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Sustainable Water Management in the İzmir Bay Sub-Basin: An Evaluation of Water Resources with the WEAP Model

İzmir Körfezi Alt Havzasında Sürdürülebilir Su Yönetimi: WEAP Modeli ile Su Kaynaklarının Değerlendirilmesi

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ABSTRACT

Water is essential for life. It plays a critical role in sustaining both natural ecosystems and urban environments. However, the sustainability of this vital resource is increasingly at risk due to growing pressures. The İzmir Bay sub-basin, located in the semiarid western region of Türkiye, holds significant economic, ecological, and social importance. However, the region's water resources are facing significant challenges due to rapid urbanization, population growth, and the impacts of climate change, with vulnerability expected to increase in the future. This study employs the Water Evaluation and Planning (WEAP) model to evaluate water potential, address domestic and agricultural water demands, and explore management strategies for sustainability of the region. The research first examines available water resources that supply water to eleven districts in the former metropolitan area of İzmir province (Balçova, Bayraklı, Bornova, Buca, Çiğli, Gaziemir, Güzelbahçe, Karabağlar, Konak, Karşıyaka, and Narlıdere) within the sub-basin. Population projections for the region up to 2050 were also estimated to understand water demand. Additionally, favorable and unfavorable scenarios were developed based on projected changes in temperature, precipitation, and flow rates under the RCP4.5 scenario. These projections utilized MPI-ESM-MR and HadGEM2-ES, both of which are state-of-the-art global climate models. Three scenarios —reference, optimistic, and pessimistic— representing varying climatic and hydrological conditions were analyzed using the WEAP model. Findings indicate a sharp rise in water demand, reaching 318.25 hm^3 by 2050 in the reference scenario, while the pessimistic scenario forecasts the highest demand at 381.59 hm^3. Unmet demand could rise dramatically under pessimistic conditions, reaching 160.9 hm^3 by 2050. This emphasizes the urgent need for mitigation strategies. The optimistic scenario demonstrates that proactive policies and climate resilience measures can prevent shortages and provide water balance. Without strategic interventions, İzmir Bay's water security will remain at risk. Forward-looking policies and effective management are essential to ensure equitable and sustainable water distribution in the face of growing demand and climate change pressures.

Keywords: climate change scenarios, İzmir Bay sub-basin, WEAP model, water resources management

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ÖZ

Su, hem doğal ekosistemlerin hem de kentsel yaşamın sürdürülebilirliği için hayati bir rol oynamaktadır. Ancak, artan baskılar nedeniyle bu önemli kaynağın sürdürülebilirliği giderek daha fazla risk altına girmektedir. Türkiye'nin yarı kurak batı bölgesinde yer alan İzmir Körfezi alt havzası, ekonomik, ekolojik ve sosyal açıdan büyük bir öneme sahiptir. Ancak, hızlı kentleşme, nüfus artışı ve iklim değişikliğinin etkileri nedeniyle su kaynakları ciddi tehditlerle karşı karşıyadır ve bu kırılganlığın gelecekte artması beklenmektedir. Bu çalışma, İzmir Körfezi alt havzasında su potansiyelini değerlendirmek, kentsel ve tarımsal su taleplerini analiz etmek ve sürdürülebilir yönetim stratejileri geliştirmek amacıyla Su Değerlendirme ve Planlama (WEAP) modelini kullanmaktadır. Araştırma, alt havzada yer alan ve eski İzmir metropol alanına dâhil olan on bir ilçeye (Balçova, Bayraklı, Bornova, Buca, Çiğli, Gaziemir, Güzelbahçe, Karabağlar, Konak, Karşıyaka ve Narlıdere) su sağlayan mevcut kaynakları incelemektedir. Ayrıca, bölge için 2050 yılına kadar su talebini anlamak adına nüfus projeksiyonları oluşturulmuştur. Çalışmada, RCP4.5 iklim senaryosu kapsamında MPI-ESM-MR ve HadGEM2-ES küresel iklim modelleri kullanılarak olumlu ve olumsuz senaryolar geliştirilmiştir. Referans, İyimser ve Kötümser olmak üzere üç senaryo, WEAP modeli ile analiz edilmiştir. Sonuçlar, su talebinin 2050 yılına kadar referans senaryoda 318.25 hm³'e, kötümser senaryoda ise 381.59 hm³'e ulaşacağını göstermektedir. Olumsuz koşullarda, karşılanamayan su talebinin 160.9 hm³'e çıkabileceği öngörülmektedir. Bu durum, acil önlem alınması gerektiğini vurgulamaktadır. İyimser senaryo, proaktif politikaların ve iklim direncini artıran önlemlerin su kıtlığını önleyebileceğini ve su dengesi sağlayabileceğini göstermektedir. Stratejik müdahaleler olmadan, İzmir Körfezi'nin su güvenliği tehdit altında kalmaya devam edecektir. Artan talep ve iklim değişikliği baskıları karşısında, uzun vadeli su sürdürülebilirliği için ileriye dönük politikalar ve etkin su yönetimi büyük önem taşımaktadır.

Anahtar kelimeler: *iklim değişikliği senaryoları, İzmir Körfezi alt havzası, WEAP modeli, su kaynakları yönetimi*

INTRODUCTION

Water resources are essential for sustaining life, economic development, and ecological balance. In the 21st century, the world is facing some major challenges such as rapid population expansion, unrestrained urban sprawl, and the ever-increasing impacts of climate change. These pressures are threatening the availability and sustainability of water resources worldwide.

Water has always been the paramount element in human endeavors within urban environments. The world is predominantly becoming a more urbanized environment, characterized by human settlements and dominant economic activities. According to the United Nations (UN), more than half of the world's population resides in urban areas today, and this number is expected to increase by 68% to reach 2.5 billion people by the year 2050 (UN, 2019). As the world undergoes these ongoing increases in population, industrialization, and urban development, the unavoidable consequence is a heightened risk of water scarcity and deficiencies in the resilience of water systems. However, the challenges of water scarcity and managing urban water effectively have become an increasingly challenging and complex undertaking (Negahban-Azar & Mosleh, 2021). Therefore, a shift from conventional supply-driven water management approaches to more sustainable and integrated strategies is required (Yılmaz & Harmancıoğlu, 2010). To ensure long-term water security, it is necessary to assess the impacts of climate change and socio-economic factors on water resources, to be able to take necessary measures and implement effective management strategies.

The İzmir Bay sub-basin, a highly significant region for İzmir, is especially vulnerable to these pressures. Expanding urban areas, industrial growth, and agricultural activities are causing increasing demand for water, while the region's supply remains heavily dependent on climatic conditions and seasonal variations. Currently, major dams supplying drinking and domestic water to İzmir, such as Balçova, Tahtalı and Gördes Dams, are experiencing historically low water levels due to prolonged droughts. This decline in water availability is a manifestation of growing climate change effects and raises concerns about the region's future water security. With the alterations in climatic and hydrological patterns, water shortages may tend to worsen. This has led to the need to analyze the region's water resources related to these impacts.

To address these challenges, researchers increasingly rely on hydrological models to analyze and predict the potential effects of climate change and land use change on water systems. Although modeling involves inherent uncertainties, it serves as a valuable tool for simulating, assessing, and understanding complex hydrological processes and future water availability (Hussain, 2023).

One of the most widely used tools for integrated water resources management was developed by the Stockholm Environment Institute (SEI) in 1989, the Water Evaluation and Planning (WEAP) system. The WEAP system enables researchers to model water resources, simulate various future scenarios, and assess the impacts of climate change and socio-economic factors on water availability (Yates et al., 2005). Its ability to represent both the physical and spatial characteristics of water resources makes it a valuable tool for assessing several scenarios based on "what if?" questions, such as "What if population growth and economic development patterns change? What if reservoir operating rules are altered? What if groundwater is more fully exploited?" (SEI, 2015). From small watersheds to large river basins, the WEAP model has been successfully applied at various scales to support decision-making and policy development in the context of water resources management (Hussain, 2023).

Several studies proved the effectiveness and credibility of WEAP in assessing water resources and addressing water management challenges. Mourad and Alshihabi (2016) assessed current and future water supply and demand in Syria until 2050, under various scenarios, including climate change, regional cooperation, and conflict with the WEAP model. According to their findings, climate change and regional tensions could worsen water scarcity, while cooperation and advanced technologies could help close the supply-demand gap. Also, the urgent need for additional water supplies was emphasized. Mounir et al. (2011) optimized water allocation among competing sectors, such as agriculture, industry, and domestic use, in the Niger River basin, by employing WEAP. Their study demonstrated the challenges of water management in a region with diverse ecosystems and increasing industrial growth. They also emphasized the importance of integrated resource planning. Comair et al. (2012) analyzed the vulnerability of groundwater resources under changing climate patterns and increasing water demand by applying WEAP to the Jordan River basin. Their findings indicate that all aquifers supplying water to Amman are at risk of depletion, and the need for sustainable management strategies was stressed. Hamlat et al. (2013) used WEAP to evaluate water resource management scenarios in western Algeria, a region affected by prolonged droughts and declining water quality. The results revealed that neither domestic nor agricultural water demands were fully met, and the necessity of improved allocation policies and demand management strategies to mitigate future shortages was reinforced.

In Europe, Blanco-Gutiérrez et al. (2011) used WEAP in the Middle Guadiana basin, Spain, to simulate large-scale irrigation systems under normal and drought conditions by integrating hydrological and economic models. Their findings highlighted the value of scenario-based planning for optimizing water allocation and policy evaluation.

In Türkiye, the WEAP model has been applied to analyze regional water resource challenges under changing climatic and socio-economic conditions. For example, Yılmaz and Harmancıoğlu (2010) evaluated different hydrological scenarios to determine the effects of climate variability on agricultural water demand in the Gediz River basin by using WEAP. The region's vulnerability to drought and the need for adaptive water management policies were demonstrated in their findings. More recently, Karahan and Elçi (2023) conducted a basin-based WEAP analysis in the Tahtalı-Seferihisar sub-basin. Their study examined multiple pressures on water resources and different future scenarios to predict water supply-demand balances until 2050. Their results indicated significant unmet demand even under optimistic conditions, and the necessity of long-term planning and sustainable resource allocation was reinforced.

Although previous studies examined water resources in nearby basins (Yılmaz & Harmancıoğlu, 2010; Karahan & Elçi, 2023), a comprehensive water budget analysis has not been conducted for the İzmir Bay sub-basin. Understanding the current and future state of water resources in this sub-basin will contribute to sustainable management and policy development. Therefore, this study aims to fill this gap by evaluating the water potential in the İzmir Bay sub-basin using the WEAP model. Three distinct —reference, optimistic and pessimistic— scenarios under different climatic conditions were developed, and water availability in the sub-basin by the year 2050 was estimated. By simulating these scenarios, this study aims to provide insights into the potential impacts of climate change and population dynamics on the future availability of water resources in the İzmir Bay sub-basin. It also aims to provide adaptive policy recommendations for the sustainable management of water in the region.

STUDY AREA

İzmir is a metropolitan city located on the western coast of Türkiye, situated between 37°45' and 39°15' north latitudes and 26°15' and 28°20' east longitudes, covering an area of 12,012 km² (Republic of Türkiye İzmir Governorship, 2024). It has a semiarid Mediterranean climate, characterized by dry and hot summers and mild, rainy winters. As of 2024, it is the third-largest city in Türkiye with a population of 4,493,242 people (Turkish Statistical Institute, 2024).

According to the last available report of the General Directorate of İzmir Water and Sewerage Administration (IZSU), approximately 307 hm³ of water was supplied to İzmir province in total in 2023. Of this total, 61.22% was derived from groundwater resources, while 38.78% was obtained from surface water resources (IZSU, 2023).

The study area is located within the İzmir Bay sub-basin, one of the five sub-basins of the Küçük Menderes hydrological basin, as shown in Figure 1. The study area represents the inner part of the Bay region and covers eleven central districts of İzmir—Balçova, Bayraklı, Bornova, Buca, Çiğli, Gaziemir, Güzelbahçe, Karabağlar, Konak, Karşıyaka, and Narlıdere—making it the most densely populated sub-basin. It covers 11.73% of the Küçük Menderes basin with an area of approximately 817 km². As reported by the Republic of Türkiye Ministry of Forestry and Water Affairs (MFWA), the annual average precipitation estimated by the Thiessen polygon method is 670 mm. The annual average surface water potential is 126 hm³/year (MFWA, 2016a). There are also many streams within the boundaries of the sub-basin, shown in Figure 2.

In the groundwater recharge assessment for the İzmir Bay sub-basin, the annual average recharge was estimated at 70.5 hm³/year, of which only 52.5 hm³/year is considered the safe groundwater recharge limit (MFWA, 2016a). According to the Küçük Menderes Basin Master Plan Final Report, 70 wells were drilled by the State Hydraulic Works within the sub-basin, while an additional 865 wells have been constructed by local users. Notably, groundwater resources are being heavily overexploited, significantly exceeding the sustainable recharge limit, with total annual groundwater consumption reported as 171.5 hm³/year (MFWA, 2016a).

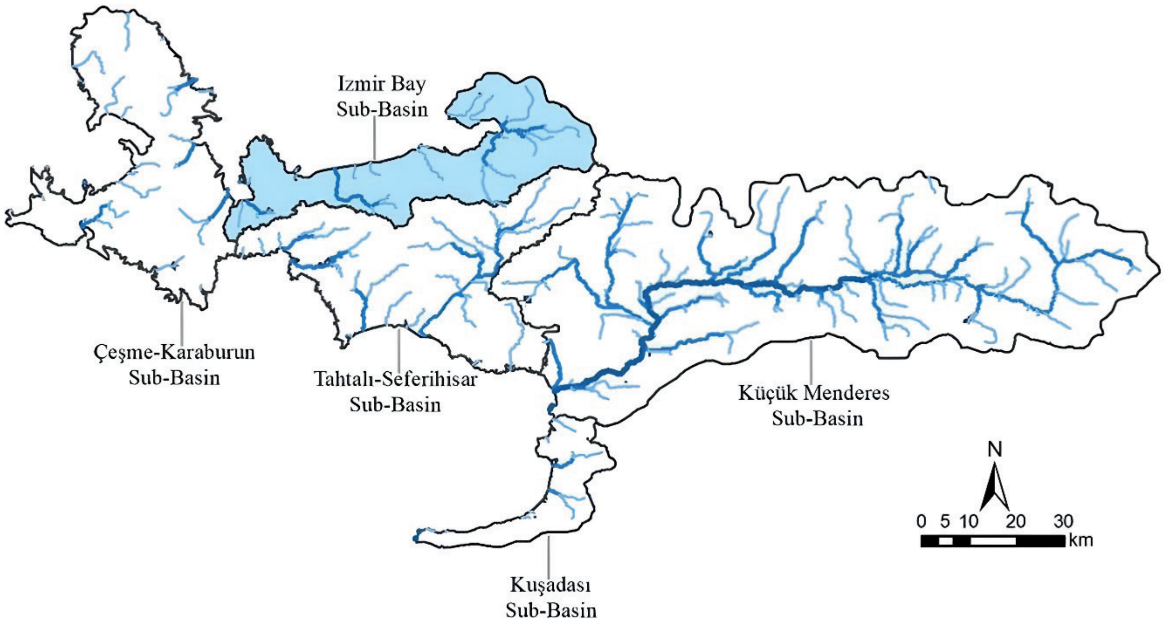

Figure 1. İzmir Bay sub-basin and other sub-basins and stream networks located in the Küçük Menderes basin.
Şekil 1. Küçük Menderes Havzası'nda yer alan İzmir Körfezi alt havzası ve akarsu ağları ile diğer alt havzaları.

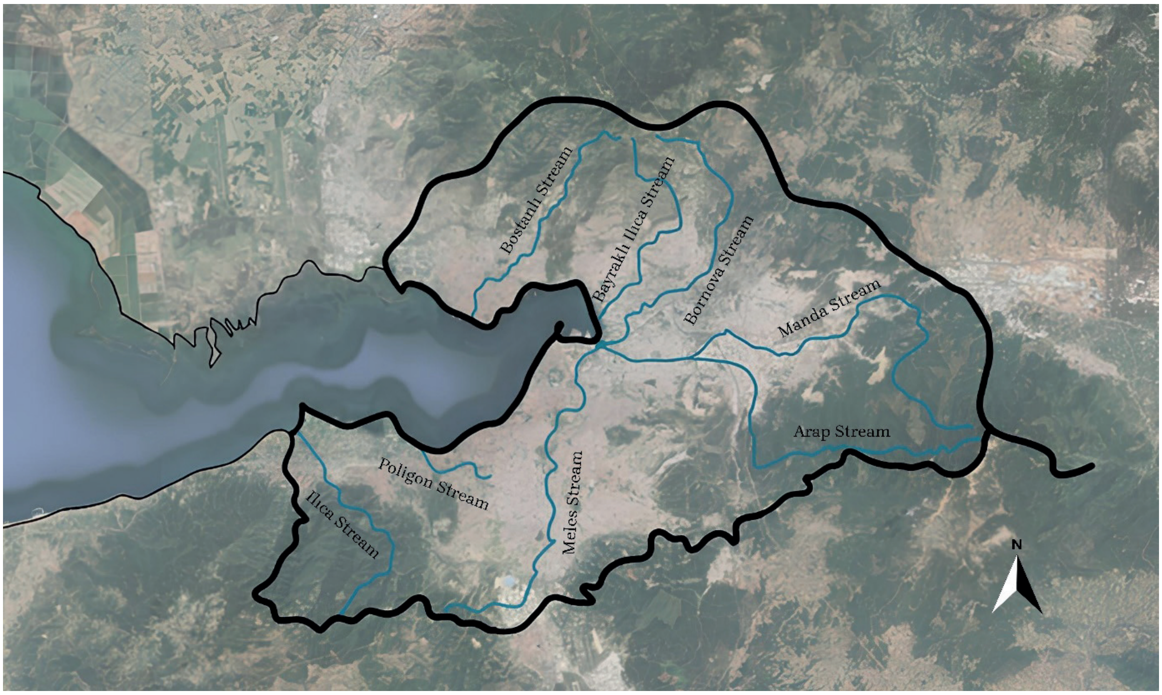

Figure 2. Streams discharging into the inner part of the İzmir Bay sub-basin.

Şekil 2. İzmir Körfezi alt havzasının iç kısmına deşarj olan dereler.

WEAP MODEL AND INPUT DATA

The WEAP model is a comprehensive, scenario-based tool developed by the SEI for water resource assessment, planning and management. It provides a holistic approach to water allocation and sustainability analysis by integrating hydrological processes, water demand, infrastructure operations, and environmental considerations (SEI, 2015). WEAP's user-friendly interface and capabilities allow for effective quick interpretation and visualization of results (Karahan & Elçi, 2023).

WEAP enables users to model both current and future water conditions in a specific region based on key assumptions (Lévite et al., 2003). The model facilitates the exploration of various supply and demand strategies to achieve a balance between environmental sustainability and development needs (Mourad & Alshibabi, 2016). It provides a holistic analysis of water systems by incorporating various hydrological, climatic and socio-economic aspects, such as water demand, supply, streamflow, and groundwater (SEI, 2015). It rapidly generates predictions through scenario-based simulations and presents results across different temporal scales and spatial resolutions. The model helps to evaluate the pressures on existing water systems by integrating external factors such as population growth, climate change, urbanization and policy interventions. By assessing water budget from multiple perspectives and identifying critical areas, WEAP provides researchers, planners, managers and stakeholders with a valuable tool for improving water resource management (Karahan & Elçi, 2023).

Thus, the WEAP model was selected as the most suitable tool for this study due to its flexibility and capability to simulate water supply and demand under various diverse scenarios, as also emphasized by previous studies within the field.

Application of the WEAP Model

There are numerous surface and groundwater resources that supply drinking water to the İzmir Bay sub-basin, some located within the basin and some transferred to the basin from other basins. The reservoirs and groundwater wells taken into account in the WEAP model were identified based on data from both IZSU and the Küçük Menderes Basin (KMB) Master Plan Final Report (2016). Accordingly, the primary surface water resources supplying drinking water to the region include the Tahtalı, Balçova (Cengiz Saran), Ürkmez, Kutlu Aktaş (Alaçatı), Güzelhisar and Gördes dams, shown in Table 1, with Balçova Dam being the only one located within the sub-basin. In terms of groundwater resources, drinking water is extracted from Halkapınar, Pınarbaşı, Buca, and Sarnıç deep-wells within the sub-basin. Additionally, water is also transferred from the Menemen, Çavuşköy, Göksu, and Sarıkız resources in the Gediz Basin to the Küçük Menderes basin to support the drinking water supply for İzmir's central districts, shown in Table 2.

Table 1. Dams and supply amounts from each dam for central districts in the İzmir Bay sub-basin.

Çizelge 1. İzmir Körfezi alt havzası merkez ilçelerine içme suyu sağlayan barajlar ve temin edilen içme suyu miktarları.

Facility Name	Transfer Basin	Purpose of Transfer	Amount of supply for drinking water (hm³/year)
Tahtalı Dam	Küçük Menderes	Drinking water	75.43
Gördes Dam	Gediz	Drinking water + irrigation	44.15
Balçova Dam	Küçük Menderes	Drinking water	5.50
Ürkmez Dam	Küçük Menderes	Drinking water + irrigation	1.22
Güzelhisar Dam	Kuzey Ege	Drinking water + irrigation +industry	9.46
Alaçatı Dam	Küçük Menderes	Drinking water	2.75

Table 2. Drinking water supply amounts from wells for central districts in the İzmir Bay sub-basin.

Çizelge 2. İzmir Körfezi alt havzasındaki merkez ilçeler için kuyulardan temin edilen içme suyu miktarları.

Wells	Basin	Amount of supply for drinking water (hm³/year)
Sarıkız	Gediz	45
Göksu	Gediz	63
Menemen and Çavuşköy	Gediz	25
Halkapınar	Küçük Menderes	45
Pınarbaşı	Küçük Menderes	2
Buca and Sarnıç	Küçük Menderes	1

In WEAP's interface, the schematic view of the calibration model illustrates the study area's water system components, as shown in Figure 3. In this layout, demand sites —where water is used for domestic, agricultural, or industrial purposes— are depicted in red, surface water resources are represented by green triangles, and groundwater wells by green squares. Transmission links, shown as green arrows, illustrate the direction and routing of water flow between supply sources and demand sites (SEI, 2015).

For the hydrological and physical characteristics of the reservoirs, data about available flow, initial storage, storage capacity, net evaporation, and volume-elevation relationships were incorporated into the "current accounts" section of the calibration model. Similarly, for groundwater resources, parameters such as storage capacity, initial storage, natural recharge, and monthly variation values were also included.

In WEAP system, the "current accounts" tool serves as the foundation for developing future scenarios (Yates et al., 2005). These scenarios project potential changes in the system for years beyond the current accounts year. The default scenario, known as the "reference scenario," extends the current account data throughout the entire simulation period and acts as a baseline for comparison with other scenarios where modifications are introduced (Hamlat et al., 2013). In this study, the existing conditions from 2005 were projected forward to the period 2006–2050 without implementing any significant alterations in this scenario. For the Gördes Dam, which started providing drinking water for İzmir in 2019, the activation year was set to that year.

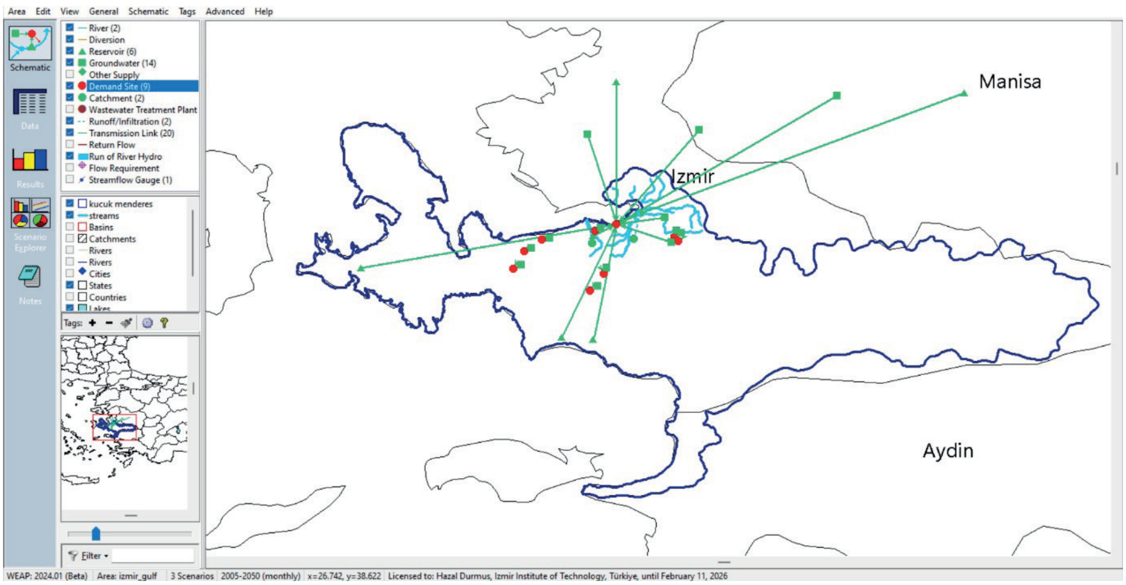

Figure 3. A screenshot of the schematic view of the calibration model from the WEAP interface. The dark blue borders represent the Küçük Menderes basin in which the study area is located, and the light blue lines represent streams within the study area.

Şekil 3. WEAP'in arayüzünden kalibrasyon modelinin şematik görünümünün ekran görüntüsü. Koyu mavi sınırlar çalışma alanının içinde bulunduğu Küçük Menderes havzasını, açık mavi çizgiler ise çalışma alanı içindeki akarsuları temsil etmektedir.

Estimation of projected population and domestic water use

In the WEAP model, in addition to the above-mentioned surface and groundwater information used in the current conditions to calculate the water budget in the sub-basin, population growth projections were also incorporated, which is an important factor affecting the future water demand.

To achieve this, official population records in the central region of İzmir for previous years were obtained from Turkish Statistical Institute, and based on this, three different methods were used to calculate the population projection to the year 2050: arithmetic extrapolation method, geometric extrapolation method and Turkish Bank of Provinces method. Among these, the *Turkish bank of provinces method* was preferred as it projects the largest long-term population and the result was used for all three scenarios in the WEAP simulation.

The Turkish Bank of Provinces method is an alternative method which is widely used for population projections in Türkiye. The projected population *Pn* for a future year is calculated using Equation 1:

$$P_n = P_2\,(1 + K/100)^{(t_2 - t_1)} \quad (1)$$

where P_n is projected population for the target year, P_2 is population recorded in the most recent census year, and K is the average annual growth rate (%). t_2 is the target year (e.g., 2050), while is the most recent census year. The growth rate K is determined by Equation 2:

$$K = \left((P_2/P_1)^{(1/(t_2 - t_1))} - 1\right)100 \quad (2)$$

where P_2 is the population recorded in the most recent census year and P_1 is the population recorded in the earlier census year. t_2 and t_1 are as defined above. The value of K is adjusted according to the following criteria:

$$K = \begin{cases} 3, & if\ K \geq 3 \\ 1, & if\ K \leq 1 \\ K, & if\ 1 < K < 3 \end{cases}$$

According to this method, the population of the İzmir Bay region is projected to reach approximately 3,992,817 people by 2050, and this estimate was used across all three WEAP scenarios.

Also, to estimate the average per capita water consumption in the study area, available data for daily per capita water consumption in İzmir were obtained from the official website of the Turkish Statistical Institute (TurkStat, 2024), given in Table 3, and used as input for the reference scenario.

Estimation of irrigation water needs

In the Mediterranean climate zone, it is expected that the effects of climate change will be strongly felt, and the irrigation water needs of crops grown in the region will inevitably be affected by alterations in precipitation and temperature values (Serbeş et al., 2018).

Table 3. Daily water consumption per person in İzmir (l/day) (TurkStat, 2024).
Çizelge 3. İzmir'de kişi başı günlük su tüketim değeri (l/gün).

	2012	2014	2016	2018	2020	2022
Daily water consumption per person in İzmir (l/day)	223	180	173	208	221	210

In the study, the corresponding irrigation water demand based on agricultural irrigation areas and crop patterns in the İzmir Bay sub-basin represents an important factor when estimating the water budget. Therefore, in order to calculate the irrigation water needs in the region, irrigation areas and crop patterns in the İzmir Bay sub-basin were determined based on the KMB Master Plan Final Report. Agricultural crops grown in the sub-basin include cereals, citrus, corn, fruit, greenhouse crops, olive, ornamental plants, tomato, vegetables and vineyard, which were determined by identifying the agricultural areas in the central districts included in the sub-basin. Accordingly, there are five public irrigation (PI) systems and three special provincial administration (SPAI) irrigation systems that are located in the İzmir Bay region, which are presented in Table 4.

Potential crop evapotranspiration, which is essential for calculating net irrigation water requirements, was estimated using the Blaney-Criddle method (Acatay, 1996; Blaney & Criddle, 1950). This method was chosen due to its ability to perform calculations with minimal input data (Serbeş et al., 2018). The relevant equations are given below in Equations 3–6:

$$U\ (mm/month) = fk \tag{3}$$

$$f = (1.8T + 32)p/100 \tag{4}$$

$$k(mm/month) = k_c k_t (25.4) \tag{5}$$

$$k_t = 0.0173(1.8T + 32) - 0.314 \tag{6}$$

where U is the potential crop evapotranspiration, expressed in millimeters per month; f is the monthly water use factor, k is the monthly water use coefficient. T is the mean monthly air temperature in degrees Celsius, and p is the annual percentage of daytime hours occurring in a given month. K_t is the climate factor, while K_c is the crop development coefficient (Serbeş et al., 2018). The constant 25.4 in the equation is due to the conversion between inches and millimeters. The coefficients 1.8 and 32 are due to the conversion between Fahrenheit and Centigrade temperature units (Koç & Güner, 2005).

Table 4. Spatial distribution of irrigation and crop types in the İzmir Bay sub-basin (ha).

Çizelge 4. İzmir Körfezi alt havzasındaki sulamaların ve ürün türlerinin mekansal dağılımı (ha).

Irrigation's Name	Area	Crop type								
		Cereals	Citrus	Corn	Fruit	Greenhouse	Olive	Tomato	Vegetable	Vineyards
Public Irrigation (PI)										
Kaynakça GW	693	69.3	-	-	304.9	-	103.95	103.95	110.9	-
Kaynakça SW	156.89	15.7	-	-	-	-	141.2	-	15.7	-
Güzelbahçe	199.43	-	39.9	-	-	45.9	83.8	-	29.9	-
Balçova	125	-	10.87	-	11.25	5	-	-	-	-
Yelki	279.92	-	140	-	-	56	-	-	84	-
Special Provincial Administration Irrigation (SPAI)										
Çatalca Şandidere	128.14	12.8	10.25	7.7	-	1.3	10.25	-	63.35	20.5
Yeniköy	280	22.4	-	-	-	2.8	22.4	-	30.8	201.6
Balabandere Bademler 9 Eylül	133.26	-	40	-	46.6	6.65	-	26.65	42.6	-

The values for each crop were entered into the WEAP program after calculating their monthly variation in irrigation areas. Accordingly, the agricultural crop patterns in the report were assumed and estimated crop water need calculations were used in the WEAP model under the current conditions. Each of the irrigation areas was taken into account as a demand site, and the priority of each demand site was equally set to 1, which is the highest priority.

SIMULATIONS OF THE SCENARIOS

In the study, temperature, precipitation, streamflow rate, and water consumption rate were selected as key climatic, hydrological, and demand-related parameters for the simulated scenarios in the WEAP model. In the reference scenario, the average temperature, precipitation, and streamflow rate values measured for the İzmir central region, as documented in the KMB Master Plan Final Report (MFWA, 2016a), were utilized. Also, to determine the average per capita water consumption value in the sub-basin, the average daily per capita water consumption data for the previously available years were obtained from TurkStat, and used as a basis in the reference scenario. The reference scenario provides a baseline for the other scenarios.

In order to construct optimistic and pessimistic scenarios, climate projection data provided in the Impact of Climate Change on Water Resources Project – Appendix for the Küçük Menderes Basin (MFWA, 2016b) were taken as the primary reference. This report includes long-term projections for key climatic and hydrological variables such as temperature, total precipitation, and streamflow under different climate change models. In the optimistic scenario, the simulation was based on the most favorable projections, such as moderate temperature rise, and increases in total precipitation. Conversely, the pessimistic scenario incorporated the most adverse projections, which reflect significant decreases in streamflow, pronounced temperature increases, and substantial decreases in total precipitation. These assumptions were incorporated into the simulations in the WEAP model to assess the future water availability in the sub-basin under contrasting climate change impacts.

According to this, for the optimistic scenario, the MPI-ESM-MR model projection, which predicts the lowest temperature increase, was selected among the available models regarding the projection of temperature. The analysis of the MPI-ESM-MR model for the RCP4.5 scenario in the Küçük Menderes Basin indicates that the annual average temperature is expected to rise by approximately 1.5 °C during the projection period relative to the reference period. Conversely, in the pessimistic scenario, the HADGEM2-ES model projection was chosen, which forecasts the highest temperature increase. The HADGEM2-ES model results for the RCP4.5 scenario suggest that the annual average temperature will increase by approximately 2.8 °C compared to the reference period (MFWA, 2016b).

As for the projection of precipitation, the precipitation projections in the report were analyzed, and the most optimistic and pessimistic model outcomes were utilized for scenario development. In the optimistic scenario, the HADGEM2-ES model projection was adopted, which predicts a 10% increase in total precipitation, as it presents a more favorable outcome compared to other model results. In the pessimistic scenario, a 25% overall decrease in precipitation was assumed based on the collective analysis of all model results (MFWA, 2016b).

Regarding the projection of flow rates, for the optimistic scenario, it was assumed that streamflows would remain at the same levels as those in the reference scenario, which implies no reduction in streamflow. In contrast, the pessimistic scenario was developed based on projections from the MPI-ESM-MR model, which estimates the most severe reductions in streamflow rates. According to this projection, a 20% decrease in streamflow is expected by 2040, followed by a more substantial decrease of approximately 60% in subsequent years (MFWA, 2016b).

Along with these, trends in water consumption were also incorporated into the scenario development. In the optimistic scenario, a 20% reduction in the average water consumption rate was assumed compared to the reference scenario, based on the premise that increased public awareness and the implementation of effective water management practices would enhance water use efficiency. Conversely, in the pessimistic scenario, a 20% increase in average water consumption was assumed, reflecting the possibility of insufficient awareness and poor management strategies, which could exacerbate future water scarcity challenges.

Descriptions of the scenarios simulated in WEAP are summarized in Table 5.

RESULTS AND DISCUSSION

The analysis of future water availability in the İzmir Bay sub-basin reveals significant variations across different scenarios. In 2005, the drinking water potential was estimated at 212.65 hm³. By 2050, the reference scenario projected an increase in demand to 318.25 hm³. The demand for drinking water is expected to rise more moderately, reaching 254.52 hm³ under the optimistic scenario; however, the pessimistic scenario forecasts the highest demand at 381.59 hm³. All results are shown in Table 6.

Table 5. Description of the scenarios simulated in WEAP.
Çizelge 5. WEAP'te simüle edilen senaryoların açıklaması.

Scenarios	Description
Reference Scenario	• Average temperature values were used • Average precipitation values were used • Average streamflow rate values were used • Average daily water consumption per capita information was used based on TurkStat reports
Optimistic Scenario	• Average temperature values were increased by 1.5 °C based on RCP4.5, MPI-ESM-MR model results • Average precipitation values were increased by 10% based on RCP4.5, HadGEM2-ES model results • Average streamflow rate values remained the same • Average daily water consumption per capita was reduced by 20%
Pessimistic Scenario	• Average temperature values were increased by 2.8 °C based on RCP4.5, HadGEM2-ES model results • Average precipitation values were reduced by 25% based on RCP4.5, estimation of all model results • Average streamflow rate values were reduced by 20% until 2040 and by 60% between 2040-2050 based on RCP4.5, MPI-ESM-MR model results • Average daily water consumption per capita was increased by 20%

Regarding delivered supply, the reference scenario results indicate sufficient supply until 2030, after which a shortage begins, and reaches a deficit of 32.4 hm³ by 2050. Under optimistic conditions, supply is expected to meet demand, as shown in Tables 6 and 7. However, in the pessimistic scenario results, delivered supply will not be able to meet demand, and shortages will rise more significantly by 2025 to 2050.

Accordingly, the pessimistic scenario results reveal a dramatic increase in unmet demand, growing from 76.4 hm³ in 2025 to 160.9 hm³ in 2050. The reference scenario results also indicate a steady increase in unmet demand at a slower rate, as shown in the Figure 5. This demonstrates that the region will face water stress, even under current assumptions. However, the optimistic scenario presents the best stable outlook, with water demand and supply remaining balanced.

In terms of irrigation water demand, the annual consumption is projected to increase from 69.45 hm³ in the reference scenario, to 75.35 hm³ under the optimistic scenario and 80.62 hm³ under the pessimistic scenario. Additionally, unmet irrigation water demand, which was 9.12 hm³ at the beginning of the simulation period, is expected to rise to 10.29 hm³ in the reference scenario, 11.15 hm³ in the optimistic scenario, and 14.15 hm³ in the pessimistic scenario. These findings suggest that rising temperatures and shifts in precipitation patterns will lead to a consistent increase in irrigation water demand and result in supply shortages across all future scenarios.

It should be added that the data used in the simulation model, such as planned water allocation values taken from official and institutional reports, suggest specific supply levels; however, real-world constraints such as prolonged droughts and inadequate infrastructure maintenance of facilities often result in lower actual allocations than simulated values. Also, while several planned water sources are mentioned in official reports for the İzmir Bay region, they were excluded from the simulations due to unimplemented status and lack of reliable data. To reduce inconsistencies and uncertainty stemming from varying assumptions across sources, only current and operational data from selected official resources were used. Nevertheless, the study still involves some uncertainties due to differences in data accuracy and consistency across multiple sources. It is important for institutions to share coordinated, up-to-date, and consistent data, allowing researchers access in order to make better evaluations and to improve the accuracy of future predictions.

CONCLUSION AND RECOMMENDATIONS

The demand for water is rising in the modern era due to factors like changing societal and economic needs, and rapid population expansion. Accordingly, water resources are severely strained as a result of excessive water use and pollution caused by urban, agricultural, and industrial activities. These factors, together with the threatening impacts of climate change, have led to a significant increase in water scarcity and inequitable access to water.

Table 6. Annual water demand for drinking water in the İzmir Bay sub-basin (hm³).

Çizelge 6. İzmir Körfezi alt havzasında içme suyu için yıllık talep (hm³).

Scenario	2025	2030	2035	2040	2045	2050
Reference	254.4	266	278.2	291	304.3	318.25
Pessimistic	305	319	333.6	348.9	364.9	381.59
Optimistic	203.44	212.76	222.51	232.7	243.37	254.52

Table 7. Annual delivered supply for drinking water in the İzmir Bay sub-basin (hm³).
Çizelge 7. İzmir Körfezi Alt havzasında içme suyu için yıllık temin edilen arz (hm³).

Scenario	2025	2030	2035	2040	2045	2050
Reference	254.38	263.88	271.5	277.64	281.97	285.85
Pessimistic	228.63	232.63	236.81	238.2	243.26	220.7
Optimistic	203.44	212.76	222.51	232.7	243.37	254.52

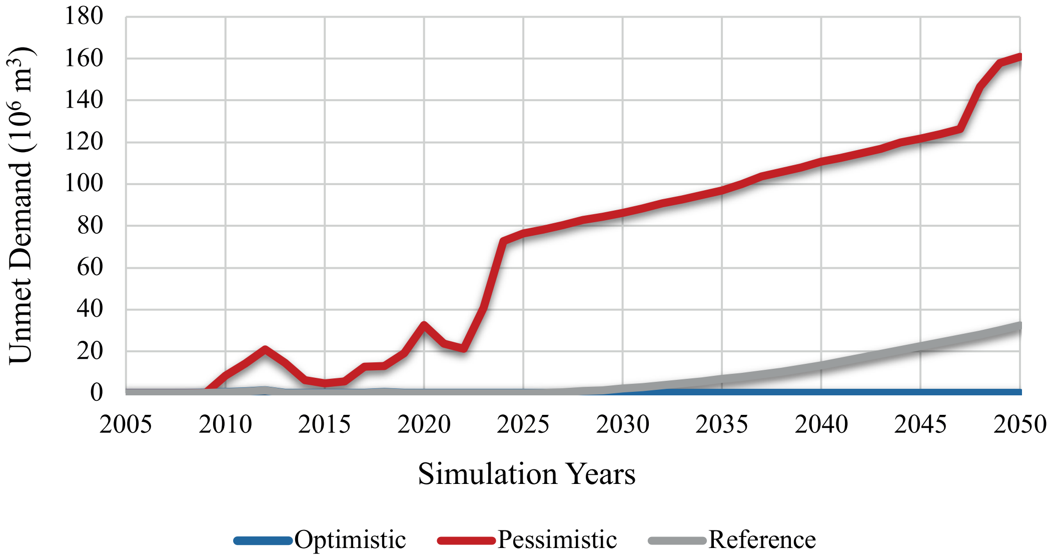

Figure 4. Annual unmet demand (hm³) for drinking water in the İzmir Bay sub-basin under pessimistic, reference and optimistic scenarios throughout the simulation years. The red, grey, and blue lines represent the pessimistic, reference, and optimistic scenario results, respectively.

Şekil 4. Simülasyon yılları boyunca kötümser, referans ve iyimser senaryolar altında İzmir Körfezi alt havzasında yıllık karşılanamayan içme suyu talebi (hm³). Kırmızı, gri ve mavi çizgiler sırasıyla kötümser, referans ve iyimser senaryo sonuçlarını temsil etmektedir.

The İzmir Bay sub-basin, characterized by a semi-arid climate and increasing vulnerability to water scarcity, was assessed using the WEAP model to evaluate its current and projected water potential through the year 2050. Scenario-based simulations reveal that both population growth and the impacts of climate change will drive an increase in domestic and irrigation water demand, thereby exacerbating water deficits throughout the sub-basin. Even under the reference scenario, total water demand for Izmir Bay sub-basin is projected to reach 318.25 hm³ by 2050, indicating an intensification of existing challenges in the near future. In the pessimistic scenario, demand is expected to rise further to 381.59 hm³, with unmet demand reaching 160.9 hm³, highlighting the severity of future supply-demand imbalances if no action is taken.

In terms of irrigation water demand, the optimistic scenario shows an 8.5% increase compared to the reference scenario, while the pessimistic scenario indicates a 16.1% rise. Unmet irrigation water demand is also projected to grow by 12.8% in the reference scenario, 22.2% in the optimistic scenario, and 55.1% in the pessimistic scenario by 2050. These results suggest that the rise in temperatures and changes in precipitation will increase irrigation water demand under all projected conditions.

While alterations in temperature and precipitation patterns are already affecting water availability, several recommendations can be considered to enhance the resilience and sustainability of water resources and to deal with long-term consequences of climate change. Future sustainable irrigation systems must use water resources more wisely. Implementing water-efficient agricultural practices, such as drip irrigation, drought-resistant crop selection, and water reuse strategies, will significantly reduce irrigation water demand. Also, improving the efficiency of existing water resources through maintenance and repair of the existing facilities, and minimization of leakages in urban water distribution systems, are necessary to ensure long-term sustainability. Along with these, protection of natural resources from pollution, controlling and preventing the excessive and illegal use of groundwater, as well as creating new alternative resources, are essential for environmental sustainability.

Moreover, a key challenge in water resource management is the lack of effective regulatory measures, in terms of reducing water use and acting responsibly. Raising public awareness through educational support and sanctions about water conservation are essential for improving responsible water use. For instance, participatory workshops involving local communities, key stakeholders, and farmers could facilitate the adoption of climate-resilient strategies and sustainable water management practices. Integrating local knowledge into policy frameworks is also useful for addressing both short and long-term climate impacts.

Overall, sustainable water management necessitates proactive strategies and effective governance. The formulation of policies aimed at improving water efficiency and minimizing losses requires coordinated efforts between local and central governmental bodies who are responsible for the regulation, management, and supervision of water resources. However, the lack of this integration between authorities, organizations, and policies may cause further complexity and drawbacks. To address these challenges, more comprehensive and collaborative approaches must be implemented. Additionally, climate adaptation strategies must be incorporated into all levels of legal and legislative frameworks to ensure long-term resilience and sustainability.

Ultimately, achieving equitable, adequate and sustainable water distribution significantly depends on well-coordinated management and planning. The optimistic scenario results in supply and demand remaining balanced, indicating the potential for maintaining a stable water supply through well-managed interventions. Therefore, it is necessary for policymakers to implement comprehensive strategies that prioritize water efficiency, conservation of resources, and adaptive management to safeguard the region's water in the face of growing population and climate change effects.

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