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Research Article/Araştırma Makalesi

Determining the impact of the Atatürk Dam on the propagation of meteorological drought by using different drought indices in Sanliurfa Province

Şanlıurfa ilinde Atatürk Barajı'nın meteorolojik kuraklığın yayılımı üzerindeki etkisinin farklı kuraklık indeksleri kullanılarak belirlenmesi

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ABSTRACT

In recent years, the increase in the frequency and severity of natural disasters such as floods, droughts, etc. is evaluated as a sign of climate change. In this context, the study conducted in Sanliurfa province, aimed to determine the spatial and temporal propagation of meteorological drought in two different periods using the De Martonne (I_{DM}), De Martonne-Gottman (I_{DMG}) and Erinc (I_m) methods. Long-term monthly total precipitation (mm), average temperature (°C) and average maximum temperature (°C) series obtained from 12 meteorological observation stations were utilized to calculate the annual drought index values for each station. Missing years in the calculated drought index series were completed by correlation and regression analysis. Taking the year 1991, when the Atatürk Dam started to hold water, as the starting year of the 2nd period, the series of stations were divided into 2 different time scales: the 1st period (1961-1990) and the 2nd period (1991-2020). "Sanliurfa Annual Climate Class Maps" for each method were produced for two different periods. Consequently, the spatial and temporal propagation of meteorological drought in Sanliurfa province according to I_{DM}, I_{DMG} and I_m methods is from south to north. The areal average of the drought index values of the methods were represented by 15.6, 7.7 and 18.3 values in the 1st period, while they were 14.5, 7.3 and 17.0 in the 2nd period, respectively. After the first period, when the Atatürk Dam began to hold water, the drought continued to propagate, becoming more severe. The Atatürk Dam is unlikely to prevent the spread of drought from south to north in and around Sanliurfa, and there is no significant difference between the methods in determining drought propagation. If global warming continues at the current rate until the end of this century, Akcakale, Ceylanpinar and Viransehir are likely to experience severe droughts and face desertification.

Key Words: Climate classification, Desertification, De Martonne, De Martonne-Gottman, Erinc

ÖZ

Son yıllarda; sel, kuraklık vb. doğal afetlerin sıklık ve şiddetinde görülen artışlar iklim değişikliğinin bir işareti olarak değerlendirilmektedir. Bu kapsamda Şanlıurfa ilinde yapılan çalışmada; De Martonne (I_{DM}), De Martonne-Gottman (I_{DMG}) ve Erinç (I_m)

yöntemleri kullanılarak iki farklı dönemde meteorolojik kuraklığın alansal ve zamansal yayılımının belirlenmesi amaçlanmıştır. Her bir istasyon için yıllık kuraklık indisi değerlerinin hesaplanmasında 12 meteoroloji gözlem istasyonundan elde edilen uzun dönem aylık toplam yağış (mm), ortalama sıcaklık (^{o}C) ve ortalama maksimum sıcaklık (^{o}C) serileri kullanılmıştır. Hesaplanan kuraklık indisi serilerindeki eksik yıllar korelasyon ve regresyon analizi ile tamamlanmıştır. Atatürk Barajı'nın su tutmaya başladığı 1991 yılı 2. dönemin başlangıç yılı alınarak istasyonlar ait kuraklık indisi serileri; 1. dönem (1961-1990) ve 2. dönem (1991-2020) olmak üzere 2 farklı zaman ölçeğine ayrılmıştır. Her bir yöntem için "Şanlıurfa Yıllık İklim Sınıfı Haritaları" iki farklı dönem için üretilmiştir. Sonuç olarak, I_{DM}, I_{DMG} ve I_m yöntemlerine göre Şanlıurfa ilinde meteorolojik kuraklığın alansal ve zamansal yayılımı güneyden kuzeye doğrudur. Yöntemlere ait kuraklık indisi değerlerinin alansal ortalaması 1. dönemde sırasıyla 15.6, 7.7 ve 18.3 değerleri ile temsil edilirken; 2. dönemde 14.5, 7.3 ve 17.0 olmuştur. Atatürk Barajı'nın su tutmaya başladığı ilk dönemden sonra kuraklık daha da şiddetlenerek yayılmaya devam etmiştir. Atatürk Barajı'nın Şanlıurfa ve çevresinde kuraklığın güneyden kuzeye doğru yayılımını engellemesi pek olası görülmemekle birlikte, yöntemler arasında kuraklığın yayılımının belirlenmesinde anlamlı bir fark yoktur. Küresel ısınmanın bu yüzyılın sonuna kadar mevcut hızda devam etmesi halinde, Akçakale, Ceylanpınar ve Viranşehir'in şiddetli kuraklıklar yaşaması ve çölleşmeyle karşı karşıya kalması muhtemeldir.

Anahtar Kelimeler: İklim sınıflandırması, Çölleşme, De Martonne, De Martonne-Gottman, Erinç

Introduction

In the global climate system, greenhouse gas emissions that exceed normal levels due to human activities cause the sun's rays to be retained more in the atmosphere, resulting in the greenhouse effect, which is considered one of the most important factors of global warming and is counted among the causes of climate change (Kayıkçıoğlu and Okur, 2012; Mikhaylov et al., 2020; Tüzer and Doğan, 2021). While the concentration of the greenhouse gas carbon dioxide in the atmosphere did not exceed 300 ppm until the industrial revolution, today it has reached 412.5 ppm (NASA, 2024; WMO, 2024). If the increase in greenhouse gas emission rates continues on this trend, the global average temperature is expected to rise approximately 2 °C by 2036 (Mann, 2014).

Although there was no significant deviation in the average values of climate elements in a period of 300-500 years in large regions, there are transitions between climate classes in drought studies with 30-year observations (Keskiner and Çetin, 2023a). Uncertainty about the process, severity, duration and impact area of drought, which is defined as a water shortage among natural disasters, creates a multiplier effect and causes more socio-economic damage to people (Özelkan, 2019; Partigöç and Soğancı, 2019). Hence, the United Nations World Water Development Report 2016 (Küçüksakarya and Göçmen, 2019) predicts that 40% of the world could face a water deficit by 2030. In this context, information on the speed (magnitude), severity, frequency and spatial extent of drought is obtained with the help of drought index and drought trend tests; important conclusions are drawn and drought-related damages are prevented (Mishra and Singh, 2010; Keskiner and Çetin, 2023b). Although many methods have been developed for determining drought and climate classes, each method has limitations, strengths and weaknesses due to different climatic conditions. The Köppen, Camargo, Standard Precipitation Index, Thornthwaite, De Martonne, De Martonne-Gottman, Aydeniz, Percent of Normal Index, Exploratory Drought Index, Palmer Drought Severity Index, Erinc Drought Index, Streamflow Drought Index, etc. methods are frequently used in climate classification and drought studies (Gümüş et al., 2016; Aktaş et al., 2018; Aparecido et al., 2020; Özmen, 2022; Keskiner, 2022). However, using different methods in meteorological drought analysis in the same study area is a significant issue in water resources and drought risk management planning. In particular, the use of techniques such as Aydeniz (Keskiner, 2022), Reconnaissance Drought Index (Soydan Oksal and Beden, 2024), etc., which analyse drought by using more variables in calculations, and SPI (Ircan and Duman, 2021), Erinc (Keskiner and Çetin, 2023b), etc., which use fewer variables in calculations, can make planning more realistic by revealing the similarities or differences between the methods.

Turkey, which is under the influence of the "Semi-arid" climate (Oğuz and Akın, 2019) in the eastern Mediterranean basin, is considered one of the countries that will suffer from climate change (Selek and Pınarlık, 2019; Yüksel Küskü and Söylemezoğlu, 2022). Therefore, it has become imperative to examine long-term climate parameters in order to determine the effects of climate change on drought due to global warming throughout the country, make future projections and take measures against drought. In the climate change projections, the Euphrates-Tigris River Basin is classified among the basins that will be most affected by climate change. In the future, drought is expected to affect agricultural activities and other sectors in the Euphrates-Tigris River basin (Bozkurt, 2013; Birpınar and Tuğaç, 2018; Gümüş et al., 2016; Tutuş and Erdem, 2023). The Southeastern Anatolia Project (GAP), planned in the Euphrates-Tigris Basin region, consists of 13 main projects, 7 in the Euphrates Basin and 6 in the Tigris Basin (Kendal and Sayar, 2013). Sanliurfa, which has 11% of Turkey's economically irrigable area, currently has a total irrigated area of 390 thousand hectares and when GAP is completed, the irrigated area will increase to 940 thousand hectares, which is approximately 50% of the GAP project. Therefore, Sanliurfa is more likely to be affected by drought-induced socio-economic losses (Demircan et al., 2017; Sepetçioğlu et al., 2018; YDO, 2018; Temur et al., 2023). Thus, Keskiner (2022) found in the spatial drought study conducted with the Aydeniz method in the province of Sanliurfa that Akcakale, Harran, Viransehir, Suruc, Ceylanpinar and the city center of Sanliurfa are threatened by meteorological drought starting from the Syrian border. In the point-scale studies conducted by Gümüş et al. (2016) and İrcan and Duman (2021) using the Standard Precipitation Index method in Sanliurfa province, it was determined that there was a significant increase in the number of repetitions of dry months in the last 30 years compared to previous years and significant increases in drought severity, frequency and duration in all stations in the study area, respectively. However, it is noteworthy that the impact of large-scale water resources projects on drought propagation by developing irrigation projects through the construction of large dams such as Atatürk Dam has not been sufficiently evaluated. Furthermore, it is also seen that more than one method is not used in monitoring drought with the help of drought index in the studies (Gümüş et al., 2016; İrcan and Duman, 2021; Keskiner, 2022; Keskiner and Çetin, 2023a). Consequently, determining the spatial and temporal trends of climatic changes in the GAP region by considering drought classes (Keskiner and Çetin, 2023a) is an important prerequisite for better water resource planning and drought risk management. In this context, the aim of the present study conducted in the province of Sanliurfa is twofold:

1. Deriving long-term annual meteorological drought index series for Sanliurfa province by De Martonne (I_{DM}), De Martonne-Gottman (I_{DMG}) and Erinc (I_m) methods,
2. The long-term I_{DM}, I_{DMG} and I_m annual series of the stations were divided into 2 different time scales: the 1st period (1961-1990) and the 2nd period (1991-2020) when Atatürk Dam started to hold water, and it was aimed to determine the effect of Atatrük Dam on the meteorological drought propagation by mapping the spatial and temporal propagation of the meteorological drought trend before and after the construction of Atatürk Dam.

Materials and Methods

Sanliurfa province which has a surface area of 19,242 km² (HGM, 2022), is located in the South Eastern Anatolia region of Turkey between 37˚49'12''- 40˚10'00'' E longitude and 36˚41'28''-37˚57'50'' N latitude. In Sanliurfa province, where continental climate characteristics are dominant and the average elevation is around 500 meters, the topography, shows a decrease in elevation from north to south, with elevation ranging between 348-1800 meters. The low elevation along the Syrian border and in the inland areas from the border to the north exacerbates the occurrence of drought in Sanliurfa from south to north due to extremely hot air masses originating from the Basra Low-Pressure Center during the summer period. The long-term average temperature in Sanliurfa province is around 18.6 ^{0}C, with long-term total precipitation averages varying between 453 mm in Sanliurfa and 287-300 mm in the Akcakale and Ceylanpinar districts, respectively (İrcan and Duman, 2021; Keskiner and Çetin, 2023b). Within the scope of the research, long-term climate parameters such as average temperature (^{0}C), total precipitation (mm) and average maximum temperature (^{0}C) obtained monthly from the observation stations of the Turkish State Meteorological Service (MGM) were used (Figure 1.).

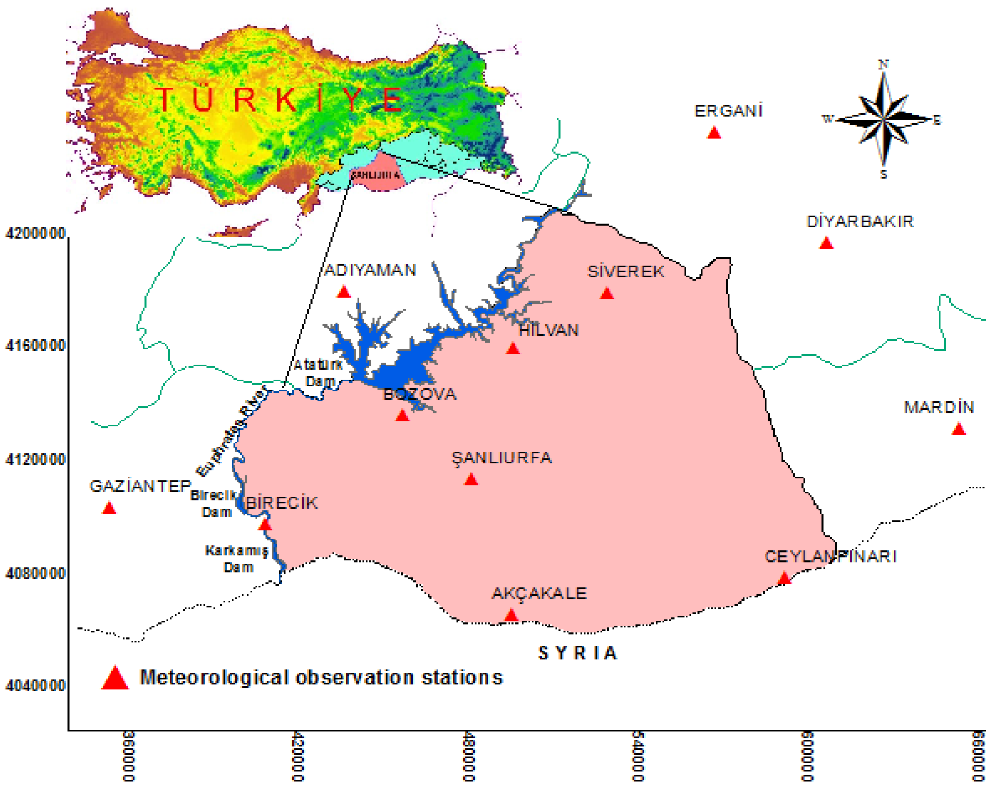

Figure 1. The UTM (Universal Transverse Mercator) coordinates (meter) of the meteorological observation stations used in the study.

Climate parameters consist of the data observed at Sanliurfa, Akcakale, Birecik, Ceylanpinar, Siverek, Adiyaman, Diyarbakir, Ergani, Gaziantep and Mardin meteorological observation stations between 1961-2020 and the data observed at Hilvan and Bozova meteorological observation stations between 1991-2020. The calculation of the locations in a projected coordinate system of the meteorological observation stations was performed according to the reference surface D_WGS_1984_UTM_Zone_37N. Table 1 provides attribute information about the climate elements used in the study and the meteorological observation stations from which these parameters are obtained. Long-term averages of climate elements were calculated by considering the complete observed series. The stations ordered by latitude from north to south show the latitudinal influence on the change in average climate parameters. However, the difference is not solely based on topographical variations in locations. Other variables like aspect, distance from the sea, etc., also play a role, making this difference non-linear. The recording periods of the climate elements obtained from meteorological observation stations were arranged in two periods every 30 years: the 1st period (1961-1990) and the 2nd period (1991-2020). Since the climate elements of Hilvan and Bozova stations did not have sufficient data length before 1991, they were included in the calculations in the second period.

Table 1. Some attributes of climate elements obtained from meteorological observation stations

Stations name	*Latitude (m)*	*Longitude (m)*	*Data period*	*Average annual precipitation (mm)*	*Average annual temperature (C^o)*	*Average annual max. temperature (C^o)*
Ergani	4235717	567009	1964-2020	744.3	15.9	21.0
Diyarbakir	4196457	606657	1961-2020	492.9	15.9	22.7
Adiyaman	4178911	436356	1963-2020	710.9	17.4	23.1
Siverek	4178373	528991	1964-2020	561.3	16.7	22.3
Hilvan	4159284	495656	1998-2020	432.1	16.9	24.2
Bozova	4135486	456912	2000-2020	401.7	17.3	24.0
Mardin	4130696	653165	1961-2020	661.4	16.2	20.4
Sanliurfa	4112732	481026	1961-2020	453.9	18.6	24.6
Gaziantep	4102634	353385	1961-2020	567.4	15.5	21.9
Birecik	4096909	408503	1964-2020	361.5	17.9	18.0
Ceylanpinar	4077686	591900	1961-2020	300.7	18.3	26.4
Akcakale	4064656	495294	1965-2020	287.8	18.4	25.7

Correlation and regression analysis

Correlation analysis determines the degree and direction of the relationship between variables, while regression analysis mathematically defines this relationship. In order to complete the missing years in the I_{DM}, I_{DMG} and I_m series that could not be calculated at the observation stations due to unobserved climate elements, the stations with statistically significant correlations at the level of 0.05 were identified using the Pearson correlation coefficient (r). A linear regression model with the highest coefficient of determination (R^2) and the smallest standard deviation between meteorological stations was then created at a significance level of α=0.05. The process of supplementing missing years in the drought index series of the stations was described in detail by Kesici and Kocabaş (1998) and Ryan and Cryer (2005).

De Martonne aridity index (I_{DM})

The De Martonne method ($I_{(DM)}$) is one of the oldest drought indices that uses annual average temperature and total precipitation values to calculate annual drought index values (Andrade et al., 2021) which can be obtained with the help of equation 1. Table 2. shows the De Martonne index value and climate classification based on the values of $I_{(DM)}$ (Hrnjak et al., 2014).

$$I_{DM}=\frac{P}{T+10} \qquad (1)$$

Where $I_{(DM)}$ is the De Martonne annual drought index, P is the annual total precipitation (mm) and T is the average annual temperature (°C) in a given time series.

Table 2. De Martonne index values and climate classification

Climate classification	*Index values (I_{DM})*
Arid	I_{DM}<10
Semi-arid	10≤I_{DM}<20
Mediterranean	20≤I_{DM}<24
Semi-humid	24≤I_{DM}<28
Humid	28≤I_{DM}<35
Very humid	35≤I_{DM}≤55
Extremely humid	I_{DM}>55

De Martonne–Gottman index (IDMG)

In 1942, De Martonne and Gottman made some modifications to equation 1 (MGM, 2016a). The new equation is as follows (Equation 2).

$$I_{DMG}=\frac{1}{2}\left(\frac{P}{T+10}+\frac{12P_d}{Td+10}\right) \qquad (2)$$

Where $I_{(DMG)}$ is the De Martonne-Gottman annual drought index, P (mm) and T (˚C) are the annual total precipitation and the average annual temperature (°C) respectively and Pd and Td are the total precipitation and the average temperature of the driest month, respectively. De Martonne-Gottman index values and the climate classes are given in Table 3 (MGM, 2016a ; Dursun and Babalık, 2021).

Table 3. De Martonne - Gottman index values and climate classification

Climate classification	*Index values (I_{DMG})*

Desert	0-5
Semi-arid	5-10
Between Semi-arid and humid	10-20
Semi-humid	20-28
Humid	28-35
Very humid	35-55
Wet	>55
Polar	<0 (T < -5°C)

Erinc's aridity index (I_m)

Erinc's Aridity Index (I_m) developed by Erinc in 1965 expresses the ratio between annual total precipitation and average maximum temperature and is represented by equation 3. Index values are classified as shown in Table 4 (MGM, 2016b; Keskiner and Çetin, 2023a).

$$I_m = P/T_{max\ \_ort} \qquad (3)$$

where I_m is the Erinc's drought index; P and $T_{max\ \_ort}$ are annual total precipitation (mm) and average maximum temperature (°C) observed in a given year, respectively

Table 4. Erinc's classification of climate types

Climate Types	Index Value (I_m)	Vegetation Cover
Severe-arid	<8	Desert
Arid	8-15	Desertification
Semi-arid	15-23	Arid
Sub-humid	23-40	Forest
Humid	40-55	Moist forest
Very humid	>55	Very moist forest

Inverse distance weighted interpolation technique (IDW)

The Inverse Distance Method (IDW) is used to estimate the values of non-sampled points using the values of known sample points (Çetin and Diker, 2003). The basis of this frequently used method is that nearby points on the surface to be interpolated have more influence (weight) on the estimates than those farther away. Mathematical equations and definitions of the Inverse Distance Method are given in detail by Keskiner and Çetin (2023a) and Taylan and Damçayırı (2016). In this study; De Martonne, De Martonne-Gottman and Erinc annual index values were spatially mapped with the inverse distance method in a GIS environment using ArcGIS software.

Results and Discussions

Missing data imputation

De Martonne (I_{DM}), De Martonne Gottman (I_{DMG}) and Erinc (I_m) values of 12 stations used in the study were calculated annually. Index values of the methods could not be calculated for the years without observations of the climate elements used in the methods. It was preferred to complete the drought index series instead of completing missing observations in climate elements. This is because average monthly temperature and monthly total precipitation values are also used in the calculation of annual index values by the De Martonne-Gottman method (Equation 2). The total missing observation period of the De Martonne-Gottman annual drought index values used in the study at all stations is 31 years. However, when Equation 2 is taken into account, the time required to complete the missing observations in monthly precipitation is 372 months and includes consecutive years. Therefore, it was decided that completing the missing years of the annual drought index series would be healthier in terms of the accuracy of the estimation. In this context, the stations with missing years in the index series (Y, dependent variable) and the stations with no missing values in the index series (X, independent variable) which are the closest to the station with missing years were identified (Table 5.).

Table 5. Pearson correlation coefficient (r) values between dependent (Y) and independent (X) variables in De Martonne ($\boldsymbol{I_{DM}}$), De Martonne Gottman ($\boldsymbol{I_{DMG}}$) and Erinc ($\boldsymbol{I_m}$) annual series

De Martonne (I_{DM}) and De Martonne Gottman (I_{DMG})							
X	Diyarbakir	Mardin	Sanliurfa	Gaziantep	Gaziantep	Gaziantep	Siverek
Y	Siverek	Ergani	Akcakale	Bozova	Adiyaman	Birecik	Hilvan
r (I_{DM})	0.87	0.72	0.82	0.72	0.89	0.89	0.89
r (I_{DMG})	0.88	0.72	0.81	0.75	0.76	0.89	0.91
Erinc (I_m)							
X	Diyarbakir	Diyarbakir	Ceylanpinar	Gaziantep	Gaziantep	Adiyaman	Siverek
Y	Siverek	Ergani	Akcakale	Adiyaman	Birecik	Bozova	Hilvan
r (I_m)	0.81	0.71	0.78	0.89	0.89	0.73	0.89

The stations with missing years and the stations with no missing years, which have a significant relationship between the stations were identified using correlation analysis and found to have high correlations (r> 0.7). Particularly, the similarities between the correlated stations and correlation coefficients of the I_{DM} and I_{DMG} methods were remarkable. After identifying the highly correlated stations, these relationships were modeled by regression analysis. As shown in Table 6, the dependent and independent variables of the linear regression models to be used to complete the missing years in the De Martonne (I_{DM}), De Martonne Gottman (I_{DMG}) and Erinc (I_m) annual series as well as the information about the missing years to be completed in the index series.

Table 6. Dependent (Y) and independent (X) variables of linear regression models to predict missing values in the annual series of I_{DM}, I_{DMG} and I_m

Methods	Y	X	Y	
			Non-missing observations	**Missing observations**
I_{DM} and I_{DMG}	Siverek	Diyarbakir	57 / 1964-2020	3 / 1961-1963
	Ergani	Mardin	57 / 1964-2020	3 / 1961-1963
	Akcakale	Sanliurfa	56 / 1965-2020	4 / 1961-1964
	Bozova	Gaziantep	21 / 2000-2020	9 / 1991-1999
	Adiyaman	Gaziantep	58 / 1963-2020	2 / 1961-1962
	Birecik	Gaziantep	57 / 1964-2020	3 / 1961-1963
	Hilvan	Siverek	23 / 1998-2020	7 / 1991-1997
I_m	Siverek	Diyarbakir	57 / 1964-2020	3 / 1961-1963
	Ergani	Diyarbakir	57 / 1964-2020	3 / 1961-1963
	Akcakale	Ceylanpinar	56 / 1965-2020	4 / 1961-1964
	Adiyaman	Gaziantep	58 / 1963-2020	2 / 1961-1962
	Birecik	Gaziantep	57 / 1964-2020	3 / 1961-1963
	Bozova	Adiyaman	21 / 2000-2020	9 / 1991-1999
	Hilvan	Siverek	23 / 1998-2020	7 / 1991-1997

Linear regression analysis was performed to complete the missing years of the I_{DM}, I_{DMG} and I_$_m$ series for the correlated stations listed in Table 6. The missing years in the annual series of I_{DM}, I_{DMG} and I_m for Siverek, Ergani, Akcakale, Bozova, Adiyaman, Birecik and Hilvan meteorological stations were completed using the regression models provided in Table 7.

Table 7. Linear regression models for estimating missing years in I_{DM}, I_{DMG} and I_m series

Y		**Regression equation**	***Coefficient of determination***	***Standard deviation***
		b_1X+b_0	**(%R²)**	**(STD)**
Y(I_{DM})	Siverek	1.092 Diyarbakir + 0.005	76.4	3.03
	Ergani	0.632 Mardin + 12.67	52.3	5.47
	Akcakale	0.577 Sanliurfa + 1.09	66.6	2.20
	Bozova	0.621 Gaziantep + 0.55	52.1	3.34
	Adiyaman	1.145 Gaziantep + 0.43	79.6	3.28
	Birecik	0.602 Gaziantep - 0.52	80.2	1.70
	Hilvan	0.791 Siverek + 0.12	72.9	2.58
Y(I_{DMG})	Siverek	1.101 Diyarbakir - 0.06	77.3	1.48
	Ergani	0.631 Mardin + 6.34	51.9	2.75
	Akcakale	0.576 Sanliurfa + 0.55	66.5	1.1
	Bozova	0.621 Gaziantep + 0.27	52.1	1.67
	Adiyaman	1.242 Gaziantep - 0.68	57.6	3.01
	Birecik	0.603 Gaziantep - 0.27	80.3	0.85
	Hilvan	0.856 Siverek - 0.75	78.2	1.21
Y(I_m)	Siverek	0.900 Diyarbakir + 5.24	46.3	5.95
	Ergani	1.216 Diyarbakir + 8.82	51.1	7.13
	Akcakale	0.790 Ceylanpinar + 2.23	61.5	2.67
	Bozova	0.392 Adiyaman + 4.81	52.5	3.39
	Adiyaman	1.152 Gaziantep + 0.94	80.3	3.94
	Birecik	0.559 Gaziantep - 0.40	79.5	1.98
	Hilvan	0.763 Siverek - 0.79	69.2	3.24

The annual index series of I_{DM}, I_{DMG} and I_m methods were divided into two different time scales based on the year 1991 when the Atatürk Dam started to hold water. The drought index values representing the stations listed in Table 8 were calculated using the median values of each period (Çetin et al., 2001).

Table 8. Median values of I_{DM}, I_{DMG} and I_m annual series of meteorological observation stations for the 1st period (1961-1990) and 2nd period (1991-2020)

Stations	I_{DM_1}	I_{DM_2}	I_{DMG_1}	I_{DMG_2}	I_{m_1}	I_{m_2}
Ergani	30.7	26.9	15.3	13.5	36.2	32.8
Diyarbakir	19.2	18.3	9.6	9.2	22.1	20.8
Adiyaman	24.8	24.6	12.4	12.3	29.6	28.8
Siverek	18.7	20.6	9.3	10.3	22.8	25.3
Hilvan	*NA**	16.2	*NA*	8.0	*NA*	18.2
Bozova	*NA*	14.1	*NA*	7.0	*NA*	16.2
Mardin	28.6	21.2	14.3	10.6	36.8	26.8
Sanliurfa	16.5	13.7	8.2	6.8	19.3	16.5
Gaziantep	21.5	22.1	10.7	11.1	25.0	25.6
Birecik	12.8	12.1	6.4	6.1	13.9	13.2
Ceylanpinar	11.7	8.3	5.8	4.4	12.3	9.0
Akcakale	10.4	8.9	5.2	4.4	11.4	9.8

NA*: Not Available

The methods showed similar behavior and drought severity tended to increase from north to south in all methods. Naturally, this is also seen in the graph drawn considering the index averages (Figure 2.). According to the Erinc method, drought severity tends to increase more from north to south (Siverek-Akcakale) in the study area compared to the De Martonne and De Martonne-Gottman methods. The increasing trend of drought severity in the De Martonne-Gottman method was found to be less than that of the other methods. Considering the trend line of the linear regression model, it is predicted that in the future, the transitions between the climate classes of each method will occur the fastest in the Erinc method.

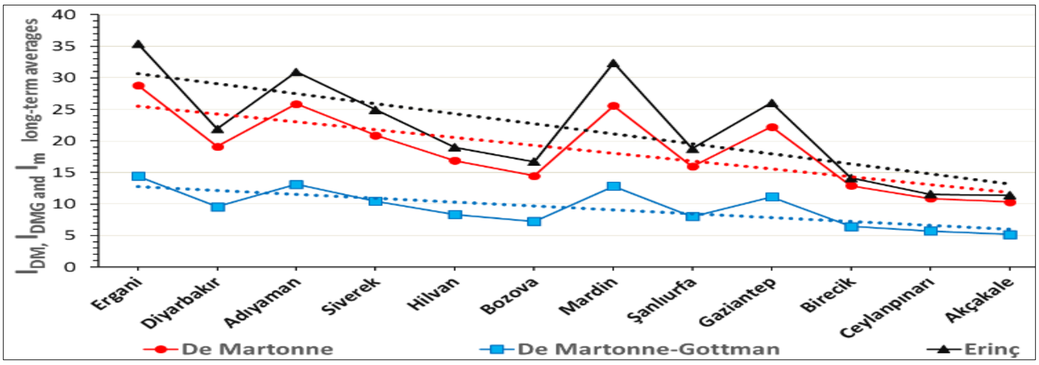

Figure 2. Long-term (1961-2020) averages of De Martonne (I_{DM}), De Martonne-Gottman (I_{DMG}), Erinc (I_m) series and trends represented by the linear regression model

The most comprehensive climate classification study in Turkey using the De Martonne-Gotmann and Erinc methods was conducted by the Turkish State Meteorological Service (MGM, 2016a; MGM, 2016b). The results obtained from the MGM study and this study were evaluated together. In this comparison based on the long-term averages, it was seen that the results significantly overlapped with each other (Table 9.). Within the scope of MGM and this research, it was determined that there were no major changes in the I_{DMG} values obtained from the long-term averages of the periods with different data lengths that would affect the climate class of the stations. According to the I_{DMG} method in both studies; Ergani, Adiyaman, Siverek, Mardin and Gaziantep were represented by 'Between Semi-arid and humid'; Diyarbakir, Birecik, Ceylanpinar and Sanliurfa were represented by 'Semi-arid' climate characteristics. However, while Akcakale station was represented by the 'Desert' climate class with an average I_{DMG} value of 4.6 in the MGM study period (1981-2010\30 years), it was defined by the 'Semi-arid' climate class with an average I_{DMG} value of 5.1 in the study period (1961-2020\60 years) within the scope of this research. In this case, it can be said that the I_{DMG} climate classification threshold value is 5 I_{DMG} may cause the small differences in the averages of the index values calculated at Akcakale station to cause climate class change.

Considering the long-term averages of the index values of MGM and Erinc method within the scope of this research, it was determined that Ergani, Adiyaman, Siverek and Mardin were represented by 'Sub-humid' climate class; Diyarbakir and Sanliurfa stations were represented by 'Semi-arid'; Birecik, Ceylanpinar and Akcakale stations were represented by 'Arid' climate classes in both studies. It was observed that the long-term averages of Erinc method index values in different periods did not create a difference that would cause a climate class change.

Table 9. The averages of the De Martonne-Gotmann and Erinc annual index series obtained within the scope of this research and by the Turkish State Meteorological Service (MGM)

Stations	Time period \ year		I_{DMG}		I_m	
	MGM	This Study	MGM	This Study	MGM	This Study
Ergani	1981-2010\30	1961-2020\60	14.6	13.6	35.2	35.4
Diyarbakir	1981-2010\30	1961-2020\60	9.2	9.5	20.9	21.9
Adiyaman	1981-2010\30	1961-2020\60	12.8	13.1	29.8	30.9
Siverek	1981-2010\30	1961-2020\60	10.7	10.2	25.2	24.9
Mardin	1981-2010\30	1961-2020\60	11.9	12.8	30.2	32.4
Sanliurfa	1981-2010\30	1961-2020\60	7.7	8.0	17.7	18.5
Gaziantep	1981-2010\30	1961-2020\60	11.5	11.1	25.4	26.0
Birecik	1981-2010\30	1961-2020\60	6.4	6.4	13.7	14.1
Ceylanpinar	1981-2010\30	1961-2020\60	5.0	5.7	10.8	11.5
Akcakale	1981-2010\30	1961-2020\60	4.6	5.1	10.2	11.4

Identifying high meteorological drought risk areas

In order to clearly reveal the spatial and temporal distributions of drought classes in Sanliurfa province, the I_{DM}, I_{DMG} and Im annual series were evaluated in two different periods. The year 1991 (DSİ, 2022), representing the period when the Atatürk Dam started to hold water, was taken as a reference within the scope of the study and accepted as the beginning of the second period. The series of stations was divided into two different time scales: period 1 (1961-1990) and period 2 (1991-2020). Since Hilvan and Bozova did not have sufficient observations of the climate elements used in the calculation of the index values in the 1st period, they were included in the calculations in the 2nd period. Using the median values of the drought index series representing the stations (Çetin et al., 2001), I_{DM}, I_{DMG} and I_m annual climate class maps of Sanliurfa were produced for 2 different periods with a resolution of 200x200 m by the Inverse Distance Method (Figure 3.- 5.).

As seen in Figure 3, according to the De Martonne method; in the 1st period (1961-1990), it was determined that the "Mediterranean" climate prevailed in Sanliurfa in a strip along the bed of the Euphrates River extending from Gaziantep to Adiyaman provincial borders and north of Siverek to the Mardin provincial border. The severity of the drought continued to increase from north to south towards the Syrian border and these areas were represented by the "Semi-arid" climate class. In the second period (1991-2020), compared to the first period, there was an increase in drought intensity of 2 "I_{DM}" from south to north. The drought has increased over the 30-year period and has spread northward. Moreover, while Harran, Akcakale and Ceylanpinar were dominated by "Semi-arid" climate characteristics in the 1st period, they were under the influence of "Arid" climate in the 2nd period. This situation is more clearly shown in Table 10, The area represented by the "Arid" climate class within the Sanliurfa province was "0" in the first period, while in the second period the area represented by the "Arid" climate class was 3334.5 km^2, which means shifting towards "Semi-arid" to the "Arid" climate class (Keskiner and Çetin, 2023a). The fact that it was determined in a study conducted by Keskiner and Çetin (2023a) in Sanliurfa that the “Semi-arid” climate type is likely to shift towards the “Arid” climate type in the future coincides with the findings obtained from our research.

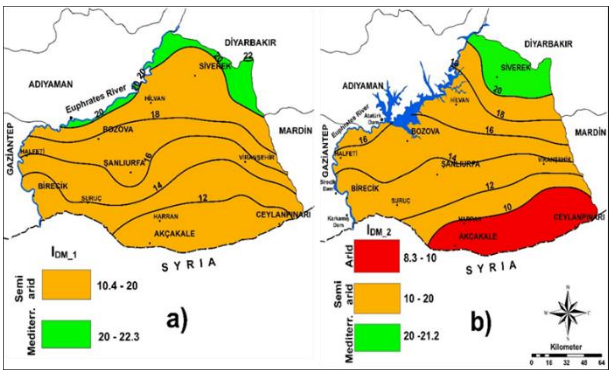

Figure 3. De Martonne (I_{DM_1}) 1st period (a) and 2nd period (b) annual climate class maps

Table 10. Surface area change of climate classes in the first (1961-1990) and second periods (1991-2020) according to the De Martonne (I_{DM}) method

Period	Climate classes	Index values	Surface area (km^2)	Surface area changing in period 2 compared to period 1	
				Climate classes changing (km^2)	I_{DM} (Areal average)
I_{DM_1}	Arid	<10	0		15.6
	Semi-arid	10.4-20	18034.8		
	Mediterranean	20 - 22.3	1331.5		
I_{DM_2}	Arid	8.3-10	3334.5	3334.5 *(Increase)*	14.5
	Semi-arid	10-20	14339.3	-3695.4 *(Decrease)*	
	Mediterranean	20 -21.2	1692.4	360.9 *(Increase)*	

In the north around Siverek, an area of 360.9 km^2 has spread from the "Semi-arid" climate class to the Mediterranean climate type, which exhibits more humid characteristics. While the areal average of the I_{DM} in the first period was 15.6, it was represented by a value of 14.5 in the second period and it was determined that the drought severity increased after the Atatürk Dam in the study area. According to the results obtained with the De Martonne method, it was determined that the Atatürk Dam could not stop the meteorological drought propagation (Keskiner and Çetin, 2023b) from south to north in Sanliurfa province. In a study conducted by Keskiner and Çetin (2023b) to determine drought trends in Sanliurfa province, it was found that the conclusions that Atatürk, Birecik and Karkamis dams are unlikely to prevent the occurrence of drought from south to north in Sanliurfa and its surroundings except Bozova are compatible with our study.

Figure 4. shows that there is no significant difference between the De Martonne-Gottman and De Martonne methods in terms of drought spread. Indeed, the I_{DMG} method indices are calculated as exactly half of the I_{DM} indices. This is because, as seen in equation 2, the value of the precipitation of the driest month (*Pd*) in arid regions such as Sanliurfa does not have summer precipitation or precipitation that would make a significant difference. When the long-term monthly precipitation of the precipitation series within the scope of the study is analyzed, the Pd value is represented by a zero value in almost all stations. Therefore, there is no significant difference between I_{DMG} and I_{DM} methods in arid regions.

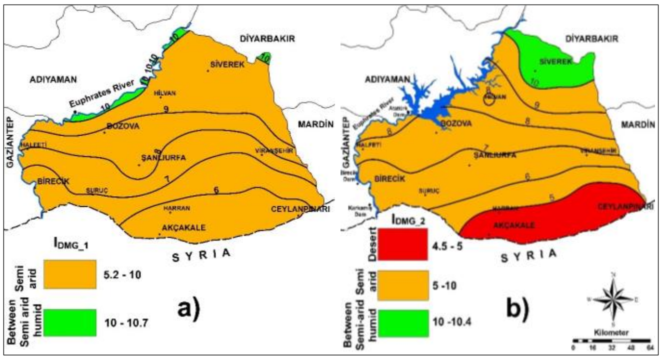

Figure 4. De Martonne-Gottman (I_{DMG_1}) 1st period (a) and 2nd period (b) annual climate class maps

According to the I_{DMG} method, it was identified that the "Between Semi-arid and humid" climate type was observed along the Euphrates river bed extending to the Gaziantep-Adiyaman provincial borders in the 1st period, while the "Semi-arid" climate type affected almost the entire Sanliurfa. The increase in drought severity from the north towards the Syrian border was also evident in the I_{DMG} method. Compared to the first period, there was a gradual increase in drought with 1 "I_{DMG}" in the second period from south to north. Similar to the I_{DM} method, the drought increased in the second period and spread northward during the 30-year period. According to the climate classification of the I_{DMG} method, Harran, Akcakale and Ceylanpinar had "Semi-arid" climate characteristics in the 1st period, while these areas were represented by the "Desert" climate class in the 2nd period. As can be seen in Table 11; while there was no area represented by the "Desert" climate class in the first period, it was determined that an area of 3108.7 km^2 in the second period transitioned from the "Semi-arid" (19005.4 km^2) climate class to the "Desert" climate class, and an area of 1167.3 km^2 around Siverek to the "Between Semi-arid and humid" climate class. Similar to the I_{DM} method, the areal average of the first and second period I_{DMG} index values decreased from 7.7 "I_{DMG}" to 7.3 "I_{DMG}" values, respectively, and the severity of drought increased in the last 30 years (Ircan and Duman, 2021). The De Martonne-Gottman method, like the De Martonne method, revealed that the Atatürk Dam could not prevent the meteorological drought propagation from south to north in Sanliurfa province.

Table 11. Surface area change of climate classes in the first (1961-1990) and second periods (1991-2020) according to the De Martonne-Gottman (I_{DMG}) method

Periods	*Climate classes*	*Index values*	*Surface area (km^2)*	*Surface area changing in period 2 compared to period 1*	
				Climate classes changing (km^2)	*I_{DMG} (Areal average)*
I_{DMG_1}	Desert	0-5	0		7.7
	Semi-arid	5.2-10	19005.4		
	Between Semi-arid and humid	10-10.7	360.9		
I_{DMG_2}	Desert	4.5-5	3108.7	3108.7 *(Increase)*	7.3
	Semi-arid	5-10	14729.3	4276.0 *(Decrease)*	
	Between Semi-arid and humid	10-10.4	1528.2	1167.3 *(Increase)*	

The Erinc method,which is another method used in the study did not show significant differences in the spatial distribution of the 1st and 2nd period drought classes (Figure 5.). Drought propagation from south to north in Sanliurfa was observed to intensify in the 2nd period similar to the other methods. However, in the Erinc method, it was determined that there was a transition area from"Semi-arid" and "Sub-humid" climate classes to "Arid" climate classes in the 2nd period, with 926.6 km^2 in the south and 862.4 km^2 in the north, respectively (Table 12.). The Erinc method, like the other two methods, found that the Atatürk Dam could not prevent the meteorological drought propagation from south to north in Sanliurfa province. On the other hand, in a study by Keskiner (2022), in which the areas at risk of meteorological drought in Sanliurfa Province were determined using the "Aydeniz Annual Humidity Coefficient ($N_{(hc)annual}$)", the spatial distribution of climate classes, and especially the south of the Suruc-Viransehir line as the regions most exposed to drought severity, is very consistent with the results obtained with the Erinc method used in our research.

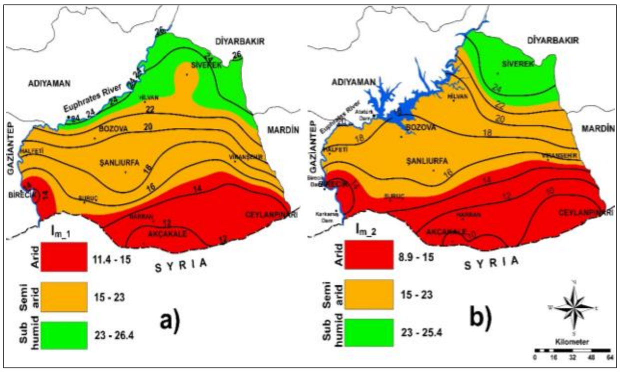

Figure 5. Erinc (I_{m_1}) 1st period (a) and 2nd period (b) annual climate class maps

Table 12. Surface area change of climate classes in the first (1961-1990) and second periods (1991-2020) according to Erinc (I_m) method

Period	*Climate classes*	*Index values*	*Surface area (km^2)*	*Surface area changing in period 2 compared to period 1*	
				Climate classes changing (km^2)	*I_m (Areal average)*
I_{m_1}	Arid	11.4-15	5538.2		18.3
	Semi-arid	15-23	10622.1		
	Sub-humid	23-26.4	3206.0		
I_{m_2}	Arid	8.9-15	7327.1	1789.0 *(Increase)*	17.0
	Semi-arid	15-23	9695.6	-926.6 *(Decrease)*	
	Sub-humid	23-25.4	2343.6	-862.4 *(Decrease)*	

As a result, the spatial averages of the Erinc indices represented by the values of 18.3 "I_m" and 17 "I_m" in the 1st and 2nd periods, respectively, are in agreement with the findings indicating that drought severity increased in the 2nd period. For example, as seen in the areal distribution of index values in Akcakale and its environs (Figure 5); while drought severity was represented by I_m = 12 in the 1st period, it was represented by I_m = 10 in the 2nd period. Drought severity has increased by 2 "I_m" in 30 years. This situation is clearly seen in the calculations made by considering the median values of annual total precipitation and annual average maximum temperature values observed from Akcakale station between 1965-1990 (Table 13.).

Table 13. Changes in drought severity at Akcakale station in the 1st period (1965-1990) and the 2nd period (1991-2020) according to I_m, I_{DM} and I_{DMG} methods

Erinc	*Median of the annual total precipitations (mm)*	*Average annual max.temperature (C⁰)*	I_m	*Changes compared to period 1*			
1.period (1965-1990)	295.2	25.5	11.6	Precip. (%)	Temp. (%)	I_m (%)	I_m (Severity)
2.period (1991-2020)	251.9	25.8	9.8	14.7	1.1	15.6	1.8
De Martonne	*Median of the annual total precipitations (mm)*	*Average annual temperature (C⁰)*	I_{DM}	*Changes compared to period 1*			
1.period (1965-1990)	295.2	18.3	10.4	Precip. (%)	Temp. (%)	I_{DM} (%)	I_{DM} (Severity)
2.period (1991-2020)	251.9	18.4	8.9	14.7	0.3	14.8	1.5
De Martonne-Gottman	*Median of the annual total precipitations (mm)*	*Average annual temperature (C⁰)*	I_{DMG}	*Changes compared to period 1*			
1.period (1965-1990)	295.2	18.3	5.2	Precip. (%)	Temp. (%)	I_{DMG} (%)	I_{DMG} (Severity)
2.period (1991-2020)	251.9	18.4	4.4	14.7	0.3	14.8	0.8

When the calculations are taken into consideration, during the thirty years in period 2, the annual total precipitation decreased by 14.7% and the annual average maximum temperature increased by 1.1%. The results obtained from the De Martonne and De Martonne-Gottman methods were similar to the Erinc method. Indeed, Bozkurt (2013) predicts that precipitation in the Euphrates-Tigris basin will decrease by 20-30% and temperatures will increase by 2.1-4.1% by the end of this century. Therefore, the south of Sanliurfa (Birecik, Suruc, Harran, Akcakale, Ceylanpinar and Viransehir) is likely to be under the influence of "Severe arid" climate according to the Erinc method, "Arid" climate according to the De Martonne method and "Desert" climate according to the De Martonne-Gottman method within this century.

Conclusions

Sanliurfa will have approximately 940.000 hectares of irrigated area with the completion of the GAP project. Therefore, it is within the scope of provinces that will be most affected by a possible drought. The De Martonne, De Martonne-Gottman and Erinc annual index series were arranged in two 30-year periods: the 1st period (1961-1990) and the 2nd period (1991-2020) when the Atatürk Dam started to hold water. "Annual Climate Class Maps" of De Martonne, De Martonne-Gottman and Erinc were produced of Sanliurfa for both periods. The areal average of the drought index values of the methods were represented by 15.6, 7.7 and 18.3 values in the 1st period, while they were 14.5, 7.3 and 17.0 in the 2nd period, respectively.

In the second period when the Atatürk Dam started to hold water, the drought continued to propagate more severely. Areas at risk of meteorological drought were determined. In this study, which aims to determine the spatial and temporal propagation of the meteorological drought trend before and after the construction of the Atatürk Dam, the following conclusions can be drawn:

Meteorological drought is more severe in the south of Sanliurfa, while its severity decreases towards the north and there is a risk of meteorological drought in the whole province

Akcakale, Ceylanpinar and Viransehir have been identified as areas that will be primarily affected by drought, and it is predicted that if global warming continues at the current rate until the end of this century, Akcakale, Ceylanpinar and Viransehir are likely to experience severe droughts and face desertification.

While the impact of climate change on drought is revealed by analysing various drought index series for different periods, it seems unlikely that Atatürk Dam in Sanliurfa province will prevent the spread of drought caused by global warming.

In order to reduce the negative impacts of climate change on dry farming and irrigated agricultural lands, it is recommended that afforestation and forest management practices be planned and implemented urgently around Sanliurfa. In drought studies to be carried out in this region; It is important to use drought analysis methods together that utilize different variables in the calculation of drought index values to make water resources and drought risk management plans based on more realistic findings.

Conflict of interest:

The authors declare that there are no personal and financial conflicts of interest within the scope of the study.

Author contributions:

ADK conceptualized the study, developed the methodology and validated the findings. TY performed data analysis and visualized the data. ADK, TY, GİT and MŞ contributed to writing, editing and reviewing the manuscript.

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