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Determination of Climatic Changes in Düzce Province Using Three Different Climate Classification Methods

Düzce İli İklim Değişikliğinin Üç Farklı İklim Sınıflandırma Yöntemi Kullanılarak Belirlenmesi

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Abstract

Aim of this study is to determine the climate characteristics of Düzce province referring to different climate classification systems. The study was carried out in Düzce province. Climate characteristics and climatic changes were analyzed by using De Martonne, Köppen, and Thornthwaite classification methods. The study utilized 60 years of precipitation and temperature data recorded by the General Directorate of Meteorology. Data analyses were conducted within five-year intervals. According to the results, the average annual temperature of Düzce province has been on the rise since 1994, and the average precipitation data for the last 10 years exceeded the 60-year average. In the simple linear regression analysis, it was determined that there was an increase in both average temperature and annual average total precipitation values. According to De Martonne climate classification, the province lies within the semi-humid climate class. Examining the data of the last 10 years, it was determined to be within the Cfak (Hot summer, cool winters, subtropical humid climate) climate class according to the Köppen-Trewartha climate classification and within the B1rB2'b4' (Humid, second-degree mesothermal region with almost no water deficit, and under the influence of oceanic climate) climate class according to the Thornthwaite climate classification. For Düzce province, both the change in climate types according to Köppen-Trewartha and Thorntwaite classifications and the changes in temperature and precipitation data in recent years may indicate climate change.

Keywords: Climate classification, Düzce province, De Martonne, Köppen-Trewartha, Thornthwaite

Özet

Bu çalışmada, farklı iklim sınıflandırma sistemlerine göre Düzce ilinin iklim özelliklerinin belirlenmesi amaçlanmıştır. Çalışma Düzce ilinde gerçekleştirilmiştir. De Martonne, Köppen ve Thornthwaite yöntemleri kullanılarak iklim özellikleri ve iklimsel değişimler analiz edilmiştir. Çalışmada Meteoroloji Genel Müdürlüğü tarafından kaydedilen 60 yıllık yağış ve sıcaklık verileri kullanılmıştır. Veri analizleri beşer yıllık aralıklarla gerçekleştirilmiştir. Sonuçlara göre, Düzce ilinin yıllık ortalama sıcaklığı 1994 yılından itibaren artış göstermiş ve son 10 yılın ortalama yağış verileri 60 yıllık ortalamanın üzerine çıkmıştır. Yapılan basit doğrusal regresyon analizine göre hem ortalama sıcaklık hem de yıllık ortalama toplam yağış değerlerinde artış olduğu tespit edilmiştir. De Martonne iklim sınıflandırmasına göre il genel olarak yarı nemli iklim sınıfına girmektedir. Son 10 yıllık veriler incelendiğinde, Köppen-Trewartha iklim sınıflandırmasına göre, Cfak (yazları sıcak, kışları serin, subtropikal nemli iklim) iklim sınıfı içerisinde, Thornthwaite iklim sınıflandırmasına göre ise B1rB2'b4' (nemli, 2. derece mezotermal, su açığı olmayan, okyanusal iklim etkisine yakın koşullar) iklim sınıfı içerisinde yer aldığı tespit edilmiştir. Düzce ili için hem Köppen-Trewartha ve Thornthwaite sınıflandırmalarına göre iklim tiplerindeki değişim, hem de son yıllardaki sıcaklık ve yağış verilerindeki değişimler iklim değişikliğine işaret ediyor olabilir.

Anahtar Kelimeler: İklim sınıflandırması, Düzce ili, De Martonne, Köppen-Trewartha, Thornthwaite

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1. Introduction

Düzce Province is located within the Western Black Sea Region of Turkey. The province of Düzce, which has significant water resources, consists of %49.9 forest and woodland, %30.3 agricultural land, %0.8 pasture and meadow areas, and %19 non-agricultural areas (Anonymous, 2018). Additionally, the rivers flowing down the mountains around Düzce Province constitute important water resources such as the Great Melen River, Little Melen Stream, Uğur Stream, Asar stream, and Aksu Stream. The streams converging at the Efteni Lake location constitute the tributaries of the Büyük Melen River. The Büyük Melen River is located within the watershed of the Büyük Melen Project, which transports potable water to İstanbul city (Anonymous, 2023). In such areas, where such important ecosystems exist, it is necessary to establish climatic classifications to ensure sustainability. Additionally, determining climate types is crucial for establishing a foundation for various scientific studies (Rolim et al., 2007).

Climate is defined as a meteorological event that characterises the variations in and average values of the atmosphere in a given region or area over a period of time, with the result that ecosystems are significantly influenced (Özyuvacı, 1999; Jylhä et al., 2010; Türkeş, 2000; Türkeş, 2010). Additionally, climate affects agricultural activities, human life, and regional geography (Erol, 1999; Dourado et al., 2013; Dursun and Yazıcı, 2022). For this reason, the climatic characteristics of an area play a crucial role in the formation and management of all natural resources within that area.

Climate classifications are methods used to determine regional and seasonal types of climates (De Castro et al., 2007; Jacobeit, 2010; Bieniek et al., 2012; Gallardo et al., 2013). In the past decades, there have been different climate classification systems proposed by climate scientists such as De Martonne (1926), Köppen and Geiger (1928), Thornthwaite (1948), Flohn (1950), Holdridge (1967), Camargo (1991). The most widely used climate classification systems among those are the Köppen and Thornthwaite methods (Spinoni et al., 2014). Climate classification methods are widely used in climate change (Mahlstein et al., 2013), climate modeling (Jylhä et al., 2014; Aparecido et al., 2016) studies, and issues such as watershed management (Şensoy and Ateşoğlu, 2018). Moreover, such climate classification methods provide a scientific basis for multi-disciplinary studies to be carried out in the regions.

In the De Martonne index, the degree of drought of in a region is determined by referring to the monthly distribution of precipitation and temperature (De Martonne, 1926;

Dursun and Babalık, 2021). Köppen climate classification method is a common method used by most countries around the world (De Castro et al., 2007; Peel et al., 2007; Kim et al., 2008; Alvares et al., 2014; Rolim and Aparecido, 2016; Aparecido et al., 2016; Dursun and Yazıcı, 2022). The Thornthwaite classification system is more complex than the Köppen system (Ács et al., 2015). However, it is a method that should be used to determine the water balance, and budget, as well as potential evaporation, in regions with specific climatic characteristics (Elguindi et al., 2014). It is seen that Thornthwaite method is generally used in some hydrology studies (MGM, 2016; Yılmaz and Çiçek, 2016; Şensoy and Ateşoğlu, 2018; Dursun and Yazıcı, 2022). The method defines the climate type as arid or humid depending on the water requirements of plants (Feddema et al., 2005; Rolim and Aparecido, 2016). In a study conducted by Rolim et al. (2007) in the state of São Paulo, Brazil, they stated that Köppen classification is effective at the macro scale, while Thornthwaite classification is effective at the meso scale, and at the same time, Thornthwaite method is more appropriate for climate issues of agricultural areas.

The province of Düzce, located in the Western Black Sea Region of Turkey, stands out with its water resources and diverse land cover. However, in recent years, flooding and inundation events have adversely affected settlements and fertile lands. In the occurrence of floods and inundations, factors such as drainage, basin shape, and topography, along with short and long-term effects of climate are also present (Ward et al., 2008; Dawson et al., 2009; Şensoy and Ateşoğlu, 2018). For this reason, in this study, the objective is to evaluate the short and long-term climate data in the provincial centre of Düzce and to classify the climate according to the De Martonne, Köppen and Thornthwaite methods.

2. Material and Method

2.1. Study area

The study area is the province of Düzce, located in the Western Black Sea Region of Turkey (Figure 1). The study utilized 60 years of precipitation and temperature data recorded by the General Directorate of Meteorology. The meteorological station in Düzce province is located between 40° 50′ N and 31° 08′ E. The obtained 60-year data have been analyzed within five-year intervals (1964-1968, 1969-1973, 1974-1978, 1979-1983, 1984-1988, 1989-1993, 1994-1998, 1999-2003, 2004-2008, 2009-2013, 2014-2018, 2019-2023). In addition, the last 30 years of data from the center of Düzce province were also included in the evaluation.

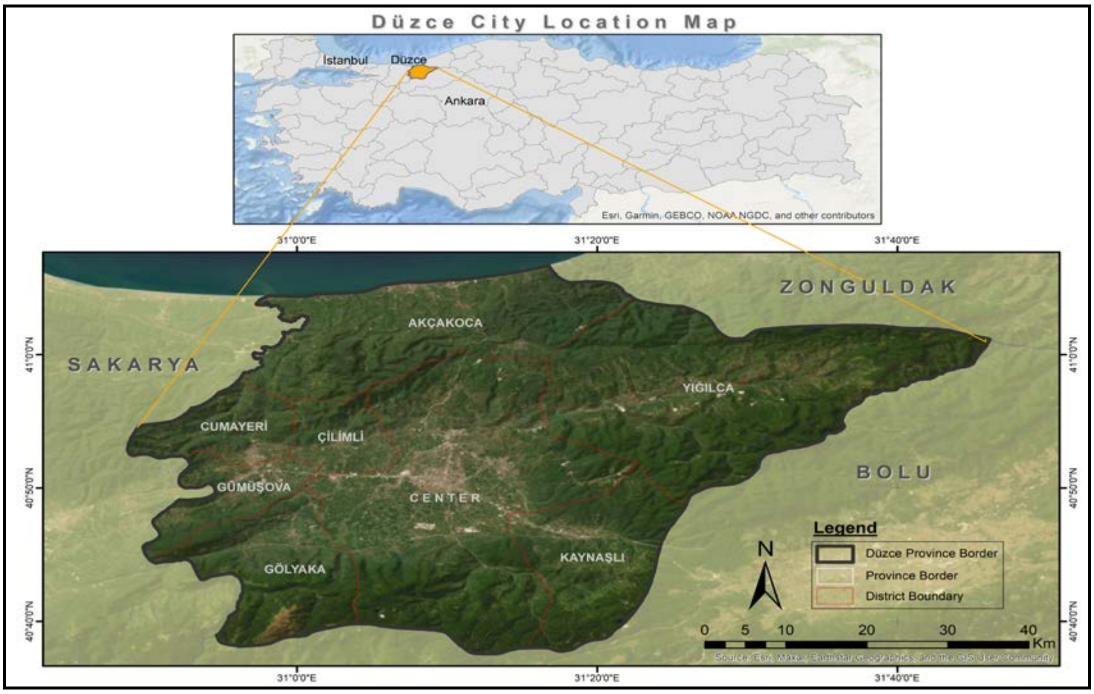

Figure 1. Location of the study area in Turkey.

The research determined whether there is a change in the climate classification of the center of Düzce province according to De Martonne, Köppen and Thorntwaite climate classification methods. In addition, changes over the years in average annual temperature, total annual rainfall, mean temperature during the summer season, and total rainfall during the summer season have been examined. A simple linear regression analysis was used for the evaluation of these data.

2.2. De Martonne ındex

In the De Martonne Index, the climatic characteristics of an area are determined through annual average temperature and total annual rainfall data (De Martonne, 1926). De Martonne made some modifications to the annual index formula with Gottman in 1942 (De Martonne, 1942). As a result of these additions, the De Martonne-Gottman index was obtained (Equation 1).

$$\mathrm{IDMG} = \frac{1}{2}\left(\frac{\mathrm{P}}{\mathrm{T}+10}\right) + \frac{12 \times \mathrm{Pd}}{\mathrm{Td} \times 10} \quad (1)$$

IDMG: De Martonne – Gottman Index, P: Total Annual Rainfall (mm), T: Average annual air temperature (°C), Pd: The amount of rainfall in the driest month (mm), Td: The average temperature of the driest month (°C)

De Martonne drought index (IDMG) data obtained from the formula are classified according to Table 1.

Table 1. De Martonne Index Classification.

IDMG	Climate Class
IDMG < 60	Very Humid
30 < IDMG < 60	Humid
20 < IDMG < 30	Semi-humid
10 < IDMG < 20	Semi-arid to Semi-humid
5 < IDMG < 10	Semi-arid
IDMG < 5	Arid

2.3. Köppen-Geiger Climate Classification

The Köppen (1900) climate classification system, developed by Köppen (1936) and Geiger (1954), is widely used for classifying climates worldwide (Aparecido et al., 2016). The Köppen climate classification system was later updated by Trewartha (1954), and is referred to as the Köppen-Trewartha climate system. The six main cliamte groups in the Köppen-Trewartha classification system are each represented by two or three characteristics. The first letter specifies the climate zone based on temperature and rainfall. The second letter is determined by the seasonal distribution of rainfall (Figure 2).

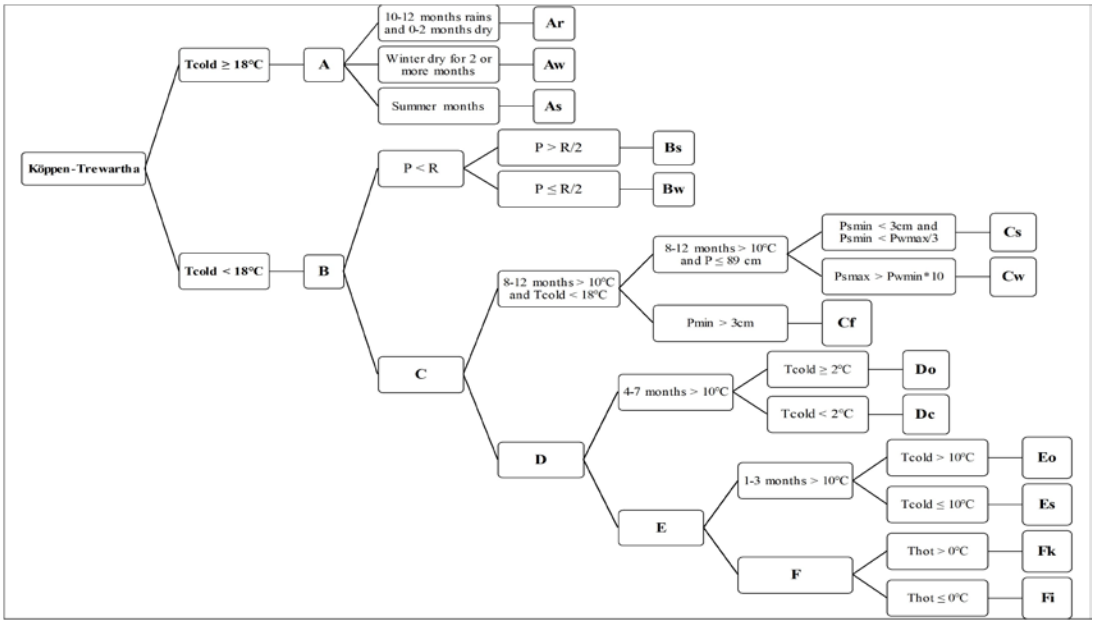

Figure 2. The rules of the Köppen-Trewartha climate classification system are organized according to Köppen and Geiger (1928) and Trewartha (1954); Tcold is the average temperature of the coldest month; Thot is the average temperature of the hottest month; T is the average annual temperature; P is total annual rainfall; Ps is summer months (April to September); Pw is winter months (October to March); Psmin is lowest rainfall in summer; Pwmin is lowest rainfall in winter; Psmax is highest rainfall in summer; Pwmax is highest rainfall in winter; Pmin is rainfall in the driest month; R is limit value.

The Köppen-Trewartha climate classification calculates the limit value (R) for the letter B (Equation 2). If the annual total rainfall (P) is less than the threshold value (R), the B climate class is recognized.

$$R = 2.3 \times T - 0.64 \times Pw + 41 \quad (2)$$

R: Limit Value, T: Average annual air temperature (°C), Pw: Percentage of annual rainfall falling during the winter months

In the Köppen-Trewartha climate classification system, each letter indicates the main climate group. The letters constituting the main climate groups are determined according to Table 2.

Table 2. Climate types according to Köppen-Trewartha climate classification system.

Climate Class	Symbol	Description
A	Ar	Tropical, rainforest climate
	Aw	Tropical savanna climate
	As	
B	Bs	Semiarid - Steppe Climate
	Bw	Arid or desert climate
C	Cs	Subtropical dry summer climate, Mediterranean climate
	Cw	Subtropical dry winter climate
	Cf	Subtropical humid climate
D	Do	Temperate Marine Climate
	Dc	Temperate Terrestrial Climate
E	Eo	Sub-Arctic Marineclimate
	Ec	Sub-Arctic Terrestrial climate
F	Ft	Tundra Climate
	Fi	Ice Climate

According to the Köppen-Trewartha climate classification system, the third and fourth letters are classified based on the universal temperature scale. Average temperatures for summer and winter months are considered in this classification (MGM, 2018b) (Table 3).

Table 3. Universal temperature scale symbols for Köppen-Trewartha climate classification.

Average monthly temperature (°C)	Symbol	Description
35°C ≤ T	i	Intensely hot
28°C ≤ T < 35°C	h	Very hot
23°C ≤ T < 28°C	a	Hot
18°C ≤ T < 23°C	b	Warm
10°C ≤ T < 18°C	l	Mild
0°C < T < 10°C	k	Cool
-10°C < T ≤ 0°C	o	Cold
-25°C < T ≤ -10°C	c	Very cold
-40°C < T ≤ -25°C	d	Intensely cold
T ≤ -40°C	e	Extremely cold

2.4. Thornthwaite Climate Classification

The Thornthwaite Climate Classification System is calculated based on the average monthly temperature, total monthly average rainfall, and the latitude of the region (in degrees) for which the climate class is to be determined (Thornthwaite, 1948). The method is commonly viewed as a physical environment where water first reaches the soil and then evaporates back into the atmosphere (Aparecido et al., 2016). In this climate classification, the concept of potential evapotranspiration becomes prominent. The average monthly temperature, the annual temperature index and the latitude correction coefficient are all used to calculate the potential evapotranspiration (Equation 3).

$$\mathrm{PET} = 16 \times \left(\frac{10 \times \mathrm{t}}{\mathrm{I}}\right)^{\alpha} \times \mathrm{G} \qquad (3)$$

PET: Potential evapotranspiration
t: Average monthly temperature (°C)
I: Annual air temperature index
G: Latitude correction coefficient

$$\alpha = 6.7510 \times 10^{-7} \times \mathrm{I}^3 - 7.7110 \times 10^{-5} \times \mathrm{I}^2 + 1.791210 \times 10^{-2} \times \mathrm{I} + 0.49239$$

After determining the potential evapotranspiration, the rainfall effectiveness (Im), drought (Ia) and humidity (Ih) indexes are calculated (Equation 4-6). These indexes are calculated based on the annual water surplus (s), annual water deficit (d), and annual potential evapotranspiration (n).

$$\mathrm{Im} = \frac{100\mathrm{s} - 60\mathrm{d}}{\mathrm{n}} \qquad (4)$$

$$\mathrm{Ia} = \frac{100\mathrm{d}}{\mathrm{n}} \qquad (5)$$

$$\mathrm{Ih} = \frac{100\mathrm{s}}{\mathrm{n}} \qquad (6)$$

Symbols are also used in the Thornthwaite climate classification system. In the classification, the first symbol is the rainfall effectiveness index (Table 4), and the second symbol is the temperature effectiveness index, determined based on the annual potential evapotranspiration (Table 5). The third symbol is the drought and humidity indexes determined based on the precipitation regime (Table 6), and the final symbol is the ratio of the potential evapotranspiration (PET) values for the summer month over the annual potential evapotranspiration value index (Table 7).

Table 4. Rainfall effectiveness index (Im) (Thornthwaite, 1948).

Im	Symbol	Climate Type
100 ≤ Im	A	Very humid
80 ≤ Im < 100	B4	Humid
60 ≤ Im < 80	B3	
40 ≤ Im < 60	B2	
20 ≤ Im < 40	B1	
0 ≤ Im < 20	C2	Sub-humid
-20 ≤ Im < 0	C1	Sub-arid to Sub-humid
-40 ≤ Im < -20	D	Sub-arid
-60 ≤ Im < -40	E	Arid

Table 5. Temperature effectiveness index (Thornthwaite, 1948).

Annual PET (mm)	Symbol	Climate Type
1141 ≤ PE	A	Megathermal
998 ≤ PE < 1141	B'4	Mesothermal
885 ≤ PE < 998	B'3	
712 ≤ PE < 885	B'2	
570 ≤ PE < 712	B'1	
427 ≤ PE < 570	C2	Microthermal
285 ≤ PE < 427	C1	
142 ≤ PE < 285	D	Tundra
PE ≤ 142	E	Perpetual ice

Table 6. Thornthwaite (1948) rainfall regime index; WD is water deficiency, WS is water surplus, WD_S is water deficiency in summer, WD_W is water deficiency in winter, WS_S is water surplus in summer, WS_W is water surplus in winter, Ia is drought index, Ih is humidity index.

Drought Index for Humid Climates (A1, B, and C2)			
Ia	**Condition**	**Symbol**	**Description**
0 ≤ Ia < 16.7		r	Without or with a minimal WD
16.7 ≤ Ia < 33.3	$WD_S > WD_W$	s	Moderate summer WD
	$WD_S < WD_W$	w	Moderate winter WD
33.3 ≤ Ia	$WD_S > WD_W$	s2	Strong summer WD
	$WD_S < WD_W$	w2	Strong winter WD
Moisture Index for Arid Climates (C1, D, and E)			
Ih	**Condition**	**Symbol**	**Description**
0 ≤ Ih < 10		d	Without or with a minimal WS
10 ≤ Ih < 20	$WS_S > WS_W$	s	Moderate summer WS
	$WS_S < WS_W$	w	Moderate winter WS
20 ≤ Ih	$WS_S > WS_W$	s2	Strong summer WS
	$WS_S < WS_W$	w2	Strong winter WS

Table 7. The index of the ratio between summer PET values and annual PET values.

PET (%)	Symbol	Climate Type
PET% < 48	a'	Full oceanic climate conditions
48 ≤ PET% < 51.9	b'4	Conditions close to oceanic climate conditions
51.9 ≤ PET% < 56.3	b'3	
56.3 ≤ PET% < 61.6	b'2	
61.6 ≤ PET% < 68	b'1	
68 ≤ PET% < 76.3	c'1	Conditions close to continental climate conditions
76.3 ≤ PET% < 88	c'2	
88 ≤ PET%	d'	Fully continental climate conditions

3. Results and Discussion

3.1. Temperature and Rainfall Averages

The average temperature in Düzce was determined to be 13.4 °C for a total of 60 years between 1964 and 2023. When the average temperature change over time is examined for Düzce Province, it is observed that the average temperature has been increasing since the year 1994 (Figure 3). If we check the temperature values during the summer months, the average temperature between 1964 and 2023 is observed to be 21.9 °C (Figure 4). During the time period after 1999, average summer temperatures have been above this value. According to a simple linear regression analysis, it is seen that the average temperature (r=0.771) and average summer period temperature (r=0.862) values increase over the years (Figure 3-4).

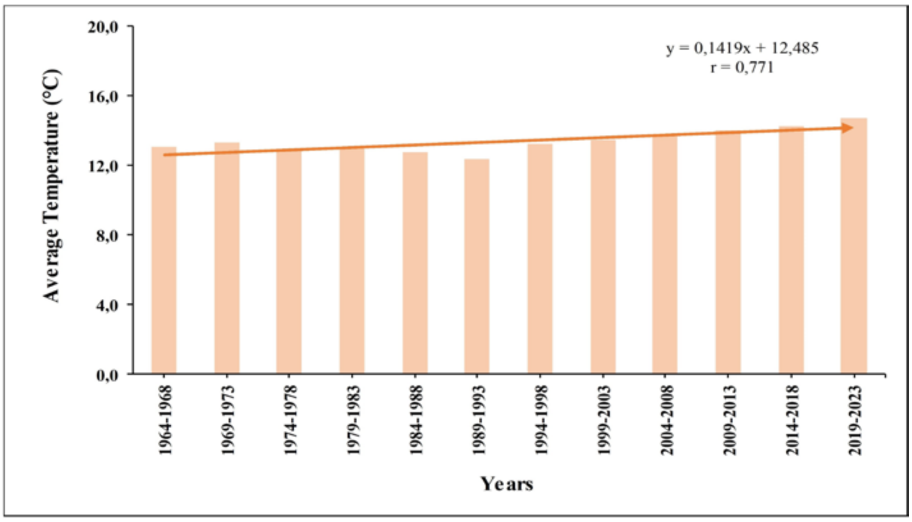

Figure 3. Change in the average annual temperature in Düzce province according to years.

Figure 4. Change in the average annual summer temperature in Düzce province according to years.

The average annual temperature, which was 12.4°C between 1989-1993, was observed to be 13.2°C between 1994-1998. According to Hansen et al (2005), it is indicated that the global average temperature has increased by 0.8 °C since the year 1900. According to this information, it can be said that the average temperatures, varying by years, were high for the Düzce Province. Bolat et al. (2018) evaluated the average temperature data between 1980-1999 and 2000-2015 and stated that the average temperature between 2000-2015 was higher than the other periods. In a study conducted by Bolat and Şensoy (2023) for the Bartın, Zonguldak and Düzce Provinces, an increase in temperature was observed between 2012 and 2021. These results are similar to the study conducted. When the change in average temperature values during the summer months are examined over time, it is observed that the average temperature has been increasing since 1984. In another study conducted for Bartın Province, which is close to Düzce Province, between the years 1965-2014, it has been determined that, similarly, the average temperature during the summer months had been continuously increasing since 1980 (Şensoy and Ateşoğlu, 2018).

Between the years 1964-2023, the average annual total rainfall in Düzce Province has been determined as 832.22 mm. When examining the average annual total precipitation change for Düzce Province over time, the average annual precipitation values for the last 10 years were above the average annual precipitation values of the last 60 years. Additionally, when analyzing the average monthly precipitation data for 60 years, it is observed that the highest rainfall reached in December, but in the last 10 years, the highest rainfall reached in January (Figure 5). Considering the values of the summer months, which are important in terms of flooding and flood risk, it was determined that the average total precipitation in Düzce in the summer months between 1964 and 2023 was 164.84 mm. However, when the data for the last 10 years were examined, it is observed that this value has increased up to 230.33 mm. In addition, the highest precipitation during the summer months for Düzce Province is observed in June (Figure 6). According to a simple linear regression analysis, there is a slight increasing trend in average rainfall ($r=0.069$), while average summer period rainfall ($r=0.246$) shows a higher increasing trend compared to annual average rainfall (Figure 5-6).

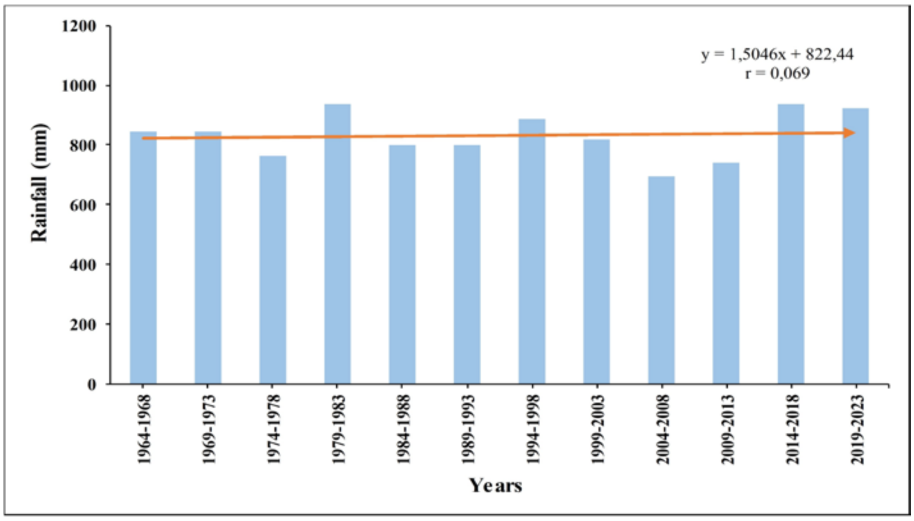

Figure 5. Change in the average annual rainfall in Düzce province according to years.

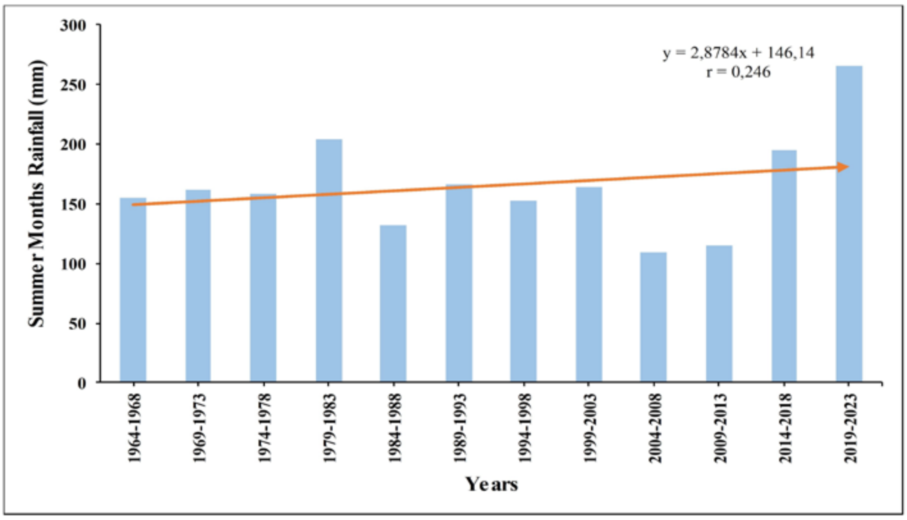

Figure 6. Change in the average annual summer rainfall in Düzce province according to years.

In a study conducted in Bartın province, which has a similar climate to Düzce province, it was stated that the average rainfall between 1965-2014 was lower than the average rainfall between 1995-2014 (Şensoy ve Ateşoğlu, 2018). This situation actually shows that there has been an increase in the average rainfall after 1995. In a study on the temperature and rainfall changes between 1980-1999 and 2000-2015 in Bartın, Zonguldak, and Düzce provinces, a decrease in rainfall data during the summer months was reported (Bolat et al., 2018). This result showed similarity when compared with the findings of this study. In a study conducted by Bolat and Şensoy (2023), it was reported that the average annual total rainfall values within Düzce province showed an increasing trend between the years 2012-2021. Furthermore, in the same study, it was stated that the average annual total rainfall between 2012-2021 was 874.22 mm. When examining the rainfall data for Düzce province, it is observed that the average annual total rainfall for the last 10 years was above this value, indicating an increase in rainfall values. When we look at the values for Düzce province, the average annual rainfall measured from 1979 to 2018 was below the average annual rainfall measured in 1979. However, when the average annual precipitation of the last 5 years is analyzed, it is seen that there is an increase that surpasses all other periods.

3.2. De Martonne-Gottman Index

According to the De Martonne-Gottman Index, Düzce province falls into the semi-humid climate class (Table 8). When the complete data for 60 years were evaluated throughout the year for Düzce Province, December and January months were classified as very humid, October, November, February, March, and April dropped within the humid class. September, May, and June were classified as semi-humid, while July and August fell into the semi-arid to semi-humid class.

Table 8. Düzce's climate type according to the De Martonne-Gottman drought index (IDMG).

Years	IDMG	Climate Type
1964-1968	26.81	Semi-humid
1969-1973	23.35	Semi-humid
1974-1978	21.25	Semi-humid
1979-1983	27.08	Semi-humid
1984-1988	19.5	Semi-arid to Semi-humid
1989-1993	26.43	Semi-humid
1994-1998	26.10	Semi-humid
1999-2003	25.24	Semi-humid
2004-2008	19.28	Semi-arid to Semi-humid
2009-2013	20.47	Semi-humid
2014-2018	26.78	Semi-humid
2019-2023	24.91	Semi-humid

Düzce Province was in the semi-humid class except for the years 1984-1988 and 2004-2008 according to the De-Martonne-Gottman index (Table 8). According to the study conducted by MGM (2018a), based on the 30-year data from 1981 to 2010, Düzce Province was classified as semi-humid. Similarly, in the study conducted by MGM (2024) between 1991 and 2020, Düzce province was classified as semi-humid. In this study as well, when the 30-year data from 1994 to 2023 is examined, Düzce Province was similarly classified as semi-humid. Partal and Yavuz (2020) conducted a trend analysis based on the De Martonne aridity index for the Western Black Sea Region. As a result of their analysis, they indicated that there is a decreasing trend in precipitation and an increase in aridity in the province of Düzce.

3.3. Köppen-Trewarthe Climatic Classification

According to the Köppen-Trewartha climate classification system, a total of 2 groups (C and D) and 4 climate classes (Do, Dc, Cf, Cs) were identified for Düzce Province between 1964 and 2023 (Table 9). Over the 60-year period in Düzce Province, the predominant climatic class was the Do class. However, in recent years, a shift towards the C group has been observed. Düzce province was in the Cs class between 2009 and 2013 and in the Cf class between 2014 and 2023. According to the Universal Temperature Index, for Düzce province between 2014 and 2023, the third and fourth letters were a and k, respectively (Table 3). In this context, when examining the data for the last 10 years for Düzce province, it is determined that it was within the Cfak class (hot summers, cool winters, subtropical humid climate).

Table 9. Düzce's climate type according to the Köppen-Trevartha (K-T) climate classification.

Years	K-T Symbols	Climate class description
1964-1968	Cfbk	Warm summers, cool winters, subtropical humid climate
1969-1973	Dobk	Warm summers, cool winters, temperate marine
1974-1978	Dobk	Warm summers, cool winters, temperate marine
1979-1983	Dobk	Warm summers, cool winters, temperate marine
1984-1988	Dobk	Warm summers, cool winters, temperate marine
1989-1993	Dcbk	Warm summers, cool winters, temperate terrestrial
1994-1998	Dobk	Warm summers, cool winters, temperate marine
1999-2003	Doak	Hot summers, cool winters, temperate marine
2004-2008	Doak	Hot summers, cool winters, temperate marine
2009-2013	Csak	Hot summers, cool winters, subtropical dry summer climate.
2014-2018	Cfak	Hot summers, cool winters, subtropical humid climate
2019-2023	Cfak	Hot summers, cool winters, subtropical humid climate

According to the classification performed by MGM (2018b) and MGM (2023a) for the period between 1981-2010 and 1991-2020, it is observed that Düzce province was in the Do group. Similarly, in this study, when the data for the 30 years from 1994 to 2023 is considered, it is observed that the climate of Düzce province falls into the Do class. However, it was determined that the climate class changed between 2014 and 2023, and entered the Cf group when the data of the last 10 years are analyzed. At the same time, according to the Universal Temperature Index, in the 30-year study conducted by MGM (2018b) between 1981 and 2010, Düzce province was in the Dobk group, study conducted by MGM (2023a) between 1991 and 2020, Düzce province was in the Doak group, while between 1994 and 2023, it was in the Doak class. In the 10 years between 2014 and 2023, Düzce Province is classified as Cfak. Sparovek et al (2007) reported, based on the Köppen (1900) classification, that the climate classes Cfa (warm temperate climate with hot summers) and Cfb (warm temperate climate with mild summers) were characterized as climates without a dry season. Based on recent years climate data for Düzce province, it is observed that it has a climate characteristic without dry season, with hot summers and cool winters and is classified as humid. Yılmaz and Çiçek (2016) indicated in their study on the detailed Köppen-Geiger climate regions of Turkey that the province of Düzce was classified as Cfa between 1971 and 2010. Similarly, Öztürk et al. (2017) reported that the Cfa climate classification is dominant in the Western Black Sea Region.

3.4. Thornthwaite Climatic Classification

According to the Thornthwaite climate classification method, the potential evapotranspiration, water deficit and water surplus values were determined for Düzce Province for the period between 1964 and 2023. The potential evapotranspiration values showed an increase starting from the year 1989. For Düzce province, it was found that there was an increase in water deficit between 1989 and 2013. However, between 2014 and 2023, the increased amount of precipitation led to a decrease in water deficit (Table 10).

Table 10. According to the Thornthwaite climate classification, the rainfall (P), potential evapotranspiration (PE), water deficiency (WD), and water surplus (WS) values.

Years	P(mm)	PE	WD	WS
1964-1968	845.1	736.2	176.7	285.7
1969-1973	845.6	740.5	179.9	284.0
1974-1978	764.2	727.2	124.9	180.2
1979-1983	935.6	729.2	119.9	326.2
1984-1988	801.5	723.6	232.2	322.4
1989-1993	799.8	718.3	156.1	237.6
1994-1998	884.1	741.4	198.0	340.7
1999-2003	818.3	753.7	204.9	269.6
2004-2008	692.7	761.8	269.0	199.9
2009-2013	740.6	774.4	273.9	240.1
2014-2018	934.2	781.8	129.8	314.6
2019-2023	924.9	798.3	122.4	273.7

The assessments for Düzce Province show that water is generally retained in the soil between October and November months. In the field, there is a surplus of water in December, January, February, March and April. In May and June, water is consumed from the stroge and in July, August and September there is a water deficit (Figure 7).

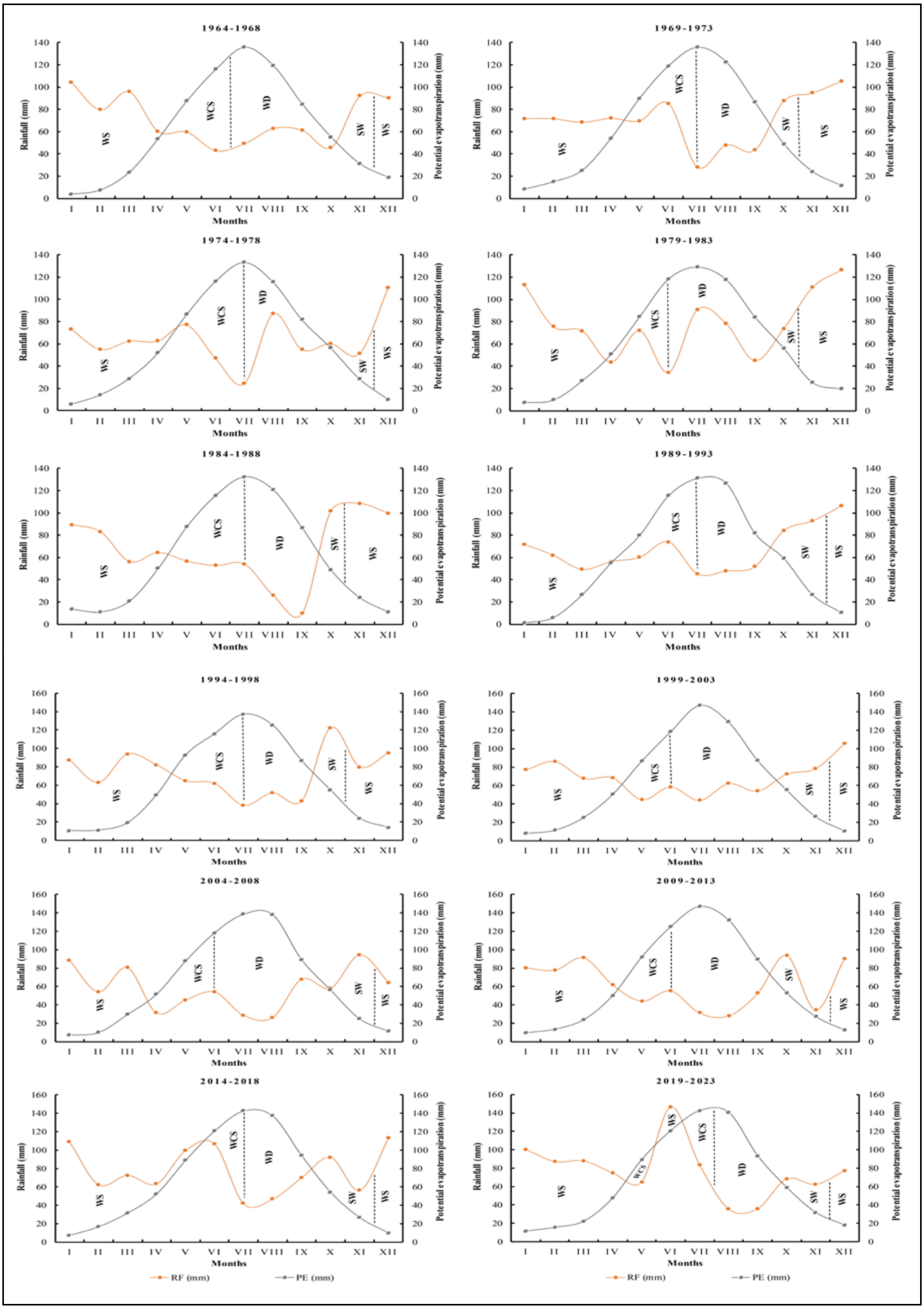

Figure 7. Water balance of Düzce province by years in Thornthwaite (1948) climate classification; RF is rainfall; PE is potential evapotranspiration; SW is the water retained in the soil; WCS is water loss from the soil, WS is the water surplus, WD is water deficit.

According to the Thornthwaite climate classification method, indexes for rainfall effectiveness (RE), temperature effectiveness (TE), rainfall regime (Ia), and the ratio of potential evapotranspirastion to the three summer months were calculated to determine the climate type (Table 11).

Table 11. RE, TE, Ia and PET values according to years in Thornthwaite climate classification.

Years	RE	TE	Ia	PET
1964-1968	24.4	736.2	24.0	50.4
1969-1973	23.9	740.5	24.2	50.9
1974-1978	14.5	727.2	17.2	50.2
1979-1983	34.9	729.2	16.4	50.0
1984-1988	25.3	723.6	32.1	51.0
1989-1993	20.0	718.3	21.7	51.9
1994-1998	29.9	741.4	26.7	51.1
1999-2003	19.5	753.7	27.2	52.3
2004-2008	5.1	761.8	35.3	51.8
2009-2013	9.8	774.4	35.4	52.2
2014-2018	30.3	781.8	16.6	51.3
2019-2023	25.1	798.3	15.3	50.7

According to the Thornthwaite climate classification method, a total of 7 different climate classes have been identified for Düzce province between 1964 and 2023. According to the Rainfall Effectiveness Indices, when the 60-year data calculated in five-year periods were evaluated for Düzce Province, the predominant climate class is found to be B1 class. Between 1974-1978 and 1999-2013, Düzce Province was classified in the C2 climate class in five-year periods. However, when the data of the last 10 years is examined, Düzce Province was in the B1, humid climate class. According to the temperature efficiency index, for Düzce province, class B2, according to the rainfall regime, class "s", and according to the annual potential evapotranspiration ratio to the three summer months, class "b4" are predominant (Table 12).

Table 11. According to Thornthwaite climate classification, the representation of Düzce province with letters.

	Years					
Climate type	**1964-1968**	**1969-1973**	**1974-1978**	**1979-1983**	**1984-1988**	**1989-1993**
	B1sB2'b4'	B1sB2'b4'	C2sB2'b4'	B1rB2'b4'	B1sB2'b4'	B1sB2'b4'
Climate type	**1994-1998**	**1999-2003**	**2004-2008**	**2009-2013**	**2014-2018**	**2019-2023**
	B1sB2'b4'	C2sB2'b3'	C2s2B2'b4'	C2s2B2'b3'	B1rB2'b4'	B1rB2'b4'

Based on MGM's (2016) classification of the 30-year period between 1981 and 2010, Düzce province falls under the B1 climate group. In addition, according to the classification made by MGM (2023b) for the 30-year period between 1991-2020, Düzce province is located in the C2 climate group. According to our study, when evaluating the average data for the 30 years between 1994 and 2023, it was determined that Düzce province similarly belongs to the C2 climate group. Similarly, in the study conducted by Baş (2023), it was determined that Düzce province was in the C2 climate group between the years 1959-2021. However, when the data for the last 10 years was evaluated, it is observed that Düzce Province is again in the B1 climate group. MGM (2016) reported that Düzce Province was indicated with the letters B1sB2'b3' between 1981 and 2010. However, according to the study conducted by MGM (2023b) between 1991 and 2020, it was reported to be indicated with the letters C2sB2'b4'. In this study, similar to MGM (2023b), it was determined that it was indicated with the letters C2sB2'b4' between 1994 and 2023. According to the Thornthwaite classification, based on the average values between 1994 and 2023, we can describe the province of Düzce Province as a region with a semi-humid climate, moderate water deficiency in summer, second-degree mesothermal, and under the influence of an oceanic climate. However, according to the data fort he last 10 years (2014-2023), Düzce Province is represented by the letters B1rB2'b4'. According to the last 10 year data, Düzce province in seen as a humid, second-degree mesothermal region with almost no water deficit, and under the influence of oceanic climate. In fact, this could be an indication that the climate class will change in the coming years.

4. Conclusions

According to the simple linear regression analysis for Düzce province, there has been an increase in both average temperature and annual average total precipitation values. Furthermore, there is a change in climate types according to Köppen-Trewartha and Thornthwaite classifications. In fact, changes in temperature and precipitation data in recent years may indicate climate change. This condition may pose considerable hazards in the coming years, including changes in land use, depletion of natural resources, a decline in biodiversity, harmful effects on hydrological systems, and a negative impact on human health. Climate change causes irregularities in the distribution and amount of precipitation over a given period of time, leading to adverse events such as flooding, especially in summer. To prevent this situation, restoration efforts in riverbeds should be increased. These restoration efforts should be evaluated ecologically, and the use of concrete and stone channels in riverbeds should be avoided. Instead of this, it is recommended to increase the number and volume of streams in the upper watersheds. Additionally, reducing the increasing concrete development in city centers and increasing green area projects instead is necessary. The green areas should be generated, which then will contribute to the water absorption by the soil and assist to mitigate the risks of flooding.

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