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# Determining the water footprint of sunflower in Turkey and creating digital maps for sustainable agricultural water management

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**Abstract**
With the rapid population growth, global warming and increasing urbanization in recent years, existing water resources are rapidly depleted and polluted. As a result of unconscious consumption and pollution of water resources, studies on the sustainable management of water have gained momentum. In recent years, the concept of water footprint has attracted attention in terms of the sustainability of water resources. The concept of water footprint refers to the amount of water required throughout the production of any service or product. In this study, the green, blue and total water footprint sizes of the sunflower in Turkey in 2017–2021 were determined and calculated as 0.803 billion $m^3$, 2.656 billion $m^3$ and 3.460 billion $m^3$, respectively. The region with the highest sunflower production and the largest sunflower water footprint was determined as the Marmara-Thrace region, and the province as Tekirdağ. The main reason for the high water footprint of the sunflower in Tekirdağ is the highest sunflower production in the province. For efficient and sustainable use of water, the blue water footprint should be low and the green water footprint high. Thus, when Turkey is evaluated, it has been determined that the highest green water footprint for sunflower is in the Black Sea region. Therefore, it seems possible for Turkey to reduce the blue water footprint of sunflowers by focusing on sunflower production in the Black Sea region.

**Keywords** Sunflower · Water footprint · Sustainability · Turkey

## 1 Introduction

The human population worldwide is increasing day by day and the available resources for food production are depleted due to the negative effects of human activities on the ecosystem (Kahramanoğlu, et al., 2020). Water is a valuable resource, especially in drought-prone regions and during drought periods anywhere in the world (Gobin et al., 2017). There is approximately 1.4 $km^3$ of water in the world, of which 97.4% is salt water and 2.6% is fresh

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water. 0.8% of the total water amount is available as fresh water, which is in a continuous state of evaporation, precipitation and flow (Polat, 2013). Increasing population, socioeconomic developments, global freshwater withdrawal, drying up rivers and high pollution levels are signs of increasing water scarcity (Ababaei & Etedali, 2017). Although water is a sustainable resource, access to it varies both spatially and temporally, and the gap between increasing demand and limited water resources is increasing (Ewaid et al., 2019). With the effect of both socioeconomic development and climate change, the water crisis has turned into a problem all over the world. Balancing limited freshwater resources remains one of the biggest policies in the world, and improving water use efficiency is seen as a key way to ensure food security and reduce water scarcity (Cao et al., 2021).

Agriculture is the major user of fresh water worldwide, accounting for almost 70% of the water supply (Ewaid et al., 2019; Gheewala et al., 2014; Kashyap & Agarwal, 2021; Qin et al., 2016; Shtull-Trauring & Bernstein, 2018; Sidhu et al., 2021). Therefore, increasing productivity and reducing water use in the agricultural sector is seen as the main way to reduce global water scarcity (Shtull-Trauring & Bernstein, 2018). Agricultural areas are approximately 1.87 billion hectares and cover approximately 14% of the world's total ice-free land area (Bulut & Canbaz, 2022; Ridoutt & Garcia, 2020). These cultivated areas sustain the majority of current food production and are therefore vitally linked to global food security (Ridoutt & Garcia, 2020).

The concept of Virtual Water was first introduced by Allan (1997) as the volume of water used in the production of a product (Sidhu et al., 2021). The concept of Water Footprint (WF), first introduced by Hoekstra (2003) and then elaborated by Hoekstra and Chapagain (2008), has been used recently for freshwater resource management (Ababaei & Etedali, 2017). WF is an indicator of the use of water resources that determines the volume of water that is directly or indirectly consumed or polluted for the production of a good or service (Novoa et al., 2019). Crop Water Footprint (CWF) refers to the volume of fresh water consumed during the growing period of the crop and is usually composed of green, blue and gray components (Cao et al., 2021). Green WF shows the volume of rainwater consumed during the growing period of the crop, while blue WF includes the volume of consumed surface and groundwater. The Gray WF measures the volume of freshwater required to absorb nutrients and pesticides that leak, escape from crop fields, and reach groundwater or surface water. The water footprint of crops is the total amount of green, blue and gray water used for their production. Crop production requires large amounts of green and blue water. (Sidhu et al., 2021).

WF regulation can increase water use efficiency and also reduce the negative impact of agricultural production on environmental water. Therefore, it is accepted as the best way to ensure efficient and sustainable use of dwindling water resources (Cao et al., 2021). WF can be reduced by using more effective irrigation systems such as drip irrigation, efficient use of rainwater, optimizing crop planting dates and selecting higher yielding varieties (Ababaei & Etedali, 2017). National, regional and global water and food security can be improved when water-intensive goods are traded from where they are economically viable to places where they are not. Food imports offer an alternative to reduce pressure on domestic water resources and enable more efficient water use, as expressed by the WF of food (Gobin et al., 2017).

In this study, the blue, green and total WF components of sunflower production in Turkey in the years 2017–2021 were calculated and digital maps were created using the ArcGIS method. Sunflower (*Helianthus annuus* L.) is one of the most important oilseed crops both in Turkey and in the world (Dağüstü et al., 2012). World total annual sunflower production was 41.3 million tons in 2014 (FAO, 2014; Yousefi et al., 2017). Sunflower is an important oil plant that can be grown in almost every region and contains high quality oil in its grains and ranks first in terms of cultivation area, production and oil production (Gül et al., 2016). Sunflower is also the oilseed plant with the largest cultivation area and production amount in Turkey, and the country obtains approximately 50% of its vegetable oil need from sunflower (Semerci & Durmuş, 2021; Semerci & Özer, 2011). According to the production data of 2009, Turkey is among the top ten countries in the world sunflower production and constitutes 2.45% of the world sunflower cultivation area and 3.30% of the production amount (FAO, 2010; Semerci & Özer, 2011).

Especially with the rapid population growth and global warming in recent years, water resources are rapidly depleting and water crises occur in various parts of the world. The concept of WF for more efficient and sustainable use of water resources has attracted a lot of attention in recent years and it is a very current issue in today's conditions. The studies on the subject still limited.

## 2 Material and method

### 2.1 Study area

Turkey, with an area of approximately 780,080 km$^2$, is located at the midpoint of the continents of Europe, Asia and Africa between 36°–42° north latitude and 26°−45° east longitude (Şenkul & Kaya, 2017; Kaya, 2017; Balcı, 2012). Surrounded by seas on three sides, Turkey is also located in the meeting area of Mediterranean, Iran-Turanian and Euro-Siberian flora regions (Şenkul & Kaya, 2017). The fact that Turkey has a projection area of 779,452 km$^2$ and a real area of 814,578 km$^2$, a difference of 35,126 km$^2$ between its projection area and its actual area shows that it has a very rough terrain. Turkey, whose population exceeded 83 million at the last census, is among the most populous countries in the world. The fact that Turkey is located in the Central Climate Zone of the Northern Hemisphere has brought the chance to have the effect of the Subtropical Middle Zone climate, which is most suitable for people's life. Toward the north of this area, the harsh snowy climate and lush vegetation limit human activities in places, while to the south, the extremely hot tropical climate and large deserts on large land masses limit their habitats (Çelik, 2020).

According to the data of Turkish Statistical Institute (TÜİK), sunflower production in Turkey is mostly seen in Thrace-Marmara region. The provinces with the highest sunflower production are Tekirdağ, Konya, Edirne, Kırklareli and Adana, respectively. As shown in Fig. 1, it is seen that Thrace-Marmara region is followed by Çorum, Eskişehir, Tokat and Central Anatolia Region.

### 2.2 Data

The 5-year production amounts, yield and cultivation areas of the plants used in the study, including the years 2017–2021, were obtained from the TUIK. The planting-harvest periods of the crops were taken from the "Turkey's General Directorate of Agricultural Researchand Policies" issued by General Directorate of Agricultural Research and Policies (TAGEM) and State Hydraulic Works (DSI) on 2017. Evapotranspiration and effective rainfall values were calculated with CROPWAT software and ArcGIS program was used to create digital maps.

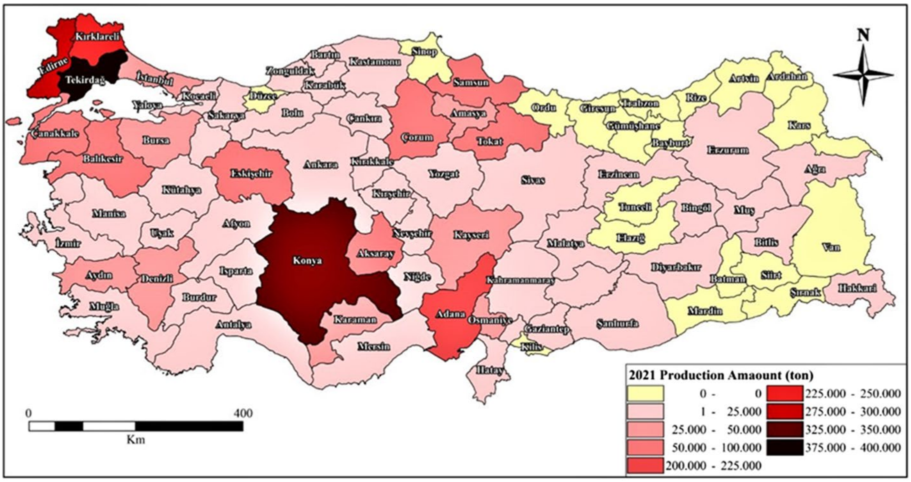



**Fig. 1** Sunflower production by province (2021)

## 2.3 Methods

In this study, the green, blue and total WF of sunflower for Turkey were investigated using the methodology developed by Hoekstra et al. (2011). The $ET_0$ data in these databases are derived using the Penman–Monteith equation given in Eq. 1 (Chapagain & Hoekstra, 2011; Allen et al., 1998). In order to calculate WF values, crop evapotranspiration ($ET_C$) and current effective precipitation ($P_{eff}$) values must be known. The $ET_C$ value can be calculated as in Eq. (2), but in this study, it was obtained from the CROPWAT model together with the $P_{eff}$ values. In order to calculate the crop water use (CWU) given in Eqs. 9 and 10, the $ET_{blue}$ and $ET_{green}$ values specified in Eqs. 3, 4, 5, 6, 7 and 8 are calculated. After calculating the plant water consumption, the virtual water content values given in Eqs. 11 and 12 are calculated. The total WF of any crop in a geographically determined area can be calculated by multiplying the virtual water content by the mass of production. The virtual water content (VWT, $m^3\ ton^{-1}$) is defined as the volume of water used per unit mass of a crop. Crop water use (CWU) is defined as the amount of water consumed by any crop from a cultivated area (Muratoğlu, 2020a).

$$ET_0 = \frac{0.408\Delta\left(R_n - G\right) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{1}$$

$$ET_C = K_C x ET_0 \tag{2}$$

$$ET_{mavi} = \max\left(0,\ ET_C - P_{eff}\right) \tag{3}$$

$$ET_{yeşil} = \min\left(ET_C, P_{eff}\right) \tag{4}$$

$$\mathrm{ET_C} \geq P_{\mathrm{eff}} \rightarrow \mathrm{ET_{mavi}} = \left(\mathrm{ET_C} - P_{\mathrm{eff}}\right) \tag{5}$$

$$\mathrm{ET_C} < P_{\mathrm{eff}} \rightarrow \mathrm{ET_{mavi}} = 0 \tag{6}$$

$$\mathrm{ET_C} \geq P_{\mathrm{eff}} \rightarrow \mathrm{ET_{yeşil}} = P_{\mathrm{eff}} \tag{7}$$

$$\mathrm{ET_C} < P_{\mathrm{eff}} \rightarrow \mathrm{ET_{yesil}} = \mathrm{ET_C} \tag{8}$$

Here, $\mathrm{ET_0}$; reference evapotranspiration (mm/day), $R_n$; net radiation on the plant surface (MJ/m$^2$day), $G$; heat exchange density of the ground (MJ/m$^2$day), $T$; air temperature (°C), $u_2$; wind speed (m/s), $e_s$; saturated vapor pressure (kPa), $e_a$; actual vapor pressure (kPa), Δ; slope of the vapor pressure curve (kPa/°C), $\gamma$; psychometric constant (kPa/°C), $K_C$; plant coefficients, $\mathrm{ET_C}$; annual evapotranspiration value of the plant (mm/year), $P_{\mathrm{eff}}$; effective precipitation (mm) and finally ETblue and ETgreen are defined as blue and green evapotranspiration values (mm/year), respectively (Muratoğlu, 2020a, b).

After calculating the plant water consumption given in Eqs. (9) and (10), the virtual water content values given in Eqs. (11) and (12) were calculated. The total WF of any crop in a geographically determined area can be calculated by multiplying the virtual water content by the mass of production. The virtual water trade (VWT, m$^3$/tonne) is defined as the volume of water used per unit mass of a crop. Crop water use (CWU) is defined as the amount of water consumed by any crop from a cultivated area (Muratoğlu, 2020a).

$$\mathrm{CWU_{blue}}\left(\mathrm{m^3/ha}\right) = 10 \sum \mathrm{ET_{blue}} \tag{9}$$

$$\mathrm{CWU_{green}}\left(\mathrm{m^3/ha}\right) = 10 \sum \mathrm{ET_{green}} \tag{10}$$

$$\mathrm{VWT_{blue}}\left(\mathrm{m^3/ton}\right) = \frac{\mathrm{CWU_{blue}}}{Y} \tag{11}$$

$$\mathrm{VWT_{green}}\left(\mathrm{m^3/ton}\right) = \frac{\mathrm{CWU_{green}}}{Y} \tag{12}$$

$$\mathrm{VWT}\ \left(\mathrm{m^3/ton}\right) = \mathrm{VWT_{blue}} + \mathrm{VWT_{green}} \tag{13}$$

$$\mathrm{WF}\ \left(\mathrm{m^3}\right) = \sum \mathrm{VWT_i}\left(\mathrm{m^3/ton}\right) x C_i(\mathrm{ton}) \tag{14}$$

Here, WF: total water footprint of production (m$^3$), $C$: amount of crop (tons), $Y$: crop yield (ton/ha), CWU: Crop water use (m$^3$/ha), VWT, VWTgreen and VWTblue (m$^3$/ha). tons): are defined as the total, green and blue water trades, respectively (Muratoğlu, 2020a, b). The factor of 10 in Eqs. 9 and 10 is used to convert water depth in millimeters to water volume per land surface in m$^3$/ha (Gheewala et al., 2014). The WF calculation steps are summarized in the diagram given in Fig. 2.

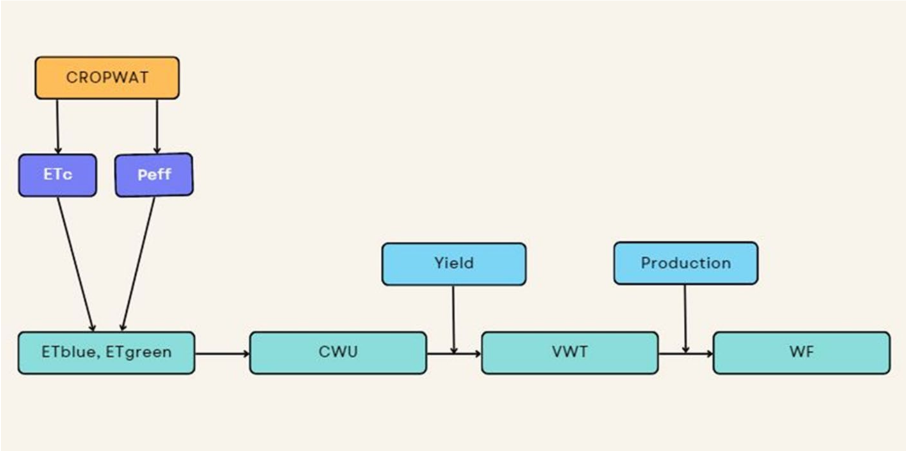


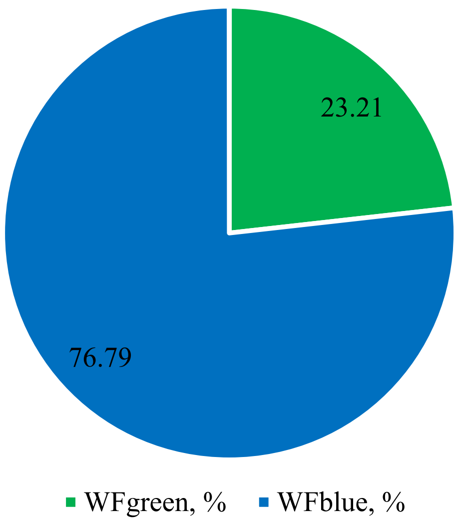

**Fig. 2** Water footprint calculation steps

## 3 Results

As seen in Fig. 1, the highest sunflower production in Turkey is in the Marmara–Thrace Region. The province with the highest production during the 5-year period is Tekirdağ, followed by Konya. According to the data obtained from TÜİK, the amount of sunflower produced in Tekirdağ and Konya for 2021 is 399,531 tons and 348,668 tons, respectively.

The five-year average WF of the sunflower, which ranks first in vegetable oil production in Turkey, in the 2017–2021 time period for Turkey has been calculated as 3460 billion $m^3$. It was determined that 23.21% of it consists of green WF and the remaining 76.79% consists of blue WF and is presented in Fig. 3. As seen in Figs. 3 and 4, the amount of blue WF is about 3 times the amount of green WF. It is seen in Fig. 4; Table 1 that the highest

**Fig. 3** Five-year average WF values of sunflower for Turkey in the time period 2017–2021



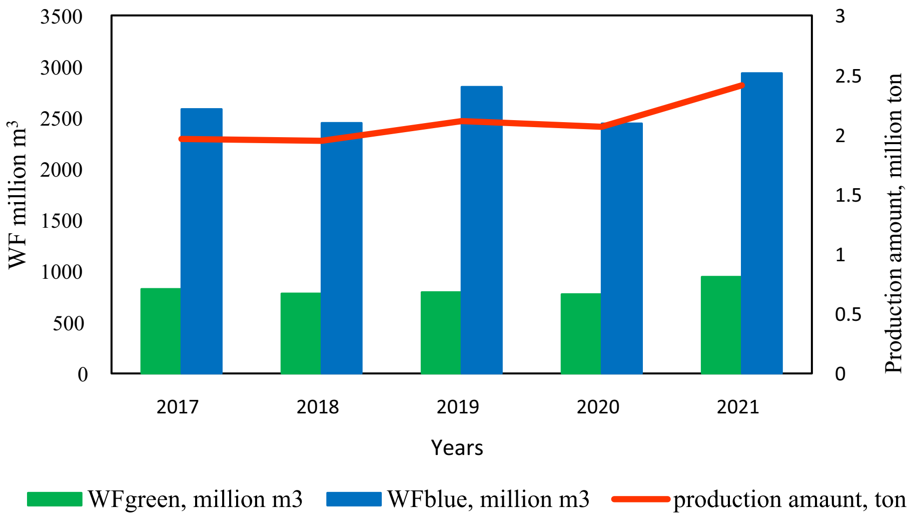


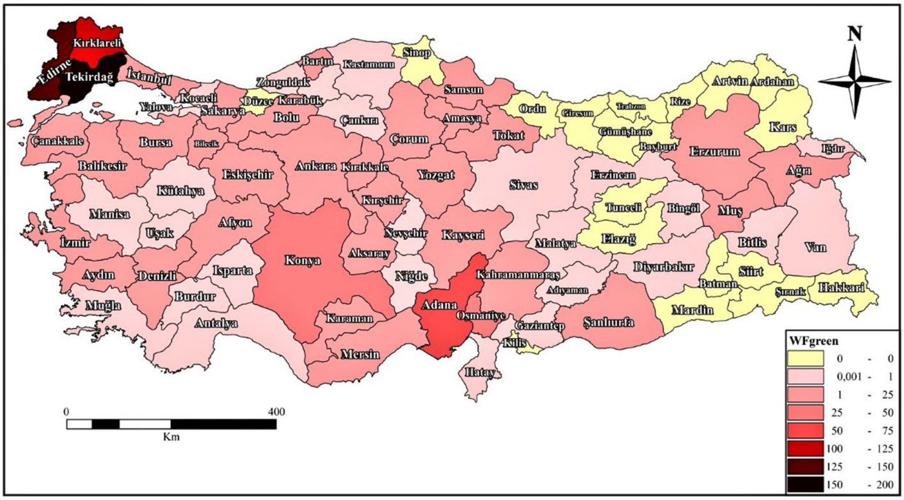

**Fig. 4** WF and production amount distribution of sunflower by years

WF within 5-year period was in 2021 with 3871 billion $m^3$ and that the production amount and WFs show parallelism by years. As seen in Fig. 5, the province with the highest WF in sunflower production in Turkey is Tekirdağ in parallel with its production amount.

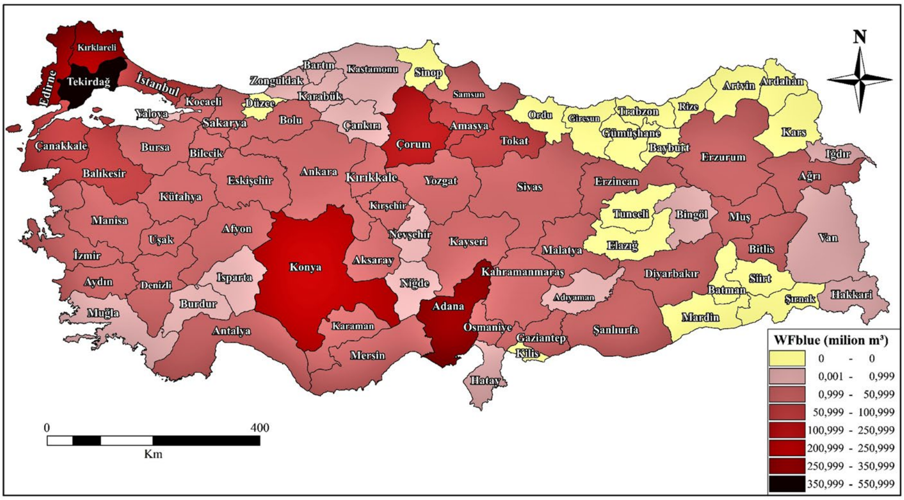
In the study, it was determined that Zonguldak is the only province where $WF_{Green}$ is greater than $WF_{Blue}$. Looking at Figs. 6 and 7, it is seen that the province with the highest $P_{eff}$ at 981.6 mm and the second lowest $ET_C$ with 383.6 mm/year is Zonguldak. The main purpose of the WF should be to reduce the blue WF rather than reducing the total WF. Because, as it is known, the green WF represents precipitation waters, and the more precipitation waters, the smaller the blue WF will be. The two most important parameters that affect green and blue WF are effective precipitation and plant water consumption. The reason why the green WF is larger than the blue WF in Zonguldak is because $P_{eff}$ is high and $ET_C$ is low.

WF konusu yeni ve güncel bir konu olduğundan dolayı yapılmış çok fazla çalışma bulunmamaktadır. Konu ile ilgili mevcut çalışmalar incelenerek sonuçlar Çizelge 2' de sunulmuştur. Mekonnen and Hoekstra (2011) yapmış oldukları çalışmada ayçiçeğinin küresel ortalama yeşil, mavi ve toplam WF' lerinin sırasıyla 3017 $m^3$/ton, 148 $m^3$/ton ve 3255$m^3$/ton olduğunu ifade etmişlerdir. Bu çalışmada 1625 $m^3$/ton olarak hesaplanan toplam WF küresel ortalamanın altında olmasına rağmen Türkiye' nin mavi WF' si küresel ortalamanın üzerinde çıkmıştır ve Türkiye için mavi WF yeşil WF' nin yaklaşık üç katı büyüklüğündedir. Çizelge 2' de farklı bölgelerde ayçiçeği için yapılmış su ayak izi değerleri verilmiştir. Çizelge 2' ye bakıldığında Mısır ve Türkiye' de mavi su ayak izinin daha yüksek olduğu, Avusturya ve Çin' de ise yeşil su ayak izinin daha yüksek olduğu görülmektedir. Ülkelerdeki bu farklılıkların ise muhtemelen ülkelerin iklim koşulları ve ekim-hasat dönemlerinden kaynaklandığı düşünülmektedir.

Since the subject of WF is a new and up-to-date subject, there are not many studies done. Existing studies on the subject are investigated and the results are presented in Table 2. Mekonnen and Hoekstra (2011) stated in their study that the global average green, blue and total WFs of sunflower are 3017 $m^3$/ton, 148 $m^3$/ton and 3255 $m^3$/



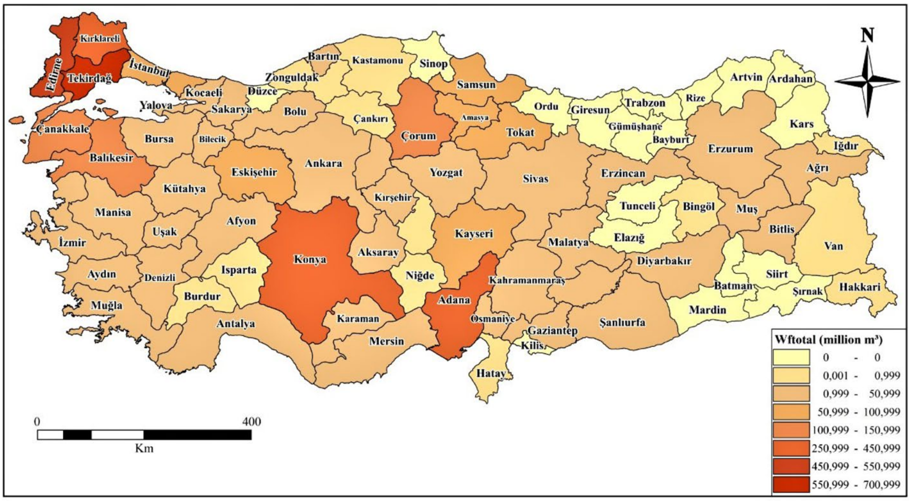

(a)




(b)

**Fig. 5** WF maps of sunflower in Turkey; **a** green WF, **b** blue WF, **c** total WF.

ton, respectively. Although the total WF calculated as 1625 $m^3$/tonne in this study is below the global average, Turkey's blue WF is above the global average and the blue WF for Turkey is about three times the size of the green WF. In Table 2, WF values for sunflower in different regions are given. Looking at Table 2, it is seen that the blue WF is higher in Egypt and Turkey, and the green WF is higher in Austria and China. It is thought that these differences in countries are probably due to the climatic conditions of the countries and the sowing-harvest periods.




(c)

**Fig. 5** (continued)

**Table 1** WF values by years

| Year | $WF_{green}$, billion $m^3$ | $WF_{blue}$, billion $m^3$ | $WF_{total}$, billion $m^3$ |
|---|---|---|---|
| 2017 | 0.807 | 2.597 | 3.404 |
| 2018 | 0.762 | 2.460 | 3.222 |
| 2019 | 0.774 | 2.816 | 3.590 |
| 2020 | 0.760 | 2.454 | 3.214 |
| 2021 | 0.914 | 2.956 | 3.871 |
| 5-year average | 0.803 | 2.656 | 3.460 |

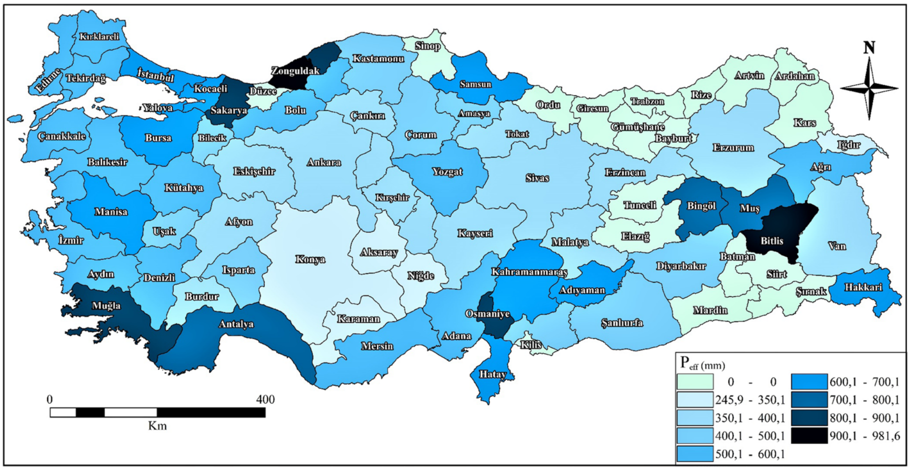



**Fig. 6** Annual $P_{eff}$ distribution of sunflower in Turkey

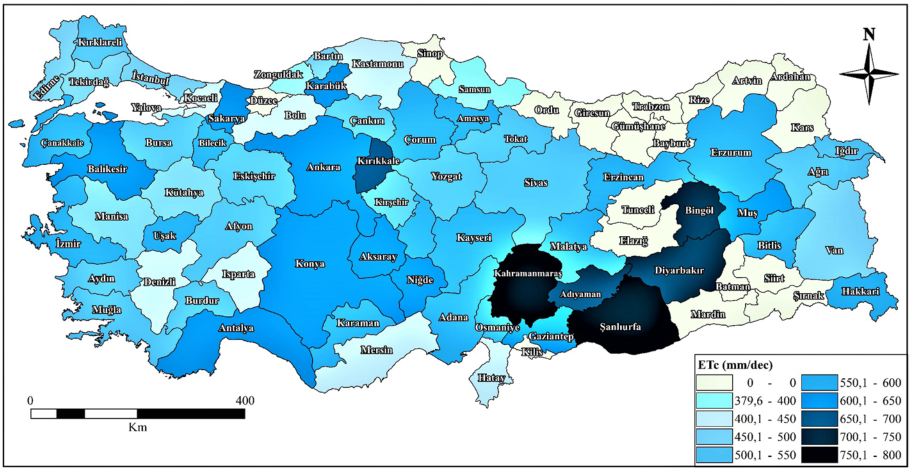



**Fig. 7** Annual $ET_c$ distribution of sunflower in Turkey

**Table 2** WF studies for sunflower

| $WF_{green}$, $m^3$/ton | $WF_{blue}$, $m^3$/ton | $WF_{total}$, $m_3$/ton | Region | References |
|---|---|---|---|---|
| 169 | 2220 | 2389 | Egypt | El-Marsafawy and Mohamed (2021) |
| 930 | 350 | 1290 | Austria | Thaler et al. (2017) |
| 1718 | 8 | 1726 | China | Qin et al. (2016) |
| – | – | 2199 | Duero River Basin | Miguel et al. (2015) |
| 3017 | 148 | 3255 | world average | Mekonnen and Hoekstra (2011) |
| 377 | 1248 | 1625 | Turkey | This study |

## 4 Conclusion

The main factor affecting the size of the WF is the amount of production. Therefore, the higher the production amount, the larger the WF will be. The main purpose of WF studies should be to reduce the blue WF rather than reducing the total WF. This requires efficient use of rainwater for proper water management and sustainability of water resources. The highest sunflower production and total WF in Turkey are seen in the Marmara–Thrace region, especially in Tekirdağ. The majority of the WF in the Thrace region consists of the blue WF. Therefore, the amount of precipitation in the Thrace Region is not sufficient for sunflower production. In the study, it was observed that sunflower production in the Black Sea Region was quite low. In fact, it has been determined that there is no sunflower production in Artvin, Giresun, Gümüşhane, Ordu, Rize Sinop and Trabzon. However, when we look at the provinces where sunflower production takes place in the Black Sea Region, it is seen that the blue and green WFs are very close to each other. In fact, the only province where green WF is higher than blue WF was determined as Zonguldak. The reason why the green WF is large in the Black Sea region is that the Black Sea region receives more precipitation.

It is known that agricultural activities are the largest water consumer in Turkey and in the world. With WF studies, water savings can be achieved by focusing on production, especially in regions where green water WFs are high and blue WFs are low. As a result of the study, it was seen that the Black Sea region, where the production is very low, is the most suitable region for sunflower production. Therefore, it may be possible to reduce the blue WF of sunflowers in Turkey by increasing sunflower production in the Black Sea region. In addition, since sunflower is a dry period plant, regions with heavy rainfall should be preferred for its production. Finally, it is possible to reduce the blue WF by using the right irrigation techniques (such as drip irrigation), taking into account the planting-harvest periods of the crops, making maximum use of precipitation water and choosing products with high efficiency.

Today and in future, WF studies will make a great contribution to the correct and sustainable management of water resources. For correct and sustainable water management, WF studies should be supported as much as possible.

**Data availability** All data used during the study are available from the corresponding author by request.

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