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# WATER FOOTPRINT ASSESSMENT OF AGRICULTURAL PRODUCTION IN BILECIK PROVINCE

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**Abstract:** The freshwater sources are under serious pressure both in terms of quality characteristics due to pollution and in terms of quantity due to the increase in parameters such as temperature and evaporation under the influence of global warming. To ensure sustainable use of these resources, it is necessary to employ high-efficiency pressurized irrigation systems and cultivate plant species that are resilient to various stress factors and highly productive. In determining the water usage characteristics of plants, rapid atmospheric effects brought by climate change, plant water and temperature stress, soil moisture should be monitored, and water production indicators should be determined. In the water-intensive agricultural sector, monitoring the water footprint has become one of the important indicators in terms of ensuring water-food-energy sustainability, efficient use and fair sharing of water resources. This study aims to determine the water footprint of agricultural production in Bilecik province and its districts located in the transitional zone. Accordingly, values of crop and livestock production throughout the province and using a volume-based approach, the water footprint of crop production is estimated at 0.6 billion cubic meters (BCM), while the water footprint of livestock production is 0.5 BCM, resulting in a total agricultural water footprint of 1.1 BCM. In crop production, green water footprint constitutes 33%, blue water footprint 59%, and grey water footprint 8% of the total water footprint. The data obtained will form the basis for developing strategies in sustainable water and food management, aligned with climate change scenarios, to achieve sectoral supply-demand balance.

**Keywords:** Agriculture, Water usage, Effectiveness, Sustainability, Water management

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## 1. Introduction

The importance of sustainable, fair, and integrated management of water resources is increasing day by day. It is clear that current usage shows signs of inadequacy due to the increasing industrial use of existing water resources and unforeseen increases in population. Ensuring food supply and secure transfer of water to the future are essential for sustainable living. According to studies conducted by the IPCC and other international organizations, extreme events occurring in meteorological parameters such as temperature and precipitation, due to global climate change, particularly adversely affect the Mediterranean Basin water resources (IPCC, 2023).

Water is used in domestic (drinking), industrial, and agricultural sectors. Globally, agricultural usage accounts for approximately 69%, industrial usage for 19%, and domestic usage for around 12% of total water usage. In the agricultural sector, which consumes the largest portion of water, the primary goal is to maximize the benefits derived from each unit of water. Evaluating and preserving surface and groundwater sources used in agricultural irrigation in terms of quantity and quality are essential. Therefore, it is important to develop scientific data-based models to strengthen sustainable water management strategies and enhance their implementation with robust indicators (DSİ, 2022; Ahi and Çakmak, 2023).

In the assessment and sustainability of resource efficiency and management, life cycle analyses such as ecological footprint, water footprint, and carbon footprint have become important indicators. Footprints represent the efficiency level of resources in meeting society's needs and are often expressed in volumetric terms. The total volume of water used by an individual, sector, and/or country in production processes is defined as water footprint, encompassing the total water resources consumed during the production of domestically produced and imported goods. Water footprint is categorized into three types: blue, green, and grey water footprint. Blue water footprint represents the total volume of surface and groundwater used in producing a product or service. Green water footprint refers to the total amount of rainwater used in the production of a commodity. Grey water footprint, an indicator of water pollution, represents the volume of freshwater used for removing or reducing pollution load based on current water quality standards (Hoekstra, 2003).

In assessing global water and carbon cycles, life cycle assessment (LCA) takes into account spatial variability and reveals the environmental, social, and economic impacts of where production occurs. Life cycle assessment (LCA) is the most widely used method to evaluate the environmental impacts of agricultural products and facilitate the transition to more sustainable production and consumption models (Notarnicola et al., 2017). This approach encompasses various environmental impact categories, including ecological footprint and water footprint. The most significant difference between ecological water footprint and water footprint lies in the fact that EF estimates reflect only consumption differences based on global average efficiencies, while WF estimates reflect both production and consumption based on actual efficiencies. However, both analyses share the common capability of being conducted for specific organizations, activities, and products across all spatial scales (Hoekstra, 2009). Thus, the concept of water footprint measures the supply and use of all humanity's freshwater resources (blue, green, and grey), identifying geographical distinctions between production and consumption regions (Hoekstra and Mekonnen, 2012).

The use of water footprint and carbon footprint indicators in crop production contributes to shaping production policies. In Italy, water consumption was evaluated using wheat production data from different regions between 2011 and 2015. The green water footprint was highest in Umbria at 6525 $m^3$/ha and lowest in Sardinia at 3125 $m^3$/ha. It was noted that the blue water footprint ranged from 42 $m^3$/ha to 88 $m^3$/ha (Casolani et al., 2016). Yousefi et al. (2017) collected data in Iran during the summer of 2012 using a random sampling method to calculate the water footprint, carbon footprint, and energy requirements of sunflower production. They reported a green water footprint of 0.63 $m^3$/kg (18%), a blue water footprint of 2.78 $m^3$/kg (82%), resulting in a total water footprint of 3.41 $m^3$/kg. Agricultural water footprint appears high in Turkey, consistent with global trends. According to a report prepared by the General Directorate of Water Management for the Büyük Menderes Basin, the total water footprint is 13.70 billion $m^3$ (SYGM, 2023), and in another thesis (Erdem, 2021), the agricultural water footprints of the Seyhan, Ceyhan, and Asi Basins were calculated as 3.53 billion $m^3$, 6.58 billion $m^3$, and 2.51 billion $m^3$, respectively. The agricultural water footprint calculated in the Konya Closed Basin irrigation networks was 1.36 billion $m^3$ (Çakmak and Torun, 2023).

This study will examine and evaluate agricultural water usage in Bilecik province from a different perspective, discussing the current situation. The water footprint approach will analyze water resource consumption at the regional level and provide guidance for future projections. It will highlight successful practices and identify necessary actions if deficiencies are found, thereby providing valuable insights to scientists and decision-makers. It will also contain valuable information for ensuring sustainability in water resource management and food supply.

## 2. Materials and Methods

### 2.1. Materials

The study was conducted using data related to agricultural and animal production as well as water resources of Bilecik province. Bilecik is located in the southeast of the Marmara Region, between 39° and 40° 31' north latitudes and 29° 43' and 30° 41' east longitudes. The altitude of the province ranges from 200 to 500 meters above sea level. Mountains cover a significant portion, approximately 32%, of the province's geography, whereas usable plains constitute only 7%. In terms of climate, Bilecik Province has a transitional climate, exhibiting characteristics of both the Marmara and Central Anatolian climates. According to log term meteorological data, the average precipitation is 453.9 mm, and the average temperature is 12.5 °C (MGM, 2023).

The main surface water source within the boundaries of Bilecik province is the Sakarya River, which traverses 80 km and has a flow rate of 100 $m^3$/s. The river water is used for irrigation and energy production purposes. In second place is the Karasu Stream, covering a distance of 65 km with a flow rate of 3.6 $m^3$/s. The only natural lake within the boundaries of Bilecik province is Lake Çerkeşli. The total surface area of natural lake surfaces is 4,790 hectares, with 3 dams totaling 5,716 hectares of net irrigation area used for irrigation purposes, and 5 reservoirs totaling 1,410 hectares of net irrigation area. The total water source volume in Bilecik province is 374.7 $hm^3$/year, with surface water potential of 320 $hm^3$/year and groundwater potential of 54.7 $hm^3$/year. The total area of the province is 430,200 hectares, with 140,743 hectares classified as agricultural land, 32,200 hectares as pasture land, 205,825 hectares as forest land, and 51,432 hectares as other types of land. In Bilecik province, irrigated agriculture is practiced on an area of 20,298 hectares (Anonymous, 2017). The areas where irrigated agriculture is concentrated include particularly the districts of Osmaneli, Gölpazarı, Söğüt, and the central district.

The agricultural and animal production data for the year 2022 used for analysis belong to Bilecik Province, sourced from the report of the Provincial Directorate of Agriculture and Forestry of Bilecik Governorship (Anonymous, 2023), while some data related to water footprint indicators were obtained from tables published by Mekonnen and Hoekstra (2011; 2012).

### 2.2. Methods

The study focused on calculating the volume-based blue, green, and grey water footprints described by Hoekstra et al. (2011). The blue water footprint ($WF_{blue}$) indicates the portion of consumed groundwater or surface water. The agricultural water footprint has been determined by calculating the total green, blue, and grey water requirements of crops grown in the region. The Green Water Footprint ($WF_{green}$) is considered as the total volume of rainwater used in the production of a product, while the grey water footprint ($WF_{grey}$) is calculated as the total volume of water needed to neutralize pollutants (Hoekstra et al., 2011; Ercin ve Hoekstra, 2012).

The method developed by Chapagain and Hoekstra (2004) for determining the water footprint of crop production has been used. In crop production, the water footprint largely depends on the water consumption of the plants. The distribution of the 2022 crop pattern by product groups in the research area is shown in Figure 1.

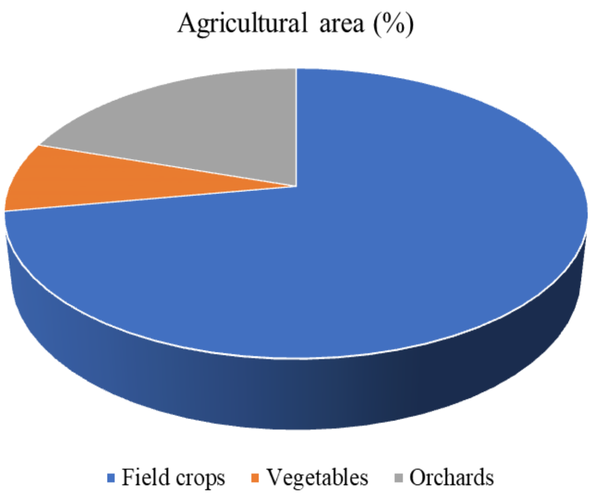


**Figure 1.** Crop cultivation rates in Bilecik province.

Plant water consumption consists of two main components: rainfall and irrigation water. In the research area, water footprint values in $m^3$/year and $m^3$/ton have been calculated using the water footprint method developed by Chapagain et al. (2006). The necessary meteorological data for the calculations were obtained from the General Directorate of Meteorology (MGM, 2023). To determine the water footprint of crop production, plant water consumption and effective rainfall were first calculated using the TAGEM-SUET (tagemsuet.tarimorman.gov.tr) application, resulting in the green and blue water needs. The Penman-Monteith method was used for plant water consumption and the USDA-SCS method for effective rainfall in the application. Plant water consumption (ET, $m^3$/ha) is calculated as the sum of the blue and green water needs (Chapagain and Hoekstra, 2004).

The water footprint components of crop water consumption ($m^3$/ha) are values dependent on the green and blue water needs of the crop during its growing season (crop water consumption ET, mm). Green crop water consumption is the amount of crop water consumption covered by effective rainfall. When effective rainfall (Peff) is equal to or greater than plant water consumption, green crop water consumption is equal to crop water consumption in equation 1. When crop water consumption exceeds effective rainfall, green crop water consumption is equal to Pe in equation 2 (Lovarelli et al., 2016).

$$ET \leq Peff \text{ then } ET_{green} = ET \tag{1}$$

$$ET > Peff \text{ then } ET_{green} = Peff \tag{2}$$

In the equations, $ET_{green}$ represents the amount of crop water consumption covered by rainfall (mm); Pe denotes effective rainfall (mm), and ET refers to total crop water consumption (seasonal evapotranspiration, mm).

The difference between crop water consumption and effective rainfall is expressed as blue crop water consumption or net irrigation water requirement. When crop water consumption is equal to and/or greater than effective rainfall, blue crop water consumption (dn, $ET_{blue\text{-}theoretical}$) is equal to the difference between crop water consumption and effective rainfall and is calculated using equation 3. When effective rainfall exceeds crop water consumption, there is no need for irrigation, so blue crop water consumption equals zero in equation 4 (Lovarelli et al., 2016).

$$ET \geq Peff \text{ then } ET_{blue} = ET - Peff \tag{3}$$

$$ET < Peff \text{ then } ET_{blue} = 0 \tag{4}$$

Blue crop water consumption ($d_n$, $ET_{blue\text{-}theoretical}$) theoretically represents the amount of irrigation water needed by the crop. This amount includes the water losses that occur as the irrigation water delivery from the water source to the crop. Therefore, blue crop water consumption has been divided by the irrigation efficiency (E) to calculate the total theoretical irrigation water requirement using equation 5 (Hoekstra et al., 2012).

Crop water use (CWU, $m^3$/ha) represents the total evapotranspiration amount (ET) during the crop growing season (lgp) and is determined by equation 6.

$$ET_{blue\text{- }theoretical} = ET_{blue}/E \tag{5}$$

$$CWU_{green/blue} = 10 \times \sum_{d=1}^{lgp} ET_{green/blue} \tag{6}$$

The water footprint of crops is obtained from the sum of green, blue, and grey water footprint components throughout the crop growth process by equation 7. Green and blue water footprints ($m^3$/ton) are calculated by dividing crop water use ($m^3$/ha) by crop yield (ton/ha) using equations 8 and 9. The green, blue, and total water footprint values during the growing season were calculated using equations 10, 11 and 12, based on the total volume of water used for crop production (Hoekstra et al., 2011). Grey water footprint for crop production has been calculated using the average water footprint per ton of commodity per country, weighted based on origin (WF* in $m^3$/ton) values described in Mekonnen and Hoekstra (2011).

$$WF_{proc} = WF_{proc\text{-}green} + WF_{proc\text{-}blue} + WF_{proc\text{-}grey} \tag{7}$$

$$WF_{proc\text{-}green} = \frac{CWU_{green}}{Y} \tag{8}$$

$$WF_{proc\text{-}blue} = \frac{CWU_{blue}}{Y} \tag{9}$$

$$WF_{proc\text{-}green}\ (m^3) = WF_{proc\text{-}green}\ (m^3/ton) \times Production\ (ton/year) \tag{10}$$

$WF_{proc\text{-}blue}\ (m^3) = WF_{proc\text{-}blue}\ (m^3/ton)\ x\ Production\ (ton/year)$ (11)

$WF_{grey}\ (m^3) = WF_{proc\text{-}grey}\ (m^3/ton)\ x\ Production\ (ton/year)$ (12)

The water footprint of livestock includes the total amount of water used directly or indirectly in the production of beef, dairy, and other products from cattle, sheep, and poultry raised in the region. In animal production, the blue water footprint per animal is obtained by multiplying the number of livestock (HSi,j) by average water footprint at end of life time (HSUi,j, $m^3$/animal) reported by Mekonen and Hoekstra (2012) using equation 13.

$Mavi\ SA_{hayvancılık} = \sum HSi, \times HSUi,j$ (13)

The blue, green, and grey water footprints of animal products such as meat, milk, and eggs were obtained by multiplying the water footprint values per ton described by Mekonen and Hoekstra (2012) with the total production quantities in Bilecik province.

## 3. Results

The total values for the water footprint of crop production, animal husbandry, and overall agricultural production covering Bilecik provincial center and districts for the year 2022 are detailed in Tables 1 and 2. The water footprint of plant production is 0.608 billion $m^3$, the water footprint of animal husbandry is 0.516 billion $m^3$, and the total agricultural water footprint is calculated as 1.12 billion $m^3$. The share of the plant production water footprint within the agricultural production water footprint is found to be higher at 54% compared to the animal production water footprint share of 46%. The total water footprint of plant production consists of 33% green water footprint, 59% blue water footprint, and 8% grey water footprint (Figure 2).

The distribution of the total water footprint of plant production across different plant product groups and crops within the province is illustrated in Figure 3. According to the graph, cereals have the largest total water footprint with 390.16 million $m^3$ (65%) in the province, followed by fruits with 152.84 million $m^3$ (25%), vegetables with 56.72 million $m^3$ (9%), and greenhouse production with 8.10 million $m^3$ (1%). The total water potential for the province has been reported as 374.7 million $m^3$ by the State Hydraulic Works (DSİ) in 2022. Even excluding the green water footprint in plant production, the total of blue and grey water footprints has been calculated as 410.3 million $m^3$.

In animal production, the water footprint calculated based on water needs per animal totals 394.65 million $m^3$, while the water footprint of animal products as milk, egg, chicken meat and beef is calculated as 121.11 million $m^3$, with the highest share being 77% attributed to the water footprint based on live animal inventory. The total water footprint in animal production is 515.76 million $m^3$. Within the total water footprint of animal product production, the share of green water footprint is 87%, the share of blue water footprint is 6%, and the share of grey water footprint is 7% (Figure 4).

**Table 1.** The green, blue and grey water footprint along process of growing crops

| Crop Category | Crop variety | Cultivated area (ha) | Crop Production (ton/year) | $WF_{proc\text{-}green}$ ($m^3$/ton) | $WF_{proc\text{-}blue}$ ($m^3$/ton) | $WF_{green}$ ($m^3$) | $WF_{blue}$ ($m^3$) | $WF_{grey}$ ($m^3$) | $WF_{proc}$ ($10^6$ $m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| Field Crops | Wheat | 30520.00 | 70391.00 | 1011.10 | 1489.77 | 71172640.00 | 104866720.00 | 13515072.00 | 189.55 |
| | Barley | 7365.80 | 15074.00 | 1139.51 | 1620.34 | 17177045.60 | 24424992.80 | 346702.00 | 41.95 |
| | Rye | 511.80 | 1518.00 | 786.24 | 1677.68 | 1193517.60 | 2546716.80 | 220110.00 | 3.96 |
| | Oats | 1980.00 | 12114.00 | 381.16 | 702.17 | 4617360.00 | 8506080.00 | 1756530.00 | 14.88 |
| | Dry Beans | 224.60 | 470.00 | 863.04 | 2651.24 | 405627.60 | 1246080.80 | 117030.00 | 1.77 |
| | Chickpea | 665.60 | 875.00 | 1373.80 | 3231.39 | 1202073.60 | 2827468.80 | 335125.00 | 4.36 |
| | Sunflower (Oil) | 8454.50 | 15324.00 | 996.40 | 4583.66 | 15268827.00 | 70239986.00 | 2160684.00 | 87.67 |
| | Sunflower | 1512.40 | 3074.00 | 888.55 | 4087.51 | 2731394.40 | 12565019.20 | 433434.00 | 15.73 |
| | Maize (Silage) | 582.50 | 30719.00 | 34.25 | 113.92 | 1051995.00 | 3499660.00 | 5037916.00 | 9.59 |
| | Sainfoin | 319.20 | 4526.00 | 294.87 | - | 1334575.20 | - | 497860.00 | 1.83 |
| | Clover | 1921.80 | 40123.00 | 200.26 | 214.49 | 8035045.80 | 8605820.40 | 1203690.00 | 17.84 |
| | Hops | 182.00 | 1047.00 | 726.78 | 229.11 | 760942.00 | 239876.00 | 15705.00 | 1.02 |
| | Total | 54240.20 | 195255.00 | 8695.96 | 20601.28 | 124951043.80 | 239568420.80 | 25639858.00 | 390.16 |
| Vegetables | Pumpkin | 148.50 | 4126.00 | 72.63 | 303.19 | 299673.00 | 1250964.00 | 169166.00 | 1.72 |
| | Kidney bean | 423.50 | 4810.00 | 177.68 | 461.71 | 854623.00 | 2220834.00 | 1197690.00 | 4.27 |
| | Peas | 101.50 | 698.00 | 293.45 | 675.31 | 204827.00 | 471366.00 | 316892.00 | 0.99 |
| | Pepper | 375.00 | 10975.00 | 68.95 | 274.85 | 756750.00 | 3016500.00 | 3643700.00 | 7.42 |
| | Tomato | 1560.20 | 108635.00 | 28.98 | 113.23 | 3148483.60 | 12300616.80 | 2281335.00 | 17.73 |
| | Beans (Fresh) | 344.70 | 3499.00 | 198.80 | 530.40 | 695604.60 | 1855864.80 | 1588546.00 | 4.14 |
| | Spinach | 147.80 | 1800.00 | 165.70 | 15.11 | 298260.40 | 27195.20 | 73800.00 | 0.40 |
| | Watermelon | 1045.60 | 68560.00 | 30.78 | 62.89 | 2110020.80 | 4312054.40 | 5827600.00 | 12.25 |
| | Melon | 536.70 | 13529.00 | 80.05 | 273.88 | 1083060.60 | 3705376.80 | 1149965.00 | 5.94 |
| | Eggplant | 53.10 | 1790.00 | 59.86 | 191.75 | 107155.80 | 343238.40 | 73390.00 | 0.52 |
| | Onion (Fresh) | 148.90 | 4013.00 | 74.88 | 59.52 | 300480.20 | 238835.60 | 140455.00 | 0.68 |
| | Onion (Dry) | 63.20 | 1236.00 | 103.19 | 391.88 | 127537.60 | 484364.80 | 43260.00 | 0.66 |
| | Total | 4948.70 | 223671.00 | 1354.95 | 3353.73 | 9986476.60 | 30227210.80 | 16505799.00 | 56.72 |
| Greenhouse production | Tomato (Table) | 214.40 | 18791.00 | 0.00 | 155.40 | 0.00 | 2920128.00 | 394611.00 | 3.31 |
| | Cucumber (Table) | 222.60 | 17034.00 | 0.00 | 123.88 | 0.00 | 2110248.00 | 357714.00 | 2.47 |
| | Lettuce | 468.30 | 14059.00 | 0.00 | 111.92 | 0.00 | 1573488.00 | 576419.00 | 2.15 |
| | Green Onion | 19.60 | 1149.00 | 0.00 | 109.51 | 0.00 | 125832.00 | 40215.00 | 0.17 |
| | Total | 924.90 | 51033.00 | 0.00 | 500.72 | 0.00 | 6729696.00 | 1368959.00 | 8.10 |
| Orchards | Cherry | 2189.30 | 14274.00 | 641.27 | 597.86 | 9153463.30 | 8533891.40 | 1213290.00 | 18.90 |
| | Peach | 2201.50 | 36651.00 | 251.14 | 354.27 | 9204471.50 | 12984447.00 | 3115335.00 | 25.30 |
| | Olive | 1751.10 | 3341.00 | 2191.36 | 460.18 | 7321349.10 | 1537465.80 | 283985.00 | 9.14 |
| | Sour Cherry | 567.60 | 1015.00 | 2338.06 | 2202.18 | 2373135.60 | 2235208.80 | 86275.00 | 4.69 |
| | Grape | 1046.60 | 6530.00 | 670.11 | 464.48 | 4375834.60 | 3033046.80 | 555050.00 | 7.96 |
| | Walnut | 5664.30 | 2166.00 | 10933.72 | 21020.15 | 23682438.30 | 45529643.40 | 184110.00 | 69.40 |
| | Quince | 474.60 | 6591.00 | 301.06 | 431.90 | 1984302.60 | 2846650.80 | 560235.00 | 5.39 |
| | Apple | 394.80 | 2816.00 | 586.17 | 577.34 | 1650658.80 | 1625786.40 | 239360.00 | 3.52 |
| | Plum | 320.30 | 1803.00 | 742.75 | 1104.62 | 1339174.30 | 1991625.40 | 153255.00 | 3.48 |
| | Pomegranate | 280.50 | 7104.00 | 165.09 | 331.59 | 1172770.50 | 2355639.00 | 603840.00 | 4.13 |
| | Pear | 84.90 | 606.00 | 585.75 | 837.51 | 354966.90 | 507532.20 | 51510.00 | 0.91 |
| | Total | 14975.50 | 82897.00 | 19406.49 | 28382.08 | 62612565.50 | 83180937.00 | 7046245.00 | 152.84 |
| Total Water Footprint of the process of growing crops, WFproc, million $m^3$ | | | | | | | | | 607.81 |

**Table 2.** Annual water footprint of animal category and some selected food products

| Water footprint of animal type | | | | Water footprint of animal products | | | | |
|---|---|---|---|---|---|---|---|---|
| Animal category | Number of animal head | $WF_{mean}$ ($m^3$/animal) | $WF_{total}$ ($10^6$ $m^3$) | Product | $WF_{green}$ ($m^3$) | $WF_{blue}$ ($m^3$) | $WF_{grey}$ ($m^3$) | $WF_{total}$ ($10^6$ $m^3$) |
| Cattle | 35461 | 1889 | 66.99 | Milk | 18986000 | 1892000 | 1584000 | 22.46 |
| Buffalo | 49 | 20558 | 1.00 | Eggs | 5412096 | 509472 | 895752 | 6.82 |
| Sheep | 122098 | 141 | 17.22 | Chicken meat | 30884040 | 2726856 | 4068504 | 37.68 |
| Goat | 40887 | 76 | 3.10 | Beef | 50636382 | 1932150 | 1584363 | 54.15 |
| Broiler | 17757 | 6 | 0.11 | | | | | |
| Egg poultry | 6515539 | 47 | 306.23 | | | | | |
| Total | | | 394.65 | | 105918518 | 7060478 | 8132619 | 121.11 |

$WF_{mean}$= Average water footprint at end of life time by Mekonnen and Hoekstra (2012).

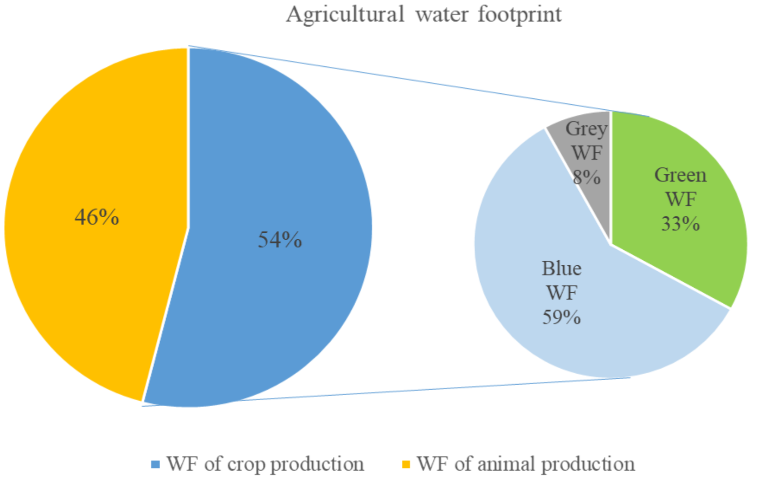


**Figure 2.** Percentages of agricultural water footprint.

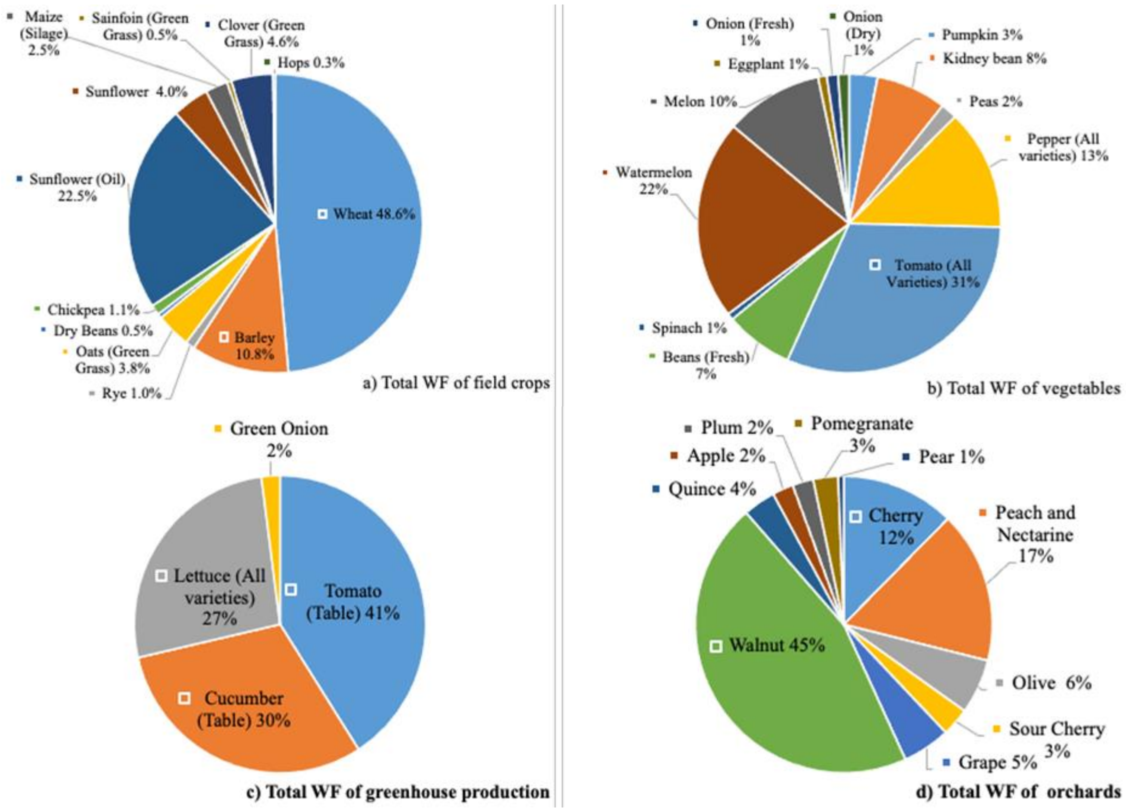


**Figure 3.** The distribution of the total water footprint of plant production across different plant product groups and crops.

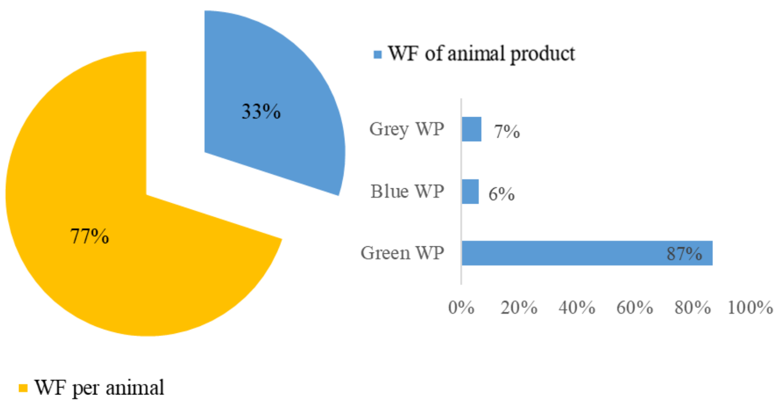


**Figure 4.** Water footprint of animal production

## 4. Discussion

According to similar studies found in the literature, agricultural production has the largest share among the components of the water footprint. On a global average, agricultural production accounts for 70% of direct water use and 90% of indirect water use. In Turkey, agricultural production accounts for 74% of direct water use, and this percentage can even reach up to 86% in arid regions with a continental climate (Mekonnen and Hoekstra, 2011; Ekinci, 2015; Batan, 2021).

In addition to the intensity of water use for agricultural purposes, rainfall anomalies are increasing in the so-called gateway regions where the study was conducted. In addition to the classical methods of studying how water is used, the use of techniques such as water footprinting, which can distinguish between more uses and assess the impacts on the ecosystem, has increased especially in the last decade. In particular, it is seen that many studies have been carried out on this subject with the need for detailed studies on the agricultural sector, which is the main user of water in our country and in the world (Ababaei and Etedali, 2017; Novoa et al., 2019; Hossain et al.2021; Yang et al., 2020; Cai et al., 2022). In the study, the total values of animal and crop water footprint were obtained as ZZ and FF%, respectively. This situation is similar to the official institution statistics where water use is explained and reveals the reliability of the results of the study (Anonymous 2023).

In watersheds or special production zones, the water footprint method can be used robustly and reliably to assess the impacts of crop and livestock production on water resources. This method explains well the reactions of crops and livestock production to water (Novoa et al., 2019; Yang et al., 2020). Specifically, field crops, vegetables, greenhouse cultivation and fruit cultivation groups were examined in the study and total water footprint values of 390.16, 56.72, 8.10 and 152.84 million $m^3$ were obtained respectively. It is seen that the dominant values belong to field crops and fruit cultivation. This situation is similar to the production statistics and other study results. In the study conducted by Novoa et al. 2019, the agricultural water footprint was obtained as 18,221 $m^3$. In the study where the water footprints of the main river basins in Europe were calculated, the river basins with the highest values were Thames, Scheldt, Rhine and Po and the agricultural water footprint values were announced as 130,363 $m^3$ $km^{-2}$, 200,524 $m^3$ $km^{-2}$, 109,720 $m^3$ $km^{-2}$ and 219,630 $m^3$ $km^{-2}$, respectively (Vanham and Bidoglio, 2014). In the study conducted by Cai et al., 2022, the agricultural water footprint in China was analyzed between 2000-2017 and the average was announced as 5.039 x 109 $m^3$/year. In the study conducted by Çakmak and Torun (2023), in Konya closed basin in our country, agricultural water footprint was evaluated for irrigation networks. The agricultural water footprint was calculated as 1.09 million $m^3$/ha in Konya Closed Basin. In the study conducted by Muratoğlu (2020) in order to evaluate the agricultural water footprint and usage of Diyarbakır Province, the average agricultural water footprint value was calculated as 3.43 billion $m^3$/year. Another study was conducted by Erdem (2021) for the water footprint assessment of Seyhan, Ceyhan and Asi Basins. The water footprint values in these basins were calculated as 3.53, 6.58 and 2.51 billion $m^3$, respectively. When the studies and the data obtained are examined, it is seen that the water footprint data varies according to the plants grown in the relevant region, plant planting rates, agricultural techniques, irrigation methods, and is also significantly affected by dry and normal rainfall conditions. The fact that it depends on many natural and artificial parameters can be considered as a positive factor in reflecting natural conditions.

The concept of water footprint includes sectoral data on general usage, as well as specific green, blue and grey water footprint components. Thanks to these components, it reflects the usage characteristics of water resources more accurately and reliably. In the study, green, blue and grey footprint values for plant cultivation are 197.5, 359.7 and 50.5 million $m^3$, respectively. Data on animal products are calculated as 105.9, 7.06 and 8.1 million $m^3$, respectively. Across the country, the total water footprint of crop production ranges between 2.13 and 114.79 billion $m^3$, while the total water footprint of animal production ranges between 0.43 and 9.98 billion $m^3$ (Muratoğlu, 2020; Erdem, 2021; Ahi and Çakmak, 2023; Çakmak ve Torun, 2023). It is consistent with many results obtained under similar conditions in the international literature conducted by Lovarelli et al. (2016), Ababaei and Etedali (2017), Novoa et al. (2019), Yang et al. (2020), Hossain et al. (2021), and Cai et al. (2022).

## 5. Conclusion

In the study, after discussing classical concepts and methods for assessing water resources, the concept of the water footprint, one of the techniques considered today, was used as a basis, and the use of water resources in agricultural production in Bilecik Province was examined. Bilecik Province and the region’s freshwater resources face challenges such as pollution and increased consumption due to factors like irregularities and reductions in precipitation, improper use of irrigation and cultivation techniques, irregular use of natural resources, poor land planning, negative impacts of industrial development on the ecosystem, and intensive migration due to its location at the intersection of transportation axes. The total water footprint of agricultural production obtained from the study (1.1 billion $m^3$) aligns with the water use statistics at the provincial level, clearly demonstrating the increase in the use of water for animal and plant cultivation in agricultural production. Bilecik Province is considered one of the areas predicted to be most affected by global climate change, along with a significant part of the Mediterranean and Aegean regions of Turkey. Therefore, due to meteorological parameters such as increased temperature-evaporation and precipitation anomalies, providing quality water in the desired amounts and times, especially for agricultural production, will become more challenging. In the future, the creation of water-intensive units such as organized industrial zones in the city, parallel population growth due to industrial development, and the transition of existing agricultural production from dry farming to irrigated agriculture highlight the importance of planning the province's future with a focus on water resources and natural resources.

**Author Contributions**

The percentage of the author(s) contributions is presented below. The author reviewed and approved the final version of the manuscript.

| | H.T.G. |
|---|---|
| C | 100 |
| D | 100 |
| S | 100 |
| DCP | 100 |
| DAI | 100 |
| L | 100 |
| W | 100 |
| CR | 100 |
| SR | 100 |
| PM | 100 |
| FA | 100 |

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

**Conflict of Interest**

The author declared that there is no conflict of interest.

**Ethical Consideration**

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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