RESEARCH

Determining climate classifications and producing climate border maps with GIS of Muğla province on the southern Aegean Sea coast of Türkiye

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Abstract

Climate is defined by the average of meteorological events observed over an extended period in a region, expressing the weather conditions of that area. Numerous scientists have developed various climate classifications. The fundamental purpose of these classifications is to distinguish different types of climates and thereby reveal similarities between regions. Such classifications can be based on factors like temperature and precipitation patterns. Understanding climate characteristics enables us to determine the boundaries of different climate types. This, in turn, is crucial for ensuring the sustainable use of regional resources and shaping land use plans. This study evaluates the process of creating climate boundary maps for Muğla province. Various climate classification methods, including Thornthwaite, Trewartha, Erinç, De Martonne, Köppen—Geiger, and Köppen, are comprehensively examined and compared. Our findings indicate that each method offers different approaches to defining Muğla's climate, each with its unique advantages and limitations. For instance, while the Thornthwaite method provides detailed data, the Köppen—Geiger method offers a more generalized approach. The results suggest that combining various climate classification methods helps in more accurately and comprehensively mapping the climate boundaries of Muğla province. This study underscores the importance of integrating these diverse methods to contribute to the determination of climate boundaries and regional planning processes.

1 Introduction

Climate not only determines the character of regions in terms of weather events but also has an influence on the determination of vegetation. Understanding the characteristics of climate ensures the identification of boundaries with different climate types, thus benefiting both resource management and sustainable land use planning (Colak

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and Memisoglu 2021). It is assessed that, like worldwide, extreme climate conditions have increased in Türkiye since the 2000s (Özüpekçe 2021). Climate change has particularly made living conditions more challenging in global southern countries (Carmin et al. 2012). Climate change also affects the stability of slopes, in other words, it influences landslide formation by increasing heavy precipitation, which is a trigger for landslides (Gariano and Guzzetti 2016). Climate change causes shorter precipitation-runoff response and reduced effective precipitation due to increased evapotranspiration and decreased soil moisture (Anagnostolpoulou et al. 2017). In recent years, along with climate change, a significant increase in the number of forest fires has also been observed in the Mediterranean Basin (Calda et al. 2020).

As stated in the IPCC reports, Türkiye is located in the Eastern Mediterranean basin, which is one of the region most sensitive to climate change (Gürkan et al. 2016). According to the 2080–2099 period summer and winter

rainfall anomalies projections made with both A1B scenarios within the scope of CMIP3 and RCP4.5 scenarios within the scope of CMIP5, decreases in precipitation are predicted in a large part of Türkiye. In the summer season projections, decreases are predicted for all of Türkiye, and increases are predicted for the coastal parts of the Black Sea Region in the winter (IPCC 2013; Gürkan et al. 2016). According to the IPCC 5th Assessment Report, temperatures in the Mediterranean basin and Europe will continue to increase throughout the 21st Century (IPCC 2013; Gürkan et al. 2016). This is a situation that should be taken into consideration for Muğla and its districts, some of which are located in the Mediterranean Region and offer Mediterranean climate characteristics.

In Türkiye, one of the countries that signed the Paris Climate Agreement, various initiatives and efforts on climate change and environmental issues are ongoing, involving both central and local governments as well as active civil society organizations (Bostancı 2022). In this context, the determination of climate characteristics is among the priority topics. The identification of climate classes is necessary for determining climate characters. Climate classification methods are used in the analysis of regional and spatial climate classification, meteorological, agricultural, and hydrological drought, humidity, forest fires, agricultural diversity, suitability for residence, tourism planning, and similar analyses. Among the frequently used methods, we can mention the Schendel (1968), Thornthwaite (1948), Trewartha (1968), Aydeniz (1985), Erinç (1949), De Martonne (1942), Köppen (1918), and Köppen and Geiger (1954) methods. Valjarević et al. (2022) analyzed four scenarios regarding climate change in accordance with the TWCC classification in their study, in which they used 4261 meteorological stations from which temperature and precipitation data were taken and two climate models representing the most extreme models in the CMIP6 database. Shanmugam et al. (2024) used the Combined Model Intercomparison Project Phase 6 (CMIP6)-based MIROC6 GCM and SSP245 and SSP585 datasets. The importance of significant changes in rainfall patterns for agriculture and the dependence of cropping systems on rainfall variability will lead to the emergence of climate-resistant agricultural system practices and agricultural policies (Lakshmi et al. 2024). Therefore, determining climate boundaries can help determine agricultural activities and plant species changes.

The region of Muğla, which is the study area, is also among the areas where water resources are negatively affected due to severe summer drought conditions in terms of climate characteristics (Türkeş and Altan 2013). Şensoy et al. (2019), as a result of their climate index trend studies in the Muğla region, have demonstrated that the increase in temperature and evaporation, along with population growth,

will increase the pressure on the province's water resources. According to Özüpekçe (2021), during the period spanning from 1951 to 2017, it has been determined that Bodrum experiences approximately one drought period every 5 years, Muğla center (Menteşe) every 9 years, and Köyceğiz and Fethiye stations every 8 years based on the frequency of drought occurrence. Furthermore, the most severe drought periods were identified as 1957 and 1987 for Marmaris, and 1976 for Datça. Yılmaz (2021) has observed that annual temperature values for meteorological stations in Muğla province show a consistent increasing trend.

Considering the fact that Muğla province, which has a population of over 1,000,000 and a high annual population growth rate (Bostancı 2022), is also located on the coast, it becomes crucial to be aware of its climate characteristics and water balances, especially in terms of both tourism activities and water requirements during the tourism seasons. Additionally, due to the majority of precipitation occurring in the winter months in the province, drought becomes prominent in the summer months (Alkayis et al. 2022). From a climate policy perspective, it is worth noting that Muğla Municipality is still in the process of developing its local climate change action plans (Bostancı 2022).

Using point data, interpolation processes have been applied to generate climatic data at various spatial scales, ranging from a few thousand square kilometers (Holdaway 1996) to continental (Hulme et al. 1995; Willmott and Matsuura 1995) and even global coverage (Willmott and Robeson 1995). Many of these studies employed local interpolation methods that utilize measured data from neighboring points to estimate data at any given point. These methods include Inverse Distance Weighting (IDW) (Willmott and Matsuura 1995; Dodson and Marks 1997), spline (Hulme et al. 1995), and Kriging (Holdaway 1996; Hudson and Wackernagel 1994; Hammond and Yarie 1996). In this study, the Kriging method was employed.

For this reason, measurement data for a 30-year period from 13 meteorological stations located in the districts of Muğla province were collected (Climate Data 2023). The obtained data were associated with their respective locations, and using the Kriging interpolation method and Thornthwaite (1948) climate classification method, the water balance of each district station were determined. In addition, climate type was determined using the climate classification methods of Thornthwaite (1948), Trewartha (1968), Erinç (1949), De Martonne (1942), Köppen and Geiger (1954) (Kottek et al. 2006) Köppen (1918).

This study offers a novelty that can be used as a basis for planning to sustain both the tourism and agricultural characteristics of Muğla province, including all its districts, and to prevent it from being affected by climate changes. It will also help in examining possible future alternative situations

of the Muğla region due to climate change. Another novelty of this study is the comparison of climate type results determined using different climate classification methods and the creation of climate boundary maps based on planning.

It is believed that this study will provide guidance for local governments in their assessments related to climate change and water crises. Furthermore, the aim of this study is to contribute to future efforts by local governments in Muğla and its districts, where climate and water policies are addressed in a comprehensive manner. Projected climate variability also needs to be taken into account in large-scale hydraulic projects (Anagnostolpoulou et al. 2017). It is evident that efforts related to climate change risk management and water resource management in Muğla, a growing province with continuously increasing tourism capacity and consequently population, will assist decision-makers in shaping the future of the region.

2 Methodology

2.1 Study area

Muğla province is located in the southwestern part of the Aegean region in Western Anatolia, Türkiye. It consists of a total of 13 districts and is bordered by Aydın and Denizli to the north, Antalya to the east, the Mediterranean Sea to the south, and the Aegean Sea to the west (Fig. 1). Muğla is one of Türkiye's significant provinces in terms of forest resources, with a total forest area of 840,108 hectares (Türkeş and Altan 2012). Physically, Muğla spans both the

Aegean and Mediterranean regions, with Bodrum, Datça, Kavaklıdere, Marmaris, Menteşe, Milas, Ula, and Yatağan districts situated in the Aegean region, and Dalaman, Fethiye, Köyceğiz, Ortaca, and Seydikemer districts located within the Mediterranean region.

Muğla has the longest coastline in Türkiye in terms of its proximity to the sea. Its average elevation from the sea is approximately 650 m. Its coastal location plays a significant role in shaping the region's climate (Oğuz et al. 2021).

2.2 Methods

To classify the climate, water balance tables were computed using long-term monthly average precipitation, temperature, and evapotranspiration values (Thornthwaite 1948). Depending on the climatic conditions, the maximum amount of water that can be lost through evaporation and transpiration is represented by potential evapotranspiration (Etp). The values for potential evapotranspiration (Etp) and actual evapotranspiration (Etr) within the study area were calculated using the Thornthwaite (1948) method based on monthly average temperature, precipitation, and relative humidity data measured at the Meteorological Stations. A geographical information system (GIS)-based surface map of climate boundaries representing the entire region was generated using the Kriging interpolation method. To determine precipitation efficiency and climate type, the Thornthwaite (1948) (Eq. 1), De Martonne (1942) (Eq. 2), Erinç (1949) (Eq. 3), Köppen (1918) (Eq. 4), Köppen and Geiger (1954) (Kottek et al. 2006), Trewartha (1968) universal temperature scale climate classification methods were

Fig. 1 Study area location map. (modified from URL-1 2024)
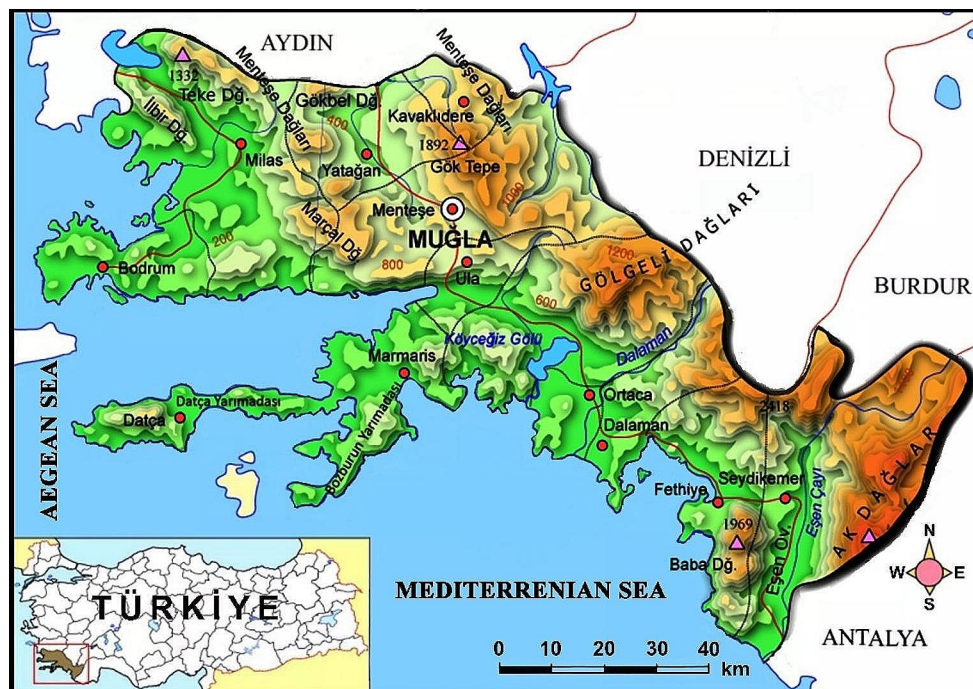
utilized. Among these methods, Thornthwaite (1948) was particularly preferred as it can reveal both precipitation efficiency and temperature indices, as well as drought-moisture and marine-continental conditions. The climate classification not only identified climate types within the study area but also delineated the climate boundaries.

$$Etp = 16 \times \left(\frac{10 \times t}{I} \right)^a \times p, \qquad i = \left(\frac{t}{5} \right)^{1.514}, \qquad I = \sum i \qquad (1)$$

$$a = 6.75 \times 10^{-7} \times I^3 - 7.71 \times 10^{-5} \times I^2 + 1.79 \times 10^{-2} \times I + 0.49239$$

where Etp is the potential evapotranspiration (mm), t is the average monthly temperature (ºC), i is the monthly temperature index, I is the total annual temperature index, and p is the latitude correction coefficient (Thornthwaite 1948).

$$DMADI = \left(\frac{P}{t+10} + \frac{12 \times P_a}{t_a + 10} \right) / 2 \qquad (2)$$

where DMADI is the De Martonne annual drought index, P is the total precipitation over long years (mm), t is the average temperature over long years (°C), Pa is the precipitation during the driest month (mm), and ta is the average temperature during the driest month (°C) (De Martonne 1942).

$$I_m = \frac{P}{T_{om}} \qquad (3)$$

In the formula, Im denotes precipitation effectiveness, P is the total annual precipitation and, Tom is annual mean maximum temperature (°C) (Erinç 1949).

$$r = 2t \qquad (4)$$

In the formula, r is the total annual precipitation (cm) and t is the annual, mean temperature (°C). If the r value is greater than the relation, it is a humid climate; if it is smaller, it is a steppe climate when the area does not receive 70% of the annual precipitation in either the hot or cold periods (Köppen 1918).

2.2.1 Kriging interpolation method

The Kriging method, developed by Danie Gerhardus Krige, represents a group of interpolation techniques for estimating unobserved values (Üstüntaş 2006). The location is predicted through a linear combination of values at surrounding locations using weights (Bostan 2017). What sets Kriging apart from other interpolation methods is its ability to calculate a variance value for each point being predicted.

This, in turn, is a factor that enhances the reliability of the calculated values (Yaprak and Arslan 2008).

The Kriging method, while providing more accurate results compared to other methods, is also capable of determining the minimum variance and the standard deviation of the prediction (Taylan and Damçayırı 2016). The variance value obtained through this method is referred to as Kriging variance (Krige 1951). The following equation has been used in the implementation of the Kriging method (Eq. 5):

$$N_p = \sum_{t=1}^{n} P_i * N_i \qquad (5)$$

In this formula, n represents the number of points, Ni represents the geoid undulation used in the calculation of Np, Np represents the sought undulation value, and Pi represents the weight associated with each Ni value used in the calculation of N (Krige 1951; Colak and Memisoglu 2021).

2.2.2 Procurement of data and creation of geographic database

Firstly, the station points where approximately 30 years of climate data for the study area were recorded have been determined. In the scope of this study, meteorological station points located in the following districts of Muğla province were selected: Menteşe (center), Bodrum, Dalaman, Datça, Fethiye, Kavaklıdere, Köyceğiz, Marmaris, Milas, Ortaca, Seydikemer, Ula, and Yatağan.

The data to be used in the study was obtained from Climate Data (2023). The obtained data was organized separately for each station point to associate it with their respective locations. Subsequently, the data obtained from Climate Data was linked to the geographical database using the location information for each province, making it ready for analysis. A flowchart diagram of the study is shown in Fig. 2.

3 Results

As a result of the calculations, water balance tables have been generated for all districts of Muğla province based on meteorological data using the Thornthwaite method (Thornthwaite 1948). The water balance of Menteşe, which is a central district of Muğla Province is provided in Table 1. The water balance tables of other districts are provided in Appendix 1.

When considering the long-term average precipitation in Muğla province, the highest annual precipitation occurs in Marmaris, while the lowest annual precipitation is observed in Seydikemer district. Seydikemer is the district in Muğla
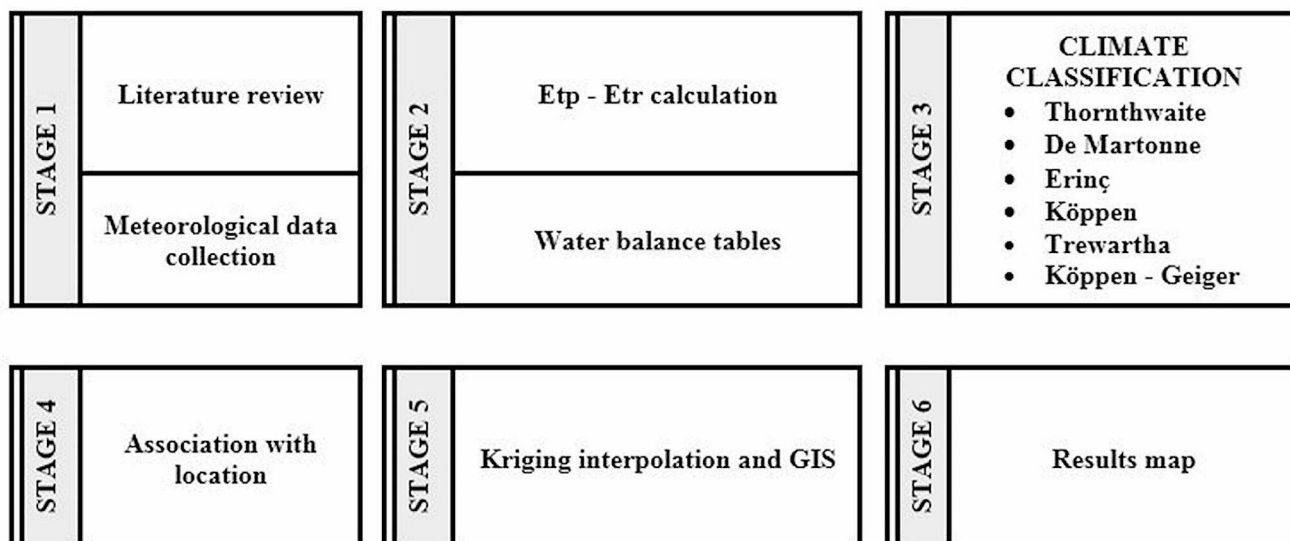
Fig. 2 Flowchart of the study

closest to the Mediterranean Region border. Real evapotranspiration (Etr) is highest in June and lowest in January in Kavaklıdere, Menteşe, Seydikemer, and Yatağan districts; in other districts, it is highest in May and lowest in July. Kavaklıdere, Menteşe, Seydikemer, and Yatağan are districts that do not have a coastline, while the other districts have a coastline. Potential evapotranspiration (Etp) is highest in August and lowest in February in Datça district, while in other districts, it is highest in July and lowest in January. Datça district, unlike the others, extends towards the sea.

In Muğla, along with all its districts, part of the surplus water contributes to surface runoff, while another part infiltrates into the soil. Surplus water and surface runoff occur in the month of March.

Thornthwaite (1948), De Martonne (1942), Erinç (1949), Köppen (1918), Köppen and Geiger (1954) (Kottek et al. 2006), Trewartha (1968) climate classification methods were utilized in order to determine precipitation efficiency and climate type in Muğla (Table 2).

According to the climate characteristics defined by Thornthwaite (1948), Muğla province, along with its districts, has a humid climate feature. Bodrum and Datça districts offer a full marine climate, while all other districts have characteristics close to ocean effect. The districts with a full marine climate extend towards the sea more than the other districts. Based on the climate characteristics according to De Martonne (1942), it is a steppe-humid climate. According to Erinç (1949), it is a humid-semi-humid climate. According to Köppen (1918), it is a steppe climate. According to Trewartha (1968), the entire region experiences hot to very hot summers and cool winters, with Bodrum, Datça, and Ortaca districts having a mild climate, while all other districts have a cool climate. Bodrum and Datça are districts

that entirely extend toward the sea, while Ortaca partially does so. According to the method of Köppen and Geiger (1954) (Kottek et al. 2006), the warm temperate climate with dry and hot summer (Csa), maximum temperatures greater than or equal to $+22$ °C, Mediterranean climate prevails in Muğla, including all its districts.

To generate a climate map covering Muğla province and its districts, the obtained result values were analyzed using the Kriging Interpolation method in GIS software. Later, climate boundary maps were created, comprising the first, second, third, and fourth letters, namely precipitation efficiency index, temperature efficiency index, drought index, and the index of the ratio of Etp to the three summer months (Figs. 3, 4, 5 and 6). As a result, climate predictions were made for areas outside of meteorological station points. In addition to evaluating climate characteristics on a district or provincial basis, this study aimed to define climate boundaries more accurately in a spatial context, as raster-based maps were generated in this work.

When Thornthwaite's (1948) precipitation efficiency index map (Fig. 3) was examined, it was observed that the index values were higher in Marmaris, Yatağan, and Kavaklıdere districts, and lower in Milas and Seydikemer districts.

When Thornthwaite's (1948) temperature efficiency index map (Fig. 4) was examined, it was observed that the index values were higher in Milas, Marmaris, Datça, and Ortaca districts, and lower in Kavaklıdere and Menteşe districts.

When Thornthwaite's (1948) drought index map (Fig. 5) was examined, it was observed that the index values were higher in Milas and Ula, and lower in Yatağan and Kavaklıdere districts and the west of Menteşe district.

Table 1 Menteşe district water balance

Menteşe	1	2	3	4	5	6	7	8	9	10	11	12	Annual
Precipitation P	109	98	82	64	54	21	7	9	21	60	84	104	713
Temperature t	3	3.9	6.9	10.7	15.8	20.9	25.1	25	20.1	14.4	9	4.7	13.3
Relative humidity h %	77%	73%	67%	62%	54%	42%	33%	35%	42%	56%	68%	76%	57%
Montly temp. index i	0.46	0.69	1.63	3.16	5.71	8.72	11.50	11.44	8.22	4.96	2.43	0.91	59.83
Latitude correction G	0.86	0.84	1.03	1.10	1.22	1.23	1.25	1.17	1.03	0.97	0.85	0.83	-
Etp	5.95	8.67	19.62	36.78	64.27	95.93	124.70	123.99	90.72	56.27	28.71	11.32	666.94
Corrected Etp	5.12	7.28	20.21	40.46	78.41	118.00	155.87	145.06	93.44	54.59	24.40	9.40	752.25
P-Etp	103.88	90.72	61.79	23.54	-24.41	-97.00	-148.87	-136.06	-72.44	5.41	59.60	94.60	-39.25
Reserve water	100	100	100	100	75.59	00	00	00	00	5.41	65.01	100	-
Etr	5.12	7.28	20.21	40.46	78.41	96.59	7	9	21	54.59	24.40	9.40	373.46
Water shortage	00	00	00	00	00	21.41	148.87	136.06	72.44	00	00	00	378.78
Water surplus	103.88	90.72	61.79	23.54	00	00	00	00	00	00	00	59.61	339.54
Runoff	51.94	71.33	53.58	27.22	5.89	00	00	00	00	00	00	29.81	239.77
Humidity rate%	20.29	12.46	3.06	0.58	-0.31	-0.82	-0.96	-0.94	-0.78	0.10	2.44	10.07	-

When Thornthwaite (1948) index map of the ratio of Etp to the three summer months (Fig. 6) was examined, it was observed that the index values were higher in Yatağan, Kavaklıdere, Menteşe and Ula Districts, and lower in Datça district.

Precipitation efficiency index map according to Erinç (1949) method (Fig. 7), universal temperature scale maps according to Trewartha (1968) method (Fig. 8a, b), precipitation-temperature relationship map according to Köppen (1918) method (Fig. 9) and a drought index map according to De Martonne (1942) method (Fig. 10) have been created. Due to all districts exhibiting the same climate class characteristics according to the Köppen and Geiger (1954) method, a single-scale map representation was anticipated, thus a climate boundary map was not created.

When Erinç (1949) precipitation efficiency index map (Fig. 7) was examined, it was observed that the index values were higher in Datça and Marmaris districts and the west of Bodrum district, and lower in Seydikemer district.

When Trewartha (1968) universal temperature scale summer index map (Fig. 8a) was examined, it was observed that the index values were higher in Milas district, and lower in Kavaklıdere and Menteşe districts. When Trewartha (1968) universal temperature scale winter index map (Fig. 8b) was examined, it was observed that the index values were higher in Datça district, and lower in Kavaklıdere and Menteşe districts.

Köppen (1918) precipitation-temperature relationship map (Fig. 9) was examined, it was observed that the index values were higher in Datça District, and lower in Kavaklıdere and Menteşe districts.

When de Martonne method (1942) drought index map (Fig. 10) was examined, it was observed that the index values were higher in Kavaklıdere, Yatağan, Menteşe, Ula and Marmaris Districts, and lower in Seydikemer district.

According to the Thornthwaite (1948) method, the study area exhibits three climate boundaries based on the precipitation efficiency index: semi-humid (C2), humid (B1), and humid (B2); two climate boundaries based on the temperature efficiency index: 2nd degree mesothermal-humid (B'2), and 3rd degree mesothermal-humid (B'3); single climate boundary based on the drought index: Water shortage is very severe in summer (s2); and exhibits three climate boundaries based on the index of the ratio of three summer months: Full marine climate conditions (a'), Close to ocean effect (b'3, b'4). In Erinç's classification, two climate boundaries were identified: semi-humid, and humid. De Martonne identified two climate boundaries: the steppe-humid and the semi-humid. Yatağan district is semi-humid and all other districts are in the step-humid climate class. Only one climate class was obtained in the Köppen and Köppen-Geiger methods. According to the Köppen classification method, it

Table 2 Climate classifications of Muğla province

Districts	Methods								
	Thornthwaite				De Martonne	Erinç	Köppen	Trewartha	Köppen - Geiger
	1.	2.	3.	4.					
Bodrum	Humid (B1)	3rd Degree Mesothermal (B'3)	Water shortage is very severe in summer (s2)	Full marine (a')	Steppe-Humid (17.1)	Humid (48.2)	Steppe (36.8)	Hot summers, mild winters	Warm temperate climate with dry and hot summer (Csa)
Dalaman	Humid (B1)	3rd Degree Mesothermal (B'3)	Water shortage is very severe in summer (s2)	Close to ocean effect (b'3)	Steppe-Humid (18.6)	Humid (45.5)	Steppe (36.6)	Very hot summers, cool winters	Warm temperate climate with dry and hot summer (Csa)
Datça	Humid (B1)	3rd Degree Mesothermal (B'3)	Water shortage is very severe in summer (s2)	Full marine (a')	Steppe-Humid (16.8)	Humid (49)	Steppe (38.2)	Hot summers, mild winters	Warm temperate climate with dry and hot summer (Csa)
Fethiye	Humid (B2)	3rd Degree Mesothermal (B'3)	Water shortage is very severe in summer (s2)	Close to ocean effect (b'4)	Steppe-Humid (18.1)	Humid (45.1)	Steppe (32.8)	Hot summers, cool winters	Warm temperate climate with dry and hot summer (Csa)
Kavaklıdere	Humid (B2)	2nd Degree Mesothermal (B'2)	Water shortage is very severe in summer (s2)	Close to ocean effect (b'3)	Steppe-Humid (19)	Humid (43.9)	Steppe (26.6)	Hot summers, cool winters	Warm temperate climate with dry and hot summer (Csa)
Köyceğiz	Humid (B1)	3rd Degree Mesothermal (B'3)	Water shortage is very severe in summer (s2)	Close to ocean effect (b'3)	Steppe-Humid (17.41)	Semi-humid (39.3)	Steppe (32.8)	Hot summers, cool winters	Warm temperate climate with dry and hot summer (Csa)
Marmaris	Humid (B2)	3rd Degree Mesothermal (B'3)	Water shortage is very severe in summer (s2)	Close to ocean effect (b'4)	Steppe-Humid (19.7)	Humid (51.2)	Steppe (36.2)	Hot summers, cool winters	Warm temperate climate with dry and hot summer (Csa)
Menteşe	Humid (B1)	2nd Degree Mesothermal (B'2)	Water shortage is very severe in summer (s2)	Close to ocean effect (b'3)	Steppe-Humid (14.8)	Semi-humid (38.1)	Steppe (26.6)	Hot summers, cool winters	Warm temperate climate with dry and hot summer (Csa)
Milas	Semi-humid (C2)	3rd Degree Mesothermal (B'3)	Water shortage is very severe in summer (s2)	Close to ocean effect (b'3)	Steppe-Humid (15.3)	Semi-humid (36.1)	Steppe (35.2)	Very hot summers, cool winters	Warm temperate climate with dry and hot summer (Csa)
Ortaca	Humid (B1)	2nd Degree Mesothermal (B'3)	Water shortage is very severe in summer (s2)	Close to ocean effect (b'4)	Steppe-Humid (18.2)	Humid (46)	Steppe (37)	Very hot summers, mild winters	Warm temperate climate with dry and hot summer (Csa)
Seydikemer	Semi-humid (C2)	2nd Degree Mesothermal (B'2)	Water shortage is very severe in summer (s2)	Close to ocean effect (b'3)	Steppe-Humid (14.3)	Semi-humid (31)	Steppe (31)	Hot summers, cool winters	Warm temperate climate with dry and hot summer (Csa)
Ula	Humid (B1)	3rd Degree Mesothermal (B'3)	Water shortage is very severe in summer (s2)	Close to ocean effect (b'3)	Steppe-Humid (16.7)	Semi-humid (39.7)	Steppe (33.4)	Very hot summers, cool winters	Warm temperate climate with dry and hot summer (Csa)
Yatağan	Humid (B2)	3rd Degree Mesothermal (B'3)	Water shortage is very severe in summer (s2)	Close to ocean effect (b'3)	Semi-humid (22.2)	Humid (48.9)	Steppe (31.8)	Hot summers, cool winters	Warm temperate climate with dry and hot summer (Csa)

is steppe climate and according to the Köppen-Geiger classification method, it is warm temperate climate with dry and hot summer (Csa). Lastly, two Trewartha climate boundaries were established, with one for hot and very hot conditions in summer and another for cool and mild conditions in winter.

4 Discussion

The creation of climate boundary maps is a significant area for exploring various issues associated with the utilization of different climate classification methods. This study investigates the process of generating climate boundary maps through diverse climate delimitation methods. The findings indicate that the employed methods serve as effective tools for identifying and delineating specific climate boundaries.

When comparing the methods used for climate classification, Thornthwaite's (1948) method stands out as more detailed. Thornthwaite (1948) addresses critical aspects such as the relationship between precipitation and soil moisture, surface runoff, and water demand. Although the primary purpose of Thornthwaite's (1948) classification is to identify different climate types, it finds extensive practical applications, particularly in areas where evapotranspiration cannot be directly calculated, such as agriculture, hydrogeology, and water resource development. However, it has

Fig. 3 Thornthwaite (1948) precipitation efficiency index map
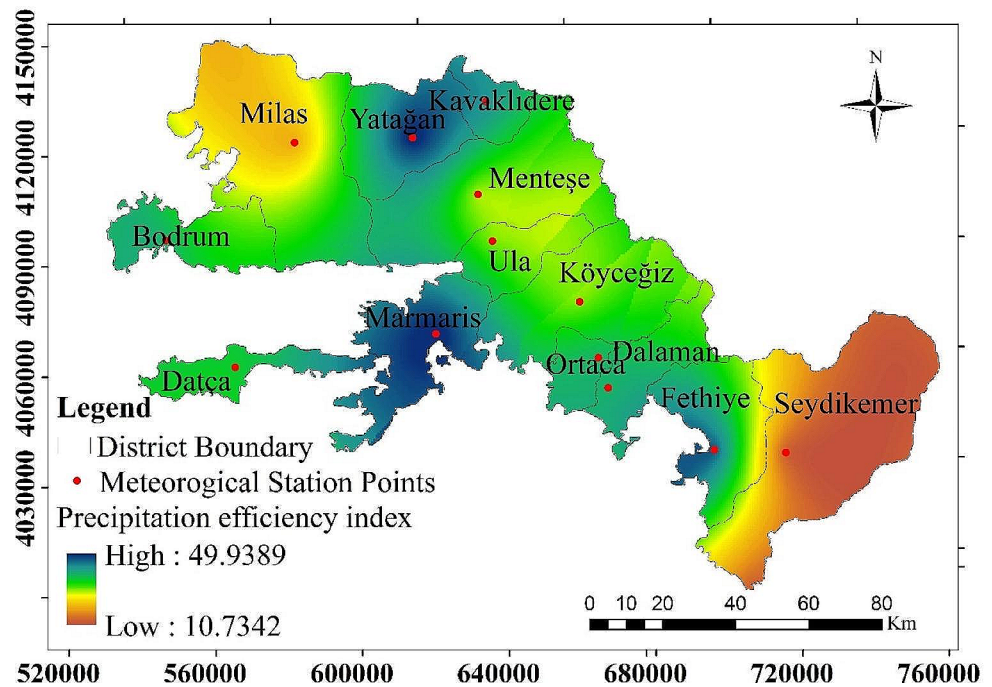
**Fig. 4** Thornthwaite (1948) temperature efficiency index map
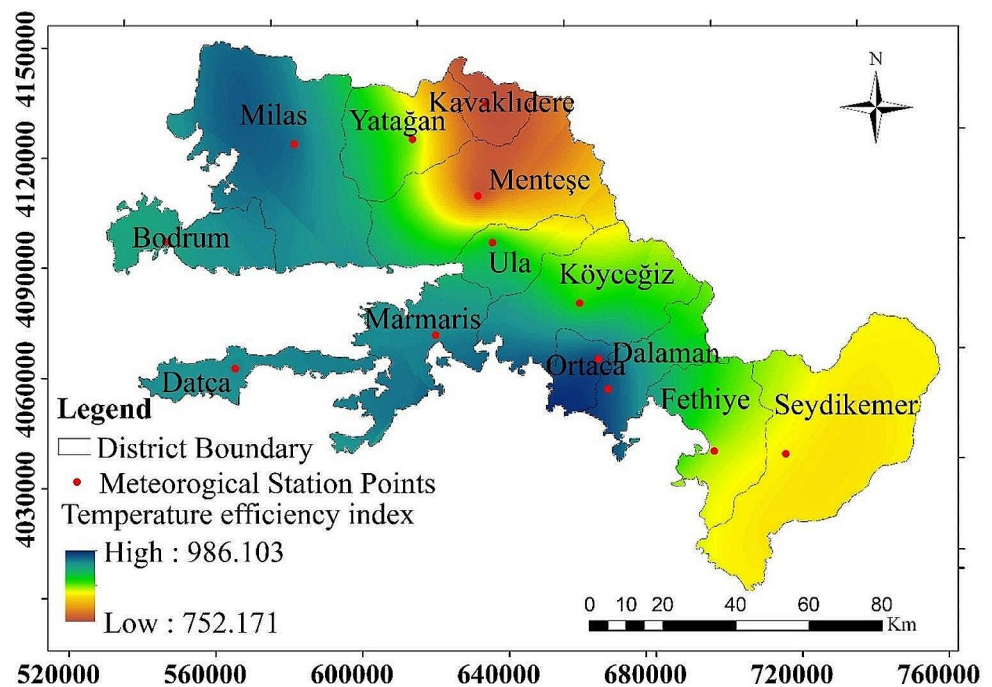
been observed that the methods used in the research gave similar results and supported each other.

The findings of this study indicate a compatible between the climate attributes identified for the Muğla province and the climate maps of Türkiye published by the Turkish State Meteorological Service (MGM) in 2024. This alignment underscores the consistency and reliability of the climate characterization presented in our study with the broader climatic patterns depicted by authoritative sources such as

MGM. In their study, Yılmaz and Çiçek (2018) employed the Köppen-Geiger method to assess the climate classification of Türkiye. The results of our analysis revealed that the climate classification assigned to the Muğla region aligns with the corresponding climate map derived from their methodology. This congruence underscores the reliability and applicability of the Köppen-Geiger method in accurately characterizing the climatic conditions of specific regions, such as Muğla. Şensoy et al. (2018) calculated Türkiye's

Fig. 5 Thornthwaite (1948) drought index map
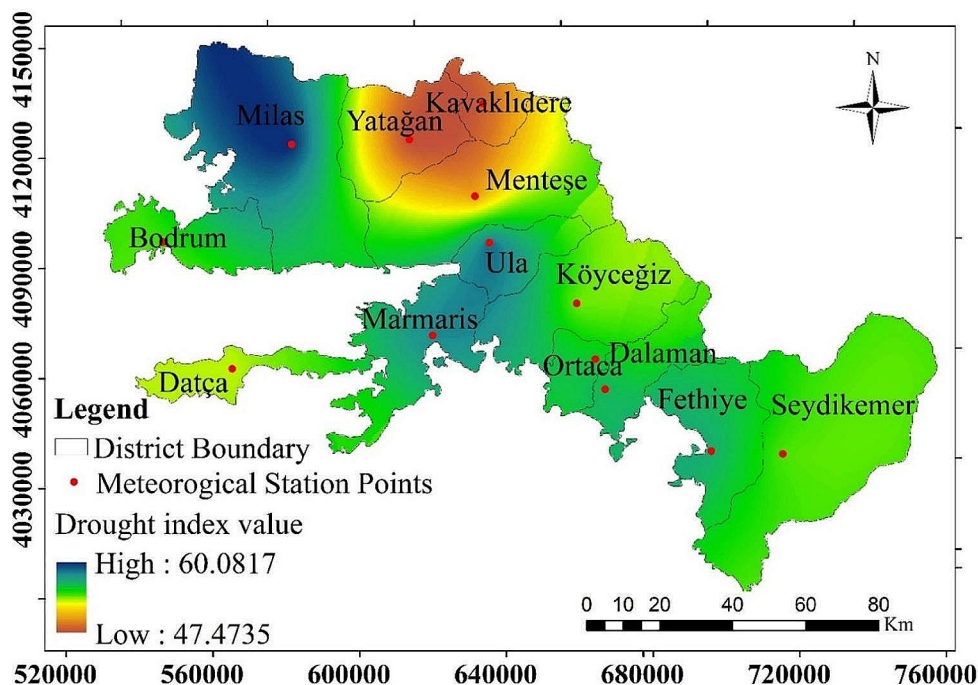
Fig. 6 Thornthwaite (1948) index map of the ratio of Etp to the three summer months
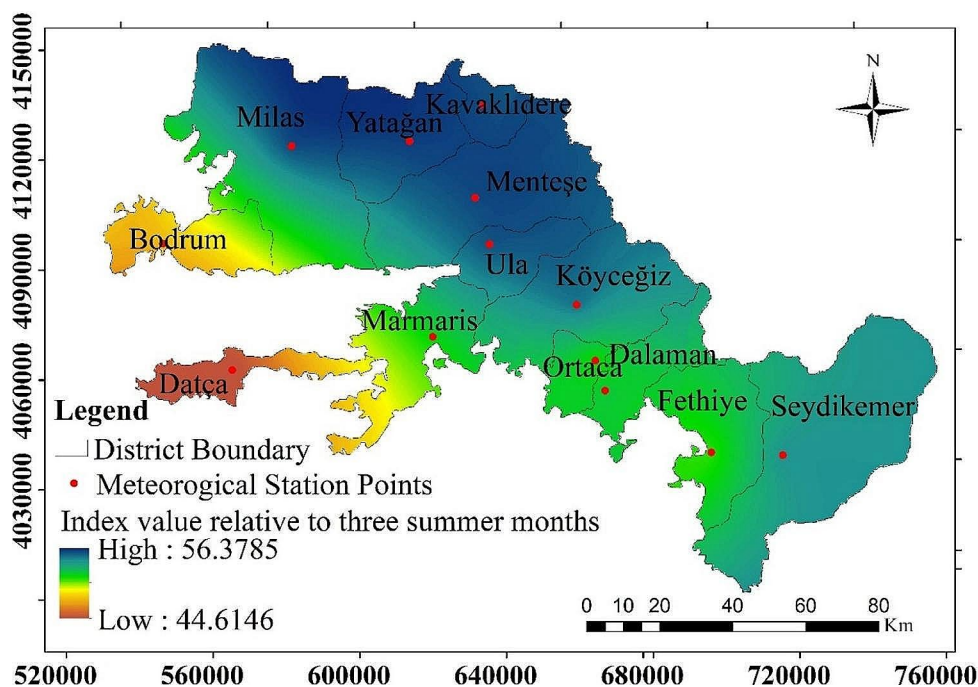
climate class according to the Thornthwaite method. The results of the study are also compatible with this study. In addition, as a result of examining the world map updated by Kottek et al. (2006) according to the Köppen-Geiger method, it was seen that the entire study area on the world map presented Csa climate class, and this situation was the same as the result of this study.

5 Conclusions

Determining climate boundaries is essential for sustainable resource management and land use planning. The findings provide valuable insights for various activities, including agriculture, industry, and forestry. Climate boundary maps aid in monitoring climate change and facilitating climate-informed planning. These results are invaluable for addressing climate-related challenges now and in the future,

Fig. 7 Erinç (1949) precipitation efficiency index map
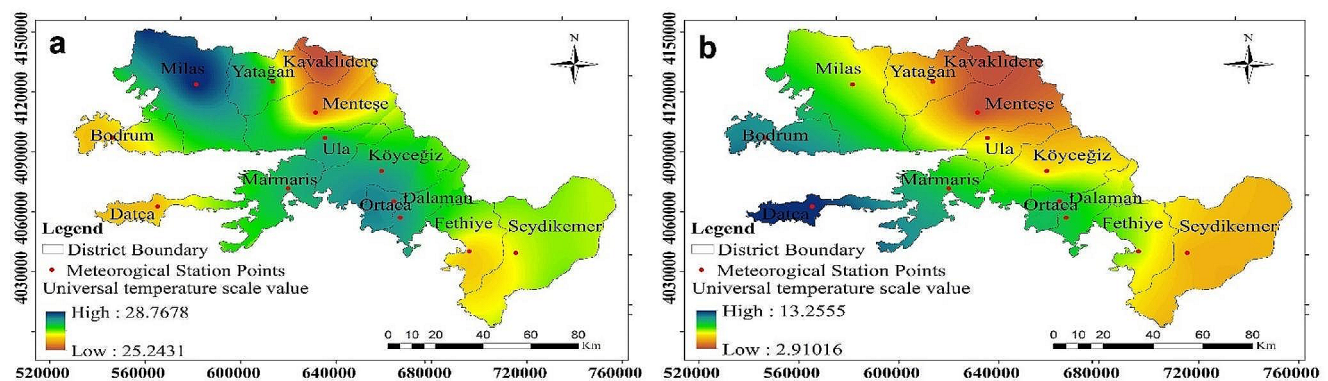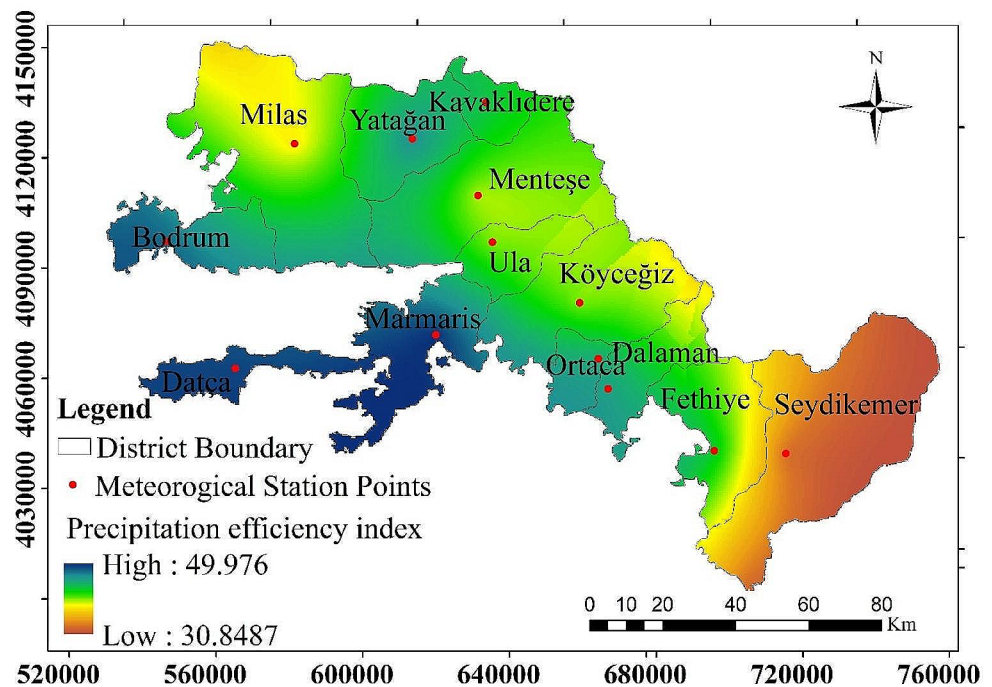
Fig. 8 Trewartha (1968) universal temperature scale maps (**a**) Summer, (**b**) Winter

contributing to effective land management and disaster mitigation efforts.

While it is seen that the summer months are rainless in Bodrum, Datça, Fethiye and Marmaris districts of Muğla province, it is seen that the summer months have very low rainfall in Milas, Ortaca, Dalaman and Ula districts. This situation prevents plants from meeting their water needs from rainfall and makes irrigation necessary.

Protecting water resources is mandatory for sustainable urban development. For this reason, the effects of artificial environments on surface and underground water resources, climate characteristics and climate change scenarios should be taken into account in urban planning.

Knowing the climate characteristics and water balances of a particular area is of great importance for planning all kinds of activities related to that region. It is used in various

fields, from planning the cultivation of crops in the area to establishing industrial facilities. Local studies should be conducted in climate classifications, and these studies are essential for those involved in soil, water, industry, forestry, and agriculture. Additionally, Thornthwaite's method is widely used in forestry activities. Especially in regions where afforestation projects are carried out, knowing the climate type and water potential is crucial for making species preferences. These methods are also used to investigate whether the drying up of afforestation areas is related to the climate.

The results obtained from this study are of significant value as they can reveal areas where the climate is changing. Therefore, they will provide support and guidance for climate-based planning or planning that may be affected by climate conditions, both now and in the future. Determining

Fig. 9 Köppen (1918) precipita-tion-temperature relationship map
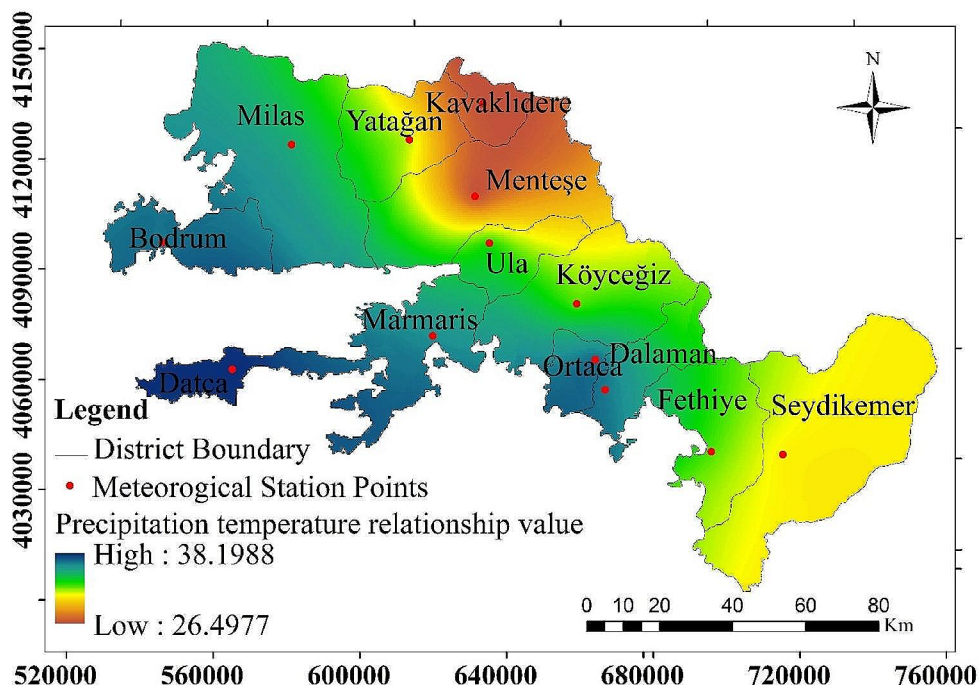
Fig. 10 De Martonne method (1942) drought index map
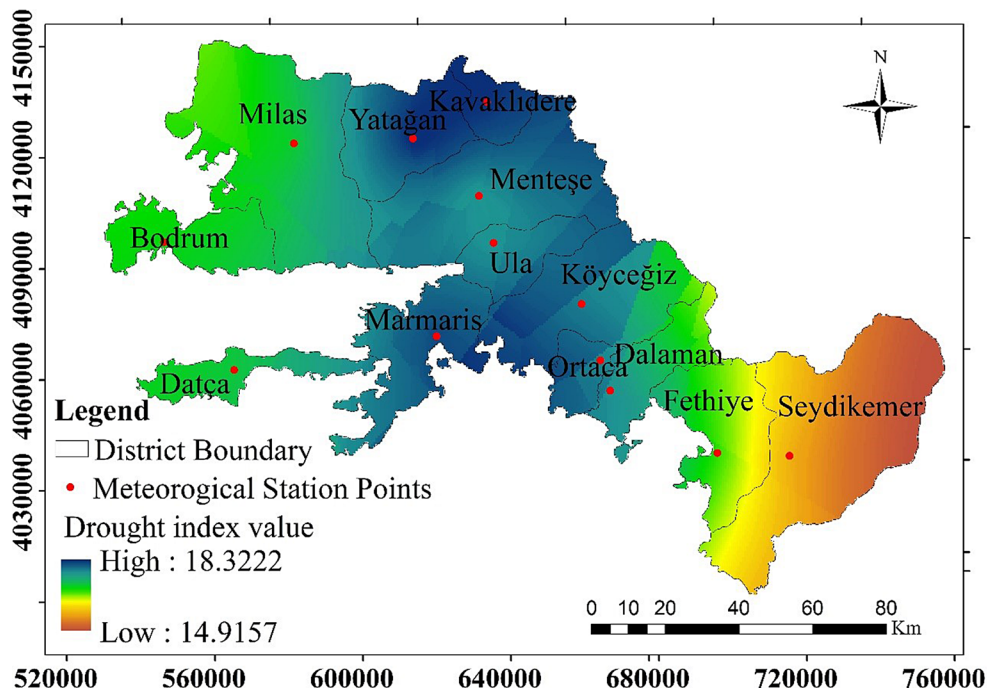
climate boundaries will allow for the examination and resolution of any changes related to land use and plant species due to climate, migration issues, slope stability, and disaster causes. Furthermore, the mapping of climate boundaries will primarily contribute to monitoring climate change and identifying its characteristics, thus assisting in climate change studies at both local and national scales.

Data availability All data and materials generated or analyzed during this study are included in this published article and its supplementary information. Data will be made available on request.

Declarations

Ethical approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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