Editorial

From Scarcity to Sustainability: Kuwait Adopts Full-Cycle Water Reuse

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Global water security is a prerequisite for realizing the 2030 United Nations Sustainable Development Goals (SDGs) [1]. Its significant role in achieving SDG 6 “Clean Water and Sanitation” was also declared during the 28th United Nations Climate Change Conference in 2023 [2]. Not only the development of adaptation strategies but also the implementation of decisive mitigation actions is vital for attaining water security [3] in different climate zones around the world [2]. More than two billion people worldwide live in countries experiencing high water stress, reflecting the urgent need for integrated water management solutions to secure reliable water [4]. In such arid regions facing water scarcity [5], the full-cycle water reuse approach—treating and reusing wastewater within a closed-loop system—significantly contributes to conserving freshwater, alleviating environmental impacts, and promoting sustainability [6].

Kuwait, situated in the Middle East, is characterized by a hot, arid desert environment. With an internal renewable freshwater availability of only around 5 m^3 per capita per year, one of the lowest figures globally, Kuwait has virtually no natural water to exploit [7]. The latest SDG 6.4.2 indicators showed that Kuwait has the highest level of water stress (~3850%) among 177 countries assessed [8]. This level far exceeds the critical threshold (80%), leading the World Resources Institute to classify the country’s water scarcity as ‘extremely high’ [8]. Moreover, rapid population growth and the effects of global climate change exert additional pressure on Kuwait’s limited natural freshwater resources, increasing national economic, environmental, and social sustainability risks [9]. To address these challenges, Kuwait has long depended on the

Received: 19 Dec 2025
Accepted: 6 Jan 2026
Published: 9 Jan 2026

expensive, energy-intensive, and ecologically detrimental desalination process of seawater from the Persian Gulf. In fact, Kuwait was the first country in the world to commission a desalination plant for drinking water in 1951 [7], exemplifying its early reliance on technological solutions for water supply. Recently, however, the country has progressively adopted the full-cycle water reuse approach as a key component of its broader strategy to strengthen national water security through innovative wastewater reclamation techniques within sustainable practices [10].

Kuwait officially began using treated wastewater effluent (TWE) in the mid-20th century to irrigate experimental farms with alfalfa (*Medicago sativa*), trees, and other plants [11]. In the 2010s, the country treated virtually 100% of its wastewater generation, which increased from 0.6 to 1.8 MCM/d in response to an expanding number of inhabitants and higher water consumption. A cornerstone of this capacity expansion was the Sulaibiya wastewater reclamation facility—at its 2004 inauguration, the world's largest membrane-based water reuse plant—capable of treating about 0.375 MCM/d of effluent via advanced ultrafiltration and reverse osmosis [12]. Although the volume of TWE reuse also increased from ~0.42 to ~0.74 MCM/d, its percentage decreased from ~70% to ~41% [10]. This indicates that a large volume of excess TWE was discharged into Kuwait Bay, raising serious environmental concerns, including marine pollution, risks to fisheries, and stress on the coastal ecosystem [13]. Indeed, recent monitoring shows that emergency outfalls releasing surplus effluent into Kuwait Bay have elevated nutrient (phosphate) levels and fecal bacteria counts above regulatory standards, highlighting significant pollution risks to the bay's marine life and public [14]. Hence, the national water security strategy, in alignment with Kuwait Vision 2035, emphasized developing wastewater treatment infrastructure, increasing reclaimed water storage capacity, and ultimately achieving zero TWE discharge into the sea, as exemplified by the Umm Al-Hayman Wastewater Treatment Plant (UAH) project.

As a flagship critical infrastructure project in the Middle East, the UAH has been operational since February 2024, employing advanced treatment technologies for purifying up to 0.5 MCM/d of wastewater from about one-third (~1.7 million) of Kuwait's population [15]. This state-of-the-art public-private partnership was developed at an investment of approximately €1.6 billion, and plans are in place to expand its treatment capacity to 0.7 MCM/d in the coming years [16]. A 450-km pipeline network, together with three pumping stations, conveys wastewater to the UAH plant and then distributes reclaimed effluent into 39 reservoir tanks with a combined storage capacity of ~0.4 MCM [17]. As a safeguard mechanism, an emergency sea outfall system discharges excess TWE into the Persian Gulf during peak flows or unforeseen disruptions [15]. Providing high-quality reclaimed water, the facility not only supports public health but also protects Kuwait Bay's marine ecosystem [18]. The UAH's advanced treatment train ensures that its effluent meets stringent quality standards,

making it suitable for safe reuse in agriculture, industry, and other non-potable [16]. Biogas generated during the treatment process provides about 40% of UAH's energy demand, while the remaining 60% is supplied by a newly constructed 300-kV power substation on site. The UAH also recovers nutrients from wastewater to produce ~100,000 CM of Class A fertilizer annually [17]. Moreover, it significantly contributes to Kuwait's long-term economic development by reducing the costs of freshwater production while creating employment opportunities during both the construction and operational phases [15]. Further reinforcing its reuse capacity, Kuwait has approved construction of the North Kabd wastewater treatment facility—poised to be the country's largest, with a 1.0 MCM/d treatment capacity—in partnership with China [19]. Although such measures play a significant role in enhancing water security and sustainability in Kuwait, the national efforts toward 100% reuse of reclaimed wastewater are a progressive goal for the country [10].

In Kuwait, the reuse of TWE has been primarily limited to agricultural (e.g., fodder crops) and landscaping (e.g., grass, plants, trees, and bushes) irrigation. To achieve full-cycle water reuse, however, the country is steadily expanding the application of TWE for industrial (e.g., boiler feed, concrete mixing, and cooling water), urban (e.g., car washing, toilet flushing, and fire protection), and environmental (e.g., hunting clubs, golf courses, and artificial groundwater recharge) purposes [10]. With the UAH, Kuwait is now also able to produce TWE specifically for oil exploration, as requested by the Kuwait Oil Company (KOC). This initiative allows the oil industry to curb its freshwater consumption: KOC plans to utilize reclaimed wastewater (including RO brine by-products) for oil field operations, thereby reducing the use of valuable desalinated or groundwater resources in petroleum [20]. Together, all these efforts position Kuwait as a leading model for how countries facing high water stress can strengthen their water resilience by developing and implementing TWE reuse strategies, while simultaneously promoting national, regional, and global sustainability [20]. Moreover, Kuwait is a founding member of the Global Water Organization—a new alliance of severely water-stressed nations—underlining its commitment to collaborative solutions for global water sustainability [19]. Sharing such national experiences can foster knowledge exchange, reduce potential conflicts, strengthen transparent decision-making, and support the communal actions crucial for international cooperation on global water security.

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How to cite this article:
Irannezhad M, Sadeqi A, Assad A, Abdulghafour Z, Abbas H, Farooq U, et al. From scarcity to sustainability: Kuwait adopts full-cycle water reuse. J Sustain Res. 2026;8(1):e260003. https://doi.org/10.20900/jsr20260003.