Insights from 20 Years of TSE REUSE in Saudi Arabia: Challenges, Future Programs, and Balancing Multi-Use Supply and Demand

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1. Introduction

Treated Sewage Effluent (TSE) reuse is a critical pillar in Saudi Arabia's efforts to address water scarcity and fulfill its sustainability goals, especially in a country where freshwater resources are extremely limited. The Kingdom has set ambitious national Key Performance Indicators (KPIs) for TSE reuse, aiming to reuse 70% of treated wastewater by 2030, a significant increase from the 15% reuse rate in 2016. This target is aligned with Saudi Arabia's Vision 2030, which emphasizes the efficient use of non-conventional water resources to reduce reliance on groundwater and desalinated water.

Achieving this KPI will require scaling up infrastructure, enhancing water treatment technologies, and ensuring widespread acceptance of TSE across multiple sectors. The presentation will explore how Saudi Arabia has progressed toward these goals over the past 20 years, while identifying the key challenges and opportunities for the future.

2. Historical Development of TSE Reuse in Saudi Arabia

2.1. Early Initiatives

The Kingdom initiated its journey into TSE reuse in the early 2000s as part of a broader effort to diversify its water resources. This was driven by increasing demand for water in industrial and agricultural sectors and a growing awareness of the need to conserve freshwater resources for more critical uses. Initial projects focused on using TSE for agricultural irrigation and industrial cooling processes, which required less stringent water quality standards.

2.2. Policy and Regulatory Framework

The regulatory framework supporting TSE reuse has evolved significantly over the past two decades, with the most recent milestone being the approval of the **Water Law in 2023** by the Ministry of Environment, Water, and Agriculture (MEWA). This law consolidates various water management regulations under a unified framework that promotes efficient water use, water conservation, and the sustainable management of non-conventional water resources like TSE. The law also outlines specific guidelines for wastewater treatment plants (STPs), ensuring that TSE meets the quality standards required for its intended reuse applications, whether in agriculture, industry, or urban landscaping.

The Water Law emphasizes the importance of Integrated Water Resource Management (IWRM) to coordinate the use of conventional and non-conventional water resources across sectors.

2.3. Technological Advancements

Over the years, Saudi Arabia has invested heavily in wastewater treatment technologies, which have evolved from basic biological treatments to advanced systems involving membrane bioreactors (MBRs), reverse osmosis (RO), and ultraviolet (UV) disinfection. These technologies have enhanced the quality of treated wastewater, enabling its use in a wider range of applications, including agriculture, industry, and municipal landscapes.

3. Key Challenges in TSE Reuse

3.1. Infrastructure Development

Despite progress, the development of infrastructure to store and distribute TSE remains a challenge. Expanding the pipeline network and adding storage capacity to serve remote agricultural areas and industrial zones is critical to meeting the 2030 reuse targets. Additionally, integrating TSE distribution with existing water supply systems poses logistical and financial challenges.

3.2. Public Perception and Acceptance

Public acceptance of TSE for uses such as agricultural irrigation and landscaping has been slow, despite comprehensive awareness campaigns. Overcoming the psychological barrier associated with using treated wastewater is essential for expanding its use in urban settings and even for aquifer recharge in future projects.

3.3. Water Quality Standards

Different sectors, such as agriculture and industry, have varying water quality requirements. Ensuring that TSE meets these sector-specific standards while minimizing treatment costs presents an ongoing challenge. The regulatory framework established by the Water Law (2023) provides a foundation, but continuous monitoring and upgrading of treatment technologies will be necessary.

3.4. Environmental and Health Concerns

While TSE reuse contributes to water sustainability, there are concerns about the long-term environmental impacts, such as soil salinity and potential contamination from trace chemicals. Continuous monitoring and research are required to mitigate these risks and ensure that TSE remains a safe and viable resource for future generations.

4. Future Programs and Strategic Initiatives

4.1. Expanding TSE Infrastructure

To meet the 2030 target of reusing 70% of treated wastewater, Saudi Arabia is planning significant investments in wastewater treatment and distribution infrastructure. New treatment plants are being developed, and existing plants are being upgraded to increase capacity. The expansion of the TSE pipeline network is also a key component of the National Water Strategy, ensuring that more remote agricultural and industrial zones can access this vital resource.

4.2. Enhancing Water Quality and Standards

Ensuring that TSE meets the specific requirements of different sectors is essential for the success of reuse programs. As sectors like agriculture, industry, and urban landscaping have varied water quality needs, Saudi Arabia has developed stringent quality control measures to ensure that treated effluent is safe and suitable for its intended applications.

A key player in this effort is the Saudi Irrigation Organization (SIO), which plays a critical role in monitoring and regulating water quality before it reaches end users. The SIO oversees a dedicated laboratory that is equipped with advanced testing technologies to carry out rigorous quality checks on treated sewage effluent. This laboratory operates under a well-designed procedural framework, ensuring that the quality of TSE is consistently monitored and maintained before it is distributed for reuse.

The SIO's laboratory conducts comprehensive testing, including the analysis of biological contaminants, chemical pollutants, and physical properties of the treated water. This process ensures that the TSE meets national and international water quality standards, particularly for sensitive applications like agricultural irrigation, where water quality can impact soil health and crop productivity.

4.3. Public Awareness and Engagement

Building public trust in the safety and benefits of TSE reuse is a priority for the coming years. Future programs will include public education campaigns aimed at shifting perceptions and increasing acceptance of TSE for non-potable purposes. Engaging stakeholders across the agricultural, industrial, and urban sectors will be essential for achieving widespread adoption.

4.4. Research and Development

Ongoing research into the environmental impacts of TSE, particularly in terms of soil health, water table sustainability, and long-term ecological effects, will be critical for future programs. Studies on the energy efficiency of various treatment technologies and the potential for TSE reuse in new sectors, such as construction, aquifer recharge, and urban cooling, are also being explored.

SIO has been actively engaging in collaborative research efforts with local universities and international research institutions to address emerging challenges in TSE reuse. These collaborations have resulted in numerous studies that focus on optimizing the technical, environmental, and economic feasibility of using treated sewage effluent in diverse applications. For instance, research is underway to evaluate the potential of TSE irrigation on various crop types and its long-term effects on soil composition and salinity levels, with the aim of developing best practices for sustainable agriculture.

Moreover, partnerships with international centers such as the International Water Management Institute (IWMI) have provided valuable insights into global best practices in water reuse. These collaborations also allow Saudi researchers to contribute to the development of innovative treatment technologies and water governance frameworks that can be adapted to local conditions.

5. Balancing Production and Multi-Use Demand

5.1. Sectoral Demand for TSE

Demand for TSE in Saudi Arabia spans various sectors, including agriculture, industry, and municipal landscaping. Agriculture remains the largest consumer of TSE, but there is increasing interest in using treated wastewater for industrial processes, urban green spaces, and even construction activities, such as dust control and concrete mixing.

5.2. Strategic Study on Demand and Supply Governance

To address the growing complexity of balancing supply and demand, the Ministry of Environment, Water, and Agriculture (MEWA) conducted a **strategic study** examining the governance of TSE demand and supply up to the year 2075. This study employs a well-designed criteria-based analysis to estimate both the production capacity of each sewage treatment plant (STP) in the Kingdom and the projected demand across various sectors.

The study provides a roadmap for optimizing TSE distribution and ensuring that critical sectors receive priority access to this resource. It also highlights the importance of **data-driven decision-making**, emphasizing the role of real-time data collection and analysis in forecasting demand and aligning it with the available supply. Data analytics will be integral in managing TSE resources in a way that maximizes efficiency while minimizing waste and environmental risks.

5.3. Integrated Water Resource Management

Saudi Arabia is embracing an Integrated Water Resource Management (IWRM) approach to ensure that TSE is effectively integrated into the broader water supply system. This approach promotes the coordinated use of all available water resources—both conventional and non-conventional—in a way that meets the needs of multiple sectors while preserving environmental sustainability. The IWRM framework will play a critical role in achieving a balance between production and demand, ensuring that TSE is allocated efficiently and equitably across the Kingdom.

6. Conclusion

Saudi Arabia's 20-year journey in TSE reuse has yielded significant achievements, but challenges remain. The Kingdom’s ambitious goal of reaching 70% TSE reuse by 2030, supported by the 2023 Water Law, outlines a clear path forward. However, infrastructure expansion, public acceptance, and sectoral coordination will be crucial to achieving these targets.

The strategic study on demand and supply governance, conducted by MEWA and SIO, provides a solid foundation for future decision-making, ensuring that TSE production and demand are balanced effectively through 2075. By integrating innovative technologies, robust policies, and data-driven governance, Saudi Arabia is well-positioned to lead in sustainable water management in the coming decades.