2000 to 2023 were plotted with time (at pixel level) is mapped.

This situation has led to significant droughts and declining water levels in reservoirs, heavily impacting the output and feasibility of farming in several areas. For instance, the output of citrus in the country faced a 32% decrease in the 2019–2020 season (Kharrou & Chehouni 2023). Consequently, it is imperative to adopt water management policies that are sustainable, especially in a country where water resources are limited and unevenly distributed. The irrigated agricultural land in Morocco is about 1.46 million hectares, representing around 17% of the country's total agricultural area (Molle & Tanouti 2017). A basin-level breakdown of the equipped and actually irrigated areas is provided in Table 1, which shows that the Oum Er-Rbiaâ system alone accounts for nearly one-third of the national irrigated area. Climate change also adds further complications with its secondary effects, such as land degradation, salinisation, and the emergence of new diseases, thereby increasing stress on local populations and wildlife. The temperature in the area is also expected to rise by 4–6 °C by the end of the century, with agriculture in the Maghreb being one of the most susceptible regions to fluctuations in rainfall, which may lead to a 30% reduction in crop yields under the worst-case scenario (Govind 2022). Due to this, the Middle East and North Africa region is poised to experience more climate change-induced migration in the near future. Such migrations in the geopolitical region would also have an impact on the neighbouring countries, with higher and variable populations adding stress on the already scarce resources.

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Table 1 Actual area equipped for irrigation and actual area irrigated in the major river basins in Morocco.

Basin	Area equipped for irrigation (ha)	Area actually irrigated (ha)
Bouregreg et côtes atlantiques	28,331	27,980
Loukkos et côtes méditerranéennes	63,600	63,600
Moulouya	155,451	152,120
Oum Rbiaâ et côtes Jadida Safi	478,448	478,448
Sebou	333,156	331,820
Souss-Massa et côtes Agadir – Tiznit	140,996	137,310
Sud-Atlasiques	125,243	125,243
Tensift et côt. Safi – Essaouira	158,935	131,490
Morocco total	**1,484,160**	**1,448,011**
Area equipped for full control irrigation	1,458,160	NA
Area equipped for spate irrigation	26,000	NA

This paper sets out to explore the agricultural management practices in Morocco, traditional and modern, tracing the evolution of successive agricultural water management policies, the improvements they made, and critically analyses them with a careful review of secondary data, identifying the policies' impacts in the background of climate change. The paper aims to add to the literature for a sustainable future for Morocco with suggestions for possible policy direction for mitigating the water scarcity while balancing economic growth in a drought-prone future in the medium to long term.

Policy analysis framework

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This study employs a dual-framework approach, integrating Integrated Water Resources Management (IWRM) and Political Ecology to analyse Morocco's agricultural water policies. IWRM provides a structured lens to assess how policies manage water resources through principles of

efficiency, sustainability, and decentralised governance, particularly in the case of Law 10-95 and PNEEI. However, since water governance is deeply intertwined with economic and social power dynamics, Political Ecology is also applied to examine how policies, such as the Green Morocco Plan (GMP; PMV), have influenced resource access, social inequalities, and environmental trade-offs. Combining these frameworks allows for a more comprehensive evaluation, capturing the technical effectiveness of water management strategies and the broader socio-political and economic impacts of agricultural intensification in Morocco.

The policies analysed in this paper – Law 10-95, the GMP (Plan Maroc Vert, PMV), the National Irrigation Water Saving Program (PNEEI), and the National Program for Drinking Water Supply and Irrigation (PNAEPI) – were selected due to their significant influence on agricultural water management in Morocco. These policies were chosen based on their direct impact on water resource allocation, agricultural productivity, and socio-economic outcomes, as well as their prominence in addressing the country's water scarcity challenges in the context of a changing climate. They are also reviewed in a chronological order as they have built upon each other to guide the national agricultural water policy.

Secondary data for this analysis were sourced from a range of materials, including government reports, academic literature, and international publications. These sources provide a robust foundation for assessing the evolution and impacts of Morocco's water management policies.

Despite the critical role of agricultural water management in Morocco, there is no comprehensive study to trace the evolution of policies and assess their long-term impacts on water resources and agricultural sustainability in the context of climate change. This paper addresses the question: How have Morocco's agricultural water management policies evolved over time, and what have been their impacts on water resources, agricultural productivity, and socio-economic outcomes? The paper thus aims to

1. Review current agricultural water management practices.
2. Evaluate existing agricultural water management policies and their impacts.
3. Recommend improvements to address the issues identified.

WATER RESOURCES AND THEIR MANAGEMENT TO SUPPORT THE AGRICULTURAL SECTOR

National scale resources and interventions

Listen

Morocco's water sources comprise surface, groundwater, and rain-fed resources. Surface water includes rivers, lakes, and reservoirs. In the arid regions, groundwater is a major source for irrigation (Skiredj Ait Chaou & Bouchaou 2019). Rain-fed agriculture is significant but vulnerable to climate variability (Schilling *et al*. 2012). Morocco's renewable water resources are estimated at about 29 billion m^3/year, with 22 billion m^3 from surface water and 7 billion m^3 from groundwater

(World Bank 2022). However, water availability varies widely across regions (Harbouze 2019). Within Morocco, rural-to-urban migration for better employment opportunities is also a concern, as it adds stress on the local water supply. The proportion of Morocco's urban population has increased from 29% in 1960 to over 64% in 2020. This significant rise is largely due to rural inhabitants moving to urban centres in search of improved economic prospects and living standards (World Bank 2022). Morocco's agricultural sector, relying heavily on irrigation due to sparse rainfall, means efficient water management is crucial for attaining food security and economic stability (Schilling *et al*. 2012). The growing population in such urban centres intensifies water demand, making efficient water management practices imperative across the country (Ezzine *et al*. 2014; World Bank 2022). Given the variability of the climate system, a blanket policy will not be effective, but region-specific policies, considering local nuances, are needed. This includes considering the geography, population, type of crops, method of agriculture, employment opportunities, and governance structures, among other variables. The major regions in Morocco that are prone to droughts are Souss-Massa, Marrakech-Saf, Tensift-Al Haouz, and Gharb-Chrarda-Béni Hssen. These areas experience frequent water shortages and are also prominent areas of agriculture, making them particularly vulnerable due to the over-extraction and insufficient recharge. This inadequacy of resources has led to lower agricultural productivity in many regions, as the irrigation infrastructure is not able to meet the demand. The Souss-Massa Draa region faces significant challenges regarding the management and sustainability of its agricultural water resources, which are compounded by climatic variability, growing water demand, and limited surface water availability. It is noted that while these are the major regions that are impacted by water scarcity in the context of agriculture, the scarcity is not limited to these regions. Any improvement in terms of water management can have ripple effects across the regions with growth and development, leading to higher social security due to employment and entrepreneurial opportunities for the local population, which is an overarching target of the government policy of PMV. The major irrigation sources in the country are categorised into surface sources, including rivers and dams, and groundwater aquifers.

Surface sources

The most important river in Morocco is Sebou, which originates in the Middle Atlas Mountains and flows westward to the Atlantic Ocean. It is a vital source of water for agriculture, irrigation, and hydroelectric power generation. Other significant rivers include the Tensift, Oum Er-Rbia, and Muluya, which also play a crucial role in supporting Morocco's water needs. However, the country's water resources are unevenly distributed, with the northern and western regions receiving more rainfall than the southern and eastern parts. This has led to challenges in water management and distribution, particularly during dry periods. However, Morocco's surface water resources are increasingly vulnerable to the impacts of climate change. Rising

temperatures, altered precipitation patterns, and more frequent droughts are posing significant challenges to the country's water security. Reduced rainfall and increased evaporation rates are leading to lower water levels in reservoirs and rivers, affecting agricultural production, hydropower generation, and domestic water supply. Additionally, climate change is exacerbating the saltwater intrusion into coastal aquifers, threatening groundwater quality and agricultural land. To address these challenges, Morocco has implemented various water conservation measures, including the construction of dams, reservoirs, and irrigation systems. Additionally, the government has promoted sustainable agricultural practices and encouraged the use of water-efficient technologies. However, the country's ability to adapt to the changing climate will require continued investment in sustainable water resource management and international cooperation.

Groundwater aquifers

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According to Hssaisoune *et al*. (2020), the aquifers of Morocco are all under severe stress due to over-extraction. The Chtoukha Aquifer in the Souss-Massa region is significantly over-extracted. Table 2 shows the percentage of land irrigated using groundwater. The annual water deficit is around 60 million m^3 due to intensive agricultural activities, including greenhouse farming. This has led to a substantial drop in groundwater levels and increased salinity, making the water less suitable for agriculture. Dakhla Aquifer, located in the Dakhla-Oued Ed-Dahab region, is also heavily over-extracted. The rapid expansion of agriculture, as pushed by policy, particularly in a region with limited natural water recharge, has placed immense stress on the aquifer.

Table 2 Percentage of land irrigated using groundwater source (Food and Agricultural Organisation AQUASTAT 2024).

Region	Area equipped for irrigation with groundwater (ha)	Area equipped fc
Chaouia/Ouardigha	35,096	8,301
Doukala/Abda	46,969	114,220
Fès/Boulemane	19,602	27,631
Gharb/Chrarda/Béni Hssen	94,177	171,167
Grand Casablanca	1,203	2,698
Guelmim/Es-Semara	11,722	23,021

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Region	Area equipped for irrigation with groundwater (ha)	Area equipped fc
Laâyoune/Boujdour/Sakia El Hamra	80	0
Marrakecch/Tensift/Al Haouz	120,189	114,228
Meknès/Tafilalet	61,505	23,468
Oued Ed-Dahab/Lagouira	65	0
Oriental	45,566	70,247
Rabat/Salé/Zemmour/Zaer	14,867	1,301
Sous/Massa/Daraâ	125,933	78,979
Tadla/Azilal	57,593	116,117
Tanger/Tétouan	20,230	32,812
Taza/Al Hoceïma/Taounate	22,405	20,033
Morocco total	**677,201**	**804,221**

Another critically overexploited one is the Souss-Massa Aquifer, with water extraction rates far exceeding natural recharge. The Souss-Massa region, a key agricultural zone, has seen groundwater levels decline by up to 30 m in the last 30 years. The aquifer is also facing issues related to seawater intrusion and water quality degradation, further exacerbating the situation. The Haouz aquifer, which supports agriculture in the Marrakech region, is facing similar challenges. Over-extraction for irrigation has caused groundwater levels to drop by about 30 m over the past 60 years (Hssaisoune *et al*. 2020). This depletion is primarily driven by intensive farming and urban water demand, with little natural recharge due to the region's arid climate. The Saïss aquifer, located in the Fez-Meknes region, is also overexploited. Groundwater levels have declined by approximately 65 m over the past 60 years. The aquifer is heavily used for agricultural and urban purposes, leading to a situation where water extraction far exceeds natural recharge. Table 3 represents the major agricultural regions of Morocco and the corresponding sources of irrigation with the major crops.

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Table 3 Major agricultural regions of Morocco and corresponding sources of irrigation with the major crops.

Region	Major crops	Source of irrigation
Souss-Massa	Citrus, vegetables	Souss-Massa Aquifer, Chtoukha Aquifer, Massa River
Gharb	Cereals, sugar beet, citrus	Sebou River, Loukkos River, groundwater
Haouz	Olives, vegetables	Haouz Aquifer, Tensift River, N'fis River
Tadla	Olives, cereals, sugar beet	Oum Er-Rbia River, Al Massira Reservoir, groundwater
Saïss	Olives, vegetables, cereals	Saïss Aquifer, groundwater
Doukkala-Abda	Cereals, vegetables	Oum Er-Rbia River, El Jadida, Safi groundwater
Oriental/Oujda	Cereals, olives, vegetables	Moulouya River, groundwater
Tensift	Vegetables, olives	Tensift River, N'fis River, groundwater
Rif	Olives, cereals, vegetables	Local rivers and streams, groundwater
Draa-Tafilalet	Dates, cereals, vegetables	Draa River, groundwater, Mansour Eddahbi Dam

Morocco has implemented several programmes to modernise agricultural water management. Notably, the GMP (PMV) (2008–2020), a major and very impactful policy in terms of boosting the country's economy, aimed to modernise and improve irrigation efficiency and promote sustainable water use (Harbouze 2019). Techniques, such as drip irrigation, automated irrigation systems, and advanced water monitoring technologies, are being adopted to enhance water use efficiency (World Bank 2022). PMV has resulted in the successful adoption of drip irrigation such that now about 50% of farmed lands use the technique, which have also brought about a rise in produce due to the targeted application of water and nutrients (Harbouze 2019). The diversification of crops and shift to higher-value crops with export potential has also raised the GDP and employment prospects. While this tells us one side of the story, there is criticism that this has also led to a competition for more land and resources for cultivating high-value crops, which puts the smaller farmers at a disadvantage (Harbouze 2019; IREF Europe 2023). Morocco's diet and the agricultural output mismatch are also another issue that needs to be addressed. Annual consumption of cereals in Morocco is at 200 kg per capita, but it has to import about 40% of it. The focus on farming more water-intensive crops before addressing the local demand

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for cereals, which require less water, is a trend that needs to be looked into to address water scarcity and food security. The shift to farming citrus and tomatoes means that, as they are water-intensive, it makes them more prone to water shortages (Saidi & Diouri 2017).

A notable national initiative was the construction of the Al Massira Dam and Al Wahda dams, which support irrigation and flood control in the Doukkala and Gharb regions. The dam helps regulate the water supply, ensuring consistent availability for drinking and agricultural purposes. This has significantly boosted agricultural productivity and reduced the impact of droughts on crop yields. In recent years, the Al Massira Dam has faced severe challenges due to prolonged droughts and climate change. The dam's water levels have dropped significantly, with recent reports indicating that it was at just 3% of its capacity in early 2024. This drastic reduction has forced authorities to suspend the use of the dam's water for irrigation since 2021, prioritising potable water supply for cities like Casablanca and Marrakesh instead (Morocco World News 2022).

These water restrictions have severely impacted agricultural productivity in the regions that rely on the dam. Farmers in the Doukkala and Settat regions have struggled with reduced water availability, reduced crop yields, and lower economic output. The subsidisation of irrigated agriculture in basins that are already under stress due to over-extraction is another concern (Molle & Tanouti 2017).

Regional scale

Listen

Water management practices vary based on water resource availability and regional needs. The Souss-Massa region, for instance, has adopted modern irrigation systems and water-saving techniques to tackle water scarcity and enhance agricultural productivity. The techniques include drip irrigation, greenhouses, and similar controlled environments for increasing productivity and reducing water loss through evaporation. In the Moulouya River Basin, the focus is on mitigating climate change impacts on water resources by adaptive agricultural practices, such as crop rotation, mulching, and no-till farming. In the Gharb region, the precision agriculture techniques have optimised water usage. Farmers use satellite imagery and soil moisture sensors to monitor crop health and water needs, reducing water wastage and improving yields (Ghiat & Bouchaou 2019). Figure 2 gives an overview of Morocco and the various risks its regions face before we look at the policies that evolved over the decades to manage and mitigate these risks impacting the agricultural sector.

Fig. 2

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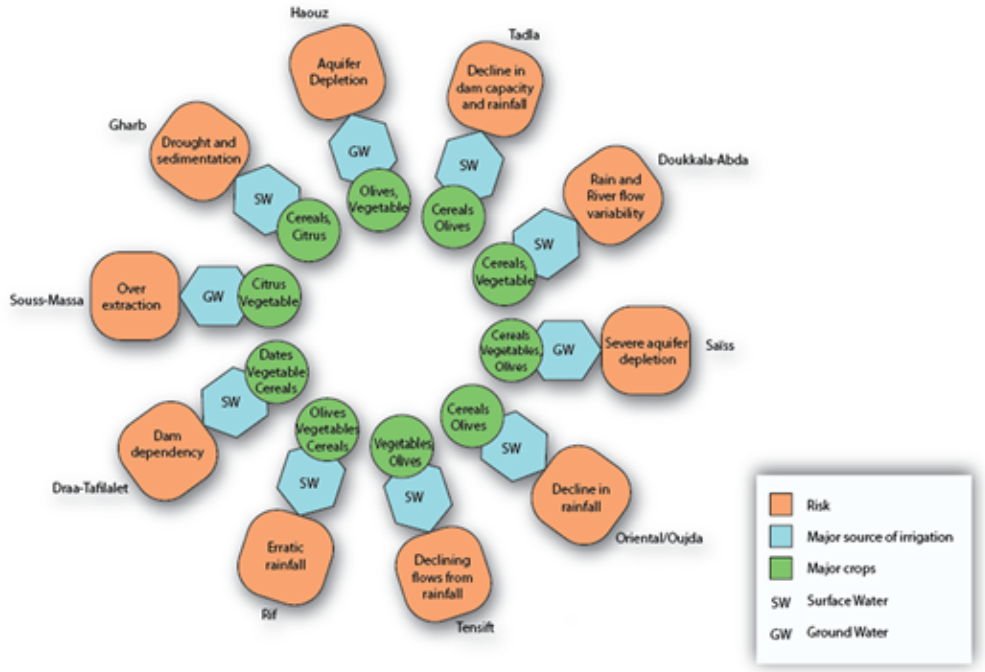

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Overview of regions of Morocco with major crops, sources of irrigation, and major risks impacting agricultural water supply. Adapted from data presented in this paper.

As opposed to traditional practices of regular interval irrigation, these techniques help conserve water as the farmers are able to take data-driven decisions. Although these technologies are effective and have been subsidised under the Green Morocco Plan, their adoption has been higher among large and wealthy farmers due to high initial costs (War on Want 2020). Under PMV, their adoption is higher among large and wealthy farmers due to the large initial investment cost and access to information, leading to a social disparity, enabled by the state's policy (War on Want 2020). The use of these technologies also demands that farmers be trained in interpreting the data, which has marginalised the smaller farms. In the Tadla region, the use of treated wastewater for irrigation has provided an alternative water source, reducing the strain on freshwater resources. The challenge here is to address the social stigma around 'recycled water', even if it is for agriculture. It is crucial that there be more community engagement from the stakeholders to inform the public about the safety and standards of the technology, and its crucial role in combating water scarcity.

Local scale

Listen

Local communities have historically relied on rainwater harvesting, terracing, and traditional open-channel irrigation methods like 'seguia' and 'khettara'. It takes a community effort to dig a khettara, which also fosters community cohesion and cooperation. Khettaras are also found in several parts of the world, including modern-day Iran, eastern Turkey, and northern Iraq, under different monikers, and studies suggest that this sustainable irrigation method may have emerged independently as a response to climate change in the past (Beraaouz *et al*. 2022).

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These methods are tailored to local climatic and hydrological conditions, as the underground canal reduces water loss through evaporation but requires regular maintenance and is vulnerable to siltation and damage (Beraaouz *et al*. 2022). These structures have historically been crucial for irrigating date palms and other crops, supporting local agriculture and livelihoods, and are also a part of Moroccan heritage, which was also made a tourist attraction in the Tafilalet oasis (Beraaouz *et al*. 2022).

Seguias are common in the High Atlas and Middle Atlas regions, where they are used to irrigate terraced fields. These are channels often lined with stone to prevent soil erosion and water loss through seepage. They are also often managed with a system of gates and shutters for water control. These systems support the cultivation of various crops, including cereals, vegetables, and fruit trees, and play a crucial role in sustaining rural agricultural communities. These traditional water management practices remain important locally, but face competition from modern electric motor pumping systems. Rainwater harvesting, terracing, and the use of seguias and khettaras continue to be employed by local communities. In some areas, like the Ziz valley, these traditional methods are combined with modern techniques to optimise water use and improve agricultural productivity. The Ziz Valley is renowned for its date palm cultivation. The introduction of drip irrigation and solar-powered pumps has significantly boosted date production. Farmers have reported higher yields and better-quality dates due to the consistent and efficient water supply (Bouziane *et al*. 2017). Another instance is in the Middle Draa Valley, where community-based approaches are effectively managing water resources. These include the formation of Water User Associations that manage the water distribution collectively. They also resolve any conflicts that arise and try to minimise the disparity in distribution. The community also takes it upon themselves to maintain the irrigation systems, fostering a sense of ownership and responsibility (Bossenbroek *et al*. 2022).

AGRICULTURAL WATER MANAGEMENT POLICIES

Law 10-95

Listen

To set a historical perspective and understand the evolution of the various policies, which are broadly illustrated in Figure 3, through the decades, we start by looking back to Law 10-95, established in Morocco in 1995, which marked a significant transformation in the country's approach to water resource management. This law was introduced in response to growing concerns about water scarcity and the need for a more comprehensive and sustainable framework. Moving away from the 'dam policy' that was in place from its time as a French Protectorate, when there were 13 dams at independence in 1956, Morocco, today, has 149 large dams, with a capacity of 19.1 billion m^3 (United States Department of Commerce 2024). The country, under King Hassan II, who was referred to as 'builder of dams', was on a dam-building

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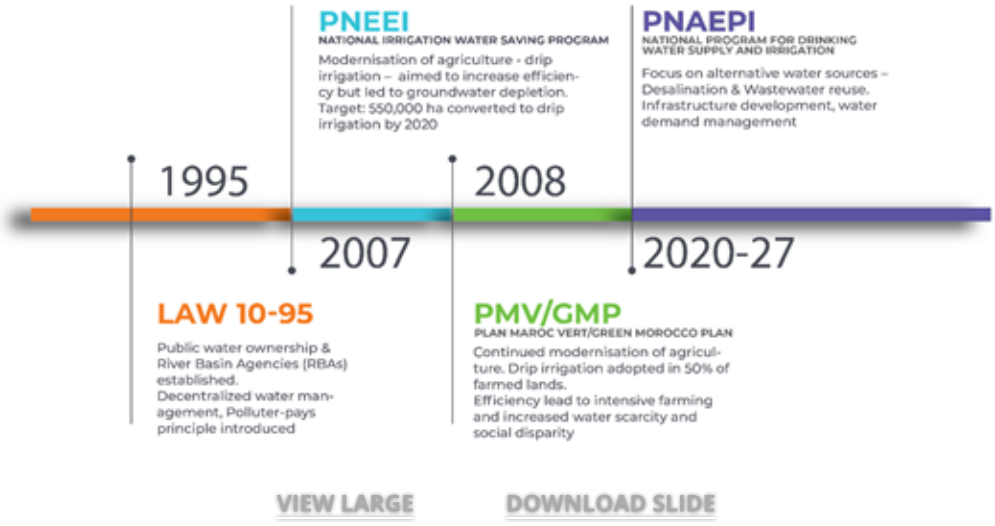
spree during the period, raising the storage capacity from 2 to 15 billion m^3 at the end of his reign. The dominant idea of water management at that time was to store as much as you could to ensure an uninterrupted supply. This supply-side management was about to take a turn with the introduction of Law 10-95.

Fig. 3



Timeline of evolution of Moroccan Agricultural Water Management Policies (adapted).

The law aligned with global trends towards IWRM, which advocates for a holistic approach that integrates water management with land use and environmental conservation. Law 10-95 emphasised the public ownership of water, declaring it a public good under state control, and introduced the concepts of decentralised management through the creation of River Basin Agencies (RBAs). These agencies were tasked with overseeing water resources within every watershed of the country, ensuring that management was tailored to the local context (Del Vecchio & Barone 2018). Additionally, the law implemented the user-pays and polluter-pays principles, ensuring that those who benefit from water use or contribute to its pollution are held financially accountable (Ait Kadi & Ziyad 2018). Moroccan policy did promote micro-irrigation as early as 1982, where there were tax exemptions for imported technology for such uses and the Fonds de Développement Agricole (FDA) offered subsidies, averaging 17% of the investment costs for micro-irrigation in the 1990s (Molle & Tanouti 2017).

The targets of Law 10-95 were ambitious, focusing on ensuring water security, promoting sustainability, achieving equity in water access, and improving water quality. The establishment of RBAs was a crucial achievement under this law, providing a decentralised framework for managing water resources effectively at the basin level. These agencies have played a vital role in planning, monitoring, and regulating water use, contributing to the modernisation of irrigation systems, particularly through the promotion of drip irrigation in agriculture. This modernisation has been essential in conserving water resources and ensuring that agriculture, which consumes about 80% of the country's water, becomes more sustainable

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(Silva-Novoa Sánchez *et al*. 2022). The major stakeholders involved in the implementation of Law 10-95 included the Ministry of Equipment, Transport, Logistics, and Water, and the Ministry of Agriculture. These ministries played central roles in policy implementation and oversight, while RBAs managed water resources at the basin level. Local authorities and municipalities were also made key players, particularly in managing local water supplies and sanitation services. The private sector has increasingly been engaged through public–private partnerships (PPPs), especially in urban areas where water supply and wastewater treatment are critical (Ait Kadi & Ziyad 2018).

Over the years, Law 10-95 has undergone significant amendments, the most notable being Law 36–15 introduced in 2016. This amendment further strengthened Morocco's water management framework by reinforcing IWRM principles, introducing stricter regulations on groundwater extraction, and enhancing the role and authority of RBAs. This has been essential in addressing the increasing water scarcity faced by Morocco (Silva-Novoa Sánchez *et al*. 2022). The legal framework established by Law 10-95, with its strong emphasis on IWRM and sustainable water management, was instrumental in supporting the objectives and laying the foundation for PMV, which will be discussed in further detail ahead, helping to increase agricultural productivity while conserving vital water resources (Ait Kadi & Ziyad 2018; Silva-Novoa Sánchez *et al*. 2022). The National Program for the Development of Micro-Irrigation was launched in 2002 to roll out the technique in target 114,000 ha, but by 2007, only 39% of the target was achieved (Molle & Tanouti 2017).

National Irrigation Water Saving Program (PNEEI) – 2007

Listen

The National Irrigation Water Saving Program (PNEEI) in Morocco, launched in 2007, was a strategic initiative aimed at addressing the country's significant water scarcity challenges and modernising its agricultural sector. This programme was deeply integrated with Morocco's broader GMP (PMV) later on, which was introduced in 2008 to transform the agricultural sector into a more sustainable and productive industry. The central principle of the PNEEI was to improve water efficiency by modernising irrigation systems. Traditional irrigation methods, such as surface irrigation, were highly inefficient and led to substantial water losses. The PNEEI aimed to replace these with more modern techniques, particularly drip irrigation. Collective and individual conversion from gravity and sprinkler irrigation systems to localised irrigation systems to save water was promoted under this programme. This shift was expected to reduce water consumption significantly while maintaining or even increasing agricultural productivity. The programme targeted the conversion of 550,000 ha of land to drip irrigation by 2020, but did not give enough importance to the loss of water efficiency, considering losses at the plot level not to be 'real losses' in comparison to the river basin's scale (Molle & Tanouti 2017). It was to bring

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about 'a revolution in Moroccan irrigated agriculture, not only with regard to irrigation water use efficiency, but also to productivity and competitiveness' (Molle & Tanouti 2017, p. 171).

The programme has also been instrumental in involving a wider range of stakeholders. The Ministry of Agriculture, Marine Fisheries, Rural Development, Water, and Forests led the implementation of the PNEEI, supported by various international organisations, such as the World Bank and the African Development Bank. These organisations provided crucial financial and technical assistance. The private sector also played a key role, particularly in supplying and maintaining the necessary irrigation equipment. With this programme, stakeholders extended more deeply into the agricultural sector, including farmers, agricultural cooperatives, and regional agricultural offices. The focus here was on encouraging the widespread adoption of water-saving technologies and practices, which required collaboration across multiple layers of the agricultural value chain.

Plan Maroc Vert/Green Morocco Plan (2008–2020)

This is perhaps the most pivotal policy that has had the greatest impact on Morocco's agricultural water usage, with its results impacting various aspects, including economy, jobs, and farmer choices, to name a few. Morocco introduced PMV, or the GMP, in 2008, against the background of a food crisis in the region. According to Moseley, Schnurr, & Bezner Kerr (cited in Moseley 2016, p. 177), the crisis resulted in a 50% rise in average food prices while that of rice went up by 100%. This clearly impacted the population severely, and a coordinated policy was launched to address the issue. The plan aimed to modernise the agricultural sector of the country and to increase productivity and profits in the agricultural sector. This was to be done through better integration of the sector into a wider, global economy, through institutional reforms and building climate resilience in the sector. PPPs were supported, and investment into the sector was also promoted to make agriculture the driver for job creation, thereby reducing poverty and unemployment in the rural areas of Morocco. Following the period of food crisis, and in line with the New Green Revolution for Africa, bringing the small-scale farmers into the international capital flow was thus a major target. It also continued the ideas and efforts of PNEEI on intensification, water valorisation, and productivity improvement.

The PMV has two pillars – Pillar I focusing on an aggressive modernisation in areas that were already agriculturally favourable, while the second Pillar carried the idea of 'solidarity agriculture' (ADA 2020). According to the government, PMV integrated all agricultural sector actors within a framework to modernise and improve the agricultural sector by integrating all stakeholders into a unified framework. Pillar I focused on developing modern, high-value agriculture in irrigated and favourable Bour areas, to establish 1,000 integrated projects benefiting 397,000 farmers.

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These projects were to be located in areas with high agricultural potential and could be undertaken individually or as aggregations of small farms. While private investment was the

primary driver, the Agricultural Development Fund (FDA) provided state support, particularly for aggregation projects. Pillar II, on the other hand, sought to increase agricultural income in vulnerable regions by implementing 911 social projects that benefited 934,000 farmers. These projects aimed to boost vegetable and animal production through state intervention in partnership with beneficiary organisations, comprehensive value chain integration, and sustainable natural resource management. Pillar II projects included reconversion projects to replace cereal crops with higher-value crops, intensification projects to enhance productivity, and diversification projects to create additional farm income through new productions like saffron, honey, and medicinal plants.

Mathez & Loftus (2023) argue that it promoted and relied on the idea that 'agriculture was an economic activity like any other' (Haimoud 2008), and that if modernised, the small-scale farmers would fit into the international economic chain with ease, much akin to the other export-oriented industries in other sectors. This outlook to maximise profits, however, made the sector more water intensive, with farmers preferring crops like citrus and olives for their high returns. While the original target was to use the scant resources more sustainably, this export-oriented farming trend meant that Morocco, with a negative agricultural trade balance, was now 'exporting water' through its crops and fruits (Akesbi 2020). This is critiqued by Moseley (2016) to be a 'modernist-productionist' approach that conforms to the neoliberal global economic order. Molle & Tanouti (2017) also concur that the aggressively incentivised intensive agricultural policy of GMP has contradicted its own water conservation policy. Morocco's trade policies also safeguard the domestic production of several water-intensive crops, which are produced at higher costs than global market prices. Eliminating these trade barriers could encourage Morocco's agricultural sector to shift towards less water-intensive crops (Taheripour *et al*. 2020). The country over the subsequent decade saw the implementation of more 'efficient' water methods of drip irrigation and sprinklers. This boosted the efficiency of farming, but farming, as promoted by the policy, moved more towards cash crops in order to meet the demand of the world market, while relying on imports to meet the traditional food demand of the population in the country (Akesbi 2020). The reliance on imports for traditional food produce impacted the country during the COVID-19 crisis in 2020, which was also a drought year, exacerbating the shortage of supplies. Agriculture's contribution to Moroccan GDP was rising while annual precipitation in the country was going down, as shown in Figure 4.

Fig. 4

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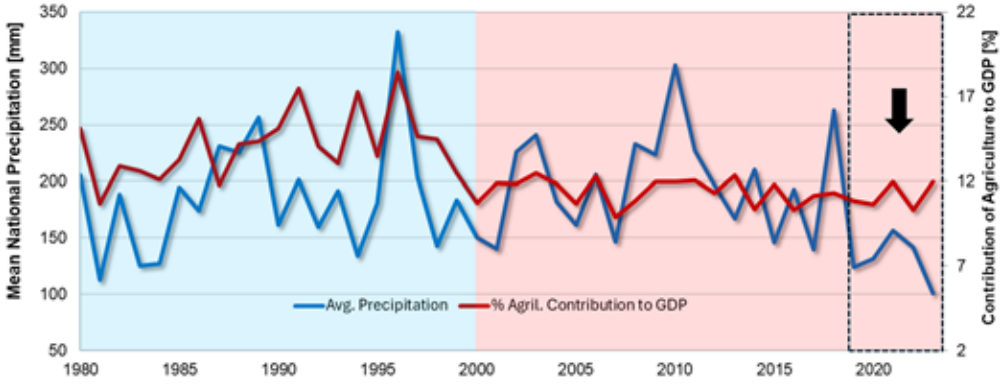

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Annual average precipitation (from TERRACLIMATE data) vs. the share of agriculture to GDP (World Bank 2020). Note the divergence before and after 2000 and the paradox since 2019, indicating continued agricultural production despite the drought, implying greater dependence on groundwater.

Subsidies formed a major part of the policy as the support for implementing micro-irrigation projects at the farm levels was always supported by the policy-makers since the 1990s, when it averaged at 17% (Molle & Tanouti 2017). This was increased to 20–40% in 2002, to 60% in 2006, before being raised to 100% for small farms in 2008 as part of PMV. The subsidy covered costs for wells, pumps, and storage facilities on the site. While farmers were initially reluctant to register their wells with the River Basin Agencies (ABHs), who regulated groundwater extraction, when it was made a prerequisite for receiving the subsidy, the numbers soared. An interesting finding that Molle & Tanouti (2017) present is that when the ABHs realised that this requirement for subsidies was leading to the over-extraction of underground water with farmers drilling new wells, they grew reluctant to grant new authorisations. The alternative given to the farmers was for them to bypass the ABH authorisation document to apply for the subsidy, and instead present an official affidavit stating how the farmland 'used to be' irrigated using wells. This eventually led to the drilling of new wells that the people were now falsely declaring as 'old' in order to avail themselves of the subsidy, which also inadvertently led to further overexploitation of groundwater in already dwindling aquifers in the country. Studies have shown that the expansion of irrigated agriculture from 1.5 million ha to nearly 1.7 million ha exacerbated this issue, resulting in the over-extraction of groundwater, particularly in regions like Souss-Massa, where the water table has dropped by as much as 3 m annually (Kuper *et al.* 2012; Molle & Tanouti 2017; World Bank 2023). The World Bank (2023) highlighted these concerns, noting that water demand in agriculture often exceeded the sustainable supply, leading to the depletion of vital aquifers. Akesbi (2020) stresses how Morocco depends on imports for 50–60% of soft wheat, sugar, and almost 100% of corn for necessary feed for the white meat industry, and almost all of seed oils. The takeaway is that the Moroccan agriculture sector's focus on generating more profit has had several disadvantages, such as its impact on food security, along with the 'export' of water from the drought-prone country when it simply cannot afford to do so. It seems to have become a case of economic myopia with people, the end-point beneficiaries of

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the PMV failed to see the long-term environmental impact of moving to water-intensive cash crops, while the trend of agriculture becoming more intensive with an increase in water-use efficiency was an externality that was not accounted for in the original PMV.

An alternative claim is that of the World Bank (2023) that, while the PMV prioritised the high-yielding value crops, it did not completely ignore the importance of cereals. The issue was identified to be the small farmers being at risk of facing losses due to these crops' susceptibility to inclement climatic conditions. As a response, using direct seeding has been one of the major, proven ideas to mitigate the losses under drought conditions, with direct-seeded crops producing significantly higher yields than the conventional method (World Bank 2023). Public services, agencies, and associations of farmers have been involved in developing the technology to adopt direct seeding in the country. This may be seen as a rarer case in the country, while the larger trend that made all the impact is the expansion of intensive, cash crops that have, as discussed, aggravated the water scarcity in Morocco (World Bank 2023). Under the PMV, the Moroccan Ministry of Agriculture initiated several programmes for the realisation of the plan. These included support to the farmers through subsidies as discussed and agricultural aid (SABA), EACCE, a system that monitored the international agricultural market, CGMS-Maroc monitoring the growth of crops, agricultural GIS through FERTIMAP, Système d'information sur les prix des produits agricoles (ASAAR) – for market price monitoring, and an irrigation warning system (Treguer 2019; Lionboui *et al*. 2022). This was a step in the right direction. For example, the creation of a national registry to identify the beneficiaries improves delivery and aids them with technology and the Internet of Things (IoT) to maximise agricultural output. The drawback here is that the maximum and efficient use of technology requires literacy and digital literacy. Lionboui *et al*. (2022) argue that with illiteracy rates of women and men at 60.1 and 34.9%, respectively, in rural areas, even though there is a push for the establishment and expansion of social networks that would serve as agricultural data collection points, many will remain excluded. It is, therefore, important to realise and push for bridging this gap. The fact that over half the population of women are illiterate is a significant loss of human capital to the economy of Morocco (Treguer 2019). In rural areas and on small farms, the family forms the workforce, of which women are an integral part (Sadiqi 2002). The education of women remains a challenge due to high dropout rates because of early marriages and other socio-cultural beliefs. According to Baruah & Najjar (2022), a trained workforce in conventionally masculine sectors, such as irrigation, marketing, and grazing, improves the visibility and social acceptance of women in agriculture.

National Program for Drinking Water Supply and Irrigation (PNAEPI) – 2020–2027

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The National Program for Drinking Water Supply and Irrigation (PNAEPI) was launched as a successor to the PMV program to build resilience to climate hazards and their adverse impacts.

As the initial phase of the broader National Water Plan (PNE) 2020–2050, the PNAEPI outlines the actions to be undertaken by various stakeholders to ensure the country's water security. Spanning from 2020 to 2027 with a budget of 115.4 billion dirhams, the PNAEPI focuses on five key areas. Firstly, the PNAEPI aims to enhance water supply through the construction of large dams, including the completion of ongoing projects and the initiation of 20 new dams, which will increase the total storage capacity to 27.3 billion m^3. Additionally, three new seawater desalination plants will be established, and small dams, aimed at local development, will be constructed with an annual budget of 600 million dirhams. The programme also emphasises securing the supply of drinking water through the enhancement and construction of necessary infrastructure and pipelines from water mobilisation projects, as well as exploring and utilising groundwater resources to bolster the supply of drinking water, support livestock, and facilitate irrigation. Secondly, the PNAEPI focuses on demand management and water efficiency by continuing the efforts of drinking water distribution operators to enhance the performance of distribution networks in cities and urban centres. Furthermore, the programme aims to modernise irrigation networks and transition to localised irrigation systems, as well as implement hydro-agricultural development projects in irrigated areas, such as the Gharb Plain and Saiss. Thirdly, the PNAEPI seeks to strengthen rural drinking water supply by continuing the execution of existing programmes benefiting 160 centres and 10,818 douars, and by implementing additional programmes for 659 centres and 7,876 douars. Fourthly, the programme targets the reuse of treated wastewater, specifically focusing on 21 golf course irrigation projects, distributed across 45 provinces and encompassing the 12 regions of the country. This initiative aims to encourage the reuse of treated water in golf courses. Finally, the PNAEPI emphasises communication and awareness through the development and implementation of an institutional communication plan, including a public campaign aimed at promoting behavioural change in the general population.

At the national level, the programme's management and monitoring are overseen by a Steering Committee chaired by the Head of Government, supported by a Technical Committee, which is chaired by the Minister of Equipment, Transport, Logistics, and Water. It is empowered to appoint Thematic subcommittees or working to address specific issues or technical matters, while Regional Committees, chaired by the Wali/Governor and supported by water basin agencies, provide oversight in the 12 regions of the country. According to the Ministry of Economy and Finance (2024), the 7-year programme will be funded up to 60% by the State's general budget, 39% by the relevant stakeholders, and the remainder through PPPs. Agricultural NGOs and farmers' associations are some crucial stakeholders that are involved in optimising the water use and helping further the programme's targets.

Internationally, the World Bank has always been a significant international stakeholder, providing financial support and expertise for Morocco. It approved a $350 million financing programme to assist in the implementation of PNAEPI, particularly in areas related to water security and resilience. The programme's main objective is to enhance water supply, particularly

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through dam construction with an allocated budget of 61 billion dirhams, managing demand, and water resources, especially in agriculture, with 25.1 billion dirhams, and improving the supply of drinking water in rural areas, with an allocated 26.9 billion dirhams. With the PNAEPI, the search for alternative sources of water intensifies. Morocco, due to its resource and climate predicament, has often been hailed as a pioneer in combating drought and trying to ensure water security. The programme includes the reuse of treated wastewater for irrigating green spaces, with a budget of 2.3 billion dirhams, and efforts in communication and awareness-raising to promote water conservation and the rational use of resources, with a budget of 50 million dirhams. As part of the 7-year plan, the country also aims to increase its desalination capacity from 13.11 million m^3 in 2011 to 400 million m^3 in 2030 (El-Ghzizel *et al*. 2021). To put it into perspective, the Chtoukha aquifer, due to over-extraction, is facing a mounting deficit of 60 million m^3 every year, with a renewable volume of about 26 million m^3/year (Bourziza *et al*. 2023). Notable projects for supplying desalinated water are Chtoukha and Dakhla, using a PPP model. Major concerns associated with this technology, which Morocco has no choice but to adopt, are the massive energy costs, financial costs, and its impact on the environment. Cost of power, estimated at about 55% of the water cost in the case of the Chtoukha project, not using renewable energy to meet this energy demand, is a concern at present (Bourziza *et al*. 2023). Desalination plants also produce brine, the release of which is a concern to increasing sea water salinity and destruction of the seabed ecosystems, which may have unforeseen consequences in the longer term. The cost of energy associated with desalination plants also presents Morocco with more impetus to move towards renewable energy production.

DISCUSSION

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While the policies have been largely successful in terms of meeting their targets of introducing more efficient techniques, such as drip irrigation, precision agriculture, and involving the community, the data show how following a policy that promotes intensive agriculture has exacerbated the issue of water scarcity. Although cultivating cash crops boosted local and national economies during the PMV period, it also raised concerns about social inequality, since larger agribusinesses benefited more from government support while the smaller farm owners faced high initial investment amidst increasing competition for more land and water. The subsidies offered for conversion to drip irrigation have been successful, but have resulted in farmers adopting more water-intensive crops, like tomato and citrus, while overlooking the demand for cereal, having to import it. There is also the tendency to falsify records to avail themselves of subsidies, which suggests that perception and mitigation of climate change impacts are not often the driver of their choice to move towards efficient irrigation systems.

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Morocco's policy measures to combat the effects of lower water supply, by looking towards desalination plants, come with their own unique set of challenges. Morocco, as of 2017, was one of Africa's top energy importers, with around 94.5% of its energy demand met through imports (Choukri *et al*. 2017). It has since then managed to reduce its dependency on countries like Algeria and Spain by focusing on the development of renewable energy systems as part of its climate commitments, as declared in the 21st Conference of Parties in 2015 and as part of its National Energy Strategy of 2008 (Bennouna 2022). Morocco's greenhouse gas emissions have also risen in the past decade, reaching about 63 million tonnes of CO_2 equivalent in 2020 (Bennouna 2022). Table 4 provides an overview of the policies discussed with the major targets, stakeholders, status of operation, and impacts per the evidence.

Table 4 Overview of the policies discussed with the major targets, stakeholders, and status of operation.

Policy	Focus areas
Law 10-95	Integrated Water Resources Management (IWR
Green Morocco Plan (PMV)	Modernisation of agriculture, Increase product
National Irrigation Water Saving Program (PNEEI)	Water efficiency improvement, Modernisation
National Program for Drinking Water Supply and Irrigation (PNAEPI)	Water supply enhancement, Desalination, Dem

CONCLUSION

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While it is easy to suggest that the country move away from water-intensive agriculture, the economic contribution of the agriculture sector on Morocco's national economy is a link that cannot be broken easily and requires strong political will and may have casualties. Small farm holders need to be engaged, consulted, and given skill development to diversify the local economies. Addressing certain issues will be key here. One is to address the issue of food security for Morocco to move away from farming to meet the international market demand and to become self-sufficient in terms of its traditional diet crops, and reduce the dependency on imports. These crops are by nature more adapted to the drier climate of the country, and there is a demand that is currently not met by the internal production. Continuing with the policy of involving small farm holders, who will be at most risk under any kind of paradigm policy shift, strengthening their capacity with awareness and educational policy is necessary, as an educated workforce may also be able to adapt better, branching out of agriculture if necessary. This would

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also be a policy shift towards managing the demand instead of entirely focusing on providing an infinite supply from alternative sources. Educating and bringing women into such a workforce will be key. There will also be a need to address some socio-cultural customs preventing this, and this would require communication and social engagement to involve maximum participation from the communities. Education would reduce their dependency on the agricultural sector for job security, especially in the rural economies, while also enabling those involved in agriculture to make the best use of the services and technologies provided by the state and policy. As part of Morocco's drive to digitise agriculture, having an educated workforce is also a necessity for maximum effectiveness.

Foster Public Engagement: Use community radio and participatory workshops to communicate climate risks, ensuring policies align with local needs. The fact that climate change is a constant reality in the backdrop, and that the trends support how precipitation over the area is decreasing year after year, is challenging to deal with due to the magnitude of the issue. Coal, being the major fuel for energy production, presents another opportunity to move away from polluting sources to greener sources, which presents an opportunity for investment and job creation. Morocco should also look towards maximising the potential of its geographical location for investing in small-scale and community-owned renewable energy projects. Africa, being a power-deficit continent in terms of renewable energy deployment, provides an ample market for Morocco to eventually become a major energy exporter in the region. Its proximity to Europe and connection through Spain is also a potential for future energy exports. Building solar farms over any existing open canal systems would also be beneficial, as in the case of a project in India, where it had a double effect of reducing evaporative loss and increasing the efficiency of the solar cells (Sairam & Aravindhan 2020). Morocco's PMV was a policy that had a dominant economic narrative, which promised economic returns and one that definitely worked in the economy's favour, but it did so at the cost of the environment.

Some recommendations may be as follows:

- *Reorient subsidies*: Shift support from water-intensive exports to drought-resistant staples, coupled with government procurement programmes to stabilise domestic markets, reduce dependency on agriculture for economic growth.
- *Empower smallholders*: Legally mandate Water User Associations (WUAs) to manage local water allocation and allocate a portion of PNAEPI's budget to community-led projects.
- *Integrate women*: Implement quotas in WUA leadership, simplify joint land titling, and launch mobile literacy programmes to bridge education gaps. Work with local leaders to ensure increased participation from women.
- *Decarbonise desalination and export green energy*: Mandate solar/wind energy for new desalination plants and pilot solar canal farms to curb evaporation and emissions. Increasing investment in renewable energy development in the rural economy would help towards attaining energy security and economic stability. This would require imparting training and

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education, and may be achieved through community outreach programmes, local ambassadors and help from NGOs.

What is needed is a collaborative agreement approach to public policy, where the citizens are involved in the policy's programme not just out of financial incentive, but due to the acceptance and understanding of reciprocity, altruism, and concern for future generations for a sustainable future. Using diffusion policy instruments to communicate the what, why, and how of adapting to climate change is necessary if there is social acceptance, as inertia is an infamous hindrance to achieving change, and awareness is a necessity for people to make informed choices. A steady and consistent trajectory of moving away from exporting water-intensive crops, to exporting clean energy, might be the silver bullet that Morocco needs and is most practically and geographically equipped for.

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Listen

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DATA AVAILABILITY STATEMENT

Listen

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

Listen

The authors declare there is no conflict.

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