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Developing an indigenous model for aligning urban water supply and demand strategies with a circular economy approach in Iran

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ABSTRACT

This research aims to develop an indigenous model for aligning urban water supply and demand strategies with a circular economy approach in Iran. The research methodology was qualitative, employing thematic analysis, with data collected through semi-structured interviews with 13 experts from Iran's water and wastewater industry. The thematic analysis results identified 6 dimensions, 27 components, and 109 indicators for the research conceptual model. The identified dimensions include: resource and infrastructure management strategies, circular economy strategies, demand and consumption management strategies, innovation and indigenous technology development strategies, water crisis resilience and management strategies, and financial and investment system strategies. The research findings indicate that the developed model, in addition to considering common concepts in global literature, pays special attention to indigenous characteristics and specific challenges of Iran in urban water management. By presenting a comprehensive model, this research provides a practical framework for policymakers and managers in the country's water industry to develop effective strategies for integrated urban water resource management with a circular economy approach.

1. Introduction

Water crisis has become one of the most serious challenges of the present century at the global level. This challenge is much more severe in countries located in the arid and semi-arid belt of the Earth, including Iran (Nazemi *et al.*, 2020). Iran, with average rainfall of about one-third of the global average and an uneven temporal and spatial distribution of precipitation, is among countries experiencing water stress (Savari *et al.*, 2021). In addition to the limitation of renewable water resources, population growth, urbanization development, industrial expansion, climate change, and inefficient water resource management have confronted the country's water resources with serious challenges

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(Ardalan *et al*., 2018). These challenges are particularly more severe in provinces with arid and semi-arid climates such as Sistan and Baluchestan, where sustainable agricultural development heavily depends on optimal water resource management. To achieve sustainable development, appropriate and optimal decisions should be made for the use of limited water resources (Hanife Dokht Ghayour *et al.,* 2020). A recent study by Sardar Shahraki *et al*. (2025) indicates that adopting appropriate mechanisms such as taxing resource-intensive and polluting agricultural activities, as well as using participatory methods in the development and promotion of sustainable agricultural activities, can help increase the resilience of the agricultural sector against drought."

Due to the rapid population and economic growth, the demand for water has increased. In addition, the natural resources are limited and degrade because of several factors such as the climate change (Naeemah Bashara and Qaderi, 2024). Under such conditions, traditional approaches to water resource management, which have mainly focused on water supply, are no longer efficient, and a paradigm shift in water resource management is needed (Feizizadeh *et al*., 2021). Wastewater treatment and reuse is one of the most promising efforts to curb the global water crisis (Pourmahmoud *et al*., 2022). One of the new approaches that has received attention from researchers and policymakers in recent years is the concept of circular economy. (Guerra-Rodríguez *et al*., 2020). Circular economy is defined as an economic-industrial system that replaces the concept of "end-of-life" with restoration and recovery of resources, use of renewable energy, elimination of toxic chemicals, and waste management through intelligent design of products, processes, and systems (Al-Saidi *et al.,* 2021).

In the water resources domain, circular economy seeks to create a closed cycle in which water of different qualities is allocated to uses appropriate to its quality, wastewater is used as a valuable resource, and secondary resources such as energy and nutrients are extracted from wastewater (Smol *et al.,* 2020). In this approach, the focus is on aligning water supply and demand strategies, such that supply and demand management are seen in an integrated manner, and while preserving water resource quality, wastewater reuse and water recycling are proposed as the main strategies (Fernandes and Cunha Marques, 2023).

The application of circular economy principles in water resource management has been extensively studied globally. Circular economy is a concept that stands opposite to the traditional linear model of "extract-produce-consume-dispose" and seeks to create closed-loop economic systems in which resources remain in the consumption cycle as much as possible (Zamany *et al*., 2024). In water resource management, circular economy means designing and managing water systems in such a way that the value of water is preserved throughout its cycle and maximum productivity is achieved from this vital resource (Smol *et al*., 2020). In the water circular economy approach, various strategies are proposed, including water consumption reduction, reuse, recycling, and resource recovery. Water consumption reduction aims to increase efficiency and productivity in various urban, industrial, and agricultural sectors. Water reuse and recycling refer to the treatment and reuse of wastewater for various purposes appropriate to its quality. Resource recovery refers to the extraction of secondary resources such as energy, nutrients, and valuable chemicals from wastewater (Fernandes and Cunha Marques, 2023).

Koseoglu-Imer *et al.* (2023) addressed current challenges and future perspectives for the full circular economy of water in European countries. By examining the current situation in different European countries, they analyzed the challenges ahead and possible solutions for the full implementation of water circular economy. The results of this research show that despite significant progress at the policy level, there are still numerous challenges at the implementation level that require cross-sectoral cooperation and changes in traditional attitudes. Rodriguez-Anton *et al.,* (2019) analyzed the relationships between circular economy and sustainable development goals. They found that circular economy can play an important role in achieving various sustainable development goals, especially in the field of sustainable water resource management. The results of this research show that implementing the circular economy approach in the water sector creates multiple synergistic effects that can help achieve other sustainable development goals. Rodrigues *et al.* (2024) presented a framework for creating appropriate conditions for wastewater reuse. In this framework, various technical, economic, social, environmental, and political-legal factors are considered, and practical solutions are proposed to overcome existing barriers. The results of this research emphasize that success in wastewater reuse requires a comprehensive and integrated approach that considers all relevant aspects.

Beyond circular economy principles, the alignment of water supply and demand strategies represents another crucial dimension in modern water resource management. In the traditional approach to water resource management, the main focus has been on water supply strategies (such as dam construction, deep well drilling, and inter-basin water transfer). In recent decades, with the revelation of the limitations of this approach, attention to demand management strategies (such as consumption pattern reform, water pricing, installation of consumption-reducing equipment, and awareness raising) has increased (Nazari *et al.,* 2018). The new approach in water resource management emphasizes the alignment and integration of water supply and demand strategies. In this approach, supply and demand strategies are seen as two sides of the same coin that must be managed simultaneously and in coordination (Santos *et al.,* 2023). The alignment of water supply and demand strategies means planning and implementing strategies in which the balance between water supply and demand is maintained, considering climatic, environmental, economic, and social conditions. The challenges of creating value, need to be understood more fully as well as how to align these components in creating a sustainable industry (Khamseh *et al*., 2021).

Vinagre *et al*. (2023) examined the challenges of integrating water management approaches and urban planning. They found that alignment between water resource management strategies and urban planning plays a key role in increasing the resilience of cities to climate change. Bouramdane (2023) examined optimal water management strategies as a key factor in the sustainability of smart cities. This research emphasizes the need for coordination between water supply and demand policies and the use of smart technologies for integrated water resource management. The results show that smart cities need a comprehensive approach to water management in which new technologies serve to optimize water supply and demand.

Studies on integrated water resource management have also been conducted in Iran (Talebi, 2024). Davoudi and Ghazavi (2020) determined appropriate management strategies for water resources in the Natanz urban watershed using the SWOT matrix. The results of this research show that defensive strategies, with an emphasis on reducing weaknesses and threats, are the most appropriate approach for water resource management in the studied area. Nezami *et al.* (2023) presented a model for improving sustainable urban water management in Isfahan city using a system dynamics approach. This research, taking into account the interrelationships between different parts of the urban water management system, analyzed various management scenarios and proposed solutions to improve system sustainability. Davoodabadi *et al*. (2018) examined the status of water resource management in Iranian cities and analyzed existing challenges. The results of this research show that urban water resource management in Iran faces multiple challenges, including lack of integration in policymaking, weaknesses in monitoring and evaluation systems, and aging infrastructure.

Numerous studies have been conducted on the application of circular economy in water resource management globally (Kakwani and Kalbar, 2024; Kyriakopoulos, 2023; Ruiz-Ocampo *et al.,* 2023). However, a review of the research background shows that in Iran, comprehensive studies specifically addressing the alignment of urban water supply and demand strategies with a circular economy approach are limited. Furthermore, models and frameworks developed in other countries are not directly applicable to conditions in Iran due to climatic, economic, social, and infrastructural differences (Karimi Alavijeh *et al*., 2021).

Given Iran's specific conditions in terms of water resource limitations, infrastructural challenges such as aging water supply networks, high water loss in distribution networks (Layani *et al*., 2020), cultural and social issues related to consumption patterns (Khalifeh *et al*., 2022), financing limitations, as well as challenges arising from sanctions in accessing new technologies, there is a need to develop an indigenous model for aligning urban water supply and demand strategies with a circular economy approach in the country.

Based on the literature review, it becomes clear that although numerous studies have been conducted on water resource management and circular economy separately, research specifically addressing the alignment of urban water supply and demand strategies with a circular economy approach in Iran is limited. There is also a gap for an indigenous model designed in accordance with Iran's climatic, economic, social, and infrastructural conditions. This research aims to fill this gap and provide an indigenous model for aligning urban water supply and demand strategies with a circular economy approach in Iran.

Therefore, the main objective of this research is to develop an indigenous model for aligning urban water supply and demand strategies with a circular economy approach in Iran, using a qualitative thematic analysis method based on the perspectives of experts in the country's water and wastewater industry. The main research question is: What are the dimensions, components, and indicators of the indigenous model for aligning urban water supply and demand strategies with a circular economy approach in Iran?

2. Materials and Methods

This research is applied-developmental in terms of its objective and qualitative in terms of data collection and analysis approach. To achieve the research goal, thematic analysis method was used. Thematic analysis is a method for identifying, analyzing, and reporting patterns within qualitative data. This method is a process for analyzing textual data and transforms scattered and diverse data into rich and detailed data (Braun *et al.*, 2021). The statistical population of this research included experts in water and wastewater, urban water resource management, and circular economy in Iran. For sample selection, purposive sampling with a snowball approach was used. The criteria for selecting experts were:

- Minimum of 10 years of relevant work experience in the water and wastewater industry, urban water resource management, or areas related to circular economy.
- Having academic expertise (minimum master's degree) or professional expertise in one of the fields of water resource management, water and wastewater engineering, circular economy, environment, or strategic management.
- Participation in at least 2 executive or research projects related to water recycling, demand management, or optimization of urban water resources.
- Having at least 3 scientific articles, books, or technical reports in related fields (this criterion was mandatory for academic experts and preferable for industry experts).
- Employment in managerial or senior expert positions in water and wastewater companies, the Ministry of Energy, environmental organizations, or research and academic centers related to the research topic for at least 5 years.

Table 1. Characteristics of experts participating in the research.

Code	Education	Specialization	Work Experience (years)	Area of Expertise
E1	PhD	Civil engineering - water	23	Urban water resource management
E2	Master's	Environmental engineering	17	Water treatment and recycling
E3	PhD	Environmental economics	19	Water circular economy
E4	PhD	Civil engineering - water	28	Water demand management
E5	Master's	Strategic management	15	Strategic planning
E6	PhD	Environmental engineering	24	New water treatment technologies
E7	PhD	Water resource management	18	Integrated water resource management
E8	Master's	Mechanical engineering	22	Indigenous water technologies
E9	PhD	Hydrology	16	Water system resilience
E10	Master's	Financial management	14	Financing water projects
E11	PhD	Environmental engineering	26	Wastewater and resource recovery
E12	Master's	Civil engineering - water	20	Recycling system design
E13	PhD	Technology management	15	Innovation in water industry

For data collection, in-depth semi-structured interviews were used. The interviews were conducted over a three-month period, and each interview lasted between 60 and 90 minutes. Interview questions revolved around topics such as current challenges in urban water resource management in Iran, the concept of circular economy in the water and wastewater industry, optimal solutions for resource and infrastructure management, opportunities for wastewater reuse, demand management and consumption reduction approaches, the role of innovation and indigenous technologies, solutions for increasing the resilience of urban water systems, financing and investment challenges, and how to create alignment between urban water supply and demand strategies. In this research, after conducting 11 interviews, theoretical saturation was achieved; however, for greater certainty, 2 more interviews were conducted, bringing the total number of interviews to 13. The characteristics of the experts participating in the research are presented in Table 1. To analyze the data from the interviews, the six-step process of thematic analysis was used, including familiarization with the data, coding the data, extracting themes, reviewing and refining themes, defining and naming themes, and preparing the report (Braun *et al.*, 2021). To ensure the validity and reliability of the results, measures such as member checking by participants, peer review, frequency analysis, comparison with the results of thematic analysis of the literature, and test-retest coding were undertaken.

3. Results and discussion

In this section, the results of the thematic analysis of interviews with experts are presented according to the different stages of the analysis process.

3.1. Familiarization with the data

In the first stage of thematic analysis, after transcribing the interviews, to gain deep familiarity with the data, the transcribed texts were studied several times. This process included active reading and searching for potential meanings and patterns in the data. For each interview, initial analytical notes were recorded in the margins of the text to identify initial ideas for coding in later stages. At this stage, it became clear that experts, in addition to emphasizing concepts common with previous studies, also referred to indigenous topics and specific conditions in Iran. For example, one of the water and wastewater industry experts stated: "In Iran, our main challenge is not only the shortage of water resources but also the severe deterioration of infrastructure, high water loss, and the mismatch between consumption patterns and the country's climatic conditions. We need an indigenous approach to circular economy that targets these specific challenges. The issue of sanctions and the necessity of developing indigenous technologies was emphasized in many interviews: "Sanctions have limited access to advanced water treatment and recycling technologies. We must focus on developing indigenous technologies appropriate to the specific climatic conditions of different regions of Iran.

3.2. Coding the data

In the second step, after gaining deep familiarity with the data, the initial coding process was carried out. At this stage, through careful study of the interview texts, key concepts and phrases related to urban water supply and demand strategies with a circular economy approach were identified and recorded as initial codes. For coding, an open coding approach was used, through which concepts and phrases related to research questions were identified and recorded. At this stage, efforts were made to extract diverse codes to provide an appropriate basis for extracting indicators and components in later stages.

In total, 274 initial codes were extracted from the interviews. Some of these codes appeared repeatedly in different interviews, indicating the importance and consensus of experts on those topics. Some of the frequently repeated codes were: "wastewater recycling," "smart distribution network," "consumption pattern reform," "leakage management," "indigenization of treatment technologies," "drought resilience," and "public-private partnership. As an example, from a section of an interview with one of the experts who had said: "One of our biggest challenges in Tehran is the aging distribution network and high water loss. In some old areas of the city, water loss exceeds 30 percent. We need a coherent program to identify critical leakage points, prioritize areas for reconstruction and renovation of old lines. Also, implementing smart pressure and leakage monitoring systems can help better manage the network," the codes "aging distribution network," "high water loss," "identifying critical leakage points," "prioritizing areas for reconstruction," "renovating old lines," "smart pressure monitoring systems," and "smart leakage monitoring systems" were extracted.

3.3. Extracting themes

In the third step, the initial codes extracted in the previous stage were analyzed, categorized, and organized to form basic themes (indicators). For this purpose, similar and related codes were placed in semantic groups, and an appropriate title was selected as a basic theme for each group. After identifying the basic themes, by examining the conceptual relationships between them, organizing themes (components) were extracted. Finally, organizing themes were also categorized into global themes (dimensions) based on conceptual relationships. At this stage, 6 global themes (dimensions), 27 organizing themes (components), and 128 basic themes (indicators) were identified. For example, the codes "aging distribution network," "old and worn-out networks," and "high age of pipes" were grouped into the basic theme "renovation of worn-out networks." This basic theme, along with other related basic themes such as "prioritization of critical network areas," "replacement of worn-out transmission lines," and "reconstruction of non-standard connections," together formed the organizing theme "reconstruction and renovation of worn-out networks." This organizing theme, along with other related organizing themes such as "integrated water resource management," "smart distribution network," "leakage and loss management," and "development of alternative water resources," were categorized as the global theme "resource and infrastructure management strategies." Table 2 shows an example of the process of extracting basic themes from initial codes and grouping them into organizing themes and global themes.

Table 2. Example of the process of extracting basic themes (indicators) from initial codes.

Initial codes	Basic themes (Indicators)	Organizing themes (Components)	Global themes (Dimensions)
"aging distribution network," "old and worn-out networks," "high age of pipes"	Renovation of worn-out networks	Reconstruction and renovation of worn-out networks	Resource and infrastructure management strategies
"prioritization of areas needing reconstruction," "identification of critical network points," "areas with high incident statistics"	Prioritization of critical network areas	Reconstruction and renovation of worn-out networks	Resource and infrastructure management strategies
"secondary treatment of wastewater," "use of wastewater in green spaces," "returning wastewater to the consumption cycle"	Treatment and reuse of urban wastewater	Recycling and reuse	Circular economy strategies
"gray water systems," "gray wastewater segregation," "recycling of bathroom and laundry water"	Gray water recycling systems	Recycling and reuse	Circular economy strategies
"monitoring industry consumption," "consumption statistics of different sectors," "segregation of domestic and commercial consumption"	Monitoring consumption of different sectors	Analysis of consumption patterns	Demand and consumption management strategies
"identification of high-consuming subscribers," "examination of consumption patterns of large subscribers," "water-intensive industries"	Identification of high-consuming uses	Analysis of consumption patterns	Demand and consumption management strategies
"tax exemption for low-consumption equipment," "tax incentives for green industries," "incentive tax policies"	Tax incentives	Financial and subsidy support	Financial and investment system strategies
"indigenous treatment technologies," "domestic manufacturing of treatment systems," "indigenization of membrane technologies"	Domestic manufacturing of treatment equipment	Indigenization of equipment and parts	Innovation and indigenous technology development strategies
"domestically produced smart meters," "domestic production of water measurement equipment," "indigenization of smart meters"	Domestic production of smart meters	Indigenization of equipment and parts	Innovation and indigenous technology development strategies
"drought prediction," "early warning systems," "advanced water resource monitoring"	Early warning systems	Crisis prediction and monitoring	Water crisis resilience and management strategies
"emergency wells," "drilling backup wells," "alternative water sources in crisis"	Emergency wells	Management of emergency resources	Water crisis resilience and management strategies

3.4. Reviewing and refining themes

In the fourth step, to ensure the validity and comprehensiveness of the extracted themes, the process of reviewing and refining themes was carried out. This review was conducted at three levels: At the first level, the relationship between initial codes and extracted indicators was examined. Some indicators were merged due to conceptual overlap, and others were removed due to insufficient relevance to the research topic. For example, the indicators "network leakage detection" and "identification of critical leakage points" were merged into the indicator "identification of critical leakage points" due to conceptual overlap. At the second level, the internal coherence of the indicators of each component was examined. Some indicators were moved between components to establish a more logical relationship with the relevant component. For example, the indicator "smart reservoir management" was moved from the component "water resource management" to the component "smart distribution network." At the third level, the alignment of components with model dimensions was examined. Some components were moved or redefined to establish a more logical relationship with the relevant dimension. For example, the component "education and awareness raising," which was initially in the dimension "stakeholder participation and cooperation strategies," was moved to the dimension "demand and consumption management strategies," as based on the content of the interviews, this component was emphasized more with the aim of influencing consumption patterns. After these reviews, the number of indicators was reduced from 128 to 109, and some components were also merged or redefined.

3.5. Defining and naming themes

In the fifth step, the finalized themes were precisely defined and named. For each global theme (dimension), organizing theme (component), and basic theme (indicator), a specific definition was provided to clearly identify its concept. At this stage, efforts were made to make the naming reflect the strategic nature of the model. Also, based on the results of thematic analysis of the literature, some themes were renamed to better align with the subject literature. The finalized global themes (dimensions) along with their definitions are presented in Table 3.

3.6. Presentation of the final model

In the final step of thematic analysis, the findings were presented in the form of an integrated model. This model includes 6 dimensions, 27 components, and 109 indicators that reflect the alignment of urban water supply and demand strategies with a circular economy approach in Iran's conditions. The results show that the model extracted from interviews with experts, while overlapping with some dimensions of the model resulting from thematic analysis of the literature (including resource and infrastructure management strategies, circular economy strategies, and demand and consumption management strategies), has added three new dimensions to the model. These new dimensions (innovation and indigenous technology development strategies, water crisis resilience and management strategies, and financial and investment system strategies) indicate the attention of experts to the specific challenges of the country and the necessity of indigenizing the model for aligning urban water supply and demand strategies with a circular economy approach. Table 4 shows the dimensions, components, and indicators of the final model in full.

3.7. Evaluation of the validity and reliability of results

To ensure the validity and reliability of the results from the thematic analysis, several measures were taken. First, after extracting the themes, the results were shared with 5 of the experts who participated in the interviews to verify the accuracy of the interpretations and inferences made from their perspectives. The feedback received led to the correction of some themes and strengthening of conceptual relationships between them. Additionally, the coding process and theme extraction were reviewed by two other researchers specialized in water resource management and circular economy. The results of this review led to the correction of some codes and themes. After applying the corrections, the coding agreement coefficient between researchers reached 85 percent, indicating the high reliability of the coding process. To ensure the importance of the extracted themes, the frequency of repetition of each code and theme in different interviews was analyzed. Themes that had been mentioned in most interviews were identified as key themes. To assess external validity, the results of the thematic analysis of the interviews were compared with the results of the thematic analysis of the literature. This comparison showed that three main dimensions of the model (resource and infrastructure management strategies, circular economy strategies, and demand and consumption management strategies) are consistent with the subject literature, but the other three dimensions (innovation and indigenous technology development strategies, water crisis resilience and management strategies, and financial and investment system strategies) indicate attention to the specific conditions of the country and the indigenization of the model.

Table 3. Definition of global themes (dimensions).

Global Themes	Definition
Resource and infrastructure management strategies	This dimension includes strategies that focus on optimal management of water resources, improvement and renovation of infrastructure, reduction of water loss, and sustainable exploitation of resources.
Circular economy strategies	This dimension includes strategies that focus on water recycling, wastewater reuse, resource and energy recovery, and development of circular business models.
Demand and consumption management strategies	This dimension includes strategies that focus on understanding consumption patterns, consumption optimization, peak demand management, and reform of the tariff system.
Innovation and indigenous technology development strategies	This dimension, which was added to the model as a new dimension based on expert opinions, includes strategies for developing technologies compatible with Iran's climate, indigenizing equipment, and developing an innovation ecosystem in the water sector.
Water crisis resilience and management strategies	This dimension, which was also added based on Iran's specific climatic conditions, includes strategies for crisis prediction and monitoring, emergency resource management, increasing infrastructure resilience, and drought management.
Financial and investment system strategies	This dimension, which was also added due to specific financing challenges in Iran, includes strategies for attracting private investment, financing circular projects, and economic optimization.

Table 4. Dimensions, components, and indicators of the model for aligning urban water supply and demand strategies with a circular economy approach in Iran.

Global themes (Dimensions)	Organizing themes (Components)	Basic themes (Indicators)
Resource and infrastructure management strategies	Integrated water resource management	Urban watershed management Protection and restoration of groundwater resources Surface water and flood management Integration of surface and groundwater resource management
	Reconstruction and renovation of worn-out networks	Prioritization of critical network areas Replacement of worn-out transmission lines Reconstruction of non-standard connections Structural improvement of old networks
	Smart distribution network	Smart pressure monitoring systems Smart meters Leakage detection systems Distribution network automation Smart reservoir management
	Leakage and loss management	Identification of critical leakage points Network pressure management Preventive maintenance Renovation of connections and valves
	Development of alternative water resources	Urban watershed plans Development of rainwater collection systems Restoration of qanats and traditional water sources Water desalination in coastal areas
Circular economy strategies	Recycling and reuse	Treatment and reuse of urban wastewater Gray water recycling systems Reclaimed water distribution networks Use of treated wastewater for green spaces
	Resource and energy recovery	Energy extraction from wastewater Recovery of nutrients from wastewater Fertilizer production from sewage sludge Heat recovery from sewage systems Biogas production from sludge
	Indigenization of treatment technologies	Energy-efficient treatment plants Decentralized treatment systems Natural treatment technologies Indigenous biological filters
	Circular business models	Water-centered services Sharing economy of water resources Water startups Local water cooperatives
Demand and consumption management strategies	Analysis of consumption patterns	Monitoring consumption of different sectors Identification of high-consuming uses Seasonal consumption segregation Consumption trend analysis
	Consumption optimization	Consumption pattern reform Upgrade of low-consumption equipment Smart green space irrigation systems Implementation of consumption-reducing technologies
	Peak demand management	Consumption reduction programs in hot seasons Smart rationing during peak times Scheduling of public and service consumptions Temporal distribution of non-essential consumptions

	Reform of the tariff system	Progressive block tariffs Incentive tariffs for low consumption Penalty tariffs for high consumption Seasonal tariffs
	Education and awareness raising	School education Media campaigns Training of local promoters Participation of public organizations Development of social responsibility
Innovation and indigenous technology development strategies	Development of climate-compatible technologies	Drought-resistant technologies Climate change-adaptive technologies Low-energy consumption systems Technologies suitable for low-water areas
	Enhancement of research and development infrastructure	Specialized water laboratories Water and wastewater innovation centers Industry-university connection Support for applied theses
	Indigenization of equipment and parts	Domestic manufacturing of treatment equipment Domestic production of smart meters Quality domestic spare parts
	Development of water innovation ecosystem	Water technology startups Specialized water accelerators Water-focused science and technology parks Venture capital funds
Water crisis resilience and management strategies	Crisis prediction and monitoring	Early warning systems Monitoring of strategic water resources Analysis of long-term resource trends Resource risk assessment
	Management of emergency resources	Strategic water storage Emergency water supply plans Mobile water tankers Emergency wells Water diplomacy in shared basins
	Increasing infrastructure resilience	Hardening of vital facilities Design of flexible networks Backup systems
	Comprehensive drought management	Gradual consumption reduction programs Various water scarcity scenarios Social resilience Water scarcity adaptation solutions
Financial and investment system strategies	Attracting private investment	Public-private partnership Buy-back contracts BOT and BOO models Service purchase guarantee
	Financing circular projects	Green participation bonds Istisna'a sukuk Low-interest bank loans National Development Fund
	Financial and subsidy support	Tax incentives Green technology subsidies Support for pilot projects Low-cost facilities
	Economic optimization	Reduction of finished cost Improvement of economic productivity Cost-benefit analysis Real finished price
	Utilization of international capacities	World Bank loans Cooperation with the Global Environment Facility International joint projects

Finally, to measure the reliability of the coding process, the test-retest method was used. For this purpose, 3 interviews from among the conducted interviews were randomly selected and recoded after a two-week interval. Comparison of the codes extracted in the two stages showed that 81 percent of the codes were similar, indicating appropriate reliability of the coding process.

The results of these measures indicate the appropriate validity and reliability of the model extracted from the thematic analysis process. It can be claimed with high confidence that the identified dimensions, components, and indicators represent well the perspectives of experts regarding the alignment of urban water supply and demand strategies with a circular economy approach in Iran's conditions. The model resulting from this research provides a comprehensive framework for aligning urban water supply and demand strategies with a circular economy approach in Iran. This model, shown in Fig 1, has been designed considering the specific conditions of Iran and based on the perspectives of experts in the country's water and wastewater industry.

The dimension of resource and infrastructure management strategies, as one of the main dimensions of the model, focuses on optimizing water resource management, renovating infrastructure, and reducing water loss. This dimension is consistent with previous studies in the field of water resource management (Xiang *et al.*, 2021; Silva, 2023). However, what stands out in the present model is the special attention to specific challenges in Iran, including aging distribution networks and high water loss in the network. Experts believed that the prerequisite for successful implementation of the circular economy approach in the urban water industry is improving the condition of existing infrastructure and reducing water loss. This finding is consistent with the results of the study by Davoodabadi *et al.* (2018), who identified aging infrastructure as one of the main challenges in urban water resource management in Iran. Smart distribution network, as one of the key components of this dimension, is consistent with the studies by Fu *et al.* (2023). They emphasized the role of artificial intelligence and smart technologies in managing urban water infrastructure in their research. However, experts in this research emphasized the necessity of indigenizing these technologies and adapting them to Iran's conditions. Development of alternative water resources is another component that is particularly important given the limitation of water resources in Iran. Restoration of qanats and traditional water sources is one of the unique indicators that has been less addressed in similar models in other countries. In addition to traditional sources, the use of unconventional water resources can help reduce pressure on conventional sources. Goudarzi's (2024) study demonstrates that a considerable amount of water condensate produced through air conditioning systems, which is usually directed to municipal sewage systems, has significant reuse potential. This water source can not only be used for various purposes but also the energy it contains can contribute to improving the energy efficiency of systems. This finding is justifiable given Iran's historical background in water resource management and the existence of numerous Qantas in different regions of the country. The dimension of circular economy strategies, as the heart of the model, focuses on water recycling, wastewater reuse, resource and energy recovery, and development of circular business models. This dimension is consistent with previous studies in the field of water circular economy (Smol *et al*., 2020; Koseoglu-Imer *et al*., 2023; Fernandes and Cunha Marques, 2023). Recycling and reuse, as one of the key components of this dimension, emphasizes the importance of treatment and reuse of urban wastewater and gray water recycling systems. This finding is consistent with the results of the study by Rodrigues *et al*. (2024). Resource and energy recovery is another component that focuses on extracting secondary resources such as energy and nutrients from wastewater. Energy extraction from wastewater, recovery of nutrients from wastewater, fertilizer production from sewage sludge, heat recovery from sewage systems, and biogas production from sludge are indicators of this component. These findings are consistent with studies by Kyriakopoulos (2023) and Ruiz-Ocampo *et al*. (2023), which emphasized resource and energy recovery from sewage systems as one of the principles of water circular economy. A notable point in the present model is the emphasis on indigenization of treatment technologies and development of circular business models. Experts believed that given the challenges arising from sanctions and limitations in accessing advanced technologies, the development of indigenous treatment technologies compatible with Iran's climatic and economic conditions is necessary. This finding indicates attention to the specific conditions of the country in designing the model.

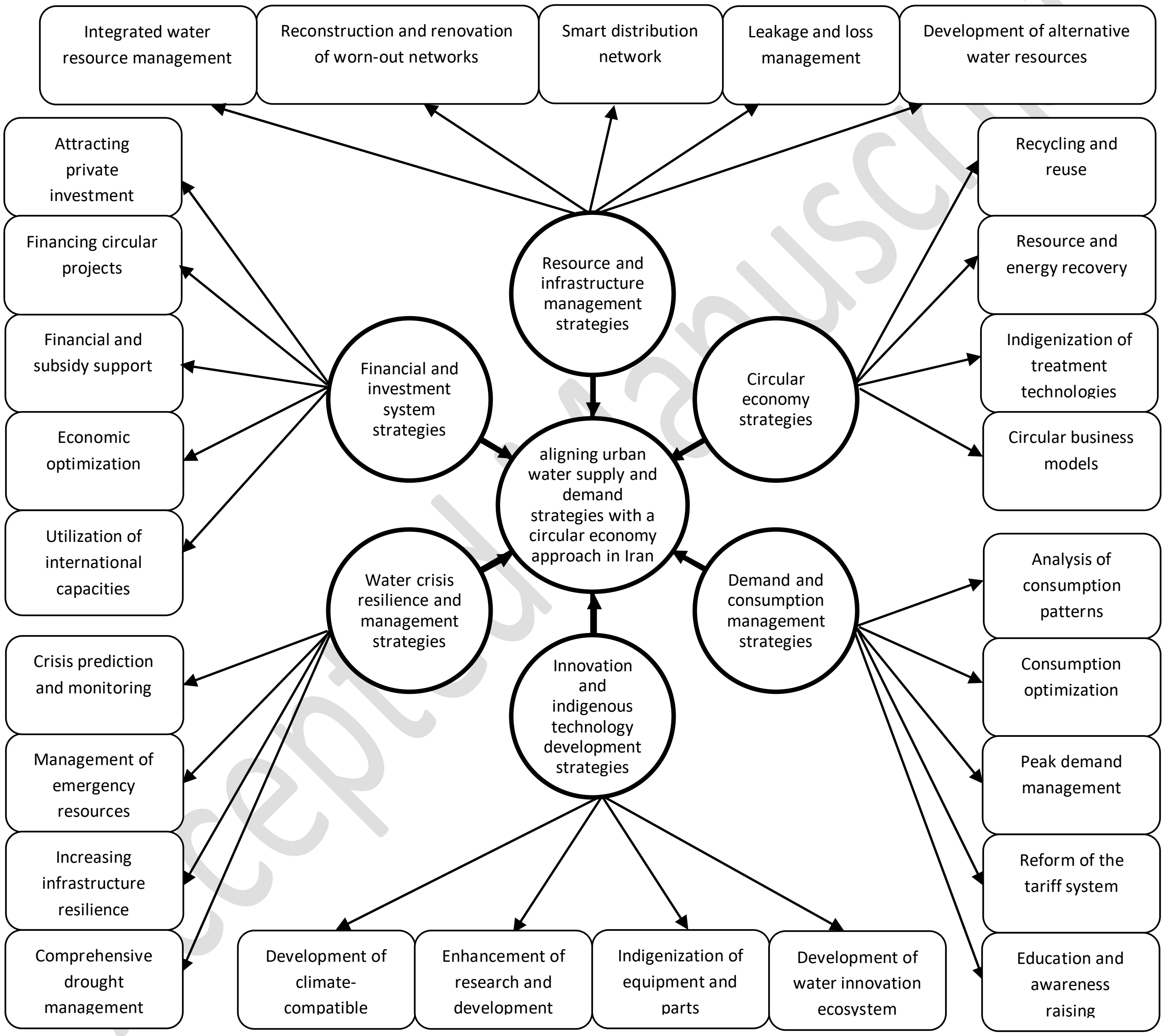

Fig. 1. Indigenous model for aligning urban water supply and demand strategies with a circular economy approach.

The dimension of demand and consumption management strategies focuses on understanding consumption patterns, consumption optimization, peak demand management, reform of the tariff system, and education and awareness raising. This dimension is consistent with previous studies in the field of water demand management (Nazari *et al.*, 2018; Shahangian *et al.*, 2022). Analysis of consumption patterns, as a basis for precise planning of demand management, is one of the key components of this dimension. This finding is consistent with the study by Ghaffari Moghadam and SardarShahraki (2023), who emphasized the importance of predicting drinking water consumption and understanding the factors affecting it. Reform of the tariff system is another component that emphasizes the importance of using economic tools for water demand management. This finding is consistent with the results of the study by Al-Saidi and Dehnavi (2019), who compared urban water pricing policies in Jordan and Iran. Education and awareness raising is a component that emphasizes the importance of public participation in water resource management. Experts believed that without proper education and awareness raising, the implementation of other strategies would not be successful. This finding is consistent with the results of studies by Valizadeh *et al*. (2018) and Savari *et al*. (2021), which emphasized the role of social and cultural factors in water resource management.

What distinguishes the model resulting from this research from similar models is the addition of three new dimensions that specifically address Iran's challenges: innovation and indigenous technology development strategies, water crisis resilience and management strategies, and financial and investment system strategies.

The dimension of innovation and indigenous technology development strategies emphasizes the importance of developing technologies compatible with Iran's climate, enhancing research and development infrastructure, indigenizing equipment and parts, and developing a water innovation ecosystem. This dimension has been added to the model due to challenges arising from sanctions and limitations in accessing advanced technologies. This finding is consistent with the results of studies by Mollahosseini *et al*. (2017) and Ahmadi *et al*. (2021), which emphasized the importance of developing indigenous technologies in Iran's energy and water sectors.

The dimension of water crisis resilience and management strategies has been added to the model considering Iran's climatic conditions and challenges arising from multiple droughts. This dimension focuses on crisis prediction and monitoring, management of emergency resources, increasing infrastructure resilience, and comprehensive drought management. This finding is consistent with the results of studies by Mohammadiun *et al.* (2018) and Nazemi *et al*. (2020), which emphasized the importance of water system resilience in crisis conditions.

The dimension of financial and investment system strategies focuses on financing challenges for projects related to water circular economy in Iran. This dimension includes components such as attracting private investment, financing circular projects, financial and subsidy support, economic optimization, and utilization of international capacities. This finding is consistent with the results of studies by Fereshtehpour *et al*. (2021) and Norouzi *et al.* (2022), which emphasized financing challenges for environmental and renewable energy projects in Iran.

The research results show that aligning urban water supply and demand strategies with a circular economy approach requires an integrated approach that considers all dimensions of the model. Experts believed that separate planning and implementation of supply and demand strategies would lead to inefficiency and ineffectiveness.

In the proposed integrated approach, resource and infrastructure management strategies (supply) and demand and consumption management strategies are coordinated and aligned with a focus on circular economy and with the support of three other dimensions (innovation and indigenous technology development, crisis resilience and management, and financial and investment system). This finding is consistent with the results of studies by Santos *et al.* (2023) and Vinagre *et al.* (2023), which emphasized the importance of integration in water resource management.

One of the notable points in the present model is the emphasis on the dual role of water recycling and wastewater reuse. On one hand, these strategies lead to an increase in available water resources (supply), and on the other hand, they help reduce pressure on primary water resources (demand) by reducing withdrawal from these resources. This dual role indicates the importance of circular economy in creating alignment between water supply and demand strategies.

4. Conclusions

This research was conducted with the aim of developing an indigenous model for aligning urban water supply and demand strategies with a circular economy approach in Iran. Using the thematic analysis method and based on interviews with 13 experts from the country's water and wastewater industry, a model with 6 dimensions, 27 components, and 109 indicators was presented. The research results showed that the model for aligning urban water supply and demand strategies with a circular economy approach in Iran, in addition to dimensions common with global models (resource and infrastructure management strategies, circular economy strategies, and demand and consumption management strategies), includes three new dimensions (innovation and indigenous technology development strategies, water crisis resilience and management strategies, and financial and investment system strategies) that specifically address Iran's challenges.

The presented model provides a comprehensive framework for policymakers and managers in the country's water and wastewater industry to develop effective strategies for integrated urban water resource management with a circular economy approach. This model has been designed considering Iran's specific conditions in terms of water resource limitations, infrastructural challenges, cultural and social issues, financing limitations, and challenges arising from sanctions.

Based on the results of this research, it is suggested that a national water circular economy document be developed with the participation of all stakeholders to provide a framework for coordinating various activities in this field. It is also necessary to define multiple pilot projects in different cities of the country with different climatic and infrastructural conditions to evaluate the feasibility and effectiveness of the model's strategies in practice. Creating appropriate institutional structures for coordination between different sectors of urban water resource management is also of great importance, as successful implementation of the model requires cross-sectoral and trans-sectoral cooperation. Development of performance indicators to monitor the success of strategy implementation and investment in research and development for indigenizing technologies related to water circular economy are among other suggestions of this research.

For future research, it is suggested that studies be conducted on prioritizing the model's strategies using multi-criteria decision-making methods to determine which strategies should be prioritized for implementation. Examining the barriers and drivers of model implementation in different cities of the country can also help better understand the executive challenges and provide appropriate solutions. Development of the model for other water-consuming sectors such as industry and agriculture, assessment of economic, social, and environmental impacts of model implementation, and design of a decision support system based on the presented model to help managers and policymakers are other suggested areas for future research.

Author Contributions

Zahra Mousavi: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing – original draft.
Mehrdad Hosseini Shakib: Conceptualization, Methodology, Validation, Writing – review & editing, Supervision.
Seyed-Javad Iranbanfard: Resources, Data curation, Writing – review & editing, Validation. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflict of interest that could have influenced the work reported in this paper.

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Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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