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Zerwal Mustapha

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PRACTICES OF WATER MANAGEMENT IN MOROCCO

Insider consultant: Dr. Ildikó Bélteki

Assistant professor

Insider consultant's Institute/department: **Institute of Agronomy / Department of Agronomy**

Created by: **Zerwal Mustapha**

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1. INTRODUCTION

Water stands as an absolutely essential and indispensable natural resource, increasingly recognized and acknowledged with growing urgency around the globe as a critical element that necessitates careful and diligent stewardship from each and every one of us. This multifaceted and complex issue concerning our precious water sources is particularly pronounced and increasingly urgent in light of its unpredictable availability and inconsistent distribution across diverse regions—this has become a stark and alarming reality that numerous communities worldwide continuously grapple with in contemporary times. The precarious and often unstable situation in which we currently find ourselves places the entire water sector at considerable and heightened risk, prompting numerous complex and interrelated challenges in adequately satisfying the varied and pressing needs of different segments of society as well as the broader economy as a whole (Modak – Ferguson, 2020).

In areas that frequently experience prolonged and devastating drought conditions, the fierce competition among various users over the limited and ever-dwindling water resources intensifies alarmingly, culminating in a dire situation that is further exacerbated by the ongoing and pervasive impacts and implications of climate change. Against this intricate and complex backdrop, Morocco emerges as an enlightening and consequential case study in the demanding and often challenging realm of water management, as its innovative and strategic approaches assume a key and vital role in addressing and meeting the increasing agricultural demands while simultaneously supporting other crucial and economically significant sectors that rely heavily on the scarce surface water resources available to them (El Amrani et al., 2023).

The heavy reliance on rain-fed agricultural practices in Morocco further emphasizes the urgent and immediate need for sustainable and effective water management strategies that can ensure both socio-economic stability and resilience in the face of climate variability and unpredictability associated with the ongoing shifts in climate patterns (World Bank, 2021). Furthermore, a comprehensive and in-depth understanding of the intricate relationship that exists between human societies and their physical environments is absolutely vital for effectively resolving conflicts over water use rights and ensuring equitable access to water resources for all stakeholders involved, regardless of their social standing, community status, or economic situation.

Moreover, it is imperative and essential to promote robust and enforceable legal frameworks that actively support sustainable water management strategies encompassing both groundwater and surface water resources. This comprehensive and proactive approach enables the establishment of cooperative governance structures among various interested parties, ensuring that all voices and concerns are heard, taken into account, and duly considered. This delicate and intricate balance is crucial for fostering long-term sustainability and promoting equitable resource distribution across competing interests, ultimately leading to an environment wherein responsible stewardship practices and conscientious usage can truly thrive and flourish. Such concerted efforts contribute positively to both community welfare and the overall ecological health of our planet, ensuring that future generations inherit a world where water is judiciously managed and sustainably utilized, thereby fostering a harmonious balance between human needs and environmental preservation, and ensuring the continuity and longevity of this vital resource for the benefit of all.

Given the critical importance of water management and irrigation systems to Moroccan agriculture and food security, this study aims to provide a comprehensive analysis of Moroccan irrigation systems and water management. Specifically, the thesis seeks to address the following research questions:

- What are the primary government policies and initiatives for water management in Morocco?
- How does the National Water Strategy address the challenges of water scarcity and growing demand in Morocco?
- What is the role of agricultural water subsidies in Morocco's water management strategy?
- What adaptation strategies have been implemented to improve water distribution and efficiency in Moroccan agriculture?
- How have technological innovations, such as drip irrigation and remote sensing, been integrated into Moroccan water management practices?
- What are some successful large-scale and community-based water management projects in Morocco, and what impacts have they had on local agriculture?
- What key insights were gathered from primary research on the obstacles and advancements in sustainable water management in Morocco?

The thesis will also explore the theoretical frameworks and methodologies that will be employed to provide a comprehensive analysis of the Moroccan water management and irrigation systems.
The Thesis is significant because it has the potential to inform policy decisions and practices that affect millions of people in Morocco and beyond. Understanding the challenges facing Moroccan water management and irrigation systems is critical to ensuring food security, sustaining livelihoods, and promoting economic development in the region.
It also has broader implications for understanding the complex relationships between water, agriculture, and development in arid and semi-arid regions around the world.
The material and method section will describe the research design, data collection methods, and analysis techniques used in the study.

2. LITERATURE REVIEW

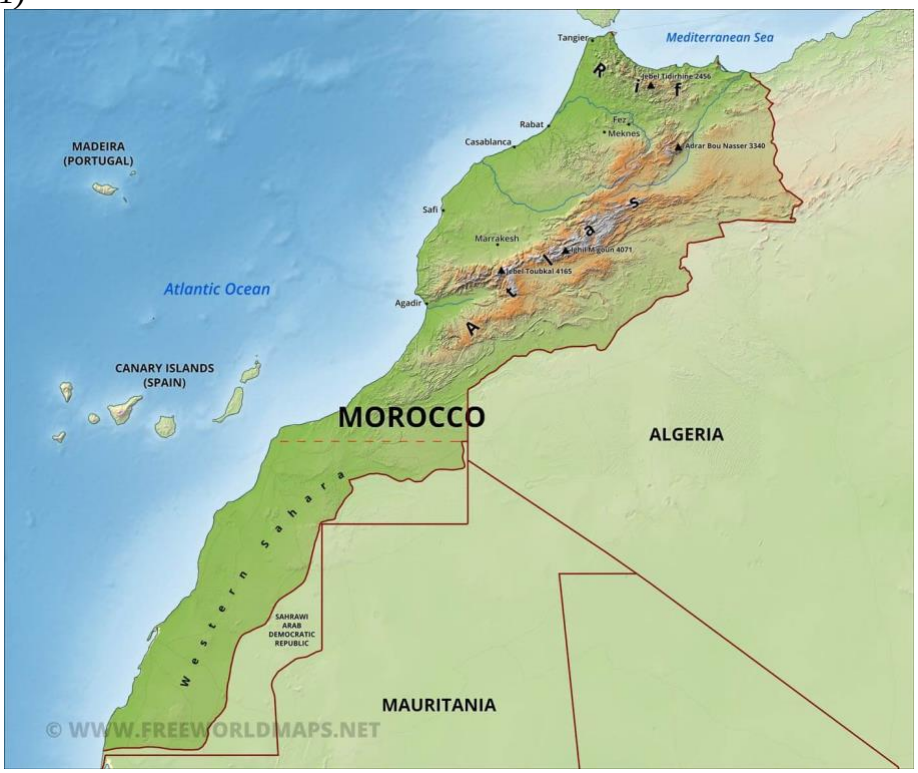
2.1. Geographical Overview of Morocco

Morocco is a northwestern African country. It has 3,500 km of shorelines, which give it access to both the Atlantic Ocean in the west and the Mediterranean Sea in the north. The Strait of Gibraltar that separates Morocco from Spain is only 40 km in width. Its coastlines are bordered by Algeria in the east and the annexed Western Sahara in the south. Geographically, it is divided into three main natural regions:

- The first is the Atlas Mountains, which run from the Middle East to the Atlantic Ocean.
- The second region includes the plains and coastal areas to the southwest. This area has extensive plateaus and coastal lowlands, extending from the Rif Mountains in the northeast to the Anfa Lagoon south of the mouth of the Bou Regreg River. The distance that separates the furthest southwestern and the highest northern latitudes is less than 520 km.
- The third region is occupied by the high low plateaus formed by the intermountain zones of the Atlas and its northern continuation. They divide the calcareous plateaus of the northern sedimentation basins, where the majority of the Moroccan population is found, from the three piedmont areas, which are depressions filled with sedimentary rocks and young alluvial and pebble deposits, occupying the coastal lowlands (Figure 1).

The most obvious and specific feature of Morocco is the mountain chain and its extensions, which divide the territory into a variety of areas with both climatic and geographic characteristics. These regions consist of microclimates, reliefs that can shift from areas of lush vegetation to inhospitable deserts over extremely small distances.

Figure 1: Physical map of Morocco
(Source: http1)



The majority of the population's economic activities are concentrated on one-sixth of the territory, which is divided, from the northeast to the southeast, by the cedar and holm oak forests and the fertile plains of the Rif and the Middle and High Atlas. These landscapes play a significant role in the national economy, notably through mining, tourism, and agriculture (Bouchaou, 1995). The Middle Atlas plains are mostly volcanic, and its farmlands are sustained by water from natural lakes. In the west and southwest, there is a region of coastal plains that receives no more than 300 mm of rain annually, making it unsuitable for agriculture. North of the mountain range, the Atlantic climate influences the Mediterranean climate. The northern mountain range prevents the Atlantic rains from arriving in the mid-east, where there are valleys, and the northern limestone plateau helps water to seep inward (Razack, 2020; Berrabhia 2023; http3).

2.2. Importance of Water in Agriculture

Providing plants with their needs might sound like an easy cycle: soil provides water and nutrients to plants while green plants provide well-being for animals and people by taking up carbon dioxide. Water can be taken from the soil by plants and evaporated into the atmosphere via two different mechanisms: the first is evaporation and the second is transpiration. Both represent the return

fraction of precipitation. This latter process has more impact on the atmosphere than the first one because the air around the ground evaporates and moves up, becoming cooler to condense and precipitate and then re-evaporate. Rain, as well as irrigation, is crucial for plant growth; in the world, plants need 25% of rain to grow while 70% is lost by evaporation and the remaining 5% is drained off from the earth by the action of rivers.

Rainwater is seasonal and not so abundant for crops during the grassland period, and therefore, people realized the necessity to capture water as much as possible; that is how irrigation was born (Nguyen, 2020; Li et al., 2021; Barker et al., 2022).

2.3. Challenges in Water Management in Morocco

The world population is expected to reach 9 billion by the year 2050 and is thus increasing the demands on water, especially for food production. Agriculture has always been a source of food security and income for the population. However, the scanty rain and unpredictable rainfall in rural regions of Morocco and the resulting water scarcity, along with increasing demand for water by agriculture, industry, and domestic sectors, have led to a deficit that exacerbates water stress in Morocco.

Generally, Morocco, as with most other countries in the Mediterranean region, is facing increasing water scarcity worsening due to declining prices for irrigation supplies, increasing demand accompanied by population growth, changing diet and industrialization, and climate change which itself can bring unpredictable fluctuations in water supplies. Because of its costs and its ethical significance, scholars have long been interested in employing non-pricing policy instruments for managing water resources. Regarding irrigation directly, economists have long pointed out the financial, physical and environmental pitfalls of non-charging, suggesting instead that governments should consider more generous but targeted support for smallholders who are likely to unduly bear the burden of charging. At the same time, these scholars and practitioners have noted the broader, interactive nature of irrigation policy. While it has been noted the need for a multi-dimensional approach to avoid irrational behavior regarding the maintenance and restoration of hydraulic infrastructures, other scholars have long noted the role of market reform; the problems of bureaucratic motivation; the potential for privatization; and the importance of community cooperation, information and capacity-building in developing sustainable irrigation management.

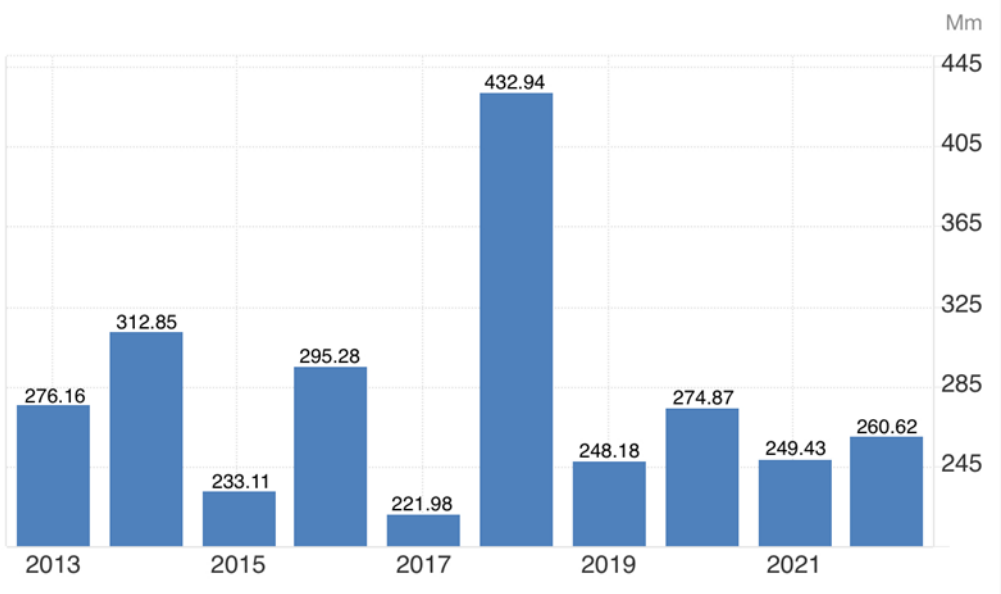
The relevance of these (and other) institutional, political economy, distributive and participatory aspects of irrigation practices have been widely accepted. However, particularly in the rolling back of the period of central management and infrastructure support, policy reform has concentrated on 'hard', not 'soft' issues, yielding at best mixed results in terms of technical efficiency, physical and environmental sustainability. Indeed, recovering central control, often traditionally and inadvertently enhancing the inequities it was supposed to moderate, has been more successful. The game remains popular, however. For the excited observer, Morocco's irrigation management experience is indeed of significant interest. At first, during the label 'Participatory Irrigation Management', and later under the flavor-of-the-decade label, the government's Pluri-annual Development Plans, Morocco made real attempts to engage farmers in the costs and responsibilities of irrigation development and maintenance (Daoudi, 2020; Attar et al., 2022).

2.3.1. Water Scarcity and Droughts

One of the major challenges facing Morocco is water scarcity and droughts that occur from time to time in different regions of the Kingdom. It is a crucial and very complex problem. Water scarcity appears at the dimension of the location on both regional and national scales due to the absence of water resources or at the quantitative level. In fact, it is manifested in the decreasing percentages of available water resources per capita and the quantitative reduction of water for agricultural irrigation. Likewise, the effects of drought are complex. They vary according to the geographical position and the ecosystems. In a sloping landscape, water fluxes are negatively affected within the deep landscape. The precarious climatic conditions encountered are due to low rainfall, arid soils, and an evaporation rate greater than the average precipitation. All these factors combined with demographic and hydraulic pressures, as well as irregular and strong fluctuations in precipitation over the years (Figure 2), will accentuate the recurrent and more frequent droughts (Asedrem, 2021).

Figure 2: Yearly Precipitation Volume in Mm 2013 – 2022

(Source: http2)



Droughts are considered a major natural phenomenon that provokes significant variations in water resources. They can cause considerable losses in crop yields or completely destroy crops. As a result, water scarcity and the frequent occurrence of droughts make water management difficult. Their effects are generally very dangerous, very destructive, and sometimes even costly. It is therefore important to fight against their harmful consequences by giving utmost attention to the dams' storage capacities, applying surface drainage techniques, diversifying agricultural cropping systems, and taking advantage of rainfall variations. In-depth analyses of these extreme events and the application of preventive actions are essential in launching agricultural development-related interventions. In support of this idea, climate management, as well as the forecasting and simulation of possible loss rates, are crucial elements in the fight against drought. Indeed, the water cycle is a factor that designs an environmental and climatic equilibrium (Arabi et al., 2024).

2.3.2. Impact of Climate Change on Water Resources

In Morocco, the general circulation models predict an increasing trend in temperature between 0.6 and 3.4 degrees Celsius by 2025, with a spatial variation of 3-7% of rainfall by 2100 and an increasing aridity trend between 20-40% by 2100, respectively. In addition to natural factors, human activities regarding increasing demands and pressures on resources have accelerated desertification, the degradation of arable land, and the drying up of natural wetlands. Increasing

urbanization, industrialization, and the change in land use will have long-term consequences on the vulnerability of water resources. Observations from the last two decades showed an increased frequency of droughts, late wet season onset, and premature or reduced wet season length, together with large-scale floods and the cessation of snow and rainfall-induced floods. It is important to also note that the northern part of the country is more vulnerable to these hydrological changes.

The seven river basins in the country show slight increases in the total annual flow or a decline and an increase in aridity, with other basins experiencing variations in the form of a decline in groundwater (Almulla et al., 2022). The total annual flow for climate-fixed GHG has seen a significant decline since 1910, and sediment transport in all river basins has declined, from a minimum of 35 mm yr^{-1} to a maximum of 83 mm yr^{-1}. The high spatial and temporal variability of the entire sub-arid region is evident. Such variations are represented in the various hydro climatology and hydrological models that describe the semi-arid aquifers.

Morocco is among the countries that will suffer the most from climate change. While the impact of the dynamics of rainfall at the country level is quite varied, at the regional level, there is a tendency for the amount of precipitation to decrease while its concentration increases.

The temperature and CO_2 have a positive impact on the number of rainy days. This finding is concerning in terms of climate change because the expected future increase in temperatures could favor an increased future frequency of rainfall, an exogenous phenomenon, which could lead to increased frequency of flooding, erosion, and hydrological overflow (Anonymus1, 2022).

2.4. Historical Development of Irrigation Systems in Morocco

When the plant doesn't have the water, it needs to grow, it can be watered with a choice of irrigation methods.

In Morocco, the first large-scale use of water for agricultural production began during the early advance of Islamic civilization in the 7th and 8th centuries (Idrisi, 2005). The Almoravids and Almohad, Berber dynasties of North Africa and Muslim Spain, and the Marinids, under whom the irrigation system was enlarged and completed, followed the Romans in the use of irrigation in Morocco. It was under the Marinids that the architectural features and water control systems of the area were expanded. Not only did water control systems become much more extensive, but the extent of irrigation agriculture also increased markedly, reaching the same level of intensity as

under the Roman colonization. The Marinids also caused canal systems to be built from the sources of a number of larger rivers, some of which did not contain water throughout the year. They designed large hydraulic structures not only to protect the city of Fez from flooding but also to store a large volume of water that could be used during the two dry seasons, which caused the city to enlarge its hydraulic facilities many times over. Later dynasties improved and reconstituted these water control systems because of their social and agricultural importance. During these various wave patterns of agricultural intensification, several sixty to ninety-year periods of severe droughts and crop failures also occurred, preventing agricultural growth for long periods of time (Shatzmiller, 2017).

2.4.1. Traditional Irrigation Methods

Traditionally, irrigation in Morocco had been realized in small areas and was carried out by moving water by carrying it on animals or by drawing it from wells. With the drought and increase of arable land, farmers started realizing community wells by association to serve and distribute water. This was followed by the installation of large diameter second-class wells or khettab wells on private land (Figure 3). The development of these wells was made after the modification of certain water rights associated with changes in the doctrine of land or community property and the Code of Personal Status. The construction of these wells, filled by the surface technique, has allowed water to irrigate a much larger area in a relatively short time. A second form of modernization of traditional irrigation systems is the installation of devices that allow for relatively regular irrigation, including in regions with more sloping relief.

Figure 3: Large diameter second-class well under construction in Morocco
(Source: http5)

Despite the development of irrigation, a relatively rigorous division of rights to water has been observed in connection with traditional volumetric measurements. The collection of these measurements made it possible to determine the durations of each user according to several criteria. Under current conditions, these modernized or newly developed systems are usually overused, which causes conveyance network malfunctions, availability issues, over-extraction, reduced life of the well, and even soil salinization. A small-scale hierarchy within water allocation has existed because it concerns subdivisions resulting from the natural canal network or intensification.

These operating rules promoted spaces adapted to different soils and crops and even allowed each user to have the area irrigated, mainly avoiding competition or conflict between users who wished to receive an irrigated area at the same time. Those who respect the hierarchy are responsible for the maintenance of the earth slabs used to bank the water and prevent the accumulation of silt. The village or community usually takes care of the main supply canal preparation, while the commune is responsible for the maintenance of the general conveyance infrastructure (World Bank, 2023).

2.4.2. Modern Irrigation Technologies

Modern irrigation technologies are designed to improve the effectiveness and efficiency of water use. They include pressurized networks, water control, and modern delivery methods. These technologies offer the potential to reduce water consumption. Drip irrigation (Figure 4) and micro-irrigation are efficient in terms of water consumption, but their application is limited to a small

geographical area, a small variety of crops, and specific characteristics of the farm. These technologies have high implementation costs and are not suitable in countries struggling with limited energy, financial, and technical capacities. A factor that deters farmers from shifting to sprinkler and drip irrigation systems is the difficulty of applying fertilizers, which involves time and labor, and consequently low utilization of the system's potential.

Figure 4: Drip irrigation system in Morocco
(Source: http4)

The choice of irrigation method, based on a variety of social, spatial, and economic variables, is wide and well-studied in relation to irrigation technologies. The selection from this variety depends on the priorities of farmers in the use of the equipment and other associated investment projects. Additional preferable options may include low-tension borehole irrigation for mature trees and deep-root crops; the installation of rain guns to irrigate bare soil; water harvesting to irrigate when water is available at low cost; and the use of micro-catchment systems with supplemental micro-irrigation. Small-scale irrigation technologies such as a drip kit could also be profitable choices for smallholders in developing countries (Azemzi – Erraoui, 2021).

2.5. Social and Economic Implications of Water Management

Overall, Moroccan territories show different social and economic implications in water management practices. There is no doubt that nowadays water is perceived as the number one wealth of the world. It plays a vital part in the balance of ecosystems, as well as in those societies that share resources on Earth. However, in practice, only the way of utilizing water as a vital factor

in the development of societies was emphasized. This profit-oriented management model of water management also created many social and economic implications. Moreover, Morocco uses a lot of water in its economic activities due to the fact, that the major contribution to the economy is supported by the services and agriculture sectors. It has been found that the agriculture sector uses 95% of the water in the country. Because the irrigation practices are not managed properly, a number of social and economic implications have arisen. The social implications of water management practices may be listed as rural migration, discrepancies in the dispersion of income, health problems, loss of employment, poverty, obstacles that women face, and social conflict.

Rural migration has derived from the rapid industrialization of the cities and the decrease in income due to the seasonal agriculture practiced in rural areas. The male population living in the region moves to cities to find jobs and extra income because there is no professional occupation other than seasonal agriculture in the region. This deprived the local economy of expertise. This drawback affects agricultural production capacity and other economic activities related to rural areas. This situation, therefore, causes social conflicts in the region, including between migrants and farmers. It is also known that in some communities of Morocco, both residents and the seasonal wave of migrants have social and economic distinctiveness. For instance, the indigenous people are mainly settled for agricultural activities, while seasonal migrants are subordinated to casual agricultural work. This situation causes horizontal discrepancies in the dispersion of income. In other words, the poverty of these practices is transferred to the female members of these communities and causes social conflict within the community. Women who are forced to leave school and the local workforce have been victims of immigration issues (Haddad, 2022).

2.5.1. Impact on Rural Communities

Management of water resources in general and water use in agriculture in particular in North Africa is essentially a public intervention activity within the framework of institutionalized public policies aimed at guaranteeing each irrigable perimeter a quantity and an acceptable quality of water in a sustainable way. In a reality check of the irrigation water supply systems there are extreme situations where full privatization has taken place: the cases of the Isa Ber and Prince Moulay Abdallah perimeters. In summary, the cases of the areas presented here raise the problem of the urgency of reforms to be adopted to achieve satisfactory coverage of the costs of the water resource,

including the construction, operation, and maintenance of the water supply systems, at least as a necessary condition for their efficient management (Food and Agriculture Organization, 2013).

2.5.2. Economic Benefits of Efficient Irrigation

More efficient use and recycling of irrigation water are ways of preserving the water resource base for expansion. Recycling the return flows can contribute to water savings in new projects and stabilize the water supply in the future. Expansion will be at the expense of losing a marginal reduction in production in the rich areas. As large volumes of water are used for the final irrigation of the farmers' fields and transpiration by the plants, the quantities normally consumed are extremely variable. The objective of water supply and conveyance is to provide personnel with maps showing this variability, at least for the main crops at different times of the year (Jouali et al., 2023).

2.6. Sustainable Water Use Practices

The sustainable practices of water use for irrigation are the minimization of water loss from sources to root zones, the reduction of water wastage during land preparation, planting, weeding steps and time, and avoiding waterlogging problems. This is accomplished by properly sited and constructed irrigation facilities matched with the required volumes of water at the correct times of application. Hence, to enhance sustainable irrigation water-use practices, the following general measures are proposed: modernization and improvement of water irrigation systems, inclusion of farmers in the decision-making process with respect to water allocation, crop choice, and the implementation of water-saving technologies and land-use conservation, effectively adopting integrated water-management tools, and improved water data collection and enforcement. The current status of these practices: In the case of Morocco, a country characterized by its semi-arid climate, low and decreasing natural surface water resources, presence of an influential agricultural sector on GDP, and dependency on rain-fed cultivation systems, understanding the demands of and cultivating more sustainable irrigation practices is crucial. Morocco is a water-stressed country where 85% of the water is allocated to the agriculture sector. The improvement of sustainable practices in the agriculture sector is vital for achieving economic growth, employment generation, and food security (Bousfai et al., 2021).

3. MATERIALS AND METHODOLOGY

The Thesis utilizes a detailed research design to thoroughly investigate water management and irrigation practices in Morocco. Both primary and secondary data were extensively analyzed to gain a comprehensive understanding of the subject matter. Primary data was obtained through an in-depth and informative interview with a knowledgeable Ministry of Water and Equipment employee, who provided valuable insights into the intricacies of water management. This primary data was supplemented with a wide range of secondary sources, including highly respected peer-reviewed journal articles, comprehensive government reports, and meticulous historical records, all carefully selected to ensure the utmost reliability and accuracy of the findings. The analysis embarked on a meticulous content analysis of the secondary sources, employing a rigorous approach to systematically extract and synthesize key themes and insights. Furthermore, the primary interview data was subjected to a thorough thematic synthesis, enabling a holistic exploration of the subject matter and the formulation of well-grounded conclusions. It is important to note that while the inclusion of primary data unquestionably enriches the research, a cautious approach was maintained due to the limitations associated with the reliance on a single interview. Nevertheless, utmost care was taken to adhere to ethical guidelines throughout the process, safeguarding the integrity and credibility of the research. Moreover, a paramount aspect of this research endeavor was the stringent commitment to proper citation practices. All sources, including both primary and secondary data, were meticulously cited in accordance with established academic conventions, ensuring transparency and accountability in acknowledging the contributions of previous studies and sources. By adhering rigorously to citation guidelines, the research upholds the principles of academic integrity and reinforces the validity of its methodology and findings. This comprehensive research endeavor provides an in-depth examination of water management in Morocco and its profound impact on long-term agricultural practices. By employing a judicious combination of firsthand observations and meticulous research, this study unveils multifaceted insights into the complex dynamics of water management and irrigation practices in the country. The integration of primary and secondary data, coupled with the implementation of rigorous analytical techniques, enables a nuanced understanding of the subject matter and paves the way for informed decision-making in the field of sustainable water resource management.

4. RESULTS AND EVALUATION

4.1. Results of the secondary research

In Morocco the government tries to encourage the effective water management by applying different tools as Government Policies and Initiatives, National Water Strategy and Agricultural Water Subsidies, which are detailed below.

4.1.1. Government Policies and Initiatives

Since 2008, to deal with the challenges of growth and globalization, the Kingdom of Morocco developed a new water strategy for a national water governance integrated into a decentralized context anchored in sustainable spatial planning and improved cultural practices (International trade administration, 2022). As part of this strategy, the National Water Plan, approved by the Ministry of Equipment, Transport and Logistics in July of the same year, provides for an investment of 169 billion MAD over 15 years. The balance of investments is essentially devoted to water resource management, large agricultural irrigated developments, the setting for treated water, and sanitation for the environment and water consumption. In water policy in Morocco, and in accordance with Article 44 of the Constitution, The State ensures the protection of the environment, the rational and sustainable use of water, forests, and natural resources, and the protection of national wealth.

4.1.2. National Water Strategy

In terms of the integrated components of the Mediterranean region, Morocco has been suffering from decreasing water availability due to persistent droughts, increasing population, and socio-economic development. As a result of the negative influence of these pressures, the available water per capita has dropped from 2860 m^3 in 1970 to 730 m^3 in 2010, and more than half of the available water resources are used for intensive agriculture. To tackle this challenging issue, the government implemented several water-related strategies, essentially based on a more integrated agricultural water management policy. Since the 1995 water law, various public policies have been drafted with the aim of improving the planning and management of water resources. In February 2009, the government published the national water plan, which stressed the importance of improving the evaluation of water resources, establishing a development priority concerning water demand, determining the cost of this development, and identifying the funds necessary to cover this new cost.

4.1.3. Agricultural Water Subsidies

In Morocco, agriculture represents 79.6% of the overall used water. In Morocco, the strong growth in water needs, especially for agriculture, cattle breeding, and industrial and urban uses, has encouraged significant withdrawals of water resources, and these withdrawals seem to exceed the inherent temporary and spatial variability of rainfall and surface water for given natural systems. As a dignity of being the largest consumer of water among other economic sectors, the Moroccan agricultural sector has made irrigation efficiency and water savings a priority for the management of the country's water resources. Currently, there are complex policies and a number of multifaceted strategies to reduce the pressure on existing water resources.

The mechanism for managing water subsidies through agricultural water pricing involves charging beneficiaries more for the water than it costs to supply. In the irrigation sector, the beneficiaries are farmers who use most resources to produce crops. As a result, water pricing reform and agricultural subsidy reduction have been particularly sensitive and contentious.

Water pricing reform in irrigation has three basic objectives. First, it has to raise the funds necessary to cover the operating and maintenance costs of irrigation and drainage infrastructure. Paying for water delivery, gate operation, and maintenance through a user fee represents a change of a modest nature, as these costs were often at least partially recovered in the past. Second, water charges are expected to play a role in managing irrigation water. By increasing irrigation water prices, more efficient water use in agriculture could be induced. Finally, the institution of a price for irrigation water, reflecting its scarcity value, is seen as a means of signaling farmers to use the scarce resource appropriately. Charging a positive price for water is sometimes seen to have the important psychological effect of making water seem a valued commodity rather than an inexhaustible and free gift of nature (Easter – Liu, 2005).

4.1.4. Adaptation Strategies

Despite the performance of the current traditional irrigation system, the Ministry of Equipment, Transport, and Logistics, in collaboration with the Ministry of Water and the Environment, has set up comprehensive programs for the regularization of irrigated developments in a collective manner. These programs aim at rehabilitating or modernizing the water supply and distribution

infrastructures, improving the overall production capacity of the irrigated perimeters concerned, and contributing to facilitating access to land.

To increase national agricultural production, the country is investing in the construction of large hydraulic infrastructures in the form of dams, reservoirs, and irrigation systems, and is also using various cropping patterns to ensure food security. There is a growing movement toward modernization in water management in irrigated areas through adjustment, adaptation, and the use of agricultural practices, including mulching, new irrigation systems, and improvement of traditional systems.

Fifty percent of the water resource development costs and 40 percent of the operation and maintenance charges are devoted to water supply and conveyance. Surface irrigation efficiency is about 35 percent, although more efficient systems may be constructed with proper maintenance. The on-farm water management practices relevant to water supply and conveyance and efficient irrigation can be classified at different levels. The farmers' practices at each level, together with design specifications and the limits of performance at the appropriate level, form an operational definition of the practices. These include soil husbandry and cropping management, field design and engineering, block design and water conveyance, and irrigation scheduling. Control and appraisal are superimposed levels of the managerial hierarchy. Their degree is expected to develop over time as the construction and rehabilitation process reaches maturity. Costs represent the main constraints in the development process.

The rural development strategy followed by Morocco has focused for many years on the development and rehabilitation of the most underprivileged and drought-prone areas. The concept of development of these regions revolves around three main axes: rehabilitation of heritage constituted by the conservation and enhancement of natural resources, family farming, and local products developed according to the comparative advantages of agricultural zones. The dams, with their significant storage capacity, greatly contribute to maintaining the minimum flows and thus help safeguard the income of 80% of the population living from agriculture using perimeters fed by dam outlets. However, irrigation performance remains modest and unequal between men and women, with a risk of inequitable water land distribution between social groups at the level of collective irrigation (Belhaj et al., 2023).

4.1.5. Technological Innovations in Water Management

Farmers in the country use old traditional methods of irrigation, either because of the shortage of water resources or because of inappropriate irrigation systems. International and national bodies are trying to develop programs and educate farmers to promote solutions for the new millennium, especially taking advantage of new technologies in the water management field.

Governments and development funds have invested considerable financial and managerial resources in the last few decades in developing new water use technologies for improving sustainable irrigation systems. The widespread dispersion of irrigation supply does not make this sector transformation easy. Centralized water management institutions often do not represent the majority of irrigators, and conflict between agencies managing water resources is very common. In this context, the introduction of new technologies could help to create incentives for the sustainable management of resources, avoid the waste of water, and increase the percentage of profits effectively used by farmers. Moreover, these goals are in line with the objectives of the government and other organizations selected by the Moroccan water policy, energizing the water managers and enhancing the services.

4.1.5.1. Drip Irrigation Systems

Local growers have been using traditional drip systems made from locally available materials for several years (YB Meir et al., 2022). These systems consist of a network of pipes set up to recycle used tins and iron containers in order to distribute water to the field. The syringe pipe is made of PVC and is equipped with a drop attachment in the soil from which the water flows. The advantages of these traditional systems are the possibility of controlling the flow, the low cost, and the ability to be managed by the grower. The disadvantages, however, are water losses from some leaks in the syringe and damage to the buried drop pipes, which can cause power outages in the field. The most commonly used drip irrigation system by larger growers is cylindrical tubing with a wall-mounted watertight passage. However, technical recommendations based on watersheds have been developed while using filters and pumps. To reduce damage, buried power cables must protect these pipes. The practical study showed that such protection is often lacking, especially in temporary straw culture on a larger scale. If the cylindrical tube collapses during cultivation, the flow of water to the plant can be used. Drips can escape the sprawling plant, however, which causes gaps between the holes and lowers mechanical performance.

4.1.5.2. Remote Sensing Applications

One of the oldest methods used for agriculture is irrigation, which is a constitutive stage for the field. Technical innovators and researchers are involved in the study of irrigation systems; each method has its own characteristics. One of the modern tools that has found success in irrigation modeling and application is remote sensing. Compared to traditional methods, remote sensing technology has shown many advantages. The collected data does not physically influence the areas, a small number of employed staff is necessary, and the availability of historical images is an important point.

4.1.6. Successful Water Management Projects

It is a pilot project for an innovation-based development program and is highly strategic with regard to the issue of water scarcity in Morocco. It is also well adapted to the internal shares of the Ministry of Agriculture's budget, which it represents, and also to the National Initiative for Human Development's priorities. The effectiveness of large engineered programs and policies requires awareness building and cooperation from all stakeholders.

4.1.6.1. Large-Scale Irrigation Projects

Regarding large-scale irrigation projects, the activity of large-scale irrigation projects and systems is defined. Factors that contribute to irrigation performance are identified, highlighting water management as a key issue in the case of large-scale irrigation projects. Facilities, secondary infrastructure, and performance in an irrigation project are identified. The objective of a large-scale irrigation project is to provide irrigation water for districts with significant economies of scale. Large-scale projects require powerful upstream isometric water supply sources with large volumes to supply several or majorly similar fields in the downstream districts.

Similarity in demand and supply functions between different districts is mandatory for justifying common management of such water sources, which might involve considerable construction and maintenance costs. Change in the case of a large-scale irrigation project is most likely to affect the commonly owned and managed secondary and even sometimes primary infrastructure. As many researchers have pointed out, the transition from a commonly managed and owner-operator system to a contractual system depended mostly on the water volume requirements of the majority of users.

4.1.6.2. Community-Based Water Management

Community organization to manage the establishment and continued maintenance of surface irrigation systems is observed. It has been successful in numerous locations and has many of the attributes of a private system, including equitable distribution of the use of water and lower maintenance and operation costs. Since the farmers make the decisions concerning operation and maintenance, there is virtually no lag in response time wherein the system deteriorates for lack of proper maintenance. With the observed benefits, the question arises as to why all the remaining irrigation systems are not under farmer management. Providing an answer requires one to recognize that the conduct of management has a feedback effect on the profitability of the system. Efficient management can produce benefits; however, there is no guarantee that these benefits will be sufficient to compensate farmers for the costs of establishing such efficient management systems.

The problems of an open irrigation system are primarily concerned with the nature of common rights. Problems arise because of the absence of land control in terms of the right of association. Without exclusive control over land, users lack the incentive to maintain the efficiency of the irrigation system. When the condition of the common irrigation system becomes inefficient, water rights must be assigned to prevent conflicts. However, assigning water rights to members of the common pool implies the loss of a part of the value of the system for those not being assigned access to it, resulting in conflicts among the non-preferred users. The second source-related problem is the lack of any restraints upon water usage, thus leading to acute water waste. The moral is that when rights in a common property resource are widespread and divisible among the users, technical and institutional constructs that assign enforcement cost obligations, access, and benefits can play a vital role in the continuous use of the resource. Creating a sense of belonging and of property value, in turn, can help develop in the users an awareness of the value of their collective resource and their incentives to defend it (Ostrom, 1990).

4.2. The results of the primary research

The primary data obtained from the interview with a Ministry of Water employee offered valuable insights into the current state of water management in Morocco, particularly within the agricultural sector. The key discoveries are outlined as follows:

4.2.1. Obstacles in Sustainable Water Management

The interview shed light on significant hurdles encountered by the Ministry in ensuring sustainable water management, particularly in rural areas. These obstacles encompass inadequate infrastructure in remote regions, ineffective water distribution systems, and the escalating demand for water due to agricultural and population growth. The official stressed the importance of upgrading water management systems to meet these demands, alongside the necessity for stricter enforcement of water regulations.

4.2.2. Integration of Technology in Water Management

The Ministry has been progressively incorporating modern technologies such as desalination and wastewater treatment into its water management strategies. According to the interviewee, desalination plants are being established to combat water scarcity in coastal areas, while wastewater treatment projects are being piloted in urban centers to recycle water for agricultural use. However, the high cost of these technologies and the need for technical expertise have presented challenges to their widespread adoption.

4.2.3. Response to Climate Change

One of the Ministry's primary focuses is adapting to the impacts of climate change, which has worsened water scarcity in Morocco. The employee outlined the Ministry's efforts to construct more resilient water infrastructure, including dams and reservoirs, to mitigate the effects of droughts. The Ministry is also promoting water conservation techniques among farmers, such as drip irrigation, which has been proven effective in optimizing water use.

4.2.4. Collaboration with National and International Organizations

The interview revealed that the Ministry collaborates closely with other governmental agencies and international organizations to address Morocco's water infrastructure needs. Collaborative projects with international donors and partners, such as the World Bank and the African Development Bank, have been crucial in funding large-scale irrigation projects. These partnerships have assisted Morocco in enhancing its water infrastructure and implementing best practices in water management.

5. CONCLUSIONS AND SUGGESTION

Morocco has a significant comprehensive policy in irrigation that has resulted in the successful development of irrigated agriculture for more than 100 years. However, irrigated agriculture in Morocco now faces a number of challenges:

- Current irrigation water management is not suitable for the present context, which requires more proactive and cooperative approaches. Significant further effort will be needed to broaden the institutional and organizational basis on which the future success of Morocco's irrigation practices is expected to be built.
- The absence of a significant economic vision is the fundamental problem of water management in Morocco.
- Certainly, it is in the interest of the country to secure its future water resources and to protect its valuable environmental resources, but significant water resource costs cannot be justified on a large scale without a direct, visible economic incentive.
- It is necessary that we continue with the current reforms to find solutions to these water management problems, considering the needs of all stakeholders, their social aspirations and relationships, as an essential element and axis of long-term sustainability, allowing equitable access to resources and improving the integration of rural areas into regional and national economic processes.

My results highlight the critical need for effective water management strategies in Morocco to ensure the sustainability of agriculture in the region:

- Considering the country's arid climate and limited water resources, innovative approaches and advanced technologies must be implemented to optimize water use and minimize wastage.
- Additionally, promoting awareness and education regarding efficient irrigation methods and water conservation practices among farmers and stakeholders is crucial.
- Collaborative efforts between the government, research institutions, and local communities must be fostered to develop and implement comprehensive water management policies that address the diverse challenges faced by the agricultural sector. These policies should focus on promoting integrated water resource management, improving irrigation infrastructure

and efficiency, investing in research and development, and incentivizing sustainable practices.

By adopting a holistic and forward-thinking approach, Morocco can effectively tackle the complex issues associated with water management, leading to enhanced food security, socio-economic development, and environmental sustainability in the country.

6. SUMMARY

Morocco grapples with formidable water management challenges, driven by its arid and dry climate, rapidly increasing population, and escalating demands from the agricultural, industrial, and urban sectors. This thesis underscores the urgent necessity for sustainable and effective water management strategies to safeguard the viability of Morocco's agriculture, which heavily relies on irrigation as a lifeline.

My thesis utilizes a detailed research design to thoroughly investigate water management and irrigation practices in Morocco. Both primary and secondary data were extensively analyzed to gain a comprehensive understanding of the subject matter. Primary data was obtained through an in-depth and informative interview with a knowledgeable Ministry of Water and Equipment employee, who provided valuable insights into the intricacies of water management.

By analysing the information collected, I obtained the following results and conclusions. While traditional irrigation methods historically supported Morocco’s agriculture, they now prove grossly inadequate in the face of intensifying water scarcity and the detrimental impacts of climate change. Morocco, however, has proactively taken notable strides through government-led initiatives, such as the comprehensive National Water Strategy, which includes a multifaceted approach to address various water-related issues. Additionally, agricultural water subsidies and collaborations with international organizations have played a pivotal role in enhancing water efficiency practices.

To effectively combat these challenges, Morocco has recognized the need for substantial investments in hydraulic infrastructure projects. These projects encompass the construction of dams, reservoirs, and pipelines, which collectively illustrate a robust response to the increasing water management difficulties faced by the country. However, it is important to acknowledge the significant financial burden associated with implementing modern irrigation technologies, such as desalination and wastewater treatment, which hampers their widespread adoption, particularly among small-scale farmers operating on limited budgets.

Nonetheless, the thesis highlights the immense potential of implementing innovative practices, including the use of drip irrigation and remote sensing technologies, which have been proven to optimize water usage and significantly reduce wastage. Therefore, the incorporation of advanced technologies remains of utmost importance for achieving sustainable water efficiency. However, it

is equally essential to emphasize the crucial role of educating and incentivizing farmers to adopt these technologies, as their active participation is paramount in driving and sustaining these transformative changes.

Furthermore, community-based water management approaches have demonstrated remarkable effectiveness in fostering local ownership, ensuring equitable resource access, reducing operational costs, and enhancing maintenance practices. These approaches empower communities to actively participate in the decision-making process and take ownership of their water resources, resulting in enhanced water governance and improved sustainability.

In summary, Morocco's water management strategies must prioritize a comprehensive approach that encompasses amalgamating cutting-edge technologies, sustainable practices, and active community involvement to adapt to the evolving demands of the present and future. Policymakers, stakeholders, and local communities must collaborate and synergize their efforts to fortify water governance, with a specific focus on integrated water resource management. Additionally, investment in bolstering irrigation infrastructure and continuous research and technology development are crucial for the long-term sustenance of water resources and the enhancement of agricultural productivity. By adopting these strategies and implementing holistic approaches to water management, Morocco can safeguard its precious water resources, enhance agricultural productivity, and foster socio-economic growth, ultimately securing a more sustainable and prosperous future in an increasingly water-scarce environment.

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DECLARATION

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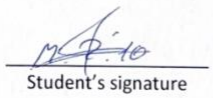

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