

FREQUENCY ANALYSIS OF THE ANNUAL AND SEASONAL DROUGHT INTENSITY-DURATION RELATIONSHIP

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ABSTRACT

Drought is the most significant natural hazard that has the greatest effect on the human life and economy. Unlike other natural disasters, drought events evolve slowly in time and their impacts generally span a long period of time. Different drought indices are used for determining the temporal and spatial specifications of droughts. Standardized Precipitation Index is a powerful and simple tool to quantify the precipitation deficit for multiple time scales and for different climatic regions.

In this study drought is analyzed using the concept of standardized precipitation index (SPI). The long term precipitation and temperature data observed in 8 raingauge stations operated by The Turkish State Meteorological Service (DMI) in the regions of South-Eastern Anatolia in Türkiye are evaluated for the period of 57 years.

The precipitation values on the raingauge stations of South-Eastern Anatolia's Region stations are investigated for the periods of 3, 6, 9, 12 and 24 months according to the classification values of the SPI method, and the frequencies of drought classes of the drought intensity-duration-frequency analysis based on annual and seasonal precipitation records are obtained. Performing further statistical analysis of precipitation data has been studied the probability distributions of the precipitation.

1 INTRODUCTION

Drought is one of the most important natural disasters. Droughts are difficult to detect and monitor due to the complexity of their nature. Drought indices, such as the Palmer Drought Severity Index (PDSI) (Palmer, 1965), Decile Index (DI) (Gibbs and Maher, 1967), Surface Water Supply Index (SWSI) (Shafer and Dezman, 1982) and Standardized Precipitation Index (SPI) (McKee et al., 1993), are the most common tools for detecting and monitoring droughts.

The SPI has several advantages over another indices. It can be calculated for several time scales. Calculation of the SPI is easier than on more complex indices (McKee et al., 1995; Komuscu, 1999). The SPI is comparable in both time and space, and is not affected by geographical or topographical differences (Lana et al., 2001). The SPI allows the determination of duration, magnitude and intensity of droughts (Hayes et al., 1999). The SPI provides a quick and handy approach to drought analysis. Other advantages of this approach are its relative simplicity and minimal data requirements.

The SPI has been extensively used for drought analysis in countries/ continents such as the U.S.A. (Hayes et al., 1999) , Europe (Vicente-Serrano, 2006; Lloyd-Hughes and Saunders, 2002b), East Africa (Ntale and Gan, 2003), South Africa (Rouault and Richard, 2003), Greece (Tsakiris et al. 2007, Loukas et al, 2004; Livada et al., 2007) and Korea (Min et al., 2003), Turkey (Sirdas and Sen, 2003; Sönmez et al., 2005), Bacanlı et al. 2008, 2011, Bacanlı, 2011), Italy (Bordi et al., 2006; Bonaccorso et al., 2003).

In this study drought is analyzed using the concept of standardized precipitation index (SPI). The long term precipitation and temperature data observed in 8 raingauge stations operated by The Turkish State Meteorological Service (DMI) in the regions of South-Eastern Anatolia in Türkiye are evaluated for the period of 38 years. The precipitation values on the raingauge stations of South-Eastern Anatolia's Region stations are investigated for the periods of 3, 6, 9, 12 and 24. The frequencies of drought classes are obtained. Also the drought period, magnitude and standardized precipitation index (SPI) values are presented to depict the relationships between drought duration and magnitude.

2 STUDY AREA AND DATA

The Southeastern Anatolia Region covers 9.7 percent of the lands in Turkey with a surface area of 75,000 km². Valleys and Plateaus occupy large areas in the south of southeast Taurus mountains. Central part is very mountainous and eastern part is generally flat. In the South-Eastern Anatolia region, summers are hot and dry, with temperatures above 30°C. Spring and autumn are generally mild, but during both seasons sudden hot and cold spells frequently occur in the region. Although mountainous areas are affected by Continental climate, western part shows typical characteristics of Mediterranean climate. Annual precipitation is between 350-800 mm.

Thanks to GAP (Southeastern Anatolian Project) the area is having great changes positively; many farming lands and dam lakes were formed lately with this project. The Southeastern Anatolian Project is the largest and most multifaceted development project in Turkey as well as one of the, largest development projects in the world. The project includes active farming with extensive irrigation systems and electricity production. It will also benefit the tourism, mining, petrol, education, health, communication, industry and transportation sectors. The Southeastern Anatolia Project covers the lower parts of the Fırat and Dicle rivers and the provinces of Gaziantep, Sanliurfa, Adiyaman, Diyarbakir, Mardin, Siirt, Batman and Sirnak, on the plains between the rivers. The project will also bring with it a change in the climate of the area (DMI, 2011).

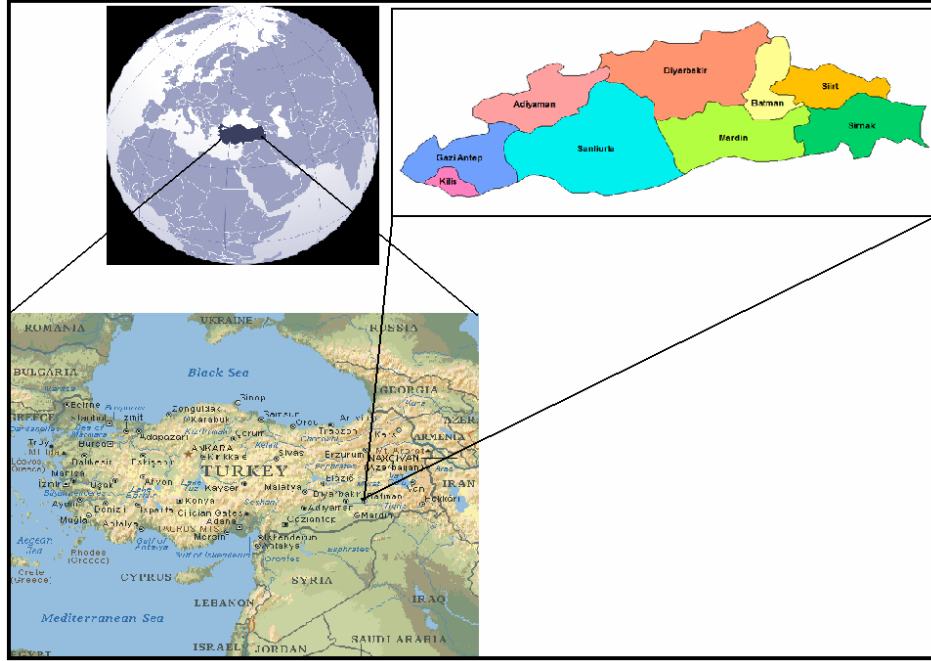


Figure 1. Location of study area in Türkiye

Table I. Characteristics of the rainfall station.

Site	Latitude	Longitude	Height (m)
Adıyaman	38 ⁰ 17'	37 ⁰ 46'	672
Batman	41 ⁰ 07'	37 ⁰ 52'	610
Diyarbakır	40 ⁰ 14'	37 ⁰ 55'	649
Gaziantep	37 ⁰ 22'	37 ⁰ 05'	854
Kilis	37 ⁰ 05'	36 ⁰ 44'	650
Mardin	40 ⁰ 44'	37 ⁰ 18'	1050
Şanlıurfa	38 ⁰ 46'	37 ⁰ 08'	547
Siirt	41 ⁰ 57'	37 ⁰ 56'	896

3 METHODS

4 STANDARD PRECIPITATION INDEX (SPI)

Mckee et al. (1993) developed the Standardized Precipitation Index (SPI). It has some advantages and disadvantages over the other drought indexes. The most important benefit of using SPI is that it may be calculated for various time periods. SPI is obtained by dividing the difference between precipitation and mean at a selected period to standard deviation (Equation 1).

$$SPI = \frac{x_i - \bar{x}_i}{\sigma} \quad (1)$$

In fact, the calculation of the index is complicated because the precipitation does not fit to normal distribution at periods of 12 months or shorter. The periods may vary according to the condition of usable water resources in the region.

Table II: Classification According to SPI Values

SPI	Drought Category
$2 \leq$	Extremely Wet
$1.99 - 1.5$	Very Wet
$1.49 - 1.0$	Moderately Wet
$0.99 - 0$	Near Normal
$0 - (-0.99)$	Mild Drought
$(-1.0) - (-1.49)$	Moderately Drought
$(-1.5) - (-1.49)$	Severely Drought
$-2 \geq$	Extremely Drought

Computation of the SPI involves fitting a probability density function (PDF). The gamma distribution is applied. The gamma distribution is defined by its frequency or PDF:

$$G(x) = \int_0^x g(x) dx = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-x/\beta} dx \quad \text{for } x \geq 0 \quad (2)$$

Where α and β are shape and scale parameters, x is the precipitation amount and $\Gamma(\alpha)$ is the gamma function. The Gamma function is undefined for $x=0$ and precipitation distribution might include zero values. In order to account for zero value probability, the cumulative probability distribution for gamma distribution is modified as:

$$H(x) = q + (1 - q) \cdot G(x) \quad (3)$$

where, q represents the probability for zero precipitation.

3.1. RUN ANALYSIS

The z-score for precipitation is simply the standardization of a given time series, X_i as $X_1, X_2, \dots, X_n$. The standardized precipitation series, x_i is:

$$x_i = \frac{X_i - \bar{X}}{S_x} \quad (4)$$

where X is the arithmetic mean and S_x is the standard.

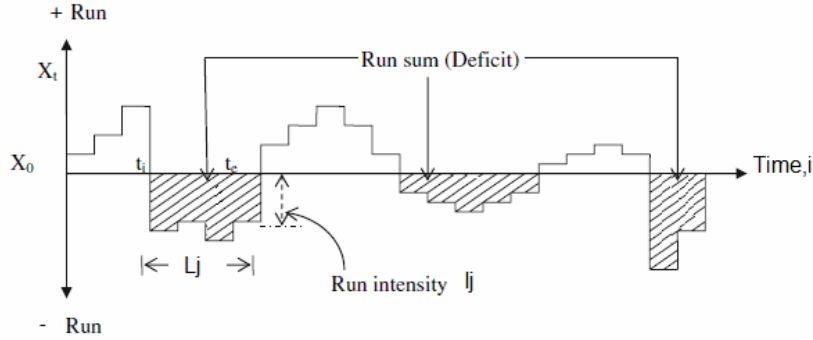


Figure 2: Drought characteristics using the run theory

Drought initiation time (t_i) is the starting of the water shortage period, which indicates the beginning of a drought event. Drought termination time (t_e) is the time when the water shortage becomes sufficiently small so that drought conditions no longer persist. Drought duration (L_j) is expressed in years/ months/weeks, etc., during which a drought parameter is the time period between the initiation and termination of a drought event. Drought magnitude, (M_j) indicates a cumulative deficiency of a drought parameter below the critical level (Bacanli, 2011).

$$M_j = \sum_{i=1}^m |X_o - x_i| \quad (5)$$

Finally, the drought intensity I_j of the j th dry period is defined as the ratio of drought magnitude to drought duration, L_j , as:

$$I_j = \frac{M_j}{L_j} \quad (6)$$

5 RESULTS

In this study, SPI was calculated for 3, 6, 9, 12 and 24 months periods. The SPI values for particular periods of which selected Adiyaman station from South-Eastern Anatolia are presented in Figure 3 to 7. It was seen (Figure 2, 3, 4, 5, 6) when the SPI values graphs are analyzed that when period increases drought is less but it lasts longer.

Drought in the 3 months time period as can be seen from Figure 3 is more common but shorter, and as the period increases the duration of drought also increases but frequency decreases. 6-12 months SPI show the drought on reservoirs' levels and on river discharges in the recent 12-24 months SPI generally shows the effect on groundwater table.

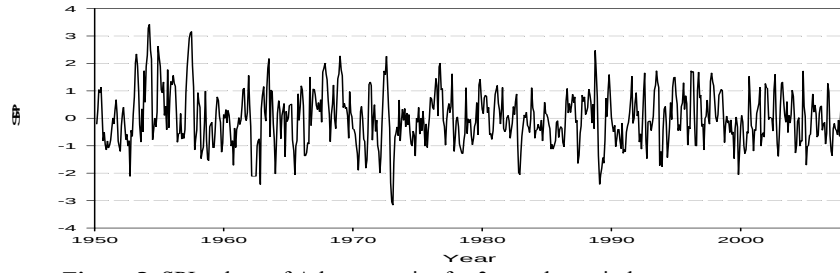


Figure 3. SPI values of Adiyaman city for 3 months period

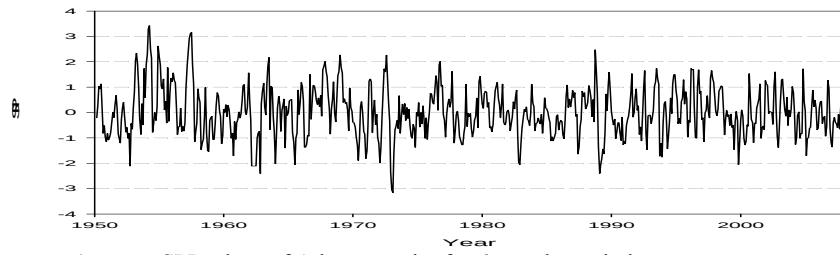


Figure 4. SPI values of Adiyaman city for 6 months period

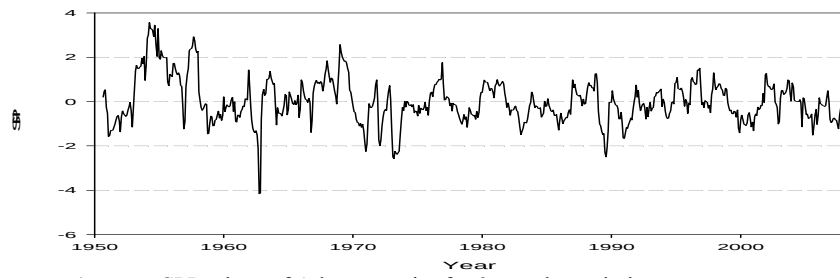


Figure 5. SPI values of Adiyaman city for 9 months period

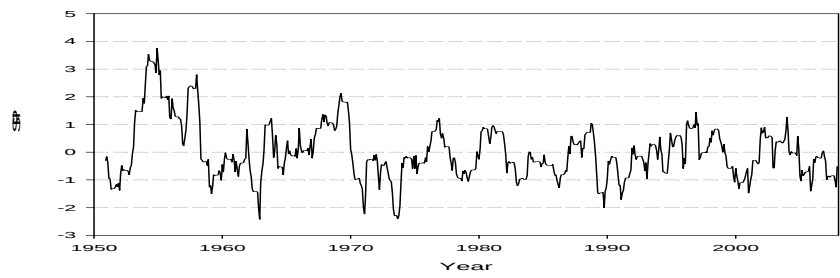


Figure 6. SPI values of Adiyaman city for 12 months period

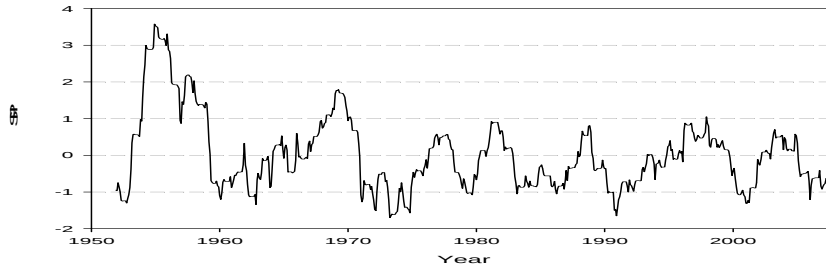


Figure 7. SPI values of Adiyaman city for 24 months period

In the presented study, the relative frequencies of the SPI results are obtained. Figure 8 is shown the relative frequencies of Adiyaman city SPI values for time periods of 3, 6, 9, 12 and 24 months.

In the study region, mild degree drought distribution in the evaluated stations in the 3 months periods vary between 33.29 % (Gaziantep) and 39.34 % (Mardin), the range for 6 months period is between 30.39 % (Gaziantep) and 40.67 % (Adiyaman); it is between 32.70 % (Gaziantep) and 45.20 % (Adiyaman) for 9 months periods; between 30.07 % (Diyarbakır) and 47.30 % (Adiyaman) for 12 months period and it varies between 29.72 % (Diyarbakır) and 45.32 % (Adiyaman) for 24 months periods.

Moderate degree drought distribution in the evaluated stations in the 3 months periods varies between 7.49 % (Mardin) and 10.37 % (Siirt), the range for 6 months period is between 6.51 % (Diyarbakır) and 11 % (Siirt) and between 6.25 % (Gaziantep) and 12.06 % (Siirt) for 9 months periods; between 6.13 % (Gaziantep) and 14.31 % (Siirt) for 12 months period and it varies between 6.54 % (Diyarbakır) and 14.86 % (Kilis) for 24 months periods.

Severe level degree drought distribution in the evaluated stations in the 3 months periods varies between 2.02 % (Adiyaman) and 3.75 % (Diyarbakır-Mardin), the range for 6 months period is between 2.75 % (Adiyaman) and 4.92 % (Mardin) and between 4.65 % (Gaziantep) and 1.6 % (Adiyaman) for 9 months periods; between 0.73 % (Adiyaman) and 4.82 % (Kilis) for 12 months period and it varies between 1.62 % (Adiyaman) and 7.79 % (Batman) for 24 months periods.

Extremely level drought distribution in the evaluated stations in the 3 months periods varies between 1.73 % (Mardin) and 2.31 % (Adiyaman -Diyarbakır-Şanlıurfa-Gaziantep), the range for 6 months period is between 1.59 % (Mardin-Siirt) and 3.46 % (Diyarbakır) and between 1.45 % (Mardin) and 3.92 % (Diyarbakır) for 9 months periods; between 1.31 % (Adiyaman) and 4.09 % (Diyarbakır) for 12 months period and it varies between 0.0 % (Adiyaman) and 4.75 % (Diyarbakır) for 24 months periods.

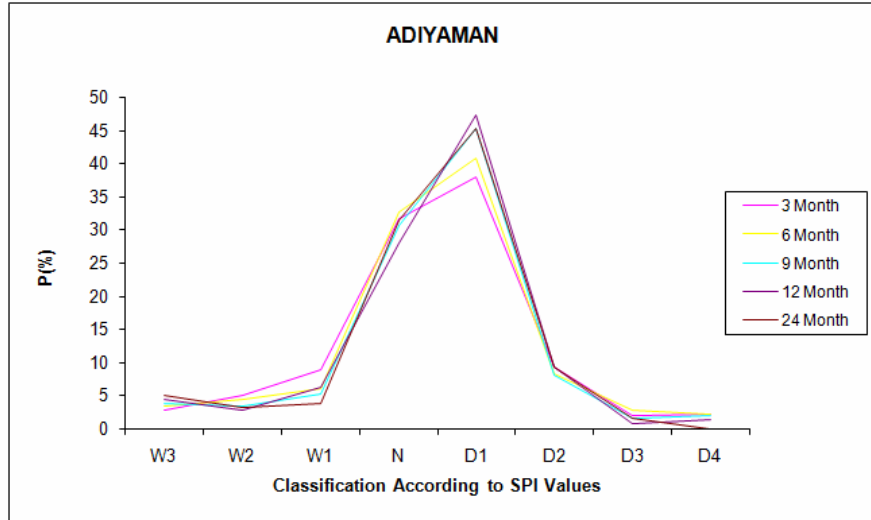


Figure 8. The relative frequencies of Adiyaman city SPI values for time periods of 3, 6, 9, 12 and 24 months

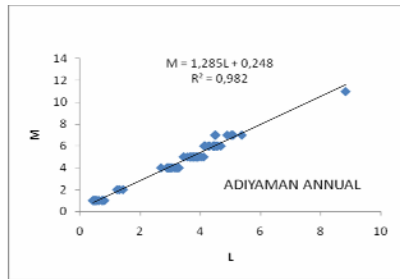


Figure 9. Magnitude (M)–Duration (L) curve at truncation level -0,4 for the annual data

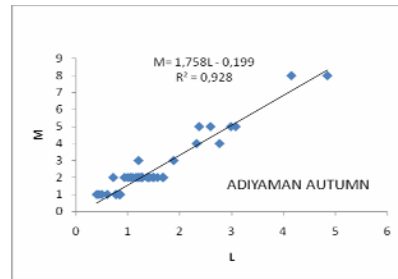


Figure 10. Magnitude (M)–Duration (L) curve at truncation level -0,4 for the autumn data

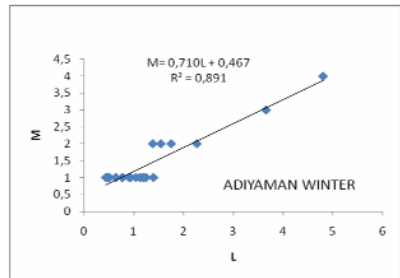


Figure 11. Magnitude (M)–Duration (L) curve at truncation level -0,4 for the winter data

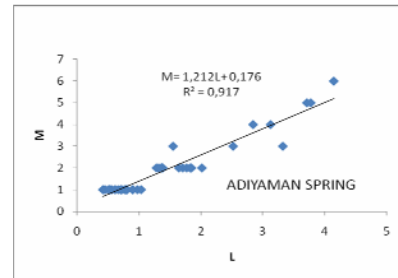


Figure 12. Magnitude (M)–Duration (L) curve at truncation level -0,4 for the spring data

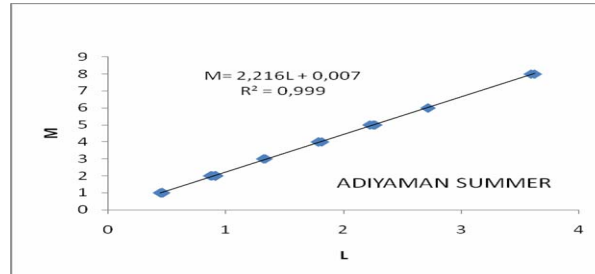


Figure 13. Magnitude (M)–Duration (L) curve at truncation level -0,4 for the summer data

Drought magnitude and drought duration between relationship for truncation level -0.4 are given Figure 9 to 13. In this study, run analysis are analysed with annual and seasonal data. As shown in Figure 9, Correlation coefficient of drought magnitude and drought duration between relationship for annual data is (R^2) 0,982. Its relationships for autumn data is 0,928 as shown in Figure 10. Its relationships for winter data is 0,891 as shown in Figure 11. Its relationships for spring is 0,917 as shown in Figure 12. Its relationships for summer is 0,999 as shown in Figure 13. Table III shows various statistical parameters concerning drought duration, magnitude and intensity based on run analysis values at standard truncation levels of 0.0, -0.3, and -0.4, respectively.

6 CONCLUSIONS

This study used the SPI calculated over time scales of 3, 6, 9 and 24 months for the period 1950-2007, because of its effectiveness in identifying hydrological and agricultural drought. In this study, the SPI was considered as short term seasonal-3 and 6 months periods, as average term 9 and 12 months periods and as a long term drought index for 24 months period. The seasonal droughts give rise to crop loss in agricultural production. Winter droughts are beginning to occur in the class of “severe”.

According to the SPI classifications in 3, 6, 9 and 24 months periods assessment for each station. The modal frequencies of the drought vary between 44.13 % and 58.68 % for the periods of 3, 6, 9, 12 and 24 months in all cities. SPI values in all stations, the highest ranges are in the normal and mild drought degrees. The investigation of SPI values show that when period increases, drought occurs less frequently but has a longer duration.

Run analyses are used for identification of various drought magnitude-duration-intensity characteristics. Run analysis applications are presented for annual and seasonal precipitation data. The relationships between drought duration and magnitude are provided in the form of scatter diagrams with the best straight-line fits for truncation level of -0.4. The run analysis results of annual data and seasonal data shown that correlation coefficient is approximately same as.

Table III: Statistical parameters of duration, magnitude and intensity for different truncation level for Adıyaman stations.

Truncation	Level=0	Max	Min	Median	Average	St deviation	Skewness
Annual	M	8,84	0,01	3,67	2,76	2,10	-0,03
	L	11,00	1,00	5,00	4,49	2,94	0,00
	I	0,82	0,01	0,61	0,52	0,24	-0,86
Autumn	M	4,84	0,40	1,20	1,42	0,91	2,01
	L	8,00	1,00	2,00	2,29	1,66	2,06
	I	0,85	0,36	0,64	0,66	0,14	-0,16
Winter	M	10,72	0,00	1,05	1,68	2,03	2,77
	L	13,00	1,00	1,50	2,64	2,80	2,36
	I	1,25	0,00	0,59	0,62	0,34	0,26
Spring	M	4,76	0,02	1,28	1,66	1,27	0,96
	L	8,00	1,00	2,00	2,95	1,99	0,95
	I	0,92	0,02	0,58	0,56	0,20	-0,55
Summer	M	6,72	0,13	1,33	1,70	1,46	1,79
	L	17,00	1,00	3,00	4,28	3,69	1,83
	I	0,45	0,13	0,42	0,40	0,07	-2,06
Truncation	Level=-0,4	Max	Min	Median	Average	St deviation	Skewness
Annual	M	8,84	0,43	3,76	3,25	1,63	-0,19
	L	11,00	1,00	5,00	4,42	2,12	-0,24
	I	0,82	0,43	0,74	0,71	0,09	-1,56
Autumn	M	4,84	0,40	1,20	1,42	0,91	2,01
	L	8,00	1,00	2,00	2,29	1,66	2,06
	I	0,85	0,36	0,64	0,66	0,14	-0,16
Winter	M	4,80	0,44	1,12	1,33	1,06	2,29
	L	4,00	1,00	1,00	1,41	0,80	2,19
	I	1,40	0,44	0,91	0,89	0,29	-0,05
Spring	M	4,14	0,42	1,03	1,42	1,02	1,30
	L	6,00	1,00	1,00	1,90	1,30	1,68
	I	1,11	0,42	0,72	0,73	0,17	0,07
Summer	M	3,62	0,44	0,91	1,15	0,86	1,52
	L	8,00	1,00	2,00	2,56	1,91	1,51
	I	0,45	0,43	0,45	0,45	0,01	-1,67

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