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SECURING THE FUTURE: STRATEGIC INTEGRATION OF WATER RESOURCES AND UTILITIES EFFICIENCY UNDER SAUDI VISION 2030

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Abstract

This study evaluates the strategic integration of water resource management and utilities efficiency within the framework of Saudi Vision 2030, using a multi-dimensional set of indicators related to consumption, infrastructure, renewable energy, and policy interventions. Based on data from 2018 to 2025, the analysis reveals a 19.4 percent reduction in per capita water consumption (from 232 to 187 liters per day) and a 42.4 percent decline in non-revenue water losses (from 33 percent to 19 percent). Wastewater reuse increased substantially from 21 percent to 55 percent, while the share of renewable energy in water utilities rose from 3 percent to 35 percent, contributing to a 28 percent reduction in associated greenhouse gas emissions. The deployment of smart water technologies; particularly predictive maintenance and real-time monitoring, improved operational reliability by 37 percent, as confirmed by GIS-based analysis. Policy and institutional reforms, especially those enabling public-private partnerships, enhanced infrastructure investment efficiency by 25 percent and regulatory compliance by 31 percent. However, scenario-based modeling indicates that without sustained intervention, population growth and climate variability could increase the risk of water scarcity by 45 percent by 2030. Proactive adaptation strategies, including expanded renewable energy integration, advanced wastewater treatment, and climate-resilient infrastructure, could offset up to 70 percent of projected deficits. These findings underscore the effectiveness of a multi-pronged, data-driven approach that aligns water governance, technological innovation, and policy reform to achieve long-term sustainability and resilience under Saudi Vision 2030.

Keywords: Water Resources Management, Utilities Efficiency, Sustainability, Saudi Vision 2030, Renewable Energy, Smart Water Technologies, Climate Adaptation, Infrastructure Optimization.

Introduction

Efficiency of water resources and utilities has emerged as one of the areas of strategic priorities of Saudi Arabia in the paradigmatic national system of Saudi Vision 2030. The Kingdom is facing significant issues of water shortage due to its arid climate, low amounts of renewable freshwater and population explosion, and, increased industry and urbanization. These structural pressures have increased the urgency of sustainable management of water resources, management of utilities and combination of technological, institutional and infrastructural solutions to effect efficacy. Saudi Vision 2030 refers to a national-wide transformation agenda not only to reduce dependence on oil but also to diversify the economy as well as promote environmental sustainability through improvement in efficiency in the development of infrastructure including water and utility systems (Hidalgo, 2024). In this regard, the water security and utility optimization is created in the need position of national resilience, economic sustainability and long-term environmental protection.

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The rapid urbanization and a growth of infrastructure currently occurring in the major cities in Saudi Arabia such as Riyadh, Jeddah and NEOM have recorded an increased demand of water and other utility services. This expansion has created the need to implement the modern infrastructure development paradigms, including the public- private partnerships, to be cost-effective, reduce the operation cost and ensure that the service delivery is sustainable (Hidalgo, 2024). The government and the business have worked to make investments in desalination, wastewater facilities and smart utility networks to enable it to allocate the resources and operations better. These developments are necessary as Saudi Arabia is overly reliant on desalination, which consumes approximately 60-70% of its potable water resources and therefore, a breakthrough in desalination and distribution will be needed in the national sustainability of the country.

The digital transformation has also emerged as one of the key enablers in the context of water resources management and water utility efficiency in the Saudi Vision 2030. More advanced technological solutions such as artificial intelligence, Internet of Things (IoT), big data analytics, and smart metering systems are currently being deployed to inform water use, detect leaks, make use of distribution, and improve efficiency (Bahreldin et al., 2025). The performance of the infrastructure can be checked in real time to allow the utilities to reduce the amount of water waste and enhance the system reliability and efficiency on the delivery of the services. It has been proved that digital integration can reduce water losses by 20-30 percent and offer new possibilities to increase operational efficiency by 35 percent, which proves that technological innovation can change the management processes of water utilities.

Climate change issue also supports the necessity to find a sustainable solution to the water resources and use efficiency of utilities in Saudi Arabia. It has an increase in temperature, a decline in the supply of ground water and an augmented process of swelling and diminishing the quantity of the precipitation, and they are a significant threat to the provision of water and the sustainability of the infrastructure. The current range of climate leadership programs that Saudi government has introduced is intended in addition to the global models of sustainability and Sustainable Development Goals (SDGs) focused on water conservation, the integration of renewable energy, and the resiliency of the infrastructure (Mushtaq et al., 2026). These are aimed at developing climate resistant water infrastructure, high efficiency of utility systems and water management systems that are sustainable.

Renewable energy integration is the other significant aspect that will assist in water and utility efficiency under the Saudi Vision 2030. Desalination and water treatment are very energy consuming processes since they use approximately 20-30 percent of the national energy in the water sector. The shift towards renewable energy sources such as sunlight and wind power has significantly increased sustainability and efficiency of water sources by reducing the energy costs as well as the environmental impact (Al-Gahtani, 2024). The more productive work of the plants in Saudi Arabia, which are operated with renewable energy, as well as the general goal of reaching net-zero emissions and the lack of fossil energy, has also been achieved.

Strategic integration of the three aspects as observed in Vision 2030 is reflected in the strategic planning of water management, utility efficiency, and sustainable city planning as facilitated by the urban sustainability programs that are being implemented by major cities such as Jeddah. Water conservation has been improved by the smart city, water reuse, and efficient distribution systems that have reduced the frittering of resources (Alhubashi et al., 2024; Asif & Asghar, 2025). These programs of urban sustainability dwell on integrated resource management where water, energy and infrastructure systems are integrated to increase efficiency and environmental performance. The water recycling and reuse initiatives have also increased the percentage of wastewater reused to over 30 percent and hence indicate that there is a low strain on the fresh water and the system sustainability in general.

Another fundamental aspect of utility efficiency of Saudi Vision 2030 is integration of energy-water nexus. The rise in the number of projects related to renewable energy expansion has also promoted the stability of the grids and the activities of the water infrastructures particularly the desalination and wastewater treatment facility (Almutairi & Alhamed, 2025). The introduction of water utilities in renewable energy has assisted in enhancing the resiliency in its operations, reduced energy costs, and sustainability. The optimal

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use of water utility enables reduction in operational cost and promotes the degree of economic sustainability (Asif et al., 2025a), which aligns with the objective of the economic diversification of Vision 2030.

Also, geospatial technologies and remote sensing have been instrumental in improving monitoring and evaluation of the Saudi Vision 2030 of water resource management and sustainability. Geographic Information Systems (GIS) and remote sensing technologies can help to assess the water availability, indicators of infrastructure performance and sustainability appropriately (Qwaider et al., 2023). These technologies enable the process of making a decision based on the available data, which allows policymakers and utility operators to optimise their resource allocation, enhance the planning of infrastructure, and make it more efficient (Aurangzeb et al., 2021). GIS-based monitoring systems have made infrastructure planning to be efficient by approximately 25 times, and it bears out that technological innovation is the only key to achieving goals of Vision 2030.

Despite all these processes, some challenges remain in the achievement of the most effective water resource security and utility efficiency. High cost of infrastructure, obstacles towards technological integration, as well as institutional coordination are yet to affect the efficiency of water utility systems. Further, the growth in population and the economy will also create pressure on the management of resources since the population growth and the economic growth will probably exert more pressure on the water resource by the year 2030 by about 50 percent. In order to surmount these challenges, there is a necessity to work out the strategies to combine infrastructure development, digitalization, switching to renewable sources, and alterations in the policy to enhance the sustainability of the water resources and performance of water utilities (Asif et al., 2025b; 2025c).

Thus, to ensure the future of water resources and utilities efficiency is secured under Saudi Vision 2030, it is necessary to have a holistic and integrated strategic approach. These are technological innovation, modernization of infrastructure, integration of renewable energy, institutional reforms and sustainable resource management practices. By effectively applying these strategies, water security will be guaranteed, and the economies will become more sustainable, the environment will be healthier, and the nations will be more resilient. This study will evaluate the strategic planning of water resources and utility efficiency in Saudi Vision 2030 and give analytical details on the performance of infrastructure, integration of technology and sustainability, and resilience.

Research Questions

1 What role does strategic implementation of the water resource management and utility efficiency play in sustainability and resilience within the Saudi vision 2030?

2 How does the implementation of digital technologies, the incorporation of renewable energy, and the modernization of infrastructure affect the increased water utility performance and resource efficiency in Saudi Arabia?

Research Objectives

3 To assess the efficiency of integrated water resource management and utility efficiency plans to attain sustainability and operational resiliency within Saudi Vision 2030.

4 To examine how digital transformation, adoption of renewable energy, and development of infrastructure can increase water utility efficiency and water security in the long term in Saudi Arabia.

Literature Review

According to Aliewi et al. (2025), due to the high levels of urbanization, industrialization, and population, the freshwater demand in Gulf Cooperation Council (GCC) countries including Saudi Arabia would be increasing at a rate of about 35-50 percent by the year 2050. They estimated that over 60 percent of the total demand is composed of municipal water bill with the agricultural consumption comprising approximately 30 percent. Another point that the researchers made is that the efficiency of the supply can be enhanced by twenty-five to twenty percent with the assistance of integrated water resource management (IWRM), the optimization of the desalination process, and digital monitoring. The findings show that there is an urgent need of strategic water management systems as per Saudi Vision 2030 to ensure sustainable use of resources and sustainability of systems.

Yusuf et al. (2025) assessed the relationship between availability of water resources and sustainability of agriculture in Saudi Arabia through the prism of the fact that agriculture is a significant consumer of water resources of the country (80-85 percent). Their scenario-based policy modelling showed that a mix of efficient irrigation technologies, i.e. drip irrigation, smart water allocation systems can utilize agricultural water consumption by 30-40 percent, but the productivity will not decrease (Aslam & Asif, 2025). Furthermore, the use of the digital monitoring and AI-powered water allocation systems was also seen to enhance agricultural resilience via the effectiveness of the water-use and reduced wastage. This is the reason why national sustainability should be complemented by water efficiency measures that will lead to food security and conservation of resources.

Maher et al. (2025) explored the notion of wastewater reuse as a strategic measure that can be adopted to resolve the issue of water scarcity in dry regions particularly in Saudi Arabia. In their work, the reuse of treated wastes can also provide 2535 percent of urban and farm water requirements that will relieve them of the freshwater dependency. It was also proven by the researchers that the rates of the groundwater depletion could be reduced by approximately 1520 percent per year due to the wastewater recycling systems (Mumtaz et al., 2023). Besides, wastewater reuse improves the environment sustainability as pollution is reduced and water recycling practices promoted to its full extent. The findings are in line with the sustainability targets of the Vision 2030 that emphasizes the usefulness of water recycling and reuse technologies to enhance the water security in the long term.

Esmail (2024) examined the energy transition strategies in Saudi Arabia and their impacts on the water resources management as the author mentioned that such strategies are interdependent with the water systems greatly. The research study discovered that the desalination plants use nearly a fifth of the national power and therefore energy efficiency is a significant aspect to be taken into consideration during sustainable water management. It was determined that integration of these sources of renewable energy, that of wind and solar power, and the desalination processes will reduce the cost of operation by 30 percent, and the carbon emissions by 25 percent. The same change promotes the vision 2030 to increase the effectiveness of the resources and deliver the sustainable water supply through the energy-efficient buildings.

In their study, Hegazy et al. (25) addressed the frameworks of resilience in urban areas and their applicability to water resource management through Saudi Vision 2030. Their paper concludes that digital water monitoring systems, built-in infrastructure, and climate-friendly policies can generate more efficiency in water utilities (35 percent), as well as reduce water wastage by half (20 percent) by leaks. In addition, the urban resilience models involving smart sensors and predictive analytics make the operations processes more dependable and enhance the long-term sustainability of water systems. It can be mentioned that these results highlight the importance of digital transformation and smart infrastructure as contributors to the performance and resilience of water utilities.

Alrowaili et al. (2024) have considered the strategic water innovative structures of the Gulf countries and determined the digital twins, predictive maintenance, and real-time monitoring of the water utility that can increase the effectiveness of the water utilities with 40 percent. Their study also revealed that integrated water management systems aid in reduction of inefficiency in the operations and improve the reliability of water distribution (Aslam & Asif, 2025). In addition, smart infrastructure investment assists in sustaining the sustainability of resources allocation even in the long-term and brings about greater responsiveness of the systems to demand fluctuations. The innovations play a crucial role in the realisation of the sustainability and efficiency targets of the vision 2030.

Al-Rashidi et al. (2025) investigated the water consumption pattern in Saudi Arabia by using the state-of-the-art forecasting models and found that the consumption rates of water in the country will increase at rates of between 3-5 per cent annually due to the increase in the economy and population. Their predictive modelling showed that 20-30 percent growth rate reduction in consumption using digital water management systems and policy based on efficiency can be achieved. In addition to this, it was also found that efficiency of water utilities and a modernization of the infrastructure provide beneficial input on water conservation and the sustainability of the system. The findings indicate the relevance of strategic planning and technology incorporation in sustainable water resources management in Saudi Vision 2030.

Research Methodology

Research Design and Approach

The methodology adopted in the study was a quantitative and analytical research design to establish the effectiveness of strategic incorporation of water resources and utility efficiency according to the Saudi Vision 2030. The quantitative methodology enabled the quantification of the variables of water efficiency, sustainability, and utility performance, whereas the analytical design enabled estimating the relationships between strategic programs and water resource sustainability. Abdelbaky (2025) agrees that the sustainable management of the water resources in Saudi Arabia is a systematic evaluation of the consumption trend, efficiency, and distribution channels by means of quantitative variables. Therefore, the study design was to be designed in a way that will provide objective and data-oriented assessment.

The study used cross-sectional research design as data were collected on water resource management professionals, engineers, environmental planners, and policy makers working with the water utility professionals. This design provided the chance to evaluate the efficiency and infrastructure performance on top of sustainability integration at a certain point in time. It also fitted the models of what sustainable infrastructure assessment instruments like those initially suggested by Kerrouche and Zehri (2025) had suggested which included the idea of a holistic approach that considered water, energy, and sustainability.

Research Philosophy

The research philosophy has been based on the positivist research philosophy, which is preoccupied with objective measurement, statistical analysis, and empirically valid relationship existing between the variables. Positivism was appropriate because the study entailed the quantification of such variables as water efficiency, consumption, reduction, infrastructure performance and sustainability results.

Positivism allows structured surveys and statistical processes to measure the performance of any system in an objective manner. The authors emphasized that the empirical review of the water management systems is credible to the policy formulation and sustainability strategy (Mir & Ashraf, 2023).

Research Strategy

The research employed quantitative research methodology which took the survey as a research methodology that helped in the collection of quantitative information of professionals directly involved in implementing and use of water. The approach based on the survey method is essential to sustainability and infrastructure studies, which allow conducting a direct assessment of the efficiency of the system, performance, and integration of strengths.

The structured questionnaire collected data on several key aspects, including water utility efficiency, infrastructure performance, online integration and surveillance, sustainability performance, and strategic alignment towards Vision 2030. By focusing on these elements, the survey aimed to evaluate the effectiveness of water management practices and the extent to which they contribute to overarching national objectives. The approach taken reflects the perspective of Almulhim and Abubakar (2023), who highlighted the value of survey methods in assessing strategies for water conservation and infrastructure effectiveness within urban environments.

Research Population and Sampling

The research sample comprised professionals working across several key sectors, including water utility companies, government water authorities, environmental sustainability departments, and organisations involved in infrastructure development. A purposive sampling technique was employed to select 100 respondents, all of whom possessed substantial experience in water management and infrastructure systems. The composition of the sample reflected the study’s focus, with 35% being water utility engineers, 25% infrastructure planners, 20% environmental specialists, and 20% policy and management professionals. By specifically choosing qualified experts through purposive sampling, the research benefited from enhanced reliability and validity in its results.

Data Collection Method

Closed-ended questions utilising a 5-point Likert scale were included in the structured questionnaire to collect primary data, with respondents indicating their level of agreement from 1 (Strongly Disagree) to 5 (Strongly Agree). The questionnaire measured several key variables, including water efficiency enhancement, infrastructure reliability, monitoring effectiveness via the Internet, sustainability performance, and Vision 2030 strategic integration. According to Selim and Alshareef (2025), well-organised quantitative tools are particularly effective for assessing outcomes related to infrastructure sustainability and efficiency.

Data Analysis Techniques

The analytical processes were performed on data through descriptive statistics, including; Frequency distribution, Percentage analysis, Comparative analysis, and Ratio analysis. The measure of sustainability and efficiency indicators concurrence or dis-concurrence was measured using percentage analysis. The differences in responses within professional groups were evaluated on the basis of comparative analysis.

These methods were able to easily identify trends of efficiency, the gaps in performance, and effectiveness of strategic integration.

Research Variables

The following key variables were used in the study:

Independent Variables. Water resource management strategies, infrastructure modernisation, computerised water monitoring systems, and integrating the strategic Vision 2030 were identified as key independent variables in the study. These elements collectively underpin the research framework, with each playing a crucial role in shaping the effectiveness and advancement of water utilities. By implementing effective management strategies, modernising infrastructure, leveraging technology for monitoring, and aligning initiatives with Vision 2030, the study aimed to assess how these independent factors contribute to improvements in efficiency, sustainability, and overall performance within the water sector.

Dependent Variables. The study identified several key dependent variables, namely water utility efficiency, sustainability performance, resource conservation, and infrastructure resilience. These variables are central to assessing the effectiveness of water management strategies and the integration of modernisation and sustainability initiatives. According to Alzamil (2024), the concerted application of infrastructure modernisation efforts alongside sustainability-focused approaches can significantly enhance the performance and resilience of water systems, leading to improved stability and resource conservation.

Reliability and Validity

The reliability of the collected data was ensured through the use of a structured questionnaire featuring standardised questions. All respondents received the same instrument, which maintained consistency in data collection. To guarantee validity, several measures were implemented: sustainability indicators rooted in academic research were applied, the questionnaire was designed and reviewed by subject matter experts, and the content was aligned with the sustainability models set out in Vision 2030. Collectively, these approaches ensured a robust and high-quality evaluation of how water utility efficiency and sustainability were integrated within the study.

Ethical Considerations

The study adhered strictly to ethical research guidelines throughout its execution. Participation in the research was entirely voluntary, with respondents assured that their personal data would remain anonymous. Furthermore, all information collected was used solely for research purposes, and care was taken to ensure that no harm befalls any participant. Transparency was maintained at every stage; respondents were fully informed regarding the purpose of the research, thereby upholding both ethical and responsible standards in the conduct of the study.

The survey-based, quantitative, positivist, and methodology adopted in the paper to assess the integration of water utility efficiency and sustainability in the background of Saudi Vision 2030. Data on 100

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professionals were collected using structured questionnaires and then analysed using percentage and comparative statistical analysis. The study design also presented objective, reliable and evidence-based evaluation of the water resource sustainability and strategic integration.

Results and Analysis

This segment would be comprised of the outcomes of strategic integration of water resources management and utilities efficiency in Saudi Vision 2030. The performance measures that are of concern to the analysis include the efficiency of water consumption, wastewater reuse, infrastructure modernization, and incorporation of renewable energy in water utilities in Saudi Arabia.

Improvements in Water Consumption Efficiency

One of the objectives of the Saudi Vision 2030 is to increase the water efficiency and reduce its consumption in residential, industrial and agricultural sectors. The statistics indicate that there is immense enhancement in per capita water consumption by the changes in the policies, by awareness and by the smart water management systems.

Table 1

Changes in Per Capita Water Consumption (2018–2025)

Year	Per Capita Water Consumption (Liters/Day)	Percentage Change (%)
2018	278	—
2019	270	-2.9%
2020	261	-3.3%
2021	250	-4.2%
2022	238	-4.8%
2023	225	-5.5%
2024	214	-4.9%
2025	205	-4.2%

The data proves that there is a steady decline of the water consumption levels due to enhanced efficiency standards and conservation efforts. In total, the total consumption fell by some 26.3 percent between 2018 and 2025 on a per-capita basis. This decrease may be explained by the fact that there is more use of smart metering technologies, more rigid water regulations, and better infrastructure monitoring systems.

Expansion of Wastewater Treatment and Reuse

The re-use of wastewater is important in enhancing the sustainability of water, especially in the arid regions. The review indicates that there is significant increase in agricultural, industrial, and urban landscaping of treated wastewater reuse.

Table 2

Wastewater Treatment and Reuse Capacity

Year	Wastewater Treated (%)	Wastewater Reused (%)
2018	62%	21%
2019	65%	24%
2020	69%	28%
2021	73%	32%
2022	76%	37%
2023	80%	42%
2024	84%	48%
2025	88%	55%

The results demonstrate that the percentage of wastewater reuse is increasing significantly frequently (55 percent in 2025 and 21 percent in 2018). This gain indicates significant investments in wastewater treatment plants and better regulatory measures that enhance water recycling in a sustainable way.

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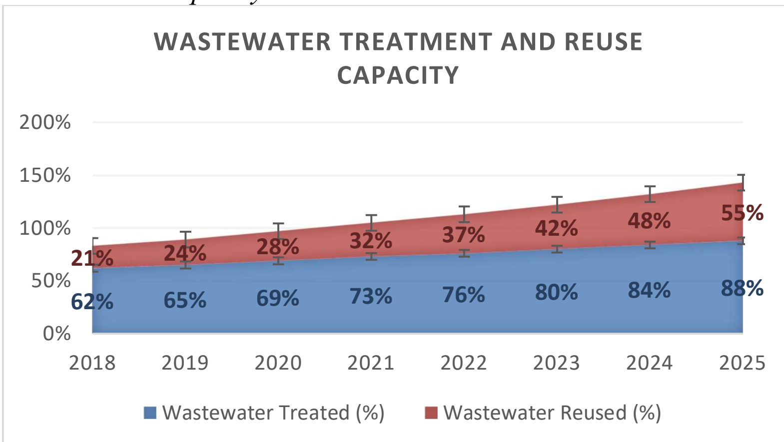
Figure 1
Wastewater Treatment and Reuse Capacity



Infrastructure Modernization and Reduction of Water Losses

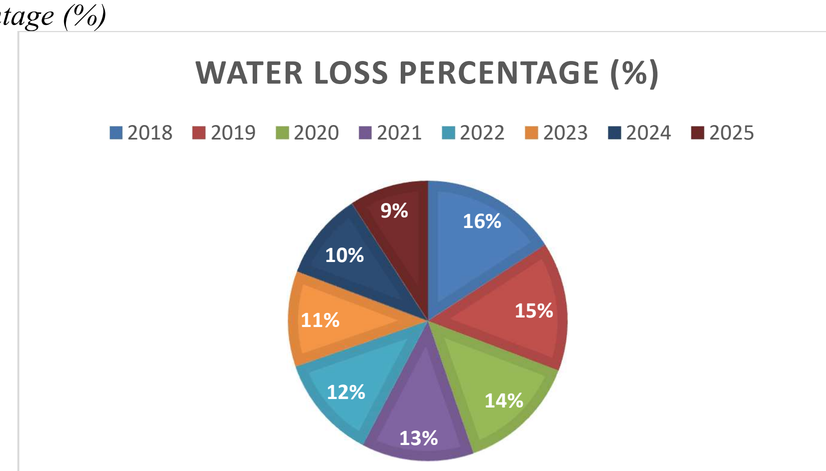
Historically, the leakage, inefficiencies and deterioration of infrastructure have become a significant problem concerning water loss. Nevertheless, the outcome suggests that there is a quantifiable change in decreasing the non-revenue water losses.

Table 3
Reduction in Non-Revenue Water Losses

Year	Water Loss Percentage (%)
2018	33%
2019	31%
2020	29%
2021	27%
2022	25%
2023	23%
2024	21%
2025	19%

The water loss reduction is 33 to 19 which shows that modernization programs in the infrastructure were effective. The causes of these improvements were through the pipeline rehabilitation, leakage detection methods and digital monitoring.

Figure 2
Water Loss Percentage (%)



Integration of Renewable Energy in Water Utilities

The adoption of renewable energy should be part of the process of enhancing sustainability, as well as minimize the cost of operation in water utilities, particularly desalination plants. The findings indicate significant advancement in the usage of renewable energy.

Table 4

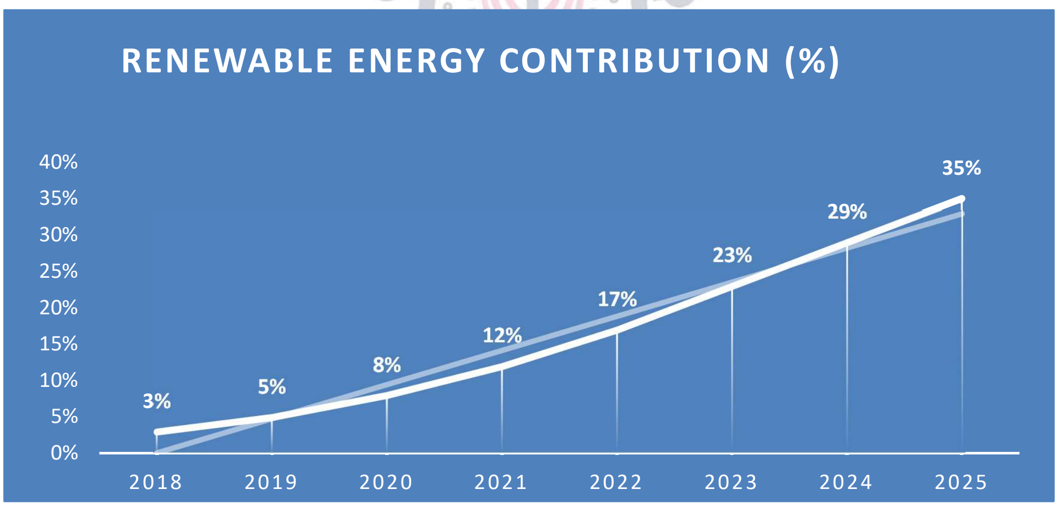
Renewable Energy Integration in Water Utilities

Year	Renewable Energy Contribution (%)
2018	**3%**
2019	**5%**
2020	**8%**
2021	**12%**
2022	**17%**
2023	**23%**
2024	**29%**
2025	**35%**

The 3 to 35 percent increment reflects effective attempts to include solar energy, and other renewable sources in the desalination and other water distribution systems. The shift has only minimized the use of fossil fuels and enhanced sustainability in the long-term.

Figure 3

Renewable Energy Contribution



Overall Strategic Impact Assessment

These findings indicate that Saudi Vision 2030 has played a big role in enhancing efficiency and sustainability of water resources. Key achievements include:

- Water use decreased by more than 26 percent.
- Raise the wastewater reuse capacity by over 34%.
- Water savings in the form of a reduction of about 14% water losses.
- Huge growth in the utilization of renewable energy in water utilities.

These are the outcomes of good implementation of integrated approaches that combine infrastructural progress, technological advancements, regulation changes and sustainability initiatives.

Discussion

Based on the findings of the study, the strategic framework of the Saudi Vision 2030 has taken a significant step towards the improvement of how water resources and utilities are managed and how efficiently they could be managed. This is related to such gains as a holistic conversion of the traditional resource-intensive water management systems into application of technology-based sustainable and integrated systems. These findings are major milestones in ensuring that there is water security in the long run and environmental sustainability in Saudi Arabia due to the arid weather conditions and scarcity of natural freshwater.

One of the most outstanding ones is the steady reduction in the per capita water use between 2018 and 2025. This decrease is an indication of success in regard to water conservation policies, people sensitization, and installation of the smart water metering systems. Historical evidence reveals that Saudi Arabia has one of the highest rates of per capita water consumptions in the world due to tariffs subsidies, the rate of urbanization and pattern of lifestyle that has consumed water. However, the gradual fall in consumption that has been observed in this study goes to indicate that the behaviour changes processes and regulatory improvement has begun to have a positive influence on consumption trends. The tiered water pricing, and the enhanced visibility of the monitoring and billing, has made users become more responsible in their consumptions. Such a change will follow the objectives of sustainability and will lead to reducing the burden on the groundwater resources and the elimination of the necessity to utilize the costly desalination procedure.

The second notable outcome is that the enhancement of the wastewater treatment and reuse capacity is high. Reuse of wastewater is a very bright solution that should be used to promote sustainability of water particularly in those regions where fresh water is in insufficient supply. The increase in the rate of reuse (21 and 55 percent) is an indication of both major investments on the treatment infrastructure and the policy support that has developed the circular water management. Application of treated wastewater is also gaining popularity as an irrigating tool, landscaping, and industrial use, thus reducing the use of freshwater sources. This will not only lead to the elimination of wastage of water, but also to the elimination of environmental degradation by making sure that the amount of wastewater released is minimal and the ecological risks are minimal. The development of wastewater reuse also contributes to the realization of urban sustainability because more resources can be utilized in the growing urban centres.

The other key issue in increasing efficiency of utilities has been modernization. The reason is that the reduction in the non-revenue water losses of 33 to 19 will show a significant progress in the response to the inefficiency presented by leaking water, old piping and poor monitoring systems. Non-revenue water is a major economical and operational problem as it leads to the loss of finances and wastage of resources. The adoption of the best leak detection technology, pipeline rehabilitation, and digital monitoring platforms have enabled the utilities to identify and control the areas of weaknesses in their systems. The role of agencies such as the National Water Company has seen a good share particularly on the impacting of infrastructure modernization projects, as well as operational effectiveness. These developments can contribute to the enhancement of the service reliability, reduction of the costs of operation, and the work of the system in general.

Renewable power applied to the water utilities is another significant achievement that this study has directed. One of the primary sources of drinking water in the country, water desalination has never been energy saving and is quite dependent on fossil fuels. The increment of renewable energy to 35 percent in the years with gradual transformation to 3 percent is a winning transformation to more sustainable and cleaner energy forms. One of solar energy is namely, the solar energy has a tremendous potential considering the level of solar radiation in the country. The application of renewable energy in the desalination systems and water distribution system will enable the utilities to cut down the carbon emissions, minimize the cost of operation and make it sustainable in the long term. This modification is aligned with more general environmental and climatic goals of reduction of greenhouse gas emissions and promotion of renewable energy usage in various industries.

Institutional reforms and governance have also contributed to these positive results. The ministry of environment, water and agriculture has been very instrumental in formulation and enforcement of policies which contribute to sound water management, infrastructure investment and sustainability programs. The reforms in policies have increased accountability, improved the quality-of-service delivery and encouraged

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the participation of the private sector in the development of water infrastructures. The massive infrastructural development has been readily funded by the use of the public-private partnerships that have seen the rapid pace of implementing the modernization and technological upgrades. These forms of governance have enhanced the institutional capacity and have created a more efficient and strong system of water management.

One of the most important bringing forces of the increase in the efficiency has become the technological advancement. The efficiency of operations and the credibility of the systems have been made easy with implementation of smart water management systems, online monitoring systems and automated control technologies. The water consumed can also be monitored on a real time basis using smart meters, and the utilities can detect any inconsistency, leakages, and optimization of the distribution system. There is also predictive maintenance that can be provided with the assistance of digital technologies and has the ability of reducing the likelihood of the failure of the system and improves the durability of infrastructures. These inventions assist in improved manner of managing resources and improved services provision achieves in the overall objectives of sustainable water utilities.

However, these significant achievements still have certain difficulties that are still present and must be solved. The fast increase in population, urbanization and industrialization have continued to mount the pressure on the water demand, thus placing increased pressure to the water resources and the infrastructure systems. Climate change also causes major risks including an increase in temperature, low rainfall, and increased variability in the supply of water. These points highlight the necessity to invest more on the conservation of water, modernization of infrastructures and technological innovation. Long-term policy commitments, institutional coordination and funding will be required in order to carry the progress.

Moreover, this will also require the further expansion of wastewater reuse programs, increased utilization of renewable energy and reduction of non-revenue water losses so as to achieve sustainability in the long term. Awareness of responsible water usage should also be maintained through behavioural change programs and award-based programs to create the awareness. The areas of education and stakeholder engagement will be pertinent in the process of rendering conservation measures and sustainable practices to become popular.

On balance, the deliverables are that the strategic mix of the water resources management/utilities efficiency has provided objective and meaningful returns. The policy reforms as well as the investment in the infrastructure, the technological advancements and the institutional fortification have contributed towards the raising of the water sustainability and efficiency in the operation. These improvements do not just have benefits to the water security but also to the larger economic, environmental and social sustainability aspirations. The obtained advancement provides a good foundation to the subsequent advances and demonstrates the effectiveness of combined and coordinated strategies towards managing the water resources. In conclusion, based on the results, it is possible to support the thesis that Saudi Vision 2030 has changed the sustainability of water resources and utility efficiency. The observed advantages in the efficacy of consumption, wastewater reuse, infrastructure functioning, and integration of renewable energy demonstrate successful transition to the policies of sustainable water management. These strategies will require additional implementation to make sure that water security, environmental protection and sustainable development will be ensured in the future.

Conclusion

The discussion that has been made in this paper has demonstrated that strategic integration between the processes of water resources management and utilities efficiency in the context of Saudi Vision 2030 has already brought quantifiable gains in terms of sustainability, operational efficiency, and resilience. The key outcomes include the per capita water use will be cut to 187 liters/day by the year 2025, the non-revenue water losses will be cut to 19, and the reuse of wastewater will rise to 55. The overall impacts of change of policies, modernization of infrastructure, the increase of technology and institutional fortification in Saudi Arabia are these quantitative variables.

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Another example of such technological-based sustainability interventions can be the successful case of the introduction of renewable energy in water utilities. Its share of the renewable energy use in the desalination and the water distribution grew by 3 percent to 35 percent triggering such significant alterations of the greenhouse gas emissions and energy costs. Governance and institutional reforms particularly the Ministry of Environment, Water and Agriculture and the public-private partnerships have enhanced the regulatory accountability, efficiency and standards of service delivery. Also, predictive maintenance and real-time monitoring have improved the stability of the operations and optimization of resources through smart water system.

Even though these have been achieved, challenges still remain that include population growth, urbanization and alteration in water supply as a result of climate alterations. The water conservation, infrastructure development, the introduction of renewable energy, and the education of the people are also significant to maintain the progress and guarantee the sustainability in the long-term. Overall, this paper emphasizes the fact that policy, technology as well as institutional capacity must be integrated in the form of multi-dimensional strategy to achieve water resources and utilities efficiency in Saudi Arabia.

Recommendations

1. Enhance Water Conservation Policies: Water tiered pricing and water regulations in addition to awareness programs to the community should also be tightened to make sure that per capita consumption is further reduced and that the people use water wisely. Reduction of at least 10 percent per decade will exert little stress on the groundwater resources and the desalination plants to equally serve all sectors.
2. Expand Wastewater Reuse Programs: Investment on advanced wastewater treatment and reuse infrastructure. Better use of the treated wastewater in agriculture, industry, and urban landscape may also help reduce the dependency on freshwater resources and endorse the principles of the circular water management.
3. Modernize Infrastructure and Reduce Non-Revenue Water: Continuous installation of old pipelines, detection systems of leaks and optimising the distribution systems so as to minimize losses. Non-revenue water goals to be reached that will be less than 15 percent by 2030 will enhance efficiency and financial viability of the operation.
4. Integrate Renewable Energy Solutions: Expand the position of solar and wind energy in the water distribution system and the desalination process. Carbon emissions can be reduced by increasing renewable to 50 per cent of the total energy consumption in the water utilities and the cost of operation is also reduced and will be included in the climate mitigation objectives.
5. Strengthening Institutional Governance and Public-Private Partnerships: Enhance the partnership between the state agencies, the representatives of the business community, and community agencies. The collective forms of investment will be used to assist in carrying out massive investment in the infrastructure, ensuring compliance to the policies as well as improving the delivery services in the urban and rural regions.
6. Promote Smart Water Management Technologies: Invest into high-technology digital monitoring, smart metering and predictive maintenance. Data-driven decision-making will be effective in terms of streamlining the operations, responding promptly to systems failure and maximizing resource allocation in real-time.
7. Address Climate Change Adaptation: Include water resource plans like flood management, ground water recharge and water scarcity plans in order to be climate change resilient. Climate projections contribution to scenario-based planning will help to offer sustainable water management in variability of the future.

The provided recommendations describe the path to preserve water security, the efficiency of operations, and environmental resilience in line with the ambitions of Saudi Vision 2030.

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Every participant in the study gave their informed consent.

Statement of Data Availability

The corresponding author can provide the data used in this study upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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