AGRICULTURAL WATER MANAGEMENT PLANNING: THE CASE OF BILECIK PROVINCE

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ABSTRACT

Water, the source of life and living things, is a resource that cannot be replaced. Water is an indispensable element of life and the basic input of agriculture. Global warming and climate change have a significant impact on rainfall regimes. This effect causes serious consequences such as drought and flood. In this study, the effects of flood-drought-water pollution on the main agricultural products produced in Bilecik Districts were examined. In the study, Arap stream and Delikbağ stream in Gölpazarı; Gümüşdere in Pazaryeri; Çöte stream basins in Yenipazar were used. The characteristics of the watershed (such as area, length, slope, curve number) and climate data (such as precipitation, temperature and evapotranspiration) were prepared and used in the WinTR-55 and DrinC model. As a result, the R^2 value between the RDI drought index result and hop yield reached the highest value among the compared districts with a value of 0.50 in Pazaryeri. The R^2 value between the RDI drought index result and wheat yield reached the highest value among the compared districts with a value of 0.80 in Söğüt. Besides, a significant decrease was observed in drought index values in Bilecik in 2017. The years when drought was most apparent in Bozüyük were 2006 and 2007. In Pazaryeri, 2007 was seen as the year when the effect of drought was felt most intensely. When the peak flow values of the 100-year return period were compared with the WinTR-55 model, Gölpazarı-Arap Stream was the area with the highest risk with 66.59 m^3/s. This was followed by Gölpazarı-Gümüşdere with 47.06 m^3/s, Gölpazarı-Delikbağ Stream with 47.00 m^3/s and Yenipazar-Çöte with 26.27 m^3/s, respectively.

Keywords: Climate change, Drought, Flood, WinTR-55

TARIMSAL SU YÖNETİMİ PLANLAMASI: BİLECİK İLİ ÖRNEĞİ

ÖZET

Yaşamın ve canlıların kaynağı olan su, yerine konulamayan bir kaynaktır. Su, yaşamın vazgeçilmez bir unsuru ve tarımın temel girdisidir. Küresel ısınma ve iklim değişikliği yağış rejimleri üzerinde önemli etkilere sahiptir. Bu etki kuraklık ve sel gibi ciddi sonuçlara neden olmaktadır. Bu çalışmada, Bilecik İlçelerinde üretilen başlıca tarım ürünlerine sel-kuraklık-su kirliliğinin etkileri incelenmiştir. Çalışmada Gölpazarı'nda Arap deresi ve Delikbağ deresi; Pazaryeri'nde Gümüşdere; Yenipazar'da Çöte Dere havzaları kullanılmıştır. Havza özellikleri (alan, uzunluk, eğim, eğri numarası gibi) ve iklim verileri (yağış, sıcaklık ve evapotranspirasyon gibi) hazırlanarak WinTR-55 ve DrinC modelinde kullanılmıştır. Sonuç olarak, RDI kuraklık indeksi sonucu ile şerbetçiotu verimi arasındaki R^2 değeri, karşılaştırılan ilçeler arasında en yüksek değere 0,50 değeri ile Pazaryeri'nde ulaşmıştır. RDI kuraklık indeksi sonucu ile buğday verimi arasındaki R2 değeri ise karşılaştırılan ilçeler arasında en yüksek değere 0,80 değeri ile Söğüt'te ulaşmıştır. Ayrıca, Bilecik'te 2017 yılında kuraklık indeksi değerlerinde önemli bir düşüş gözlenmiştir. Bozüyük'te kuraklığın en belirgin olduğu yıllar 2006 ve 2007 olmuştur. Pazaryeri'nde kuraklığın etkisinin en yoğun hissedildiği yıl 2007 yılı olarak görülmüştür. 100 yıllık tekerrür periyoduna ait pik debi değerleri WinTR-55 modeli ile karşılaştırıldığında, Gölpazarı-Arap Deresi 66,59 m^3/s ile en yüksek riske sahip alan olmuştur. Bunu sırasıyla 47,06 m^3/s ile Gölpazarı-Gümüşdere, 47,00 m^3/s ile Gölpazarı-Delikbağ Deresi ve 26,27 m^3/s ile Yenipazar-Çöte izlemiştir.

Anahtar Kelimeler: İklim değişikliği, kuraklık, sel, WinTR-55

1. INTRODUCTION

Water is the source of life and living things. Therefore, water resources need to be protected and need to used sustainably. Protection of water resources refers to the measures taken to prevent pollution and depletion of water resources. Sustainable usage of water resources refers to ensure their protection for future generations [1]. Water is an indispensable element of life and it is the basic input of agriculture. Irrigation enhances agricultural production. On the other hand, it can be harmful for environment and endamages the natural balance if it applies excessively. The agricultural sector is in danger in terms of two major problems. They are the increasing population and climate change. As water resources are consumed unconsciously, the agricultural sector will have more difficulty accessing water and world food security will be in danger [2]. Reasons such as population growth, urbanization, industrialization and increased agricultural activities enhance the need for water. This situation leads to excessive consumption and pollution of water resources [3]. In the globalizing system of the 21st century, the population of humanity has increased rapidly and has exceeded 8 billion [4]. According to United Nations (UN) reports, the world population will reach 10 billion in 2050. Therefore, cities might be uninhabitable and the water might be undrinkable [5].

At the 1972 Stockholm Conference, the United Nations emphasized that environmental protection requires "protection of water, soil, air and natural ecosystems for future generations through planning or management." The aims of the UN Conference on Environment and Development organized in Rio de Janeiro (Brazil) in June 1992 were strengthening relationships between different water-related programs and developing approaches to ensure coordination across sectors [6].

Turkey's total water potential is estimated as 501 billion m^3/year. 166 billion m^3/year of this amount passes directly into the flow. 67% of the remaining water is lost through percolation, evaporation and transpiration. The total flow rate of our rivers is on average 186.1 billion m^3/year with the contribution of water leaking underground. The amount of water stored in dams and ponds is approximately 91.1 billion m^3/year. A total of 111 billion m^3/year of water (consisting of rivers, lakes and groundwater) is accepted as usable water potential [7]. When we look at the sectoral distribution of water usage, it is seen that on average 74% is for agricultural irrigation, 13% is for industry, and 13% is for domestic usage [8].

The atmosphere consists of different gases. Gases such as CO_2, CH_4, N_2O, O_3, CFC (chlorofluorocarbon) in the atmosphere insulate some of the heat coming from the sun to the earth and they allow the earth to remain at a certain temperature [9]. The increase in earth temperature is called global warming. The warming affects the whole world and living things and it causes important environmental changes [10]. The temperature on the earth's surface can be determined with the help of factors such as the amount of sunlight received and reflected by the earth, the retention of heat by the atmosphere, the evaporation and condensation of water vapor [11].

As a result of global warming, direct and indirect problems in water resources will cause a decrease in agricultural and forest products, energy shortage and population movement from coastal areas to inland areas [12].

Climate is the average of weather conditions observed in any place on earth over many years. The limits of this average are determined by the highest and lowest values. Climate change is the alteration in the average state or change of the climate over decades or longer [13]. Climate change lead to dense droughts and floods [14].

Reduction of poverty and protection of ecosystems are necessary to ensure food security. Much more food can be produced per unit of water in an agricultural system. For sustainable water management, a major policy shift is required in irrigated and rain-fed agriculture. Remarkable developments occurred in water resources and agriculture in the last 50 years. Major developments in hydraulic infrastructure have made available water for people. As the world population has increased from 2.5 billion in 1950 to 6.5 billion for today, irrigated area has doubled and water usage has tripled. Water management plans should be made for each city. Water quantity and quality of the cities are at risk. They might be negatively affected by water-related disasters such as drought and flood [15].

Global warming and climate change have a significant impact on rainfall regimes. This effect causes serious results such as drought and flood. It is predicted that the problem might increase further in arid areas. On the other hand, much more rain might fall in rainy cities [16]. Long-term trends in drought occurrence, heat stress, and floods highlight geographic variation in the impact of climate change on agriculture [17]. The most important cause of global warming is the greenhouse gas effect. Greenhouse gases accumulated in the atmosphere prevent the sun's rays, which have turned into infrared radiation from leaving the atmosphere. This causes global warming. As a result, global warming leads to climate change. This changes the physical and human geography of our planet [18].

Studies on the impact of climate change on water resources were summarized below. Alkan (2021) investigated the effect of climate change on drought and wheat yield in the Porsuk Stream basin and he determined that the basin was in an arid region. It was determined that hydrological and agricultural droughts were common and a meteorologically normal climate prevailed for the past period. The researcher states that the Porsuk Stream watershed will become arid meteorologically, but a normal climate will prevail hydrologically in the future [19]. Sırdaş and Şen (2003) determined the spatial distribution of monthly precipitation data of 60 large stations in Turkey between 1930 and 1990. They also state that our country is in a semi-arid region and they stated that drought is a constant threat for Turkey [20].

Richter and Semenov (2005) investigated the effects of drought risks on wheat yield by modeling for future climate changes in the United Kingdom. They determined that the warming will increase in the region between 2020 and 2050, which will have a positive impact on agricultural production. Another result is that the average wheat production will increase by 1.5-2 tons per hectare [21].

Türkeş (2012) found that the significant decrease in frost and snowy days especially in the 1900s in the Eastern Mediterranean and Turkey. The researcher also found that climate parameters such as the number of warm days and nights and the air temperatures (average, lowest at night and highest during the day) have increased [22].

Kapluhan (2013) examined the impact of drought on agriculture in Turkey. The study emphasized that the effects of drought was generally firstly seen in agriculture and gradually spread to other sectors. The researcher stated that Turkey is among the high-risk group countries in terms of the negative effects of the warming. Especially, the Mediterranean and Central Anatolia regions will be more affected by climate change in the future. Besides, it was determined that reducing the negative effects of agricultural drought might be possible by taking precautions before the drought begins. [23].

Studies on agricultural water quality were summarized below. Öktüren Asri et al. (2013) conducted a study to determine the quality of well water used for irrigation purposes in greenhouse cultivation in Osmaneli district of Bilecik province. They took water samples from 46 well waters and determined the values of pH, EC, Ca^{+2}, Mg^{+2}, K^{+}, Na^{+}, HCO_3^{-}, Cl^{-}, SO_4^{-2} and B. Besides, they determined quality classes by calculating SAR and Na% values. In addition, it was determined that 41.30% of the samples were in the C_2 salinity class and 47.82% were in the C_3 salinity class. All irrigation water samples were classified as 1st class water in terms of sodium adsorption rate (SAR) [24].

Alkan and Meral (2024) comprehensively investigated agricultural water quality in Bilecik Karasu River. According to the results, in Bozüyük county, in 2023, SAR in June is 0.1 (A1), SAR is 0.45 (A1) in September. SAR in June 2023 is 0.83 (A1) in Bilecik, SAR in September is 0.93 (A1). As a result, no problems were observed in terms of agricultural water quality in Bilecik and Bozüyük [25].

Drought indices are usually calculated by manually applying the relevant equations or using tools designed for this purpose. Some of the calculation tools of drought index are [26] SPI_SL_6, SPATSIM, SPEI package program and CDI. The software package called DrinC was developed at the Center for Assessment of Natural Disasters and Proactive Planning and the Laboratory of Land Reclamation and Water Resources Management at the National Technical University of Athens. DrinC can be used to calculate drought indices suitable for drought characterization, drought monitoring, spatial analysis of drought risks and exploration of climate scenarios [27].

The main goal in the design of the DrinC software is to provide the widest applicability for different drought types and various locations such as meteorological, hydrological and agricultural drought. Based on these criteria, DrinC consists of Reconnaissance Drought Index (RDI), Streamflow Drought Index (SDI), Standardized Precipitation Index (SPI) and Precipitation Deciles (PD).

Studies on agricultural drought were summarized below. Menteşe and Akbulut (2023) investigated the drought situation of Bilecik station (1964–2021) and Bozüyük stations (1964–2021) with the help of Standardized Precipitation Index (SPI). Researchers determined that the dry, normal and humid period rates of the two districts are similar to each other. Arıkan Uysal (2022) applied trend analysis methods for Bursa's rainfall and temperature values between 1990 and 2019. As a result, she found no statistically significant trend in precipitation data and She observed increasing trends in temperature data. According to SPI and SPEI indices, “normal” drought class prevailed [28]. Bacanlı and Kargı (2018) conducted drought analysis in Bursa with the Standard Precipitation Index (SPI). While normal or mild droughts were more common in short-term periods (3-6 months), severe and very severe droughts were observed in long-term periods (12-24-48 months) [29]. Karaer and Gültaş (2018) determined that drought was generally seen in the summer months for Bilecik province using the SPI method [30].

Studies on agricultural floods were summarized below. Bayazıt (2021) examined the effects of urbanization on flood risk in Bilecik province. It was determined that Bozüyük district is under constant flood risk. It is also found that agricultural lands have a higher flood risk than forest areas in the study [31]. Dursun (2022) examined the flood risk in Osmaneli district of Bilecik using a geographical information system. In the study, the weight values of the flooding parameters were calculated using the Analytical Hierarchy Process (AHP) Method. Besides, the areas with flood risk were determined. As a result, very high risk with 11.94%, high risk with 35.98%, risky with 28.72%, low risk with 20.61% and no risk with 2.75% areas were determined. It was also determined that the risk of flood occurrence is generally higher in areas close to river basins [32].

Alkan (2016) estimated flood flow values in Bursa Province using the WinTR-55 model, Mockus, Rational and DSI synthetic methods. As a result, it was found that the WinTR-55 model predicted higher flood flow compared to other methods in fifteen of the seventeen basins [33].

In this study, the sensitivity of the main agricultural products in Bilecik Province was analyzed in terms of flood, drought and water pollution. For this purpose, agricultural product data in Bilecik was accessed from Turkish Statistic Institution. Climatic data was accessed from Bilecik Meteorology Directorate. Firstly, studies on the subject was compiled and evaluated. Later, a comprehensive result that would be beneficial for the stakeholders in the city was reached through this study.

2. MATERIAL AND METHODS

2.1. Materials

2.1.1. The research area

Bilecik is located in the southeast corner of the Marmara Region. The region intersect to the Marmara, Black Sea, Central Anatolia and Aegean regions. It is located between 39° and 40° 31' north latitudes and 29° 43' and 30° 41' east longitudes. It is adjacent to the provinces of Bolu and Eskişehir in the east, it is adjacent to Kütahya in the south, the region is adjacent to Bursa in the west and Sakarya in the north (Figure 1). The ranking of surface area (4321 km^2) of Bilecik is 65th in Turkey. Bilecik's land structure varies from hilly areas to eroded plains divided by steep and deep valleys. The borders of Bilecik contain the Northern Anatolian Mountains, the Central Anatolian Plateaus and fluvial plains of the Marmara Region. Bilecik's average altitude above sea level is 500 meters. As you go towards Karasu Valley, the altitude decreases and goes down to sea level in Istasyon District.

Figure 1. Map of Bilecik [31]

Bilecik is a province located in the southeast of the Marmara Region. Being adjacent to different geographical regions and topographic diversity also affects the climate of the province. For this reason, there are three different climate types in Bilecik. They are below.

• Marmara Region Climate: It is dominant in the Central, Gölpazarı, Osmaneli and Söğüt districts. In these regions, winters are warm and rainy. Besides, summers are hot and dry.

• Central Anatolia Region Climate: It is seen in Bozüyük, Pazaryeri and Yenipazar districts. In these regions, winters are cold and snowy. Besides, summers are hot and dry.

• Micro-climate Climate: It is seen along the Sakarya River coastline of Gölpazarı, Osmaneli and Söğüt districts. A milder climate prevails in these regions due to the influence of the river.

The average annual rainfall in Bilecik is 450 kg/m². Precipitation is generally concentrated in January and May. In terms of cloudiness, 92 days of the year are clear, 96 days are muggy and 177 days are cloudy. The data used in the WinTR-55 model were shown in Tables 1 and 2.

Table 1. Physical characteristics of the basins in Bilecik for the WinTR-55 model

Name of the watershed	Area of the watershed (km^2)	Length of the watershed (km)	Harmonic slope of the watershed	T_c (Time of concentration, hour)	CN (Curve number)
Gölpazarı-Arap stream	3.4	3.3	0.094	0.005	75
Gölpazarı- Delikbağ stream	2.4	2.7	0.04	0.007	75
Pazaryeri-Gümüşdere	4.91	5.82	0.038	0.014	74
Yenipazar-Çöte	3.87	4.9	0.028	0.014	74

Table 2. 24-hour rainfall amount of the watersheds (mm)

Name of the watershed	Return period (year)	24-hour rainfall amount (mm)
Gölpazarı-Arap stream	2	29.42
	5	44.12
	10	56.02
	25	73.88
	50	89.39
	100	107
Gölpazarı- Delikbağ stream	2	29.42
	5	44.12
	10	56.02
	25	73.88
	50	89.39
	100	107
Pazaryeri-Gümüşdere	2	32.07
	5	42.57
	10	50.13
	25	60.37
	50	68.54
	100	77.17
Yenipazar-Çöte	2	31.64
	5	41.08
	10	47.32
	25	55.21
	50	61.06
	100	66.87

2.1.2. Determination of the study data

For drought analysis, average temperature and precipitation data for the period 1990-2021 for Bilecik-Central (Station No: 17120), for the period 2005-2022 for Pazaryeri (Station No: 17701), for the period 1990-2020 for Bozüyük were used. For this purpose, rainfall data measured in the periods of the relevant years were obtained from the General Directorate of Meteorology.

2.2. Methods

In this study, DrinC and WinTR-55 programs were used. The method equations used by the programs were explained below.

2.2.1. DrinC program

In the study, monthly maximum and minimum temperature, monthly average temperature and precipitation data of the Meteorology Station were processed in the format requested by the DrinC program. Indexes used in the DrinC model are Reconnaissance Drought Index (RDI), Streamflow Drought Index (SDI), Standardized Precipitation Index (SPI) and Precipitation Deciles (PD).

The Reconnaissance Drought Index (RDI) was developed to more accurately refer water deficit as a balance between input and output in a water system [35]. It is based on both cumulative precipitation (P) and potential evapotranspiration (PET). The initial value of RDI (α_k) is calculated in the k (month) time period for the i. year and is given in Equation (1).

$$\alpha_k = \frac{\sum_{j=1}^{k} P_{ij}}{\sum_{j=1}^{k} PET_{ij}}, i = 1(1)N \quad (1)$$

Where:

P_{ij}: Precipitation for month j for year i

PET_{ij}: Potential evapotranspiration for month j for year i

N: Total year

k: Month

Assuming that the lognormal distribution is valid, the calculation of RDIst is given in Equation (2).

$$RDI_{st}^{(i)} = \frac{y^{(i)} - \bar{y}}{\bar{\sigma}_y} \quad (2)$$

Where:

$y^{(i)}$: Logarithm of the αk value of year i

$\bar{y}$: Arithmetic mean of all αk values

$\bar{\sigma}_y$: Standard deviation of logarithms of αk values

2.2.2. WinTR-55 program

WinTR-55 model is based on the NRCS-TR 55 method in calculating the rate of peak surface flow. The NRCS-TR 55 method can be used safely in small, rural and urban basins if the area of the basin is less than 900 ha and the average slope is greater than 0.5%. The WinTR-55 model can be used safely in basins with a maximum of 10 sub-basins, where the curve number (CN) is greater than 40, where Tc is between 0.1 and 10 hours, and whose area is up to 6500 hectares. The method equation used in the model is also given in Equation (3).

$$q_p = q_u A\ Q\ F_p \tag{3}$$

Where:

q_p: Peak runoff discharge (m^3/s)

q_u: Unit peak runoff discharge (km^2/cm)

A: Watershed area (km^2)

Q: Surface runoff depth (mm) resulting from 24-hour rainfall in the desired return period

F_p: Correction factor determined according to the ratio of lakes and swamps in the basin fp value is shown in table 3.

Table 3. Correction factor, Fp (Huffman et al. 2013)

Percentage of lakes and swamps in the basin	***Fp***
0	1
0.2	0.97
1	0.87
3	0.75
5	0.72

After calculating Tc by using Equation (4), unit peak runoff amount (qu) can be determined by using Tc and la/p parameters from Figure 2 [33]. Figure 2 should be use for Type II Storm (A kind of precipitation distrubition).

$$T_c = L^{0.8}\left[\frac{\left(\frac{1000}{CN}-9\right)^{0.7}}{4407\,(s_g)^{0.5}}\right] \tag{4}$$

where:

T_c: Concentration time (hours), L: Longest waterway length, which is from the farthest point of the basin to outlet (meters), CN: Runoff curve number, S_g: Average basin slope (m/m)

Precipitation distribution in the United States of America (USA) is divided into four different categories. They are Type I, Type IA, Type II, and Type III (Figure 3) [33]. The Type II precipitation distribution dominates most part of the USA. We have entered the distribution type II into the WinTR-55 model for the pond basins in Bilecik because this type represents an average distribution.

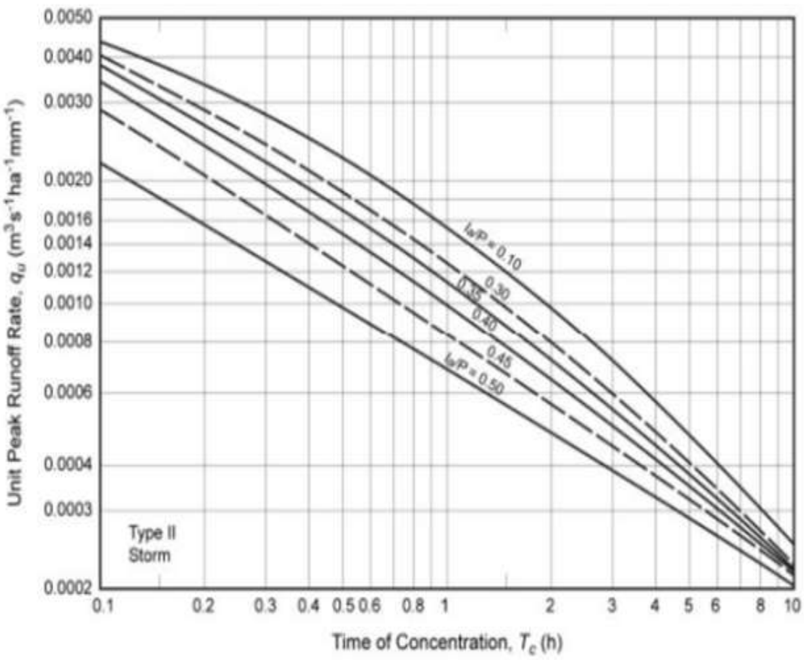

Figure 2. Unit peak runoff for NRCS Type II precipitation distribution

Figure 3. Precipitation distribution in the USA

In addition to calculating CN and Tc values, the WinTR-55 model also has the ability to calculate surface flow volume and peak flow rate. Basin characteristics such as size, shape, slope, soil type, land use, geological structure, vegetation and climate of the basin are among the factors. Besides, they affect the T_C value. There are different formulas developed to calculate the T_C value. Some of these formulas divide flow into categories such as channel flow and sheet flow. On the other hand, the others calculate Tc by using a single equation. In order to calculate the required CN value in the WinTR-55 model, the class of the soil group is shown in Table 4.

Table 4. The groups of soil class

Soil class	Description	The limit value that the infiltration capacity will reach as rainfall progresses, fc (mm/h)
A	Lowest runoff potential	8-12
B	Slightly low runoff potential	4-8
C	Slightly high runoff potential	1-4
D	Maximum runoff potential	0-1

The NRCS graphical (CN) method is shown below with its formula Equation (5) [33].

$$Q = \frac{(l-0.2S)^2}{l+0.8S} \quad (5)$$

Where:

Q : Runoff amount (mm) l: Storm rainfall amount (mm) S: Maximum potential difference between Runoff and Precipitation (Water holding capacity) (mm)

$$S = \left(\frac{25400}{CN}\right) - 254 \quad (6)$$

Where:

CN: Unoff Curve Number

l_a: 0.2S

l_a: The factors such as delay losses, surface deposits, infiltration etc

3. RESULTS AND DISCUSSION

In the study area, the effect of drought on crop production was analyzed spatially and temporally as follows.

3.1. Spatial variation of agricultural drought

In order to analyze the effect of drought on agricultural production, Durum wheat (Triticum Durum) and Hops (Humulus lupulus) plants were selected in this study and an analysis was made on their R^2 values (Determination coefficient between RDI and yield). The analysis results showed that the R^2 values for Durum wheat were 0.80 in Söğüt, 0.18 in Bilecik city center, 0.43 in Bozüyük and 0.0095 in Pazaryeri (Table 5). It can be seen that the region where Durum wheat is directly affected by drought is Söğüt with an R^2 value of 0.80, and Pazaryeri is the region where drought affects wheat yield the least with an R^2 value of 0.0095. As a result of the analysis, the R^2 value for hops was found to be 0.50 in Pazaryeri and 0.01 in Bilecik city center (Table 6). Agricultural drought affected Durum wheat and hop production in different ways. For Durum wheat yield, Bilecik was much more affected by drought compared to Pazaryeri. For Hop yield, Pazaryeri was much more affected by the drought compared to Bilecik. In order to examine the effects of drought on plant physiology and yield in more detail, the plant varieties used in studies can be increased.

Table 5. R^2 Determination coefficient results for Durum wheat (correlation with RDI)

R^2 results for Durum wheat	
Bilecik/City center	0.18
Bozüyük	0.043
Pazaryeri	0.0095
Söğüt	0.8

Table 6. R^2 Determination coefficient results for Hop (correlation with RDI)

R^2 results for Hop	
Bilecik/City center	0.01
Pazaryeri	0.5

Uzun (2024) found the high density of drought susceptibility in the area surrounding the Yenişehir Plain. In particular, this study reached the similar result in terms of results of Bilecik City center which was closed to Yenişehir Plain [36].

Taylan (2024) found that Bozuyuk reached positive SPI values. This study reached the similar result with the increasing trend of SPI too [37].

3.2. Temporal variation of agricultural drought

In this research, it was analyzed how the drought values of Bilecik, Bozüyük and Pazaryeri changed over the years. A significant decrease in drought index values was observed in Bilecik in 2017 and a significant increase in the index value was observed in 2011 (Figure 4).

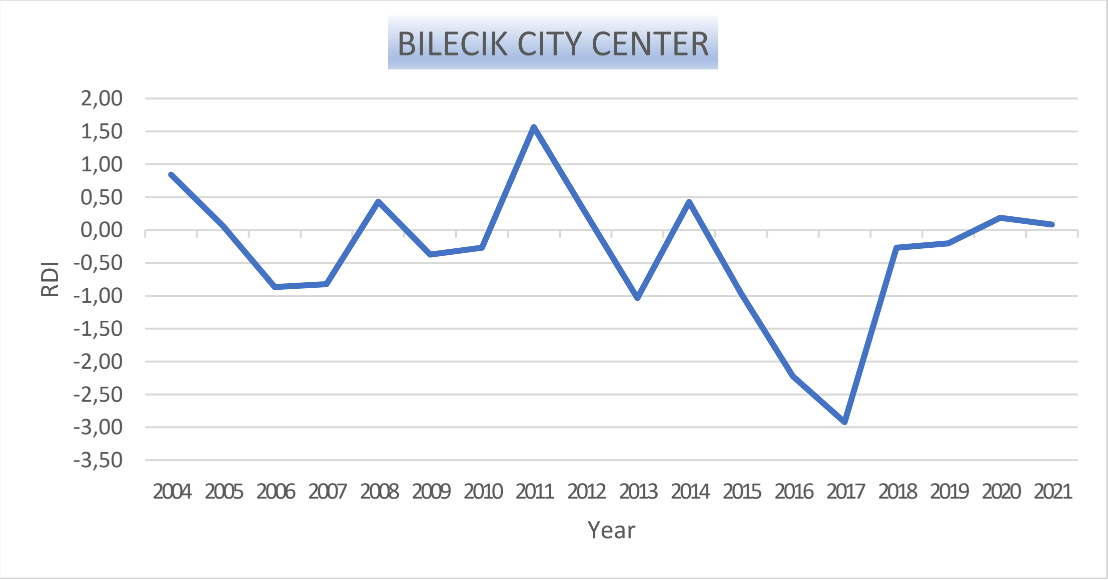

Figure 4. Temporal drought change of Bilecik

2006 and 2007 were most severe drought in Bozüyük. In 2004, there was an increase in the index value (Figure 5). In Pazaryeri, the drought was felt most intensely in 2007. In 2011 and 2015, an increase in drought index values was observed (Figure 6).

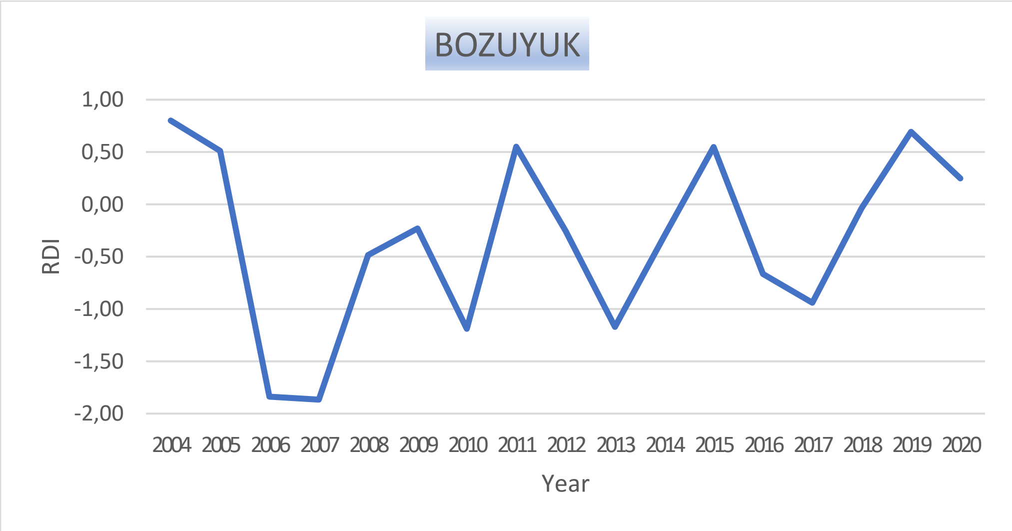

Figure 5. Temporal drought change of Bozüyük

Figure 6. Temporal drought change of Pazaryeri

3.3. The results related to reconnaissance drought index (RDI)

To compare with water quality results in the literature, the RDI values of Bilecik and Bozüyük in June and September in 2023 were taken and the correlation between them and the SAR water quality index was discussed in the conclusion section. RDI results were calculated with the help of DrinC model. RDI values were prepared based on the months of June and September in Bilecik and Bozüyük. While RDI was 1.18 in Bozüyük in June, it dropped to 0.17 in September and became more drier condition. In Bilecik province, the RDI value, which was 0.8 in June, decreased to 0.37 in September and started to trend towards drought (Figure 7)

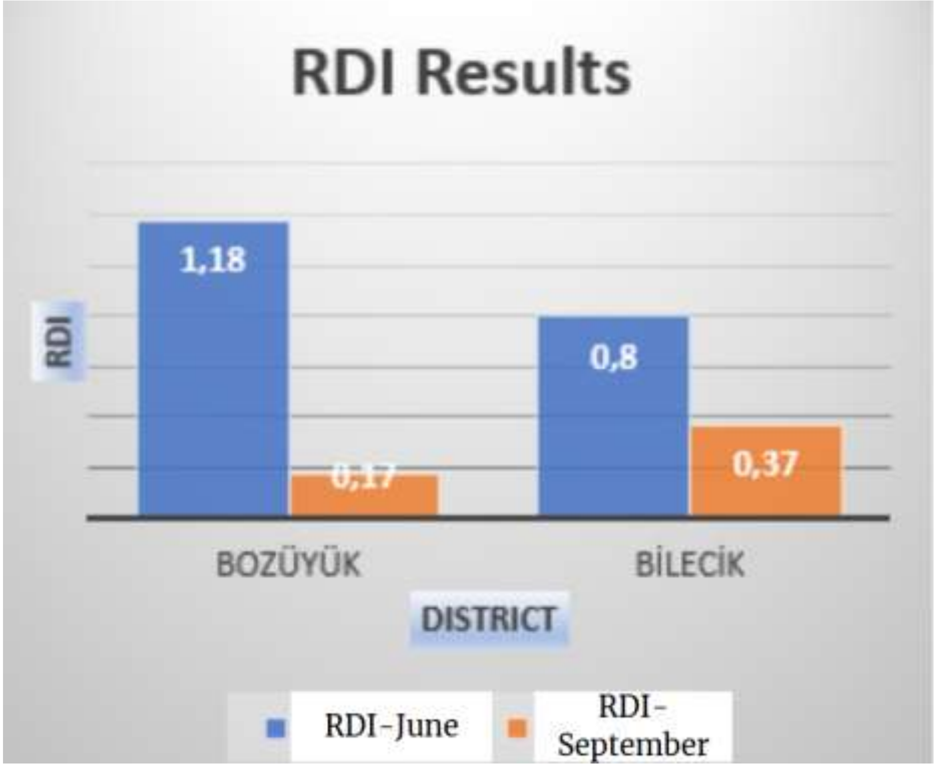

Figure 7. RDI change on a spatial and temporal basis

Kartal (2024) used RDI to determine the drought periods for between 1979 and 2022 years in Elazığ. He revealed that Ağın and Baskil County were drought regions [39]. Başakın et al. (2024) investigated determine of the correlation SPEI and scPDSI index [40].

As in these examples, there are widespread publications in the literature on the determination of the correlation between the drought indices and spatial distribution of drought. However, as in our study, there is very little research on the determination of the relationship between drought and crop yield. The results of our study are also very valuable in this respect.

3.4. Results related to agricultural flood

A comparative analysis of the flood risk was made by determining the peak flow values (m^3/s) of each research area at different return periods with the help of WinTR-55 model. For this purpose, peak flow values for 2, 5, 10, 25, 50 and 100 year return periods were calculated Table 7.

Table 7. Possible peak flow value for different return period

Watershed name	**Return period (year)**	**Peak flow (m^3/s)**
Gölpazarı-Arap stream	2	0.75
	5	7.82
	10	15.74
	25	31.54
	50	47.28
	100	66.59
Gölpazarı- Delikbağ stream	2	0.53
	5	5.52
	10	11.1
	25	22.26
	50	33.38
	100	47
Pazaryeri-Gümüşdere	2	1.65
	5	8.64
	10	15.16
	25	25.38
	50	35.46
	100	47.06
Yenipazar-Çöte	2	1.13
	5	5.9
	10	9.94
	25	15.79
	50	20.65
	100	26.27

The flood risk of each research area was compared based on the peak flow values of the 100-year return period. Gölpazarı-Arap Stream is the area with the highest risk with 66.59 m^3/s. This is followed by Gölpazarı-Gümüşdere with 47.06 m^3/s, Gölpazarı-Delikbağ Stream with 47.00 m^3/s and Yenipazar-Çöte with 26.27 m^3/s, respectively (Figure 8).

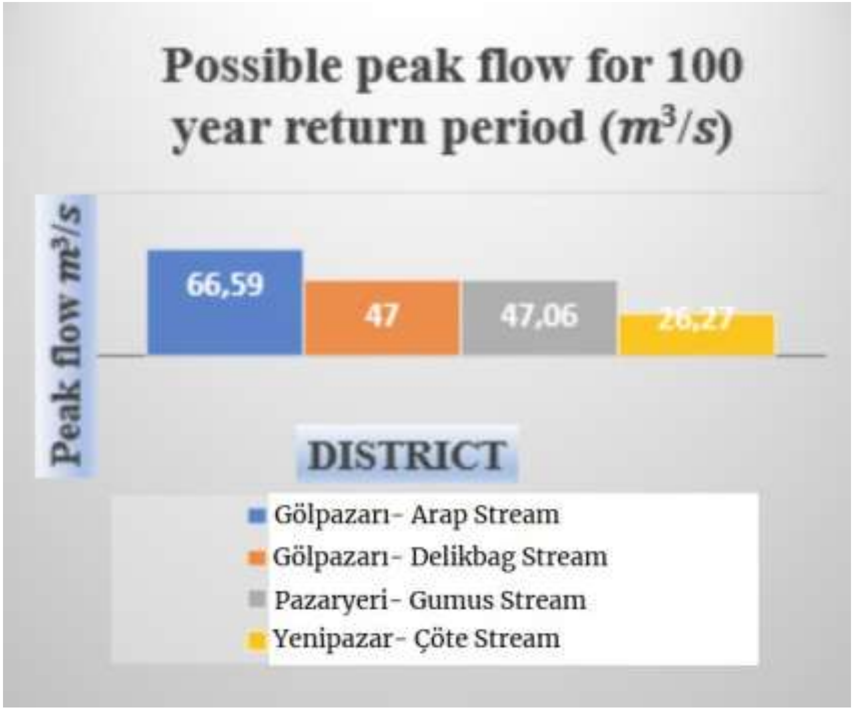

Figure 8. Possible peak flow for 100 year return period

Tarate et al. (2024) said that hydrologic models are so valuable in ungauged watersheds. The models are crucial for accurate runoff estimation. Besides, the NRCS-CN method is fertile and superior. WinTR-55 hydrologic model (NRCS-CN method inside of it), which are populer methods in the literature was used in this study [38].

Aktaş and Uncu (2024) stated that hollow areas carry flood risk. They especially draw attention to the fact that Gölpazarı district is quite mountainous and hollow [41]. The result of our study also coincides with this information in the literature. It is expected that very high peak flow rates will be observed in our Arap and Delikbağ basins in Gölpazarı.

Bathis and Ahmed (2016) used the HEC-HMS model in Doddahalla watershed [42]. The model is very similar to WinTR-55 medel. Both of these models are very valuable in ungauged watersheds and water-scarce regions where limited monitored data exist.

4. CONCLUSION

Menteşe and Akbulut (2023) found that the dry, normal and humid period rates of Bilecik and Bozüyük were similar to each other. They also noted that both weather stations are not facing a serious drought yet. Our study shows that the drought relationship between Bilecik and Bozüyük districts is similar and supports the study of Menteşe and Akbulut (2023). However, when the R^2 values of Durum wheat are compared, the values of 0.043 in Bozüyük and 0.18 in Bilecik show that Durum wheat is much more affected by drought in terms of yield in Bozüyük compared to Bilecik City center. It is also important to consider that different plant varieties may have different levels of tolerance to drought. Therefore plant yield values and drought severity will not always correlate strongly. Future research should focus on examining the tolerance levels of different plant varieties to drought and adaptation strategies of crop against the drought.

Menteşe and Akbulut (2023) said that 2017 was a "very dry" year for Bilecik. In addition, Uysal (2022) examined 2017 for Bursa with the SPEI method and found that it was a less drier year than the estimation of SPI method. Our research evaluates Bilecik in terms of agricultural drought, which is similar to the results of Uysal (2022) conducted in Bursa. This shows that the drought assessment method used has a significant impact on the results. While the SPI method tries to evaluate drought severity using only precipitation data, the SPEI method offers a more comprehensive evaluation by consider other factors such as evapotranspiration and precipitation. Therefore, the SPEI method is expected to give more accurate results than the SPI method in different climatic regions and seasons. When compared to the results in these researches, the drought results of Menteşe and Akbulut (2023) and Uysal (2022) for 2017 show that the SPEI method is much more reliable than the SPI method. Therefore, it would be more appropriate to use the SPEI method in drought analyses. Drought indices are only indicators. To fully evaluate the effects of drought, other factors (soil moisture, plant stress, etc.) should also be considered.

Alkan (2016) found that for the Osmangazi Güneybayır basin, the peak flow rate, which may occur once in 100 years, reached 156.96 m^3/s. This value is quite above the peak flow rate values of the 4 regions selected as research areas in our research. Therefore, it is thought that this is due to the fact that the construction in the Osmangazi region of Bursa is more dense compared to the 4 regions in our research. On the other hand, the researcher found a peak flow rate of 41.13 m^3/s in the Bayramdere region of Karacabey Kocadere Village, and a peak flow rate of 47.06 m^3/s in the Pazaryeri-Gümüşdere region and 47 m^3/s in the Gölpazarı-Delikbağ stream in our Bilecik study. Since these basins are regionally close to Bursa and have similar hydrological characteristics, it can be said that their peak flow rates are similar.

Among these 4 regions investigated in the research, the fact that the peak flow values that may occur in 100 years in the Gölpazarı-Arap stream, Gölpazarı-Delikbağ stream and Pazaryeri-Gümüşdere region are higher than the Yenipazar-Çöte region. It shows that all 3 regions are higher in terms of construction and slope than Yenipazar-Çöte. Other factors that may affect peak flow values should also be considered. For example, factors such as land use, rainfall amount, concentration time and climate change may also play an important role.

Gölpazarı-Arap Stream has a higher flood risk than other research areas. This area should be considered as a priority to manage flood risk and take preventive precautions. Detailed flood risk maps should be created for each research area. Awareness and education activities should be carried out against flood risk. Necessary steps should be taken for the protection and sustainable management of water basins.

Alkan and Meral (2024) said that the sodium absorption rate in Bozüyük increased (350%) from 0.1 in September to 0.45 in June, and this caused the water quality to deteriorate. Similarly, in Bilecik province, it was observed that the sodium absorption rate increased by 12% from 0.83 to 0.93 and the water quality deteriorated. When the researcher's results are compared with the changes in the RDI values found in our research, it is seen that the deterioration of water quality rises and drought rises are directly proportional. The RDI value in Bozüyük, which was 1.18 in June, decreased to 0.17 (by 594%) in September, and the RDI value in Bilecik, which was 0.8 in June, decreased to 0.37 (by 116%) in September. The 594% decrease in the RDI value and the 350% increase in the SAR value in Bozüyük reveal a significant decrease in the availability of irrigation water. In Bilecik, the RDI value decreased by 116% and the SAR value increased by only 12%. The results indicate that Bilecik has a better water resource than Bozüyük and the quality of this water resource is less affected by drought. In Bilecik, the deterioration in water quality is also less because the drought effect is less.

As a result, factors such as floods, drought and water pollution can lead to yield losses in agricultural production and can lead to degradation of agricultural lands. Therefore, regional disaster risk maps should be created and irrigation planning should be made according to these maps.

As a result of this study, the sensitivity of the main agricultural products in Bilecik against the drought was determined. Besides, the amount of flood water likely to occur in Bilecik was determined. This study will contribute to the literature by examining major disasters such as drought and flood in Bilecik all together. This study has made a difference especially in terms of examining the relationship between drought index result and crop yield with the coefficient of determination.

It is recommended that the results obtained using different drought indices and hydrological models for the region in the future should be compared with the results of this study.

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