International Journal of
Agriculture, Environment and Food Sciences

e-ISSN: 2618-5946 https://dergipark.org.tr/jaefs

DOI: https://doi.org/10.31015/jaefs.2024.4.5 Int. J. Agric. Environ. Food Sci. 2024; 8(4): 768-778

Developing and modeling precipitation duration curves and determining spatial and temporal distributions of precipitation over different percentages of time

Ali Demir Keskiner[1] Mahmut Cetin[2]

[1]Department of Agricultural Structures and Irrigation, Faculty of Agriculture, Harran University, Sanliurfa, Turkiye
[2]Department of Agricultural Structures and Irrigation, Faculty of Agriculture, Cukurova University, Adana, Turkiye

Article History
Received: August 3, 2024
Revised: October 28, 2024
Accepted: November 1, 2024
Published Online: December 09, 2024

Article Info
Article Type: Research Article
Article Subject: Agricultural Hydrology

Corresponding Author
Ali Demir Keskiner
adkeskiner@harran.edu.tr

Available at
https://dergipark.org.tr/jaefs/issue/87864/1527449

Abstract

Determining the temporal distribution of precipitation is of critical importance for engineering hydrology, agricultural yield forecasting, and drought monitoring. The aims of the research carried out in this context were threefold: a) to develop *"precipitation duration curves"*, i.e., PDCs, of long-term total precipitation series, b) to investigate likely mathematical models of PDCs of each meteorological station studied, and c) to determine spatial and temporal distributions of precipitation that occur equalled or exceeded at 50% and 80% of the time. In line with the objectives, the PDCs were developed for each meteorological station. To this end, long-term annual precipitation data series were obtained from a total of 11 meteorological stations located in and around the borders of Sanliurfa province. PDCs of meteorological stations were modelled using the fifth-order regression equation at the 5% significance level. The mathematical forms of the developed model equations were used to predict precipitation amounts for each station at 50% and 80% of the time. The predicted precipitation data were mapped to delineate the spatial distribution of precipitation, and then hypsometric curves were generated from these maps. It was found that the standard errors (SE) of the *"precipitation duration curves"* models showed an increasing tendency as the standard deviation of the rainfall series increased. Regression analysis results showed that the SE values of the models change in direct proportion to the increase in extreme precipitation values. Considering the amount of precipitation that exceeds or equals 50 per cent of the time, it can be concluded that *"Semiarid"* climate characteristics prevail in the south of Hilvan meteorological station and *"Humid"* climate characteristics in the north. The precipitation, which occurs 80% time equaled or exceeded, indicates *"Arid"* climate characteristics in the southern parts of the Harran district and *"Semiarid"* climate characteristics in the northern parts of the study area. Considering the area averaged precipitation values corresponding to the two exceeded or equalled the percentage of time ratios, i.e., 50% and 80%, it can be concluded that *"Semiarid"* climate characteristics are dominant in Sanliurfa province and its surrounding geography.

Keywords: Regression analysis, Distribution of precipitation over time, Precipitation duration curve modelling, Drought, Sanliurfa

Cite this article as: Keskiner, A.D., Cetin, M. (2024). Developing and modeling precipitation duration curves and determining spatial and temporal distributions of precipitation over different percentages of time. International Journal of Agriculture, Environment and Food Sciences, 8(4): 768-778. https://doi.org/10.31015/jaefs.2024.4.5

INTRODUCTION

Water is crucial for life and plays an important role in biological, geological and chemical processes. The total amount of water in the world is about 1.338 billion km^3 (Dikmenli et al., 2024). Although 97.5% of this amount is found as salty water in the oceans and seas and the remaining 2.5% as fresh water in solid, liquid and gaseous form, only 0.4% of the freshwater available as surface water (lakes, rivers and swamps) is usable. Furthermore, only 0.001% (12.900 km^3) out of 1.338 billion km^3 of water on Earth is present as water vapour in the atmosphere (Gleick, 1996; USGS, 2024; NASA, 2024a). Of the 577000 km^3 of water in the hydrological cycle, 458000 km^3 falls to the ocean and 119000 km^3 to the land as precipitation. The amounts of evaporation from the ocean surface and land are 505000 km^3 and 72000 km^3, respectively (Shiklomanov, 2009). As it can be understood, the amount of fresh water available in our world is very limited, and the spatiotemporal distribution of precipitation as well as freshwater resources is irregular. Just like everywhere else, the distribution of precipitation in Turkiye is remarkably irregular. Topographical differences and the resulting 7 different climate zones are the main reasons for this irregularity in precipitation distribution.

Studies carried out in recent years have shown that Turkiye's long-term average annual rainfall has been 574 mm. Although the eastern Black Sea region receives the most precipitation (1200-2500 mm/year), the central Anatolian region (around Lake Tuz) receives the least (250-300 mm/year) (Cetin, 2020). Total annual rainfall yields 501 billion cubic meters of water in Turkiye each year. Of this water, 274 billion m^3 is returned to the atmosphere by evapotranspiration, 69 billion m^3 of this water recharges groundwater system, and 158 billion m^3 is discharged into the seas and lakes by river or surface runoff (Çiçek and Ataol, 2009; Usta, 2016). Turkiye has a technical and economic water potential of 112 billion m^3 including 98 billion m^3 of surface water and 14 billion m^3 of groundwater. However, 57 billion m^3 of the 112 billion m^3 water potential can be utilised. Of this amount, 44 billion m^3 is used in irrigation (Cetin, 2020) and 13 billion m^3 is used for domestic and industrial purposes (DSİ, 2024). According to the Falkenmark water stress index, Turkey is among the “water scarce” countries with an annual water potential of 1000-1500 m^3/year per capita (Wolf et al., 2003; Aydın et al., 2017). Recent studies have shown that 40% of the world's population will be living in regions with severe water shortages by 2035, which will cause the ecosystems that provide freshwater resources to be increasingly compromised (Guppy et al., 2017). Under these conditions, considering the undeniable importance of precipitations in water management in Turkey, determining the distribution of precipitation over time is a much-needed issue. The irregular distribution of precipitation in time and space in Turkiye, the determination of the temporal distribution of precipitation series, observed at a meteorological station, using the methodology of the development of *"flow duration curves"* can have many practical advantages.

Turkey's location between temperate and subtropical regions, together with the influence of the Mediterranean macroclimatic zone (Türkeş, 2021), causes it to be more exposed to extreme weather events in summer and winter (Yılmaz et al., 2021). The average temperature in Turkey is expected to increase by 2.65 °C in the next 100 years due to changes in extreme weather events such as drought and heat waves caused by global warming. Moreover, spatial and temporal temperature distributions already pose risks (Tonkaz and Cetin 2007; Aksu, 2021; Coşkun et al., 2021; CCP, 2024; Çeliktopuz, 2024). Climate change is not only about increasing temperatures and droughts but also about the spatial and temporal distribution of precipitation across the globe. Especially, causing extreme precipitation events to occur more frequently in different parts of the world (Nordling et al., 2024; NASA, 2024b). Similarly, the number of recurring extreme wet and dry events in Turkey is increasing day by day (Sılaydın Aydın and Kahraman, 2022; Keskiner and Şimşek, 2024). According to climate projections, precipitation is expected to decrease in all river basins of Turkey, and the *Euphrates-Tigris* basin in the Southeastern Anatolia region is among the basins that will be most affected by climate change. Therefore, Turkey is one of the countries that will suffer the most from the negative impacts of climate change (MGM, 2014; Demircam et al., 2017) and it would be overly optimistic to expect that long dry periods will not be experienced in drought-prone regions in the future. Moreover, the fact that the Southeastern Anatolia Project (GAP), one of Turkey's most important development projects with an irrigable agricultural area of 1.78 Mha, is located in a semi-arid region makes it inevitable that the agricultural sector will be negatively affected by drought events (Küçüközcü and Avcı, 2020; Keskiner and Cetin, 2023a; Kılınçoğlu et al., 2021).The gradual impact of drought on many economic sectors and the unpredictability of its onset and end - the inherent uncertainty of a drought event - have a multiplier effect on drought-related losses. Many drought indices have been developed to monitor and mitigate the negative effects of drought and the most important variable used in the calculation of these indices is precipitation (Erinç, 1965; Aydeniz, 1985; McKee et al., 1993). Therefore, determining the spatial and temporal distribution of precipitation is of vital importance for risk management in agricultural production. In rain-fed areas, such as those around the province of Sanliurfa in the GAP project area, rainfall is the only form of insurance for agricultural production. In this context, 11% of Turkiye's economically irrigable area and about 50% of the GAP project irrigation areas are within the borders of Sanliurfa province (Keskiner and Cetin, 2023b), which is exposed to drought risk.

The main objectives of this study were to: a) develop *"precipitation duration curves"*, i.e., PDCs, of long-term total precipitation series, b) to investigate likely mathematical models of PDCs of each meteorological station studied, c) determine spatial and temporal distributions of precipitation that occur equalled or exceeded at 50% and 80% of the time, d) derive *“precipitation hypsometric curves”* for the specified time ratios to figure out the changes in the areal average values of precipitation within the province.

MATERIALS AND METHODS

Description of Study Area and Data Source

This study was conducted in and around Sanlıurfa province, which is located between 37˚49' 12"- 40˚10' 00" E longitude and 36˚41' 28" - 37˚57' 50" N latitude in the Southeastern Anatolia Region of Turkiye. The study area covers an area of approximately 19 242 km² (HGM, 2022). Topographically, the south of Sanliurfa is a plain. In the north, Karacadag Mountain (1957 m), which stretches across Diyarbakır and Sanliurfa provinces, is located in the Siverek district. Mandal Hill (1895 m) is the highest point in Sanliurfa. Altitude decreases from Siverek towards the Syrian border, it is about 360 meters around Akcakale and Ceylanpınar. The low elevation along the Syrian border in Sanliurfa and in the inland areas from the border to the north causes extremely hot air masses originating from the Basra Low-Pressure Centre to be effective in the region during the summer period. This situation aggravates the occurrence of droughts that stretch from south to north in Sanliurfa. In the province of Sanliurfa, which is dominated by a continental climate on a macro scale, the long-term average temperature is around 18.6 ^{0}C. The long-term average of the total annual precipitation varies from 558 mm in Siverek, to 448 mm in Sanliurfa, to 285 mm and 295 mm in the districts of Akcakale and Ceylanpınar, respectively (İrcan and Duman, 2021; Keskiner and Cetin, 2023a). Understandably, annual precipitation amounts decrease significantly from north to south in the study area. Long-term annual total precipitation series acquired from meteorological stations of Ergani, Diyarbakır, Adıyaman, Siverek, Bozova, Mardin, Sanliurfa, Gaziantep, Birecik, Ceylanpınar and Akcakale, located in and around Sanliurfa province (Figure 1) and operated by the General Directorate of Meteorology, were used in this study. The location of the meteorological observation stations in the projected coordinate system was calculated in accordance with the D_WGS_1984_UTM_Zone_37N reference surface. In Table 1, the long-term averages of total annual precipitation values and some attribute information of meteorological observation stations are given in latitude order.

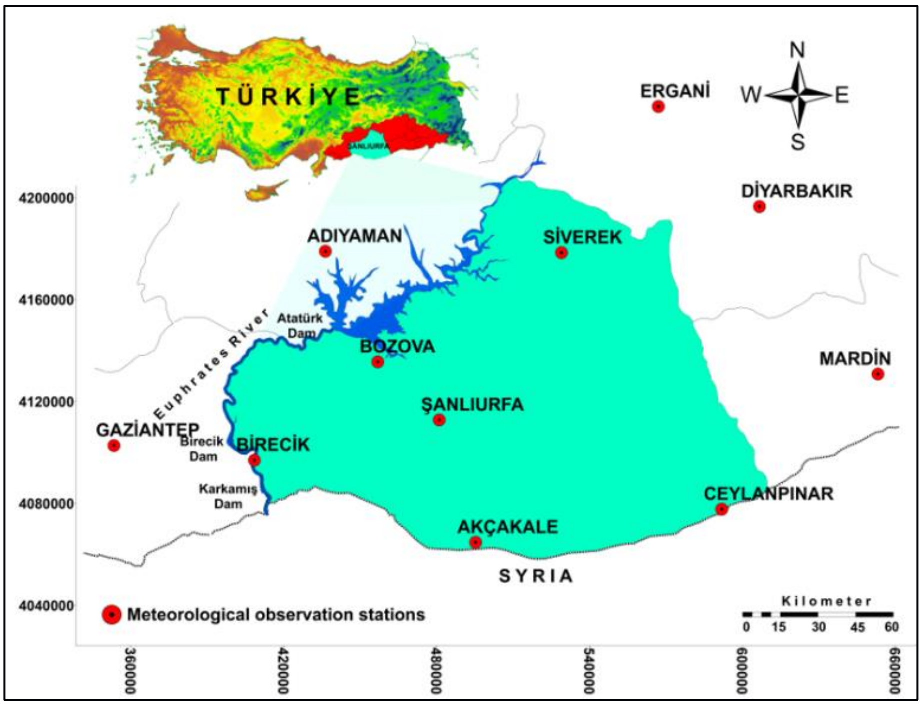

Figure 1. Location of the study area in Turkiye and spatial distribution of meteorological observation stations over the study area

Table 1. Some attributes of the meteorological stations used in the study

Station Name	Latitude (^{0})	Longitude (^{0})	Altitude (m)	Observation Period	Average Annual Precipitation (mm)
Ergani	38.267	39.766	986	1965-2023	735
Diyarbakır	37.909	40.213	680	1950-2023	494
Adıyaman	37.755	38.277	672	1963-2023	709
Siverek	37.752	39.329	801	1966-2023	558
Bozova	37.365	38.513	622	1982-2023	387
Mardin	37.310	40.728	1040	1955-2023	644
Sanliurfa	37.160	38.786	550	1955-2023	448
Gaziantep	37.058	37.351	854	1959-2023	557
Birecik	37.013	37.971	347	1966-2023	354
Ceylanpınar	36.841	39.933	360	1957-2023	295
Akcakale	36.727	38.947	365	1965-2023	285

Developing Precipitation Duration Curves

In this study, the method used in obtaining *flow duration curves* (Beşiktaş, 2010; Demir and Tona, 2021) was employed to develop the *precipitation duration curves* (PDCs). A PDC is a cumulative frequency curve showing the percentage of time when precipitation is greater than or equal to a certain P_i value. In other words, PDC is a relationship between precipitation value and the exceeded or equalled percentage of the time. By using these curves, the precipitation exceeding a certain percentage of the time can be determined practically or the percent of time indicated precipitation was equaled or exceeded may be estimated for hydrological design purposes. To this end, the *precipitation duration curve* may be derived by labelling the vertical axis with precipitation values *(P)* and the horizontal axis with the percentages of time when the precipitation considered is equal to or greater than a certain value. The choice of time unit is determined by the purpose for which the curve is to be used (Bayazıt, 1999; Karakoyun et al., 2018). In this study, the *precipitation duration curve* for each meteorological station was derived by imitating the *flow duration curve* development procedure, which is widely used in hydrology. In order to obtain the *precipitation duration curve*: a) Precipitation time-series of a meteorological station is ordered from largest to smallest, b) The number of rows (m_i) of each P_i precipitation is obtained, c) The rank number of precipitation (m_i) is divided by the total number of observations (N) to calculate the exceedance percentage or exceedance rate (AO_i) of the considered precipitation P_i (Equation 1), d) The *precipitation duration curve* of the meteorological station in question is obtained by plotting the P_i values on the vertical axis and the AO_i ratios on the horizontal axis (Raudkivi, 1979).

$$AO_i = \frac{m_i}{N} * 100 \tag{1}$$

Regression Analysis

Precipitation duration curves (PDCs) can be described in mathematical terms by means of a polynomial. In this study; the regression model shown in Equation 2 was used for modelling the *PDCs*. For model selection, the *"CurveExpert"* software (Hyams, 2020) was used due to its ease of use. Mathematical forms of *PDCs* have been obtained with linear regression models up to the fifth order. The statistical significance of the parameters in Equation 2 and the model was determined by analysis of variance (Ryan and Cryer, 2005) at α=0.05 level of significance and the appropriate model was selected based on the highest R^2 and the *smallest model standard error (SE)*.

$$P_i = b_0 + b_1\, AO_i + b_2\, AO_i^{\,2} + b_3\, AO_i^{\,3} + b_4\, AO_i^{\,4} + b_5\, AO_i^{\,5} + e_i \tag{2}$$

Where: P_i is the dependent variable (annual total precipitation, mm); AO_i is the independent variable (the percentage of time in the long-term total precipitation series that indicates that the precipitation was equal to or higher during the observation period); b_i are the regression coefficients and e_i are the error term.

Development of "*Precipitation Hypsometric Curves*"

Hypsometric curves have been widely used to simulate the spatial distribution of regional variables such as surface runoff (Vivoni et al., 2008), drought indices (Keskiner et al., 2020), salinity (Cetin, 2003), groundwater (Cetin and Kirda, 2003; Keskiner et al., 2018), etc. In order to develop the *precipitation hypsometric curves*, first, the precipitation value P_i at the specified time percentage (x%) is estimated by using the mathematical model of the *PDC* of each meteorological station. A map is then drawn up using the estimated $P_{i,x\%}$ values as the basis. Eventually, the *precipitation hypsometric curve* for $P_{i,x\%}$ is derived by using the value of the precipitation at each pixel in the map and the areas that are covered by this value. In this study, the precipitation values exceeded 50% and 80% of the time ($P_{i,50\%}$: exceeded precipitation value of station *i* at 50% of the time, mm) were estimated by using the *precipitation duration curve* model of each station. These estimated precipitations were mapped at 200 m x 200 m resolution by inverse distance weighted interpolation technique (Liu et al., 2021; Keskiner and Cetin, 2023a) in a geographic information systems environment and their areal distributions were obtained. With the help of these maps, precipitation hypsometric curves were developed for 50% and 80% time ratios by applying the method (Chow et al., 1988) to obtain the catchment height-area relationship.

RESULTS AND DISCUSSION

Descriptive Statistics of Precipitation Series

Some characteristic values of meteorological observation stations are given in Table 1. Descriptive statistics of the annual total precipitation series of meteorological stations considered were calculated and presented in Table 2. Given the latitude at which the stations are located, it is noteworthy that the averages ($\overline{P}$) of Ergani-Siverek-Sanliurfa-Birecik-Ceylanpınar-Akcakale stations decrease with latitude in precipitation values from north to south, although not with a constant slope due to the effect of factors such as topography, aspect, etc. (Table 2). In other words, average precipitation observed at the stations tends to decrease from north to south. When $\overline{P}$ and median values of the precipitation series were compared, the median values of all stations were found to be smaller than the mean, indicating that the precipitation series are characterised by a right-skewed distribution. This conclusion was confirmed by the values of the coefficient of skewness *(C_{skew})*. Given the C_{skew} coefficient, Akcakale station was found to have the largest skewness coefficient ($C_{skew}=1.22$). The conclusion was that it would be more accurate to use the *Med* value of the data set as a representative value in project design studies (Hayes, 2007) instead of using $\overline{P}$ values in Akcakale station. It was found that the magnitude of the C_{skew} coefficient and the *STD* value were not compatible. However, it is clear that the magnitude of the range *(R)* of the data set directly affects the *STD* value. It was determined that the *STD* value of Ergani station *(STD=195.4)*, which has the largest *R*-value *(R=1006.1 mm)*, is represented by the largest value after Mardin station *(STD=217.5)*. When all the stations used in the study are taken into consideration, it can be said that the similarity of precipitation between the years is low in Ergani, Mardin and Adıyaman stations since the difference between the average precipitation values and the observed precipitation values is the largest. When minimum precipitation values (P_{min}) are considered; Ceylanpinari (P_{min})=70.6 mm) and Akcakale stations (P_{min})=108.4 mm) are predicted to be more at risk of drought than other stations (Keskiner and Cetin, 2023a). Considering the maximum precipitation (P_{max}) values of the stations, it was concluded that extreme precipitation was effective (Kılınç et al., 2023) in Ergani (P_{max}=1351.9 mm), Mardin (P_{max}=1193.9 mm) and Adıyaman (P_{max}=1152.8 mm) stations. When the coefficient of variation *(CV)* is analysed, the variability in precipitation series at all stations was found to be $CV \geq 25\%$. This statistic provided evidence of significant variability in the temporal distribution of precipitation. When the *STD* values and averages of the precipitation series are evaluated jointly, it is understood that the variability varies between 25%-37%. Therefore, the variability in annual precipitation observed in and around Ceylanpınar and Akcakale stations is larger compared to other stations. As explained by Nordling et al. (2024), the reason of this situation is because precipitation diminishes the closer you get towards the Syrian border, the standard deviation values do not decrease at the same rate and the high variation observed in the precipitation series. Conversely, the high CV at these stations may reflect the high drought impact. The higher the *CV*, the greater the dispersion in the precipitation events, indicating that data points in the precipitation series are more dissimilar and inconsistent, and that extreme values become more likely.

Table 2. Descriptive statistics of data sets of yearly precipitation totals observed in meteorological stations

Station Names	$\overline{P}$ (mm)	*Med* (mm)	*STD* (mm)	P_{min} (mm)	P_{max} (mm)	*R* (mm)	C_{skew}	C_{kurt}	*CV* (%)
Ergani	734.8	721.8	195.4	345.8	1351.9	1006.1	0.68	0.95	27
Diyarbakır	493.7	476.1	136.0	146.3	854.7	708.4	0.14	0.14	28
Adıyaman	708.9	678.0	192.8	364.8	1152.8	788.0	0.42	-0.59	27
Siverek	557.6	537.3	155.5	255.0	893.0	638.0	0.35	-0.56	28
Bozova	386.5	354.8	109.9	177.2	655.9	478.7	0.75	0.18	28
Mardin	644.3	627.8	217.5	247.6	1193.9	946.3	0.52	-0.24	34
Sanliurfa	448.0	425.3	147.0	160.5	854.7	694.2	0.80	0.59	33
Gaziantep	557.1	540.4	140.7	325.1	994.0	668.9	0.68	0.55	25
Birecik	354.2	337.0	102.8	187.6	614.0	426.4	0.64	-0.02	29
Ceylanpınar	294.6	273.7	107.9	70.6	546.1	475.5	0.46	-0.31	37
Akcakale	284.9	269.9	105.8	108.4	646.2	537.8	1.22	2.11	37

Modelling of Precipitation Distribution Over Time

The first step in developing *precipitation duration curves (PDC)* for each station used in the study was to plot the annual precipitation value of a station versus *the exceeded or equaled percentage of time* over a given period. A 5th-order polynomial (Equation 2) represents the mathematical forms of the resulting *PDC* distributions. Figure 2 shows the 5th-order regression models for the precipitation duration curves and the scatterplot fits of the P_i-AO_i values. Table 3 shows the model coefficients, correlation coefficients *(r)*, coefficients of determination *(R^2)* and standard errors *(SE)* of the regression models fitted to the *PDC*s. One of the most remarkable characteristics of the models is that the model *SE* values of Mardin (Pmax=1193.9 mm), Ergani (Pmax=1351.9 mm), Gaziantep (Pmax=994.0 mm) and Adıyaman (Pmax=1152.8 mm) stations increase in parallel with the size of maximum precipitation observations in the time series. In other words, the larger the maximum precipitation in te series, the larger the *SE* value of the *PDC* model. In turn, the SE values of these stations are 19.72 mm, 19.362 mm, 16.132 mm and 13.27 mm, which are larger than the model standard error of the other stations, respectively. This may be due to the fact that the maximum precipitation data in the precipitation series may be an outlier. However, it can be said that the maximum precipitation is effective in increasing the error of the regression model. Therefore, our recommendation is that before analyses are performed, outliers must be removed from the data. It was found that the precipitation series of Bozova, Birecik, Ceylanpınar and Akcakale stations, where the SE values of the *PDC* regression models of the stations are less than 10 mm, have the smallest STD values. The SE values of the *PDC* regression models of the precipitation series of these stations are 9.91 mm, 6.04 mm, 9.00 mm and 9.34 mm, respectively. The Siverek station, which is located in a topography with a high difference in altitude compared to the other stations, does not show any similarity to this structure with a value of STD=155.5 mm, although SE is 8.36 mm. However, as pointed out by Carter (2013), the small standard deviation (STD) values of the precipitation series are an indicator of low variability in the data, which can be said to contribute to reducing the model error. In other words, the variability of the data (STD and CV) affects the prediction error (SE) of the models.

Table 3. Regression model coefficients and model goodness-of-fit statistics representing the precipitation duration curves of the observation stations

İstasyonlar	b_0	b_1	b_2	b_3
Ergani	1381.725562756870	-57.1761359002948	2.36553998142426	-0.0486887247871676
Diyarbakır	852.631827388411	-25.1970616562749	1.01487445375872	-0.0231161714340396
Adıyaman	1172.872452246460	-20.8384015641572	0.47465384293105	-0.0080878250930805
Siverek	919.250273509813	-14.6518299919079	0.29673242451598	-0.0056301326359867
Bozova	706.451732731845	-18.7093008025387	0.54448144215318	-0.0102563571054207
Mardin	1238.566182448110	-39.1954490683444	1.46302277930733	-0.0317335856990392
Sanliurfa	920.549972447308	-35.6600798800292	1.25726081486108	-0.0240060035833074
Gaziantep	979.758067858816	-31.7162156414739	1.19366620090969	-0.0239670327815119
Birecik	639.605983402985	-15.4835267305092	0.35034635537457	-0.0042324696024038
Ceylanpınar	570.724095653920	-14.5408265637939	0.42707168364310	-0.0089058185584778
Akcakale	681.932075897924	-36.5291137524379	1.50150095617332	-0.0311388803925949

İstasyonlar	b_4	b_5	r	R^2	SE (mm)
Ergani	0.000465714672729440	-0.0000016840716109069100	0.995	0.991	19.36
Diyarbakır	0.000250145231017204	-0.0000010207656320505700	0.997	0.994	10.49
Adıyaman	0.000075366969471655	-0.0000002899280462248350	0.997	0.995	13.27
Siverek	0.000064712760415137	-0.0000002995734002435610	0.998	0.997	8.36
Bozova	0.000102334755298633	-0.0000004056523498547760	0.996	0.992	9.91
Mardin	0.000327241949987971	-0.0000012692887558356100	0.996	0.992	19.72
Sanliurfa	0.000225087858060502	-0.0000008252088936940450	0.997	0.993	12.49
Gaziantep	0.000227858174113607	-0.0000008256104963221600	0.993	0.987	16.13
Birecik	0.000023528243097752	-0.0000000525958714241227	0.998	0.996	6.04
Ceylanpınar	0.000096877886073248	-0.0000004081119182073870	0.996	0.993	9.00
Akcakale	0.000304646044900108	-0.0000011273305059528100	0.996	0.992	9.34

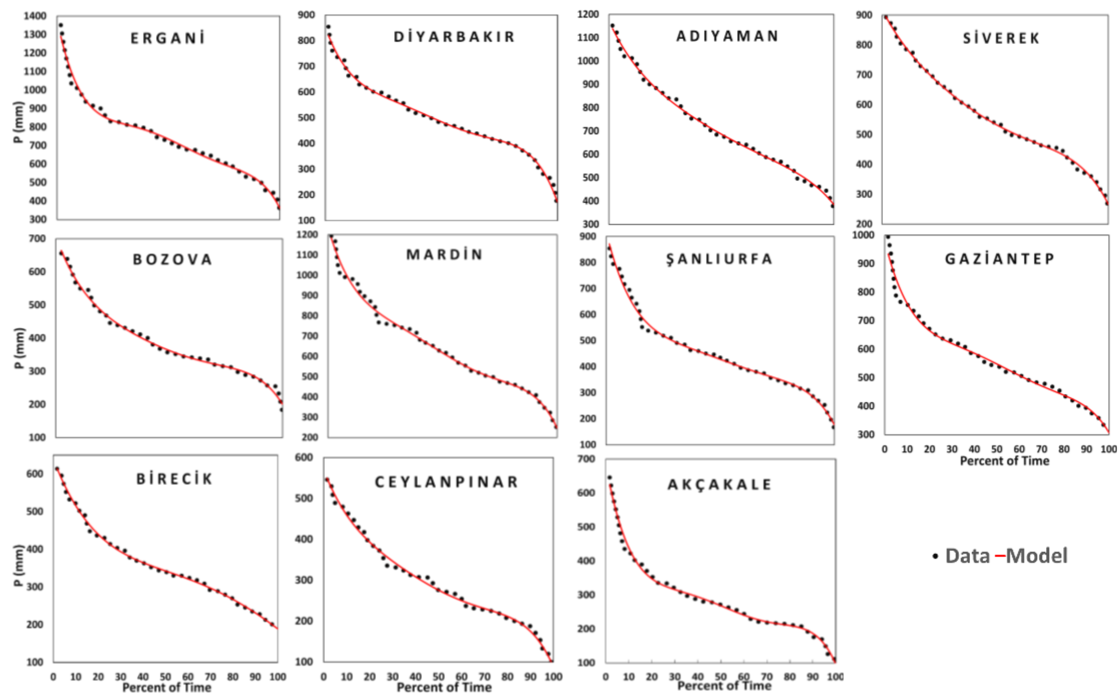

Figure 2. Annual precipitation values versus the exceeded or equalled percentage of time with regression model fits (*PDCs*) of the meteorological stations used

Spatial Distribution of *Precipitation Duration Curves*

Evaporation, which is very effective in the cause of drought, is highly dependent on temperature. However, drought indices such as *standardized precipitation index (SPI), percent of normal index* (*PNI)* etc. define drought severity by using only precipitation values. In the definition of climate, aridity also plays an important role in agricultural water management as well as rainfed farming. Therefore, there are studies by IPCC (2007), Huang et al. (2016) and Thomas (2011) in which aridity is grouped based on mean annual precipitation. For example, Holzapfel (2008), referring to areas with high evaporation during the growing season, classified drought into 4 groups based on *total annual mean precipitation* (Table 4). Indeed, Sanliurfa is one of the provinces with low relative humidity, high average temperature and high evaporation demand during the growing season (Elgalı, 2020; Ürün et al., 2023). In this context, the values of precipitation expected to be exceeded or equalled 50% and 80% of the time were calculated for Sanliurfa using the *PDC* models. Table 4 has been taken into account in the interpretation of the spatial and temporal distribution of these calculated precipitations. Figure 3 shows the precipitation that was exceeded (present) in 50% of the cases, depending on the observation period of the stations. Those curves given in Figure 3 may be used to estimate the percent of time that a specified precipitation will be equalled or exceeded in the future or to estimate discharge for a given percent of duration. Such estimates are required for drought mitigation studies.

Table 4. Grouping drought/climate categories in areas with high evaporation during the plant-growing season (Holzapfel, 2008)

Type of Aridity	Amount of mean annual precipitation (mm)
Extreme Arid	less than 60-100 mm
Arid	from 60-100 to 150-250 mm
Semiarid	from 150-250 to 250-500 mm
Nonarid (Mesic)	above 500 mm

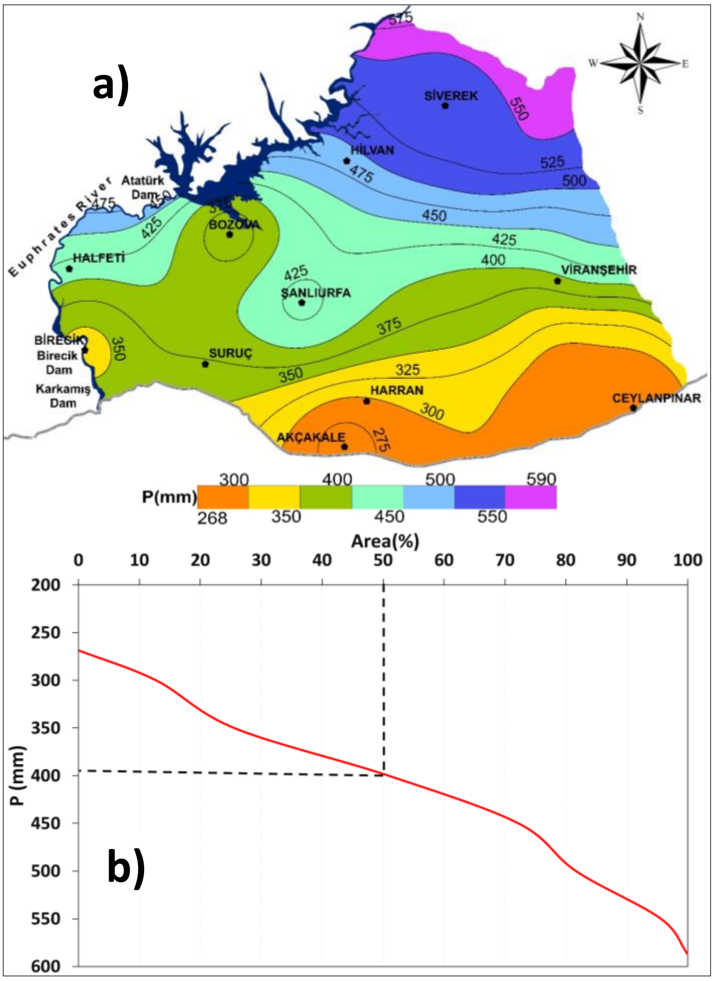

Figure 3. a) Spatial distribution of precipitation values exceeded 50% of the time ($P_{50\%}$) and b) *Precipitation hypsometric curve* for $P_{50\%}$

As can be seen in Figure 3, the precipitation values that occur 50% of the time in Sanliurfa can be considered as the boundary line (500 mm precipitation contour) dividing the north and south of Hilvan into two distinct climate types of *"Humid*" and *"Semiarid"*, respectively. From the south of Hilvan to the Syrian border, the *"Semiarid*" climate character is dominant, while the amount of precipitation decreases from north to south. This remarkable decrease in precipitation can be attributed to the high level of aridity prevailing in Syria. Taking into account the criteria given by Santos et al. (2022), which are based on precipitation that falls 50% of the time, it can be concluded that the expected yield of agricultural production cannot be achieved without irrigation in the south of Hilvan. On the other hand, given the remaing 50% of the time, the north of Hilvan, Siverek and its surroundings are under the influence of the humid climate. From the analysis of the hypsometric curves of precipitation, it can be concluded that the average areal precipitation in the province of Sanliurfa is 390 mm 50% of the time and that it is under the influence of a *"Semiarid"* climate regime (Keskiner and Cetin, 2023b).

Likewise, the spatial and temporal distribution of precipitation over 80% of the time is determined using the *PDC* models, as shown in Figure 4. Significant differences were found in the spatial distribution of the precipitation amounts that occurred 80% of the time compared to precipitation amounts that occurred 50% of the time. It was found that the amount of precipitation falling 80% of the time decreased and the severity of drought in the study area increased. Especially around the settlements of Harran, Akcakale and Ceylanpınar, exceeded precipitation of 250 mm or more in 80% of the time means that the precipitation falling on the site in the remaining 20% of the time will be less than 250 mm, indicating that the region can expect severe rainfall deficiencies once in five years (İrcan and Duman, 2021). This constitutes evidence that Arid climate characteristics prevail in the region 20% of the time. It was found that the Harran meteorological station and its surroundings constitute a border between *"Semiarid"* and *"Arid"* climate characteristics. In turn, findings are a precursor of the "*Arid*" climate type in the southern parts of the study area in the future. On the other hand, in the north of Harran district, it was determined that the humidity continued to increase towards Siverek and the *"Semiarid"* climate characteristics were effective in the north of Harran. However, considering the amount of precipitation exceeded 80% of the time, it is an undeniable fact that the expected yields cannot be obtained without irrigating agricultural crops. This means that dry farming will be even more at risk in the future. The average value of precipitation exceeded 80% of the time is 320 mm. For this reason, Sanliurfa and its surroundings have a *"Semiarid"* (Keskiner and Cetin, 2023a) climate regime 80% of the time, and an *"Arid"* climate type is preponderant for the remaining 20% of the time.

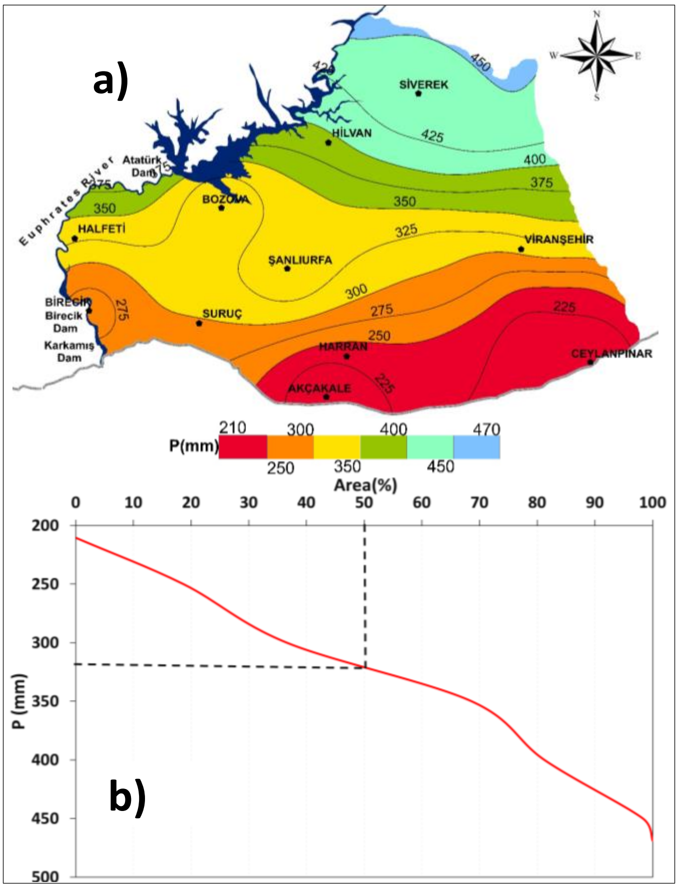

Figure 4. Spatial distribution of precipitation values exceeded 80% of the time $(P_{80\%})$ and b) *Precipitation hypsometric curve* for $P_{80\%}$

CONCLUSIONS AND RECOMMENDATIONS

The South East Anatolia Project (GAP) aims to irrigate an area of 1.78 million hectares. Approximately 940 000 ha of this irrigable area is within the borders of Sanliurfa province. Therefore, it is important to know the distribution of precipitation that is exceeded in a certain percentage of time in and around Sanliurfa province in terms of irrigation water management. Sanliurfa province is expected to be more affected by a potential drought than other provinces located in the GAP area due to its large irrigated areas. Within the framework of this study, the *precipitation duration curves* of the long-term total annual precipitation series of each meteorological observation station located in the GAP area have been developed and these curves have been mathematically modelled. Spatial and temporal distributions of the precipitation amounts exceeded 50% and 80% of the time were determined using the model equations obtained for each station. *Precipitation hypsometric curves* were derived from the maps drawn for the specified time ratios, i.e., the exceeded or equalled percentage of time. With the help of precipitation hypsometric curves, the spatial variation of areal means of total annual precipitation exceeded 50% and 80% of the time in the study area was revealed by generating precipitation maps. Conclusions that were drawn in light of the results of this study are listed below:

- ✓It was observed that as the STD values in the annual precipitation series increased, the SE values of the *precipitation duration curve models* also increased. The SE values of the models were directly proportional to the increase in maximum precipitation.
- ✓It is recommended that the outliers are analysed prior to performing the PDC analysis and that the outliers are removed from the data if sufficient evidence can be found.
- ✓Model equations for precipitation duration curves can be used to instantly calculate or estimate precipitation amounts that exceed a certain percentage of the time. In this context, it was determined that rainfall exceeding 50% of the time had a drought-reducing effect. On this time scale, the province of Sanliurfa is characterised by *"Semi-arid*" and *"Humid"* climate types which are harbingers of ongoing drought events.
- ✓A reduction in the amount of precipitation that occurs 80% of the time, increased the severity of drought in the study area. It was found that *"Arid"* climate characteristics were dominant in and around the Harran, Akcakale and Ceylanpınar meteorological stations due to the impacts of severe arid conditions in Syria's territory. Considering the precipitation in this time scale, "Semiarid" and "Arid" climate characteristics prevailed in the province and "Humid" climate characteristics were not observed.
- ✓Considering the areally averaged precipitation occurring in these two time scales; it is concluded that the *"Semiarid"* climate characteristic is dominant for Sanliurfa province.
- ✓*Precipitation duration curves* and *precipitation hypsometric curves* can be used operationally in and around the study area by practitioners in water resource planning, irrigation management and drought monitoring studies, etc.

Compliance with Ethical Standards

Peer-review

Externally peer-reviewed.

Declaration of Interests

The authors declare that they have no competing, actual, potential or perceived conflict of interest.

Author contribution

The contribution of the authors to the present study is equal. All the authors read and approved the final manuscript. All the authors verify that the text, figures, and tables are original and that they have not been published before.

Funding

No financial support was received for this study.

Acknowledgments

The authors are thankful to the Turkish State Meteorological Service for providing the dataset.

REFERENCES

Aksu, H. (2021). Nonstationary analysis of the extreme temperatures in Turkiye. Dynamics of Atmospheres and Oceans, 95: 101238. https://doi.org/10.1016/j.dynatmoce.2021.101238

Aydeniz, A. (1985). Toprak Amenajmanı-I, Ankara Üniversitesi Ziraat Fakültesi Yayınları, Ankara.

Aydın, O., Ünaldı, Ü. E., Duman, N. & Çiçek, İ. (2017). Türkiye'de su kıtlığının mekânsal ölçekte değerlendirilmesi. Türk Coğrafya Dergisi (68), 11-18 (in Turkish). https://doi.org/10.17211/tcd.314754

Bayazıt, M. (1999). Hidroloji. İTÜ İnşaat Fakültesi Matbaası.

Beşiktaş, M. (2010). Determination of flow duration curves by regression analysis in the eastern black sea and current estimation. Istanbul Technical University, Graduate School of Natural and Applied Sciences, Department of Civil Engineering, MSc Thesis, Istanbul, Turkiye, 71 pp.

Carter, R.E. (2013). A standard error: distinguishing standard deviation from standard error. Diabetes. 62 (8): e15. https://doi.org/10.2337/db13-0692.

CCP (2024). The climate of Turkiye. Retrieved in June, 11, 2024 from https://www.climatechangepost.com/Turkiye/climate-change/

Celiktopuz, E. (2024). Forecasting some climate parameters of Türkiye using the SSP3-7.0 scenario for the years 2040–2059. International Journal of Agriculture, Environment and Food Sciences, 8 (1), 62- 71. https://doi.org/10.31015/jaefs.2024.1.7

Cetin, M. & Kirda, C. (2003). Spatial and temporal changes of soil salinity in a cotton field irrigated with low-quality water. Journal of Hydrology (272):238–249.

Cetin, M. (2020). Agricultural Water Use. In: N. B. Harmancioglu, D. Altinbilek (eds.), Water Resources of Turkiye, Chapter 9, World Water Resources, Vol. 2, https://doi.org/10.1007/978-3-030-11729-0_9, Springer Nature Switzerland AG 2020, ISBN 978-3-030-11728-3, pp. 257-302. WOS:000487756200012

Chow, V.T., Maidment, D.R. & Mays, L.W. (1988). Applied hydrology, McGraw-Hill, Inc., Civil Engineering Series, New York.

Coskun, C., Ertürk, M.İ., Arcaklioğlu, E., Balci, K. & Oktay, Z. (2021). The climate change impact projections on seasonal residential sector CO_2 emissions and energy demand forecasting for Turkish provinces. International Journal of Global Warming, 24, (3/4), 281-306.

Çiçek, İ. & Ataol, M. (2009). Türkiye’nin su potansiyelinin belirlenmesinde yeni bir yaklaşım. Coğrafi Bilimler Dergisi, 7(1), 51-64 (in Turkish). https://doi.org/10.1501/Cogbil_0000000094

Demir, V. & Tona, A.U. (2021). Debi-Sürek Eğrisi yardımıyla taban akımının hesaplaması: Samsun Kürtün Irmağı Örneği. Avrupa Bilim ve Teknoloji Dergisi, (24), 502-507. https://doi.org/10.31590/ejosat.916024 (in Turkish).

Demircan M., Gürkan H., Eskioğlu O., Arabacı H. & Coşkun M. (2017). Climate change projections for Turkiye: Three models and two scenarios, Turkish Journal of Water Science and Management, 1 (1):22-43. https://doi.org/10.31807/tjwsm.297183

Dikmenli, M., Ozkan, V. K., Kilic, S. & Cardak, O. (2024). An analysis of the concept of water in secondary school biology textbook. Journal of Education in Science, Environment and Health (JESEH), 10 (1), 1-17. https://doi.org/10.55549/jeseh.1417888

DSİ (2024). Toprak su kaynakları. Retrieved in June, 11, 2024 from https://dsi.gov.tr/Sayfa/Detay/754

Elgali, E.F.H. (2020). Kurak iklim koşullarında seraların iklimlendirilmesi: Sanliurfa örneği. Çukurova University, Graduate School of Natural and Applied Sciences, Department of Agricultural Structures And Irrigatıon, MSc Thesis, Adana, Turkiye, 115 pp.

Erinç S. (1965). Yağış müessiriyeti üzerine bir deneme ve yeni bir indis. Edebiyat Fakültesi, Coğrafya Enstitüsü Yayınları, No: 41, İstanbul.

Gleick, P. H. (1996). Water resources. In Encyclopedia of Climate and Weather, ed. by S. H. Schneider, Oxford University Press, New York, vol. 2, pp.817-823.

Guppy, K. A., Mehta, P. & Nagabhatla, N. (2017). Global water crisis: The facts. United Nations University Institute for Water, Environment and Health, Hamilton, Canada, pp.1-13.

Hayes, M.J. (2007). Drought indices. Western Water Assessment, Feature Article From Intermountain West Climate Summary, 3, 2-3.

HGM (2024). Türkiye il ve ilçe yüz ölçümleri. Retrieved in June, 11, 2024 from https://www.harita.gov.tr/urun/il-ve-ilce-yuzolcumleri/176

Holzapfel, C. (2008). Deserts. In: Jørgensen, S.E., Fath, B.D. (Eds.), Encyclopedia of Ecology. 2nd edition, 2, pp. 447–466, Elsevier, Oxford.

Huang, J., Ji, M., Xie, Y., Wang, S., He, Y. & Ran, J. (2016). Global semi-arid climate change over last 60 years. *Clim Dyn* 46, 1131-1150 https://doi.org/10.1007/s00382-015-2636-8

Hyams, D.G. (2020). CurveExpert Professional Documentation Release 2.7.3.Retrieved in June, 11, 2024 from https://www.curveexpert.net/docs/curveexpert/pro/pdf/CurveExpertProfessional.pdf

IPCC (2007). Summary for Policymakers. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 7-22.

İrcan, M. R. & Duman, N. (2021). Standartlaştırılmış yağış indisi (SYİ) yöntemi ile Sanliurfa ili kuraklık analizi. Coğrafya Dergisi, (42), 1-18 (in Turkish).

Karakoyun, Y., Dönmez, A.H. & Yumurtacı, Z. (2018). Comparison of environmental flow assessment methods with a case study on a runoff river–type hydropower plant using hydrological methods. Environ Monit Assess, 190, 722. https://doi.org/10.1007/s10661-018-7107-3

Keskiner A. D., Çetin M., Şimşek M., Nagano T. & Akın S. (2018). Taban suyu derinlikleri için grid tabanlı yeni bir optimizasyon modeli geliştirilmesi: Aşağı Seyhan Havzası örneği. Harran Üniversitesi Mühendislik Dergisi, 3(3): 70-80 (in Turkish with English abstract).

Keskiner, A. D., Çetin, M., Şimşek, M. & Akın, S. (2020). Kuraklık riski altındaki havzalarda gölet haznelerinin tasarımı: Seyhan havzasında bir uygulama. Teknik Dergi, 31 (5), 10189-10210. https://doi.org/10.18400/tekderg.505584 (in Turkish).

Keskiner, A.D. & Simsek, O. (2024). Evaluation of the sensitivity of meteorological drought in the Mediterranean region to different data record lengths. *Environ Monit Assess* 196, 602,https://doi.org/10.1007/s10661-024-12726-8

Keskiner, A. D. & Çetin, M. (2023a). Kuraklık gidiş ve büyüklüğünün zaman ve mekan boyutunda belirlenmesi: Güneydoğu Anadolu Projesi (GAP) alanında bir uygulama. Politeknik Dergisi, 26 (3), 1079-1089. https://doi.org/10.2339/politeknik.1000596 (in Turkish).

Keskiner, A. & Cetin, M. (2023b). Modelling spatiotemporal tendencies of climate types by Markov chain approach :A case study in Sanliurfa province in the south-eastern of Turkiye. MAUSAM, 74(3), 621–638. https://doi.org/10.54302/mausam.v74i3.872

Kılınçoğlu, N., Cevheri, C. İ., Cevheri, C. & Nahya, H. Y. (2021). Effects of exogenous glycine betaine application on some physiological and biochemical properties of cotton (G. hirsutum L.) plants grown in different drought levels. International Journal of Agriculture Environment and Food Sciences, 5(4), 689-700. https://doi.org/10.31015/jaefs.2021.4.30

Kilinc E., Altindal S. & Kiris S. (2023). Doğal afetler için acil durum uygulaması: AfetAp, Türk Deprem Arastirma Dergisi, 5 (2), 301-313, https://doi.org/10.46464/tdad.1351700 (in Turkish).

Küçüközcü, G., & Avcı, S. (2020). Tolerance of forage pea cultivars to salinity and drought stress during germination and seedling growth. International Journal of Agriculture Environment and Food Sciences, 4(3), 368-375. https://doi.org/10.31015/jaefs.2020.3.17

Liu, Z. N., Yu, X. Y., Jia, L. F., Wang, Y. S., Song, Y. C. & Meng, H. D. (2021). The influence of distance weight on the inverse distance weighted method for ore-grade estimation. Scientific Reports, 11. https:// doi. org/ 10. 1038/s41598- 021- 82227-y

McKee, T.B., Doesken, N.J. & Kleist, J. (1993). The relationship of drought frequency and duration to time scales. 8th Conference on Applied Climatology, 17-22 January, Anaheim, 179-184.

MGM (2014). İklim projeksiyonlarına göre akarsu havzalarında sıcaklık ve yağış değerlendirmesi. Retrieved in June, 11, 2024 from https://www.mgm.gov.tr/FILES/iklim/yayinlar/2014/iklim-Projeksiyonlari-ve-Havzalar-2014.pdf

NASA (2024a). The water cycle. Retrieved in June, 11, 2024 from https://earthobservatory.nasa.gov/features/Water

NASA (2024b). Warming makes droughts, extreme wet events more frequent. Retrieved in June, 11, 2024 from https://www.nasa.gov/centers-and-facilities/goddard/warming-makes-droughts-extreme-wet-events-more-frequent-intense/

Nordling, K., Fahrenbach, N. & Samset, B. (2024). Climate variability can outweigh the influence of climate mean changes for extreme precipitation under global warming, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2024-1068

Raudkivi, A. J. (1979). Hydrology: An Advanced Introduction to Hydrological Processes and Modelling. Pergamon Press.

Ryan, B.F. & Cryer, J. (2005). Minitab handbook fifth edition regression and correlation. Belmont, California.

Santosh, S.P., Saurav, K., Thomas, P., Girisha, K.G., Vijayasatya, N.C. & Zhuping, S. (2022). Comparing the effect of different irrigation water scenarios on arid region pecan orchard using a system dynamics approach. Agr. Water Manag. 265, 107547. https://doi.org/10.1016/j.agwat.2022.107547

Shiklomanov, I.A. (2009). Hydrological Cycle. In Atmospheric Precipitation of the Earth, ed. by V.I. Babkin, Encyclopedia of Life Support Systems Publishers Company Limited, Oxford, vol. 2, pp.18-47.

Sılaydın Aydın, M. B., & Kahraman E. D. (2022). Aşırı yağışlardan kaynaklanan sellere karşı Türkiye kentlerinin kırılganlık düzeylerinin belirlenmesi. Eksen Dokuz Eylül Üniversitesi Mimarlık Fakültesi Dergisi, 3(1), 34-45.

Thomas, D.S.G. (2011). Arid zone geomorphology: process, form and change in drylands, 3rd edn. Wiley-Blackwell.

Tonkaz, T. & Cetin, M. (2007). Effects of urbanization and land-use type on monthly extreme temperatures in a developing semi-arid region, Turkiye. Journal of Arid Environments, 68, 143-158. https://doi.org/10.1016/j.jaridenv.2006.03.020

Türkeş, M. (2021). Türkiye’nin su iklimi, iklim değişikliği ve 2019-2020 kuraklığı. EKOIQ, 92, 90-97 (in Turkish).

USGS (2024). How much water is there on Earth? Retrieved in June, 11, 2024 from https://www.usgs.gov/special-topics/water-science-school/science/how-much-water-there-earth

Usta, A. (2016). Türkiye’nin su potansiyelinin belirlenmesi üzerine bir araştırma. Küresel Mühendislik Çalışmaları Dergisi, 3(2), 107-115 (in Turkish).

Ürün, İ.H., Tuylu, G.İ. & Keskiner, A.D. (2023). Mapping monthly average reference evapotranspiration in geographic information system environment: A case study in Sanliurfa, 5th International Black Sea Modern Scientific Research Congress, Volume: II, November 8-10, Rize/Türkiye

Vivoni, E.R., Benedetto, F.D., Grimaldi, S. & Eltahir, E.A.B. (2008). Hypsometric control on surface and subsurface runoff. Water Resources Research, 44, W12502, doi:10.1029/2008wr006931

Wolf, A. T., Yoffe, S. B. & Giordano, M. (2003). International waters: identifying basins at risk, Water Policy, 5, 29-60.

Yılmaz, E., Akdi, Y. & Uğurca, E. (2021). Precipitation cycles in Turkiye. Theoretical and Applied Climatology, 143, 1299-1314. https://doi.org/10.1007/s00704-020-03490-z