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Analyzing Drought Based on Annual Total Rainfalls over Tokat Province

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Abstract

Numerous indices derived from hydroclimatic data were designed to quantify agricultural, hydrological and meteorological droughts. In this study, we taken into account Standardized Precipitation Index (SPI) and the Rainfall Anomaly Index (RAI) for the identification and the assessment of drought events based on total annual rainfalls over Tokat province. The SPI values belonging to each rainfall station showed that the region experienced extreme wet and severe drought for observation years. Tokat province selected as the study area was grouped two hydrological homogeneous region using L-moment approach to analyze regional drought. Generalized Extreme Values (GEV), 3-parameter Log Normal (LN3) and Pearson Type III (PE3) for first region and Generalized Logistic (GLO) for second region were selected as the regional distributions. The RAI was used whether there is existence of linear trend in the observed data in term of drought. But, the RAI values concerning with two region showed that there was no trend.

Key words: Annual Rainfall, Drought, Standardized Precipitation Index, L-moments, Rainfall Anomaly Index

INTRODUCTION

Drought is one of the most serious problems for human societies and ecosystems arising from climate fluctuations and variations. Although its impact does not come through sudden events, such as flood and storms, drought is one of the most damaging types of natural disasters over long periods. Human beings often increase the impact of drought because of a high use of water that cannot be supported when the natural supply decreases. Drought is difficult to define precisely, but operational definitions often help to define the onset, severity and end of droughts. Le Houerou [1] stated that droughts are experienced in almost all types of agricultural land in the world, but that arid lands are most susceptible.

Drought is classified as agricultural, hydrological or meteorological. Agnew and Warren [2] described agricultural drought as a spatial phenomenon that causes significant reductions in agricultural productivity, mainly due to an inadequate supply of soil moisture. Hydrological drought refers to deficiencies in surface and subsurface water supplies [3]. Meteorological drought is usually measured by how far from normal the precipitation has been over a certain period of time [4].

Ranking the severity of droughts in cropping areas is difficult, due to the varying impact of rainfall at different times of the year. Drought intensity and duration must always be related to a calendar of crop sensitivity to rainfall. Assessing drought severity requires a measure of effective rainfall in relation to soil moisture and plant conditions, rather than just totaling rainfall deficiencies [5]. In addition, agricultural drought durations are affected by soil moisture capacity and evapotranspiration [6]. As well as being directly affected by drought, crop yield is a regionally sensitive measure that integrates the temporal and spatial distribution of rainfall anomalies over a region. In a mix of cropping and livestock activities, it is the agronomic indicator most sensitive to rainfall fluctuations [7].

In times of drought, agricultural productivity (particularly food productivity) declines significantly. A period of only a few weeks without precipitation may cause serious problems for the farmer. In arid and semi-arid regions, drought effects on crops may be reduced or eliminated by reserving enough water from available sources. Therefore, it is very important to know the drought duration in the growing season in terms of scheduling irrigation.

Numerous indices were designed to quantify agricultural, hydrological and meteorological droughts. Drought indices derived from hydroclimatic data are supposed to provide a concise information about drought of a region. These indices are used for making decisions on water resources management and water allocations for minimizing the impact of drought. In the recent, researchers have focused on Standardized Precipitation Index (SPI) to examine the problems such as drought, flood and crop yields.

Loukas and Vasiliades [8] examined the temporal and spatial characteristics of meteorological drought to provide a framework for sustainable water resources management in the region of Thessaly, Greece by using the Standardized Precipitation Index (SPI) as an indicator of drought severity, the characteristics of droughts. Yamoah et al. [9] investigated the effects of the standardized precipitation index and fertilizer nitrogen (N) rate on yields and risk of maize-based cropping systems in northeast Nebraska. They expressed that the SPI can be used as an indicator to choice of crops, N levels, and management decisions to conserve water in rainfed cropping systems. Stelier et al. [10] used SPI as a tool for monitoring flood risk affecting the sothern Cordoba province in Argentina. Giddings et al. [11] implied that the SPI has been used with notable success in various aplications as an indicator of drought severity or excessive wetness. Alatise and Ikumawoyi [12] applied four techniques namely, the Stochastic Component Time Series (SCTS), the Rainfall Anomaly Index (RAI), the Cumulative Rainfall Information (CRI) and the Drought Severity Index (DSI) to a 73-year rainfall data from Lokoja in Nigeria for the evaluation of drought in the area. They expressed that the Rainfall Anomaly Index proved to be the most appropriate techniques because of its ability to supply more information on drought occurrence in the study area more than the other three techniques. Oladipo [13] examined performances of three drought indices namely, the rainfall anomaly index (RAI), Bhalme and Mooley drought index (BMDI) and the Palmer drought index (PDI) by using data from Nebraska. They stated that the three indices appeared to be effective in detecting drought periods.

In this study, we taken into account Standardized Precipitation Index (SPI) by McKee et al., [14] and the Rainfall Anomaly Index (RAI) by Van Rooy [15] for the identification and the assessment of drought events based on total annual rainfalls over Tokat province.

MATERYAL AND METHODS

The Study Area

Tokat province selected as study area is bounded 39º 45' N and 40º 45' N latitudes, 35º 30' E and 37º 45' E longitudes, covering approximately 10160.7 km^2. About 30% of the area is occupied by cropland. Wheat is the major food crop (average sowing area is 68.5% of the total cropped area) not only in the district, but in the entire Turkey. The major source of irrigation is rainfall, canal and groundwater. Total annual rainfalls from the rainfall gauge stations controlled by Turkish State Meteorological Service and General Directorate of State Hydraulic Works were used as material in the study. The approximate location of the rainfall gauge stations was given in Figure 1.

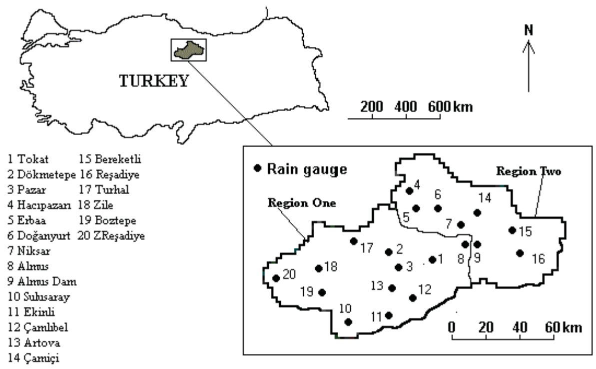


Figure1. Rainfall Gauge Station over Tokat Province Drought Indices

Drought indices enable an information us in a consistent way for a given time interval and place by using climatic variables as precipitation and temperature. These indices are used for making decisions on water resources management and water allocations for mitigating the impact of drought. But, it is known that these indices are not sufficient to reflect changes in how drought affects us. In this study, standardized precipitation index (SPI) and rainfall anomaly index (RAI) were selected as drought indices for analyzing of drought related to Tokat province.

Standardized Precipitation Index (SPI) Algorithm

The Standardized Precipitation Index (SPI) developed by McKee et al. [14] is a way of measuring drought based only on precipitation. The SPI are used to monitor conditions on a variety of time scales. Technically, the SPI is the number of standard deviations that the observed value would deviate from the long-term mean, for a normally distributed random variable. The SPI have some advantages for the following reason. Precipitation is only variable in the SPI calculation. Therefore, this index can be applied in regions where the avaliability of climatic varibales limit the use of other well-accepted indices as Palmer Drought Index (PSDI). SPI, which has a wide spectrum of time scales, make this index more flexible for either short-term and long-term drought monitoring [16, 17]. The SPI algoritm is conceptually equivalent to z-score commonly used in statistic:

$$SPI = \frac{p_i - \sum_{i=1}^{n} p_i / n}{\sigma_p} \qquad (1)$$

Where *SPI* represent the standardized precipitation index, p_i total annual rainfall for a given year, *n* the total length of record, σ_p standard deviation.

McKee et al. [14] used the classification system shown in Table 1 to define intensities resulting from the SPI. A drought event occurs any time when the SPI is continuously negative and reaches an intensity where the SPI is -1.0 or less. The event ends when the SPI becomes positive.

Table 1 Standardized Precipitaion Index Clasification

SPI Values	Classifications
2.0 and more	Extreme Wet
1.5 to 1.99	Very Wet
1.0 to 1.49	Moderately Wet
-0.99 to 0.99	Near Normal
-1.00 to -1.49	Moderate Drought
-1.50 to -1.99	Severe Drought
-2.0 and less	Extreme Drought

Rainfall Anomaly Index (RAI) Algorithm

Rainfall anomaly index (RAI) by Van Rooy [15] is used to describe annual rainfall variability, and is calculated as follows for positive and negative anomalies:

$$RAI = \pm\left[\frac{RF - M_{RF}}{M_{E10} - M_{RF}}\right] \qquad (2)$$

where *RAI* represents the annual RAI, *RF* total annual rainfall for a given year, M_{RF} mean for the total length of record, M_{E10} the mean of the 10 extreme values (highest and lowest) of rainfall on record.

Oladipo [13] expressed that the RAI was a very effective index for detecting drought periods, and the differences between the RAI and more complex indices as Palmer Drought Index (PSDI) and Drought Area Index by Bholme-Mooley [18] were negligible.

Regionalization of Drought Based on SPI

Regionalization includes delineating homogeneous regions based on homogeneity measure of site characteristics and identification of suitable regional frequency distribution. For this study, L-moment approach commonly preferred in the regional frequency analysis was used to establish an SPI value with any return period of occurrence. Hosking and Wallis [19] defined L-moments as a linear combination of Probability Weighted Moments introduced by Greenwood et al. [20]. Based on L-moments, there are two statistics which are used to stabilize a homogenous region.

First, the study area is checked to see whether or not the region has any discordant station. A station is called discordant when it has a different probabilistic behavior comparing to other stations in the region. Hosking and Wallis [19] present a discordancy measure to form groups of stations that satisfy the homogeneity condition. In this approach, the L-moments ratio (L-coefficient of variation, L-skewness and L-kurtosis) of a site is used to describe that site as a point in three-dimensional space. A group of homogeneous sites will form a cluster of such points. If any point does not appear to belong to the cluster of such points on the L-moment diagram, that is, is far from the center of the cluster, the site related to that point should be removed from the region due to non-homogeneity condition. The discordancy measure of a site, D_i, is calculated based on a vector $u_i = \left[\tau_2^i, \tau_3^i, \tau_4^i\right]^T$ related to sample l-moments (L-cv, L-cs and L-ck) of site i. The discordancy measure is then written as:

$$D_i = \frac{1}{3}(u_i - \bar{u})^T S^{-1}(u_i - \bar{u}) \quad (3)$$

Generally, any site with Di > 3 is considered as discordant. In such a case, the site may properly belong to another region.

At the second step, homogeneity of the region is measured using homogeneity measures which are based on sample L-moments. The homogeneity measures, H1, H2 and H3, are based on the simulation of 500 homogeneous regions with population parameters equal to the regional average sample L-moment ratios [19]. The heterogeneity (H) statistic and V statistic for the sample and simulated regions take the form, respectively:

$$H = (V_{obs} - \mu_V) / \sigma_V \quad (4)$$

$$V = \left\{ \frac{\sum_{i=1}^{N} n_i (\tau_2^i - \tau_2^R)^2}{\sum_{i=1}^{N} n_i} \right\}^{1/2} \quad (5)$$

n_i is record length at site i, τ_2^i is the sample L-coefficient of variation (L-cv), τ_2^R is the regional average sample L-cv, μ_V is the mean of simulated V values, σ_V is the standard deviation of simulated V values. The value of H-statistic indicate that the region under consideration is acceptably homogeneous when H<1, possibly heterogeneous when 1≤ H <2, and definitely heterogeneous when H ≥2.

The regional frequency distribution is chosen based on the goodness-of-fit-test, Z^{DIST}. The statistics is written as the following,

$$Z^{DIST} = (\tau_4^{DIST} - \bar{\tau}_4 + \beta_4) / \sigma_4 \quad (6)$$

Where DIST refers to a candidate statistical distribution, τ_4^{DIST} is the population L-kurtosis of selected distribution, $\bar{\tau}_4$ is the regional average sample L-kurtosis, σ_4 is the bias of regional average sample L-kurtosis, σ_4 is the standard deviation of regional average sample L-kurtosis. The $\left|Z^{DIST}\right|$ ≤ 1.64 should be for an appropriate regional distribution. But, the distribution giving the minimum $\left|Z^{DIST}\right|$ is considered as the best-fit distribution for the region.

RESULTS AND DISCUSSION

Drought characteristics based on Standardized Precipitation Index in Tokat region

Drought analysis based on Standardized Precipitation Index (SPI) was carried out for Tokat Region, using total annual rainfall depths measured in rainfall stations on the region. Figure 2 shows extreme SPI values belonging to each station numbered from 1 to 20 in Figure 1 for observation years. The SPI values related to the annual time series belonging to each rainfall station showed that the region experienced extreme wet (Doganyurt rainfall station symbolized as 6 in Figure 1) and severe drought (Dokmetepe rainfall station symbolized as 2 Figure 1) for observation years.

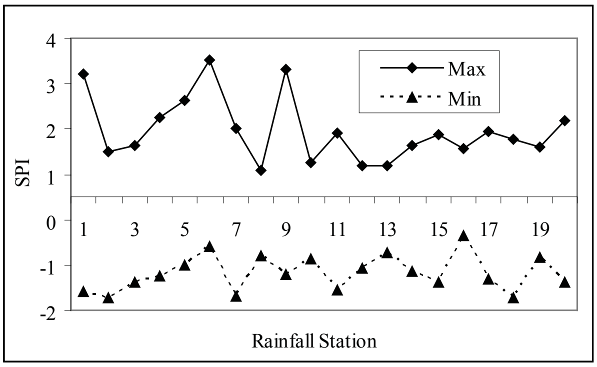


Figure 2. Extreme SPI values of the rainfall stations

L-moment approach by Hosking [21] was used to analyze regional drought on Tokat region. For the purpose of regionalization, Initial group(s) was firstly designated by using discordancy measure calculated according to the L-moments ratio (L-coefficient of variation, L-skewness and L-kurtosis) concerning with SPI of each site (rainfall station). It is important to check the existence of discordant station and homogeneity of the region. Table 2 shows L-moments and discordancy measures, D_i, for the selected stations in Tokat region. As can be seen from this table, the D_i of all stations are smaller than 3 and, thus, no discordant station is observed in the region. However, when all stations were taken into consideration as a single group, some stations was discordant.

The homogeneity measures (H) for these two groups are -0.25 and -0.21, respectively. Based on the homogeneity measure, as all of these measures are less than 1, the region can be considered homogeneous. Thus, we can try to determine the best regional frequency distribution for each region in the next step.

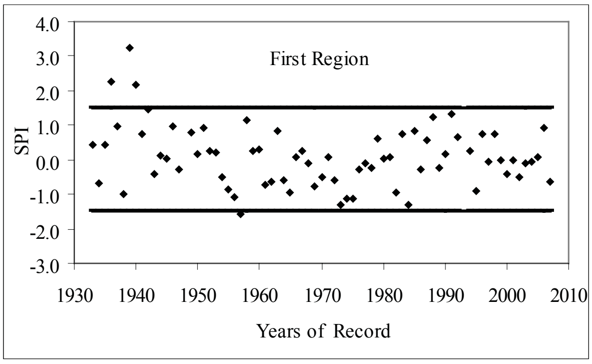
The goodness of fit test measure, Z^{DIST} for two homogeneous regions, were calculated for five distributions, Generalized Logistic (GLO), Generalized Extreme Values (GEV), Generalized Normal or 3-parameter Log Normal (LN3), Pearson Type III (PE3) and

Table 2. L-moments and discodancy measures (Di) for two groups

Stations	Sample Size	L-CV	L-CS	L-CK	D_i
Group one					
Tokat	74	0.099	0.061	0.181	0.48
Zile	74	0.115	0.019	0.084	0.90
Ekinli	33	0.140	-0.088	0.261	1.80
Turhal	56	0.089	-0.039	0.093	0.07
Sulusaray	32	0.090	-0.119	0.075	0.35
Artova	23	0.094	0.052	-0.015	1.45
Çamlıbel	11	0.113	-0.258	0.211	1.83
Almus	16	0.061	-0.150	0.023	1.77
Boztepe	20	0.073	0.009	0.095	0.53
Pazar	21	0.099	0.063	0.062	0.53
Zreşadiye	36	0.090	0.194	0.211	2.27
Dökmetepe	42	0.092	-0.011	0.100	0.02
Group Two					
Reşadiye	24	0.081	0.186	0.218	1.65
Hacıpazarı	30	0.098	0.043	0.163	0.25
Çamiçi	13	0.116	-0.130	0.164	0.91
Bereketli	26	0.110	-0.130	0.203	1.42
Niksar	65	0.102	-0.052	0.124	0.79
Erbaa	48	0.101	0.045	0.203	0.13
Doğanyurt	25	0.079	0.416	0.327	1.86
Almus Dam	43	0.094	0.181	0.185	0.98

Generalized Pareto distributions (GPA) which are 2.99, -0.90, 0.12, 0.09 and -7.88 for group one (first region) and -1.49, -3.56, -3.23, -3.32 and -7.53 for group two (second region), respectively. Among these distributions, GEV, LN3 and PE3 for first region and GLO for second region had the smallest Z^{DIST} values and could be considered as the regional distributions. The regional SPI quantiles for probability of non-exceedance based on the selected distributions for two regions are given in Table 3. Table 3 shows that the selected regional distributions for first region predict similar quantiles. Therefore, each one of these distributions can be use in regional frequency analysis belonging to SPI for first region.

Figure 3 shows comparison of SPI values from rainfall stations with maximum record length for two homogeneous, Tokat rainfall stations for first region and Niksar rainfall station for second region, with some SPI critical values (Table 1) suggested by McKee et al. [14]. As can be seen Figure 3, the calculated SPI values from the homogeneous regions for record years were commonly located between moderately Wet (1.50) and moderate drought (-1.5) limitations.



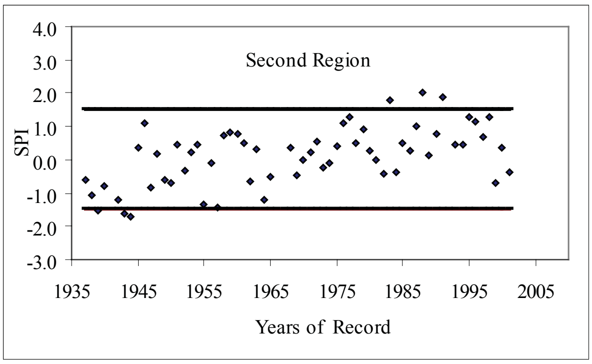


Figure 3. Comparison of the calculated SPI values from the selected rainfall station for each region with critical SPI values.

Drought characteristics based on Rainfall Anomaly Index in Tokat region

Rainfall Anomaly Index (RAI) exhibits whether there is existence of linear trend in the observed data in term of drought. For this reason, the positive and negative RAI values calculated by using the total annual rainfalls of Tokat and Niksar rainfall stations related to two homogeneous regions grouped based on L-moment approach showed that there was no trend (Figure 4 and 5).

Table 3. Regional SPI values in different return periods for two regions

Return Period-Year		1.01	1.11	1.33	2	5	10	25	50	100
Probability- %		99	90	75	50	20	10	4	2	1
First Region	GEV	-1.92	-1.07	-0.54	0.07	0.85	1.24	1.63	1.86	2.05
	LN3	-1.98	-1.06	-0.52	0.07	0.82	1.22	1.64	1.91	2.15
	PE3	-1.98	-1.06	-0.52	0.07	0.82	1.22	1.64	1.91	2.15
Second Region	GLO	-1.93	-0.99	-0.50	0.02	0.73	1.18	1.76	2.20	2.65

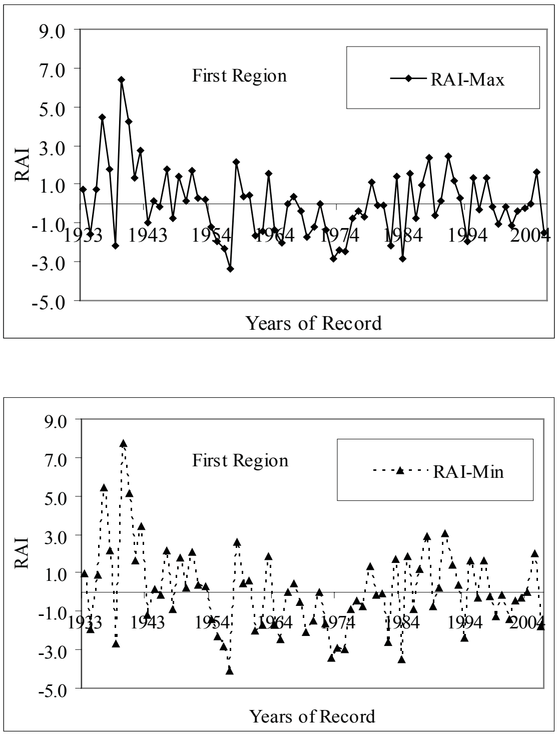


Figure 4. Graph of Rainfall Anomaly Index for first region

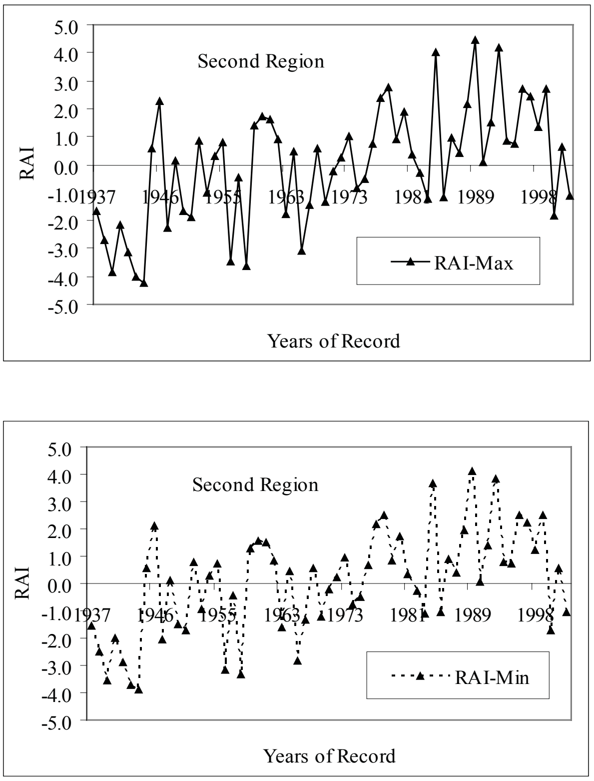


Figure 5. Graph of Rainfall Anomaly Index for second region

CONCLUSION

Numerous indices were designed to quantify agricultural, hydrological and meteorological droughts. Drought indices derived from hydroclimatic data are supposed to provide a concise information about drought of a region. These indices are used for making decisions on water resources management and water allocations for minimizing the impact of drought. In this study, we taken into account Standardized Precipitation Index (SPI) by McKee et al., [14] and the Rainfall Anomaly Index (RAI) by Van Rooy [15] for the identification and the assessment of drought events based on total annual rainfalls over Tokat province.

The SPI values related to the annual time series belonging to each rainfall station over Tokat Province showed that the region experienced extreme wet (Doganyurt rainfall station) and severe drought (Dokmetepe rainfall station) for observation years. Tokat province selected as the study area was grouped two hydrological homogeneous region using L-moment approach to analyze regional drought. Generalized Extreme Values (GEV), 3-parameter Log Normal (LN3) and Pearson Type III (PE3) for first region and Generalized Logistic (GLO) for second region were selected as the regional distributions. The RAI was used whether there is existence of linear trend in the observed data in term of drought. But, the RAI values concerning with two region showed that there was no trend.

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