EVALUATION OF DRINKING WATER TREATMENT PLANTS IN TERMS OF CAPACITY: THE CASE OF ISTANBUL, ANKARA, AND KOCAELI

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Abstract

Global population growth is increasing the pressure on water resources day by day. At the same time, changes in land use, especially due to increased urbanization, affect hydrological processes. Considering both population and urbanization, the management of water resources with the right planning becomes inevitable. In this study, the worst-case scenario was handled and it was investigated how much more the city could meet its water needs if the drinking water treatment plants in the provinces of Istanbul, Ankara and Kocaeli were operating at full capacity. In the analyzes handled with the current water losses, the population projections and the future change in the per capita water need are revealed. According to the results obtained, it was determined that when the existing drinking water treatment plants in Istanbul are used at full capacity, there may be water shortages in 2039. Under the same conditions, it was determined that Ankara would not be able to meet its water needs in 2036. In Kocaeli, it was determined that in 2031, the existing facilities will be insufficient for the water demand. The results of the study showed that the necessary measures should be taken immediately for the water crisis, which is expected to be one of the most important problems of our country in the future.

İÇME SUYU ARITMA TESİSLERİNİN KAPASİTE BAKIMINDAN DEĞERLENDİRİLMESİ: İSTANBUL, ANKARA VE KOCAELİ ÖRNEĞİ

Anahtar Kelimeler
Su kaynakları
İçme suyu
Nüfus
Şehirleşme
Arazi Kullanımı

Öz

Küresel nüfus artışı, su kaynakları üzerindeki baskıyı her geçen gün artırmaktadır. Aynı zamanda özellikle de şehirleşmedeki artıştan dolayı arazi kullanımındaki değişiklikler hidrolojik süreçleri etkilemektedir. Hem nüfus hem de şehirleşme göz önüne alındığında su kaynaklarının doğru planlama ile yönetilmesi kaçınılmaz hale gelmektedir. Bu çalışmada en kötü senaryo ele alınarak İstanbul, Ankara ve Kocaeli illerindeki içme suyu arıtma tesislerinin tam kapasitede çalışması durumunda şehrin su ihtiyacını ne kadar daha sağlayabileceği araştırılmıştır. Mevcut su kayıpları ile ele alınan analizlerde nüfus projeksiyonları ile kişi başına su ihtiyacının gelecekteki değişimi ortaya konmuştur. Elde edilen sonuçlara göre İstanbul'daki mevcut içme suyu arıtma tesisleri tam kapasite ile kullanıldığında 2039 yılında su sıkıntısı yaşayabileceği belirlendi. Aynı koşullar altında Ankara'nın 2036 yılında su ihtiyacını karşılayamayacağı belirlendi. Kocaeli'de ise 2031 yılında mevcut tesislerin su talebine yetersiz kalacağı belirlendi. Çalışma sonuçları, gelecekte ülkemizin en önemli problemlerinden biri olması beklenen su krizi için gerekli önlemlerin ivedilikle alınması gerekliliğini göstermiştir.

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1. Introduction

One of the most basic needs for human beings and other living beings to survive is water. Water covers approximately 71% of the earth's surface, with oceans accounting for approximately 96.5% of this water (USGS, 2019). In addition to playing an inevitable role in the ecosystem, water resources also play a critical role in the socioeconomic development of countries and regions (McGinn et al., 2021).

One of the main problems that mankind will face in the future will be getting access to water. With the increase in freshwater demand, freshwater scarcity poses a serious threat to the sustainable development of human society. Considering the potential effects of water scarcity, it appears to be one of the biggest global risks (Mekonnen & Hoekstra, 2016). Considering population growth, economic growth, and many different factors, it is seen that the pressure on water resources has increased. It is predicted that many parts of the world will face water scarcity due to factors such as global population growth and climate change (Moya-Fernández et al., 2021). In a study, it was determined that approximately 4 billion people experience water scarcity in at least one month of the year, and about half of these 4 billion people live in India and China (Mekonnen & Hoekstra, 2016).

In addition to the aforementioned factors such as climate change and population growth, changes in land use due to increasing urbanization, which contribute to climate change, have a significant impact on water resources by affecting the flow regime (Gashaw et al., 2018). Rapid urbanization causes problems such as insufficient water resources, a decrease in water quality, and environmental pollution (Qin et al., 2011). For these reasons, rapid urbanization is one of the biggest challenges to increasing water stress (Koç et al., 2020).

Since the population is one of the most important factors in changes in land use due to urbanization, the relationship between urbanization and the population should be considered (Xu et al., 2020). For this reason, in this study, besides examining the changes in population and water demands, the relationship between urbanization and population will also be examined. In this study, population projections will be made by using the population data of Istanbul, Ankara, and Kocaeli provinces. The populations obtained will be analyzed together with the projections of the water consumption data, and it will be determined how sufficient the current drinking water treatment capacity of each province will be. At the same time, the relationship between urbanization and population will be revealed for the provinces mentioned. The results from the study will offer the planners a chance to get a general idea. Authorities will be able to benefit from this study in the planning and management of water resources as well as in the planning of drinking water treatment plants.

2. Material and Methods

2.1. Study Area

Istanbul, Turkey's most populous city and selected as the European Capital of Culture in 2010, Ankara, the capital of Turkey, and Kocaeli were chosen as the study areas. The locations of the study areas are given in Figure 1.

Figure 1. Locations of Study Areas

2.2. Data Collection

2.2.1. Population Data

Population data for the study areas were obtained from the Turkish Statistical Institute (TÜİK) data (TÜİK, 2022). Population data for the years 2000-2021 for Istanbul, Ankara, and Kocaeli, which are also used in the regression analysis, are given in Table 1.

Table 1. Population Data of Istanbul, Ankara, and Kocaeli

	Istanbul	Ankara	Kocaeli
2000	11,076,840	3,889,199	1,192,053
⋮	⋮	⋮	⋮
2015	14,657,434	5,270,575	1,780,055
2016	14,804,116	5,346,518	1,830,772
2017	15,029,231	5,445,026	1,883,270
2018	15,067,724	5,503,985	1,906,391
2019	15,519,267	5,639,076	1,953,035
2020	15,462,452	5,663,322	1,997,258
2021	15,840,900	5,747,325	2,033,441

2.2.2. Drinking and Utility Water Data

Data on drinking and utility water were obtained from annual reports published by each province's drinking and sewerage administrations. These institutions are the Istanbul Water and Sewerage Administration (İSKİ) for Istanbul, the Ankara Water and Sewerage Administration (ASKİ) for Ankara, and the Kocaeli Water and Sewerage Administration (İSU) for Kocaeli (İSKİ, 2022a; ASKİ, 2022a; İSU, 2022). While estimating the per capita water consumption in Istanbul and

Ankara in the coming years by using the current data, the equations in Figure 2 were used. Due to the sudden changes in the per capita water consumption data of Kocaeli, the regression analysis was not performed because the determination coefficient obtained was very small. Instead, the average per capita water consumption in Kocaeli in 2003–2020 is taken, and it is accepted that the average amount of consumption will continue in the coming years.

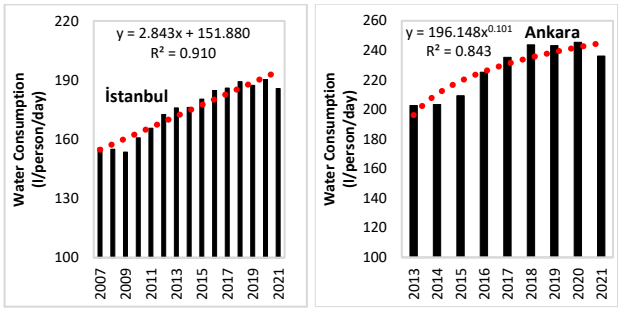

Figure 2. Per Capita Water Consumption in Istanbul and Ankara

2.2.3. Land Use Data

The land use data for the study areas were obtained from the Ministry of Agriculture and Forestry of the Republic of Türkiye (TCTOB, 2022). At the same time, satellite images of land use were obtained from the Copernicus Land Monitoring Service (CLMS), which is a part of the Copernicus Program (CLMS, 2022). Land cover maps by year are given in Figure 3.

2.3. Methods

In this study, per capita water consumption was calculated by dividing the total amount of water supplied to the cities annually by the total population of the cities. And with the regression analysis, population projections and water consumption projections for the study areas were obtained. The water loss rates obtained for the cities examined in the study show the total water loss. While considering the worst-case scenario, it has been calculated how long the cities can be sustained without facing a water shortage if the water treatment facilities already in place in the provinces under consideration are operating at full capacity. In order to analyze this situation, it is necessary to make a projection of the data for the coming years. For this reason, it is of great importance to analyze the data in the most accurate way statistically. Regression analysis is a statistical tool used to examine the relationship between two or more variables (Angelini, 2019).

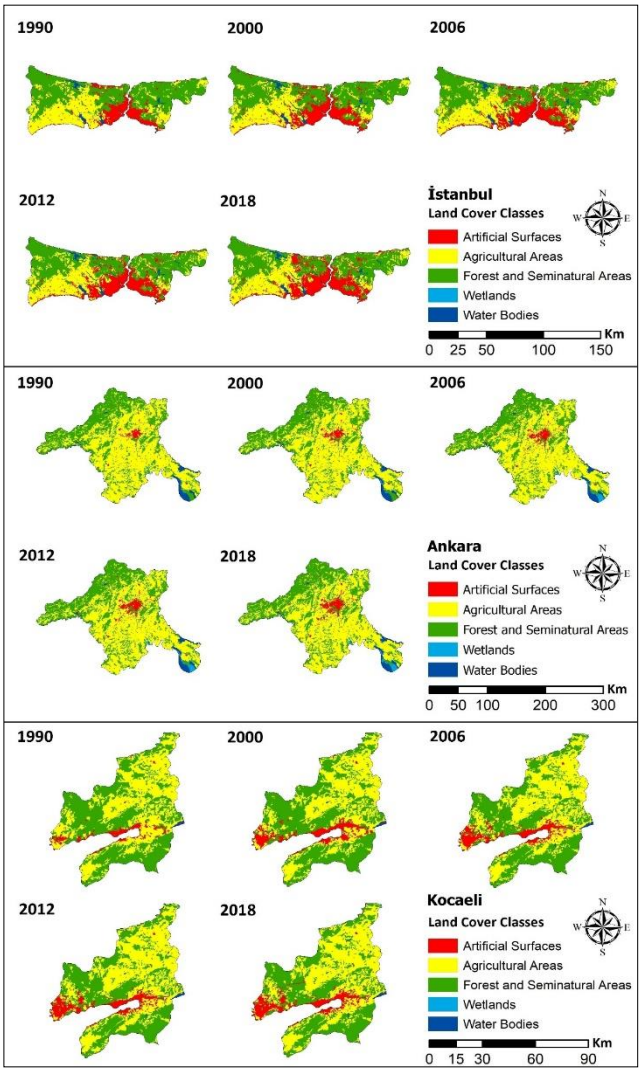

Figure 3. Land Cover Maps by Year

In this study, different regression models (simple linear, exponential and power) were used while performing the regression analysis. The reason for this is to achieve statistically more accurate results. The coefficient of determination (R^2), a concept belonging to regression analysis, is a measure of the rate of variance explained by the regression model (Di Bucchianico, 2008). Accordingly, in the study, the coefficients of determination of the relations between the variables were calculated for different regression models, and the regression model with the highest coefficient of determination was used. This process was applied separately in each study area when determining the water consumption and population projections. This method has also been used in different studies (Koç et al., 2017). At the same time, correlation analysis was carried out to reveal the relationship between population and urbanization in the study. In addition, the P-value was calculated by performing a hypothesis test to reveal the statistical significance of the data. The

path followed in the study is given schematically in Figure 4.

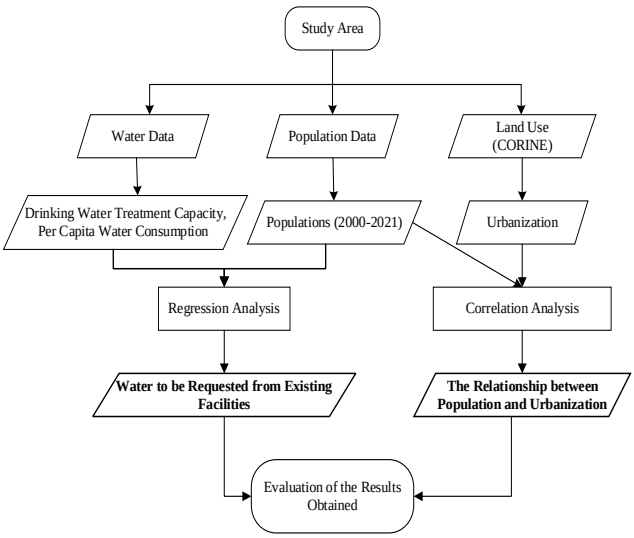

Figure 4. Flowchart of the Study

3. Results and Discussion

3.1. Results

3.1.1. Istanbul

As a result of the analysis carried out for the province of Istanbul, it has been concluded that even if the existing drinking water treatment plants in the province are operated at maximum capacity, there may be a water problem between 2038 and 2039. Figure 5 shows the amount of water per capita and water consumption per capita in Istanbul by year.

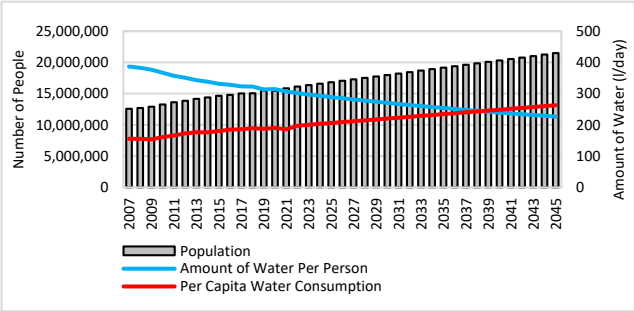

Figure 5. Amount of Water Per Capita and Per Capita Water Consumption in İstanbul by Years

When Figure 5 is examined, it is seen that the amount of water per capita decreased due to the increase in population. At the same time, the projection made depending on the amount of water consumed per capita between 2007 and 2021 in Istanbul has an increasing trend.

Istanbul will have a population of approximately 20 million at the beginning of 2038. At the same time, the amount of water per capita for this year is 244.9 l/day. Per capita water consumption is expected to be 242.8 l/day in the aforementioned year. Hence, in 2038, a person's daily water needs can hardly be supplied. The amount of water demanded by a person during the year will become unaffordable by the existing facilities.

It is known that while the loss-leakage rate in Istanbul's drinking water network was 23.61% in 2017, it decreased to 20.52% in 2021 (İSKİ, 2022b). Unfortunately, if water losses continue at this level and the capacities of the existing treatment plants are not increased, a water shortage in Istanbul may occur in 2038. Efficient use of the city's water resources is of great importance with the efforts to reduce network losses. Drinking water network losses have been reduced below 10% in developed countries (TCOSB, 2017). If the network losses for Istanbul can be reduced to these levels, the current capacity will be sustainable until 2045.

In the simplest definition, urbanization is the process of increasing the number of people migrating from the countryside to the city, and it leads to the increase of artificial areas both vertically and horizontally (Hassan Rashid et al., 2018). The relationship between population and urbanization in Istanbul is given graphically in Figure 6.

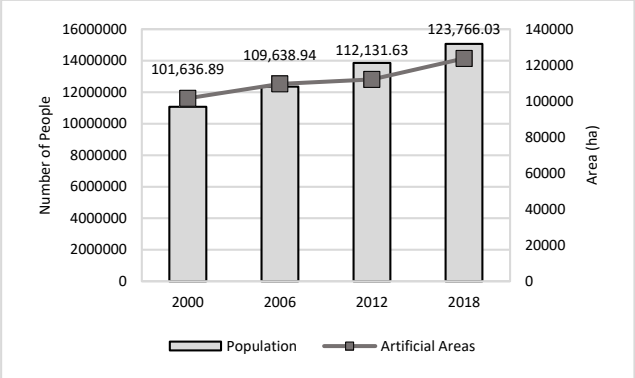

Figure 6. Population and Urbanization in Istanbul by Years

While Istanbul had an artificial area of 71,983.09 ha in 1990, this figure reached 101,636,89 ha in 2000. This shows an increase of approximately 41%. If we look more recently at Figure 6, in 2018, artificial areas cover 22.65% of Istanbul, with an area of 123,766.03 ha. This figure also constitutes the highest artificial area in the examined years.

A correlation analysis was performed using the data given in Figure 6. The correlation coefficient obtained to reveal the relationship between population and urbanization is 0.96. In order to reveal the statistical significance of the relationship, hypothesis testing was performed and the P-value was calculated (Asuero, et al., 2006). The P-value of the relationship was found to be 0.038≤0.05. This situation reveals that the relationship is statistically significant.

3.1.2. Ankara

As a result of the analysis, it has been determined that Ankara will not be able to meet its water needs in approximately 2035, even when the existing drinking water treatment plants in Ankara are operating at maximum capacity. Despite this, the year 2035, which is predicted to experience water shortages, is a very close date. Therefore, the number or capacity of drinking water treatment plants should be increased as soon as possible. In Figure 7, per capita water consumption and per capita water amounts are given in Ankara by year.

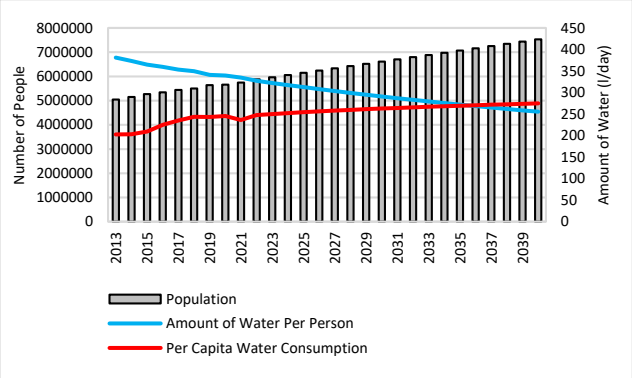

Figure 7. Amount of Water Per Capita and Per Capita Water Consumption in Ankara by Years

In Figure 7, per capita water consumption in 2021 is 236.14 l/day. The daily amount of water per person for the same year is 334.70 l. Therefore, the amount of water demanded per person in 2021 can be easily met. However, in Ankara, which is expected to have a population of more than 7 million in 2035, the per capita water consumption is 269.5 l/day, while the per capita water amount is 272 l/day. By 2036, the city's water needs will no longer be met. In the calculations made according to the reports of the Ankara water administration, the current water network losses are 37.25%. This rate is quite high. The relevant municipality is planning to reduce it to 30% in the first stage and then to 25% in target planning related to reducing losses. However, considering that this rate is around 10% in developed countries, it can be said that if this rate is reduced to these levels, there will be no water shortage until 2063 with the current capacity.

In Figure 8, populations and artificial areas in Ankara are given by years.

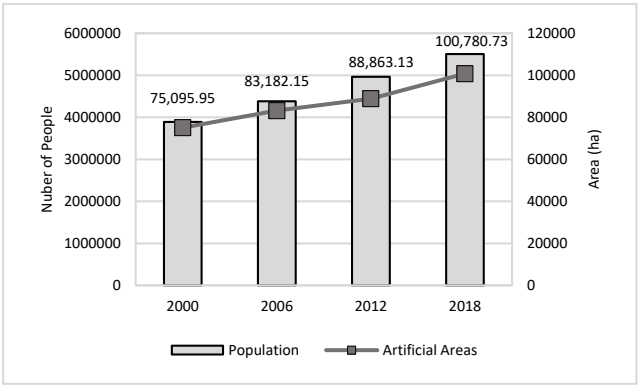

Figure 8. Population and Urbanization in Ankara by Years

It can be seen in Figure 8 that urbanization (artificial areas) has increased continuously in Ankara. While the artificial zone area of Ankara was 55,045.59 ha in 1990, this area was 100,780.73 ha in 2018. This shows that urbanization has increased by more than 80% in 2018 compared to 1990. From 2012 to 2018 alone, urbanization in Ankara increased by about 13%.

A correlation analysis was performed using the data given in Figure 8. The correlation coefficient obtained to reveal the relationship between population and urbanization is 0.98. In order to reveal the statistical significance of the relationship, hypothesis testing was performed and the P-value was calculated. The P-value of the relationship was found to be 0.012≤0.05. This situation reveals that the relationship is statistically significant.

3.1.3. Kocaeli

The total capacity of the existing drinking water treatment plants in Kocaeli is 579,900.00 m^3/day. It has been observed that even in the case of these facilities operating at full capacity, Kocaeli province may experience water shortages in the near future. In Kocaeli, which may experience water shortages shortly, the per capita water amounts and per capita water consumption by year are given in Figure 9.

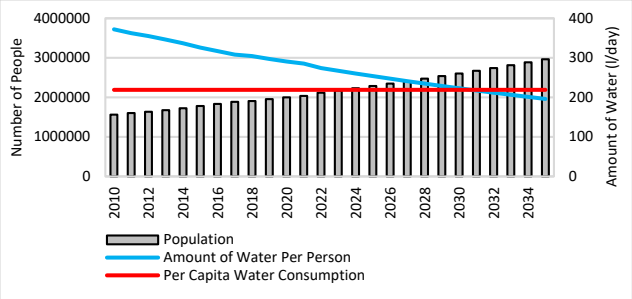

Figure 9. Amount of Water Per Capita and Per Capita Water Consumption in Kocaeli by Years

In Figure 9, per capita water consumption in Kocaeli has not changed over the years and is 219 l. This is because sudden changes in consumption data and a strong linear or exponential relationship between the data have not been determined. Therefore, a projection based on the regression analysis for water consumption was not performed. Instead, an average of 18 years of water consumption between 2003 and 2020 is taken. It is accepted that water consumption will be at the same level in the coming years. In 2021, while the water per capita in Kocaeli is approximately 285 l/day, the water consumption is 219 l. This means that the water demand per capita is met. However, it has been calculated that the amount of water per capita in 2030 will be 212.8 l/day. This figure is very close to the per capita water consumption value of 219 l/day. Therefore, the water demand in 2030 can hardly be met, but unfortunately, the amount of water demanded per person during the year will not be met. These calculations were made by taking into consideration the current network losses of Kocaeli (26%). Kocaeli water administration continues to work to prevent water losses and leaks. While network losses were 38% in 2016, it decreased to 26% in 2021. However, further reduction of this rate will make the existing drinking water capacity more sustainable. If water losses are reduced to 10%, the current drinking water capacity is expected to last until 2036.

Figure 10 displays statistics about Kocaeli's population and urbanization in a graphical format.

In Figure 10, artificial zone areas in Kocaeli were 14,107.64 ha in 1990, while this area reached 30,309.62 ha as of 2018. At the same time, the correlation coefficient obtained from Kocaeli's population and urbanization data is given in Table 5.

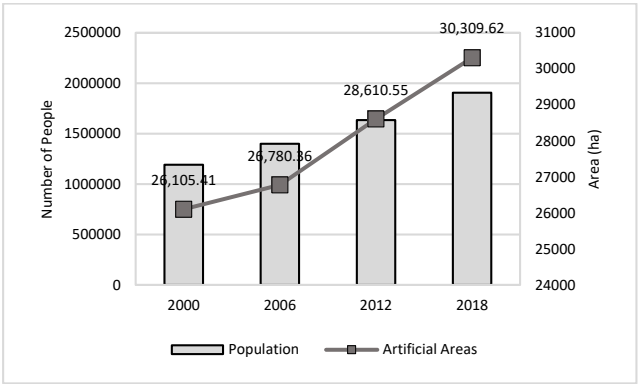

Figure 10. Population and Urbanization in Kocaeli by Years

A correlation analysis was performed using the data given in Figure 10. The correlation coefficient obtained to reveal the relationship between population and urbanization is 0.99. In order to reveal the statistical significance of the relationship, hypothesis testing was performed and the P-value was calculated. The P-value of the relationship was found to be $0.009 \leq 0.05$. This situation reveals that the relationship is statistically significant.

3.2. Discussion

In the report published by Kocaeli Water and Sewerage Administration (İSU), it is stated that the city will need 255,000,000 m3 of water in 2040 (İSU, 2021). In this study, the total water requirement in Kocaeli for the same year was calculated as 269,000,000 m3. In the drinking water and sewerage master plan report prepared for Istanbul, it has been calculated by the Cohort Component Technique that the population of Istanbul will be around 21 million in 2053. In this study, it was determined that Istanbul will have a population of 21 million in 2043. In the report published at the same time, it is predicted that per capita water consumption will be around 210 l/day in 2053. In this study, it is calculated that this figure will be reached in 2028 (İSKİ, 2022c). According to the report published for Ankara, population estimation was made according to three different scenarios to determine the population in the coming years. According to these scenarios, the population of Ankara in 2040 is expected to be between 7.8 million and 8.1 million. The population estimate for the same year in this study is approximately 7.6 million. According to the report, the per capita water consumption estimate for the metropolitan city for 2030, based on three different scenarios, varies between 188 l/day and 267 l/day. In this study, per capita water consumption for 2030 was estimated as 262 l/day. This figure is closer to the 267 l/day value obtained from the high consumption scenario in the report (ASKİ, 2022b). Therefore, the results obtained from the analysis in this

study are similar to the results in the published reports, especially in the reports published for Ankara and Kocaeli.

The method applied to determine water consumption and water demand in the coming years was used in a different study (Koç et al., 2017). However, in the study, network losses are taken into account in the analysis with their current values. However, municipalities continue to work on reducing network losses. In addition, it should not be forgotten that the years when water shortages are expected are for the worst-case scenario, since the case of drinking water treatment plants operating at full capacity is used in the analysis. Many studies have been carried out on both the determination and reduction of water losses (Ananda, 2019; Azevedo & Saurin, 2018; Saldarriaga & Salcedo, 2015). At the same time, researchers can achieve better results if they can determine the actual operating efficiency of drinking water facilities, which are assumed to operate theoretically with 100% efficiency in this study. In a study conducted in Chile, it was revealed that this rate varies depending on environmental factors, and only one of the facilities examined in the study has more than 81% efficiency (Molinos-Senante & Maziotis, 2022).

4. Conclusion

According to the results obtained in this study, it has been determined that drinking water treatment plants will not be able to meet the water needs of the population in Istanbul, Ankara, and Kocaeli in 2039, 2036, and 2031, respectively. Especially for Kocaeli, the results obtained from the study are quite worrying. Therefore, the authorities should speed up their current work on drinking water facilities in Kocaeli, taking this work into account. The status of the existing drinking water treatment plants in Istanbul and Ankara is better than in Kocaeli. However, in all cities in the study, planning should be done by taking into account the increasing population and urbanization. Otherwise, the water problem will become inevitable.

Water losses in these cities and in Turkey are quite high. According to an official report published, it has been revealed that the water loss rate in metropolitan municipalities in Turkey is approximately 50% (TCKB, 2018). While the water loss rate is more than 35% in Ankara in 2020 without including illegal uses, the total water loss in Kocaeli is 28% for the same year (ASKİ, 2021; İSU, 2021). In 2019, the only physical water losses in Istanbul are 20% (İSKİ, 2022b). In this context, the Ministry aims to create models that will provide technical and financial support in order to reduce water losses (TCKB, 2018). In a study conducted in 2019, it was suggested that the total water loss worldwide in 2006 was 346 million cubic meters per day (Liemberger & Wyatt, 2018). Considering the 6.5 billion world population in 2006, the per capita water loss is around 50 l/day (PRB, 2006). This shows that water losses are a worldwide problem rather than a regional problem that only concerns Turkey. Therefore, reducing water losses is important for future generations to meet their water needs. In order to achieve this, it is necessary to increase the number of studies in this field and put them into practice by the authorities (Al-Washali et al., 2016; Al-Washali et al., 2020; Covas et al., 2008).

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Contribution of Researchers

Selami Yurdan Özgül contributed to the writing and analysis of the study. At the same time, this study emerged from S. Y. Özgül's master's thesis.

Yıldırım BAYAZIT contributed to the review of the study and the evaluation of the results.

Conflict of Interest

There is no conflict of interest.

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