EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology, 2025, 26(8), 247–267
https://doi.org/10.12912/27197050/207238
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Received: 2025.06.02
Accepted: 2025.07.17
Published: 2025.08.01

Advancing treated wastewater reuse in Morocco as a pathway to sustainable water management: A review

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ABSTRACT

With limited freshwater resources and rising demand, Morocco is under increasing pressure due to overexploitation, inefficient usage, and the accelerating impacts of climate change. In 2023, per capita water availability fell to just 606 m³, far below the 1,000 m³ threshold of water scarcity. As a result, treated wastewater reuse (TWWR) has emerged as a strategic pillar of Morocco's National Water Strategy (SNE) to enhance water security. The article begins by examining national water trends and the increasing volume of wastewater generated, from 48 Mm³ in 1960 to a projected 1,026 Mm³ by 2040. In response, Morocco has launched several initiatives, particularly National Plan for Reuse (PNREU), targeting 80% treatment rate, 60% reduction in pollution, and reach 300 Mm³ of reuse annually by 2030. The purpose of this review is to examine the actual performance of TWWR across key sectors in Morocco, namely agriculture, urban landscaping, and industry, while identifying the main barriers to its broader adoption. It draws on national and international data, as well as published research to trace trends in wastewater generation and reuse, highlighting gaps between technical potential and current use. For example, despite a reuse capacity of over 40 Mm³ expected in the landscaping sector, only about 9.8 Mm³ is utilized annually. Industrial reuse shows more promising results, approaching the 15 Mm³ annual target. In contrast, agricultural reuse remains very limited. Despite the vast potential, only 0.3% of Morocco's TWW is used for irrigation, well below the 4% reported in Egypt and 24% in Tunisia. Several factors contribute to this gap, particularly limited tertiary treatment capacity, weak enforcement of regulations, and lack of public awareness or trust in the safety of reuse practices. Grounded in a comprehensive review, this study contributes to the scientific literature by synthesizing the current status of technological trends and usage patterns of TWWR in Morocco. It identifies priority actions needed to unlock the full potential of this resource. This study offers new perspectives for researchers and establishes the basis for further exploration into the environmental, health, and institutional implications of large-scale wastewater reuse in Morocco.

Keywords: water management, water scarcity, sustainable management, wastewater treatment, wastewater reuse.

INTRODUCTION

The growing concern over climate change stems from its deep and widespread impact on life across the planet. Among its most pressing challenges is the depletion of water resources, a critical issue that has increasingly captured the attention of researchers and policymakers alike (Ciampittiello et al., 2024). These changes lead to catastrophic events such as floods and droughts. Morocco is particularly vulnerable to these phenomena due to its geographical position. Since the early 1980s, drought has become a persistent issue in Mediterranean basin countries, as highlighted by climate simulations, alongside the challenges posed by flooding (Ouharba et al., 2024). While the challenge of meeting water demand is shared across the Mediterranean, the approaches to addressing it differ significantly. Developed nations in southern Europe often have greater resources and infrastructure to manage these challenges, whereas developing countries in northern Africa must navigate more complex hurdles with limited means (Noto et al., 2023; Ortega-Pozo et al., 2022). Morocco, like other southern Mediterranean nations, faces a particularly unwarranted water situation in this context. The country is grappling with water stress, growing scarcity, declining water quality, and the far-reaching impacts of climate change (Othman et al., 2022).

Recent data indicate that Morocco's average natural water resources amount to 22 billion m³ annually, comprising 18 billion m³ of surface water and 4 billion m³ of groundwater. This corresponds to 606 m³ per capita per year in 2023, which is significantly below the commonly accepted threshold of 1,000 m³ per capita per year: the level at which water shortages and potential crises begin to emerge (Boutaib aziz, 2023).

This critical situation of water resources is attributed to several factors, including the overexploitation of groundwater resources, the inadequate utilization of mobilized water resources, especially in agriculture, and the deterioration of water quality due to delays in sanitation, wastewater treatment, and the reuse of treated wastewater. The current trend scenario indicates that most river basins will face deficits by 2030 (Faour-Klingbeil & Todd, 2018).

Recognizing the urgency of this situation and the untapped potential of wastewater, Morocco has taken proactive steps to promote the reuse of treated wastewater as a sustainable resource to mitigate water scarcity and adapt to climate change. Based on the data provided in the Report of "Projet de Renforcement des Capacités sur l'Utilisation sans danger des Eaux Usées en Agriculture", the annual volumes of wastewater discharges have significantly increased over the past three decades. Between 1960 and 2005, they rose from 48 million to 600 million m³, reaching 700 million m³ in 2010. According to forecasts, these discharges will continue to grow rapidly, potentially reaching 900 million m³ by 2030 (Sebbaj Fatiha, 2012).

To harness this significant potential of wastewater, Morocco prioritizes, through its National Strategy for Water (SNE), the large-scale expansion of treated wastewater reuse. The strategy aims to reach an annual target of approximately 300 million cubic meters by 2030. Most of this water is intended for agricultural use, the irrigation of urban green spaces and golf courses, as well as groundwater recharge (The Secretariat of State for Water and the Environment, 2011).

The practice of organized and controlled wastewater reuse offers undeniable advantages. The National Plan for Water, developed by the Superior Council of Water and Climate, highlights the most significant benefits associated with wastewater reuse:

- it allows the mobilization of additional water resources, providing great regularity and helping to address local water shortages;
- it protects the environment and public health when carried out according to appropriate standards;
- it utilizes the nutrients present in wastewater, thereby reducing the use of chemical fertilizers (Superior Council of Water and Climate, 2013).

Wastewater, even though it can be a resource, can also be a source of contamination that transports a diverse range of organic and inorganic solids, pathogens, and toxic elements (Faour-Klingbeil & Todd, 2018). Therefore, the continuous and uncontrolled wastewater reuse can lead to significant environmental and health risks, requiring strict monitoring and meticulous surveys of both soil and groundwater quality in irrigated areas (Chaïeb et al., 2024).

Recognizing the growing importance of treated wastewater reuse (TWWR) in Morocco's water policy as a solution to address water scarcity, this review takes a comprehensive look at the potential of this non-conventional water resource. The article begins by examining Morocco's geographic and climatic context, which significantly influences water availability and demand. It then delves into the current state of the country's water resources, both surface and groundwater, highlighting their limitations and vulnerabilities.

From there, the focus shifts to practical actions for tackling water shortages, including demand management, resource conservation, and institutional reforms. Central to this discussion is the potential of TWWR as a sustainable and transformative solution.

This review sets out to better understand how Morocco is progressing in the reuse of TWWR across key sectors like agriculture, landscaping, and industry. While the country has set ambitious targets, there remains, as outlined in this review, a clear gap between what is technically possible and what is currently being achieved. This gap raises important questions: What's holding Morocco back from making the most of this valuable resource? What lessons can be learned from existing efforts, and what can be done to move forward more quickly and effectively?

By pulling together data from national and international reports, scientific literature, and regional comparisons, this study aims to identify not only trends and achievements but also the real barriers, be they technical, regulatory, or social, that slow down progress. It offers a timely synthesis in a context where up-to-date, comprehensive data is often lacking.

GEOGRAPHIC AND CLIMATIC CONTEXT

Providing an overview of geographic location, population, and climatic conditions is essential when discussing water resources, as these factors directly influence water availability and demand. Together, they create the context needed to understand the challenges and strategies for sustainable water management.

Geographical location of Morocco

Located in the extreme north-west of the African continent, the Kingdom of Morocco covers an area of 710,850 km^2, much of which is desert (Figure 1). It is bordered to the north by the Mediterranean Sea, to the west by the Atlantic Ocean, to the south by Mauritania, and the east by Algeria (Berriane et al., 2010). Morocco has a vast maritime frontage, with 3,500 km of coastline, including 512 km on the Mediterranean in the north and 2,934 km on the Atlantic Ocean in the west. Morocco comprises four distinct geographical regions:

- The Rif Mountains (western and eastern), in the north of the country. These mountains face the Mediterranean and experience a Mediterranean climate.
- The Atlas Mountains extend from the southwest to the northeast. This mountain range is subdivided into the Middle Atlas in the north, the High Atlas in the center, and the Anti-Atlas in the south, acting as a barrier against Atlantic influences.
- The coastal plains, where the majority of the population is settled.
- The desert lands in the east and south, bordering the Sahara. This area features oases, palm groves, rocky plateaus, and sand dunes, known for its ergs, regs, and other desert plains.

The Main rivers in Morocco are Loukkous, Sebou, Bouregreg, Moulouya, Drâa, Oum Rabia, Souss, Tensift, Ziz (Superior Council of Water and Climate, 2013).

Climate situation

Because of its geographical location, Morocco experiences a diverse climate, Mediterranean in the northern regions, and arid in the southern and southeastern areas beyond the Atlas Mountains. The country typically alternates between a hot, dry season and a cooler, wetter season (Khomsi et al., 2016).

Figure 1. Geographical location of Morocco

Morocco's rainfall pattern is characterized by high spatial variability. Average annual rainfall is distributed as follows:

- more than 800 mm in the rainiest northern region.
- between 400 and 600 mm in the Centre region;
- between 200 and 400 mm in the Oriental and Souss regions;
- between 50 and 200 mm in the south-atlantic areas;
- and less than 50 mm in the Sakia El Hamra and Oued Eddahab basins (The Secretariat of State for Water and the Environment., 2011).

Morocco's climate is shaped by the influence of the Atlantic Ocean, the Mediterranean Sea, and the Sahara Desert, resulting in significant regional variation. Most rainfall occurs between September and May, with the Rif region receiving up to 1,200 mm annually, while the southern areas remain extremely arid with less than 100 mm.

Average annual temperatures range from over 22 °C in the south to below 18 °C in mountainous areas, where winters can be harsh with snow and sub-zero temperatures. However, climate change is increasingly disrupting these patterns (General Directorate of Meteorology & Ministry of Equipment and Water, 2024).

Between 1970 and 2019, Morocco's average temperature rose by 1.36 °C, while rainfall became both scarcer and more unpredictable, triggering more frequent droughts and floods. These shifts are undermining agricultural productivity and broader economic stability. Future projections are alarming, with temperatures expected to rise by up to 4.1 °C and rainfall potentially dropping by as much as 36% by 2080, threatening Morocco's long-term resilience and sustainable development goals (Ouharba et al., 2024; World Bank - International Bank for reconstruction and development, 2023; World Bank Group, 2023) (Figure 2).

One clear takeaway from Morocco's context is that its geographic position at the crossroads of the Mediterranean and Atlantic regions, combined with its predominantly arid and semi-arid climate, significantly shapes its water resources. The country experiences variable rainfall patterns, limited surface water availability, and increasing pressure on groundwater reserves.

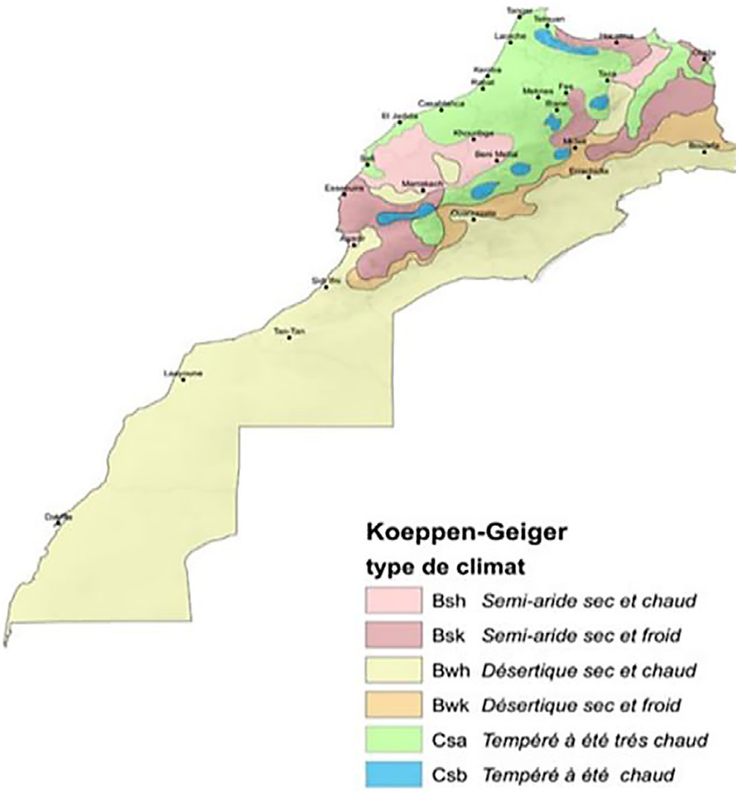

Figure 2. Climate of Morocco according to the KoeppenGeiger index (1981–2010). Data source: climate parameters observed at the CPM of the DGM then interpolated on a regular grid (~ 10 km) according to the AURELHY interpolation method

These factors, coupled with its exposure to climate change impacts, make water resource management a critical challenge. Morocco's geographic and climatic context highlights the urgent need for innovative and sustainable strategies to secure its water future.

MOROCCO'S WATER RESOURCES

As previously highlighted, Morocco faces significant water limitations. According to the most recent estimates, the country's renewable natural water resources amount to approximately 22 billion cubic meters annually, equivalent to around 606 m³ per capita per year. By the end of the current decade, Morocco may approach the critical threshold of 500 m3 per capita per year, indicating severe water scarcity. This has pushed Morocco into a state of structural water stress, comparable to many countries in the Middle East and North Africa (MENA) region (Mohamed Aboufirass, 2018; World Bank Group, 2023).

More than half of Morocco's water resources are located in the northern basins and the Sebou region, which together cover only about 7% of the national territory. In addition to this limitation, rising pollution levels have led to a decline in water quality (Salama et al., 2014). However, as it is shown in Figure 3, World Bank analysis indicates that since 1979, Morocco's surface water inflows have decreased significantly.

The annual average dropped from 22 billion cubic meters between 1945 and 1978 (blue line) to 15 billion cubic meters between 1979 and 2018 (purple line). Moreover, the likelihood of receiving an annual inflow of 15 billion cubic meters, which was 80 percent between 1945 and 1978, has fallen to just 50 percent between 1979 and 2018 (World Bank Group, 2023).

Total renewable water resources are identical, as there are no inflows of either surface or groundwater into the country. The country's dependency index is therefore also zero. On the other hand, 0.23 billion m³ /year of surface water leaves the country for Algeria via the Oued Ghir, which forms the eastern border of the southern Atlas basins, as well as 0.003 billion m³ /year of groundwater (Hssaisoune et al., 2020a; Mohamed, 2013).

Surface water resources

According to Morocco's Master Plan for Integrated Water Resources Management (PDAIRE), average annual surface water inflows vary widely by basin, from as little as 390 Mm³ in the Saharan regions to 5,600 Mm³ in the Sebou basin, contributing to a national average of about 18 billion m³. These resources are unevenly distributed, with the Loukkos, Sebou, and Oum Rabia basins alone accounting for 68.1% of the nation's total surface resources (Hssaisoune et al., 2020b; Mohamed Aboufirass, 2018).

Surface water availability fluctuates significantly year to year. During dry years, water supplies can diminish to less than 30% of the average. To address this spatial and temporal disparity, Morocco has constructed large dams to store water during wet periods and has implemented inter-basin transfers to support more equitable regional development (Moulay Hassan El Badraoui & Mohamed Berdai, 2011).

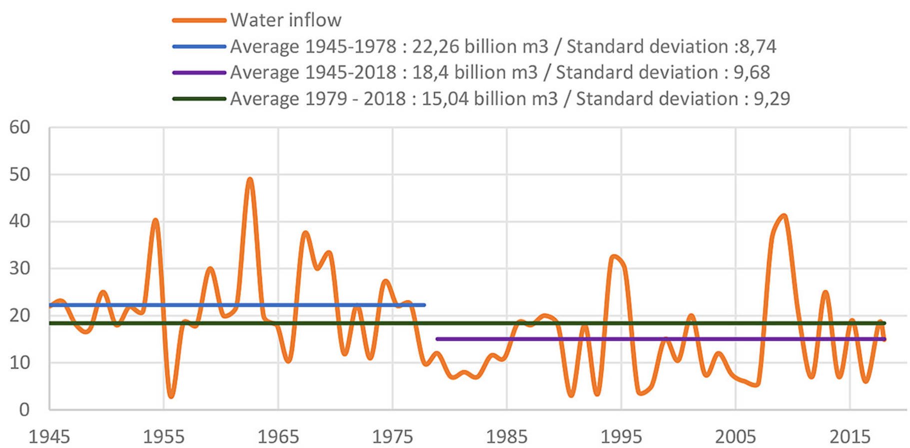

Figure 3. Morocco's water inflows (in billion m³/year).
Source: World Bank team's calculation based on PNE 2020

Table 1. Average surface water runoff per river basin

River basin	Surface area (km²)	Surface area (%)	Average surface water runoff (Mm³/year)	Runoff (%)
Loukkous	12,805	1.8	3,600	19.6
Sebou	40,000	5.6	5,600	30.5
Moulouya	74,145	10.5	1,300	7.1
Bou Regreg and Chawia	20,470	2.9	852	4.7
Oum Rabia	48,070	6.7	3,300	18.0
Tensift	24,800	3.5	1,140	6.2
Souss-Massa-Draa	126,480	17.8	1,502	8.2
Ziz, Rheris, Guir	58,841	8.3	626	3.4
Saquiat El Hamra and Oued Eddahab	305,239	42.9	390	2.1
Total	710,850	—	18,340	—

Note: source – The Directorate of Water Research and Planning - DRPE 2016.

Groundwater resources

The National Water Plan Project estimates that the potential groundwater resources in Morocco are approximately 3.9 billion m^3 per year based on current knowledge, with nearly 1 billion m^3 coming from irrigation return flows. Table 2 provides the distribution of these resources by aquifer (Hssaisoune et al., 2020b; Aboufirass, 2018). Unlike surface water, groundwater resources are more evenly distributed across the territory. They form a significant part of the nation's water resources, playing a strategic role in the country's water supply. These resources contribute to the drinking water supply for the majority of rural populations, nearly 30% of urban populations, and about 30% of the irrigated land. Of the 130 aquifers, 32 are deep water tables and 98 are superficial water tables (Aboufirass, 2018). Looking ahead, projections from the World Bank Group paint a concerning picture for Morocco's water future. The country can expect a significant reduction in water resources over the next few decades:

- water availability is currently about 606 m³/capita/year, and it is already in a situation of structural water stress. This rate could fall below the shortage threshold of 500 m³/capita/year by 2030, due to demographic pressure and rising demand, combined with the impact of climate change on water resources;
- a drop in groundwater recharge and a worsening of overexploitation, which already amounts to 1.1 Bm³ per year;
- an increase in the salinity of coastal aquifers due to the invasion of marine waters (Aziz, 2023; El Meknassi, 2022; World Bank Group, 2023).

Table 2. Potential groundwater resources per basin in Mm^3

River basin	Surface area (km2)	Natural renewable resources (Mm³/year)
Loukkous	12,805	406.3
Sebou	40,000	267.5
Moulouya	74,145	1,561.8
Bou Rehreg	20,470	74.1
Oum Rabia	48,070	619.3
Tensift	24,800	167.5
Souss-Massa	27,880	212.8
Guir-Ziz-Rheris	58,841	287.7
Draa	98,600	312.6
Saquiat El Hamra and Oued Eddahab	305 239	2.5
Total	710,850	3,912.1

Note: source – The Directorate of Water Research and Planning - DRPE 2016.

ACTIONS FOR COMBATING WATER SHORTAGES IN MOROCCO

Morocco has embraced Integrated Water Resources Management (IWRM) as a foundation for transforming water into a driver of sustainable development (The Secretariat of State for Water and the Environment, 2011). This commitment was formalized in the 2009 National Water Sector Development Strategy and reinforced by Water Law 36-15, leading to the implementation of the National Water Plan (PNE) (World Bank Group, 2018).

These efforts mark a shift toward a more integrated and proactive water policy, designed to meet the needs of population growth and adapt to climate change. The strategy focuses on six key sectors: agriculture, energy, industry, infrastructure, tourism, and environmental protection, as identified by the World Bank and national reports. The next sections of this work delve into each of these strategic axes (Mohamed, 2013).

a) Water demand and efficiency management (2.5 Bm^3/year):
- in agriculture, transitioning to modern irrigation techniques and upgrading existing systems could yield significant water savings, estimated at 2.4 billion cubic meters per year;
- in urban areas, enhancing the efficiency of water supply networks, particularly through leak reduction, and promoting water-efficient technologies in the tourism sector could save an additional 120 million cubic meters annually (World Bank Group, 2018) (Figure 4).

b) Supply management and development (2.6 Bm^3/year) – to strengthen water supply and secure an additional 2.6 billion cubic meters annually, Morocco's strategy combines several large-scale initiatives. Key among them is the construction of 60 large and 1,000 small to mid-sized dams by 2030, aimed at mobilizing 900 million m^3/year. A major inter-basin water transfer project will redirect 800 million m^3/year from the Loukkos and Sebou basins to more arid regions. Desalination and brackish water demineralization are expected to provide 500 million m^3/year, while rainwater harvesting pilot projects aim to generate 100 million m^3/year. Finally, treated wastewater reuse is set to contribute 300 million m^3/year for non-potable applications like irrigation and landscaping (World Bank Group, 2018) (Figure 5).

c) Preservation and protection of water resources, natural habitats and sensitive areas – Morocco has launched several integrated initiatives. The National Rural Sanitation Plan targets 90% wastewater treatment access in rural areas by 2030, while the National Plan for the Prevention and Control of Industrial Pollution aims

Figure 4. Management of water demand and efficiency.
Source – World Bank Group (2018)/Managing Urban Water Scarcity in Morocco

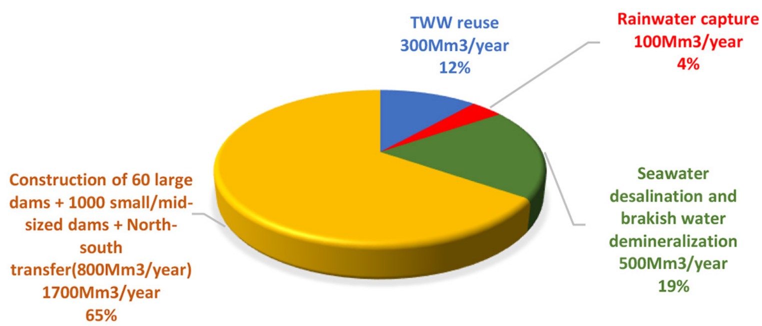

Figure 5. Management of water demand and supply.
Source: World Bank Group (2018)/Managing Urban Water Scarcity in Morocco

to regulate industrial effluents and encourage cleaner production. The country is also improving solid waste management to reduce water contamination and promoting the demineralization of brackish water for agricultural and drinking use. Additionally, groundwater management includes restricting over-extraction and supporting aquifer recharge, alongside efforts to protect watersheds and combat desertification to safeguard natural (World Bank Group, 2018).

d) Reducing vulnerability to natural hazards and adaptation to climate change:
- improved protection of people and property against flooding,
- combating the effects of drought: drought management plans by river basin (Mohamed, 2013).

e) Continuation of institutional and regulatory reforms (World Bank Group, 2018).

f) Upgrading information systems and capacity building and skills (World Bank Group, 2018).

In summary, Morocco's water resources are deeply shaped by its geography and climate, making the country inherently vulnerable to drought and scarcity. The country has adopted a proactive and long-term approach to managing its water crisis. The adoption of the national strategy for water (SNE) and its operational framework, the national water plan (PNE), represent significant milestones in addressing water security. These initiatives reflect a more integrated and collaborative approach, aligning with the principles of integrated water resources management (IWRM) to bring together all key sectors in the quest for sustainable water use.

As illustrated in the graphic below, climate change has a critical impact on Morocco's water resources while the national water plan (PNE) plays a vital role in mitigating water deficit. In the absence of climate adaptation measures or PNE implementation, water demand is projected to far exceed supply by 2050, resulting in a severe deficit of 3,976 million m³. Climate change intensifies this imbalance, pushing the gap to 7,036 million m³ due to declining water availability. However, with the PNE in effect, the deficit is considerably reduced to just 196 million m³, underscoring its effectiveness in strengthening water management and combating climate-induced challenges (Figure 6).

CURRENT STATUS OF WASTEWATER EFFLUENTS AND TREATMENT IN MOROCCO

Global overview of wastewater

Over the past few decades, global municipal volume of wastewater produced has significantly increased due to a rapid rise in population, industrialization, and changes in consumption habits (Singh, 2021).

In fact, the total worldwide wastewater production is estimated at 359.4 billion m³ annually. Of this volume, 63% is collected, and 52% undergoes treatment, highlighting significant potential for reuse. (Jones et al., 2021)

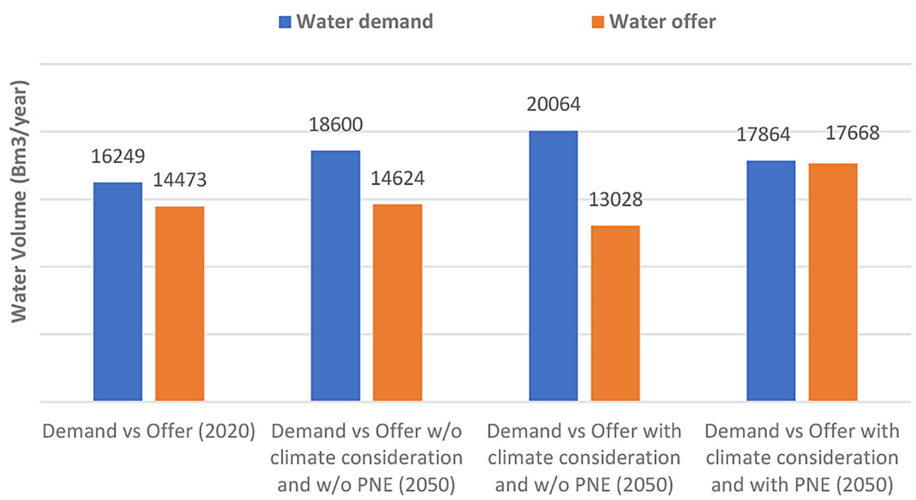

Figure 6. Projected water deficit over the period 2020–2050 (with and without climate considerations, with and without PNE). Source: World Bank team's calculation based on PNE 2020

The United Nations World Water Development Report 2017 reveals that 80% of wastewater globally is discharged into the environment without proper treatment, posing serious challenges. Much of this untreated wastewater flows directly into natural water bodies, degrading water quality and reducing availability for downstream users. Treatment levels vary significantly by region: around 70% of wastewater is treated in high-income countries, compared to 38% in upper-middle-income countries, 28% in lower-middle-income countries, and only 8% in low-income countries. (UNESCO, 2017)

Trend of wastewater production in Morocco

During the 20th century, Morocco's population growth stimulated rising demand for potable water in urban areas, increasing connections to both drinking water and wastewater systems. (Baroudy, 2005)

As cities expanded and sewerage networks grew, annual wastewater discharges surged from 48 million m^3 in 1960 to 600 million m^3 in 2005, reaching 700 million m^3 by 2010, of which only 36% (250 million m^3) was treated. By the end of 2018, treated wastewater volumes rose to 305 million m^3, representing 38% of total discharges, up from just 8% in 2005.

Wastewater volumes are expected to grow 3–4% annually, with urban areas like Casablanca, Rabat, and Marrakech generating the largest shares, 35%, 20%, and 15% respectively (Figure 7). Meanwhile, rural areas lag, with only 40% of the population having access to sewage systems, mostly rely on septic tanks, and a mere 10% and 3% connected to formal sewer networks and WWTPs, respectively (Moroccan Ministry of Energy Transition and Sustainable Development – Department of Sustainable Development, 2022)

The large share of about 42% of wastewater in Morocco is discharged without advanced treatment with disposal methods varying based on geographic location. Inland options include direct discharge into rivers and streams, land sprinkling, or release into lakes. In each case, this may cause contamination of water bodies and soils, especially agricultural land and natural habitats of the respective areas. In Morocco, discharge of inland wastewater is heavily concentrated in the river basins of Sebou and Tensift, where the basins are of vital importance in their function of supplying water for agriculture and domestic use. (Moroccan Ministry of Energy Transition and Sustainable Development – Department of Sustainable Development, 2022)

In the coastal areas, however, the residual wastewater is usually discharged into the sea, particularly on the Atlantic coast, where a good number of Morocco's major urban centers are found, contributing a very high wastewater volume either untreated or minimally treated into this ocean. Although the sea has a very high dilution capacity, the continuous discharge of effluent creates environmental hazards in the form of marine pollution, destruction of inshore aquatic life, and alteration of coastal ecosystems. (Moroccan Ministry of Energy Transition and Sustainable Development – Department of Sustainable Development, 2022)

According to predictions by Morocco's Ministry of the Interior, a total volume of 1,026 million m^3 of wastewater is expected by 2040, of which almost 40% will be discharged directly into the sea. The table below summarizes this water potential by basin for 2030 and 2040 (Mohamed Aboufirass, 2018) (Table 3).

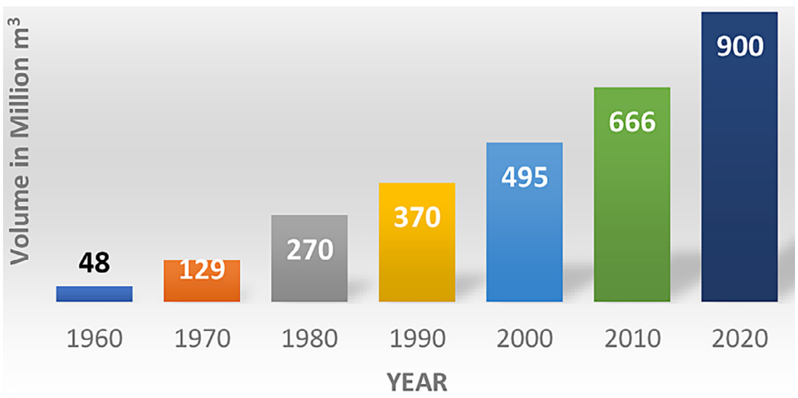

Figure 7. Trend of wastewater production in Morocco (MnEnvr, 2015)

Status of wastewater treatment systems in Morocco

Wastewater treatment and sanitation in Morocco is managed by the National Liquid Sanitation and Wastewater Treatment Program commonly known as the PNA, launched in 2005, it was a collaborative effort by the Ministry of the Interior, the Ministry of Energy, Mines, and the Environment, along with the Ministry of Economy, Finance, and Administration Reform. Its goal was to enhance liquid sanitation infrastructure across the Kingdom of Morocco. This program aims to tackle the delays in wastewater treatment and the issues related to water scarcity. This initiative seeks to improve health conditions for 10 million residents in 330 Moroccan cities and towns by the year 2020, with an estimated investment of 43 million dirhams (about 4.3 million US dollars) (Belloulid et al., 2018; Programme National d'Assainissement Liquide, 2015).

More concretely, the PNA was revised in 2008 to improve the pace of its implementation and to integrate purification up to tertiary level with the reuse of treated wastewater (Moroccan Ministry of Energy Transition and Sustainable Development – Department of Sustainable Development, 2022)

In terms of achievements at the end of 2019, significant progress has been made within the framework of the PNA.

The current situation is as follows:

- connection rate: 76% versus 70% in 2005;
- wastewater treatment rate: 52.9% versus 8% in 2005;
- 141 wastewater treatment plants (WWTP) completed, 60 of which have tertiary treatment;
- 76 WWTP under construction;
- the number of centers that have benefited from liquid sanitation projects is 255 out of the 330 planned as part of the PNA review.

The latest PNA dashboard for 2019-2020 shows that the sewage treatment plant fleet includes 141 WWTP and 8 completed marine emitters; the volume of wastewater treated is 394.6 million m^3 (without emissaries). The volume treated up to tertiary level, and therefore available for reuse, amounts to around 200 million m^3 in 2019, i.e. 51% of the total volume treated (Comité Scientifique et Technique sur l'Eau Agricole, 2022).

Figure 8 illustrates the growth of wastewater purification rates in Morocco, increasing from 8% in 2005 to 48% in 2017. It demonstrates the country's consistent progress in enhancing its wastewater treatment infrastructure and capacity, driven by key national sanitation programs such as the PNA and PNAR.

The rate is projected to reach 80% by 2040, with accelerated growth anticipated in the long term. Additionally, the ministries involved in developing the PNA have established a new program aimed at pooling the National Liquid Sanitation and Urban and Rural Wastewater Treatment Programs along with the Treated Wastewater Reuse Program. This mutualized program, named PNAM, was approved in 2018 and launched in 2019.

The new PNAM sets the following specific objectives for the 2030 and 2040 horizons:

Table 3. Wastewater potential prediction by basin

River Basin	2017 In million m^3	2030 In million m^3	2040 In million m^3
Loukkous	89	113	131
Moulouya	49	62	71
Sebou	128	156	180
Bourehreg	252	301	348
Oum Rabia	64	81	93
Tensift	53	57	80
Souss-Massa	10	15	18
Draa	44	60	73
Guir-Ziz-Rheris	6	8	9
Saquiat El Hamra and Oued Eddahab	11	17	23
Total in million m^3	706	870	1,026

Note: Source – mutualization of national liquid sanitation programs (PNA and PNAR) and wastewater reuse programs. Minister of Interior 2017.

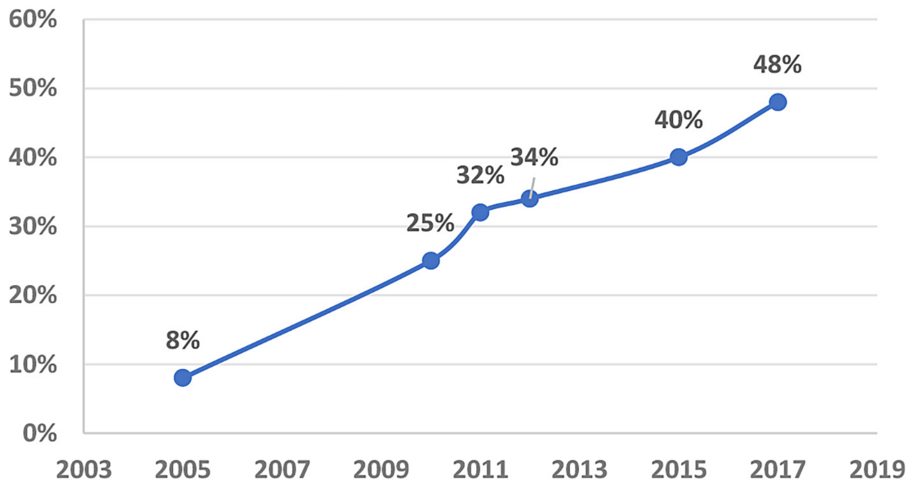

Figure 8. Evolution of wastewater purification rate.
Source: pooling of National Liquid Sanitation Program (PNA and PNAR) and wastewater reuse (Ministry of

- accelerate the implementation of the PNA to achieve a connection rate of 95% and a decontamination rate of 80%, including outfalls, by 2040;
- sanitize the main town centers of the Communes to achieve connection rates of 50% by 2030 and 80% by 2040, as well as a depollution rate of 40% by 2030 and 60% by 2040;
- promote the reuse of treated wastewater to mobilize 474 million m^3/year by 2030 and 573 million m3/year by 2040 (Ministry of Energy, Mines and Environment - Department of the Environment, 2020).

Within this program, Morocco has significantly invested in enhancing the efficiency and expanding the coverage of its wastewater treatment and sanitation systems. As shown in Figure 9, the proportion of treatment plants relying solely on primary treatment has sharply declined, from 17% in 2014 (DIAEA, 2014) to 6% in 2019 according to the PNAM report. Concurrently, secondary and tertiary treatment levels rose from 42% and 41% in 2014 to 51% and 43% in 2019, respectively.

Regarding wastewater treatment methods, Figure 10 presents a detailed overview. Natural lagooning remains the most widely used approach, followed by the activated sludge process, a shift toward diversifying treatment technologies is evident. The high reliance on natural lagooning, where natural biological processes treat

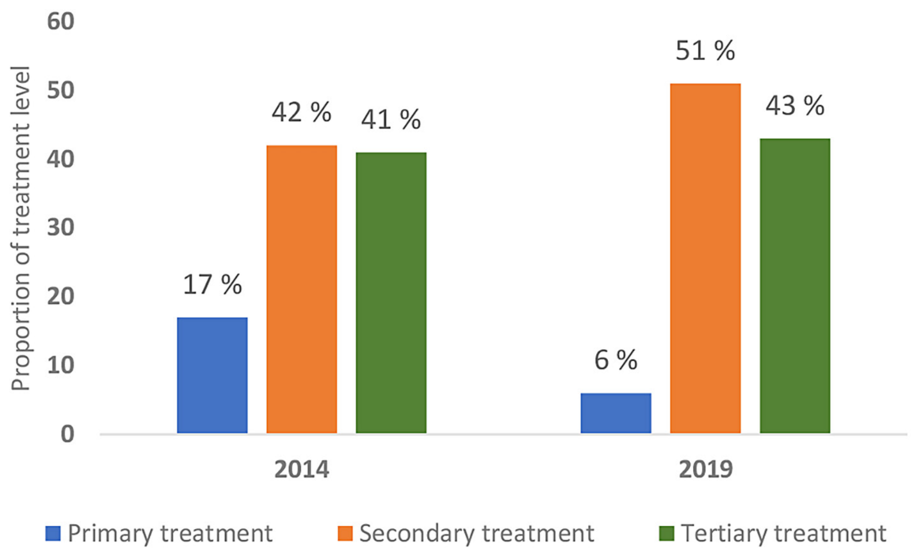

Figure 9. Shares of wastewater treatment levels. Source: DIAEA, 2014

wastewater, suggests that the wastewater treatment approach prioritizes low-cost, low-maintenance systems, preference for more ecologically integrated systems.

To promote wastewater reuse, Morocco is increasingly implementing tertiary treatments with enhanced disinfection and filtration. For specific uses, such as golf course irrigation or in environmentally sensitive areas, additional treatment steps, including denitrification and dephosphorization, are also applied to meet environmental safety standards.

MOROCCAN FRAMEWORK OF WASTEWATER REUSE

As previously discussed, Morocco has adopted several integrated water resource management strategies to address increasing water scarcity, with a strong focus on non-conventional sources. The National Strategy for Water (SNE 2010–2030) and the National Plan for Water (PNE 2020–2050) highlight two key actions: seawater desalination and brackish water demineralization to provide 500 million m³/year, and the reuse of treated wastewater (TWWR) for agriculture, landscaping, and golf courses, targeting 300 million m³/year. Though the reuse of marginal-quality water has historical roots, global figures show only 11% of treated wastewater is reused, 15% in the MENA region, over 80% in countries like the UAE and Kuwait, while in Western Europe it is around 16% (Hussain et al., 2019; Jones et al., 2021). Wastewater reuse has wide applications, including agriculture, industry, urban use, and groundwater recharge (Pandey, 2022).

Since 1960, Morocco has mobilized its water resources to address population growth and support its social and economic development, but limited hydrological potential now necessitates turning to TWWR to conserve water resources. Furthermore, Morocco's experience in this field has demonstrated that the reuse of water is a viable practice (Hirich & Choukr-Allah, 2013)

Around 70 million m³ of untreated wastewater is used every year in agriculture without proper sanitation, irrigating over 7,000 hectares of diverse crops, including fodder, vegetables, arable land, and orchards (Boularbah et al., 2024)

Reusing TWW provides a sustainable alternative, reducing pressure on freshwater, enhancing climate resilience, and conserving ecosystems (Saoud & Suzan, 2018; Tallou et al., 2020)

Under the National Liquid Sanitation and Wastewater Treatment Program (PNA 2005–2030), Morocco aims to reduce pollution by 60%, expand treatment coverage by 80%, and build 300 WWTPs to meet the 300 million m³/year reuse goal set by the National Plan for Reuse (PNREU). These programs also promote the circular economy and water system resilience (Tallou et al., 2020; World Bank Group, 2018)

We offer an overview, in the Table 4, of the projected potential for treated wastewater reuse across Morocco's various river basins by the year 2030. According to preliminary estimates from the DIAEA Master Plan, Morocco plans to reuse 300 million m³ of treated wastewater annually, with allocations across key sectors as shown in Figure 11. Specifically, 46% will be used for agriculture, 43% for irrigating green spaces and golf courses, 6% for groundwater recharge, and 5%

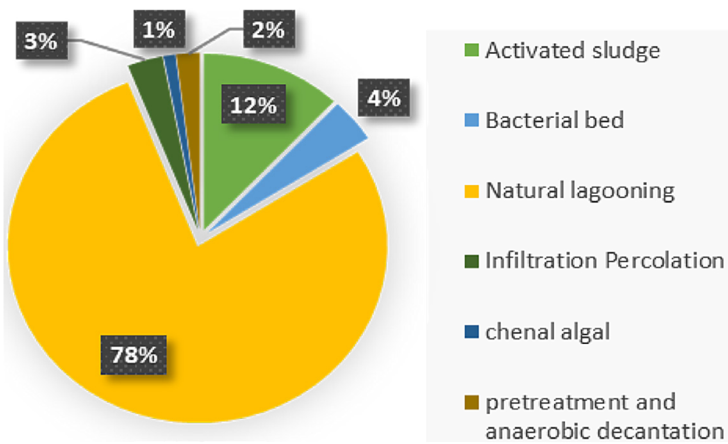

Figure 10. Shares of wastewater treatment methods

for industrial applications (Comité Scientifique et Technique sur l'Eau Agricole, 2022)

This large proportion given to the agricultural sector is explained by the importance of this sector in Morocco's economy. According to FAO's Global Information System on Water and Agriculture, Morocco is a major producer and exporter of agricultural goods. In 2019, the agri-food sector contributed around 15% to the national GDP and employed over 33% of the active population, making it one of the country's key sources of foreign exchange (FAO, 2015)

In this context, the irrigation sector in Morocco is currently the largest water consumer, accounting for approximately 88% of the total water consumption (Tallou et al., 2020). The country has 8 million hectares of arable land, which represents about 18% of its total land area. The potential area for year-round irrigation is estimated at 1,364,250 hectares, or roughly 16% of the agricultural land in use. Additionally, there are around 300,000 hectares of land that can be irrigated on a seasonal basis (Frenken & Gillet, 2012).

CURRENT SITUATION OF WASTEWATER REUSE IN MOROCCO

In Morocco, the practice of reusing wastewater is considered a sustainable, vital alternative to address the gap between demand and water resources. Through it Morocco has the opportunity to cover more than 13% of total water demand if appropriately treated and reused (Alhamed et al., 2018).

An analysis of the data previously mentioned reveals that the agricultural sector accounts for the largest share of water consumption. To reduce this significant demand, it is crucial to harness non-conventional water resources, with a particular focus on wastewater reuse. Currently, the reuse of treated wastewater (TWWR) in Morocco

Table 4. Wastewater reuse potential per basin by 2030

Volume of reused treated wastewater per year by river basin (Million m³/year)					
River basin	Irrigation for agriculture	Industry	Landscaping/golf courses	Artificial recharge of aquifer	Total
Loukos	20	-	7	-	27
Moulouya	12	-	9	-	21
Sebou	34	-	15	10	59
Bouregreg	19	-	1	-	20
Oum Rabia	15	16	4	-	35
Tensift	1	1	56	-	58
Sous Mass	38	-	40	10	88
Sud Atlas	3	-	1	-	4
Total	142	17	133	20	312

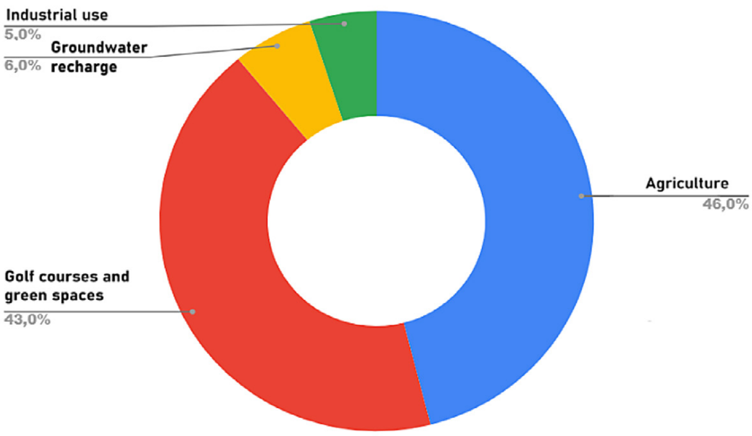

Figure 11. Proportion of the reuse options in relation to the target of 300 million m³ in 2030

is minimal, but there are effective options for its reuse, particularly in agriculture.

Currently, Morocco is either implementing or has completed 46 wastewater reuse projects, with a focus on green spaces, golf courses, and agriculture. By the end of 2019, 19 wastewater treatment plants involved in these initiatives were mobilizing an estimated 60 million m³ of treated wastewater annually. Approximately 51% of this volume is reserved for irrigating urban green spaces and golf courses, while 17% supports industrial operations, including significant usage by OCP. This robust effort highlights Morocco's commitment to sustainable water management and the efficient repurposing of valuable water resources (Aziz, 2023). By default, mobilizable wastewater can be referred to as any wastewater that has undergone appropriate tertiary treatment and is ready for reuse (Comité Scientifique et Technique sur l'Eau Agricole, 2022).

Agricultural use

Agriculture is expected to absorb the largest share, around 46%, of the ambitious treated wastewater reuse (TWWR) target, amounting to nearly 140 million m³ per year. However, in practice, the actual reuse remains minimal, only 0.3% of wastewater produced is currently used for agricultural irrigation, significantly lower than the 4% in Egypt and 24% in Tunisia (Frascari et al., 2018).

Moreover, merely 1% to 2% of the total irrigable area benefits from treated wastewater systems. This limited reuse in Morocco is primarily due to low public acceptance, driven by insufficient awareness of its advantages, coupled with inadequate monitoring and oversight of wastewater quality (Frascari et al., 2018; Jeuland, 2015).

About 1,100 hectares of agricultural lands have been designated for irrigation using treated wastewater. The crops planned for this are primarily fruit trees, wheat, alfalfa, olive trees, cereals, and fodder crops (namely alfalfa) (Mansir et al., 2024).

Numerous projects aimed at reusing treated wastewater for crop irrigation have been carefully planned, finalized, and are now in the process of being put into action. These projects are taking place in various regions, including Boujaâd, Oued Zem, Guelmim, Settat, Tiznit, and Oujda. The government, alongside key stakeholders such as the Water Department, is dedicating substantial efforts to ensure the successful implementation of these initiatives (Benlemlih et al., 2024; Comité Scientifique et Technique sur l'Eau Agricole, 2022).

For example, the potential volumes from the Oujda, Settat, and Tiznit WWTPs, totaling around 20 million m³, remain unused because additional treatment processes are lacking, preventing the wastewater from meeting the necessary health standards for agricultural irrigation. In contrast, the Boujaad WWTP serves as a model for effective reuse, as its treated wastewater is safely utilized for both irrigation and aquaculture without any harmful effects (Faouzi et al., 2020).

Another significant example can be seen in the Sous Massa region, where treated wastewater is reused for irrigating citrus crops, made economically feasible through subsidies. The Tiznit wastewater treatment plant is a standout initiative in the area, facilitating the irrigation of around 430 hectares of diverse crops (Bourouache et al., 2019).

The reuse of wastewater in Tiznit has significantly improved farmers' incomes and living standards. This practice has not only boosted crop yields but also enabled farmers to reduce their reliance on chemical fertilizers. The presence of macronutrients (N, P, K) and micronutrients in the wastewater reduced the need for additional fertilizers, resulting in considerable cost savings (Ofori et al., 2021).

By aligning the cost of treated wastewater with that of freshwater, its adoption could be encouraged across 59% of the cultivated area, leading to substantial conservation of freshwater resources (Oubelkacem et al., 2020).

Research and studies have also explored additional possibilities for reusing treated wastewater in agriculture across various regions. In Al Hoceima city per example, a study by Bel Haj et al. demonstrated the successful and safe reuse of treated wastewater for irrigating lettuce and coriander. The Imzouren-Bni Bouayach wastewater treatment plant, which employs a natural lagooning process, supplies 10,800 m³/day of treated wastewater, this has been shown to deliver irrigation productivity comparable to conventional water sources while enhancing crop yields due to the nitrogen, phosphorus, and potash minerals present in the effluent. These nutrients will significantly improve the production of lettuce and coriander (Bel Haj et al., 2023a). Additionally, the treated wastewater serves as a reliable alternative water source, supporting stable crop growth without causing adverse effects on plants or soil quality (Bel Haj et al., 2023b).

Overall, Morocco's wastewater quality standards are less rigorous than those in developed countries. However, the country has significant potential to expand wastewater reuse for agricultural irrigation. Enhancing regulations and adopting advanced treatment technologies are crucial to meet international export market demands (Ortega-Pozo et al., 2022).

On paper, national strategies such as the PNREU are ambitious, aiming for about 140 Mm^3/year of reused wastewater for agriculture by 2030. However, such targets are undermined by limited public awareness, weak regulatory oversight, and fragmented local governance. Without clear accountability mechanisms and inter-institutional coordination, these targets risk remaining aspirational.

Golf courses and Landscape irrigation

In Morocco, reusing treated wastewater for golf courses and landscape irrigation is proving to be a strategic solution to alleviate pressure on freshwater reserves. Guided by the directives of the nation's highest authority, this approach of mobilizing approximately 43 million m^3 of reusable treated wastewater annually is set to be widely implemented to ease the strain on conventional water sources (Chahouri et al., 2019; Ortega-Pozo et al., 2022).

Research, including studies by Chahouri et al. (2019) and Ortega-Pozo et al. (2022), confirm the potential benefits of this option of reuse, highlighting its role in sustainable water management and resource conservation.

For instance, the M'zar treatment plant in Agadir generates up to 10,000 m^3 of treated wastewater per day, a volume that meets both national and international standards for physicochemical and microbiological quality. This sustainable water source is more than adequate to cover the entire irrigation needs of green spaces throughout Grand Agadir, providing a dependable solution for urban landscaping (Chahouri et al., 2019; Mouhanni et al., 2012). Several golf courses, including Océan Golf in Agadir, Bouskoura, and Ben Slimane, have been specifically designed to operate exclusively on treated wastewater, with no reliance on alternative water sources. Meanwhile, many existing courses are progressively shifting towards this sustainable practice. Despite the 43 million m^3 of treated wastewater available annually, current utilization remains limited to just 9.8 million m^3, highlighting significant untapped potential. As of today, 23 golf courses and landscaped areas across cities like Rabat, Tangier, Tetouan, M'diq-Martil, Agadir, Bouskoura, Benslimane, Bouznika, and Marrakech are irrigated using treated wastewater (Comité Scientifique et Technique sur l'Eau Agricole, 2022).

Furthermore, the WWTP in Ben Slimane city treats approximately 5600 m^3 /day to the tertiary level. Its effluent is used to irrigate a golf course by sprinkler irrigation and supplying about 308 kg of Nitrogen (Hirich & Choukr-Allah, 2013).

A remarkable example of wastewater reuse in Morocco is the collaborative effort between the Moroccan government, RADEEMA (the local wastewater reuse agency in Marrakech), golf course owners, and the municipality. Together, they launched a pioneering project aimed at protecting the environment, supporting tourism and urban development, and meeting the city's growing water needs.

Designed to supply 24,000 m^3 of treated wastewater per day, this initiative provides 8 million m^3 annually to irrigate 18 golf courses, green spaces, the palm grove, and 26 public gardens and parks in Marrakech. However, at present, only 8 golf courses have adopted treated wastewater, utilizing 5.86 million m^3 per year. With the expansion of wastewater reuse projects, this volume is expected to grow, further strengthening Marrakech's commitment to sustainable water management (Benlouali et al., 2017; Mateo-Sagasta et al., 2022; Mohamed Aboufirass, 2018).

Official data indicate that the master plan for the Tensift basin river aims to generate 56 million m^3 of treated wastewater for reuse. As part of this effort, ongoing projects focus on expanding wastewater use to irrigate all green spaces across the city of Marrakech, to achieve an annual reuse volume of 26 million m^3 (Maadialna, 2024).

REDAL and AMEDIS are two private companies responsible for liquid sanitation in Rabat and the Tangier-Tetouan region, respectively. Both are operated by Veolia, a key player in the treated wastewater reuse sector. Over 80% of green spaces in these areas are irrigated by the REUSE (Veolia Maroc, 2023). The reuse of treated wastewater for irrigating green spaces in Rabat has conserved approximately 4 million cubic meters of freshwater in the year of 2022, which is equivalent to the drinking water supply for two small cities, each with a population of 25,000 (Bakkali, 2024).

Amendis has harnessed its expertise in wastewater treatment and reuse to support the irrigation of golf courses and public green spaces across Tetouan, M'diq, Fnideq, and Martil. Between 2016 and 2022, this initiative successfully preserved 8.7 million m³ of water, significantly easing pressure on freshwater resources. Looking ahead, the agency aims to save an additional 2.8 million m³ annually, a volume equivalent to the drinking water needs of 55,000 people (Veolia Maroc, 2023).

At the heart of this strategy is the Boukhalef wastewater treatment plant (WWTP), the largest facility in the region, with a daily capacity of 42,700 m³. In 2019, its reuse network was extended to Tangier's city center, facilitating the irrigation of municipal green spaces and the Tangier Royal Golf Course, spanning 141 hectares (Mateo-Sagasta et al., 2022).

A collaboration between the LYDEC Foundation and ARADD (Association for Research-Action for Sustainable Development) giving birth to an experimental garden in the Mediouna WWTP, this project demonstrates that the reuse of treated wastewater for agricultural irrigation purposes is possible within the framework of urban and organic agriculture: 1,600 m² of experimental urban agriculture space bringing together more than 80 plant species irrigated by treated wastewater from the Mediouna WWTP. This initiative will enable the city of Casablanca to use this unconventional resource for watering gardens and green spaces in several districts near the Mediouna WWTP (LYDEC, 2024).

Despite the strategic importance and institutional support given to the reuse of treated wastewater (TWW) for landscape and golf course irrigation in Morocco, the actual implementation remains far below the national target of 130 million m³ annually (expected share for this option in the National Strategy for Water). With 43 million m³ of mobilizable treated wastewater, only 9.8 million m³ is currently being reused, just over 7% of the projected goal, reflecting a significant underutilization of this resource.

This gap between potential and actual reuse is due to several critical factors, in particular, limitations in infrastructure technical operation. Many golf courses and green spaces are still not connected or equipped to use TWW despite proximity to WWTPs. Some WWTPs, such as those in Oujda or Tiznit, lack advanced treatment technologies required to meet strict irrigation standards. In other cases, reuse plans exist on paper, but the actual infrastructure for distribution and usage is not yet in place.

Industrial use

Despite Morocco's advancements in wastewater treatment, its use in industrial applications remains limited. Yet, integrating treated wastewater into industrial processes presents a powerful opportunity to ease pressure on freshwater resources while fostering sustainable economic growth (Bakkali, 2024; Salama et al., 2014)

Industries can repurpose treated wastewater for cooling systems, boiler feed, and process water, reducing dependency on conventional water sources. However, this practice comes with technical challenges. Aerosol dispersion must be carefully managed to protect workers and the public, while additional treatment is often required to prevent scaling, corrosion, biological buildup, fouling, and foaming. Overcoming these hurdles will be crucial to unlock the full potential of treated wastewater in Morocco's industrial sector, paving the way for responsible water management and long-term resilience (Hala Alhamed et al., 2018).

Treated wastewater is repurposed for industrial processes in the Sidi Yahia Gharb region, particularly for cooling systems. This initiative was led by the ONEP (Office National de l'Eau Potable) (Hirich & Choukr-Allah, 2013).

One of the most notable examples of industrial reuse in Morocco is found in the phosphate mining operations of OCP Group in Benguerir, Khouribga, and Youssoufia. Each year, 10.31 million m³ of treated wastewater is effectively mobilized and fully utilized for phosphate washing (Comité Scientifique et Technique sur l'Eau Agricole, 2022).

Another remarkable example of industrial use in Morocco is the strategic partnership between the Moroccan government, Renault, and Veolia. Leveraging Veolia's environmental expertise, Renault's factory has achieved zero liquid industrial waste while decreasing its water intake for industrial processes by 70%. By optimizing industrial processes, Veolia has enabled the full recycling of industrial effluents, transforming them into purified water for vehicle manufacturing. This collaboration showcases how synergy between industry and environmental experts can drive sustainable solutions, benefiting both business efficiency and ecological preservation (Veolia Maroc, 2023).

OCP's phosphate washing, Renault's zero liquid discharge plant, and Veolia's partnerships prove that industrial TWWR works. These cases offer ready-to-replicate models in other industrial fields (e.g., food processing, textiles, paper).

While treated wastewater reuse (TWWR) in agriculture and landscape irrigation faces significant structural, regulatory, and social challenges (low public acceptance, quality standards, and infrastructural gaps), the industrial reuse option stands out as the most promising and scalable avenue in the short to medium term.

This option lies in the fact that industrial settings operate within controlled environments, making it easier to enforce water quality standards and install advanced on-site treatment systems when necessary. Unlike agriculture or urban landscape irrigation, industrial reuse does not depend on public acceptance or decentralized infrastructure, which simplifies both implementation and monitoring.

Artificial recharge of the aquifer

Beyond the reuse options already outlined, Morocco is actively exploring new options, including artificial aquifer recharge. This is projected to absorb around 6% of the total treated wastewater volume, contributing to groundwater replenishment and enhancing long-term water resilience (Comité Scientifique et Technique sur l'Eau Agricole, 2022).

In the Souss River Basin, the Managed Aquifer Recharge (MAR) program plays a crucial role in safeguarding water resources, particularly in times of drought. In the Biougra aquifer, this initiative combines direct recharge techniques, such as retention sills and tributary infiltration, with rainwater harvesting to enhance groundwater replenishment. Together, these techniques contribute to the sustainable replenishment of groundwater reserves and the long-term availability of water in the region (Managed Aquifer Recharge in a Semi-Arid Basin, 2024).

At present, the project to recharge the Biougra aquifer has stalled, as no treated wastewater has managed to infiltrate the system. This issue is primarily due to the clogging of the infiltration basins by suspended solids (Comité Scientifique et Technique sur l'Eau Agricole, 2022). In the Gharb region of northwestern Morocco, an additional method to recharge aquifers is being applied. Treated wastewater helps combat seawater intrusion, which has resulted from overexploiting groundwater. This practice not only increases the water supply but also enhances its quality by diluting substances like nitrates (Hirich & Choukr-Allah, 2013).

Artificial recharge of aquifers holds high potential for long-term resilience in Morocco's water strategy. However, its effectiveness depends heavily on site-specific adaptation, technical rigor, and proper integration of wastewater treatment processes. The contrast between Biougra's stalled project and Gharb's success reveals both the promise and pitfalls of this reuse pathway.

Silviculture

While this option may seem limited in scope and not included as part of the ambitious target of water strategy by 2030, it still plays a crucial role in conserving freshwater. For example, in the Kenitra region, treated wastewater is used to irrigate eucalyptus trees in forest, which help stabilize dunes and support wood production. It's also widely used to irrigate pastures for livestock. (Hirich & Choukr-Allah, 2013)

In Ait Melloul, the municipality opted to irrigate 400 hectares of Argania forest with 4 Mm^3 of treated wastewater each year generated by the M'zar station. (Benlemlih et al., 2024) In the case of the Marrakech palm grove, a 10-hectare demonstration plot has been established in the El Oulja Palm Grove to capitalize on the proximity of the wastewater treatment plant (WWTP) operated by RADEEMA. Plans are underway to expand the project to cover a total area of 350 hectares. (Comité Scientifique et Technique sur l'Eau Agricole, 2022)

In conclusion, the reuse in Morocco is focused on agriculture, urban green spaces, and industrial processes. Despite challenges like limited public acceptance, regulatory gaps, and technical constraints, notable projects include the irrigation of 1,100 hectares of crops and the use of wastewater in golf courses, industrial cooling systems, and aquifer recharge. Examples like the Souss-Massa citrus irrigation and urban landscaping in Marrakech highlight the economic and environmental benefits of treated wastewater reuse. However, to achieve the target of reusing 300 million m^3 of TWW, the country must strengthen its regulatory and institutional framework and public awareness to fully harness the potential of this sustainable practice.

CONCLUSIONS

Morocco's water security is under growing threat due to geographical limitations, erratic rainfall, overexploitation, and climate change. As the country advances towards its 2030 target of reusing 300 million m³ of treated wastewater annually, TWWR stands out not only as an alternative resource but as a central pillar of national water policy. From agriculture and landscaping to industrial operations, the flexibility and sustainability of this non-conventional water source offer a promising avenue for alleviating water scarcity.

Significant progress has already been made, with supportive legislative frameworks, national programs, and pilot initiatives showing encouraging results. However, regional disparities, limited tertiary treatment infrastructure, and lagging public perception continue to hinder its full deployment. Addressing these constraints is vital to unlock the transformative potential of TWWR in building a resilient and inclusive water future for Morocco.

Yet, challenges remain. Regional disparities, inadequate infrastructure, and regulatory limitations hinder the full potential of this resource. Additionally, public perceptions and concerns about health risks have slowed adoption in certain sectors, particularly agriculture. Furthermore, an estimated 70 million m³ of untreated wastewater are still being used for irrigation annually, posing serious environmental and public health risks. Addressing these issues is not only a necessity but also an opportunity to create a resilient water management framework that benefits both the environment and the economy.

To bridge the gap between ambition and implementation, Morocco must continue to invest in advanced treatment technologies, improve governance frameworks, and increase public trust through transparent monitoring and targeted awareness campaigns. Learning from regional leaders like Tunisia, where strong regulatory enforcement and subsidy mechanisms have enabled higher reuse interest, can provide actionable pathways to elevate Morocco's performance across all reuse sectors.

Through this review, we have successfully evaluated Morocco's progress toward its national target for treated wastewater reuse (TWWR), while also examining how this ambition fits within broader strategies for water security and climate resilience. By critically synthesizing national data and sectoral examples, we have uncovered significant gaps between the technical potential of TWWR and its real-world application across agriculture, landscaping, and industry.

In doing so, we help bridge a gap in the existing literature by providing a coherent and up-to-date overview of TWWR in Morocco, an area that has long been fragmented across technical reports, legal texts, and isolated case studies.

This study offers new perspectives for researchers and establishes the basis for further exploration into the environmental, health, and institutional implications of large-scale wastewater reuse in Morocco.

Aknowledgment

The authors gratefully acknowledge the support and guidance provided by colleagues and institutions involved in the research. Special thanks to all anonymous reviewers for their valuable time, insightful comments, and constructive suggestions.

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