WATER GLOBAL PRACTICE • SUMMARY REPORT

Managing Urban Water Scarcity in Morocco

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Acknowledgement & disclaimer

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ABBREVIATIONS ET ACRONYMS

ABH	Agences de Bassins Hydrauliques – River Basin Agencies
ABHOER	Agence du Bassin Hydraulique de l'Oum Er Rbia – Oum Er Rbia Basin Agency
ABHT	Agence du Bassin Hydraulique du Tensift – Tensift Basin Agency
CC	Climate Change
ELL	Economic Level of Leakages
GCM	Global Circulation/Climate Model
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
IPCC	Intergovernmental Panel on Climate Change
IUWM	Integrated Urban Water Management
IWRM	Integrated Water Resources Management
lpcd	Liter per capita per day
MAD	Moroccan Dirham
MENA	Middle East and North Africa region
Mm^3	Million de mètres cubes
NRW	Non-Revenue-Water fraction
OCP	Office Chérifienne de Phosphate
ONEE	Office National de l'Électricité et de l'Eau
PDAIRE	Plan Directeur d'Aménagement Intégré des Ressources en Eau
PNE	Plan National de l'Eau
RADEEMA	Régie Autonome de Distribution d'Eau et de l'Électricité de Marrakech
RCP	Representative Concentration Pathway
RO	Reverse Osmosis
SNE	Stratégie Nationale de l'Eau
STEP	Station d'Épuration des eaux usées
UFW	Unaccounted for Water
WWTP	Waste Water Treatment Plant (STEP)

Acknowledgement

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Executive Summary

Important challenges such as population growth, urbanization, economic expansion and climate change are looming over urban water security in Morocco. While urban water demand is expected to rise by 60% to 100% in most large cities by 2050, climate projections suggest reduced precipitation and a sharp decline in water resources availability. Morocco is expected to enter a situation of extreme water stress in less than 25 years.

The Water Law 36-15 recognizes these risks and provides the relevant policies, institutions, regulations, mechanisms and procedures for integrated water resources management and created the necessary tools for its implementation. The Law emphasizes the need for integrated, decentralized, participative management of water, and recognizes the importance of developing planning mechanisms to address water scarcity. Institutions have been set up at all levels of government and rules are in place to involve civil society and the private sector in water management.

Even though the Water Law 36-15 bestows priority on potable water supply over other usages, particularly irrigation, Urban Water Security cannot be addressed in isolation and need to be considered within the context of broader water resources management issues in the river basin in which the urban area is located. With growing water stress and major water shortages likely to hit the agriculture sector in the future, competition for water will become fierce between users. Integrated Urban Water Management needs to go hand in hand with Integrated River Basin and Water Management, and urban water managers must contribute their fair share of saving and reusing urban water for the benefit of other water dependent sectors.

Marrakesh and by extension other cities and municipalities in Morocco hold a diverse menu of options to tackle urban water security challenges. Many non-conventional solutions in tandem with demand management measures are shown to be promising and cost-effective, with fewer social and environmental impacts than large scale infrastructure projects relying on dams and inter-basin transfers.

Further improvements in the institutional and regulatory frameworks could be considered to accelerate the adoption of solutions such as wastewater reuse, rainwater harvesting and leakages reduction, which are identified in the *Stratégie Nationale de l'Eau* (2009) as critical to bridge the future water supply-demand gap. Strengthening groundwater governance will also be fundamental to better regulate competitive water uses between municipal and non-municipal actors, and to leverage aquifers' potential to act as buffers against climate variability.

For the city of Marrakesh, this study points towards a portfolio of solutions that aims to build the city's resilience to climate shocks and diversify water sources to hedge against risks on any of them. This portfolio differs from the one envisaged in the *Plan National de l' Eau* (2015), which relies primarily on the inter-basin transfer from the North. The technical, financial and institutional feasibility of promising scenarios need to be assessed in greater detail than possible under this study. But at this pivotal moment in the engagement of large scale infrastructure projects in Morocco, a full review of options integrating the micro (city), meso (basin) and macro (inter-basin) scales could help define an optimal pathway forward and yield substantial benefits.

1. Introduction

In 2015, 60% of Morocco's population was residing in urban areas, a figure projected to reach 74% by 2050. With rapid urbanization, population growth and commensurate economic developments, the competition for water resources across all water dependent sectors of Morocco is steadily rising and many traditional groundwater sources are showing signs of depletion. At the same time water sources are increasingly exposed to contamination through changes in land use patterns, poor solid waste and stormwater management, inadequate wastewater treatment, aging infrastructure, and unbridled formal and informal urban expansion. Climate change is adding more uncertainty and vulnerability to these challenges. These challenges are putting the country on a path towards a major water crisis. Unless they manage to balance rising demands with limited and often variable supplies, Morocco's cities are thus facing a water-insecure future.

While water allocations priority de facto given to drinking water supply, focusing exclusively on urban water service delivery may put cities on a dangerous path. Urban areas are rapidly developing to the detriment of the agriculture sector and in some cases already uses some of irrigation water allocations to satisfy urban water demand. This may appear manageable on the long term as volumes required to cover urban water demand are relatively marginal compared to those supplied for irrigation. But with growing water stress and social and economic consequences in the rural sector, competition between water users is likely intensify and tapping on agriculture water allocations to cover urban water deficit may not be considered as a sustainable solution.

Urban water management must therefore embrace broader water resources management issues. Securing and sustaining water resources for the expanding cities under increasing hydrological uncertainty and variability can be achieved through the mobilization of new water resources, improving system efficiency and water conservation efforts, along with expanding traditional water supply solutions. Tackling urban water scarcity then requires overcoming significant challenges at many levels, *inter alia* at political, institutional, financial, social and technical levels.

The Government of Morocco is already addressing the growing gap between water supply and demand in its urban areas and for irrigated agriculture, amongst others through implementing large water infrastructure projects, inter-basin water transfer projects and desalination plants for its coastal cities. Moreover, through various nation-wide programs the country is working on improving access to water supply, domestic and industrial wastewater collection and treatment and integrated water resources management, implemented by nine river basin agencies.

The overarching objective of this report is thus to provide guiding principles for managing the urban water cycle in Morocco in a holistic sustainable manner, while duly recognizing the broader water resources issues. The document first reminds the key concepts and principles of Integrated Urban Water Management (IUWM) in the context of urban water scarcity (Section 1). It then discusses their relevance in the case of Morocco (Section 2) through a review of the current water-related challenges in the large urban areas, and analyses how the country can best reap the benefits of this approach (Section 3). Finally, a deep dive review focusing on the city of Marrakesh is proposed to illustrate its relevance and identify concrete options to build the city's resilience to water scarcity in the most cost-effective manner.

2. What is Integrated Urban Water Management in the context of water scarcity

With many sectors relying on the limited water resources in a river basin, the competitive dynamics at play require a paradigm shift to an integrated approach to urban water management. In response to these challenges, *Integrated Urban Water Management (IUWM)* aims to improve the way resources are managed across the urban water cycle, while taking into account all water users in the wider catchment area. The World Bank (2012[1]) defines IUWM as "a flexible, participatory and iterative process, which integrates the elements of the urban water cycle (water supply, sanitation, stormwater management and solid waste management) with both the city's urban development and river basin management to maximize economic, social and environmental benefits in an equitable manner". IUWM offers a holistic approach to strategic planning by managing competing water users at the level of the watershed, recognizing the needs of the city as well as those of upstream and downstream water users. It encourages nutrient, water and energy recovery from waste, including from wastewater, for reuse within or close to the city.

Integrated Urban Water Management aim to optimize the management of urban and water-related resources, as described in Box 1. Its overarching principle is the sustainable management of water resources in the context of IWRM at river basin level, as is well recognized in Morocco's new Water Law 36-15 (Box 1). IWRM is a cross-sectoral approach designed to promote the coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner, without compromising the sustainability of vital ecosystems and the environment.

- IUWM recognizes the value of alternative water sources
- IUWM differentiates the qualities and potential uses of water sources ("fit-for-purpose" water sources)
- IUWM views water storage, distribution, treatment, recycling and disposal as one management cycle
- IUWM seeks to protect, conserve, and use surface water and groundwater at its source
- IUWM accounts for non-urban users who are dependent on the same water source within the wider basin
- IUWM aligns formal institutions (organizations, legislation and policies) and informal practices (norms and conventions) that govern water in and for cities
- IUWM recognizes the relationships among water resources, land use and energy
- IUWM simultaneously pursues economic efficiency, social equity and environmental sustainability
- IUWM encourages participation by all stakeholders

Source: Bahri, 2012: Integrated Urban Water Management. Stockholm: Global Water Partnership

Box 1: Key Principles of Integrated Urban Water Management (IUWM)

In a context of urban water scarcity[2] a typical IUWM portfolio of measures aimed at improving the resilience of urban water systems and achieving urban water security includes *inter alia*: i) *increasing the supplies from conventional resources* such as surface water reservoirs, aquifers and inter-basin transfers, ii) *diversification by increasing the supplies from non-conventional resources* such as rainwater harvesting, reuse of treated wastewater, storm water runoff and seawater desalination, iii) *conservation by reducing urban water needs* through demand management and loss reduction, and iv) *increasing water allocations* through cooperating with other water users. Generally, interventions that are based on an

[1] World Bank, 2012: Integrated Urban Water Management Case Study: Buenos Aires. Washington, DC

[2] In a broader context, IUWM would typically capture other dimensions of the urban water cycle (i.e. onsite sanitation, flood and solid waste management) and their interconnections,

IUWM approach are found to work best in an institutional setting that is (World Bank, 2016[3]): i) administratively vertically integrated; ii) sectorally horizontally integrated; iii) backed by sustained analytical work, data and information; and iv) underpinned by strong governance and clear institutional mandates and capacity in the water sector.

Economic, social and environmental changes, identified by Daniell[4] et al (2015) as potential drivers for the transition to IUWM, are largely prevalent in Morocco. They include: i) strong urban population growth, increasing urbanization and a growing demand for water supply and sanitation & wastewater treatment services under increasing climate uncertainty; ii) increasing resource scarcity; iii) technological innovation; iv) new water governance approaches and systems; v) changing water cultures and higher demands for environmentally friendly approaches; and vi) ecosystem degradation and the growing awareness of the need to protect river ecosystems in urban environments.

3. Why is Integrated Urban Water Management relevant for Morocco?

Population growth, rapid urbanization, changes in the household structure and increasing economic prosperity lead to increasing urban water demands. According to World Bank[5] and UNDESA[6] statistics urban population of Morocco stood in 2015 at 20.7 million and is projected to increase till 32.3 million (+56% growth) by 2050, as illustrated in Figure 1. Rural population has become stagnant and is even projected to slightly decline in the upcoming decades. Two-third of the urban population lives in the country's 20 largest cities identified in Figure 2. The largest demographic growth is expected for Tanger, El Jadida and Berrechid, with more than a doubling of population between 2014 and 2050.

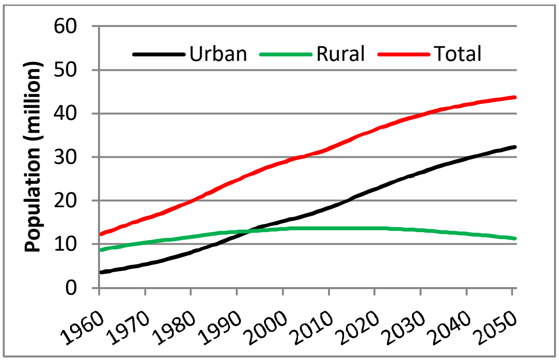


Figure 1 - Demographic projections

[3] World Bank, 2016: https://openknowledge.worldbank.org/handle/10986/24430
[4] Daniell, Katherine, Jean-Daniel Rinaudo, Noel, Chan, Celine Nauges and R. Quentin Grafton, 2015: Understanding and Managing Urban Water in Transition
[5] http://data.worldbank.org/country/morocco
[6] UNDESA, 2015 : The 2015 Revision of World Population Prospects, Key findings and Advance Tables https://esa.un.org/unpd/wpp/Publications/Files/Key_Findings_WPP_2015.pdf

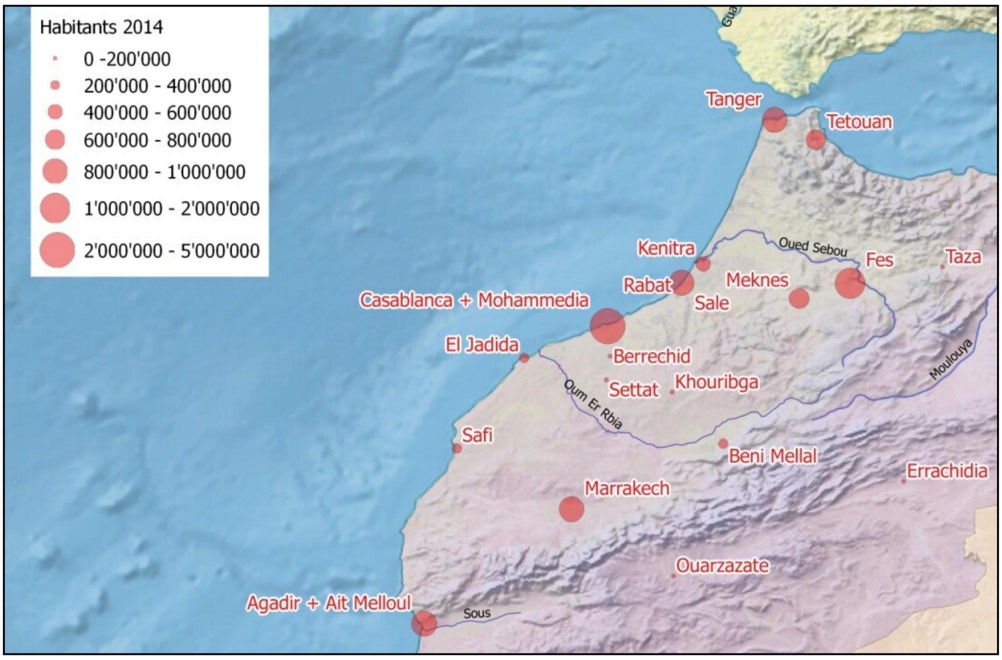


Figure 2 - Major urban population centers

Urban water demands may further increase due to rapid socio-economic changes. In Marrakech of example, the average number of persons per household was 4.3 in 2014, down from 5.4 in 1994. The rapid decrease in households size may put an upward pressure on urban water demands, similar to the overall increase in purchasing power and changes in lifestyle of the modern urban population. Demand projections show a rapid growth in urban water demands: the Plan National de l'Eau (PNE, 2015) assessed Morocco's demands for domestic and industrial water supply at 1,437 Mm^3/year in 2010 and 2,368 Mm^3/year by 2030, which represents a 65% growth. Certain cities, such as Tanger and Tetouan could even experience a doubling of their urban water demand, as illustrated on

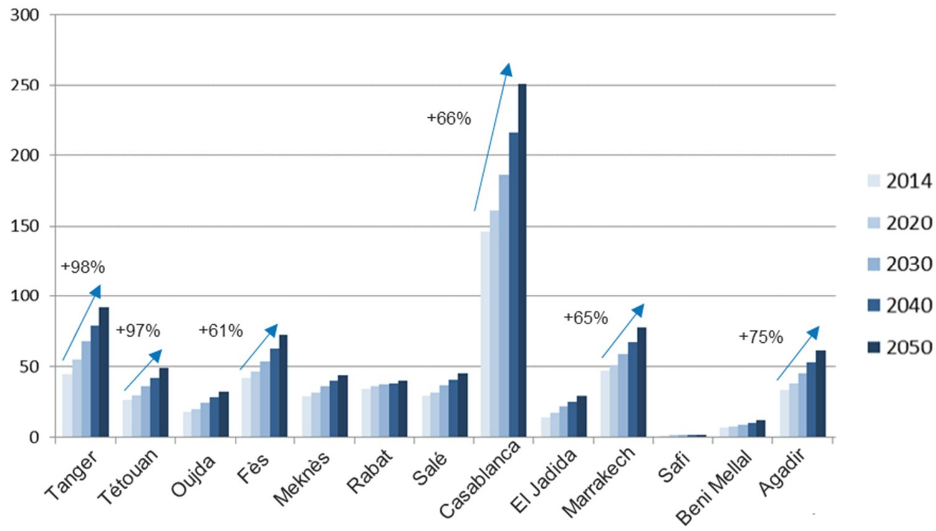


Figure 3.

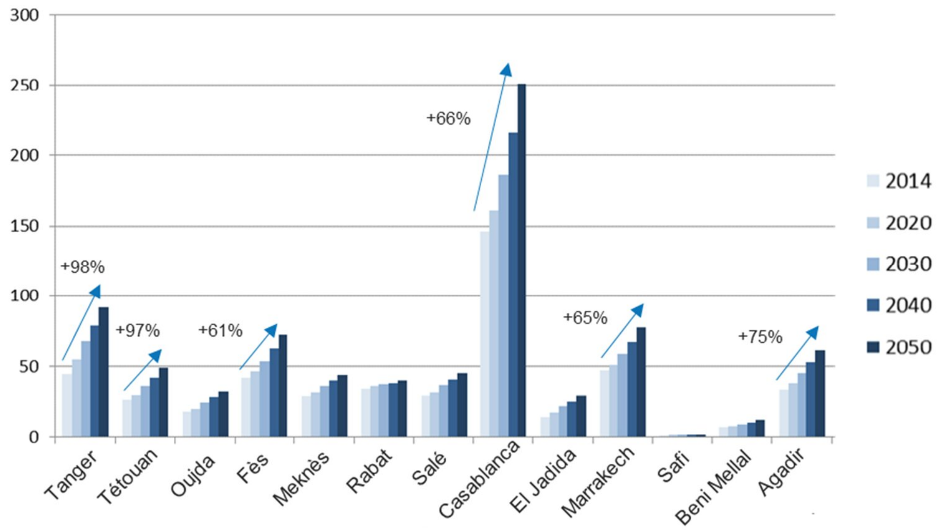


Figure 3 - Water demand projections 2014-2050 (liters per capita per day) – source: ONEE

Morocco is likely to face extreme water scarcity by 2050. Eighty percent of Morocco's territory is arid to semi-arid. Due to a combination of strong population growth in the 20th century, economic development, a strong decline since 1980 in precipitation (-15% to -20%) and a commensurate decline in river runoff (-30% to -40%), water resources availability is already under severe pressure. Water availability in Morocco has dropped from 3,500 m^3 per person per year in 1960 to 730 m^3 per person in 2005 and 645 m^3 per person in 2015, well below the "water poverty level" of 1,000 m^3 per person per year[7]. Even without further change in water resources availability, a projected population of nearly 44 million inhabitants by 2050 would yield a ratio of 510 m^3 per person per year by 2050, which is near the "extreme water scarcity" level of 500 m^3 per capita.

Considering the severe and negative impacts of future climate change, the country could be pushed over the next decades well below the "extreme water scarcity" level. Since an abrupt change in rainfall occurred around 1980, annual availability of surface water has already been substantially less, for example -30% to -40% in the Oum Er Rbia River basin, aggravated by an increased inter-annual variability of river runoff. Most projections of global circulation models (GCM) project *a drier and hotter future* for the region, as shown on Figure 4. GCMs project on average a further reduction of 20% in rainfall, albeit varying from no changes to about -40%. In turn, this would yield severe reductions in surface water availability (possibly up to at least -50%) and recharge of groundwater, in magnitude similar to the reductions in runoff and recharge that have already occurred since 1980. Thus,

[7] https://www.globalwaterjobs.com/News/countryinfocusmorocco.html

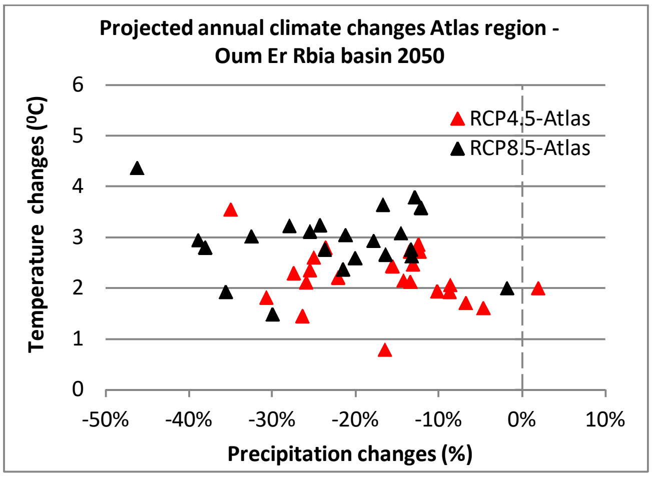


Figure 4 - Projected climate changes Oum Er Rbia basin (2050)

The steady decline in available water resources is aggravated by a degradation of water quality due to inadequate wastewater treatment, diffuse agricultural pollution, and the loss of regulated volumes of reservoirs due to sedimentation. Meanwhile, groundwater is abstracted well beyond the level of sustainable abstraction. In this perspective, the World Resources Institute (Luo[8] et al, 2015) classified Morocco as a country with high water stress in 2010 and extremely high water stress in 2040, in a future water supply and demand scenario analysis based on a combination of Representative Concentration Pathways (RCP) and shared socio-economic pathways from IPCC's 5th Assessment Report. In this context of scarcity, the gap between supply and demand will increase each year.

Urban water demand will face increasing competition with the irrigation sector. Despite its limited water potential, Morocco has made agriculture a key sector of its economic and social development, and agricultural water demands will remain high in the foreseeable future. Faced with a large rural population, whose main source of employment and income is agriculture, and with a view to ensuring a minimum level of food security for the country, the Government has focused its efforts on further developing irrigated agriculture, albeit increasingly through the application of drip irrigation. Presently, more than one million hectares has been developed for irrigated agriculture, using more than 80% of the country's scarce water resources. While the introduction of drip irrigation aims at saving water, it is often accompanied by agricultural intensification, yielding more output for the same input of irrigation water rather than yielding substantial water savings. Whereas the Water Law 36-15 allots the highest priority to domestic and industrial water supply, increasing demands for urban water supply and decreasing availability of water resources will lead to growing water shortages for irrigated agriculture. Most critical will be farmers' ability to respond to increasing water shortages, and these impacts of shortages on agricultural yields and rural economies. According to field surveys conducted in the Tensift basin (comprising the city of Marrakesh), the valuation of irrigation water varied in terms of agricultural production between 0.5 MAD per m^3 for Alfalfa to 17 MAD per m^3 for peaches and plums – to be compared to a current urban water tariff of 4.5 MAD per m^3 in Marrakesh. Further important impacts will be a decrease in land rent, a decrease in rural employment and multiplier impacts on other sectors of the rural economy. Even if impacts on water availability are curtained to the rural sector, inaction may therefore entail significant economic cost for the region and enhance urban-rural inequalities.

[8] Luo, T., R. Young, P. Reig, 2015: Aqueduct Projected Water Stress Country Rankings, Washington, D.C.: World Resources Institute; http://www.wri.org/publication/aqueduct-projected-water-stress-country-rankings

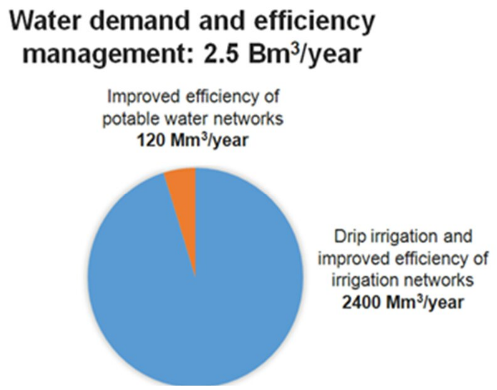
In this context of increased water stress and competition with other sectors, cities' water sector resilience will rely on (i) the ring fencing of part of their water resources portfolio from competing water demands, (ii) promoting water conservation practices, and an overall reduction of urban water demand. An Integrated Urban Water Management approach is well positioned to help Morocco achieve these two objectives.

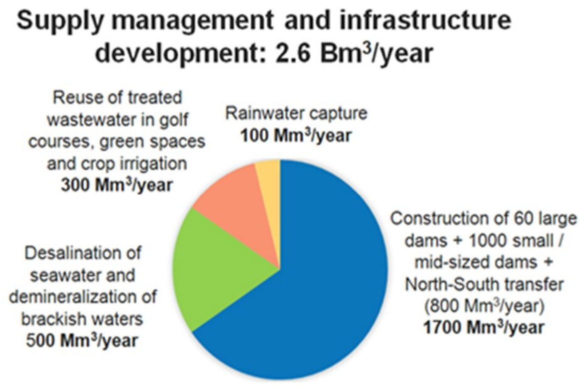
4. How can Morocco best reap the benefits of integrated urban water management?

4.1. A solid legal and institutional framework for IWRM at national level to build on

Morocco is committed to an Integrated Water Resources Management approach under its National Water Strategy (SNE[9]), National Water Plan (PNE) and new Water Law 36-15 (2016). The SNE (2009) addresses water demand management and valorization of water, the development and management of water supply, risk reduction and adaptation to climate change, and the protection of water resources and ecosystems, along with institutional reforms, capacity building and information systems. It argues that a business as usual approach would create at the national level a gap of 5 Bm^3/year by 2030. To close the ever-increasing gap between supplies and demands, the SNE proposes multiple measures described in Figure 5, in order to increase supplies with 2.5 Bm^3/year and reduce demands in parallel with 2.5 Bm^3/year. These include both conventional infrastructure measures such as reservoirs and inter-basin transfers aimed at increasing supplies and non-conventional measures aimed at reuse of treated wastewater, desalination, demand and system efficiency management, and rainwater harvesting.

Urban water utilities must make substantive contributions to closing the gap between water demands and supplies. This includes a range of measures such as demand management, improving the efficiency of water distribution networks and the creation of "new water" (NouvEau). These and other more conventional solutions and opportunities are discussed further in this Chapter. An IUWM approach can contribute to the equitable sharing of available water resources between various users and sectors help deliver a significant contribution from the potable water sector towards reducing the burden of droughts on other sectors (particularly the agricultural sector), as prescribed in the SNE (2009).





[9] SNE = Stratégie National de l'Eau (2009); PNE = Plan National de l'Eau (2015)

Figure 5 - Water demand, efficiency and supply management measures proposed in the SNE (2009)

The Water Law 36-15 provides the relevant policies, institutions, regulations, mechanisms, and procedures for integrated water resources management and created the necessary tools for its implementation and effectively addressing the risks of urban water scarcity. The Law emphasizes the need for integrated, decentralized, participative management of water, and recognizes the importance of developing planning mechanisms to address water scarcity. Institutions have been set up at all levels of government and rules are in place to involve civil society and the private sector in water management.

Several improvements could be considered in the design and application of the legal and institutional framework to could to improve the efficiency and resilience of the water sector. In view of the inevitable water crisis descending upon the country, it would be highly recommended to increase the planning horizon used for water resources management till 2050 instead of the presently adopted 2030 horizon, and to incorporate climate change scenarios in those analyses. Also, a stricter compliance with water allocations will improve their predictability among all users, set clear consequences for profligacy and foster improvements in sector efficiency among all users. This would be facilitated by the establishment and enforcement of *Contracts for the Aquifer*, setting clear rules and monitoring mechanisms for groundwater abstraction at basin level. Finally, in the context of Morocco's regionalization process, which aims at decentralizing responsibilities for social and economic development, it will be critical to involve more formally the Regions in decisions on water allocations and management.

4.2. Some potential water savings through water conservation and demand management

Much of the drinking water infrastructure in Morocco has been in service for decades and can be a significant source of water leakages. Physical non-revenue water in urban networks vary between 17% in Salé and 45% in Fez, on average 27% across Morocco. This compares to 20% to 60% in the MENA region as shown on Figure 6. The Economic Level of Leakages (ELL) is the one below which the marginal cost of reducing leakages outweigh associated economic benefits. This value is highly context dependent. However, based on levels achieved in many countries (16% in the USA in 2008, 14% in Windhoek and one-digit losses in many western European, US and Australian cities and in Singapore), water utilities in Morocco are likely to have significant room for improvement. The PNE (2015) targets a non-revenue water level of 20% till 2030 nation-wide.

However, a key issue to be addressed is that in Morocco water utilities do not bear the costs of water production and bulk conveyance, and therefore may have a distorted perception of the ELL. If maintaining equity of bulk water tariffs across the country remains a national priority, the setting of customized NRW performance targets considering the full cost of water may be a preferred approach to foster further efficiency gains. A utilities level, a pro-active "predict and prevent" strategy should include *inter* alia an enhanced leakage detection program, a rapid response unit for attending to leakages, variable pressure management to control excessive leakage losses, and the rehabilitation and replacement of water mains.

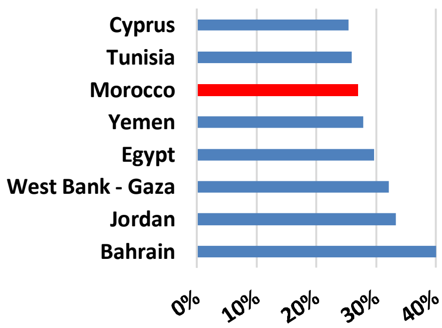


Figure 6 - Average physical losses in urban areas of the MENA region (IBNet, Author)

There is only a limited scope for residential water demand management due to prevailing relatively low domestic consumption rates, which varied in 2014 between only 80 and 120 liters per capita per day. These consumption levels are consistent with those of water scarce cities in other middle-income countries, including Egypt, Jordan, Tunisia, Turkey, India (Northwest) and Brazil (Nordeste region). There is a larger scope for savings on non-residential water use, such as for hotels, green spaces in cities and golf courses, but this only concerns a limited share (about 20%) of total water consumption. An ongoing national program aims to promoting water conservation in the tourism and industry sectors.

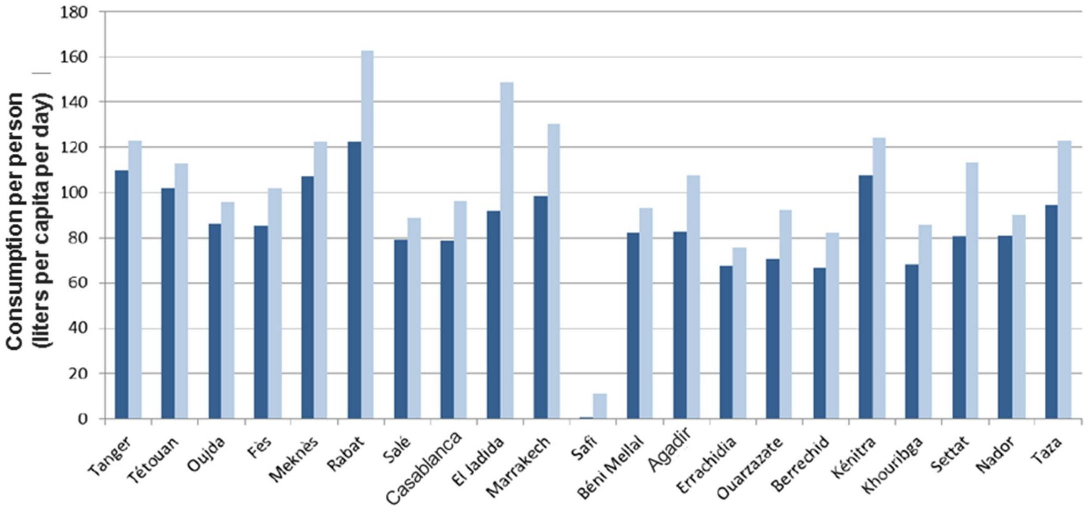


Figure 7 - Domestic (dark blue) and total (light blue) water consumption in Morocco in 2014 (in lpcd)

4.3. Options for increased supplies through non-conventional solutions

Treated waste water provides an important potential source of water, for closing the gap between water demands and supplies. In Morocco, the present reuse capacity of 38 Mm^3/year is limited to a few cities, particularly Marrakech (7 Mm^3/year) and Salé, and the phosphate industry. The SNE (2009) and the National Reuse Plan (PNREU, 2015[10]) aim at increasing the reuse of treated wastewater by 2030 to 325 Mm^3/year, for a total investment of about 8 billion MAD. The PNREU has identified 28 reuse projects for priority development, including the rehabilitation and upgrading of existing WWTPs to include reuse. Most of the planned reuse infrastructure would serve agricultural needs (45%) and the irrigation of green spaces and golf courses (43%), with a small portion designated for aquifer recharge (6%).

While wastewater reuse is recognized in the new Water Law 36-15 as a viable resource and necessity to meet the country's water requirements, efforts towards the creation of supporting policies and regulations would be critical to scale it up. The slow progress with the reuse of treated wastewater can be attributed to several key challenges. This includes the difficulty to develop reuse for agriculture (its main market), in areas where groundwater use, most likely a cheaper option, is not tightly regulated. Also, the set-up of reuse arrangements represents a very complex and lengthy administrative process and adequate institutional and regulatory arrangements would be required to streamline procedures. This is sometimes compounded by the absence of clear cost-sharing between utilities (producers) and users (farmers). Above all, the low level of secondary treatment appears as the main challenge to expand reuse. Since launching the National Wastewater Treatment Plan (NSP) in 2006, the percentage of wastewater treated has risen from just 7% in 2005 to 41% in 2015, but just 20% at secondary level. Presently only 12%

[10] Plan National de Réutilisation des Eaux Usées, PNREU; December 2015

of Morocco's current tertiary treatment capacity is being leveraged for reuse. Based on a net domestic waste water restitution rate of 80 liters per capita per day, urban wastewater would increase from about 600 Mm^3/year in 2015 to about 750 Mm^3/year in 2030 (covering 5% of the country's water demand under drought condition) and 900 Mm^3/year by 2050.

Decreasing technological costs, its drought-proof nature and the production of superior water quality are among the reasons why desalination is becoming rapidly a water treatment technology of choice in the MENA region. Water utilities around the world have effectively adopted seawater desalination as a promising alternative to dwindling water supplies. In 2016 the total world-wide desalination capacity of seawater and brackish water stood at about 22 billion m^3/year. Morocco has also embraced desalination as a promising option, and intends to produce by 2030 more than 500 Mm^3 potable water per year. The country started to build small-scale desalination plants in 1995 and had completed 15 (mostly relatively small) installations by 2016, reaching a desalination capacity of 132 Mm^3/year. Larger scale projects are now being planned, such as in Casablanca and Agadir. While desalination is still relatively expensive and energy-intensive, declining solar and wind energy cost move the gate posts in its favor. The MENA desalination market is mature and yielded some of the lowest cost projects in the world, typically between 0.6 and 1 US$/$m^3$ from larger to smaller installations. As emerging technologies evolve into reliable full-scale desalination systems over the next 10 to 15 years, desalination is expected to experience a quantum leap into sustainability and affordability. The Water Law 36-15 recognizes desalination as a viable resource and provides for concessions as an option for private sector involvement. However, clear mechanisms for cost-sharing at regional or national scale and inter-sectoral coordination (water-energy) are yet to be established. The successful development of desalination projects will rely on large private investments and needs efficiently procured PPP schemes, which the water sector in Morocco has not yet been able to achieve.

Stormwater collection and rainwater harvesting provide an independent water supply during regional water restrictions and is often used to supplement the main supply. Rainwater harvesting and stormwater capture are ancient traditions in Morocco. The SNE (2009) envisions to revive these ancient practices with pilot projects to capture 5 to 15 Mm^3/year in river basins with severe water shortages, such as the Oum Er Rbia, the Tensift and the Souss basins. Rainwater harvesting improves households' resilience to short term droughts, and can also benefit the city by reducing the stormwater volumes in sewer system. To promote a large-scale development of these approaches in Morocco, the identification of their institutional home would be critical, as they currently lie at the intersection of the functions of local governments, basin agencies in charge of water resources management and water service providers. This undermines responsibility and ownership over these practices. It would therefore be beneficial to clarify define institutional responsibilities for their management, monitoring and use, and to set up a regulatory framework incentivizing their large-scale implementation. With still fragmented experience in this area, Morocco will need to capitalize on existing pilots, actively operationalize and disseminate this know-how – an effort currently supported by GIZ (German development agency).

The artificial recharge of groundwater provides an alternative option for building large reservoirs for storage of surface water. Unlike the building of a large reservoir capacity over the last fifty years, there has been no significant increase in the controlled use of aquifers for groundwater storage. Groundwater is a valuable strategic resource for development, particularly in arid or semi-arid regions, but the overexploitation of groundwater at the national level averages close to one billion m^3 per year. It is therefore imperative to implement management strategies that include natural and artificial recharge for the preservation of groundwater. Artificial recharge is necessary for restoring overexploited aquifers and is potentially a viable alternative to storage in reservoirs (reasonable cost, no loss through evaporation, possibility of using treated wastewater and no eutrophication problems). The SNE has planned multiple actions for the conservation and replenishment of aquifers, including an artificial groundwater recharge program (storage of 180 Mm^3/year) and reinjection of wastewater after treatment for coastal water tables used for irrigation (100 Mm^3/year by 2030).

4.4. Conventional infrastructure: increasing water supply through reservoirs and water transfer

Dams are built to meet human needs, but history shows that their many benefits combine often with numerous environmental and social costs. In the past, the "policy of large dams" has enabled the water sector to support the development of large irrigation schemes. This policy increased the number of large dams from 16 in the early 1960s to 139 at present, reaching a total reservoir capacity of about 18.5 Bm^3 in 2014. Even though most of the water resources of the country have already been developed, the SNE (2009) still plans to invest 21 billion MAD more over the period 2015 – 2030 in new small to mid-sized dams and reservoirs, in order to mobilize an additional 1.7 Bm^3, equivalent to 10% of the existing storage capacity.

Another promising conventional infrastructure option is the transfer of surplus surface water from the North-West to the Centre of the country, where deficits are normal. Due to the uneven spatial distribution of precipitation, as shown on Figure 8, there is a surplus of surface water of about 850 Mm^3/year in the Loukkos and Sebou basins and some small basins in the North-western part of the country. On the other hand, large scale urban and irrigated agricultural developments exceeding their renewable water resources in the central Oum-Er-Rbia, Souss-Massa-Draa, Tensift and Moulouya river basins lead to structural water shortages up to of 1,750 Mm^3 per year. In fact, at national level 50% of the available water originates from the Sebou and Loukkos basins, while the other basins represent 92% of the country's water demands. To take advantage of this water imbalance the PNE (2015) has planned an inter-basin water transfer from the Loukkos and Sebou basins in the North to the central basins of Morocco, through a canal system reaching as far south as Al Massira dam in the Oum-Er-Rbia basin, along with new irrigation development along its route. Further details on this plan are provided in Section 4.4. The project would allow the pooling of reservoir storage capacities in the Laou, Loukkos, Sebou and Oum Er Rbia basins, in particular in the Al Massira reservoir with an important surplus storage capacity, for the purpose of mobilizing additional water resources currently lost at sea. The investment costs for the project are estimated at 31 billion MAD and the unit cost of water reaching the Al Massira reservoir is estimated at 7.4 MAD/m^3.

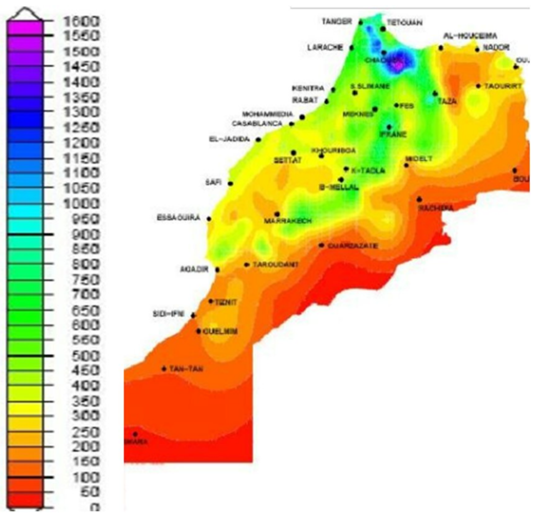


Figure 8 - Spatial precipitation variability (source : ONEE-IEA, 2014)

5. How is this relevant for the city of Marrakesh?

5.1. A structural water deficit bound to increase

The urban area of the Greated Marrakesh is home to more than a million inhabitants. It is located on the Tensift River in the centre of the basin. Since 2002 water resources of the Tensift basin are managed by the Tensift River Basin Agency (ABHT). Within the Greater Marrakesh area, the autonomous water and electricity utility RADEEMA (Régie Autonome de Distribution d'Eau et de l'Électricité de Marrakesh) services about one million inhabitants in its five districts (Marrakesh-Médina, Menara, Gueliz, Sidi Youssef Ben Ali and Annakhil), the municipality Mechouar-Kasba, part of the rural communes of Al Ouidane, Ouahat Sidi Brahim, Saâda and Tassoultante and also part of the commune of Tamesloht, where some important tourist projects are implemented. Bulk water is provided by the Office National de l'Électricité et de l'Eau (ONEE). The economy of the region is based on agriculture and livestock, tourism and crafts, industry and mining. Marrakesh city is particularly dependent on the tourism and industry sectors, which are characterized by high water use. The city and its numerous golf courses attract annually some two million visitors.

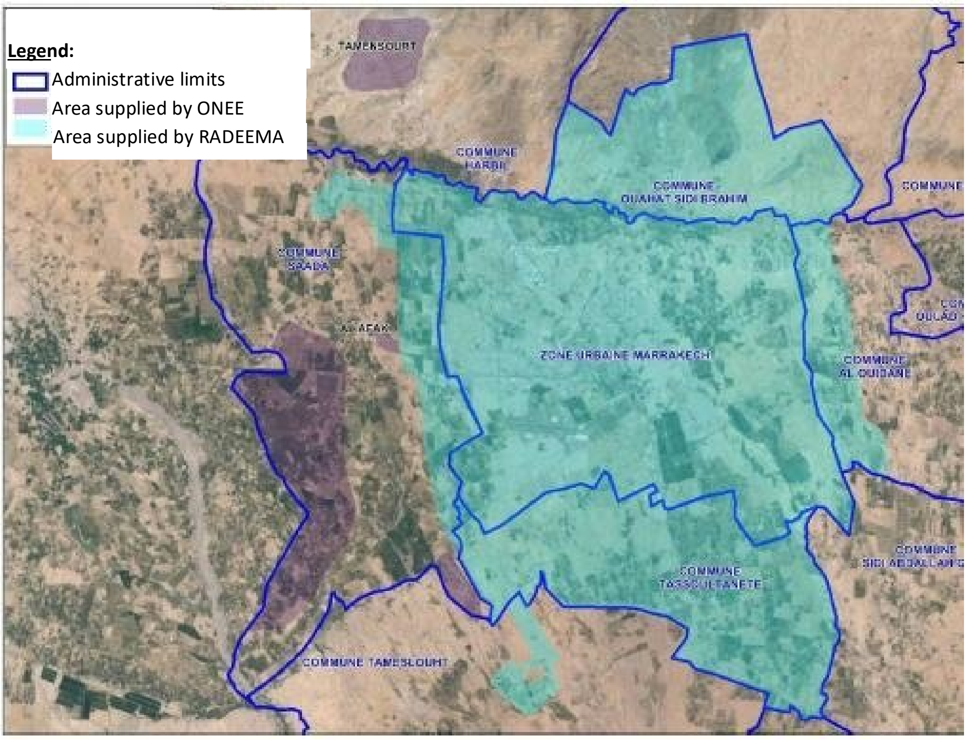


Figure 11: Urban area of the Greater Marrakesh region serviced by RADEEMA

Currently Marrakesh water demand slightly exceeds allocations. Water demand in the RADEEMA service area represents 66 Mm^3 per year (2015) for potable water and an additional 6 Mm^3 per year to cover the irrigation of golf courses and public green spaces. This is to be compared to a water demand for irrigation of about 1,650 Mm^3 per year (2010). Presently, most of this demand is provided through the Canal de Rocade from the Hassan 1er reservoir in the Oum Er Rbia basin and the Lalla Takerkoust complex South of Marrakesh, as illustrated on Figure 9. The city has been allocated 57 Mm^3 per year from these water sources by ABHT. The already over-exploited Haouz aquifer provides a minor contribution, and most of the needs for irrigation of golf courses and public green spaces are covered through water reuse. To cover 9 Mm^3 supply gap, Marrakesh uses freshwater allocations from the irrigation sector.

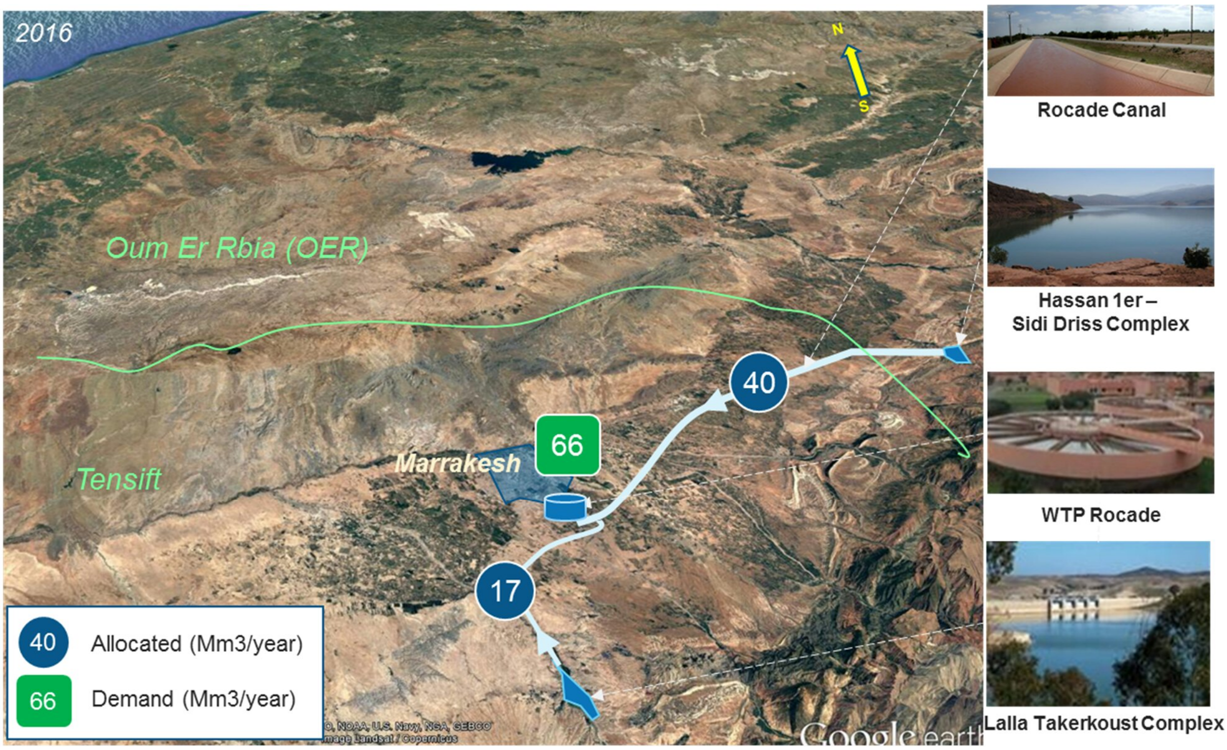


Figure 9 – Greater Marrakesh bulk water supply scheme – current situation

Upcoming transfer infrastructure will help address the water balance gap temporarily at Greater Marrakesh level. Under a medium growth scenario, the population serviced by RADEEMA is projected to increase to 1.4 million by 2050 and water demand to reach 93 Mm^3 per year. In parallel, the silting of the Lalla Takerkoust complex will inexorably cause a reduction of allocations from this source, threatening to widen the current water deficit. To reduce abstractions from the Canal de Rocade to the 57 Mm^3/year allocation and prevent further use from irrigated agriculture allocation, ONEE is constructing a pipeline from the Al Massira reservoir to Marrakesh, to become operational in 2018 with a capacity of 95 Mm^3/year. An interconnection between the Al Massira pipeline and the Canal de Rocade, as illustrated on is required to avoid water shortages in Southern parts of Marrakesh. Additional investments will be required to respond to growth of the region's potable water demand beyond 2025, lest more of the already dwindling water allocations for irrigated agriculture would need to be diverted to urban water supply. The pipeline from Al Massira to Marrakesh could be doubled in 2030.

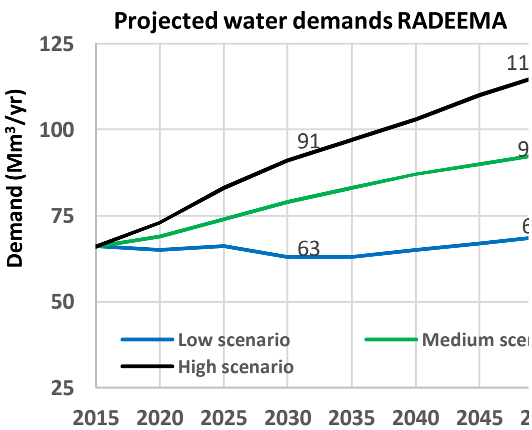


Figure 10 - Projected potable water supply system

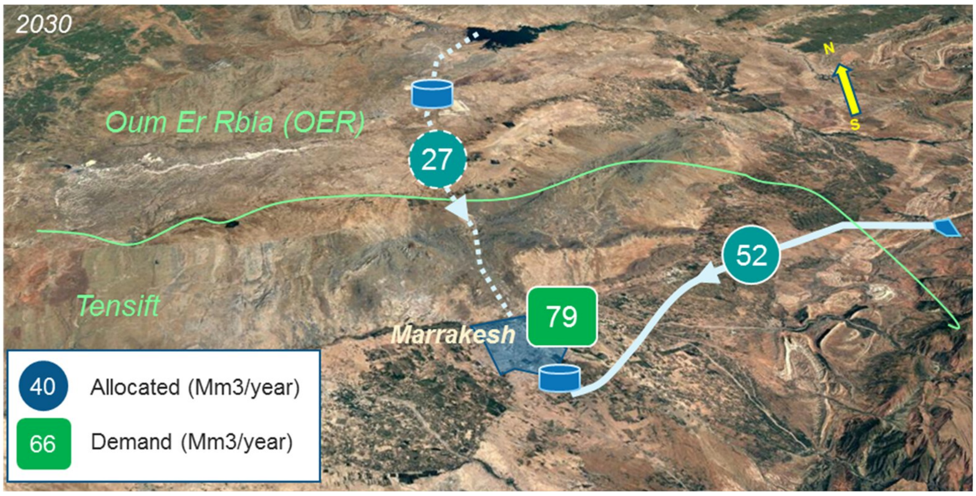


Figure 11 – Greater Marrakesh bulk water supply scheme - 2030

While water deficit is marginal at the level of the city of Marrakesh level, at basin level, the water balance gap is already chronic. Water resources in are characterized by a high inter-annual variability and a significant reduction in water resources availability around 1980, respectively 40% and 15%, as shown on Figure 12. Water demands for irrigation constitute about 92% of all demands in the Tensift basin, while total demands for the basin exceed availability in an average year already by 300 Mm^3/year, aggravating to 900 Mm^3/year under one-in-five years' drought conditions. At the level of the Canal de Rocade, surface water deficits amount to 170 Mm^3/year in an average year and 280 Mm^3/year under the above drought conditions. Given the priority given to potable water supply over other uses, irrigated agriculture responds to these shortages through unsustainable over-exploitation of groundwater from the Haouz aquifer, notably 176 Mm^3/year over the period 2001 – 2013 (GIZ, 2016[11]). In the Oum Er Rbia basin, water deficits already exceed 1,000 Mm^3 per year (2010), and the upcoming Al Massira bulk water transfer will come at the expense of irrigated agriculture in the Oum Er Rbia basin.

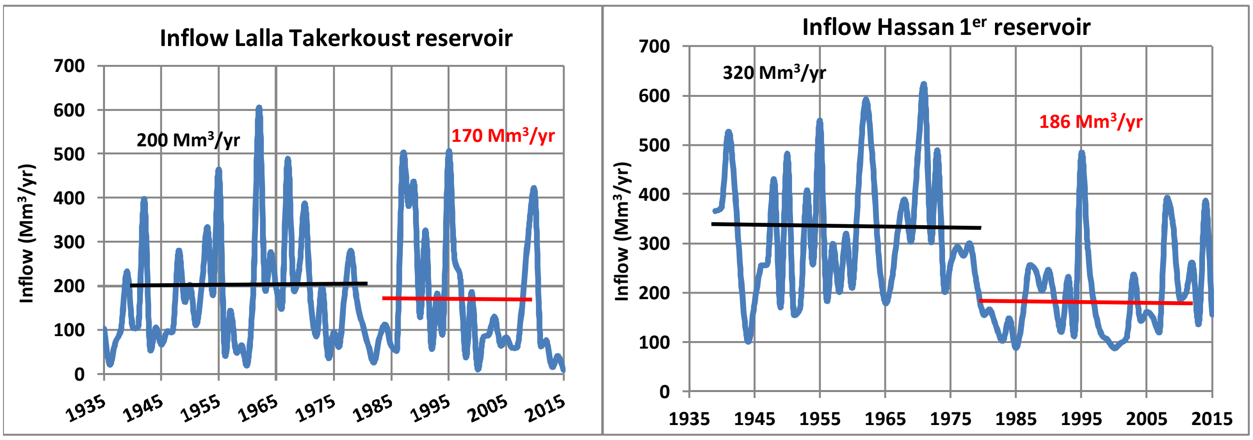


Figure 12 - Evolution of inflow of the Lalla Takerkoust and Hassan 1er reservoirs

[11] GIZ, 2016 : Élaboration de la convention GIRE du Bassin de Haouz-Mejjate, Diagnostic du bassin global.

These deficits are expected to surge due to climate change. Most global climate models project a drier and warmer future for the Maghreb region, on average projecting 20% reduction in rainfall, albeit with a large variance. This yields in turn severe reductions and increased variability in surface water availability (possibly up to at least -50% or even more) and in recharge of groundwater, potentially surpassing the reductions in runoff and recharge that have already occurred since 1980. Table 1 below combines projected climate changes with existing climate variability to project plausible scenarios of severely reduced water availability by 2050, which have been translated in Table 2 describing potential *additional* future (2050) water shortages in the Marrakesh region.

			Reduction in basin runoff by CC		
			Low	*Average*	*High*
			0%	*25%*	*50%*
Reduction in basin runoff due to variability	*Average year*	*0%*	0%	25%	50%
	Dry year (20% decile)	*40% - 60%*	50%	62.5%	75%
	Very dry year (10% decile)	*60% - 80%*	70%	77.5%	85%

Table 1 - Scenarios for reduced water availability by 2050 – combined effects on climate change and variability

The combined effects of climate change and climate variability could by 2050 translate to an additional water deficit of 400 Mm³/year in an average year and up to 1,000 Mm³/year in a dry year (20% decile) or even more than 1,300 Mm³/year in the most catastrophic scenario, as described in Table 2. This deficit would be added to the deficit already observed, notably a deficit of 170 Mm³/year at the level of the Canal de Rocade and a groundwater deficit of 176 Mm³/year. The projected surface water deficit largely surpasses the ability of the Oum Er Rbia basin for inter-basin transfer, while increasing groundwater deficits will risk aquifer depletion and increasing competition of irrigated agriculture for surface water. Irrigated agriculture will undoubtedly face significant reductions in the projected future, in order to address the balance gap and guarantee a sufficient supply of potable water in the region.

Climate change scenario	Low	Average	High	Low	Average	Low	High	Average	High
Variability scenario	Average year	Average year	Average year	Dry year	Dry year	Very dry year	Dry year	Very dry year	Very dry year
Combined impact on water deficit:									
%	**0%**	**25%**	**50%**	**50%**	**63%**	**70%**	**75%**	**77.50%**	**85%**
Mm³/year	**0**	**400**	**800**	**767**	**982**	**1,073**	**1,183**	**1,205**	**1,3367**
Surface water	*0*	*324*	*648*	*615*	*791*	*861*	*956*	*970*	*1,079*
Groundwater	*0*	*76*	*152*	*152*	*191*	*212*	*227*	*235*	*258*

Table 2 - Synthesis of estimated impacts of combined scenarios of climate change and climate variability on the water balance of the Marrakesh region (2050 horizon)

5.2. Building a climate resilient and diversified water supply for the region of Marrakesh

While water allocations priority is given by law to drinking water supply, increased competition with the irrigation sector may put Marrakesh on a dangerous path. Urban water needs are rapidly growing to the detriment of the agriculture sector. Marrakesh already uses a fraction of irrigation water allocations to satisfy its water demand. These volumes appear marginal compared to the total allocation to irrigation, which may suggest that the city will always be able to use agriculture water as a buffer to cover future deficits. But with expected severe water shortages at basin level and possibly severe social and economic consequences in the rural sector, competition for water between users is likely to become fierce in the future.

In this context, the urban water sector needs to consider how it can contribute reducing its water demands and creating new water sources for the benefit of other sectors, under an Integrated Urban Water Management approach. Various options for building a climate resilient and diversified water supply for Marrakesh city have been designed adhering to the following general principles: (i) demand management to reduce urban economic dependence on water use; (ii) diversification of water resources to hedge against risks of specific resources; (iii) focus on local water resources to reduce competition for scarce resources with other users, and (iv) development of a buffer against climate variability. The considered solutions are clustered under three categories of options:

- **Demand management** options: i) Reduction of physical losses through network rehabilitation; and ii) best practices for demand management, including landscaping of urban green spaces;
- **Non-conventional options for water** supply augmentation: i) Desalination, ii) reuse of treated waste water; iii) reuse of grey water in hotels; iv) rainwater harvesting; and v) recharge of aquifers;
- **Conventional** options for water supply augmentation: i) Construction of new barrages; ii) increasing dam heights of existing reservoirs; and (3) inter-basin water transfers.

5.2.1 Demand management and water conservation options

Further gains can be achieved through network rehabilitation, leak detection and accompanying measures. Physical losses in RADEEMA's distribution network amount presently to 25% or 17 Mm^3/year (2016), which is a major improvement since the early 2000's, when non-revenue water represented close to 44% of distributed water. Under the status quo this would increase to 25 Mm^3/year by 2050. RADEEMA is currently aiming to reduce losses to 23% by 2019 following an action plan costed below MAD 100 million. The cost of this intervention is therefore estimated under DH4 per m^3 saved, which is significantly lower than the avoided financial cost of importing water from Northern basins (around DH12 per m^3), and even lower than the avoided economic cost that would incorporate the value of water savings. The Economic Level of Leakages (ELL) is therefore likely to be far below 23%, if calculated for the full water production and distribution cycle. However, since RADEEMA's mandate is limited to water distribution and ONEE's bulk water sales tariff (MAD 3.5 per m^3) is far below its actual cost, incentives are limited for the operator to target the ELL. Based on international experience, it would seem realistic to consider an ELL in the range of 10% to 15%. For the sake of economic analysis and comparisons later in this study, improved distribution network efficiency to 85% by 2030 and 90% by 2050 will be considered, leading to water savings of 10 Mm^3/year in 2030 and 15 Mm^3/year by 2050.

The initial investment is estimated at MAD 100 million, with additional investments of MAD 15 million per year. Positive externalities are a reduced competition and pressure on the scarce water resources of the region, while on the negative side the recharge by leaked water of the Haouz aquifer may be reduced.

The scope for water savings through residential water demand management appears more limited. The current level of residential water consumption in Marrakesh hovers around 110 liters per capita per day, and offers little scope for significant demand reductions, even though consumption rates are even slightly lower in some other cities in the country, as shown on

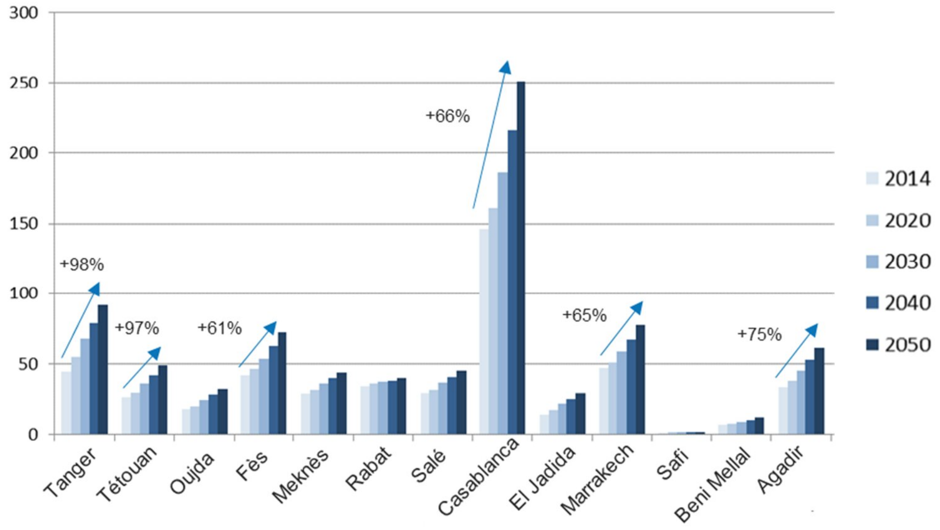


Figure 3. Nonetheless, demand management needs constant attention to ensure that urban consumption rates will not increase in the future due to economic development and increasing prosperity of citizens. As discussed in Section 3.2, water conservation can be achieved *inter alia* through the promotion of awareness regarding water scarcity and water conservation, adequate pricing of potable water, universal metering, incentive programs and labeling schemes to encourage water efficiency. Positive externalities are a reduced competition and pressure on the scarce water resources of the region and the environmental and economic benefits of generating and treating less wastewater. In parallel, the Government of Morocco is implementing an ambitious program to improve water use efficiency in the irrigation sector, as described in Box 2.

The government's sectoral programs are intended to build the resilience of the agricultural sector while increasing farmer incomes. Under the Morocco Green Plan (Plan Maroc Vert), the government is supporting farmers in introducing climate-smart technologies such as direct seeding, climate-resilient varieties, and enhanced water management techniques, linked to improvements in quality and phytosanitary services, aggregation, and processing which expand economic opportunities. To increase the productivity of water in agriculture, the government of Morocco (GoM) has put in place a National Plan for Saving Water in Irrigation (Plan national d'économie de l'eau d'irrigation, PNEEI). The PNEEI promotes more productive water use by introducing efficient irrigation technologies (mainly drip irrigation) over 555,000 ha of the country's irrigated land by 2020, of which 335,000 ha are on private farms, and 220,000 ha are in large-scale irrigated perimeters. The government supports this process through the agricultural development fund, with up to 100 percent subsidies for the adoption of drip and micro-sprinkler irrigation (under a maximum per hectare amount), and with 70 percent subsidies for sprinkler irrigation.

Box 2: Key Principles of Integrated Urban Water Management (IUWM)

Alternative approaches to landscaping and gardening in public areas could however yield tangible benefits. Urban landscaping of the royal and urban gardens is a domain where immediate concrete water savings can be achieved through the introduction of drought resistant plants and drip irrigation in public green spaces and around the greens of golf courses (xeriscaping). Presently, the watering of green areas results in excessive groundwater consumption, primarily due to water-intensive irrigation methods and plants selection (e.g. grass instead of cactus plants). It is estimated that annually 12 Mm^3 of water is used to water 1,500 ha of public green spaces in the Marrakesh area. The introduction of partial pavement, drought resistant plants and the generalization of drip irrigation over a public area of 500 ha could potentially reduce water demand by 2 Mm^3 per year through an investment of MAD 250 million. Given the importance of maintaining the attractiveness of the city, such type of intervention would require extensive consultation and awareness building with stakeholders.

Figure 13 - Xeriscaping -Marrakesh golf course

5.2.2 Non-conventional options for water supply augmentation

Through virtual water transfers, seawater desalination can be a major asset for the inland city of Marrakesh. The desalination market in the MENA region is mature and has yielded some of the lowest desalination cost projects in the world. The PNE (2015) provides for the construction of seawater desalination plants to produce nearly 515 Mm^3/year in 2030. The planned supply of potable water to the coastal cities of El Jadida and Safi from the desalination of the sea water will allow the recovery of significant volumes currently allocated from the Al Massira reservoir or the Kasba Tadla dam to these cities. If water losses from evaporation along the canals between Al Massira Dam and the two cities, estimated at 25% to 30%, are factored in, this will represent an additional allocation of 60 Mm^3/year by 2030 and 75 Mm^3/year by 2050 for Marrakesh. Figure 14 illustrates the possible virtual transfer associated to the implementation of these desalination plants.

Desalination will however remain a costly solution, even if the virtual nature of the transfer avoids major conveyance costs from the coast 800 meters up to the city. The cost of transferring equivalent volumes of the Al Massira dam or the Kasba Tadla dam to Marrakesh (MAD 900 million) must indeed be considered. The capital costs of extending an equivalent capacity of the existing desalination plants of Safi and Jorf Lasfar with 56 Mm^3/year by 2050 represent about MAD 1,480 million (including MAD 240 million for connecting structures). This equates to MAD 8,000 per m^3/day or an investment of MAD 22.5 per m^3 of installed annual capacity, not including the cost of connecting structures. Even if this virtual transfer optimizes the water-energy nexus, negative externalities include GHG emissions related to energy generation (unless wind and solar power would be used). The impacts of the discharge of residual brine on the marine environment require as well careful assessment.

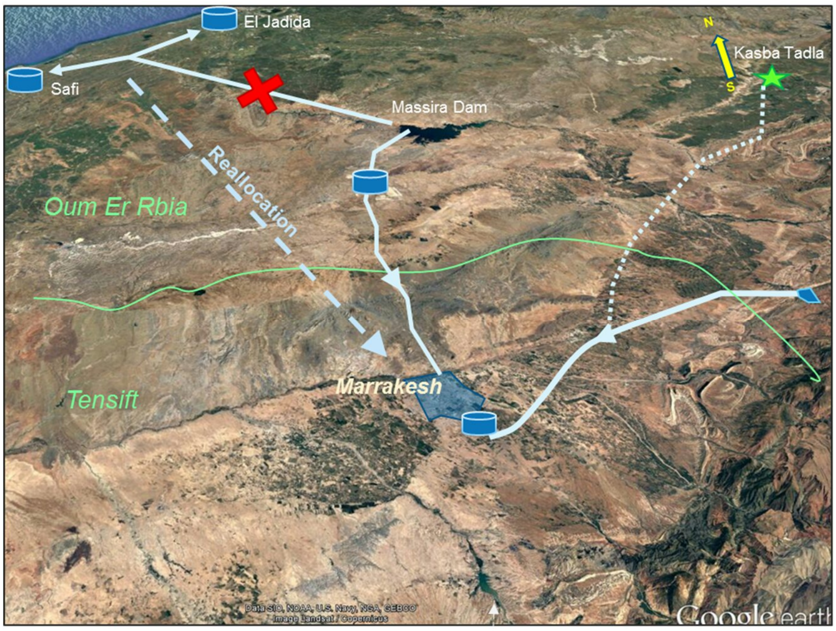


Figure 14 - Lay-out of the option with seawater desalination and virtual transfer

After pioneering the reuse of treated wastewater in the 2000's, Marrakesh has a menu of options to significantly increase the use of this water resource. In a context of increasing water stress, Marrakesh was confronted in the mid-2000's with a strong demand for the development of water-intensive golf tourism industry. The planned 20 golf resorts projects would require a 20 Mm^3 increase in water supplies, about of third of the amount already delivered at that time. The city turned to wastewater treatment and reuse with strong political and financial support, particularly from the central government of Morocco, in exchange for strict non-revenue water improvement targets. While the capacity of the existing wastewater treatment plant (WWTP) is nearly saturated at 33 Mm^3/year, presently only 7 Mm3/year is utilized at the Palmeraie and at golf courses, as all resort projects have not been implemented or fully abandoned their use of groundwater. Thus, utilization of the existing capacity may appear as a priority, for purposes such as the watering of green urban spaces, additional supplies to golf courses and to the Palmeraie (up to 20 to 25 Mm^3/year), artificial recharge of the Haouz aquifer and irrigated agriculture near the city. The current treatment capacity could be even, in the future, expanded to 60 Mm^3/year (potential by 2050) to enable those various possible usages. Maximizing the sale of this water to golf courses would require the enforcement of agreements and so-called "Aquifer Contracts" with these entities. Reuse for irrigation could capitalize on the high nutrient content (N, P) of treated effluent, and close monitoring and other practices like dilution can help ensure that quality standards are respected. In any case, well-designed and targeted communication will be required to foster farmers' acceptance of this resource for irrigation.

Leverage existing infrastructure could help mitigate the cost of reuse infrastructure development. The investment costs for the extension of the STEP for an additional volume of 30 Mm^3/year are estimated at MAD 1 billion, including MAD 200 million for the tertiary treatment. The distribution system for the reuse of treated wastewater would cost MAD 300 million. Since primary and secondary wastewater treatments are mandatory with or without reuse, the corresponding investment and operating costs for these treatments are not taken into account in the cost estimates for reuse, and the total investment for this option is estimated at MAD 500 million, almost MAD 17 per m^3 installed annual capacity. Positive externalities of this option concern a reduced discharge of nutrients into the environment.

While there is some scope to promote greywater reuse in hotels, the associated costs may be relatively high. The present water consumption of hotels in Marrakesh has been assessed at 3.5 Mm^3/year, of which about 50% becomes greywater with a low pollution load, adequate for on-site treatment. The lodging capacity is expected to at least double by 2030, offering opportunities to apply double piping standards in new buildings. A greywater reuse program has been conceptualized based on the water demands to irrigate hotels' green spaces and toilets flushing (around 1.7 Mm^3 per year in 2030). Such intervention would require an investment of MAD 400 million for the separate collection of greywater, treatment systems and reuse infrastructure, equivalent to MAD 235 per m^3 installed capacity. Costs can therefore be comparatively high, with limited quantitative gains and build, like wastewater reuse, the city's resilience to climate shocks. This solution does not entail major externalities.

Rainwater harvesting in rural and urban environments appears as the costliest option due to diseconomies of scale, but it could offer a lifeline solution in remote areas. The proposed small-scale rural rainwater harvesting program for the Greater Marrakesh area aims at providing part of the water supply to populations in the city's peripheral areas, as well as recharging the aquifer. This in turn frees-up additional potable water supplies for the city. The proposed intervention includes the construction of hillside lakes with a total capacity of 4 Mm^3, collective subterranean water tanks (Métfias) with a total capacity of 60,000 m^3, and the rehabilitation of collective and individual Métfias. These measures could in due time generate a water volume of 3 Mm^3 per year at an investment cost of MAD 130 million, equivalent to MAD 43 per m^3 installed capacity. The cost of rainwater harvesting in the urban areas of Marrakesh is much higher, estimated at MAD 90 million for a relatively small volume of 0.2 Mm^3/year, equivalent to MAD 450 per m^3 installed capacity. The proposed program includes the construction of 15 covered retention basins, 500 rainwater harvesting projects at government buildings and schools, and 1,000 individual tanks to be built by the population. Externalities include, on the positive side, the reduction of stormwater conveyance and wastewater treatment needs, while on the negative side, a possible reduction of aquifer recharge and downstream river flows.

Aquifer recharge could be very promising, but it would require strengthening of groundwater governance. This option includes the construction of up to 100 low water infiltration dams along tributary rivers of the Tensift River, notably the Ghdat, Zat and Rheraya, which offer adequate locations for the artificial recharge of the Haouz aquifer, as shown on Figure 15. It is estimated that the recharge volume through these infiltration schemes could reach 50 Mm^3/year. Investment costs are estimated at MAD 300 million, equivalent to MAD 6 per m^3 installed capacity, the lowest cost of all options considered. However, given the uncontrolled exploitation of this aquifer across its catchment basin, only a share of these volumes may be directly available for Marrakesh, the rest spreading beyond the city's abstraction perimeter. Strong groundwater governance and clear cost and benefit sharing mechanisms between urban and non-urban users would therefore be required to scale-up this approach. Such intervention would also help mitigate flooding risk in the downstream urban areas.

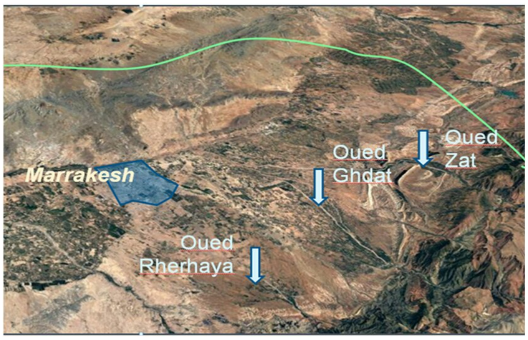


Figure 15 – Location of possible aquifer recharge sites

5.2.3. Conventional options for water supply augmentation

The SNE (2009) has planned to invest 21 billion MAD over the period 2010 – 2030 in new dams and reservoirs and raising the levels of existing dams, with the objective to mobilize annually an additional 1.7 Bm^3. This is to be achieved both through the construction of new dams and augmentation of the storage capacity of existing reservoirs.

The construction of new dams could yield a significant increase in water supplies, but at a major economic cost. This option considers the construction of the Ait Ziat dam with a storage capacity of 95 Mm^3, as illustrated on Figure 16 (left panel), to store surface water for municipal water supply. The reservoir dam would allow from 2030 onwards to reinforce the irrigation downstream of the dam and to allocate an additional amount of 30 Mm^3/year to the potable water supply of Marrakesh. This option makes use of the existing but insufficiently utilized capacity of the Canal de Rocade and the existing water treatment plant south of Marrakesh, and reduces the need for operating costs of pumping such large volume from Al Massira to Marrakesh through the pipeline under construction.

The investment cost is estimated at MAD 900 million, of which approximately MAD 450 million would be allocated to the drinking water portion, equivalent to an investment of 15 MAD per m^3 installed annual capacity. This solution would however entail substantive social and environmental impacts including the resettlement of people, with associated economic costs estimated at MAD 176 million. In addition, as other solutions relying on surface water, it would not reduce Marrakesh's vulnerability to the effects of climate change.

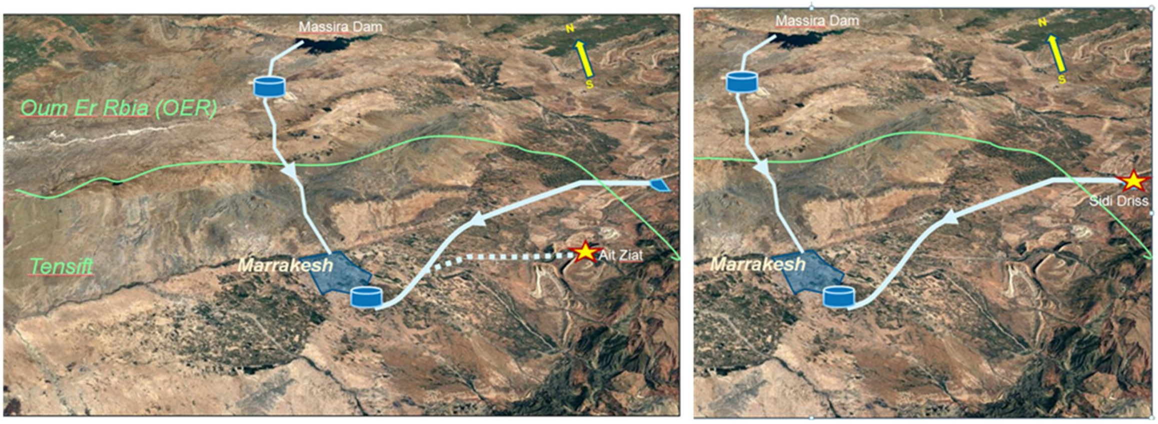


Figure 16 - Location of the new Ait Ziat dam (option SW4; left panel) and the existing Sidi Driss dam (SW5)

Less impactful, but as vulnerable to climate change, could be the augmentation of the storage capacity of existing reservoirs (SW5): This option considers the raising of the existing Sidi Driss dam located on the Lakhdar River, as identified on Figure 16 (right panel). The increase of the dam height by nearly 40 m would allow from 2030 onwards to increase the storage volume from 1.2 Mm^3 to approximately 73 Mm^3 and to increase the water allocation for the Canal de Rocade with about 50 Mm^3/year, of which 27 Mm^3/year could be allocated to the water supply of Marrakesh. As in the above case, this would make use of existing conveyance and treatment capacities, as well as reduce the needs for operating costs for the pipeline from Al Massira dam to Marrakesh.

The investment costs are estimated at MAD 605 million, of which approximately MAD 350 million would be allocated to the drinking water portion, equivalent to an investment of 13 MAD per m^3 installed annual capacity. This solution reportedly does not entail significant environmental impacts. Furthermore, it would allow for an increase in energy production at the Ammouguez hydropower plant downstream, for increased water supplies for small towns and irrigation downstream and for the development of recreational areas.

Inter-basin transfers, notably one from the North are currently considered as the baseline solutions to address Marrakesh water security challenges. The PNE (2015) envisages an inter-basin water transfer from the less water scarce Loukkos and Sebou basins in the North to the central basins of Morocco through a canal system reaching Al Massira dam in the Oum-Er-Rbia basin, as illustrated on Figure 17. Phase I of the pipeline project (discussed in 5.1) is expected to be operational in 2018, and the cost of water treatment and conveyance from Al Massira dam to Marrakesh are estimated at 7 MAD/m^3. Upstream, the cost of the water transfer until it reaches Al Massira dam from the North is estimated at 7.4 MAD/m^3, which makes a total 14.4 MAD/m^3. This option then includes: Phase II of the Al Massira transfer project linking the pipeline with the RADEEMA water supply system in the South of Marrakesh, while Phase III concerns a second parallel pipeline from Al-Massira to Marrakesh.

Investment costs for phases II and III are estimated at MAD 2.75 billion, making in the long-term (>2045) an additional volume of 108 Mm^3 per year available for Marrakesh. Investment needs are estimated at 4.7 MAD/m^3 and the total cost of water transferred from the north via the Al Massira Dam to Marrakesh will thus rise to about 12.1 MAD/m^3 for Phases II and III, against 14.4 MAD/m^3 for Phase I. Since Phase I is already under construction, this analysis considers the investment cost for Phase I as sunk cost.

Figure 17 - Outline of the inter-basin water transfer projects to Marrakesh via Al Massira dam or Kasba Tadla dam (source: PDAIRE Tensift)

Alternatively, a more cost effective inter-basin transfer from Kasba Tadla Dam to Marrakesh could be considered in replacement of Phases II and III of the inter-basin transfer through Al Massira reservoir. Instead of transferring water from the north via the Al Massira dam to Marrakesh as envisaged under option WT1a above, water will, in this option, be diverted at the level of the existing Kasba Tadla dam, located upstream of Al Massira dam on the Oum Er Rbia River. This will reduce the inflow in Al Massira reservoir and would need to be off-set by the water transfer from the Northern basins. This option is designed for providing 60 Mm^3 per year for Marrakesh, beginning as early as 2025. The investment costs for the supply of 60 Mm3 per year to Marrakesh are estimated at MAD 900 million, for the cost of linking Kasba Tadla to the Canal de Rocade through partially existing canals (green in Figure 18) and new infrastructure (red bold sections). These costs are equivalent to MAD 15 per m^3 installed annual capacity. The cost price of the water is estimated at 3.2 MAD per m^3 from Kasba Tadla onwards, and the total cost of water transferred from the North to Al Massira and from the Kasba Tadla dam to Marrakesh will thus rise to about 10.6 MAD per m^3, hence 1.5 MAD per m^3 below the previous inter-basin transfer option (through Al Massira reservoir). Positive impacts of this option would also include reduced water losses by evaporation and infiltration on the Oum Er Rbia River between Kasba Tadla and Al Massira, reduced pumping needs and the use of the existing water treatment capacity at the Canal of Rocade plant South of Marrakesh. Environmental impacts of this option are expected to be minimal.

5.3. Comparison of water supply options for Marrakesh

Diversification options for addressing the looming water scarcity in Marrakesh are evaluated using financial and economic analyses. Through the financial analysis, the cost price of water in MAD per m^3 is calculated for all options. The financial analysis of the options is based on an estimate of the Net Present Value (NPV) of the investment and operating costs as well as of the volumes of water made available up to 2050, at a discount rate of 5%. These specific cost estimates enter the economic analysis as a "cost-effectiveness" criterion, which also takes into account other criteria such as sustainability, resilience to climate change and the risks related to each option. A 20% contingency surcharge is factored in all cost. The results of the financial analysis are summarized Figure 18.

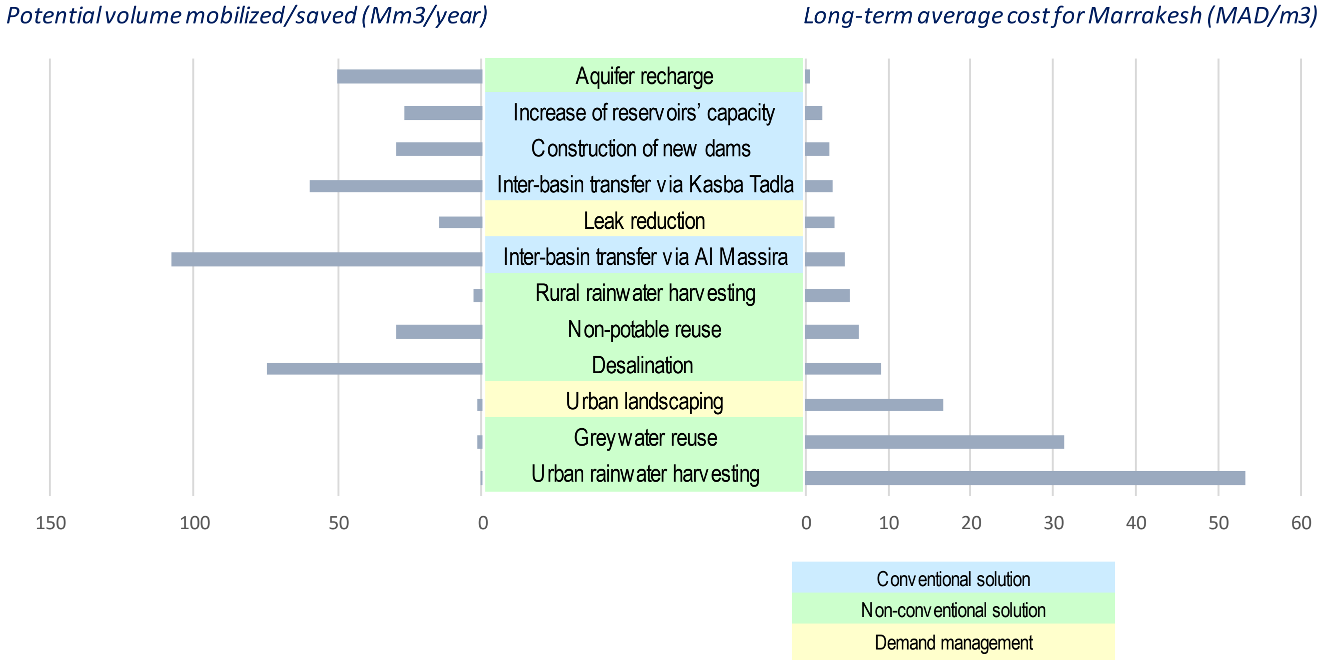


Figure 18 – Costs of measures and annual volumes of water generated for different options by 2050

From a financial perspective, artificial recharge of the Haouz aquifer through appears to be the most attractive option, with a large potential volume of water storage. All conventional options (dam and transfer projects) also promise to provide copious amounts of water at reasonable cost. The option with transfer from Kasba Tadla dam to Marrakesh, using as much as possible existing infrastructure is slightly advantageous compared to building a second pipeline from the Al Massira reservoir.

If the cost of water conveyance from the North to Al Massira is included (7.4 MAD per m^3), the transfer options become relatively expensive compared to most other solutions. The full costs of the Al Massira or Kasba Tadla dam transfer options reach 12.1 and 10.6 MAD per m^3 respectively, exceeding those of wastewater reuse (6.5 MAD per m^3) and seawater desalination (9.0 MAD per m^3). Those non-conventional solutions are of particular interest due to their moderate cost and significant climate-insensitive volume potential. Desalination cost is likely to further decrease in the future due to reduced solar energy costs.

Urban rainwater harvesting, the graywater reuse and demand management (urban landscaping) appear as the most expensive solutions, and less promising in terms of volumes of water generated. Rural rainwater harvesting may be of interest to resolve local water shortage issues. Finally, the cost of leak reduction is still cost-competitive at the current level of NRW. Its economic relevance on the long term will depend on the cost of water supply, i.e. on the portfolio of water supply solutions put in place to ensure Marrakesh's future water security.

5.4. Multi-criteria comparison of water supply options for Marrakesh

The different water supply options for the Marrakesh region were evaluated using a multi-criteria analysis based on a set of weighted evaluation criteria that are presented in Appendix A, considering criteria such as sustainability (including climate risks and resilience), volumes of supply versus demand, water quality, economy (cost effectiveness) and risk management (including environmental, social risks and other risks). A valuation of social and environmental risks was beyond the scope of this study. The results of the analysis are summarized in Table 3.

	Sustainability / Resilience	Demand satisfaction	Water quality	Cost effectiveness	Risk management	Total Score	*Ranking compared to financial analysis*
	30%	20%	10%	20%	20%	100%	
Aquifer recharge	3.4	4.0	5.0	5.0	3.4	**4.0**	=
Desalination	3.1	5.0	4.0	4.0	3.7	**3.9**	
Non-potable reuse	3.9	4.0	3.0	4.0	3.7	**3.8**	
Increase of reservoirsôcapacity	2.7	4.0	4.0	5.0	3.0	**3.6**	
Leak reduction	3.0	2.0	5.0	4.0	5.0	**3.6**	=
Inter-basin transfer via Al Massira	3.0	5.0	4.0	4.0	2.3	**3.5**	=
Inter-basin transfer via Kasba Tadla	3.0	5.0	4.0	4.0	2.3	**3.5**	
Construction of new dams	3.0	4.0	4.0	4.0	2.7	**3.4**	
Rural rainwater harvesting	2.2	2.0	3.0	4.0	3.4	**2.8**	
Urban landscaping	2.5	1.0	3.0	3.0	4.7	**2.8**	=
Greywater reuse	3.3	2.0	3.0	2.0	2.7	**2.6**	=
Urban rainwater harvesting	1.8	1.0	3.0	2.0	3.4	**2.1**	=

Conventional solution
Non-conventional solution
Demand management

Table 3 - Summary of the economic analysis of options designed for the water supply of Marrakesh

Seawater desalination and wastewater reuse become favorable compared to inter-basin transfer when the cost of transfer from the North to Al Massira, environmental risks and climate vulnerability are

considered. Resilience to climate change and variability strengthens significantly the scoring of non-conventional solutions that are not climate sensitive such as the reuse of treated wastewater and desalination. Social and environmental impacts affect negatively the scoring of conventional large surface water infrastructure, such as new dams and inter-basin transfer infrastructure, as well as silting issues and their vulnerability to climate change. Aquifer recharge by infiltration remains a very valuable option, with technical and institutional feasibility aspects requiring further analysis. The scoring of demand management (leak reduction, urban landscaping) and decentralized supply augmentation (rainwater harvesting, greywater reuse) interventions is undermined by the limited volumes at stake, in addition to relatively high costs in most cases. Overall, these multi-criteria assumptions point toward the prioritization of:

Solution	Volumes (Mm3 per year)
Aquifer recharge	50
Desalination	75
+ inter-basin transfer via Kasba Tadla *(to support the desalination scheme)*	60
Non-potable reuse	30
Increase of reservoirs' capacity	27
Network leakages reduction	15

While the scoring approach is in principle subjective, it highlights the importance of various factors for decision-making in a context of urban water scarcity management. This preliminary analysis points towards a portfolio of solutions different from the one envisaged in the PNE, which relies primarily on the inter-basin transfer from the North. Further investigations would be required to refine each solution's feasibility and performance against these various dimensions. But at this pivotal moment in the engagement of large scale infrastructure projects in Morocco, a full review of options integrating the micro (city), meso (basin) and macro (inter-basin) scales could yield substantial benefits.

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