JAEHR
Journal of Advances in Environmental Health Research
J Adv Environ Health Res, 2023; 11(1): 60-71. doi: 10.34172/jaehr.2023.08
http://jaehr.muk.ac.ir

Review Article

Municipal Wastewater Treatment in Iran: Current Situation, Barriers and Future Policies

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Article history:
Received: April 3, 2022
Accepted: May 31, 2022
ePublished: March 30, 2023

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Abstract
With population and economy growth, water usage, wastewater generation and treatment, treatment plants capacity and innovation ability in Iran have increased dramatically in the last decades. Currently, Iran is in the grip of severe water scarcity, with renewable water availability of less than 1700 m^3/capita/y. Total municipal wastewater generated in Iran is 4.61 billion m^3/y out of which only 42% is treated. The conventional activated sludge process accounted for the largest share (>60%) in municipal wastewater treatment in Iran. The treatment plants operational costs usually amount up to 0.2 US $/$m^3$ wastewater. About 55% of treated municipal effluent is reused in Iran, with an emphasis on the agricultural sector. The electricity consumption in municipal wastewater treatment facilities amounts for 0.1% (241 million kWh/y) of the total electricity consumption of the country. Meanwhile, the current laws and policies are sometimes inefficient or do not prompt the ideal outcomes. Thus, the present study provides an overview of municipal wastewater treatment in Iran by describing the current situation and collecting data from 68 treatment plants, and defining key barriers and future policies needs towards Iran's sustainable municipal wastewater management (up to 2040). Here, the opinions of 50 experts from the governmental sector, industry division, and faculty members were surveyed through the meetings of the technical and steering committee. Overall, sustainable municipal wastewater management in Iran would be obtained by developing water resources, increasing the population covered by wastewater facilities (90%), improving effluent discharge standards, and lowering energy usage to 0.45 kWh/m^3 wastewater.
Keywords: Water resource, Municipal wastewater treatment, Sludge, Energy, Reuse, Policy

Please cite this article as follows: Akbarzadeh A, Valipour A, Meshkati SMH, Hamnabard N. Municipal wastewater treatment in Iran: current situation, barriers and future policies. J Adv Environ Health Res. 2023; 11(1):60-71. doi:10.34172/jaehr.2023.08

Introduction
Rapid population growth, a change in rainfall pattern, a decrease in rainfall, and an inefficient temporal and spatial distribution of rainfall in Iran have all contributed to social tensions over water resources.[1,2] Improper exploitation of groundwater resources, which is the main source of water supply in arid areas, has also led groundwater aquifers to face severe quantitative and qualitative decline.[2] On the other hand, the untreated discharge of municipal, industrial, and agricultural wastewaters in Iran has created serious pollution of the water resources and environment.[3] For example, direct discharge of wastewater in river or reuse for irrigation may cause heavy metal and microbial contamination as well as pathogenic interaction in soil and crops. Moreover, this can lead to soil salinity, which grows with regular use of untreated wastewater.[4] In this regards, safe, economical, efficient disposal and reuse of wastewaters could be considered as one of the solutions.[5] Although municipal wastewater is regarded a waste, it is increasingly recognized as a valuable source of water, nutrients, metals, and energy.[6] Therefore, a reliable planning for the management and treatment of municipal wastewater, in addition to protecting the environment and increasing the health of the community, can protect water reserves and reduce water supply costs in Iran. This is a practice that has been performed for many years in developed countries, and it is necessary to pay special attention to this valuable matter in developing countries.

In Iran, the National Water and Wastewater Engineering Company (NWWEC) is one of the subsidiaries of the Ministry of Energy (MoE), which is responsible for organizing the official activities in water and wastewater affairs. After approval of the act on the establishment of the provincial water and wastewater companies in December 1990, these companies took over the operational task in the provinces under the supervision of the NWWEC. Hereafter, serious and special attention has been paid to the issue of wastewater collection and treatment, as one of the primary and fundamental duties of water and wastewater companies. However, with economic progress and increasing public and governmental awareness in the field of environmental protection, Iran's capacity for municipal wastewater treatment has been also increased rapidly. As such, there is a need to summarize and assess the current situation, as well as propose future policies in order to accomplish sustainable wastewater management. However, the reports on the status of municipal wastewater treatment in Iran are very rare.

The main objectives of this study are: (1) providing a glimpse of the current status of renewable water resources in Iran, (2) describing the current status of municipal wastewater sector by collecting data from the MoE and NWWEC, and 68 municipal wastewater treatment plants from 12 provinces of Iran, (3) discussing the barriers related to the municipal wastewater treatment industry, (4) highlighting the proposed policies that can be required to overcome the barriers. Additionally, this paper establishes a systematic decision support framework that can be used to guide the decision-making process of the government and other stakeholders to create a secure and resilient municipal wastewater sector in Iran. This paper is valuable for application in both the national and international levels.

Methods

Study Area

Iran is a vast country with a total land area of about 1.6 million km^2. It is the Middle East's second-largest country (after Saudi Arabia), and the 18th largest in the world.[7] Geographically, Iran is located between 25 degrees 3' to 39 degrees and 47' north latitude, and 44 degrees 5' to 63 degrees 18' east.[8] Approximately, 88% of Iran is placed in arid and semi-arid regions.[9] Temperatures can range from -20 to + 50 ºC across the country and throughout the year.[7]

Data Collection

The data were collected and analyzed from government's national sites and portals,[10-15] and 68 municipal wastewater treatment plants from 12 provinces of Iran. During field studies, the information on wastewater treatment plants, such as type of treatment process, population covered, plant capacity, starting year of operation, operational lifetime, total operation cost (sum of the personnel, chemicals, maintenance, and energy costs), and nitrogen removal conditions, was collected. The barriers and proposed future policies related to the municipal wastewater treatment industry in Iran were identified through the interview by forming technical working group (39 people) and steering committee (11 people) and holding 10 sessions. The members of the working groups were selected from scientific experts, faculty members, and senior managers of the NWWEC, and government and the non-government sectors. The main tasks of technical working groups were reviewing the current situations, challenges, and opportunities, as well as determining the desired status and providing the proposed policies to achieve the desired conditions. Besides, the main task of the steering committee was to review the output of specialized working groups to be documented as a project achievement. Accordingly, a period of 20 years — from 2020 to 2040 — was identified as the timeframe to define policies. In Iran, the reported statistical periods start from 1st March and ends on 31st March of the following year.

Determination of Achievable Goals

The achievable goals were determined by examining the upstream documents and obtaining the opinions of experts from technical working groups. The most important read upstream documents included the MoE vision document, the Iran 5-year-development plans, and the general policies on related issues such as land-use planning, consumption pattern reform, etc.

Snapshot of the State of Renewable Water Resources in Iran

Iran is ranked 130 among the 200 countries in the world in terms of total renewable water resources.[16] The average annual precipitation in Iran is about 251 mm, which is less than one-third of the world's average precipitation (831 mm/y). This country possesses only 0.39% (413 billion m^3 annually) of all precipitation from the lands on the earth (107 000 billion m^3 annually), while the land area of Iran is 1.1 % of all lands (149 million km^2) [17]. Meantime, it is reported that there are about 6 billion m^3 of overdrafts from groundwater aquifers in Iran annually.[18] Given that, the total groundwater depletion has been stated at about 74 km^3 from 2002 to 2015 with variable rates of change at basin and sub-basin scales.[19] Correspondingly, the effect of the decrease in Iran's groundwater reserves has currently been specified by excessive overdrafts in about 77% of Iran's land area, increasing soil salinity throughout the country, and increasing the frequency and rate of land subsidence in Iran's plans.

Figure 1 illustrates the trend developed for population growth and potential share of renewable water per capita

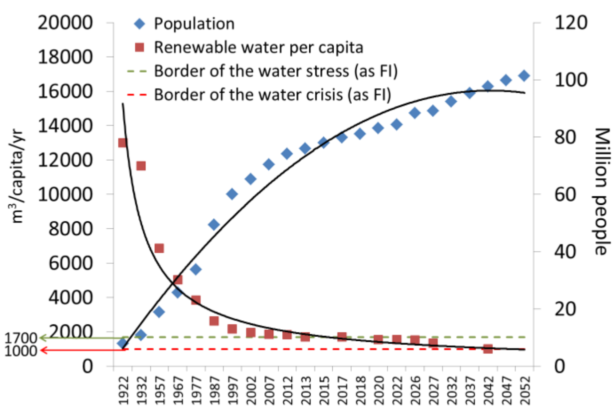

Figure 1. Trend Developed for Population Growth and Potential Share of Renewable Water Per Capita in Iran From 1922 to 2052 (FI=Falkenmark indicator).

in Iran from 1922 to 2052. The data are adopted from a database of the Statistical Center of Iran (SCI)[10] and literatures.[20-22] As can be seen in Figure 1, the population of Iran increased (90%) from about 8 million to 83 million from 1922 to 2020 and is projected to reach about 101 million by 2052. Meanwhile, the amount of renewable water per capita in Iran has reduced from about 13 000 m^3 in 1922 to less than 1700 m^3 in 2020 (i.e., falls between water stress and crisis threshold of the Falkenmark indicator), and it could be projected to reach below the water crisis (1000 m^3/capita/y) in 2042 onwards. Furthermore, since the average of 72% (about 93-94 billion m^3/y) of the total renewable water (about 130 billion m^3/y) is used annually,[16] to maintain the status quo until 2025, it is predicted that about 112% should be added to the extractable water resources in Iran.[23] This could currently be difficult and even impossible due to the potential and growing needs of domestic, agricultural, and industry sectors and the protection of natural resources. Meanwhile, the estimation based on the statistics of the last five years has shown that the country's renewable water resources have reduced from about 130 billion m^3 to about 104-106 billion m^3 per year. This issue has been in form of unofficial statistics, and it has been repeatedly stated by the officials of the MoE, and in the official scientific forums of Iran.[24] Of course, it should be noted that, if the total annual renewable water resources are about 130 billion m^3, by considering the 9 billion m^3 of renewable border water resources, the actual annual volume of renewable water resources in Iran will be about 139 billion m^3.[25]

Status of Wastewater Production and Treatment in Iran

According to the latest statistics provided by the NWWEC of Iran (up to the end of March 2020), about 33 million people in urban areas and 0.1 million people in rural areas are covered by wastewater facilities.[11] However, the population has been estimated at about 62 million in urban areas and 21 million in rural areas in the same year (total country's population: ~83 million people).[10] This indicates that about 53% of the urban population and about 0.5% of the rural population in Iran are covered by wastewater facilities (i.e. 40% of the total population). Also, the number of cities and villages with wastewater facilities was reported to be 331 cities and 74 villages in March 2020. Besides, the number of domestic sewage subscribers in urban and rural areas was estimated at 7.2 and 0.02 million, respectively. Based on the reports obtained, the length of the sewage collection network and sewage transmission lines in the cities were about 64500 and 3400 km, respectively, and in the villages were in order of 1125 and 185 km. In addition, 237 urban wastewater treatment plants with an operating capacity of about 5.3 million m^3/d, and 37 rural wastewater treatment plants with an operating capacity of about 0.01 million m^3/d are under operation.

Figure 2a displays the number of wastewater treatment plants under operation with their nominal and operating

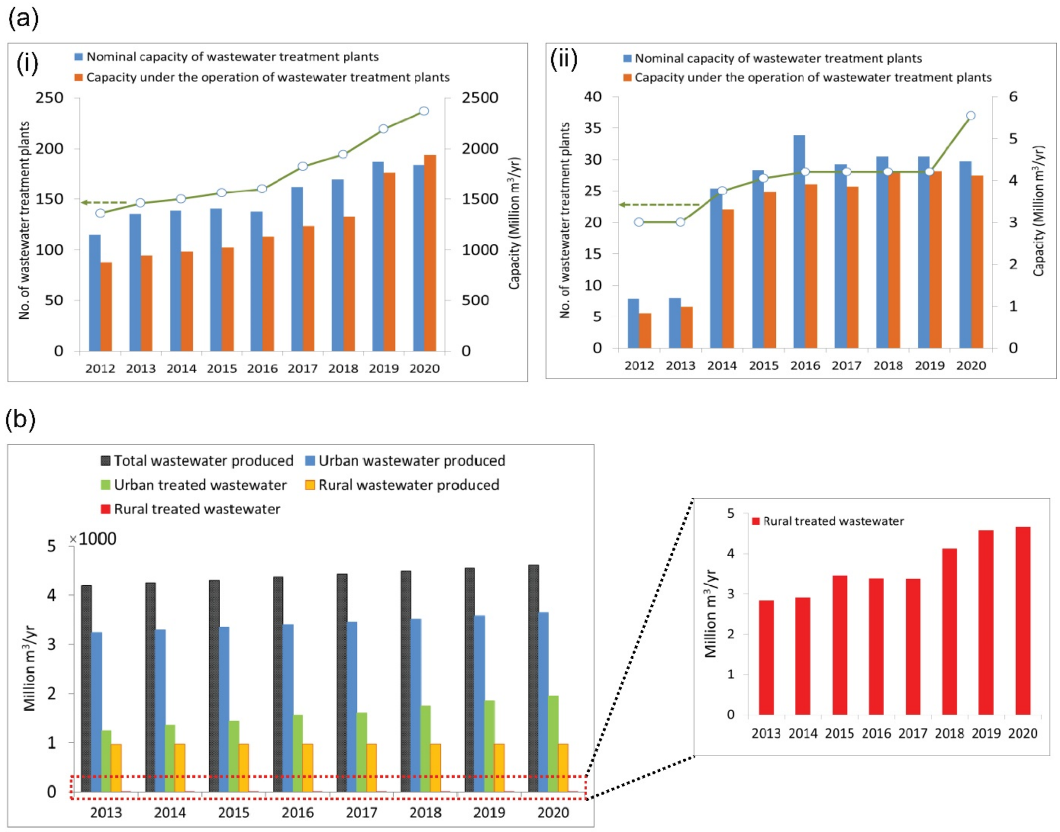

Figure 2. a) Number of wastewater treatment plants under operation with their nominal and operating capacity in the (i) urban and (ii) rural areas from 2012 to 2020, b) Calculated amount of municipal wastewater produced in and its urban and rural Iranian areas, and the volume of treated wastewater in the urban and rural areas from 2013 to 2020.

capacity in the urban and rural areas from 2012 to 2020, whose data are taken from the databases of the NWWEC[11] and SIN-MoE.[12,13] As shown in Figure 2a-i, the number of wastewater treatment plants in the urban areas has gradually increased with a gentle slope over the last nine years (from 136 in 2012 to 237 in 2020). In the rural areas (Figure 2a-ii), the number of wastewater treatment plants has increased from 20 in 2012 to 28 in 2019. In contrast, the number of wastewater treatment plants in rural areas increased significantly from 2019 to 2020 (from 28 to 37 treatment plants). Furthermore, the nominal capacity of wastewater treatment plants in urban and rural areas has been more than their operational capacity in the mentioned years (except 2020 in the urban areas). The more operational capacity compared to the nominal capacity in urban areas in 2020 may be attributed to the increase in urban population, which leads to more wastewater production and lack of development of wastewater treatment plants (Figure 2a-i).

Figure 2b illustrates the calculated amount of municipal wastewater produced and its urban and rural areas in Iran, as well as the volume of produced treated wastewater in the urban and rural areas from 2013 to 2020. In this regard, the total amount of municipal wastewater produced in Iran, as well as wastewater produced in urban and rural areas, is calculated based on equations 1, 2, and 3. And, treated wastewater produced in the urban and rural areas is calculated based on equations 4 and 5.

$$TWWP = RWWP + UWWP \quad (1)$$

$$UWWP = (P_U \times LPCPD) \times 0.8 \times 365 \quad (2)$$

$$RWWP = (P_R \times LPCPD) \times 0.8 \times 365 \quad (3)$$

$$TUWWP = (UWWP \times [(P_{CU} / P_U) \times 100]) \quad (4)$$

$$TRWWP = (RWWP \times [(P_{CR} / P_R) \times 100]) \quad (5)$$

In the above equations, TWWP, UWWP, RWWP, TUWWP, and TRWWP are the total produced wastewater, wastewater produced in the urban areas, wastewater produced in the rural areas, treated wastewater produced in the urban areas, and treated wastewater produced in the rural areas, respectively (as billion m^3/y). LPCPD is the capita water consumption (as L/d). P_U and P_R are the total urban and rural area populations in different years studied, respectively. Likewise, P_{CU} and P_{CR} are the urban and rural area populations covered by municipal wastewater facilities in different years studied. In these equations, the water consumption per capita in urban and rural areas is assumed to be 200 and 160 liters per day, respectively. The capita water consumption in Iran has generally known to be between 170 and 233 liters for urban areas and between 140 to 180 liters for rural areas. The total population size and the population covered by municipal wastewater facilities for urban and rural areas are taken from the databases of the SCI[10] and NWWEC.[11] Here, the water-to-wastewater conversion ratio is 0.8.

As can be seen in Figure 2b, the annual total municipal wastewater production has increased from 4.20 to 4.61 billion m^3 between 2013 and 2020. This is due to the increase in the population of the country from 76 million to 83 million people over these years.[10] During this period, the volume of urban wastewater generation has risen from 3.24 billion to 3.64 billion m^3 per year (400 million m^3 increased), and the urban population leaped from about 55 million to 62 million. However, the annual rural wastewater generation has elevated slightly from about 965 to 967 million m^3 (2 million m^3 increased). This could be related to the low population growth in rural areas that occurred due to the migration from villages to cities or the transformation of villages to cities. More specifically, the rural population has grown from 20.66 million in 2013 to 20.71 million in 2020.

On the other hand, as illustrated in Figure 2b, the annual treated urban wastewater has risen from 1.25 billion to 1.95 billion m^3 between 2013 and 2020 (700 million m^3 increased). However, the annually treated wastewater in rural areas has changed minimally over these years (from 2.83 to 4.67 million m^3/y) and has increased by only 1.84 million m^3. This could be due to the lack of significant growth in the rural population covered by wastewater treatment facilities (as mentioned elsewhere).

Municipal Wastewater Treatment Technologies in Iran

Treatment Processes

To study the status of wastewater treatment processes in Iran, data were collected from the municipal wastewater treatment plants (68 plants) of 12 provinces (59 cities/counties), and then it was analyzed (data collected in 2018) (Table S1). Accordingly, the total amount of wastewater available with different treatment processes in each province is illustrated in Figure 3a. It is worth mentioning that the treatment processes included conventional activated sludge (CAS), extended aeration (EA), anaerobic-anoxic-aerobic (A_2O), sequencing batch reactor (SBR), aerated lagoon (AL), stabilization pond (SP), and constructed wetland (CW). The type of processes used to treat municipal wastewater varies depending on some factors as mentioned elsewhere. The total amount of municipal wastewater received by selected treatment plants in Tehran (246 million m^3/y) and Isfahan (173 million m^3/y) provinces are more significant (45%-97%) than that received by selected treatment plants in other provinces, whilst the studied treatment plant in Tehran province received 30% higher wastewater than the total treatment plants studied in Isfahan. It should be noted here that the selected treatment plant for study in Tehran Province receives the majority of Tehran city municipal wastewater.

In almost all selected treatment plants (Table S1), except treatment plants in Yazd and Khorasan Razavi provinces, the CAS process is one of the systems that have been used in municipal wastewater treatment. In treatment plants of Yazd province, A_2O, and SBR processes, and treatment plants of Khorasan Razavi province, AL and SP processes have been employed. The selected treatment plants in Tehran, Qom, and Hormozgan provinces have used merely the CAS process. In other provinces, in addition to CAS, other processes such as AL, SP, SBR, and EA have been applied for municipal wastewater treatment. The CW process has been merely used in a selected treatment plant in Kermanshah province. Further, only 12 of the 68 treatment plants have an operating age of 20 years or older (calculated up to 2021). CAS, AL, and SP are the processes used in these treatment plants. It was also found that about 35% of the treatment plants studied (24 out of 68 treatment plants) have the potential to remove nitrogen, including CAS, A_2O, SBR, SP, and CW processes.

According to the collected data (Table S1), CAS, EA, A_2O, SBR, AL, SP, and CW processes covered about 8.2, 0.24, 0.29, 0.38, 1.50, 1.62, and 0.02 million people in the selected treatment plants, respectively. Likewise, these processes are responsible for treating about 556, 13, 16, 32, 96, 88, and 0.80 million m^3 of municipal wastewater per year. As a result, the CAS process has the largest share (~69%) in municipal wastewater treatment among existing processes (Figure 3b). In that order, the AL and SP processes are in the next ranks with a share of about 12% and 11%, respectively. The wastewater treatment by CW method has the least share (~0.1%). Less use of CW for wastewater treatment in Iran can be due to a lack of knowledge of its operation.

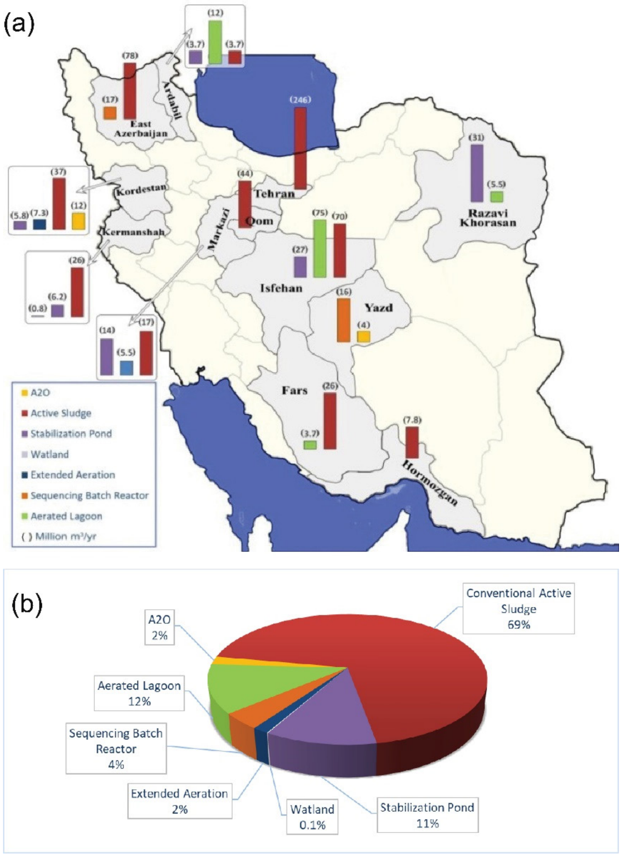

Figure 3. (a) Total amount of municipal wastewater available with different treatment processes in the 12 provinces, (b) Share of treatment processes in the studied treatment plants of the 12 provinces

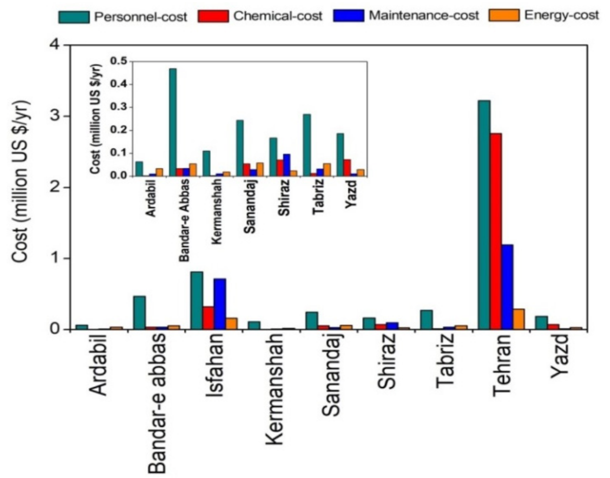

Figure 4. Operating Costs of the Sum of the Municipal Wastewater Treatment Plants in the Centers of 9 Provinces of Iran.

Economic Analysis of Wastewater Treatment Technologies in Iran

No doubt, it is not easy to obtain accurate cost information related to wastewater treatment plants or benchmarking data for various treatment processes. Regarding the total costs of wastewater treatment plants, operation costs play a crucial role. Accordingly, several factors can affect operation costs in wastewater treatment plants, including site location, raw wastewater characteristics, discharge standards, treatment process type, treatment plant size, wastewater inflow volume, treatment plant age, sludge treatment and management type, energy price, monitoring and process control level, and the treatment plant's organization and management method [26]. Therefore, to estimate the costs of existing municipal wastewater treatment plants in Iran, the available information on the total operation cost of 49 treatment plants was evaluated (Table S1). Based on the collected data, the total operating cost for different treatment processes in Iran has been estimated to be ≤ US $~0.2 per m^3 (sludge management costs not included in this analysis).

Figure 4 displays the details of operation costs of the sum of municipal wastewater treatment plants located in the center of 9 provinces (according to the data collected in 2018). The treatment plants are included in the treatment plants of the cities of Ardabil, Bandar-e Abbas, Isfahan, Kermanshah, Sanandaj, Shiraz, Tabriz, Tehran, and Yazd (Table S1). These treatment plants have been selected due to the complete availability of information regarding operational costs. CAS, SBR, and AL are the processes used in these plants. From Figure 4, the municipal wastewater treatment plants of Tehran and Isfahan have sequentially higher total operating costs (>70%) than the others. The total operating cost of the treatment plant in Tehran (US $7.46 million/y) is 73% higher than those in Isfahan (US $2 million/y). The personnel, chemical, maintenance, and energy costs in the treatment plants of Tehran and Isfahan are in order 3.22 and 0.81, 2.76 and 0.32, 1.19 and 0.71, and

0.29 and 0.16 million US $ per year.

Sludge Management in the Municipal Wastewater Treatment Plants of Iran

Many municipal wastewater treatment plants in Iran are currently dumping large amounts of sewage sludge without any treatment into the environment. Among all municipal wastewater treatment plants in Iran that employ the activated sludge process for wastewater treatment, only treatment plants of the south of Tehran, north of Isfahan, south of Isfahan, Shahin Shahr, Tabriz, and west of Ahvaz use anaerobic digestion for sludge stabilization. The treatment plants of Kermanshah, Bandar-e Abbas and Shiraz have anaerobic digesters, but they are not operated.[27] The lack of sludge management in most municipal wastewater treatment plants in Iran could be because of the fact that sludge treatment has a high annual cost and requires a lot of skilled labor. Moreover, there was no written law concerning sludge until 2021 in Iran, although it was mostly applied in lands.[28] In this regard, a new standard has recently been released in 2021 by the Iranian National Standardization Organization (INSO) on municipal wastewater treatment plant biosolids' separation and monitoring (ICS: 13.060.30; 13.030.020). This standard addresses the following issues: definitions, objectives and applications, biosolid application risk, stabilization degree, contaminant limits, pathogens and vectors control, decision-making process, biosolid classifications, authorized biosolid consumption, management practices, operational standards, sampling and analysis, documentation, and reporting. However, policy and legislation related to sludge usage and sludge management generally depend heavily on local, national, and regional conditions.[29] It has been reported that the sludge handling and management costs typically range from 20 to 60% of the total operating cost of the treatment plant.[30] Of course, the quantity and quality of sludge are dependent on the characteristics of raw wastewater, the type of treatment process, and the method of plant operation.[31]

Energy Consumption in the Municipal Wastewater Treatment Plants of Iran

Worldwide wastewater treatment consumes about 1% (200 terawatt-hours) of world energy consumption.[32] In Europe, wastewater treatment accounts for about 1% of total electricity consumption.[33] Despite this, other percentages may be found in the literature. According to some studies, wastewater treatment accounts for roughly 0.7% of total electricity consumption in Germany, 0.6% in the United States, and 0.5% in South Korea.[34,35] In China, wastewater treatment electricity usage is cited from 0.21 to 0.49% of total electricity use.[35,36] In Iran, the total amount of electricity consumed in the water including water treatment, transmission, and distribution facilities and municipal wastewater including wastewater collection, transfer, and treatment sectors is about 2% (4920 million kWh/y) of the total electricity consumption (236 billion kWh/y) of the country. Accordingly, the amount of electricity consumption merely in municipal wastewater treatment facilities of Iran has been stated about 241 million kWh/y.[37] This value is about 4.9% of the total electricity consumption of the water and municipal wastewater sectors, and about 0.1% of the total electricity consumption in the country. Besides, based on the greenhouse gas emission from the municipal wastewater sector, the average energy consumption of wastewater in Iran has been reported to be 0.6 kWh/m^3.[38] However, only 40% of the total population in Iran is covered by municipal wastewater facilities (evaluated up to the end of 2020).[11] Meanwhile, a lack of attention to waste sludge management may in turn have an impact on electricity consumption in the municipal wastewater treatment sector in Iran. Energy consumption in the municipal wastewater sector is expected then to increase seriously in the future with the development of the population covered by the wastewater treatment facilities. One frequent reason for the high electricity demand in municipal wastewater treatment facilities in Iran is that treatment plants were typically designed to treat wastewater based on activated sludge processes, which specifically require aeration in a biological tank. This component can account for 50%-70% of the total electricity used in a wastewater treatment plant.[39] Energy consumption for activated sludge processes, trickling filters, and lagoons has typically been reported to be 0.3-0.6, 0.18-0.42, and 0.09-0.29 kWh/m^3, respectively.[40] Therefore, efforts to control and optimize energy consumption in municipal wastewater treatment plants of Iran are unavoidable principle.

Treated Municipal Wastewater Reuse in Iran

Firstly, it should be noted that the information on the quantitative and qualitative characteristics of treated effluents and their reuse is very rare in Iran and there is a serious challenge in this regard.[41] Based on the latest data taken from a database of SIN-MoE[14] and the literature,[41] the total volume of output effluent from the municipal wastewater treatment plants in Iran was about 500 million m^3 per year up to March 2009. Meanwhile, about 276 million m^3 of this treated effluent has been reused annually (in almost 18 provinces) (Figure 5). From this, the volume

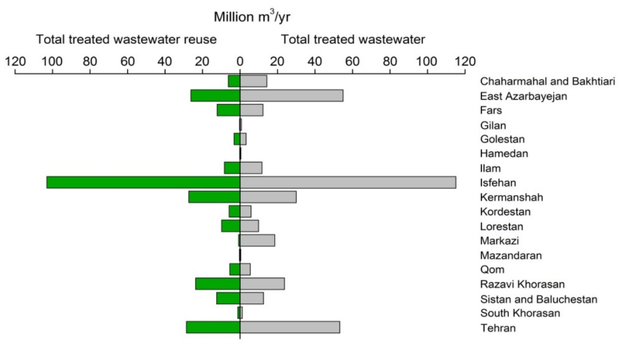

Figure 5. The Volume of Treated Municipal Wastewater Produced and Treated Wastewater Reuse in 18 Provinces of Iran in 2009.

of treated effluents for agricultural, industrial, and irrigation of green space use was about 226 (82%), 15 (5%), and 31 (11%) million m^3 per year, respectively. The volume of effluents intended for artificial recharge of groundwater was about 4 million m^3 per year (1%). Accordingly, most of the treated effluent produced by municipal wastewater treatment plants in Iran is either used in agriculture or discharged to surface water resources, and the share of consumption of this effluent in other sectors (industrial use, groundwater recharging, and general urban use) is less than 20%.

From Figure 5, Isfahan province with the use of about 103 million m^3 per year of treated wastewater has first place among other provinces. Further, Tehran, Kermanshah, East Azerbaijan, and Razavi Khorasan provinces, respectively, with the use of about 29, 27, 26, and 24 million m^3 per year of treated wastewater are in the next places. The volume of reused treated effluent in other provinces is less than 13 million m^3 per year. It should be noted that this statistic is related to the treatment plants under operation. Tehran south treatment plant which receives the majority of municipal wastewater of the city of Tehran (as mentioned elsewhere) was not under operation up to 2010 (see Table S1); hence, it was not considered in this figure.

Here, given the fact that 92% (85-86 billion m^3/y) of the total usable water resources (93-94 billion m^3/y) in Iran are used in agriculture[16]; thus, the agricultural sector has the greatest potential for the reuse of treated wastewater. The use of treated wastewater in agriculture can be a valuable tool for promoting sustainable agriculture, reducing pressure on water resources, preserving scarce water resources, lowering agricultural water costs, increasing agriculture crops, decreasing pollution burden on the environment, and maintaining environmental quality. It implies that the laws and guidelines for wastewater reuse in agriculture in Iran should be developed, and specialized for various products.

Treated Wastewater Discharge Standard and Quality of Iran

Table 1 shows treated wastewater standards for discharge to surface water and wells, as well as reuse for agriculture and irrigation in Iran. Nevertheless, this standard is old and needs to be updated compared to the effluent discharge standards in other countries.[42-44] Accordingly, the values to be considered in the development of treated wastewater discharged standards depend on several factors; for instance, population size, treatment technology, treated effluent characteristics, reclaimed water quality requirements, reuse type, receiving water body, water environment, investment costs, water quality monitoring, and assessment methods. This is while the development and updating of treated wastewater discharge standards is a very imperative issue for water reclamation in Iran at present.

Some examples of treated wastewater quality characteristics in municipal wastewater treatment plants of Iran are presented in Table 2. From Table 2, it can be thought that the characteristics of treated wastewater in most municipal wastewater treatment plants of Iran

Table 1. Standards for Wastewater Discharge to Environment and Effluent Reuse in Iran[15]

Parameter	Unit	Treated Wastewater Discharge Standard		
		Surface Water	Well	Agriculture and Irrigation
pH	-	6.5-8.5	5-9	6-8.5
BOD_5	mg/L	50	50	100
COD	mg/L	100	100	200
Turbidity	NTU	50	-	50
TSS	mg/L	60	-	100
Oil and grease	mg/L	10	10	10
Ammonium (NH_4^+)	mg/L	2.5	1	-
Nitrite (NO_2^-)	mg/L	10	10	-
Nitrate (NO_3^-)	mg/L	50	10	-
Phosphate (PO_4^{3-}) as P	mg/L	6	6	-
TC	No./100 mL	1000	1000	1000
FC	No./100 mL	400	400	400

BOD_5: biochemical oxygen demand; COD: chemical oxygen demand; TSS: total suspended solids; TC: total coliform bacteria; FC: fecal coliform bacteria.

Table 2. Examples of Treated Wastewater Characteristics in Municipal Wastewater Treatment Plants of Iran

Province	Treatment Plant	Treatment Process	Parameters											Reference
			pH	COD (mg/L)	BOD_5 (mg/L)	Turbidity (NTU)	TSS (mg/L)	NH_4^+ (mg/L)	NO_2^- (mg/L)	NO_3^- (mg/L)	PO_4^{3-} (mg/L)	TC (No./100 mL)	FC (No./100 mL)	
Ardabil	Ardabil	AL	7.8	78	40	24	34	-	54	72	-	-	14	45
East Azerbaijan	Tabriz	CAS	7.4	38	30	1	21	0.49	2	52	6	1100	1100	46
Hormozgan	Bandar-e Abbas	CAS	7.5	85	46	41	63	-	-	4	-	-	453	47
Isfahan	Sepahan Shahr	AL	-	125	55	-	51	-	-	-	-	-	-	48
	Foolad Shahr	SP	-	111	43	-	55	-	-	-	-	-	-	
	Karchegan	AL	7.4	148	57	28	-	-	-	-	-	2.3×10^5	2.3×10^4	49
Markazi	Arak	CAS	7.5	90	25	6	-	-	-	-	-	150	39	50
Razavi Khorasan	Olang	SP	-	146	83	-	109	-	-	-	-	-	-	51
Yazd	Ardakan	A_2O	-	14	7	-	3	-	-	-		41	11	52

are not much appropriate, and may not suitably meet the national needs for release to the environment and reuse when compared to existing effluent discharge standards (Table 1). As can be seen in Table 2, the use of conventional treatment processes, lack of application of advanced technologies, improper operation, skill-shortage of labor, and not updated wastewater discharge standards can be the main reasons for the poorly treated effluent quality in the municipal wastewater treatment plant in Iran. For instance, the adoption of the A_2O process and the efficient operation of Ardakan municipal wastewater treatment plant have made the treated effluent from this treatment plant far more suited for use in agriculture, irrigation, or discharged into receiving water bodies than the other treatment plant listed in Table 2. Moreover, the treated effluent from Ardabil treatment plant using the AL process was found to be more qualities for reuse or release to the environment than Sepahan Shahr and Karchegan treatment plants in Isfahan province with similar treatment processes. Karchegan treatment plant also possesses lower treated effluent quality compared to Ardabil and Sepahan Shahr treatment plants. This could possibly be related to how ALs are managed and operated in these treatment plants. Similarly, the treated effluent quality from Arak, Bandar-e Abbas, and Tabriz treatment plants with CAS process could be considered to be in line with wastewater quality discharge standards.

Major Barriers of Municipal Wastewater Treatment Industry in Iran

Generally, the barriers associated with the municipal wastewater treatment industry are diverse and differ not only according to the wastewater control laws but also to regional characteristics and socioeconomic conditions.[53] Thus, it is difficult to identify a common barrier applicable to all situations. However, there is no doubt that the implementation of a cost-effective and high-performance wastewater treatment system is important. Herein, major barriers to the municipal wastewater treatment industry in Iran were identified in four key groups, including barriers related to wastewater treatment plants, environmental and standards, economic aspects, and treated wastewater reuse, as follows:

- Wastewater treatment plants: The barriers associated with treatment plants are typically those related to *1- Treatment technology:* (a) inadequate design criteria of treatment plants in accordance with quantitative and qualitative characteristics of inflow wastewater and regional climate conditions, (b) insufficient attention of entrepreneurs to the development of domestic technologies in the wastewater sector, (c) low usage of advanced and novel technologies, (d) insufficient attention to decentralized treatment systems, (e) insufficient growth in the use of in-house manufacturing equipment, *2- Energy:* (a) high energy consumption, (b) scarcity of energy recovery and generation from wastewater, *3- Operation:* (a) existence of poor documentation, (b) improper operation of treatment plants because of inadequate trained manpower, (c) lack of adequate equipment for online monitoring, (d) insufficient attention to odor control, and *4- sludge management:* (a) lack of knowledge on the sludge management technologies, (b) lack of support for sludge processing and stabilization, (c) uncompetitive market of composted sludge against chemical and animal fertilizers.
- Environmental and standards: The potential barriers in this area could include (a) the presence of specific and emerging pollutants in wastewater and insufficient knowledge about their effects and methods of their removal, (b) being old and not updated wastewater discharge standards, (c) vulnerability of wastewater treatment plants to natural disasters, and (d) low attention on the environmental impact of effluent discharge.
- Economic aspects: The economic barriers in the municipal wastewater treatment sector are included (a) lack of sustainable financial resources for the development of treatment facilities, (b) high operation costs of some wastewater treatment plants due to the use of inefficient technologies and labor, (c) low revenues from the sale of treated wastewater, and (d) inadequacy of the treated effluent tariff with the provision of operation costs and upgrading of the treatment plant.
- Treated wastewater reuse: The barriers in this area are included (a) low public acceptance of the reuse of wastewater as a water resource, (b) insufficient trust in the quality of treated wastewater, and (c) insufficient attention to treated wastewater and it's recycling for various uses as a sustainable water source.

Future Perspective

Proposed Policies for the Municipal Wastewater Management in Iran

The proposed future policies required to develop the municipal wastewater treatment industry have been defined up to 2040 based on the as-mentioned barriers (Figure 6). As can be seen, Figure 6 consists of two dimensions of time (horizontal axis) and proposed policies (vertical axis).

Achievable Goals

Based on research conducted, the macro goals of the national strategy for the development of wastewater treatment technologies can be categorized into three main areas: wastewater treatment management, development of new technologies for wastewater treatment, and environmental protection (Table 3).

Given these goals, achieving high-quality treated wastewater can be expressed as a debate between protection and development. It is an effort to obtain clean and safe water and a desire to achieve an economically developed society.[54] On the other hand, due to increasing

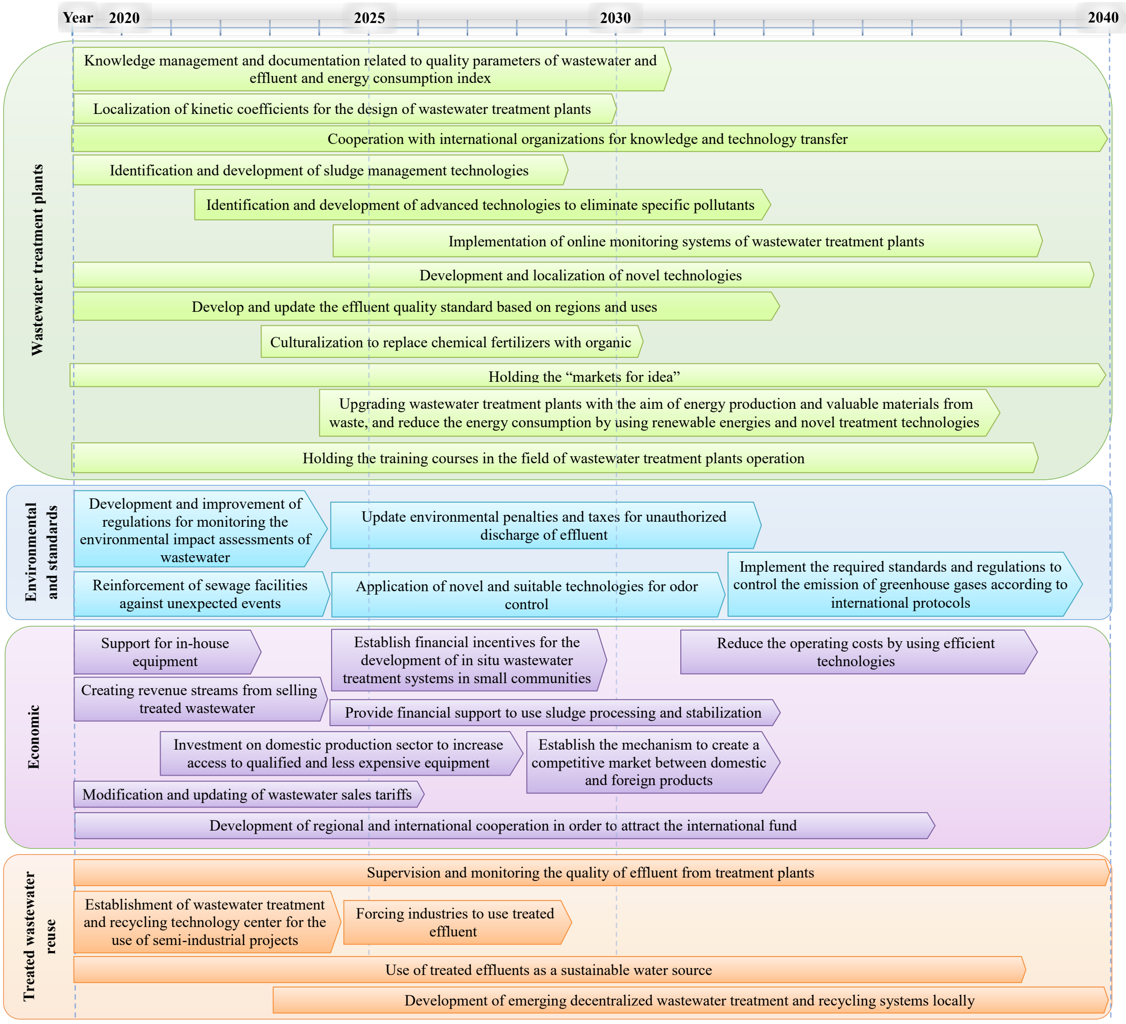

Figure 6. Proposed Policies for the Development of Municipal Wastewater Treatment Industry in Iran.

Table 3. Macro Goals of the National Strategy for the Development of Wastewater Treatment Technologies

Area	Macro Goals
Management	• Rising population covered by the sewerage network in urban and rural areas • Use of treated wastewater in agriculture, industry, and irrigation • Enhancement of urban and rural sanitation coverage
Development	• Localization of wastewater treatment technologies • Acquisition of a superior scientific position in the wastewater treatment field in the Middle East • Encouraging private sector investment in research and development for wastewater treatment infrastructure
Environment	• Upgrading of wastewater treatment systems to reduce sludge production and energy consumption • Efforts to improve treatment plant performance in achieving high effluent quality based on their use • Development of wastewater treatment technologies using the advantages of renewable energy • Development of wastewater treatment systems by focusing on energy generation and valuable materials production

public awareness and concerns about water issues, and enforcement of environmental legislation in Iran, wastewater treatment plants must enhance the rate of removal of pollutants. Here, it is stated that the percentage of the population covered by wastewater facilities in urban and rural areas should reach 90% and 15%, respectively, by 2040. Likewise, the values of the quality parameters in the treated effluent entering natural water resources should be equal to or less than 25 mg/L for biochemical oxygen demand (BOD_5), 50 mg/L for chemical oxygen demand (COD), 2 mg/L for total phosphorus (TP), and 30 mg/L for total nitrogen (TN). The energy consumption from the wastewater sector should also reduce to a maximum of 0.45 kWh/m^3 wastewater. This energy consumption reduction can be achieved by improving the performance of the processes and increasing energy efficiency in wastewater treatment plants. The values for the horizon of 2040 are chosen based on studies conducted in our research and their compliance with the current situation in Iran.

Conclusions

This study highlights the current status and barriers to municipal wastewater management in Iran, as well as future policies needed to achieve a sustainable wastewater management. From this study it is indicated that municipal wastewater generated by nearly 40% of the population in Iran receives adequate treatment out of which only about 50% is reused. From 68 treatment plants assessment it found that conventional activated sludge is the most widely used process to treat municipal wastewater (69%), most treatment plants have operational lifetimes of less than 20 years (82%), most are incapable of removing nitrogen (65%), and operational costs of treatment plants usually amount up to 0.2 US $/m^3 wastewater. Besides, electricity consumption for municipal wastewater treatment facilities in Iran is as high as 241 million kWh/y. This consumption amounts to about 4.9% of electricity consumption in the water and municipal wastewater sectors, and 0.1% of the total consumption of the country. It is estimated here that by 2040 the population covered by wastewater facilities reach 90% in urban areas and 15% in rural areas, the qualitative parameters in treated effluent should be equal to or less than 25 mg/L for BOD_5, 50 mg/L for COD, 2 mg/L for TN, and 30 mg/L for TP, and energy consumption from the wastewater sector reduce as high as 0.45 kWh/m^3 wastewater. Overall, this study may provide useful information for understanding and successfully implementing municipal wastewater management strategies.

Acknowledgments

We would like to thank the National Water and Wastewater Engineering Company (NWWEC) for their valuable support to accomplish this research.

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Competing Interests

The authors declare that they have no conflict of interest.

Ethical Approval

Not applicable.

Funding

The present work is a part of the national project of roadmap for the development of wastewater treatment technology in Iran, which has been completed by the authors themselves, and financially supported by Iran's NWWEC (project code: 37796).

Supplementary Files

Supplementary file 1 contains Table S1.

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