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Sustainable Wastewater Management: Treatment Plant Investment Predictions in Türkiye

Sürdürülebilir Atıksu Yönetimi: Türkiye'de Arıtma Tesisi Yatırım Tahminleri

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ABSTRACT

In this study, it is aimed to examine the future treatment plant investment projections for the sustainable development of wastewater management in Turkey. In today's conditions, where increasing population, industrialization and urbanization processes lead to an increase in wastewater production, which puts pressure on water resources, effective wastewater treatment is of great importance. In line with Turkey's global cooperation on environmental policies, sustainable development and environmental protection, investments in wastewater treatment plants are expected to be increased. In this context, the number of wastewater treatment plants in Turkey between 2001 and 2022, the amount of wastewater treated, the population provided with waste service, the total amount of wastewater discharged, and the amount of wastewater discharged per capita were discussed by using TURKSTAT data. By using the automatic ARIMA and ARIMA methods, 3 periods between 2023-2025 were estimated. Eviews 12.0 software was used in the analysis of the data. As a result of the analyzes, it has been determined that 1923 wastewater treatment plants will be needed for 2025 in terms of the amount of wastewater treated, 1858 in terms of the population with waste service, 1922 in terms of the total amount of wastewater discharged and 1928 in terms of the amount of wastewater discharged per capita. The projections emphasize that the capacity of treatment plants should be increased with the cooperation of local governments and the private sector, and that this process will provide not only environmental but also economic and social benefits. In addition, the emphasis is on the implementation of advanced treatment technologies, innovative financing models and increasing the environmental awareness of local people. In this direction, taking concrete steps to ensure sustainable development by protecting Turkey's water resources becomes evident as an important strategy in wastewater management in the coming years.

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ÖZ

Çalışmada Türkiye'de atık su yönetiminin sürdürülebilir bir şekilde geliştirilmesi için geleceğe yönelik arıtma tesisi yatırım öngörülerini incelemek amaçlanmıştır. Artan nüfus, sanayileşme ve şehirleşme süreçlerinin atık su üretimindeki artışa yol açtığı, bunun da su kaynakları üzerinde baskı oluşturduğu günümüz koşullarında, etkili atık su arıtımı büyük bir önem taşımaktadır. Türkiye'nin çevre politikaları, sürdürülebilir kalkınma ve çevre koruma konusunda küresel işbirliğine uyumlu olarak, atık su arıtma tesislerine yapılan yatırımların arttırılması beklenmektedir. Bu bağlamda TÜİK verilerinden yararlanılarak Türkiye'de 2001-2022 yılları arasındaki atıksu arıtma tesisi sayısı, arıtılan atıksu miktarı, atık hizmeti verilen nüfus, deşarj edilen toplam atıksu miktarı, kişi başına deşarj edilen atıksu miktarı ele alınmıştır. Otomatik ARIMA ve ARIMA yöntemlerinden yararlanılarak 2023-2025 yılları arasındaki 3 dönemin tahmini yapılmıştır. Verilerin analizinde Eviews 12.0 yazılımı kullanılmıştır. Yapılan analizler sonucu 2025 yılı için arıtılan atıksu miktarına göre 1923, atık hizmeti verilen nüfus açısından1858, deşarj edilen toplam atıksu miktarı 1922 ve kişi başına deşarj edilen atıksu miktarı açısından 1928 atıksu arıtma tesisine ihtiyaç duyulacağı tespit edilmiştir. Yapılan öngörüler, yerel yönetimler ve özel sektör işbirliği ile arıtma tesislerinin kapasitesinin arttırılması gerektiğini ve bu sürecin yalnızca çevresel değil, aynı zamanda ekonomik ve sosyal faydalar sağlayacağını vurgulamaktadır. Ayrıca, ileri düzey arıtma teknolojilerinin uygulanması, yenilikçi finansman modelleri ve yerel halkın çevre bilincinin artırılması gerektiği üzerinde durulmaktadır. Bu doğrultuda, Türkiye'nin su kaynaklarını koruyarak sürdürülebilir kalkınmayı sağlamaya yönelik somut adımların atılması, atık su yönetimi konusunda gelecek yıllarda önemli bir strateji olarak belirginleşmektedir.

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1. INTRODUCTION

Rapidly increasing population, industrialization and urbanization processes around the world cause the depletion of natural resources and deepen environmental problems. While water is one of the basic elements of life, it is becoming an increasingly limited resource. In this context, wastewater management is of great importance in terms of environmental sustainability and public health. Although Turkey has taken important steps in the field of wastewater treatment, especially in recent years, the increase in the amount of wastewater caused by the increasing population and industrial activities causes the existing infrastructure to be insufficient.

Efficient use and protection of water resources is of great strategic importance. Reusing wastewater without causing harmful effects on the environment contributes to the protection of water resources and reduces the pressure on the ecosystem. For this reason, the development of wastewater treatment plants and increasing the capacity of existing facilities stand out as an important goal for sustainable water management and environmental protection (Khan, 2024: 2). The wastewater load brought about by the increasing population and industrialization for Turkey increases the need for more efficient treatment plants. Investments to comply with the European Union's environmental standards and improve water quality play a critical role in supporting environmental sustainability and local economies (Aydin et al., 2024:10461-10463). In this context, investment projections to increase the capacity of wastewater treatment plants in Turkey should be considered not only as a part of environmental policies but also as part of economic growth and development strategies.

Sustainable wastewater management is not only limited to reducing environmental impacts, but also requires a comprehensive approach that includes economic and social dimensions (Ejairu et al., 2024: 83-87). Sustainable planning of investments in wastewater treatment plants in Turkey is critical to ensure that these facilities can operate efficiently in the long term and that resources are used effectively. This study aims to determine the investments to be made in wastewater treatment plants for the period of 2025 in Turkey and to put forward the necessary strategies for the sustainable implementation of these investments. In addition, the results of the study can be effective in making wastewater management more efficient throughout the country with projects to be carried out in cooperation with local governments and the private sector.

2. CONCEPTUAL FRAMEWORK

2.1. Important Steps towards Achieving the Sustainable Development Goals

Sustainability has become a critical issue for the whole world with its environmental, economic and social dimensions. In this context, many international meetings, conferences and summits have been held around the world, and issues such as sustainable development, environmental protection, climate change and social equality have been discussed in these meetings. The decisions taken at these meetings have led to important steps towards global cooperation and the achievement of sustainable development goals (Yazıcı et al., 2025: 2-5). The most important of these steps can be listed as follows:

- *Rio Conference (1992):* The United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro, Brazil in 1992, was a turning point when the concept of sustainability began to be widely discussed internationally for the first time (Wagner, 2024: 134-136). This conference adopted the "Rio Declaration", which aims to achieve the balance between environment and development worldwide. This declaration, which contains 27 basic principles, emphasized that environmental protection and economic development should go hand in hand (Bergquist and David, 2024: 17-23). In addition, an action plan called Agenda 21 was adopted at the conference. This plan drew attention to the need for cooperation between states, local governments and the public to ensure sustainable development in the 21st century.
- *Kyoto Protocol (1997):* The Kyoto Protocol, adopted during the Conference of the Parties (COP3) to the Framework Convention on Climate Change held in Kyoto, Japan in 1997, is an important milestone in the fight against climate change (Degirmenci and Aydin, 2024: 4932). This protocol has made it mandatory for developed countries to reduce their greenhouse gas emissions by a certain percentage. The entry into force of the Kyoto Protocol in 2005 has led to worldwide commitments to reduce greenhouse gas emissions, but the protocol has only been adopted by a limited number of countries and the goal of an agreement covering all countries on a global scale has not yet been fully achieved (Mor et al., 2024: 692-698).
- *Rio+20 Conference (2012):* The Rio+20 Conference held in Rio de Janeiro in 2012 coincided with the 20th anniversary of the Rio Conference in 1992 (Devi, 2025: 16). This meeting was held by world leaders who met again to discuss sustainable development goals and environmental protection priorities. At the conference, the concept of Green Economy came to the fore and it was emphasized that development processes should be compatible with environmental sustainability. As a result of the conference, the basic principles for the "Sustainable Development Goals" (SDG) were determined (Axon, 2024: 5). This laid the foundation for the sustainable development goals adopted in the following years, which are targeted to be achieved worldwide by 2030.
- *Paris Agreement (2015):* The United Nations Climate Change Conference (COP21), held in Paris in 2015, is a critical juncture in the fight against global climate change (Izuchukwu et al., 2025: 12). The Paris Agreement has been recognized as the first universally legally binding agreement aimed at limiting climate change. This agreement encourages all countries around the world to reduce their carbon emissions, keep the global temperature rise below 2°C and not exceed the 1.5°C limit (Schneider, 2024: 329-330). The agreement stated that each country should identify its nationally determined contributions (NDCs) and take steps to achieve these goals. This is an important step in collaborating on a global level for sustainability.
- *Sustainable Development Goals (SDGs) – 2015:* In 2015, the United Nations adopted a global agenda consisting of 17 goals and 169 sub-targets, called the Sustainable Development Goals (SDGs) (Urbieta, 2024: 5005-5006). These goals are the roadmap set to achieve sustainable development all over the world by 2030. The SDGs cover a wide range of social, environmental and economic development areas such as ending poverty, eradicating hunger, quality education, equity, clean water and sanitation, combating climate change, and just and peaceful societies (Bayram, 2023: 3-4). Implementation of these goals requires collaboration between national governments, the private sector, civil society and local communities around the world (Velempini, 2025: 1-4).
- *COP26 (2021):* COP26, held in Glasgow in 2021, was another important summit to strengthen global cooperation in the fight against climate change (Cohen et al., 2022). The summit provided an opportunity to assess whether progress has been made in achieving carbon neutral targets after the Paris Agreement. In this meeting, issues such as reducing carbon emissions, transition to green energy, financial support and investment in renewable energy sources were discussed intensively (Ma et al., 2023: 1-4). At the same time, it was decided that developing countries should be provided with financial support to combat climate change and that fossil fuels should be phased out.

These meetings held around the world reveal the importance of global cooperation on sustainable development and environmental protection. Each summit has contributed to a great process of consciousness and change on a global scale (Bayram, 2024: 92-95). However, more effort and commitment are still required to achieve the sustainable development goals. These meetings underline the need for governments, the private sector and societies around the world to act together to achieve a sustainable future.

2.2. Wastewater Management within the Framework of Sustainability

Wastewater refers to polluted water caused by human activities and can be derived from many sources such as domestic, industrial, and agricultural. Wastewater contains various pollutants such as microorganisms, chemicals, heavy metals and nutrients that can harm human health (Dhokpande et al., 2024: 1-6). If wastewater is discharged into nature without proper treatment, it can pollute water resources, causing damage to ecosystems, depletion of water resources and deterioration of human health (Lako and Como, 2024: 92). In addition, in regions where access to clean water is limited, wastewater recovery creates a great opportunity to save water and achieve sustainable development goals.

Wastewater management has become not only an environmental issue, but also a global issue that addresses socio-economic and health dimensions. Effective wastewater management is essential for the conservation and efficient use of water, and this management process covers a wide range from the installation of treatment plants to the reuse of wastewater (Tsalas et al., 2024: 1-3). Wastewater treatment is the process of removing pollutants from the contents of the water. This process is usually done by a combination of physical, chemical and biological methods (Mmonwuba et al., 2024: 572-573). By using these methods, treatment plants make water reusable and ensure that it is discharged to nature without harming the environment. The methods used in the treatment of wastewater are:

- *Physical Treatment Methods:* This method allows the separation of large solids, sludge and oils in wastewater. Usually, precipitation is carried out by simple processes such as filtration and separation at the liquid level (Kato and Kansha,2024: 51064-51067). These processes are often used in the initial stage of wastewater.
- *Chemical Treatment Methods:* Chemical treatment uses chemical reactions to purify water from contaminants. For example, with the addition of acidic or basic substances, some pollutants are precipitated (Obiuto et al., 2024). This method is particularly effective in the treatment of heavy metals and harmful chemical components.
- *Biological Treatment Methods:* Biological treatment is when microorganisms oxidize and digest organic pollutants in wastewater. Aerobic and anaerobic biological processes are among the most common methods of such purification processes (Sravan et al., 2024: 1-5). These methods are particularly effective in removing organic matter and nutrient load.

The sustainability approach in wastewater management can be considered as environmental sustainability, economic sustainability and social sustainability:

- *Environmental Sustainability:* Effective treatment of wastewater is of great importance in terms of preventing water pollution and protecting ecosystems. The discharge of untreated wastewater to nature leads to pollution of groundwater and surface water resources, resulting in biodiversity losses and ecosystem degradation. Sustainable wastewater management includes practices such as minimizing the energy and chemicals used in treatment processes, proper disposal of waste, and adopting a zero waste approach in treatment plants. In addition, the use of advanced treatment technologies can improve the quality of the water, which makes it possible to reuse wastewater (Wu et al., 2024: 24745-24746). Providing a sustainable environment by protecting Turkey's water resources is directly related to the efficient operation of treatment plants.
- *Economic Sustainability:* The installation and operation of wastewater treatment plants are processes that require large costs. However, in order for these investments to be economically sustainable, long-term financial planning is required. In addition to investment costs, reducing the operating costs of facilities and keeping maintenance costs under control are critical for economic sustainability (Hauashdh et al., 2024: 1-6). For this reason, choosing energy-efficient technologies and using renewable energy sources can reduce the costs of treatment plants in the long run. Economic sustainability can also be achieved by promoting the reuse of wastewater. The treated wastewater can be used for irrigation in agriculture, cooling water in industrial production, or landscape irrigation (Ulusoy et al., 2024: 1-5). This helps to create new water sources by making water reusable and reduces water supply costs. In this way, wastewater management becomes profitable not only from an environmental point of view, but also from an economic point of view.
- *Social Sustainability:* Collective sustainability is important in terms of protecting public health, raising awareness of local communities and providing social benefit in wastewater management (Silva, 2024: 1-8). Treatment plants, when operated correctly, improve the quality of life of local people and contribute to the protection of water resources. However, the societal acceptance of these facilities depends on increasing the environmental awareness of the public and the proper management of the facilities. Education and awareness-raising activities play an important role in increasing environmental awareness (Moustairas et al., 2022: 2-6). In addition, the social sustainability of wastewater management has the potential to create local jobs. Qualified workforce is needed for the operation, maintenance and management of treatment plants. This is an element that will contribute to the local economy. However, wastewater treatment projects can contribute to increasing agricultural production and therefore local development by enabling the reuse of water in rural areas (Manjari et al., 2024).

Sustainable wastewater management is a critical strategy in line with Turkey's goal of protecting water resources. Investments in treatment plants should be planned to support environmental, economic and social sustainability. The success of this process is possible not only by strengthening the technical infrastructure, but also by raising social awareness, using innovative technologies and implementing effective policies. Investments to be made for the 2025 period will lay the foundations for Turkey's future water management policies and make significant contributions to the achievement of sustainable development goals.

2.3. Studies on Wastewater in Turkey

When the literature is examined, studies on wastewater in Turkey are encountered. However, there is no study in the literature that deals with wastewater investments and predicts wastewater investments to be made in the future. A large part of the studies on wastewater includes chemical studies. Topics such as wastewater treatment methods, the degree of cleanliness obtained as a result of treatment, the amount of wastewater/rainwater in a certain period of time and modeling are discussed. This situation increases the original quality of the exploration work of wastewater treatment investments. Table 1 below shows the studies on wastewater in Turkey.

Table 1. Studies on wastewater in Türkiye

Author (Year)	Research findings
Sidal, F., & Altun, Y. (2003)	Both models were compared, and it was determined that the model developed with artificial neural networks performed better than the model developed with multiple regression analysis.
Efe, M. (2006)	With the help of modeling programs, the deficiencies of wastewater or stormwater systems were identified, and which measures should be taken at which points were determined.
Açıkalın, S. (2007)	The data used in model development in the study consisted of wastewater temperature, pH, average flow rate, chemical oxygen demand, biological oxygen demand and suspended solids parameters. The Multilayer Sensor model, which is one of the models created using the data of the Adapazarı Urban Wastewater Treatment Plant, has adapted to the real data with a very good result.
Pekel, L. C. (2009)	In the study, it was understood that the "generalized predictive control system" is a suitable control system for pH control. The spectrophotometric values of the purified water obtained after the control studies were examined.
Yılmaz, E. C. (2009)	According to the results of the research, it has been seen that the artificial neural networks model is a much more effective model in the estimation of biological oxygen demand than Multiple Regression Analysis and gives very close results to reality.
Sinan, R. K. (2010)	In the study, the output values of parameters such as biological oxygen demand, chemical oxygen demand and plant efficiency in wastewater treatment plants were estimated with the help of equations developed depending on the concentration of microorganisms and substrates in the activated sludge process and determined by output measurement.
Yalçın, Ö. B. (2011)	In the study, uncertainty analysis was performed using the Monte Carlo method and the probability distributions of the discharge-induced bacterial concentrations to reach the beach closest to the discharge point were obtained. Risk analysis was performed using the results obtained from the probability distributions and infection risks for wastewater-borne Enteropathogenic E. coli were obtained.
Öztemel, E., & Dügenci, M. (2016)	In the study, estimates of suspended solids (ACM) and chemical oxygen demand (COD), which are of primary importance in terms of pollution, were made at the rates of 78.9% and 86.5%. The temperature value of the treated water at the outlet of the plant was successfully estimated with an accuracy of 91.1% and the pH value with an accuracy of 92.9%, and the prediction success rate of these four parameters was found to be 86.9.
Yapıcıoğlu, P., & Demir, Ö. (2017)	It has been determined that biomimicry-based methods, innovative treatment techniques and microalgae systems can be applied to reduce the effects of climate change on treatment plants and the greenhouse effect in treatment plants. It has been determined that nitrite-dependent anaerobic methane oxidation or biochar (biochar) application, which reduces greenhouse gases, can be used in wastewater treatment.
Demir, N. M. (2017)	The findings of the study explained the nonlinear nature of chemical oxygen demand, total Kjeldahl nitrogen and total nitrogen removal yields of treatment processes.
Gülhan, H. (2017)	As a result of the research findings, it was recommended to keep the sludge age long enough to prevent increased greenhouse gas emissions. It has been stated that in order to control greenhouse gas emissions from aeration, plants should be operated in such a way that the oxygen level in the aerobic zone is optimal.
Baki, O. T., & Aras, E. (2018)	Multiple regression analysis and multivariate adaptive regression curves methods were used in the study. The multivariate adaptive regression curves model was found to have the best predictive outcome.
Gülhan, H., Özgün, H., Erşahin, M. E., Dereli, R. K., & Öztürk, İ. (2018)	In the study, it was determined that the process configuration, the development level of the treatment process, the wastewater chemical oxygen demand/TKN ratio and the nitrogen removal efficiency affect the greenhouse gas formation from wastewater treatment plants. In particular, it has been observed that there is a need for research on the effect of nitrogen removal processes on the formation of N2O gas emissions and the factors affecting these processes.
Selvi, E. (2019)	From the developed models, both the support vector machine (SVM) learning algorithm and the passive aggressive regression learning algorithm gave very good results for the estimation of biological oxygen demand and it was understood that they could be used for estimation in treatment plants.
Baran, B. (2019)	In the study, the success of Extreme Learning Machines was measured by comparing the estimated and mathematical classification results.
Yıldız, A., Elevli, S., & Odabaş, M. S. (2025)	In the study, the daily flow data of Samsun's East Advanced Biological Wastewater Treatment Plant within a year were used and the performances of the models were compared. As a result of the research, it was determined that the ARIMA (2, 1, 2) model performed with higher accuracy.

2.4. International Trends and Comparisons in Wastewater Management

Wastewater management is of great importance in terms of environmental sustainability, public health and economic efficiency. The main international trends and comparisons in this field are listed below:

- Circular Economy Approaches: Europe plays a leading role in reusing and recycling wastewater. In particular, it adopts circular economy principles by investigating ways to use water as irrigation in agriculture and as a raw material in industry (Mannina et al.,2022).
- Microplastic Filtration and Treatment: In developed countries such as the USA and Japan, new technologies are being developed for the filtration of microplastics in wastewater treatment plants. This is a significant development from both an environmental and health perspective (Kataoka et al., 2019; Mason, et al., 2016).
- Power Generation and Wastewater: Germany is adopting innovative methods such as the use of biogas for energy production in wastewater treatment processes. Biogas both saves energy and reduces greenhouse gas emissions in treatment plants (Schäfer et al., 2020).
- Smart Water Management: In countries such as Canada and Australia, the efficiency of systems is increased by using IoT (Internet of Things) technologies and data analytics in water management. These systems optimize wastewater management and save resources (Aivazidou et al., 2021).
- Legal and Regulatory Approaches: Switzerland provides strong legal frameworks for wastewater management, leading to an example of protecting and improving the quality of water. Similar regulations need to be increased in other countries (Varone et al., 2002).
- Social Awareness: Within the framework of the United Nations' Sustainable Development Goals, many countries carry out campaigns to raise awareness of the society on wastewater management. This is an important step towards sustainable water use (Obaideen et al., 2022).

These trends illustrate how countries' wastewater management strategies are evolving and their efforts to achieve their environmental sustainability goals. It is vital for each country to develop solutions suitable for its own conditions and resources.

2.5. Challenges Encountered in Treatment Plant Investments

In order for treatment plant investments to be successful, various difficulties must be overcome. These challenges arise from technological, economic, environmental and managerial factors. Treatment plant installation and operating costs are quite high. The construction of new facilities, infrastructure investments, and the maintenance and repair of treatment processes can create a significant financial burden (Ojo, 2024: 108-111). In developing countries, these costs can lead to difficulties with budgets. In addition, the implementation of new technologies may require higher initial costs. Despite the rapid development of treatment technologies, finding the most efficient and environmentally friendly technologies can often be complex and expensive (Saud et al., 2024: 29088-29092). This situation may create difficulties in the necessity of technological infrastructure investments and updating existing systems. In addition, the applicability of new technologies may be limited in some regions.

The use of innovative financing models in wastewater investments and management plays a critical role in achieving sustainable development (Obaideen et al., 2022). While traditional financing methods are generally insufficient in infrastructure projects that require large investments, next-generation financing approaches offer an important solution with tools such as private sector partnerships, crowdfunding and green bonds (Beckerd and Muñoz, 2021). Such innovative models strengthen the cooperation between the public and private sectors, enabling more efficient use of resources and faster implementation of projects. At the same time, it contributes to minimizing environmental impacts and encouraging technology transfer.

Innovative financing models increase risk sharing in wastewater management, reduce financing costs and ensure financial sustainability in long-term projects (Furlong et al., 2017). For example, performance-based financing or result-oriented financing methods allow project outputs and impacts to be measured; Thus, investors can track the success of projects with more concrete data. In addition, flexible financial structures created through these models can better respond to the needs of local governments and communities, strengthening social acceptance by increasing the participation of local people in projects.

In addition, climate change is putting enormous pressure on water resources. Rising temperatures, drought, and fluctuations in water levels can affect the efficiency of treatment plants. Therefore, treatment plants must be flexible and adaptive to adapt to climate change. Good cooperation between local governments and central governments is necessary for treatment plants to function effectively. In addition, environmental laws and regulations can directly affect the effectiveness of facilities. Inadequate legal framework can adversely affect the effectiveness of facilities.

3. MATERIALS AND METHODS

In this study, a comprehensive analysis was carried out in order to determine the treatment plant investment projections for the sustainable development of wastewater management in Turkey. The main purpose of the research is to examine the effects of increasing population and industrialization on wastewater production and to estimate the need for a wastewater treatment plant for the future. Considering the importance of wastewater treatment in terms of environmental protection and sustainable development, it is aimed at contributing to the creation of investment plans.

In this context, the data of the Turkish Statistical Institute (TUIK) were used as the main data source. The number of wastewater treatment plants in Turkey between 2001-2022, the amount of wastewater treated (thousand m3/year); The population provided with waste service, the total amount of wastewater discharged (thousand m3/year), the amount of wastewater discharged per capita (liter/day) were used in the estimation of the 3 periods between 2023-2025 by using TUIK data. These data are of great importance in terms of understanding the current situation in Turkey's wastewater management and predicting future needs.

Time series analysis methods were used for data analysis. Using Automatic Regressive Integrated Moving Average and ARIMA methods, treatment plant needs between 2023 and 2025 were estimated. Eviews 12.0 software was used for analysis. This software provides convenient tools for the analysis and forecasting of time series data, increasing the reliability of research findings. The results of the study provide important findings that the capacity of treatment plants should be increased with the cooperation of local governments and the private sector, and that this process will provide economic and social benefits.

In order to estimate the number of wastewater treatment plants that municipalities should establish between 2023-2025, automatic ARIMA and ARIMA estimation methods were used in this study. ARIMA is a statistical analysis model that is used to better understand the data set or to predict future trends. A statistical model is autoregressive if it predicts future values based on historical data in the automated ARIMA forecasting method. For example, an ARIMA model may attempt to predict the future prices of a stock based on its past performance or to predict a company's earnings based on past periods (Kwiatkowski et al., 1992).

Automatic ARIMA prediction is a method of estimating values for a single series based on an ARIMA model. EViews provides advanced tools for predicting and working with ARIMA models using the familiar equation object. EViews offers an automated ARIMA prediction series procedure that allows the user to quickly identify an appropriate ARIMAX specification and use it to forecast the series into the future. In non-seasonal models, the yt series follows an ARIMAX(p, d, q) model in the following cases (IHS Markit, 2024a:538):

If $D(yt, d) = \beta Xt + vt$;

$v_t = \rho_{1vt-1} + \rho_{1vt-2} + ... + \rho_{pvt-p} + \Theta_{1\varepsilon t-1} + \Theta_{2\varepsilon t-2} + ... + \Theta_{2\varepsilon t-q}$

In the automated ARIMA method, usually the exogenous variables (X) are simply a single constant or trend term. In such cases, the only decision the estimator has to make to construct his estimates is the format of the detail variable, the level of differentiation (I or d), and the number of terms AR (p) and MA (q) (In this study, the level of differentiation is assigned as I=0 since the vary's first-order difference is taken (D(GII) is used). One method of selecting the number of AR and MA terms is through model selection/evaluation techniques. In this study, since stationarity was observed in the second differences of the variables, the term I (d) was determined as 2 from the ARIMA model terms (AR=p, I=d, MA=q) [ARIMA(p,2,q)].

In the second stage of model identification, the correlation was checked to determine p for the AR component and q for the MA component of the ARIMA Model. Autocorrelation and partial autocorrelation functions were examined to determine p and q values. In the autocorrelation (AC) and partial autocorrelation (PAC) charts, bars extending beyond the dashed lines are taken into account. The bars remaining within the line mean that the correlation of residuals is not significantly different from 0. On the ACF chart, the bars that extend beyond the line indicate how much moving average is needed to remove the autocorrelation from the stationary time series (IHS Markit, 2024a:462). When the autocorrelation (AC) graphs were examined, it was understood that there was no moving average in the NWTP, WSP, AWDPC series and it was determined as MA(q)=0 [ARIMA(p,2,0)]. Since there was only 1 out-of-line overflow in the AWT and TAWD series, it was understood that 1 moving average was required and it was determined as MA(q)=1 [ARIMA(p,2,1)].

When the PAC graphs were examined, it was determined that none of the delays were significantly out of the limit for NWTP, WSP, AWDPC series, so AR(p)=0 for NWTP, WSP, AWDPC series [ARIMA(0,2,q)]. Since only 1 of the delays for the AWT and TAWD series were found to be outside the limit, AR(p)=1 for the AWT and TAWD series was determined as [ARIMA(1,2,q)].

Finally, it is necessary to determine which of the static and dynamic estimation methods is suitable for ARIMA forecast models. In the static forecasting model, the values of the explanatory variables are used, while in the dynamic forecasting model, the previous predicted values of the dependent variable are used. In estimating the values of the dependent variable between 2023-2025, first of all, it was necessary to estimate the values of the independent variables for the years 2023-2025 by the automatic ARIMA method. In the prospective estimation of the independent variables, only the dynamic estimation method was used since no exogenous independent variables were used. On the other hand, with the help of the data of previous years, the estimation of the dependent variable was also carried out without independent variables.

ARIMAX models can be estimated by a number of different methods, including converting the model to a nonlinear least squares specification or using GLS or maximum likelihood estimation. Since the maximum likelihood estimator does not require dropping observations from the start of the series or backcasting to generate observations, it contributes optimally to automated ARIMA model selection/comparison algorithms (IHS Markit, 2024a:539).

Table 2. Observed data between 2011 and 2022

Year	NWTP	AWT	WSP	TAWD	AWDPC
2001	126	1.193.975	18.455.498	1.186.181	147
2002	145	1.312.379	18.955.305	1.297.780	154
2003	156	1.586.549	20.109.347	1.586.372	173
2004	172	1.901.040	24.369.119	1.901.039	174
2005	178	2.020.767	27.006.189	2.017.686	178
2006	184	2.140.494	29.643.258	2.134.333	181
2007	210	2.196.037	31.080.788	2.192.958	177
2008	236	2.251.580	32.518.318	2.251.582	173
2009	281	2.485.366	35.284.518	2.485.817	178
2010	326	2.719.152	38.050.717	2.720.051	182
2011	393	2.988.066	40.797.227	2.990.224	186
2012	460	3.256.979	43.543.737	3.260.396	190
2013	532	3.370.383	46.451.003	3.372.121	186
2014	604	3.483.787	49.358.268	3.483.846	181
2015	743	3.663.069	52.687.503	3.663.099	182
2016	881	3.842.350	56.016.738	3.842.351	183
2017	936	4.039.384	58.272.457	4.039.385	186
2018	991	4.236.418	60.528.175	4.236.418	188
2019	1.030	4.297.344	60.910.489	4.297.345	189
2020	1.068	4.358.269	61.292.803	4.358.272	189
2021	1.192	4.494.935	62.016.460	4.494.937	193
2022	1.315	4.631.601	62.740.116	4.631.601	197

NWTP: Number of wastewater treatment plants; AWT: Amount of wastewater treated (thousand m3/year); WSP: Waste serviced population (person); TAWD: Total amount of wastewater discharged (thousand m3/year); AWDPC: Amount of wastewater discharged per capita (liters/day).

In this study, in addition to the dynamic estimation method without external independent variables (automatic ARIMA), the static estimation method in which external independent variables are also used was used in the estimation of the number of treatment plants. The only difference from automatic ARIMA is that exogenous arguments are added to the model.

4. RESULTS AND DISCUSSION

Table 2 shows the observed data of the series between 2001-2022.

Data observed between 2001 and 2022 is shown in Figure 1 below.

According to the observed data in Table 1, the number of wastewater treatment plants, the amount of wastewater treated (thousand m3/year); The population provided with waste service, the total amount of wastewater discharged (thousand m3/year), the amount of wastewater discharged per capita (liter/day) show a continuous upward trend.

Table 3 below shows the results of correlation between observed data.

According to the correlation findings in Table 3, it was determined that there was a high correlation between the dependent variable and the independent variables (r>0.70). The correlation between the independent variables was also very high, and VIF and tolerance values (VIF>10; When the tolerance values <0.20) are taken into consideration, it is understood that their coexistence in the model that will predict the dependent variable will lead to the problem of multiple connections. Therefore, each independent variable will be used separately in estimating the number of wastewater treatment plants needed in the future.

Stationarity tests of the variables were performed before the ARIMA model and are shown in Table 4.

When the stationarity test results (Elliott-Rothenberg-Stock DF-GLS) in Table 4 were examined, it was determined that the series were not stationary at the level and when the first difference was taken, and the average became stationary when the second difference was taken. Since stationarity was observed in the second differences of the variables, the term I (d) was determined as 2 [ARIMA(p,2,q)], which is one of the ARIMA model terms (AR=p, I=d, MA=q).

In the second stage of model identification, the correlation was checked to determine p for the AR component and q for the MA component of the ARIMA Model. Autocor-

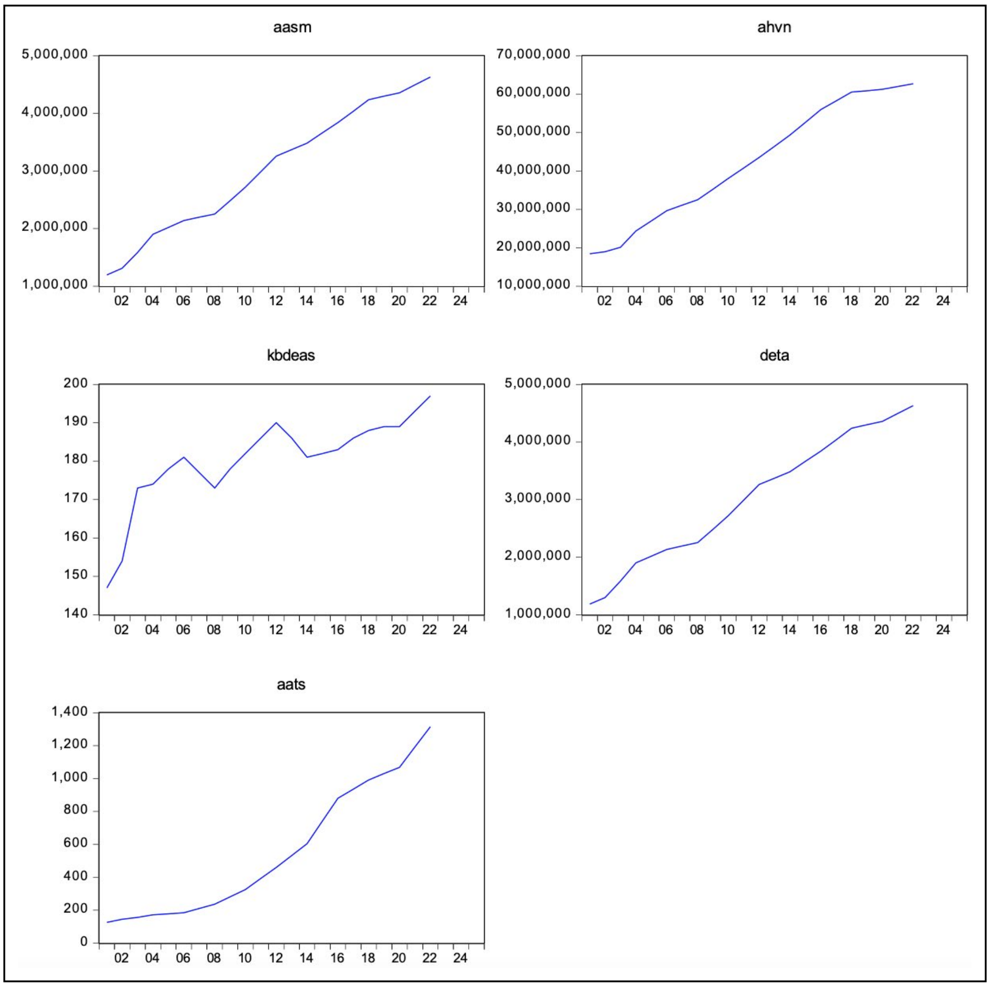

Figure 1. Data observed between 2001 and 2022.

relation and partial autocorrelation functions were examined to determine p and q values (Fig. 2).

In the autocorrelation (AC) and partial autocorrelation (PAC) graphs in Figure 2, bars that extend beyond the dashed lines are taken into account. The bars remaining within the line mean that the correlation of residuals is not significantly different from 0. On the ACF chart, the bars that extend beyond the line indicate how much moving average is needed to remove the autocorrelation from the stationary time series (IHS Markit, 2024a:462). When the autocorrelation (AC) graphs in Figure 3 were examined, it was understood that there was no moving average required since there was no outflow in the NWTP, WSP, AWDPC series, and it was determined as MA(q)=0 [ARIMA(p,2,0)]. Since there was only 1 out-of-line overflow in the AWT and TAWD series, it was understood that 1 moving average was required and it was determined as MA(q)=1 [ARIMA(p,2,1)].

Table 3. Correlation between observed data

Year	1	2	3	4	5	Tolerans[a]	VIF[a]
1- NWTP	1	0.958**	0.957**	0.957**	0.717**		
2- AWT		1	0.996**	1.000**	0.845**	0.003	313.81
3- WSP			1	0.996**	0.809**	0.004	259.586
4- TAWD				1	0.846**	0.144	6.930
5- AWDPC					1	0.000	187319

VIF: Variance inflation factor; NWTP: Number of wastewater treatment plants; AWT: Amount of wastewater treated (thousand m^3/year); WSP: Waste serviced population (person); TAWD: Total amount of wastewater discharged (thousand m^3/year); AWDPC: Amount of wastewater discharged per capita (liters/day). [a]: Tested for independent variables.

Table 4. Stationarity test results of series

Variable	Level	1.Difference	2.Difference
NWTP	1.228	-1.509	-4.318**
AWT	-0.922	-0.973	-7.896**
WSP	-1.971	-2.377	-4.816**
TAWD	-0.987	-0.982	-7.906**
AWDPC	-0.568	-5.051**	-5.502**

NWTP: Number of wastewater treatment plants; AWT: Amount of wastewater treated (thousand m3/year); WSP: Waste serviced population (person); TAWD: Total amount of wastewater discharged (thousand m3/year); AWDPC: Amount of wastewater discharged per capita (liters/day). Test: Augmented Dickey-Fuller.

Table 5 provides the specifications of the Automatic ARIMA model.

According to the analysis results in Table 5 in line with the PAC graphics, it was determined that none of the lags for the NWTP, WSP, and AWDPC series significantly exceeded the bounds; therefore, AR(p)=0 for the NWTP, WSP, and AWDPC series [ARIMA(0,2,q)]. It was found that only 1 lag of the AWT and TAWD series exceeded the bounds, thus AR(p)=1 for the AWT and TAWD series [ARIMA(1,2,q)].

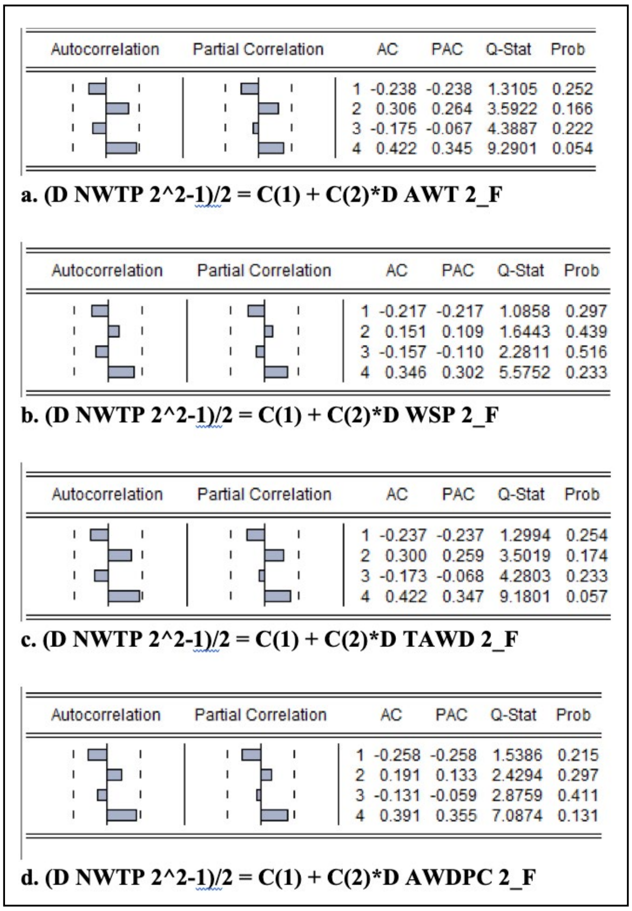

Figure 3. Correogram graph for residuals of series.

Table 5. Automatic ARIMA model specifications

	AR (p)	I (d)	MA (q)	ARIMA
NWTP	0	2	0	0,2,0
AWT	1	2	1	1,2,1
WSP	0	2	0	0,2,0
TAWD	1	2	1	1,2,1
AWDPC	0	2	0	0,2,0

NWTP: Number of wastewater treatment plants; AWT: Amount of wastewater treated (thousand m3/year); WSP: Waste serviced population (person); TAWD: Total amount of wastewater discharged (thousand m3/year); AWDPC: Amount of wastewater discharged per capita (liters/day).

The automatic ARIMA forecast results for the years 2023-2025 performed with the model specifications in Table 4 are shown in Table 6.

Finally, it is necessary to determine which of the static and dynamic estimation methods is suitable for ARIMA forecast models. In the static forecasting model, the values

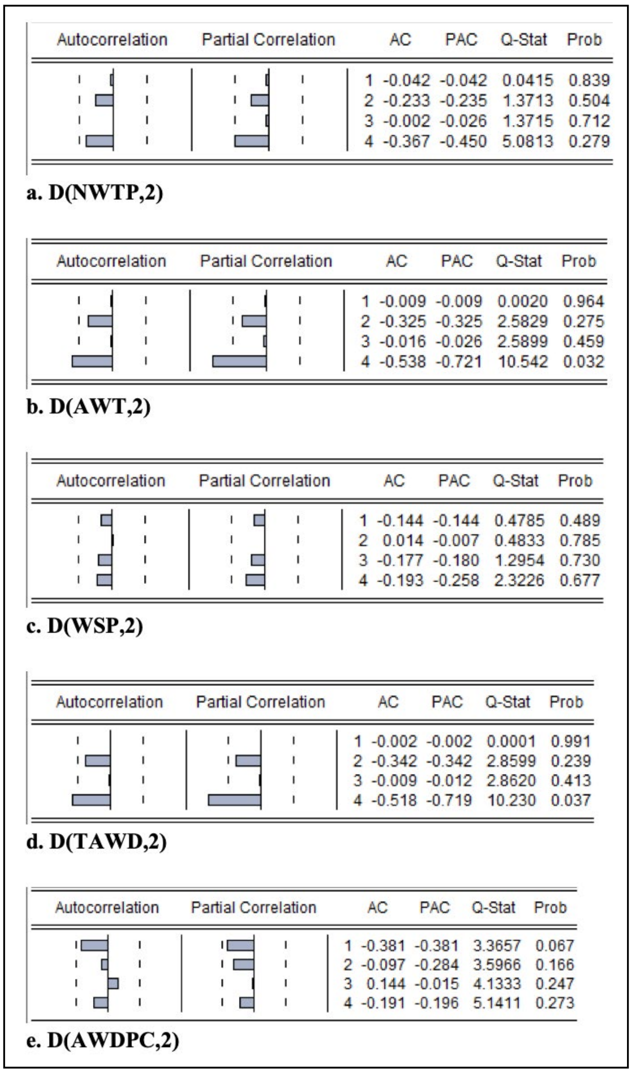

Figure 2. Correogram graph for residuals of series.

Table 6. Automatic ARIMA forecast results for 2023-2025

	NWTP	AWT	WSP	TAWD	AWDPC
2023	1.470	4.883.678	64.485.875	4.883.613	207
2024	1.657	5.180.443	67.253.737	5.186.859	223
2025	1.876	5.592.219	71.043.701	5.604.859	245

NWTP: Number of wastewater treatment plants; AWT: Amount of wastewater treated (thousand m3/year); WSP: Waste serviced population (person); TAWD: Total amount of wastewater discharged (thousand m3/year); AWDPC: Amount of wastewater discharged per capita (liters/day). *: Estimates of the differences have been converted to actual value.

of the explanatory variables are used, while in the dynamic forecasting model, the previous predicted values of the dependent variable are used. In estimating the values of the dependent variable between 2023-2025, first of all, it was necessary to estimate the values of the independent variables for the years 2023-2025 by the automatic ARIMA method. In the prospective estimation of the independent variables, only the dynamic estimation method was used since no exogenous independent variables were used. On the other hand, with the help of the data of previous years, the estimation of the dependent variable was also carried out without independent variables.

According to the estimation results in Table 6, the number of waste facilities to be established has been determined as 1876 for 2025. Considering the number of facilities in 2022 (1315), it was estimated that 561 facilities would be needed.

Autocorrelation (AC) and partial autocorrelation (PAC) graphs for equations were examined in order to determine the AR and MA specifications in ARIMA models with exogenous independent variables to be realized by including each of the independent variables separately. Figure 3 below shows the Correlation graph for residuals of equations.

When the autocorrelation (AC) and partial autocorrelation (PAC) graphs of the equations in Figure 3 were examined, it was understood that there was no need for a moving average since there was no out-of-line overflow in all of the equations, and it was determined as MA(q)=0 [ARIMA(p,2,0)]. When the PAC graphs were examined, it was determined that none of the delays in the equations were significantly outside the limit, so AR(p)=0 [ARIMA(0,2 q)].

Table 7 below gives the results of the Correogram graph for residuals of series.

The ARIMA static estimation results with exogenous independent variables for the years 2023-2025, which were performed with the model specifications in Table 7, are shown in Table 8.

In the ARIMA model, where the AWT (amount of wastewater treated) series is the independent variable, the number of wastewater treatment plants for 2025 is estimated as 1,923. In other words, when the observed data for the years 2001-2022 and the estimates between 2023-2025 regarding the amount of wastewater treated are accepted as correct, it is estimated that 608 new treatment plants will be needed in addition to the treatment plant (1,315) in 2022.

In the ARIMA model, where the WSP (population with waste service) series is the independent variable, the number of wastewater treatment plants for 2025 is estimated as 1,858. In other words, when the data observed for the years 2001-2022 and the estimates between 2023-2025 of the population provided with waste services are accepted as correct, it is estimated that 543 new treatment plants will be needed in addition to the treatment plant (1,315) in 2022.

In the ARIMA model, where the TAWD (total amount of wastewater discharged) series is the independent variable, the number of wastewater treatment plants for 2025 is estimated as 1,922. In other words, when the observed data for the years 2001-2022 regarding the total amount of wastewater discharged and the estimates between 2023-2025 are accepted as correct, it is estimated that 607 new treatment plants will be needed in addition to the treatment plant (1,315) in 2022.

In the ARIMA model, where the AWDPC (amount of wastewater discharged per capita) series is the independent variable, the number of wastewater treatment plants for 2025 is estimated as 1,928. In other words, when the observed data for the years 2001-2022 regarding the amount of wastewater discharged per capita and the estimates between 2023-2025 are accepted as correct, it is estimated that 613 new treatment plants will be needed in addition to the treatment plant (1,315) in 2022.

It is seen that the lowest value in all three of the RMSE, MAE and MAPE estimation methods, which were examined regarding the estimation accuracy of the models, was in the model with the AHVN (waste served population)

Table 7. Correogram graph for residuals of series

Independent variable	Dependent variable	AR (p)	I (d)	MA (q)	ARIMA
AWT	NWTP	0	2	0	0,2,0
WSP	NWTP	0	2	0	0,2,0
TAWD	NWTP	0	2	0	0,2,0
AWDPC	NWTP	0	2	0	0,2,0

NWTP: Number of wastewater treatment plants; AWT: Amount of wastewater treated (thousand m3/year); WSP: Waste serviced population (person); TAWD: Total amount of wastewater discharged (thousand m3/year); AWDPC: Amount of wastewater discharged per capita (liters/day).

Table 8. ARIMA static forecast results with independent variables for NWTP

	Independent variable			
Forecast Year	**AWT**	**WSP**	**TAWD**	**AWDPC**
2023	1.480	1.467	1.479	1.479
2024	1.681	1.648	1.680	1.683
2025	1.923	1.858	1.922	1.928
Difference	608	543	607	613
RMSE	31,694	30,528	31,674	31,778
MAE	22,242	20,405	22,220	22,376
MAPE	202,282	180,160	202,018	203,895

NWTP: Number of wastewater treatment plants; AWT: Amount of wastewater treated (thousand m3/year); WSP: Waste serviced population (person); TAWD: Total amount of wastewater discharged (thousand m3/year); AWDPC: Amount of wastewater discharged per capita (liters/day); RMSE: Root mean square error; MAE: Mean absolute error; MAPE: Mean absolute percentage. Difference: The difference between the estimated number of wastewater treatment plants in 2025 compared to the observed data in 2022 (the number of new wastewater plants needed).

independent variable. In other words, the variable that estimated the amount of wastewater in 2023-2025 with the least error was AHVN (population with waste service). On the other hand, RMSE, MAE and MAPE values are very close in all four models. Since the correlation coefficients in Table 3 show a high relationship between these independent variables, it is seen that all four independent variables can be used to estimate the amount of wastewater.

5. CONCLUSION

For the year 2025, it has been determined that 1923 wastewater treatment plants will be needed in terms of the amount of astewater treated, 1858 in terms of the population with waste service, 1922 in terms of the total amount of wastewater discharged and 1928 in terms of the amount of wastewater discharged per capita.

Projections for the 2025 period reveal that the capacity of treatment plants should be increased in cooperation with local governments and the private sector in order to make Turkey's wastewater management targets more sustainable. This process will not only provide environmental benefits, but will also make it possible to achieve significant economic and social gains. In particular, elements such as the use of advanced treatment technologies, the development of innovative financing models, and increasing the environmental awareness of local people are critical for sustainable wastewater management.

The implementation of projects such as increasing the capacity of treatment plants, modernizing existing infrastructure and building new facilities will help protect water resources and make significant contributions to sustainable development goals. Local governments can ensure that treatment plants are planned and operated in accordance with local needs, while private sector investors can provide financing and know-how to these projects. The public-private partnership model has great potential, especially in terms of the realization of emerging technologies and the realization of large-scale projects. These collaborations will minimize environmental impacts by providing the necessary financing and technical infrastructure for the efficient operation of the facilities. In addition, increasing the capacity of treatment plants will ensure the reuse of water and thus ensure more efficient use of water resources. In order for Turkey to achieve its sustainable wastewater management goals, it needs to have a strong legal framework and policy support. It is important for the Ministry of Environment and local governments to implement regulations that encourage wastewater treatment investments and to ensure their effective management. In addition, it is necessary to develop incentive mechanisms for local governments and the private sector in order to comply with the principles of the European Union on this issue and to raise environmental standards.

In addition, digitalization and the use of smart systems offer significant advantages in monitoring and managing treatment plants. With smart sensors and data analysis methods, the performance of facilities can be monitored in real time, and energy and water consumption can be optimized. Such technological advances can improve both the environmental and economic sustainability of wastewater treatment plants. In addition, energy-efficient treatment systems can reduce the energy consumption of facilities and reduce operating costs. The use of renewable energy sources in treatment processes plays an important role in ensuring the energy independence of treatment plants. Alternative energy sources such as solar energy and biogas can contribute to environmental sustainability by reducing the operational costs of water treatment plants.

The construction and modernization of treatment plants are projects that require large capital investments. Therefore, it is of great importance to go beyond traditional financing methods and adopt innovative financing models. Among these, the creation of special financial instruments for environmental investments, the use of green bonds, and the design of financial models with public-private sector cooperation are among the important alternatives. Green bonds are a financing tool that encourages investment in environmentally friendly projects and can be an effective method to raise funds, especially for environmentally sensitive projects. In addition, the creation of special financial incentives for treatment plants can allow these projects to be implemented more quickly. Support can be obtained from sources such as international financial institutions and climate change funds. Such funds can accelerate the capacity expansion of treatment plants by providing financial support to local governments and private sector companies investing in sustainable water management and environmentally friendly projects.

Sustainable wastewater management should be supported not only by infrastructure investments and technological developments, but also by social awareness and environmental awareness. Environmental awareness of local people is of great importance in the correct management and reuse of wastewater. In this context, environmental education and public awareness is an important step to ensure the sustainability of wastewater management. Local governments should organize programs to increase environmental awareness in schools, public spaces and community centers and raise awareness in this area. In addition, ensuring the active participation of the public in wastewater management processes will be an important strategy to encourage environmentally friendly behaviors. This will build strong community support for water conservation, wastewater reuse and minimisation of environmental impacts.

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