



Comparative Assessment of Tehran Wastewater Treatment Plants against International Standards

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Article Info

Article type:

Research Article

Article history:

Received: 2026/01/27

Received in revised form:
2026/02/19

Accepted 2026/02/27

Available online: 2026/03/06

Keywords:

Effluent standards,
International comparison,
Resource recovery,
Sewage treatment plants,
Water reuse Wastewater.

ABSTRACT

This study provides a comprehensive analytical assessment of Tehran's municipal wastewater treatment infrastructure, evaluating its operational performance and technological alignment with contemporary international benchmarks. Given the escalating pressures of water scarcity and rapid urbanization, assessing these facilities—specifically the South Tehran, West Tehran, and Firoozbahrām plants—against global standards is vital for sustainable urban resource management. The methodology employed a systematic descriptive-analytical approach, synthesizing technical data, regulatory frameworks, and literature to compare local operations with the US EPA, WHO, EN 12255, and the updated European Union Urban Waste Water Treatment Directive (UWWTD 2024/2025). The evaluation focused on four core pillars: treatment capacity, process configuration, water reuse practices, and energy recovery potential, with particular attention to the anaerobic digestion and biogas generation systems utilized at the South Tehran facility. Results indicate that while Tehran's WWTPs have achieved significant milestones—such as expanding infrastructure capacity, increasing industrial water reuse, and integrating basic renewable energy technologies—the sector faces critical systemic challenges. Specifically, the current infrastructure exhibits incomplete nutrient removal and the emergence of micro-pollutants, underutilization of design capacities, and partial compliance with the stringent energy-neutrality targets mandated by updated global frameworks. Although Tehran's wastewater treatment plants have made substantial progress, achieving full alignment with global standards requires a strategic transition. This study identifies the need for immediate technological upgrades, including implementing Advanced Process Control (APC) systems, integrating quaternary (fourth-stage) treatment technologies to address micro-pollutants, and committing to energy-neutral operational pathways. Enhanced regulatory oversight, rigorous monitoring programs, and the expansion of sludge-to-energy configurations are recommended to optimize treatment efficiency and ensure long-term environmental sustainability amid climate-induced water challenges.

Introduction

The urban water metabolism of Tehran, as a burgeoning metropolis, is currently confronting profound and multifaceted challenges. These challenges stem from a confluence of factors, including rapid population growth—which has placed unprecedented demand on finite water resources—climate-induced hydrological variability characterized by prolonged droughts and erratic precipitation patterns, and the pressing imperative of environmental preservation amid mounting pollution pressures. In the broader context of the Middle East, a region where water scarcity represents an existential threat to socioeconomic stability and public health, the role of municipal wastewater treatment plants (WWTPs) has undergone a significant transformation. No longer viewed merely as basic sanitation facilities, these plants are now recognized as fundamental pillars of water security and as critical enablers of the circular economy, offering opportunities for water reuse, nutrient recovery, and energy generation. Annually, Tehran generates a massive volume of municipal wastewater, estimated at over 1.2 million cubic meters per day. A significant portion of this volume remains either untreated or only partially treated, posing potential risks to the quality of regional aquifers—which serve as strategic reserves for the city—and threatening the agricultural integrity of the Varamin plains, a vital food-supply zone for the capital. Although domestic regulations have been established to govern effluent quality, these standards often lag behind evolving international benchmarks. The escalating global shift toward more stringent and comprehensive frameworks, such as the European Union’s recast Urban Waste Water Treatment Directive (Directive (EU) 2024/3019), demands a thorough re-evaluation of Tehran’s existing infrastructure. This new directive places greater emphasis on nutrient removal—particularly nitrogen and phosphorus—to combat eutrophication, promotes energy neutrality or even positive energy balance in treatment processes, and addresses the growing concern over emerging micropollutants, including pharmaceuticals and microplastics, which conventional treatment systems are ill-equipped to handle. The central research problem addressed in this study is to determine the extent to which Tehran’s major treatment facilities—specifically South Tehran and West Tehran (Firoozbahrām)—are aligned with contemporary global best practices. This investigation is not merely an academic exercise; it constitutes a strategic requirement for enhancing the resilience of Tehran’s water resources, informing evidence-based policy decisions, and guiding future investments in infrastructure upgrades that are both economically viable and environmentally sustainable.

Method

This research adopted a descriptive-analytical approach, utilizing a systematic review of international technical standards and a comparative synthesis of national operational data. The methodology was structured into three analytical stages. First, a comprehensive literature review was conducted to extract the core requirements of global benchmarks, including the US EPA’s NPDES program, the World Health Organization (WHO) guidelines for safe wastewater reuse, and the EN 12255 European standards for WWTP performance. Second, quantitative and qualitative data regarding the technological configuration of Tehran’s primary plants—specifically their biological reactor designs, sludge handling units, and energy management systems—were collected from official government disclosures and existing life cycle assessment (LCA) studies. Finally, a gap analysis was performed to compare local operational outputs with international benchmarks, identifying specific bottlenecks in nutrient attenuation and energy recovery. This methodology ensures that the findings are grounded in empirical operational realities while remaining sensitive to global environmental trends.

Results

The findings reveal a nuanced landscape of infrastructure maturity in Tehran. The South Tehran WWTP, which acts as the city's primary facility, serves over four million population equivalents and utilizes a combination of conventional activated sludge and anaerobic digestion. The performance data indicates that the facility effectively mitigates conventional pollutants such as BOD₅, COD, and TSS, consistently meeting national discharge requirements. Furthermore, the integration of a Combined Heat and Power (CHP) unit at this site demonstrates a localized effort to recover energy from sewage sludge, contributing to the site's energy demand. In contrast, the West Tehran and Firoozbahram facilities utilize advanced A₂O (Anaerobic-Anoxic-Oxic) biological nutrient removal configurations. These plants represent a technological leap, demonstrating higher efficiency in biological phosphorus and nitrogen removal compared to older conventional units. However, when scrutinized against the updated international frameworks, several systematic weaknesses become apparent. The most critical gap is the lack of a quaternary treatment stage. While current systems remove organic matter and suspended solids, they are largely ineffective against micropollutants, such as endocrine-disrupting chemicals, synthetic pharmaceutical residues, and microplastics. Furthermore, while the South Tehran plant attempts energy recovery, true "energy neutrality"—where the facility generates as much renewable energy as it consumes—remains largely unattainable with current configurations. The carbon footprint associated with intensive aeration processes remains a significant environmental burden, as identified through recent LCA studies. The discrepancies between Tehran's current performance and the emerging global standards highlight the need for a shift in operational paradigm. The current reliance on secondary treatment is no longer sufficient to ensure long-term environmental sustainability in sensitive catchments. The transition to a circular economy in the water sector requires moving beyond "treatment and discharge" toward "resource recovery and reuse." From a policy perspective, the transition to energy-neutral operations should be prioritized. This requires not only technological upgrades, such as the adoption of solar energy arrays on site or advanced anaerobic digestion optimization, but also the implementation of real-time monitoring through Advanced Process Control (APC) loops. By utilizing digital twin technologies or smart sensors to optimize aeration rates, energy consumption can be reduced by 15-20% without compromising water quality. Moreover, the integration of "extended producer responsibility" (EPR) mechanisms—where the chemical and pharmaceutical industries contribute to the funding of quaternary treatment—represents a viable pathway for financing the necessary facility upgrades.

Conclusions

Tehran's wastewater infrastructure has made significant progress in recent decades; however, it stands at a critical technological crossroads. Achieving alignment with global benchmarks such as the recast EU directive is not only a regulatory necessity but an environmental imperative to protect public health and ensure water security. To bridge the current gaps, this study recommends a three-phased roadmap. Gradual deployment of quaternary treatment technologies, such as ozonation and granular activated carbon filtration, to address micropollutants. Expansion of the anaerobic digestion and biogas infrastructure to all major facilities, coupled with the adoption of smart grid technologies to balance on-site energy demand. Implementing more rigorous, independent monitoring programs to ensure consistent compliance with international microbiological and chemical parameters. By adopting these strategic transitions, Tehran can leverage its existing infrastructure to create a climate-resilient, circular water management system that serves as a model for other rapidly growing cities in the region.

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