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Growing the portfolio: circular economy through water reuse in Iran

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In Iran, water scarcity is increasing due to the rapid growth in economy and population, but also due to waste and overuse. Marginal water resources (unutilized water of lower quality) can provide important options to augment water supply or replace freshwater use. In this way, they can reconcile the seemingly opposing views of water development and water management. Encouraging reuse and circulation of marginal water can enhance water availability and conserve freshwater. This paper analyses water reuse options and policies in Iran. It explains policy constraints based on the type of water for reuse and compares the water reuse policies in Iran to regional experiences. Such a contextualization of Iran's policies from a regional perspective provides opportunities for mutual learning and lessons for policy reforms. For Iran, there is a need for investments and comprehensive reuse policies. New water sources need to be appropriately identified, treated, delivered and accepted by end-users and society.

KEYWORDS

water reuse, circular economy, Iran, wastewater treatment, marginal water resources, food security

1 Introduction

The decrease in water resource availability and quality represents a key challenge for future development in Iran. Due to the rapid growth of the economy and the population, the *per capita* share of renewable water resources is expected to drop from over 1,700 cubic meters in 2014 to below 1,000 *per capita* per year by 2030, thus indicating conditions of water stress (FAO, 2019). Agriculture lies at the heart of the increase in water demand (around 92% of total water consumption) (FAO, 2019). Particularly after the Islamic Revolution in1979, water has been heavily subsidized in order to achieve self-sufficiency in essential foods, thus resulting in cheap food prices, increased food demands, food waste, and the promotion of consumerism culture (Amid, 2007; Saatsaz, 2019). Adding to the water crisis in Iran are other combined factors such as mismanagement, overuse, economic sanctions, and expansion of the cultivation area in the context of food sufficiency policies (Dehnavi, 2015; Madani et al., 2016).

Supplying the growing population with sufficient amounts of food of decent quality without causing a deterioration of water resource availability and quality is an important challenge. This population is largely urban, with the urban proportion of the population at around 74% for Iran in 2017, much higher than the global average of around 55% (World Bank, 2019). One way to provide additional water quantity is to adopt circular economy approaches through the reuse and regeneration of resources. In this sense, circular water economy can be achieved through encouraging the utilization of neglected water sources that can be treated and (re)used. Unconventional water resources of marginal utilization (marginal water resources) should be considered as one part of the solution to the increasing scarcities and recurrent shortages. In Iran, the use of these water types has only started recently but is still not sufficiently highlighted in comparison to other water management problems; for example, the high leakage of water from potable water distribution networks (unaccounted-for water (UFW)) of around 32% (Saatsaz, 2019). Although some marginal water resources such as treated sewerage effluents are being increasingly used, mostly for non-edible agriculture (i.e., uses and products not directly for human consumption such as landscaping or forage cultivation), there are many other unused resources and unexplored use purposes.

The (re)use of marginal water resources in Iran is beginning to materialize but is still far from its full potential. This paper investigates the status quo of water reuse policies and practices in Iran with a focus on opportunities to develop neglected reuse options. The aim is to introduce concrete policy options addressing constraints and challenges with regard to the emerging topic of circular water economy. A key novelty of this study is the expansion of the analysis of key policy obstacles in Iran through a comparison with regional experiences that can provide valuable lessons for Iran. Using secondary academic literature and public strategies, this paper presents the water reuse option in Iran as an important way to reconcile the debate about the development vs. the management of Iran's vulnerable water resources. After presenting obstacles and regional lessons, it discusses practical recommendations for the further development of water use in Iran.

2 Reconciling the water management vs. development debate through circulation and reuse

The need for sustainable management of water resources has been the subject of recent debates since the late 20th century. Especially after the Second World War, the main water-related public policy task was perceived to be the development of water resources. This task has been fulfilled through engineering projects mainly for the water and energy sectors, such as dams and irrigation reservoirs. Allan (2006) describes the expansion of availability and accessibility of water resources (water development) since the second industrial revolution in the late 19th century until the 1980s as the "hydraulic mission," which was then challenged by green movements (particularly in the global North) advocating sustainable water management. With increased water withdrawals in the Middle East and North African (MENA) region, water scarcity conditions became predominant while MENA countries introduced water policy reforms in order to increase the value of water and improve its use efficiency. The countries became increasingly reliant on virtual water trade (i.e., importing water-intensive food products) (Allan, 2002), although the renewable water resources in most MENA countries are still highly vulnerable and overused (World Bank, 2018).

The key reform item with regard to (sustainable) water management was the concept of Integrated Water Resources Management (IWRM) introduced in early 1992. IWRM reforms became widely adopted in the MENA region through the creation of separate water ministries and basin institutions and the establishment of national water strategies aimed at integrated management; i.e., balancing water demand and supply and regulating water uses in agriculture, households, and industry. IWRM-based reforms were not always successful. A key factor in the failure of many IWRM reforms has been the conflict between "old" water stakeholders advocating the interests of water development (e.g., farmers and agricultural institutions) and "new" stakeholders advocating sustainable management (e.g., water ministries and regulators) (Al-Saidi, 2017). In practical terms, this conflict is over the conservation and efficient use of freshwater resources. With the advancement of treatment technologies in the last couple of decades, it is now possible to develop and utilize marginal water resources, thus reconciling the two perspectives of the debate on water development vs. management.

In this paper, marginal water is defined as water that is neglected or underutilized in comparison to other water resource types. The marginality refers to the relational use pattern of marginal water of often lower quality (e.g., unutilized saline, brackish, treated, or storm water) in comparison to higher-quality water (e.g., freshwater or desalinated water). For the utilization of this neglected option, it is important that marginal water resources are identified, analyzed, treated, delivered and accepted by the producers and the end consumers. Encouraging the reuse and circulation of marginal water can improve water availability and help conserve vulnerable freshwater resources. Marginal water can also be seen as an entry point and a means for the dissemination of the ideas of de-growth and the circular economy in the agricultural sector in the MENA region. With regard to circular economy, this concept has several connotations and encompasses a wide range of strategies. According to Kirchherr et al. (2017), it involves several principles such as Reduce, Reuse, Recycle or Recover, while it relates to broader socioeconomic objectives of sustainable development. In applying this concept to the water sector, Al-Saidi et al. (2021) described the variety of issues such as reducing water losses, sustainable consumption, recovery of materials from wastewater or the reuse of wastewater. In this paper, we focus on the issues related to the circular consumption strategies described in Al-Saidi et al. (2021): namely, the reuse, recycling and recovery of water during consumption and consequential uses. In this case, we explore the wastewater reuse in different sectors in Iran and identify directions, challenges, and lessons from other regions. Al-Saidi and Dehnavi (2021) have provided a contextualization of wastewater reuse within the circular economy for several MENA countries, including Iran. In Iran, treated wastewater is not yet systematically used (e.g., through large public investments), and some use purposes such as groundwater recharging are still rare. Furthermore, there are many potential uses of other types of marginal water resources, which will be discussed in the following sections.

3 Materials and methods

This policy and practice review paper uses recent academic reviews, primary sources, and policy documents to highlight directions for marginal water use in Iran, and to contrast it with regional experiences mainly from the countries of the Gulf Cooperation Council (GCC) and Jordan. It does not provide details on technologies, projects, or trends in marginal water use per type and region, since such data are largely unavailable and/or inconsistent. The paper's contribution consists of highlighting the wide variety of reuse options with regard to different (combinations of) marginal water types. So far, the academic literature on Iran has focused on the development of treated wastewater. Furthermore, there are no existing studies with a comparative perspective on regional experiences. The lessons from the experiences in the GCC region and Jordan can provide highly valuable insights due to the specific features of these experiences. The GCC region provides important lessons on the use of different types of marginal water and also the deployment of more advanced technologies. Jordan's experience of water reuse in the agricultural sector presents an illustrative case, since a high percentage of treated wastewater is reused by utilizing indirect discharge to surface-water resources (which are available also in Iran while largely absent in the GCC region).

The analysis in this paper is presented in two parts. First, a contextualization of the water reuse issue in Iran was carried out through a conceptualization of this issue within broader water policies (Section 2), and a review of the academic literature on this issue (Section 4). For the literature review, a Scopus-based search was carried out in February 2024 of all peer-reviewed papers that have the following keywords in the title, abstract, or keywords: Iran *and* water; *and* any of the terms "circular economy," "wastewater" *or* "water reuse"; *and* any of the terms "policy" *or* "strategy." Note that this broad scope of search (i.e., not solely focusing on the circular economy concept in the water sector) is necessary since there are only very few studies on "circular economy" and "Iran" (29 in Scopus in February 2020, of which only two are on the water/food sectors and the rest mostly on waste management). The resulting initial dataset from the literature search was 118 papers. However, after a review including abstracts, the overwhelming majority of these papers are generic water publications that either do not focus on the reuse issue (i.e., not pertinent to the topic) or offer purely technical applications (i.e., not pertinent to the policy focus of this paper). A small set of papers (10) were subsequently included in the review (Section 4).

Secondly, the assessment of policy options and opportunities was carried out using primary policy texts and additional academic literature. The status of the use of different water types was presented using publicly available data and data from the academic literature (Section 5.1). Through mapping Iran's water policies with regard to water reuse, existing promotional policies were introduced and the main constraints summarized (Section 5.2). Finally, policy opportunities were presented using regional cases focusing primarily on the GCC countries and Jordan (Section 5.3). For this part, we used academic literature known to the authors (themselves water policy experts on the two cases) pertaining to the lessons learnt on the water reuse issues in those cases that can be of potential use for the case of Iran.

4 Case study and literature: circular economy and water reuse in Iran

In recent decades, Iran has invested heavily in the development of freshwater resources, mainly for agricultural purposes. For example, the total dam capacity increased more than sevenfold in the period between 1960 and 2015 (FAO, 2019). Recently, due to increased water scarcity, Iran's water policies have moved toward more sustainable water management, adopting some principles based on the IWRM concept (Salimi et al., 2019). However, the IWRM system is not consistently developed; for example, there are no IWRM legal frameworks at the level of catchments, and both participation and long-term planning are lacking (Kalantari et al., 2018). Furthermore, the primacy of the agriculture sector is evident in the lack of economic valuation of water; for instance, by the failure to recover costs through the introduction of water charges (Al-Saidi and Dehnavi, 2019). Public policies in Iran have for a long time had a bias toward promoting agriculture through groundwater abstractions (Madani et al., 2016), while water reuse receives increasingly more attention from policymakers (through constructing treatment plants) (Charkhestani et al., 2016). Kayhanian and Tchobanoglous (2016) argue that for IWRM to be (fully) implemented in Iran, water reuse should be systematically addressed; for example, through reclaiming, treating, and using wastewater and thus reducing the reliance on surface- and groundwater. The need for increasing water reuse in Iran is quite urgent considering the high water scarcity in the majority of the countries' regions (Figure 1). Many of the infrastructural investments in Iran have focused on expanding the collection of municipal wastewater plants. In 2015, there were around 150 municipal water and wastewater plants covering 23 million inhabitants, with the municipal and rural wastewater produced estimated at around 5 billion cubic meters by 2021 (Charkhestani et al., 2016). Table 1 shows the status of municipal wastewater treatment facilities in major provinces and Iran.

Our initial literature review of studies relating to circular water economy in Iran identified only a few studies contextualizing the water reuse issue within the circular economy (see Section 3). Overall, most of the related studies focus on the reuse of certain water types and do not review different reuse options, practices and challenges, nor do they compare the status quo in Iran to the comparable countries. Therefore, there is a need to complement the current academic literature by synthesizing water reuse practices and contextualizing policies in the regional context. In the following, we summarize insights from the reviewed studies reiterating the relevance of water reuse in different sectors, and stating some obstacles.

Considering the overall water balance in Iran, the agricultural sector seems to be the one with the most potential to save water through reuse. According to Barati et al. (2023), Iran has currently has 106 billion cubic of renewable water, but, due to evapotranspiration, most of it is lost naturally, so that the maximum quantity of available water is around 30% of total renewable water. This means that the total available amount of renewable water (supply) in Iran is around 31 billion cubic meters annually. However, the demand (as total amount of water withdrawn) is estimated at 103.5 billion (7.6 bn for the drinking and health sectors, 1.9 bn for the industrial sector, 70 bn for agricultural consumption, and 24 bn as wasted agricultural water through agricultural water transmission canals) (Barati et al., 2023). The difference between total water demand and available renewable water supply indicates a large deficit that is made up through the exploitation of non-renewable water resources, particularly groundwater. Besides, this very high gap of *ca.* 72.5 billion cubic meter per year could increase in the future, particularly due to precipitation changes that can reduce the annual total renewable water from currently 106 billion cubic meters to 37.9 billion by the next 50 years (Barati et al., 2023). Therefore, water reuse strategies in Iran will become even more important in the future to close some parts of the supply–demand gap.

Considering the large proportion of water use in agriculture, the reuse potential in the agricultural sector is highly relevant. In a similar vein, Charkhestani et al. (2016) show that water reuse in the agricultural, municipal, and industrial water sectors in Iran will result in significant increases in the total annual runoff available for human use (the Falkenmark indicator), mostly due to the reuse of agricultural wastewater. They calculated that Iran's Falkenmark indicator will

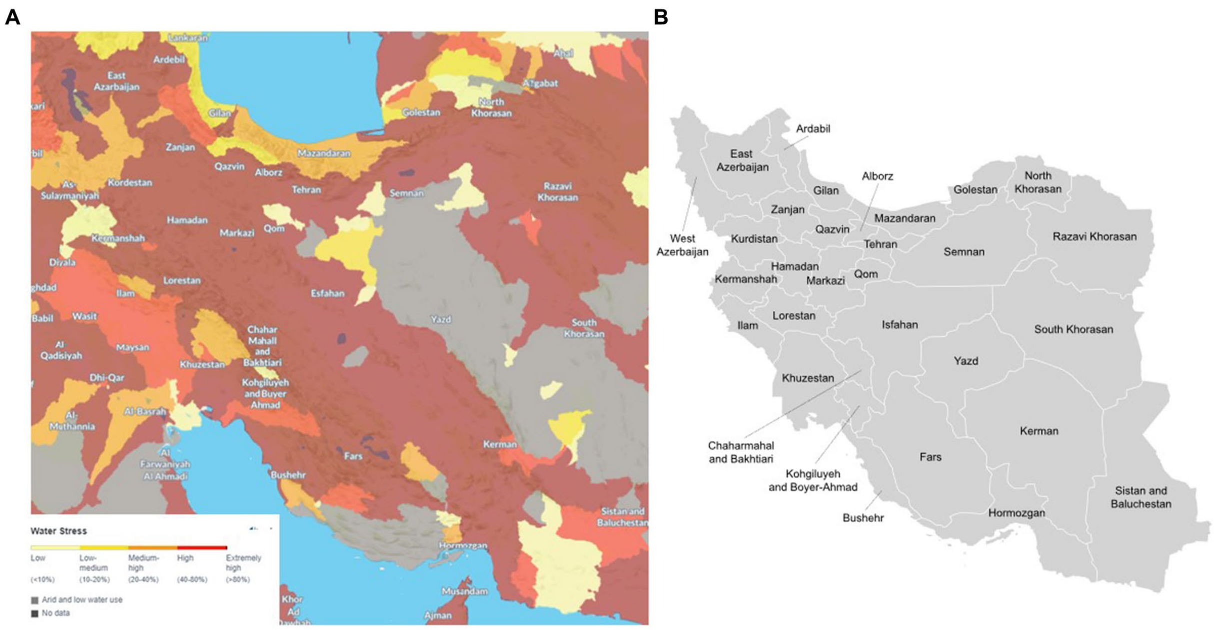

FIGURE 1
Water stress and provinces in Iran [Sources: **(A)** retrieved from WRI-Aqueduct, **(B)** open source from Wiki Creative Commons by Ali Zifan].

TABLE 1 Treated municipal wastewater in major provinces of Iran.

Province	Number of plants	Treatment capacity in million cubic meters per year	Population covered (x 1,000)
Ardabil	4	19.35	354
East Azerbaijan	9	94.65	1,485.99
Fars	2	29.2	510
Hormozgan	1	7.78	320
Isfahan	19	172.63	2,809.09
Kermanshah	7	33.36	553.3
Kurdistan	5	62.55	880
Markazi	9	36.66	810.6
Qom	3	43.99	610
Razavi Khorasan	3	36.58	541
Tehran	1	246.38	3,150
Yazd	2	19.53	268

Data for 2018 from Akbarzadeh et al. (2023).

be 816 cubic meters in 2025, while a 100% reuse scenario can provide an increment of 447 cubic meters (370 m^3 of which from agricultural wastewater), and a 50% scenario can provide 335 cubic meters (277 m^3 from agriculture). Golfam et al. (2021) stress that, considering climate change impacts, the best scenario for increasing synergies between water, climate change, and agriculture is to reduce the cultivation area and invest in the reuse of agricultural wastewater. With regard to industrial wastewater, Piadeh et al. (2022) show that the aim of reusing industrial treated wastewater is to avoid pollution as well as providing some on-site applications.

The academic literature on the circular water economy has also revealed some initial limitations in Iran. One major issue is quality control together with the acceptance of reuse, particularly with regard to municipal wastewater. Esfandiari et al. (2022) conclude that education and awareness campaigns together with quality standards are important for promoting the use of municipal treated wastewater in agriculture. To this end, public institutions in Iran have focused on improving public knowledge and developing more standards for the reuse of municipal treated wastewater in agriculture (Kalavrouziotis et al., 2013). Generally, consumers are inclined to accept the reuse of wastewater for low-contact usage, for example using grey water for washing houses or flushing toilets (Moshtagh and Mohsenpour, 2019). However, not all constraints are related to acceptance. Maleksaeidi et al. (2018) show that the use of low-quality untreated wastewater in agriculture is driven by water scarcity and the need to increase yield while decreasing production costs. Farideh and Abdi (2015) argue that, in Tehran, the water and wastewater company faces centralized governance and bureaucratic hurdles to improving performance and adaptively reacting to the needs of the water consumers. Collecting, treating, and reusing wastewater also comes at an environmental cost (e.g., harmful emissions), and thus water demand management is an important factor to consider for saving water and reducing environmental impacts in Iran (Safarpour et al., 2022).

5 Results: policy options, constraints, and opportunities

5.1 Extending the options: status of water reuse types and purposes

The options for incorporating marginal water resources as a part of overall sustainable water management in urban settings are plenty, but they are largely not approached systematically in Iran. The periodic development plans of Iran have advocated the use of different types of marginal water resources, although most of the current use for agricultural purposes is unplanned and uncontrolled (Karandish and Hoekstra, 2017). The main focus has, however, been on wastewater, where the central government assumes the lead role for the development of this water source. In Iran, water and wastewater supply are highly centralized, with the Ministry of Energy and the National Water and Wastewater Engineering Company (NWWEC) (under the latter ministry) supervising a number of provincial urban, municipal, and provincial rural water and wastewater companies (WWC). As most wastewater effluents are currently not treated, the NWWEC's Vision 2021 foresees an increase in wastewater treatment to 60% in urban areas and 30% in suburban areas by 2021 (Ministry of Energy, 2016). In the new National Strategy for the Development of Wastewater Treatment Technologies, the wastewater treatment coverage of the population in urban and rural areas should reach 90 and 15%, respectively, by 2040 (Hadi et al., 2022). Alongside wastewater use, there are other types of marginal water that can be used in Iran such as drainage water, stormwater runoff, rainwater harvested from rooftops, greywater (e.g., for use in households for toilet flushing, etc.) or saline water. However, up until now, most of these types are not used systematically.

5.1.1 Agricultural drainage water reuse

The most important reuse option in agriculture in Iran is related to drainage water from irrigation, which could amount to around 30 billion cubic meters by 2021 (Charkhestani et al., 2016). This type of water can be used in conventional or saline agriculture (e.g., for irrigation of halophytes, which grow in low and moderate salinity levels) as well as for livestock and restoring or sustaining wetlands. However, the reuse of such water requires careful management to match the cropping pattern to the quality of the water, and also to introduce practices of integrated drainage management that considers the overall drainage system design together with the soil and water quality aspects (Charkhestani et al., 2016). In order to exploit this potential in full, it is also necessary to upgrade infrastructure and develop holistic policies to promote sustainable (re)use of irrigation water (Nazari et al., 2018).

5.1.2 Reuse of treated wastewater

Treated wastewater is an important emerging source of reused water in Iran. According to official figures from the NWWEC [National Water and Wastewater Engineering Company (NWWEC), 2018], in 2017, 1.785 billion cubic meters were collected, and 74% (1.33 bn m^3) of this volume was treated in 194 wastewater treatment plants. The number of wastewater treatment plants in 2017 was 4.97 times higher than in 2001. Another 109 plants are under construction. The volume of wastewater produced is much higher (4.5 billion cubic meters) (Charkhestani et al., 2016), but wastewater treatment plants serve only about 27% of cities and 48.9% of the urban population in Iran. There is a need to invest in connecting the remaining population in less accessible areas.

In 2010, around 0.33 billion cubic meters of treated municipal wastewater (compared to *ca.* 0.86 billion cubic meters in 2012) was used for irrigation; i.e., applied directly for irrigation, used indirectly through dilution with freshwater to grow crops and fruit trees, or used for landscaping and forestry (FAO, 2019). Although the official number is low, the unsystematic or spontaneous (defined here as unintentional) use is higher and can amount to 90% of the treated wastewater in Iran (Tajrishy, 2012). Unintentional wastewater reuse can cause different problems due to the lack of monitoring of water quality and its long-term impacts. For the intentional reuse of wastewater, it is usually mixed with stormwater or water in tributaries of large water bodies before being used mostly for irrigation of low-value crops, particularly in suburban areas. Often, the wastewater treatment plants discharge water to the environment, where it mixes with freshwater and is then withdrawn by unregulated users downstream (Tajrishy, 2012). In the same process, intentional groundwater recharge happens around the major cities. In this case, the plants release the effluent to recharge brackish water aquifers, and then it is later used through springs and qanats by farmers downstream for irrigation purposes (Tajrishy, 2012). In addition, the transportation of treated wastewater directly to the point of use is becoming more common. Farmers can negotiate the right for direct use of treated wastewater through special contracts.

Different literature sources report direct use of partially treated or untreated wastewater for agricultural purposes (Jimenez and Asano, 2008; Tajrishy, 2012). This raises concerns about monitoring of treated wastewater quality for irrigation and health- or soil-related problems. The untreated wastewater mixed with stormwater or small streams or tributaries of larger water bodies – in order to allow for self-purification – is used for irrigation, especially downstream of urban centers where wastewater treatment facilities are inadequate. Increasing the capacity for wastewater treatment and reuse could reduce the amount of indirect use of untreated wastewater for agricultural purposes (Tajrishy, 2012).

Much of the treated wastewater can be used for urban areas due to the closeness of wastewater treatment plants to urban areas. If these plants were to become more integrated with urban agriculture, the beneficial uses of this water resource would be numerous as it could replace earlier-mentioned freshwater use for non-edible agriculture, or in the case of indirect use, replace groundwater abstractions. Other water reuse options are related to the use of water provided by municipal wastewater treatment plants for industrial parks, landscaping in cities, construction of lagoons, or even as indirect potable water reuse if the reused water is mixed with other water of better quality (Kayhanian and Tchobanoglous, 2016; Ministry of Energy, 2016; Karandish and Hoekstra, 2017).

5.1.3 Produced water reuse

Iran holds 10% of the world's crude oil reserves, with 70% located in onshore areas and the remainder offshore (Bagheri et al., 2018). Iran is also a significant producer of both oil and gas energies, and considering the high ratios of associated water production (e.g., a rough worldwide ratio of 3 water barrels for 1 oil barrel) (Al-Saidi, 2020), produced water from the oil and gas industries is an important marginal source in Iran. Although the total volumes of produced water in Iran are not available, and this water type is highly salinic, there are technological options to recover materials from produced water, reduce the amount of re-injected produced water into the ground, or improve the quality before re-injection (Bagheri et al., 2018). Internationally, produced water is increasingly considered as a resource (if adequately treated) with many beneficial uses such as saline agriculture, industrial uses, hydrological uses, or the extraction of important chemicals (Al-Saidi, 2020).

5.1.4 Combining different water types

Alongside the expansion of the reuse of agricultural drainage water, treated wastewater, or produced water, there are many opportunities for utilizing or combining other types of marginal water such as seawater, stormwater (i.e., water falling as rain on the ground), or even rainwater (i.e., cleaner water directly harvested from rain into storage tanks). Furthermore, saline water and wastewater can be used for combined marine–terrestrial agriculture, while harvested or drained water is often suitable for vertical farming. Saline water for fisheries through aquaculture has been expanding in urban and peri-urban areas, for example in African cities (e.g., in Nigeria) exhibiting high population growth rates (Miller and Atanda, 2011). Aquaculture can also be developed using wastewater, and this specific use is rising globally (Bunting and Edwards, 2018).

In Iran, the Caspian Sea can be utilized since its water is diluted by the inflow of freshwater and its salt concentration is one third of that in open water bodies. At the same time, major cities in Iran are in the inner regions while the bulk of aquaculture projects in Iran are concentrated in the southern coastal parts of the country (Hadipour et al., 2015). For the major urban areas in Iran, the reuse of wastewater and the recovery of drainage water constitute the primary marginal water utilization forms under consideration, while other sources such as stormwater and rainwater have not been systematically explored.

5.2 Addressing the constraints: domestic promotional policies

Several domestic measures need to be taken to promote the use of marginal water in Iran (see Table 2 for an overview). These include an increase in the number and quality of treatment plants, improvements to collection networks, water reallocation to more productive uses, expansion of seawater desalination to accommodate additional potable water use demands, improved monitoring networks, enhanced drainage systems in irrigation, removal of regulatory barriers, and increased public acceptance through (religious) education (Charkhestani et al., 2016; Kayhanian and Tchobanoglous, 2016). Some of these regulatory barriers include the absence of guidelines for the construction and operation of wastewater treatment plants, the need for clear water-quality standards for various uses of marginal water including potable use, and the lack of environmental monitoring regarding wastewater quality and suitable uses of this water. Furthermore, there are conflicting responsibilities with multiple agencies working on water reuse issues and no clear national guidance for mainstreaming roles and enhancing cooperation (Kayhanian and Tchobanoglous, 2016). Hadi et al. (2022) have reported similar challenges with regard to implementation of unified wastewater quality standards, updating water prices, or investing in human capacities, knowledge management and data regarding the water and sanitation sectors.

The bulk of the research available on Iran has focused on promoting the use of treated wastewater (i.e., higher collection, treatment, and reuse rates). Some of the main obstacles were the need to create appropriate technologies for different reuse purposes, improving the decentralized wastewater treatment systems as well as enhancing social acceptance (Rezaee and Sarrafzadeh, 2017). For example, a study by Hamidi and Yaghubi (2018) shows that the availability of high-quality potable water for irrigation purposes is the main constraint to the use of treated wastewater in urban agriculture. The reuse of treated wastewater could foster the use of the correct water quality for the correct agricultural purpose. Furthermore, considering the vast urban and industrial landscaping area in Iran, expanding the reuse of treated wastewater for landscaping purposes could reduce the pressure on water resources.

Environmental guidance for the reuse of treated wastewater was developed by the Ministry of Environment in 2011, stipulating the quality standards for different uses of the treated wastewater. The main sectors that take in the treated municipal water are those of irrigation, landscaping, and forestry near to urban areas. The use of treated wastewater for aquifer recharge is a second priority (Ministry of Energy, 2010). In some major cities, seepage pits and effluents from wastewater treatment plants are used to recharge groundwater aquifers. The long-term goal is to use water from these recharged aquifers and underground strata for irrigation in some urban communities. At the same time, despite concerns about water quality, treated wastewater can be used directly for irrigation, or to augment water supplies and reduce pressure in the case of droughts (e.g., in the city of Mashhad) (Kayhanian and Tchobanoglous, 2016).

In order to encourage water reuse, the Expediency Discernment Council of Iran (an administrative body appointed by Iran's Supreme Leader) has outlined several plans for recycling water nationwide. The proposed policies and strategies include the replacement of the agricultural water right for fresh water with treated effluents, promoting reuse of treated effluents, use of low-quality water instead of high-quality urban water to create green spaces, and the expansion of relevant research projects (Tajrishy, 2012).

Overall, governmental policies focusing on water reuse seem to have prioritized the urban sector. This can be explained through several economic and practical reasons. Firstly, the urban water sector generally has a higher rate of return on public investments. While the per cubic meter treatment costs of agricultural drainage might be less than the treatment cost of municipal water, investing in municipal water brings additional economic welfare benefits in terms of job creation, fighting poverty, or encouraging more productive sectors. This is because urban centers host sectors such as services or industry which produce higher-value commodities than in the agricultural sector. Therefore, the water supply and sanitation sector is often prioritized in water policies since, in developing countries, a 1-dollar investment in water and sanitation can provide a return rate of 5 to 28 dollars (Hutton and Haller, 2004). Moreover, in Iran, the coverage rate of wastewater treatment plants is still low (see Section 5.1.2), and therefore the prioritization of this sector is justified in order to improve the collection and treatment rates, and later use the wastewater directly or indirectly in other sectors.

For the agricultural sector, capturing agricultural wastewater would mean investments in drainage canals and irrigation systems. However, in Iran, irrigation modernization through governmental support is happening at a very low rate of *ca.* 50,000 hectares per year (Barati et al., 2023). The reuse of agricultural drainage water also poses challenges with regard to salt accumulation and the contamination of soil and groundwater by nutrients, pesticides, and other elements. It thus requires proper assessments via experimentation with on-farm drainage management or the use of drainage in salty agriculture (Charkhestani et al., 2016). Despite these difficulties, experiences in large agricultural countries facing water problems such as Egypt have shown that it is important to invest in the reuse of agricultural drainage alongside investments in the treatment and reuse of municipal wastewater (Hosney et al., 2023). Egypt has built a large water treatment for agricultural drainage in Bahr Al-Baqar that can process large amounts of drainage water at a low cost. Besides, there are also low-cost technologies for drainage water improvement that can be deployed in the short run (Ashour et al., 2021).

5.3 Opportunities and lessons from abroad

For growing the water reuse portfolio in Iran, there are several opportunities for using more advanced technologies, exploiting water reuse for saline agriculture, diverting wastewater reuse to irrigation schemes, and developing more integrated reuse systems. These opportunities and lessons from abroad are explained briefly in the following sections (see Table 3).

5.3.1 Regional experiences

Some interesting experiences from the Middle East with regard to water reuse can provide some lessons for Iran. The first lesson is with regard to the deployment of more advanced technologies promoting wastewater reuse or combining different marginal water uses. Here, countries of the GCC have promoted the wastewater reuse industry through ambitious government goals for collection, treatment and reuse. The use of treated wastewater for forage production and groundwater recharge is currently promoted on a wide scale in the region (Aleisa and Al-Zubari, 2017). One can argue that the water treatment and reuse industry in GCC countries exhibits higher levels of planning and control. In GCC states, the establishment of treatment plants is carried out through public works authorities, while the operators of the plants are in charge of finding suitable users for the treated water in the short run (e.g., landscaping companies, district cooling plants, or farming). In addition, national water supply providers can engage in major projects for aquifer recharge and infrastructural development (e.g., construction of pipelines) for the transfer of treated water for recharge sites. Despite this national-level involvement, some quantities of treated wastewater are left unused in treatment plants. This is due to acceptability problems and safety concerns that are not necessarily supported by evidence related to water quality (Aleisa and Al-Zubari, 2017). Still, the GCC case stands out in terms of technological advancement and the existence of ambitious reuse plans. By contrast, some of the treated wastewater in Iran is used spontaneously by farmers in semi-urban areas, or in times of drought to augment irrigation supply (Charkhestani et al., 2016; Kayhanian and Tchobanoglous, 2016). At the same time, GCC states are promoting the use of seawater for saline agriculture or fishery production through aquaculture plants and combined terrestrial production. With most of the major cities in the GCC region located in close proximity to the Gulf water body, saline water is a convenient resource under consideration for utilization for the production of halophytes, fish, or feed (Brown et al., 2018).

Another interesting area of experience is Jordan, where 98% of collected wastewater is treated, and 93% of treated wastewater is used for agriculture (Al-Saidi and Dehnavi, 2021). Jordan has developed an extensive network of canals and dams for transporting the produced wastewater to irrigation schemes, for example in the Jordan valley. The produced water is blended with freshwater to improve its quality, and the government has concluded agreements with agricultural user associations to replace freshwater use (i.e., groundwater abstractions) with use of the treated and diluted wastewater. To advance this wastewater reuse option, relatively clear strategies on wastewater reuse and its integration with delivery infrastructure exist (Al-Saidi and Dehnavi, 2021). Jordan is also promoting smart farming systems and supply-chain innovation using different types of water.

5.3.2 Opportunities for more integrated and circular systems

The analysis of the Iran water reuse case shows an unused opportunity for developing more circular and integrated approaches, which can link the treatment site to different kinds of uses. First, it is important to consider integrating treatment plants with accompanying networks to deliver the correct water amounts with the right quality to the right place. The integration of treatment plants in closed-loop systems with the water users – i.e., water consumption sites linked directly to treatment plants producing water for reuse – can help deliver water of different qualities for different purposes, and effluents can be treated after such use. The users can produce edible agriculture or forage, or mix the water with other water types such as harvested water from rain or saline water in order to produce other products. It is therefore important that, while some new distribution networks can be constructed, the sites for use of treated wastewater are carefully chosen – e.g., near wastewater treatment plants. This is especially important for the (re)use of marginal water resources for urban food production since such a practice demands careful design with regard to space as well as energy and nutrient supply.

Secondly, international experience with the utilization of marginal water resources for urban food agriculture points to multiple benefits of, and the need for, more integrated systems. For example, with wastewater reuse in urban agriculture, there is a good potential for nutrient recycling and the reduction of carbon emissions (Miller-Robbie et al., 2017). Furthermore, Iran can benefit from more comprehensive approaches in applying circular economy strategies beyond the issue of the treatment and reuse of wastewater. For example, in the GCC states, municipal wastewater is increasingly seen as a multipurpose resource that can be used for the water, agricultural, and energy sectors (Al-Saidi et al., 2021). Besides, integrating water

TABLE 2 Assessment of water reuse status quo and potential in Iran.

Marginal water type	Importance for the reuse portfolio	Prevalence of use	Existence of promotional policies	Main constraint
Drainage water	High High volumes due to the large size of agricultural sector; several opportunities for quality improvement and reuse	Moderate Narrative evidence indicates regular reuse but below full utilization and with no accurate data on current use patterns	Moderate Planned for expansion of the secondary drainage and irrigation systems to 500,000 hectares per year during the sixth development plan (2017–2021)	Little research on agricultural drainage reuse for crop production; need for monitoring of quality standards; lack of catchment-level planning; small and scattered farm areas; unregulated use of drained water by users nearby to the farm; need for infrastructure update; lack of support to farmers in irrigation and drainage system management
Treated wastewater	High Increasingly important due to increasing volumes and viability for reuse, particularly in agriculture	Moderate Despite increasing trends, collection and treatment rates still below full potential	Moderate Relatively ambitious sector targets for increasing wastewater treatment, but no evidence of follow-up strategies/investments	Regulatory and acceptance barriers for extending reuse purposes; need for monitoring of quality standards; conflicting responsibilities; unregulated use of produced water by users nearby to the plants; need for infrastructure update
Stormwater/rainwater	Moderate High volumes due to sizable precipitation but neglected use due to availability of other water types	Low Rarely systematically reclaimed and used	Low Little consideration in sectoral water (re)use policies	Infrastructure requirements for reclamation; little research on the potential; lack of consideration for policy-making
Combination of water types	Moderate Relevant opportunities for development of aquaculture or integrated terrestrial agriculture, although more relevant to southwestern regions	Low Projects exist for combining saline water with fresh or treated water, but no systematic use	Low No consistent strategies with clear targets and investments plans	Major water users, particularly industrial cities built in water-scarce regions of central Iran; need for more investment in water production, utilization and transfer capacities in the southern regions; need for supporting private sector in developing pilot projects and farms
Produced water	Low Despite high volumes, difficult to use due to bad quality and high treatment cost	Low Used in experimental cases or pilot projects	Low Little considered as a viable water source	Identifying viable project uses that can tolerate the bad water quality; minimizing energy cost; lack of research on reuse potential

and nutrient reuse systems (e.g., by reuse of nutrient-rich water in sanitation) with crop production sites can be a viable resource recovery system that enhances sustainable sanitation and urban agriculture in arid regions (Woltersdorf et al., 2018). Such coupled systems of wastewater and nutrients need to also monitor the salt flow in order avoid soil salinization (Woltersdorf et al., 2016).

In order to replace some quantities of freshwater reuse in agriculture, integrated urban systems (treatment plants linked to vertical farming or water use sites) are increasingly considered in the MENA region (Al-Saidi and Dehnavi, 2021). Water-efficient systems such as hydroponics and aquaponics can be coupled in order to produce crops with less water requirements (Blidariu and Grozea, 2011). Combining terrestrial and marine agriculture or using produced water are also emerging options for replacing some amounts of freshwater use in agriculture (Brown et al., 2018). Moreover, additional circular economy strategies for the water sector in Iran could include improving groundwater recharge, harvesting more rainwater and investing in bioretention systems in order to store water for use in several sectors such as agriculture or green spaces, or domestic use (Jokar et al., 2021). In the agricultural sector, there are

TABLE 3 Key opportunities for enhancing water reuse options in Iran.

Policy opportunity	Current status	Potential improvement	Relevant water types	Cases of practice	Required reforms or interventions
Technological exploitation	Municipal water treated partially with quality standards not allowing reuse or discharge to the environment (Akbarzadeh et al., 2023), while agricultural water is largely untreated (Nouri et al., 2023)	Improving treatment technologies for producing higher quality of wastewater for direct or indirect reuse	All marginal water types (particularly municipal wastewater and agricultural water)	GCC states (Brown et al., 2018); Egypt for the treatment of agricultural drainage (Tawfik et al., 2024)	Update of treatment plants, public expenditure; R&D investments for utilization of varying water qualities
Infrastructure development	No large-scale water dilution projects for the reuse of municipal wastewater	Improving infrastructure for wastewater dilution and delivery to agriculture use sites	Municipal wastewater	Jordan (Al-Saidi and Dehnavi, 2021)	Investments in irrigation infrastructure investments; water purchase agreements with farmers or farm associations
Integration of treatment plants	Spatial planning of municipal treatment sites does not consider other sectors' needs (e.g., agriculture)	Locating (decentralized) wastewater treatments close to potential use sites	Municipal wastewater	Often used in developed countries, e.g., USA (Tchobanoglous, 2019)	Strategic spatial planning for wastewater infrastructure; incentives for wastewater users for relocations
Coupled systems for urban agriculture	Lack of investments in urban agriculture through water reuse	Promoting water and nutrient reuse systems for urban crop production	Municipal wastewater, stormwater or rainwater	Projects in arid developing countries such as Namibia (Woltersdorf et al., 2018)	Policies for low-carbon urban development; promotion of green buildings; R&D and infrastructure investments

many opportunities to harvest more water in Iran through controlling soil evaporation or building different types of catchment-harvesting infrastructure (Nouri et al., 2023).

6 Discussion and the way forward

For expanding the water reuse portfolio in Iran, it is necessary to adopt more comprehensive reuse strategies that consider the different types of water and reuse purposes. Such strategies should also include infrastructural investments and measures to promote the acceptance of reused water. The water reuse acceptance issue is quite complex as it is often a long-term social process that involves several public and private debates concerning risks and adaptation possibilities associated with the different water sources, use purposes, and treatment technologies (Al-Saidi, 2021). Public involvement is crucial for improving public trust and providing guidance, regulations, and finance for infrastructure and research. It is also important for making water reuse an economically viable option. For this, the utilization of treated, and often expensive, water might be difficult to upscale if the price of freshwater is low. In fact, low freshwater prices represent a major impediment to efficient and sustainable use of scarce water resources in both the urban and agricultural sectors (Al-Saidi and Dehnavi, 2019).

Regarding reuse purposes, agriculture use seems to be a viable option for wide application of the circular economy through water reuse. The use of marginal water for food production brings with it additional challenges related to quality, infrastructure, cost, acceptance, and the existence of low or non-existent volumetric prices of water. However, with available technologies, it is possible to upscale food production using treated or saline water, or to replace some groundwater abstractions in agriculture with marginal water. For this, leadership from the public sector through subsidies, research development, and investments is needed.

Water reuse can be embedded within higher strategies to promote circular economy in basic supply by considering the wide range of possible applications in the areas of responsible consumption, reducing losses, extracting materials, and recycling water (Al-Saidi et al., 2021). However, for Iran, it is highly relevant to focus on the large water footprint of the agricultural sector. While the bulk of water reuse policies in Iran have focused on the municipal sector, the reuse of agricultural wastewater is considered the most effective way to close the water demand–supply gap (Golfam et al., 2021). This can be done through investments in on-farm drainage management, and the use of drainage water in agriculture for saline agriculture, initial reclamation of salt-affected lands, or bioremediation of wetlands (Charkhestani et al., 2016). If agricultural wastewater is to be reused for irrigation, this requires investments in the rehabilitation of drainage infrastructure, a careful study of the quality of this wastewater, and eventually some treatment. In the sense of the circular economy of water, agricultural wastewater should be considered as a resource that can be used for several purposes including the provision of irrigation water, the recovery of nutrients, and also for aquifer recharge (Golfam et al., 2021).

Alongside utilizing the huge amounts of agricultural drainage water, it is also possible to replace some freshwater uses through alternative agricultural production systems, such as the use of saline water or the cultivation of microalgae, although these directions need some initial subsidization (Brown et al., 2018). Furthermore, in order to ensure high-quality water supplies for urban agriculture, countries are investing in advanced wastewater treatment technologies using membranes, as these tend to minimize unwanted constituents in treated wastewater for urban irrigation (Bunani et al., 2015).

This paper has also presented opportunities for enhancing Iran's reuse policies using regional cases. While Iran can benefit from water reuse developments in cases such as the deployment of higher-level treatment technologies for municipal wastewater, or the development of infrastructure for water transfer, there are some differences worthy of mention. For example, in the GCC, there is more direct national-level support for the development of treatment infrastructure and the cooperation of treatment plants with potential users of the treated wastewater. In the GCC region and Jordan, the governments also invest in infrastructure for indirect reuse; for example, for agriculture in Jordan, or for aquaculture, aquifer recharge, or non-edible agriculture in the GCC region. In contrast, Iran has much more amounts of other types of water such as agricultural drainage water, and stormwater. While it further develops its reuse infrastructure, the reuse purposes will be primarily for lowering pressures on its groundwater aquifers (e.g., through replacing some freshwater needs in agriculture). Further comparative policy research is needed to understand the differences in policy portfolios for water reuse, the feasibility of large-scale reuse projects, and the role of national-level, local state-level, as well as civil society actors in the success of these projects.

7 Conclusion

Promoting the circular economy through water reuse in Iran can alleviate major concerns related to increasing incidents of water resources overuse and depletion in Iran. Reused water can augment supplies or replace vulnerable freshwater resources, ultimately leading to a decoupling of agriculture production (as the most common use sector) from water depletion. Furthermore, maximizing water reuse can help reconcile the debate of water development vs. water management by providing sustainable alternatives. Overall, this paper has emphasized the need for comprehensive water reuse policies in Iran that cover different types of marginal water sources. Concurrent investments in different underutilized water sources (particularly municipal water and agricultural drainage) can accelerate the transition toward a circular water economy in Iran which is highly needed considering the current and the expected water deficit.

Alongside the reuse of agricultural drainage water and municipal wastewater, other sources such as saline water, greywater, rainwater, or produced water are inadequately considered. By comparison regionally, Iran exhibits higher water availability, and as such has significant potential for different kinds of marginal water types. At the same time, Iran can learn from regional experiences such as the more ambitious, technologically driven and planned expansion of wastewater reuse in the GCC countries, or Jordan's experience in linking wastewater reuse infrastructure to irrigation.

The current use efforts in Iran have focused on the expansion of wastewater treatment and reuse capacities. The reuse levels are still far from achieving the ambitious future targets for municipal wastewater. Some of the major challenges include the lack of infrastructure, monitoring, and regulations to ensure that treated wastewater is delivered for its desired use to the right users at the right time and of adequate quality. There are several unexploited reuse purposes such as the recharge of vulnerable aquifers or wide-scale use in urban agriculture. These options are contingent on public acceptance and the commitment of public authorities to move beyond experimentation and single reuse initiatives to full utilization.

A major focus of the water reuse efforts in Iran is on food production. Alongside irrigation with treated marginal water sources, there are complementary options through the promotion of aquaculture, and combined marine–terrestrial systems in coastal cities with high-value fish products. Coherent regulatory and investment policies, as well as the right economic and pricing incentives, are needed alongside better public engagement and awareness. Furthermore, urban planning systems that provide integrated infrastructure between the treated water and nutrient sources and the suitable agricultural production sites are required. Future research can engage with more site-specific designs of integrated systems, the quality and health impacts, the acceptability of the end products to the consumers, and the integration of renewables components, such as solar energy and bioenergy, in order to minimize the costs and negative environmental impacts.

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Conflict of interest

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