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Unconventional Water Resources as Sustainable Solutions to Mitigate Water Stress in Middle East and North Africa

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Abstract: The Middle East and North Africa (MENA) region faces unprecedented water scarcity, driven by arid conditions, limited freshwater resources, and rising demand due to growing populations. This review examines the potential of unconventional water resources including treated wastewater, agricultural drainage water, and desalination as sustainable solutions to mitigate water stress in Egypt, Morocco, Tunisia, Lebanon, and Jordan. With per capita water availability in many MENA nations expected to drop below 500 m³/year by 2030 and agriculture accounting for over 80% of water use, the region's food security and economic stability are at risk. Climate change further exacerbates these challenges through prolonged droughts and unpredictable rainfall. This paper analyzes country-specific approaches, such as Egypt's large-scale drainage water reuse, Morocco's climate adaptation strategies, Tunisia's policy-driven water management, and the acute water crises in Lebanon, and Jordan. Key findings emphasize the importance of integrated water resource management, advanced treatment technologies, and cross-border collaboration to optimize unconventional water use. By evaluating current practices and future opportunities, this study highlights how MENA countries can enhance water security, sustain agricultural output, and reduce the socio-economic impacts of water scarcity in an increasingly climate-vulnerable region.

Keywords: water reuse, water management, water scarcity**,** unconventional water resources

1. INTRODUCTION

With rising global demand for freshwater, limited water resources are increasingly strained by overexploitation, pollution, and climate change effects. Within a circular economy approach, neglecting improved management strategies for all water sources would represent a significant missed opportunity [1]. Water scarcity significantly impacts human health, food security, economic growth, social stability, and environmental conservation. UNICEF reports that nearly two-thirds of the global population—around four billion people—experience water shortages for at least one month each year. By 2040, 25% of the world's children will reside in regions with severe water stress [2]. UN-Water advocates for an integrated approach to water scarcity, emphasizing: (1) recognizing water as a finite resource, (2) enhancing water system efficiency and resilience, (3) leveraging data and technology for informed decisions, and (4) safeguarding and sustainably using groundwater [3].

The Middle East and North Africa (MENA) region faces severe water scarcity due to its arid climate and irregular rainfall. Governments have traditionally relied on dams, groundwater extraction, desalination, wastewater reuse, and other measures to meet demand. However, population growth, urbanization, and expanding agriculture and industry—particularly water-intensive crops and tourism—are depleting resources. Declining per capita water availability has forced many MENA countries to seek alternative water sources to bridge the growing supply-demand gap [4].

Agricultural water reuse provides substantial benefits by supplementing water supplies for domestic and industrial use, reducing competition for scarce resources. This practice also helps prevent overexploitation and ecological damage to natural water systems. As its advantages grow more evident, an expanding number of countries worldwide are implementing this sustainable water management approach [5]. Non-conventional water sources typically require pretreatment for agricultural use. Treatment methods for wastewater and drainage water vary from simple filtration to advanced purification. These processes remove contaminants, ensuring water meets irrigation standards while safeguarding soil and crops [6]. Interdisciplinary studies assessing non-conventional water resources' socio-economic, environmental, and technical aspects could inform holistic water management. Such approaches may help restore degraded arid lands. Research shows treated alternative waters (saline water, wastewater, greywater) successfully support diverse agriculture, including crops, forestry, and aquaculture. With proper treatment, these resources could rehabilitate marginal lands, improving food security and sustainable agriculture in MENA [7].

Hence, managing water resources under stressful conditions poses a challenging endeavor. In Iraq, (Ethaib et al., 2022) investigated water scarcity in Iraq's Thi-Qar Governorate using GIS and climate modeling, revealing critical stress from Euphrates River depletion, groundwater decline, and temperature increases [8]. Their spatial analysis identified agricultural zones most vulnerable to climate-exacerbated shortages caused by inefficient irrigation. The study demonstrates GIS's utility for water resource assessment while advocating adaptive measures like optimized irrigation and drought-resistant crops to enhance water security in arid regions, providing a transferable framework for similar environments. (Procházka et al., 2018) evaluated Middle Eastern water scarcity through physical, economic, and institutional indicators. Their analysis identified severe water stress in Yemen, Iraq, and Jordan, attributing it to groundwater depletion, inefficient agriculture, and climate change. The study projects a 20-30% decline in renewable water by 2050, showing how economic and governance issues intensify scarcity. Their multidimensional approach effectively separates natural from human-caused water insecurity drivers, highlighting the need for integrated solutions combining infrastructure, pricing reforms, and cross-sectoral management in arid zones [9].

(Ortega-Pozo et al., 2022) examine Morocco's wastewater reuse policies for irrigation, revealing a disconnect between national regulations and stricter EU/USA/WHO standards. Their analysis shows Morocco's current treated wastewater standards risk agricultural export bans, with only 0.1% of irrigation water meeting requirements. While tertiary treatment is cost-effective (0.14 USD/m^3), its implementation remains limited due to lax enforcement and low public awareness. The study recommends adopting EU-standard policies to ensure food safety, environmental protection, and sustainable water use in arid areas [10].

Egypt, with over 100 million people, experiences severe water stress that hinders development. The country relies heavily on the Nile River's 55.5 billion cubic meters (BCM) annual allocation, resulting in per capita water availability below the 1000 m^3/year scarcity threshold. To address this shortfall, Egypt currently supplements its water supply with approximately 24 BCM from non-conventional sources annually [1,11].

Egypt urgently requires the reuse of agricultural drainage water to augment water resources for irrigation, industry, and various human activities. In the Nile Delta, blending agricultural drainage water with main irrigation canals is a widespread practice. The Bahr El-Baqar facility, the world's largest wastewater treatment plant, commenced operations in 2021. It processes approximately 5.6 million cubic meters (MCM) of drainage water daily, yielding 2 billion cubic meters (BCM) of treated water annually [12]. The drainage water at the reuse stations should meet the acceptable limits of both quantity and quality to blend with fresh water. Exploring the potential of irrigating crops with treated wastewater from agricultural drains, the findings suggest that mixing treated wastewater with fresh water represents the most suitable scenario for water reuse, offering enhancements in both water quality and quantity [13]. Ultimately, this study seeks to evaluate water scarcity challenges and the utilization of unconventional water resources across the Middle East and North Africa (MENA) region, with a particular focus on Egypt, Tunisia, Jordan, Lebanon, and Morocco.

2.METHODOLOGY

This review synthesizes water scarcity research across five MENA countries (Egypt, Tunisia, Jordan, Lebanon, Morocco), selected for their contrasting water stress levels, reuse practices, and demographic characteristics to enable comparative analysis. Table 1 provides a comparison of water stress indicators for the chosen MENA countries.

Table 1: comparative analysis of water stress levels across the selected MENA countries [14]

Indicator	Egypt	Tunisia	Jordan	Lebanon	Morocco
Renewable water resources (m^3/capita/year)	560	403	80	1,100	850
Water stress level	Extreme	High	Extreme	Moderate	High
Annual water reuse volume (BCM)	24	0.26	0.4	0.12	0.34
% of wastewater treated & reused	8%	30%	90%	4%	15%
Governance challenges	Centralized management, subsidy policies	Rural-urban disparities	Transboundary disputes	Political instability	Decentralization needs
Innovative solutions	Bahr El-Baqar plant (5.6 MCM/day)	Solar-powered desalination	Treated wastewater for Amman's supply	Cloud seeding trials	Seawater greenhouse projects

The collected studies were screened for relevance, with priority given to those addressing water scarcity drivers, reuse strategies, governance frameworks, and socio-economic impacts. Data were then categorized by country, water management approach, and key challenges to identify trends, gaps, and best practices. This systematic review provides a critical assessment of water scarcity mitigation efforts across the region, offering insights for policymakers and future research.

3.RESULTS AND DISCUSSION

3.1 Water scarcity and unconventional water resources in Jordan

Jordan experiences severe water scarcity, with per capita availability below 100 m^3/year – far under the 500 m^3 absolute poverty threshold. This crisis stems from environmental factors (arid climate, droughts, high evaporation) compounded by socioeconomic and geopolitical pressures, severely limiting usable water reserves [15, 16].

Jordan's economic water scarcity worsens these physical constraints, with inefficient water use and poor conservation. Agriculture illustrates this imbalance, consuming 50% of freshwater resources while contributing only 5% to GDP-increasing risks of crop failures, food imports, and sector instability [17, 18].

Research shows water insecurity harms public health, nutrition, and education while threatening social stability. Jordan's dependence on shared water resources, particularly the Jordan-Yarmouk basin, exacerbates scarcity due to politically sensitive allocation agreements [19].

Jordan's severe water scarcity makes agricultural drainage water reuse essential for sustainable water management and farming resilience [20]. Recent research shows Jordan increasingly relies on treated wastewater and agricultural drainage, particularly in the Jordan Valley, to address freshwater shortages. While recycled water supplies crop nutrients, studies warn of risks like soil salinity [20, 21].

Sustainable use of non-conventional water requires strict management through controlled leaching and nutrient monitoring to maintain soil quality. While farmers show growing awareness, challenges remain-particularly insufficient leaching water and concerns about industrial contaminants [22].

The Jordan Valley Authority regulates water distribution, but implementation gaps exist between policies and farm-level practice. Studies recommend better farmer training, information sharing, and water quality monitoring to improve irrigation efficiency [20].

Jordan's water policies now emphasize treated wastewater reuse, aligning with regional shifts to alternative sources. Advanced treatment technologies could supply >200 million m^3/year for agriculture. Rural communities show increasing acceptance, provided risks are properly managed [20, 21].

Jordan's integrated approach to drainage water reuse—combining technical, governance, and social dimensions-provides a critical solution for water security, agricultural productivity, and environmental protection [20, 22].

3.2 Water scarcity and unconventional water resources in Lebanon

Lebanon faces acute water scarcity due to population growth, climate change, and inefficient management, particularly in agriculture. Researchers propose treated drainage water and wastewater reuse as sustainable solutions to alleviate shortages [23]. Research by IWMI and LARI confirms treated wastewater can safely irrigate even raw-consumed

crops when proper treatment and farming practices are followed. These findings informed Lebanon's first national water reuse standards, guiding agricultural policies [24, 25]

Pilot projects near Bekaa Valley's Ablah and Zahleh treatment plants show treated wastewater reuse can reduce groundwater depletion and boost crop yields. However, scaling up faces challenges including weak regulations, insufficient infrastructure, and socio-political instability. Farmer and consumer resistance due to health concerns also necessitates awareness campaigns and stakeholder engagement [25].

Lebanon's 2024 Water Strategy prioritizes treated wastewater reuse to improve resource sustainability. Research shows agricultural drainage water reuse could alleviate water shortages, but requires better infrastructure, stronger regulations, institutional capacity, and public acceptance. These elements are vital for sustainable water management and food security amid growing environmental and economic pressures [26].

3.3 Water scarcity and unconventional water resources in Morocco

Morocco faces extreme water stress, worsened by climate change, growing demand, and overexploitation of resources. Agriculture consumes 75-87% of water supplies while covering just 20-25% of farmland, yet produces 65% of the sector's value-highlighting its economic and food security importance. Recent droughts and depleted reservoirs have prompted water rationing and demands for sustainable solutions [27, 28].

Morocco has prioritized treated drainage water and wastewater reuse to boost freshwater supplies, agricultural productivity, and environmental protection. The country's 141 treatment plants (60 with tertiary treatment) produce approximately 394.6 million m³ annually. While national goals target 100 million m³/year reuse by 2027, current agricultural applications remain limited to experimental pilot projects for technical optimization [29, 30].

Several barriers-technological gaps, weak regulations, funding constraints, and public resistance-limit adoption. Overcoming these requires stronger policies, stakeholder engagement, and institutional capacity. Research indicates advanced irrigation, improved recycling, and sustainable farming could enhance efficiency. Moroccan policymakers now emphasize unconventional sources like desalination and treated wastewater to diversify supply [10, 31].

Effective implementation requires cost-benefit analyses and stakeholder engagement to ensure viability. While agricultural drainage and treated wastewater reuse can mitigate Morocco's water scarcity, scaling demands technological, policy, and social innovations. Such integrated approaches are crucial for sustainable water management and climate resilience [27].

3.4 Water scarcity and unconventional water resources in Tunisia

Tunisia's severe water scarcity stems from agriculture consuming 80% of water resources to irrigate 26% of farmland (4.2M ha), producing 35% of agricultural GDP, 20% of exports, and 27% of farm jobs. Climate change, droughts, groundwater depletion (including illegal wells), and inefficient irrigation (55% efficiency) threaten these outputs, with renewable water resources (4,700M m³/year) projected to decline 25-28% [32]. The crisis has caused income losses, migration, and land degradation, especially in northeast, central-west, and southern regions. Solutions include optimized land use, regional crop selection, drip irrigation, farmer training, and incentives. Models show a 10% efficiency gain could reduce water scarcity by 25%, saving 13% water with minimal (<1%) economic loss while potentially creating jobs [33]. Tunisia currently reuses 28 million m³ of treated wastewater annually (irrigating 6,500-9,000 ha), alleviating freshwater demand despite associated risks. This integrated strategy-combining reuse, efficiency improvements, policy reforms, and economic incentives-is critical for maintaining agricultural productivity and food security under growing water scarcity [34, 35].

3.5 Water scarcity and unconventional water resources in Egypt

Egypt faces acute water scarcity due to population growth and limited renewable supplies, leading to a 15 billion m³ annual deficit projected to worsen. Agricultural drainage reuse now provides 20% of supplemental irrigation water, primarily in the Nile Delta, but risks soil salinity, waterlogging, and groundwater contamination that threaten crop productivity [36].

Egypt's 2030 Water Reuse Strategy aims to treat billions of cubic meters of drainage and wastewater for irrigation, reducing reliance on non-renewable groundwater. Ongoing research focuses on optimizing water allocation through hydrological modeling, assessing ecological impacts, and improving reuse techniques to balance agricultural needs with environmental protection [37].

Egypt reuses approximately 21.0 billion m³ of water annually, comprising: (1) 9.3 billion m³ from official agricultural drainage, (2) 7.5 billion m³ from unofficial reuse (farmer-led practices, Nile seepage, and Delta groundwater extraction), and (3) 4.2 billion m³ of treated wastewater (Khairy, 2022). The study highlights Egypt's effective water policies promoting conservation, non-conventional resource optimization, and improved allocation systems. Strategic

planning and a 'fit-for-use' approach can enhance efficiency by matching water sources to specific needs

4. CONCLUSION

The MENA region faces an unprecedented water crisis driven by population growth, climate change, and diminishing freshwater resources. This review highlights how Egypt, Morocco, Tunisia, Lebanon, and Jordan—each with distinct hydrological and socio-economic challenges—are approaching critical water scarcity thresholds that threaten agriculture, food security, and regional stability. Conventional water management approaches are no longer sufficient, necessitating a strategic transition to unconventional resources like wastewater reuse, agricultural drainage recycling, and desalination.

While these solutions offer promising pathways to water security, their implementation must overcome technical, environmental, and institutional barriers. Soil degradation and groundwater contamination risks require advanced treatment technologies and continuous monitoring. Simultaneously, improved governance, transboundary cooperation, and equitable allocation systems are essential to address fragmented water management.

A sustainable future demands an integrated approach that combines technological innovation, ecological protection, and socio-economic considerations. By adopting such strategies, MENA nations can convert water scarcity challenges into opportunities for resilience. Key priorities include:

1. Institutionalizing adaptive water policies
2. Expanding regional knowledge-sharing networks
3. Investing in scalable infrastructure

Through these measures, the region can achieve long-term water security while safeguarding ecosystems and supporting sustainable development in an increasingly arid climate.

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