Estimating Actual Evapotranspiration Using the Metric Model and Comparing it to In-Situ Hydrological Measurements in an Irrigated Catchment

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Abstract. Accurate estimation of actual evapotranspiration (ETa) is crucial for enhancing water use efficiency in large-scale irrigation networks. Furthermore, quantifying elements of the basin-scale water budget is crucial for assessing variations in water components and identifying potential deficits or surpluses. This study examines the results of hydrological research acquired during the 2023 water year in the Akarsu irrigation scheme, which covers 9,495 hectares in the Lower Seyhan Plain (LSP) of the Eastern Mediterranean Region of Türkiye. The objectives were to: (1) measure water inflows and outflows at key points in order to calculate the components of the basin-scale water balance; (2) estimate ETa using the METRIC model and comparing it with crop evapotranspiration (ETc) derived from the two-step crop coefficient (Kc) method; and (3) assess water balance closure errors using ETa and ETc estimates. To estimate ETa at a spatial resolution of 30 × 30 metres, a total of 20 Landsat images (from Landsat 7, 8, and 9) were used, along with meteorological data from two local stations. Daily measurements of net irrigation inflow and drainage outflow were collected throughout the study period. The total ETa was estimated to be 914.1 mm in the 2023 water year, with a net irrigation input (Inet) of 1,852.3 mm, a precipitation (P) input of 543.6 mm, and a net drainage outflow (Qnet) of 840.6 mm. These inputs resulted in a net water storage change (ΔW) of +642.2 mm. Using ETa in water balance calculations yielded minor closure errors compared to those based on ETc estimates. These findings demonstrate that satellite-derived ETa provides a more accurate representation of actual water consumption, thereby improving the precision of hydrological assessments. Consequently, integrating remote sensing into irrigation water management practices has great potential to support precision agriculture at the basin scale.

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1 Introduction

Water scarcity poses a significant challenge to agricultural sustainability in many parts of the world, particularly in regions with arid and semi-arid climates. Therefore, in arid and semi-arid zones, which characterize much of Türkiye (Cetin, 2020), food security and sustainable agricultural production heavily depend on the availability of irrigation water, as well as effective irrigation practices. As emphasized by Yadav et al. (2024), expanding irrigated agriculture is essential for ensuring uninterrupted agricultural output. Achieving this, however, requires not only the development of water resources and extensive irrigation infrastructure but also effective irrigation planning (Kirnak, 2019). Given the substantial costs involved, state support plays a critical role, particularly in large-scale irrigation networks, which are typically constructed by the government and often require long implementation periods (Cetin, 2020). In this regard, the irrigated area in Türkiye expanded from 142,596 ha (0.14 Mha) in 1950 to a gross total of 7.1 Mha by 2023. Of this, 3.58 Mha was under the management of the State Hydraulic Works (DSI) as net irrigated land (DSI, 2023a). According to DSI (2023b), the target is to increase this figure to 7.52 Mha by the end of 2026. This growth reflects a gradual expansion of irrigated agriculture, driven by state-led investment and influenced by prevailing economic conditions (DSI, 2021). As a consequence, water use for irrigation has also risen significantly. By the end of the 2023 water year, 57 km^3 of Türkiye's total water potential was allocated, with 44 km^3 (77%) used for irrigation and the remaining 13 km^3 (23%) designated for domestic and industrial purposes (DSI, 2023a; DSI, 2023b).

On the other hand, globally, the agricultural sector is the largest consumer of freshwater resources, accounting for approximately 70% of total withdrawals, and is highly vulnerable to increasing water scarcity driven by climate change, population growth, and competing demands from other sectors (FAO, 2021). In *water-stressed countries* such as Türkiye, where arid and semi-arid climatic conditions prevail across large regions, the volume of water available for agricultural use represents a critical constraint on sustainable development. To illustrate this with a specific example, national assessments by the State Hydraulic Works (DSI) (Web-1) indicate that Türkiye's annual per capita usable water availability—as defined by Falkenmark and Lindh (1976)—has steadily declined from 1,652 m^3 in 2000 to 1,544 m^3 in 2009 and to 1,346 m^3 in 2020. These figures place Türkiye within the *"water stress"* category, highlighting increasing pressure on its water resources. Compounding this challenge are inefficiencies in irrigation systems: national development plans report that actual irrigation efficiency remains around 48%, while the irrigation rate is approximately 68%, both of which are well below international best practice benchmarks (Web-1; KB, 2018; DSI, 2021). The 12th Development Plan (CB, 2023) of Türkiye, covering the period 2024–2028, aims to raise the irrigation rate to 72% by 2028, up from 68% in 2023; however, it does not include a specific target for improving irrigation efficiency. This underscores the urgent need for policies that not only expand irrigated areas but also enhance water use efficiency to ensure the long-term sustainability of agriculture in Türkiye amid increasing water scarcity.

Given that the agricultural sector utilizes 77% of the total water made available for use in Türkiye (DSI, 2023b), the importance of efficient water use in this sector is indisputable. Therefore, alongside efforts to evaluate and utilize water resources through the construction of storage-based facilities for multi-purpose use, there is a need to expand key practices within irrigation network operations, including—but not limited to—the following: a) preventing water losses; b) ensuring more efficient and effective use of water; c) promoting the adaptation of crop varieties that are low in water consumption or more drought-tolerant; d) encouraging controlled and measured water distribution within irrigation systems; e) initiating the measurement of return flows not only in irrigation canals but also in drainage networks, and establishing an effective hydrometric monitoring network; f) modernizing traditional open-channel irrigation systems into pressurized or closed systems wherever technically and economically feasible, and promoting the widespread use of these systems; and g) implementing incentive measures aimed at improving irrigation rates and efficiency. The key practices and/or measures outlined above will contribute to the more effective use of the country's total available water potential.

According to DSI (2017) and Aksoy (2020), Türkiye's total usable surface and groundwater potential was estimated at 112 km^3. However, detailed water budget studies conducted in 2023 (DSI, 2023b) indicate that the technically and economically usable surface water potential is 91.9 km^3, while the groundwater potential is 18.6 km^3, resulting in a total annual usable water potential of approximately 110.5 km^3.

As irrigation water demand in the agricultural sector continues to rise, Türkiye's usable water potential is showing a declining trend. This underscores the urgent need for water balance-based assessments within irrigation networks and highlights the importance of quantitatively identifying current water use conditions. In such studies, the basic hydrological water balance equation is commonly employed (Cetin, 2020; Cetin et al., 2023). As detailed by Allen et al. (2007), estimating actual evapotranspiration is a crucial step in this process. However, in-situ measurements face significant challenges in large irrigation schemes. On the other hand, in large-scale irrigation networks, determining actual evapotranspiration (ETa) is essential for improving water use efficiency. Furthermore, calculating basin-based water budgets is crucial for understanding changes in water budget components and identifying whether there is a water surplus or deficit within the basin. The objectives of this study are threefold: a) to measure water discharges at the inlet and outlet points of the study area and identify the components of the basic hydrological water balance equation; b) to estimate ETa using the METRIC model over a large-scale irrigation scheme and calculate crop water consumption (ETc) using the conventional two-step crop coefficient (Kc) method; and c) to analyze water balance closure errors by comparing results obtained using ETa and ETc values.

2 Materials and Methods

2.1 Study Area

The study was conducted in an agricultural drainage basin covering 9,495 hectares, known as the Akarsu Irrigation Area, located in the Lower Seyhan Plain (LSP) in the Southeastern Mediterranean Region of Türkiye (Figure 1). A Mediterranean climate characterizes the study area and its surroundings.

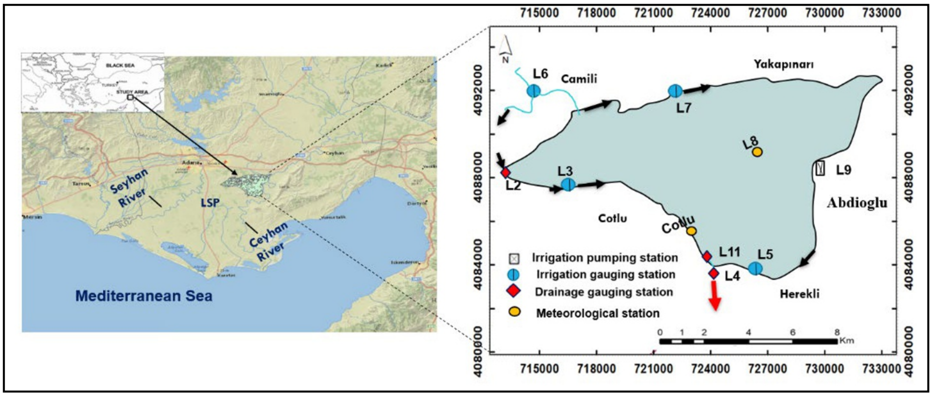

Fig. 1. Location of the study area in Türkiye, including irrigation and drainage measurement stations (limnigraph points) and meteorological stations.

2.2 Quantifying Inflow and Outflow Components in Basin-Scale Water Budget Analysis

The study was conducted during the 2023 water year using the fundamental hydrological water balance equation. To calculate the water budget of the agricultural drainage basin for the 2023 hydrological year, irrigation inflows and drainage outflows were measured hourly and converted into daily discharge values, following the approach described by Cetin et al. (2023). For this purpose, data from flow monitoring stations installed on drainage canals (L2, L4, and L11) and irrigation canals (L3, L5, and L6) within the study area, as shown in Figure 1, were utilized. In addition, to determine the volume of irrigation water delivered from the Ceyhan River to the study area, pump operating hours for the Abdioglu Pumping Station (L9 in Figure 1) during the 2023 water year were obtained from the Left Bank Irrigation Union of the Lower Seyhan Plain (LSP). These operation hours were multiplied by pump capacities to calculate daily pumping volumes. Furthermore, precipitation data and the meteorological variables required for estimating reference evapotranspiration (Alsenjar et al., 2023) were obtained from meteorological observation stations located within the study area (Figure 1: L8 and Cotlu) and were processed according to the methods described by Cetin et al. (2020) and Karahan et al. (2024).

Reference evapotranspiration (ETo), representing the water consumption of a standard grass crop under ideal conditions, was estimated using the standardized Penman–Monteith method (ASCE–EWRI, 2005; Zotarelli et al., 2020). Crop water consumption (ETc), which reflects the optimal water use by actual crops, was calculated using a two-step approach described by Allen et al. (1998) and Cetin (2020), involving the multiplication of ETo by crop-specific coefficients (Kc).

2.3 Approach to Calculating Actual Evapotranspiration

The actual evapotranspiration (ETa) values required for this study were calculated using the METRIC model, as detailed by Allen et al. (2007). To this end, the *'water'* package in *R* (Alsenjar et al., 2023; Cetin et al., 2023) was utilized. Twenty Landsat satellite images (Landsat 7, 8, and 9) with a spatial resolution of 30 m × 30 m were downloaded from the USGS website. Instantaneous meteorological data observed at two meteorological stations within the study area were incorporated into the model to obtain ETa values corresponding to the satellite overpass dates. The METRIC method calculates ETa based on surface energy balance components and involves complex procedures. Allen et al. (2007), Olmedo et al. (2016), Alsenjar et al. (2023), Cetin et al. (2023), and Karahan et al. (2024) provide the sequence of steps, important considerations, and methodological details for ETa calculation using METRIC.

2.4 General Water Balance Equation and Calculation of Budget Closure Error

In this study, the fundamental hydrological water balance equation, as described by Loucks & van Beek (2005) and Cetin et al. (2020), was applied (Equation 1):

$$P + (I_{in} - I_{out}) - (Q_{out} - Q_{in}) - ET = \pm \Delta S \qquad \textbf{(1)}$$

where P represents precipitation; I_{in} and Q_{in} denote the irrigation and drainage water entering the study area, respectively; I_{out} and Q_{out} indicate the irrigation and drainage water leaving the area; ET is evapotranspiration; and ΔS refers to the change in water storage within the system or basin. It is noteworthy that the term ΔS is also commonly expressed as ΔW in many studies (Cetin et al., 2023). All variables in Equation (1) are expressed in the same unit, and this study, they were calculated in millimeters (mm). In the equation, the term $(I_n - I_{out})$ represents the net irrigation water applied to the study area, while $(Q_{out} - Q_n)$ denotes the net drainage water generated within the area.

Once the water balance components are determined and substituted into Equation (1), a closure error, represented by ±ΔS, can be calculated at the catchment level for any given period, such as monthly, seasonal, or annual timescales. This closure error can be quantified as a percentage using Equation (2) (Ibrikci et al., 2015; Taseski & Krstovski, 2022; Cetin et al., 2023).

$$\Delta\, error = 200 * \frac{\text{Total Inputs} - \text{Total Outputs}}{\text{Total Inputs} + \text{Total Outputs}} \qquad (2)$$

3 Results and discussion

3.1 Comparison of Actual Evapotranspiration (METRIC ETa) and Crop Water Consumption (ETc) Estimates

Since the study area is located in the Mediterranean climate zone, the hydrological year (also referred to as the water year) runs from October 1 to September 30 of the following year. This study was conducted during the 2023 water year, covering the period from October 1, 2022, to September 30, 2023. Actual evapotranspiration (ETa) values, based on the METRIC model, were obtained for the dates of satellite overpasses. For non-overpass days, ETa values were estimated through interpolation using the values calculated for the satellite overpass dates (Aksu & Arıkan, 2017). Additionally, reference evapotranspiration (ETo) was calculated using the Penman–Monteith method, and crop water consumption (ETc) was derived by multiplying ETo with crop coefficients (Kc) for the crops grown in the field, following the conventional two-step approach (Allen et al., 1998; Cetin, 2020).

For the 2023 water year, the total actual evapotranspiration was found to be ETa = 914.1 mm/year, while the annual ETc, calculated using the conventional method, was 829.5 mm/year. Notably, ETc was lower than ETa. The reference evapotranspiration (ETo) for the same period was estimated to be 1222.9 mm/year, following the order: ETo > ETa > ETc. During the summer months, ETo values increased significantly, reaching peak levels, which naturally resulted in a higher demand for irrigation water. Monthly variations of the estimated ETo, ETa, and ETc values, derived using different methods, are presented in Table 1. The observed differences between ETa and ETc values can be attributed to differences in the estimation capabilities of the methods employed.

The results of this study align with those of previous basin-scale studies conducted in irrigated agricultural areas, as reported by Allen et al. (2007), Cetin et al. (2023), Alsenjar et al. (2023), and Karahan et al. (2024). These studies have shown that actual evapotranspiration values derived from the METRIC model exhibit greater representational accuracy compared to crop water consumption values estimated using the ETc method (Allen et al., 2007; Cetin et al., 2023).

Table 1. Reference evapotranspiration (ETo), actual evapotranspiration based on METRIC (ETa), and optimal crop water consumption (ETc) are estimated using the standardized Penman–Monteith method.

ET	October	November	December	January	February	March	April	May	June	July	August	September	**Total**
ETo	92.7	50.4	37.7	40.9	53.5	77.9	104.7	145.5	147.9	184.8	159.7	127.2	**1222.9**
ETa	65.6	51.9	31.2	26.9	55.0	82.9	79.3	119.0	94.3	108.4	120.3	79.2	**914.1**
ETc	48.3	21.8	19.2	23.1	31.4	53.7	78.1	110.2	110.0	141.2	115.6	76.9	**829.5**

3.2 Assessment of Inflow and Outflow Components of the Water Balance During the 2023 Water Year

Irrigation and drainage inflows, outflows, and precipitation were measured in the study area during the 2023 water year. The corresponding hydrological and meteorological data are summarized in Table 2, with all values reported on an annual basis. As shown in Table 2, the total annual precipitation (P) in the study area for the 2023 water year was 543.6 mm. The net irrigation water applied to the area during this period was 1,852.3 mm/year (Inet), while the total net drainage outflow was 840.6 mm/year (Qnet). Using the fundamental water balance equation (I + P – Q – ETa = ΔW), the closure error (ΔW, in mm) can be calculated. As presented in Table 1, actual evapotranspiration (ETa) was estimated using the METRIC model, while optimal crop water consumption (ETc) was derived using the conventional crop coefficient method (Allen et al., 1998). Substituting the measured values into the water balance equation—where Inet = 1,852.3 mm/year, P = 543.6 mm/year, and Qnet = 840.6 mm/year—results in a closure error of ΔW = +642.2 mm/year (1.76 mm/day).

When ETa, estimated using the METRIC model, is used for the water balance closure calculation, the relative error (ΔError) is approximately 27%. In contrast, substituting ETa with ETc leads to a closure error of ΔW = +726.8 mm/year (≈2.0 mm/day), corresponding to a relative error of approximately 36%. This represents a 14% increase in error compared to using ETa.

These findings underscore the importance of the method used to estimate evapotranspiration in basin-scale water balance studies. As actual evapotranspiration cannot be directly measured at the basin scale, but must be estimated through modeling, selecting the most accurate and reliable estimation method is critical to minimizing water balance closure errors.

Table 2.

Summary of hydrological water balance components in the study area.

Water Budget Components	**2023 water year**
Precipitation (P, mm)	543.6
Net irrigation water (I_{net}, mm)	1852.3
Net drainage (Q_{net}, mm)	840.6
Reference (potential) evapotranspiration (ETo, mm) (Grass-based reference crop water use)	1222.9
Actual crop water consumption (ETa, mm)	914.1
Optimal crop water consumption (ETc, mm)	829.5

In this study, the use of ETc resulted in higher closure error values (ΔError), whereas the application of ETa reduced these errors. This difference is primarily due to the fact that ETa calculations are more representative (Allen et al., 2007; Cetin et al., 2023), while ETc does not account for evaporation from bare soil (Ibrikci et al., 2015) or from aquatic environments such as drainage and irrigation canals.

Water budget closure error calculations for the 2023 water year indicate a positive error, suggesting unmeasured outputs or uncertainties within the system. This could indicate an increase in soil moisture or groundwater reserves, or significant deep percolation losses. Additionally, many drainage canals in the study area exhibit continuous flow, with water subject to consumption by aquatic weeds and constant evaporation from the open water surface. As these evaporation losses were not included in the calculations, they may have contributed to the observed closure error.

These uncertainties arise from limitations in direct measurement. The study area is complex, with both deterministic and stochastic uncertainties. Direct measurement of deep percolation is nearly impossible in such a large basin, making the estimation of it reliably challenging. During the irrigation season, using ETa resulted in a closure error of approximately 34%, while the error during the non-irrigation season was around 7%. The relatively low closure error of 7% during the non-irrigation season (Cetin et al., 2023) suggests that the hydro-meteorological measurements and observations in the study area are reliable.

The higher closure error observed with ETc, which omits bare soil evaporation, highlights the importance of accurately representing all hydrological processes in water balance studies. This reinforces the need for more reliable ETa estimates in large-scale irrigation systems, as they directly affect the accuracy of water balance calculations and subsequent management decisions.

Despite the uncertainties, the low closure error during the non-irrigation season supports the overall reliability of the hydro-meteorological data, indicating that the modeling methods used in this study are robust. These methods can be confidently applied to future studies in similar Mediterranean climates.

4 Conclusions

The following conclusions can be drawn based on the findings obtained as a result of the materials and methodology used in this study:

This study was conducted in a large-scale agricultural drainage basin situated in a semi-arid climate zone. It utilized hydro-meteorological observations from the 2023 water year.

The instruments and equipment installed in the study area enabled the precise determination of the components of the hydrological water budget.

While the values of reference evapotranspiration (ETo), actual evapotranspiration estimated using the METRIC model (ETa), and optimal crop water consumption calculated using the conventional “two-step” procedure were relatively close, the order observed was consistently ETo > ETa > ETc. Specifically, the fact that the ETo values for each month consistently exceeded the ETa values indicated that the crop coefficients (K_c) were typically ≤ 1.0, which is a logical and meaningful finding for the study area.

Water budget closure error analysis revealed that ETa estimates based on the METRIC model produced smaller ΔError values, confirming the accuracy, reliability, and representativeness of ETa calculations for irrigated areas at the catchment level. This suggests that ETa has greater representational capacity and is better suited to large-scale water balance studies.

Based on these findings, the application of METRIC-based ETa is strongly recommended for future water resource planning, irrigation network management, drought action plans, and optimizing water management strategies in semi-arid regions. Future research should be encouraged to evaluate and quantify key water budget components, such as deep percolation, bare soil evaporation, and open-channel evaporation, to reduce uncertainties in the water balance components.

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References

1. Aksoy, H. (2020). Surface Water. In N. B. Harmancioglu, D. Altinbilek (eds.), Water Resources of Turkey, Chapter 5, World Water Resources 2, https://doi.org/10.1007/978-3-030-11729-0_9, Springer Nature Switzerland AG 2020, ISBN 978-3-030-11728-3, pp. 127–158. {For details: https://www.springer.com/gp/book/9783030117283}.
2. Aksu, H., & Arikan, A. (2017). Satellite-Based Estimation of Actual Evapotranspiration in the Buyuk Menders Bain, Turkey. Hydrology Research, 48 (2), 559–570. DOI:10.2166/nh.2016.226
3. Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. United Nations FAO, Irrigation and Drainage, N.Y., Paper No. 56, (February 5, 2007). http://www.fao.org/docrep/X0490E/X0490E00.htm
4. Allen, R., Tasumi, M., Morse, A., Trezza, R., Wright, J. L., Bastiaanssen, W., Kramber, W., Lorite, L., & Robison, C. W. (2007). Satellite-Based Energy Balance for Mapping Evapotranspiration with Internalized Calibration (METRIC)-Model. J. Irrig. Drain. Eng., Vol. 133, No. 4. DOI: 10.1061/(ASCE)0733-9437(2007)133:4(380)
5. Alsenjar, O., Cetin, M., Aksu, H., Akgul, M. A. & Golpinar, M. S. (2023). Actual Evapotranspiration Estimation Using METRIC Model and Landsat Satellite Images Over an Irrigated Field in the Eastern Mediterranean Region of Turkey. Mediterranean Geoscience Reviews (2023) 5:35 49. https://doi.org/10.1007/s42990-023-00099-y
6. ASCE–EWRI (2005), The ASCE Standardized Reference Evapotranspiration Equation. ASCE–EWRI Standardization of Reference Evapotranspiration Task Committe Rep., ASCE Reston, Va.

7. CB (2023), On İkinci Kalkınma Planı (2024-2028). T. C. Cumhurbaşkanlığı Strateji ve Bütçe Başkanlığı, 253 s., Ankara, Türkiye, TBMM Karar No: 1396, Karar Tarihi: 31.10.2023.
8. Cetin, M. (2020). Agricultural Water Use. In N. B. Harmancioglu, D. Altinbilek (eds.), Water Resources of Turkey, Chapter 9, World Water Resources 2, https://doi.org/10.1007/978-3-030-11729-0_9, Springer Nature Switzerland AG 2020, ISBN 978-3-030-11728-3, pp. 257–302. {For details: https://www.springer.com/gp/book/9783030117283}.
9. Cetin, M., Alsenjar, O., Aksu, H., Golpinar, M. S., and Akgül, M. A. (2023). Comparing Actual Evapotranspiration Estimations by METRIC to In-Situ Water Balance Measurements over an Irrigated Field in Turkey. Hydrological Sciences Journal, 68(8): 1162–1183, DOI: 10.1080/02626667.2023.2198649.
10. Cetin, M., Kaman, H., Kirda, C., & Sesveren, S. (2020). Analysis of Irrigation Performance in Water Resources Planning and Management: A Case Study. Fresenius Environmental Bulletin (FEB), vol 29. 05: 3409–3414.
11. DSI (2021). Haritalı İstatistik Bülteni. T.C. Tarım ve Orman Bakanlığı, Devlet Su İşleri Genel Müdürlüğü, Strateji Geliştirme Dairesi Başkanlığı, 793 s., Ankara, Türkiye.
12. DSI (2023a). DSİ'ce İnşa Edilerek İşletmeye Açılan Sulama ve Bataklık Islahı Tesisleri (2023 Yılı). DSİ Genel Müdürlüğü, İstatistik Değerlendirme ve Geliştirme Şube Müdürlüğü, 259 s., Ankara, Türkiye.
13. DSI (2023b). DSİ 2023 Yılı Faaliyet raporu. DSİ Genel Müdürlüğü, Strateji Geliştirme Dairesi Başkanlığı, 153 s., Ankara, Türkiye.
14. DSI (2017). Su Kaynaklarinin Gelistirilmesi ve Hidroloji Calisma Grubu Raporu, Orman ve Su Isleri Bakanligi, DSI Genel Mudurlugu, 2. Ormancilik ve Su Surasi, 5–7 May 2017, Afyonkarahisar, Türkiye.
15. Falkenmark, M., & Lindh, G. (1976). Water for a starving world. Boulder: Westview Press.
16. FAO (Food and Agriculture Organization of the United Nations), 2021. The Europa Directory of International Organizations 2021. https://doi.org/10.4324/9781003179900
17. Ibrikci, H., Cetin, M., Karnez, E., Flügel, W. A., Tilkici, B., Bulbul, Y. &, Ryan, J. (2015). Irrigation-Induced Nitrate Losses Assessed in a Mediterranean Irrigation District. Agric. Water Manage., 148: 223–231. http://dx.doi.org/10.1016/j.agwat.2014.10.007
18. Karahan, H., Cetin, M., Can, M. E., & Alsenjar, O. (2024). Developing a New ANN Model to Estimate Daily Actual Evapotranspiration Using Limited Climatic Data and Remote Sensing Techniques for Sustainable Water Management. Sustainability, 16, 2481. https://doi.org/10.3390/su16062481
19. KB (2018). On Birinci Kalkınma Planı (2019-2023).: Tarımsal Toprak ve Suyun Sürdürülebilir Kullanımı Özel İhtisas Komisyonu Raporu,. T. C. Kalkınma Bakanlığı (KB), YAYIN NO: KB: 2984 - ÖİK: 766, Ankara.
20. Kirnak, H., Irik, H. A. and Unlukara, A. (2019). Potential Use of Crop Water Stress Index (CWSI) in Irrigation Scheduling of Drip-Irrigated Seed Pumpkin Plants With Different Irrigation Levels. Scientia Horticulturae, 256, 108608.
21. Loucks, D.P. & van Beek, E. (2005). Water Resources Systems Planning and Management. Studies and Reports in Hydrology, 1–680, UNESCO.
22. Olmedo, G. F., Ortega-farias, S., & Fonseca-luengo, D. (2016). Tools and Functions to Estimate Actual Evapotranspiration Using Land water : Tools and Functions to Estimate Actual Evapotranspiration Using Land Surface Energy Balance Models. The R Journal, Vol. XX/YY, AAAA 20ZZ, ISSN 2073-4859. https://doi.org/10.32614/RJ-2016-051

23. Taseski, G., N. (2022). Numerical Analysis to Determine the Technical Water Losses in a Water Supply System. In: Szydłowski, M. (2022), Water Management and Hydraulic Engineering – WMHE 2022, Proceedings Book of 17th International Symposium on Water Management and Hydraulic Engineering, 14-18 September 2022, Sopot, Poland, ISBN 978-83-7348-874-8.
24. Web-1: https://dsi.gov.tr/Sayfa/Detay/754, Son erişim tarihi: 26 September 20024.
25. Yadav, A., Narakala, L. M., Upreti, H., & Singhal, G. D. (2024). Evaluation of Crop Water Stress İndex of Wheat by Using Machine Learning Models. Environ Monit Assess 196, 970. https://doi.org/10.1007/s10661-024-13113-z
26. Zotarelli, L., Dukes, M. D., Romero, C. C., Migliaccio, K. W. & Morgan, K. T. (2020). Step by Step Calculation of the Penman-Monteith Evapotranspiration (FAO-56 Method). IFAS Extention, Institute of Food and Agricultural Sciences, University of Florida, 10 pages, Original publication date February 2010, Reviewed August 2020. http://edis.ifas.ufl.edu