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Probabilistic Analysis of Variability in Reference Evapotranspiration

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Abstract: The amounts of hydro-meteorological data have varied over time due to human-induced global climate change. Obtaining the data to be used in the estimation of the crop water consumption parameter, which is of vital importance especially in the context of agricultural water management, under stationary conditions is a necessity in terms of reliability. The differentiation of data over time means that its frequency distribution behaviour also changes. The main goal of this study was on this change in question. For this purpose, annual reference evapotranspiration (ETo) values of Amasya and Samsun stations were used as material. The change in ETo data was analyzed with the ITA and PITA approaches. The ITA analysis regarding the Amasya station showed a statistically increasing change in the ETo data, whereas there was no statistically significant change for the Samsun station. Probability distributions fit most approximate to the data sequences of the first halve (FH) and second halve (SH) obtained by dividing the full data according to the PITA technique were Gama and Gumbel for the Amasya station, respectively. The normal distribution was found for two halves of the Samsun station. This finding confirmed that the data of the Amasya station has changed statistically over time. Remarkable differences were detected in the quantiles at especially higher risk levels for the Amasya station.

Keywords: Reference evapotranspiration, ITA approach, frequency analysis

Referans Evapotranspirasyondaki Değişkenliğin Olasılıksal Analizi

Öz: Hidro-meteorolojik verilerin miktarları, insan kaynaklı küresel iklim değişikliği nedeniyle zaman içinde değişmiştir. Özellikle tarımsal su yönetimi bağlamında hayati önem taşıyan bitki su tüketim parametresinin tahmininde kullanılacak verilerin durağan koşullarda elde edilmesi güvenilirlik açısından bir zorunluluktur. Verilerin zaman içinde farklılaşması, frekans dağılım davranışının da değiştiği anlamına gelir. Bu çalışmanın ana hedefi bahse konu bu değişim üzerine oldu. Bu amaçla Amasya ve Samsun istasyonlarının yıllık referans evapotranspirasyon (ETo) değerleri materyal olarak kullanılmıştır. ETo verilerindeki değişim ITA ve PITA yaklaşımları ile analiz edilmiştir. Amasya için ITA analizi, ETo verilerinde istatistiksel olarak artan bir değişim ortaya çıkarırken, Samsun istasyonu için istatistiksel olarak anlamlı bir değişiklik olmadı. Tam verilerin PITA tekniğine göre bölünmesiyle elde edilen birinci yarı (FH) ve ikinci yarının (SH) veri dizilerine en yakın olan olasılık dağılımları Amasya istasyonu için sırasıyla Gama ve Gumbel olmuştur. Samsun istasyonunun iki yarısı için normal dağılım bulunmuştur. Bu bulgu, Amasya istasyonuna ait verilerin zaman içinde istatistiksel olarak değiştiğini doğrulamıştır. Amasya istasyonu için özellikle daha yüksek risk düzeylerinde niceliklerde dikkate değer farklılıklar tespit edilmiştir.

Anahtar Kelimeler: Referans evapotranspırasyon, ITA yaklaşımı, frekans analizi

1. Introduction

Crop water consumption (ET), which is an important component of the hydrological cycle, has a key role in the successful assessments of water resources, especially in terms of drought and effective use of water (Yang et al. 2015). Therefore, the reliable prediction of this parameter in the optimal planning and operation of freshwater resources is of crucial importance. Although there are alternative estimation approaches for obtaining ET, the crop coefficient-based methodology is often accepted because it is easy and not expensive (Allen et al. 1998; Yee et al. 2015; Soubie et al. 2016). Allen et al. (1998) highlighted that crop water consumption was commonly calculated based on reference evapotranspiration (Eto) by using meteorological components. The FAO-56 Penman-Monteith relationship (FAO-PM) has been recommended as a reference approach in the literature in the calculation of the Eto. Global warming, which has been effective since the middle of the 20th century, has disrupted the natural functioning of meteorological events in the atmosphere (Akgül & Dino, 2020). Therefore, changes in meteorological parameters such as temperature, pressure, wind speed, airflow, precipitation, and relative humidity would impact reliable ET estimation. Allen et al. (2011) and Liu et al. (2021) highlighted that even small errors in the calculation of Eto based on climate components would cause remarkable negativities in the planning and operation of water resources.

Considering the explanations above, it is necessary to scrutinize the variability in the ET parameter which has critical importance for agricultural water management or the effective use of water resources under changing climatic conditions. Pettitt (1979) underlined the existence of a change-point when the separated parts of a given time series had different frequency distribution shapes. The innovative Trend Analysis (ITA) approach by Şen (2017) has recently been a favored tool to detect variability in the meteorological time series. Şen (2020) presented an approach (PITA) to the literature. The approach was based on the comparison of the frequency distributions of the split two halves considering the ITA technique. Under changing global climate conditions, it is necessary to examine whether the reference evapotranspiration time series is stationary over time in the context of effectively using water resources and agricultural water management of a region. The study was conducted on finding out variability in the Eto time series with the ITA technique and revealing probabilistically the difference in the frequency distribution shape of the Eto series over time.

2. Material and Method

The study was realized for two meteorology stations (Amasya and Samsun) in the Central Black Sea Region to analyze the variability of the Eto data sets. The geographical locations of the two stations are shown in Figure 1. The climatic parameters measured from 1984 to 2019 of these stations, which are wind speed, minimum and maximum relative humidity, minimum, maximum and average temperatures, and sunshine duration, were used as materials to form Eto datasets. The Eto data sequences on a monthly basis were obtained based on FAO-56 Penman-Monteith relationship, which is detailed In Allen et al. (1998). In the study, the annual Eto data series was formed by summing the Eto values of all months for each year, and then the annual Eto data sequences were used to be analyzed probabilistically with the PITA approach introduced by Şen (2020). For this purpose, first of all, the annual data was divided into two halves (First Halve and Second Halve) according to the ITA approach, the details of which were in Yurekli (2021). Thus, along with the application of the ITA technique, information was also obtained about the trend of annual Eto data sets. The probability distributions, namely Normal (N), Lognormal (LN), Three-parameter lognormal (LN3), Two-parameter gamma (G), Gumbel (EV), Generalized extreme value (GEV) and , Three-parameter gamma (Pearson III) was applied to determine the distribution that best fit the annual data of the first halve (FH) and second halve (SH) for the PITA analysis.

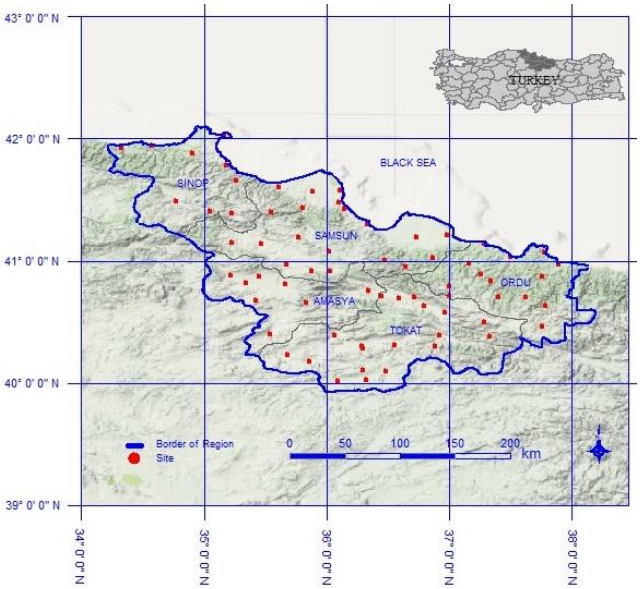

Figure 1. Geographical location of Amasya and Samsun Provinces selected for the study

Şekil 1. *Çalışma için seçilen Amasya ve Samsun İllerinin coğrafi konumu*

In the study, the Bayesian Information Criterion (BIC) suggested by Schwarz (1978) was used to identify the most adequate probability distribution model that fit the annual Eto data. According to the approach, among the candidate distributions, the distribution with the smallest BIC value was chosen as the most approximate model that best fit the data. The BIC is formulated as

$$BIC = -2\,logL(\hat{\Theta}) + klog(n)$$

In equation, where $L(\hat{\Theta})$ is maximum likelihood function; the “k” and “n” terms are the number of parameters and data points, respectively.

3. Results and Discussion

In the study, first of all, the homogeneity analysis of the annual Eto data was performed with the Mann-Whitney U test, details of which are given in Yurekli (2015). The null hypothesis for the Eto series of both stations was accepted. In other words, it was concluded that the datasets were statistically homogeneous. Then, the existence of the change in the Eto data sequences over time was determined by the ITA method. For this purpose, the annual Eto data sequences of the two stations were divided into two equal parts, the first and the second half. According to the ITA analysis, while the annual Eto data for Amasya station showed a statistically increasing change, a statistically insignificant decreasing trend was determined for

Samsun station. The calculated ITA test values of these stations were found to be 2.128 (± 1.885) and -1.550 (± 2.536), respectively. The values in parentheses indicate critical values. Visually scattering of the Eto data points of the two halves according to each other is shown in Figure 2. The scatter plot of the Amasya station shows that the stationary from small to large in the annual Eto data deteriorates. On the other hand, for Samsun station, it seems that stationarity is provided from small to large in Eto data. However, it should not be overlooked that there is a decreasing change in smaller data.

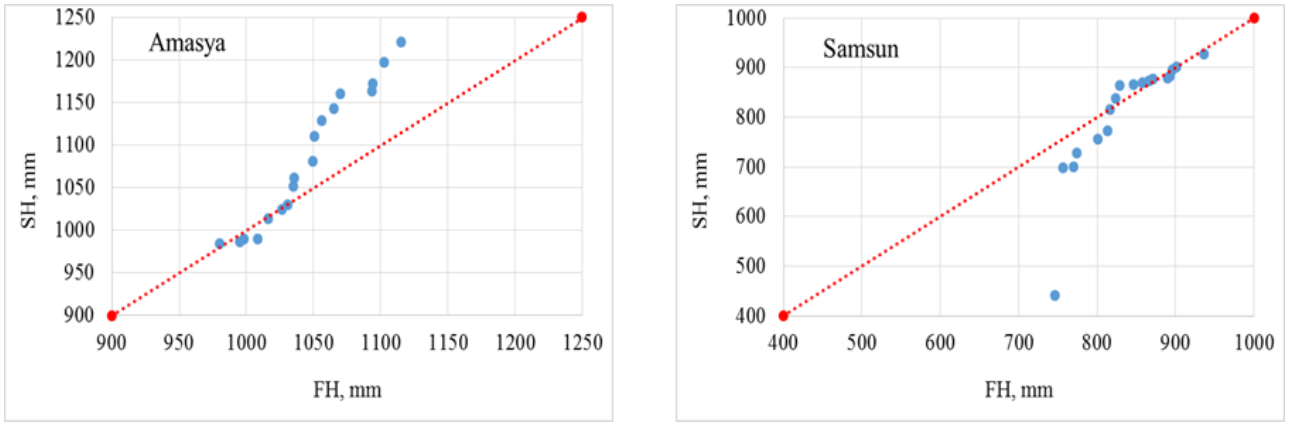

Figure 2. The scatter plots of data points in two halves according to each other
Şekil 2. *İki yarıdaki veri noktalarının birbirine göre dağılım grafikleri*

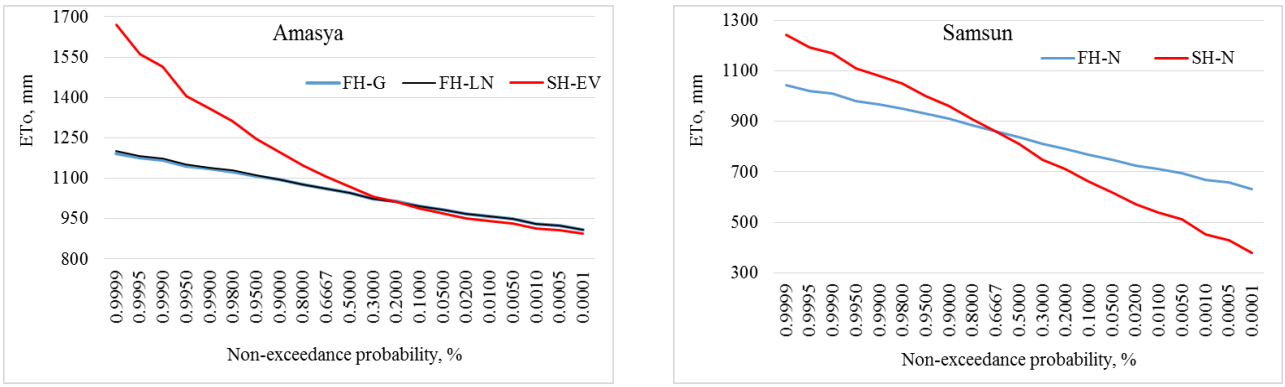

Figure 3. Variation of the quantiles obtained for the FH and SH (G, LN, EV, and N in the figure correspond to Gama, Lognormal, Gumbel, and Normal distributions)
Şekil 3. *FH ve SH için elde edilen niceliklerin değişimi (şekildeki G, LN, EV ve N Gama, Lognormal, Gumbel ve Normal dağılımlarına karşılık gelmektedir)*

For the Amasya station, the two-parameter Gamma distribution for the Eto data of the first halve (FH) and the Gumbel distribution for that of the second halve (SH) formed the smallest BIC values for the Eto data sequences. The BIC values of FH and SH for the aforementioned distributions are 187.75 and 213.0, respectively. However, the BIC value (187.76) of the lognormal distribution applied to the Eto data set belonging to the FH was very close to that of the gamma distribution. Although the data of the FH fit both gamma and lognormal distribution, the fact that the SH followed the Gumbel distribution was an indication that there was a change in the data, as stated by Pettitt (1979). Therefore, the stationarity of the Eto data series belonging to the Amasya station has deteriorated over time. Table 1 deals with the quantiles obtained from the distribution fitting most approximately to the Eto series associated with the FH and SH at different return periods. On the other hand, the Eto data sequences of both halves for the Samsun station followed the normal distribution as the most approximate distribution model. This finding is in line with the ITA results. The Normal distribution indicated the smallest value of the BIC when compared with those of the candidate distributions under consideration. The quantiles results associated with both halves for the normal distribution are available in Table 1. As can be seen in Table 1, the quantile results of the SH had a partial difference from those of the FH. The reason for this could be explained by the fact that the Eto data set of the SH showed a statistically

insignificant increase over time. Figure 3 shows the variation of the estimated quantiles for the non-exceedance probabilities between 0.9999 and 0.0001. For the Amasya station, the difference between the estimated quantiles became evident with the increase in the non-exceedance probability for the Eto data series of the FH and SH. The quantiles predicted toward smaller probabilities almost overlapped each other. On the other hand, although the FH and SH data sets of the Samsun station had the same probability distribution characteristics, the estimated quantiles for both halves showed an inverse difference variation structure at a 0.6667 probability level.

Table 1. Quantiles at some return periods (T) for non-exceedance probability
Çizelge 1. *Aşılmama olasılığı için bazı tekrarlanma periyotlarındaki (T) nicelikler*

T Year	Amasya			Samsun	
	FH(G)	FH(LN)	SH(EV)	FH(N)	SH(N)
100	1136.04	1139.87	1357.90	966.57	1080.81
50	1125.14	1128.33	1310.41	951.55	1049.13
20	1108.93	1111.24	1247.03	929.02	1001.62
10	1094.66	1096.26	1198.06	908.99	959.39
5	1077.53	1078.39	1147.01	884.74	908.23
2	1045.27	1045.05	1069.92	838.38	810.47
1.25	1013.69	1012.74	1012.61	792.02	712.70
1.11	997.47	996.23	988.25	767.76	661.55

4. Conclusion

Different methodologies have been developed for the estimation of crop water consumption parameters, which are of vital importance in the planning, management, and operation of water resources. Among them, crop coefficient-based ones are preferred because of being their easy and not expensive. However, one of the main problems in estimating in this way is the concern of making unreliable results by using climate data obtained under changing climate conditions, that is, under non-stationary conditions. Therefore, it is a necessity to analyze whether the assumption that the data to be used in the estimation of crop water consumption does not change over time overlaps with real conditions. This study was carried out to determine the change in annual reference evapotranspiration (ETo) values based on the FAO-56 Penman-Monteith relationship by using the climate data of the Amasya and Samsun stations. For this purpose, innovative trend analysis (ITA) and probabilistic innovative trend analysis (PITA) methods were used. According to ITA, a statistically increasing trend was detected in the annual ETo data for the Amasya, while a statistically insignificant increasing trend was found for the Samsun station. The PITA approach also confirmed this finding. The probability distributions most approximately followed for the first halve (FH) and second halve (SH) data sequences formed by dividing the full data based on the ITA approach were Gamma and Gumbel for the Amasya, respectively. Therefore, the different distribution behavior of the two halves is an indicator of the variability in the data. On the other hand, both halves of the Samsun station showed the best fit to the normal distribution. Significant differences became between the quantiles estimates from the Gamma and Gumbel distributions for the Amasya station, especially at higher risk levels. Although both halves of the Samsun station showed the same distribution characteristics, differences were found between the quantiles obtained according to the normal distribution at smaller and larger risk levels. Even if there is a statistically insignificant increase in the ETo data of the Samsun station, it should not be overlooked that this situation causes differentiation between the estimated quantiles.

Another important finding obtained with this study is that, based on the analysis made with the Mann-Whitney U test, although there was homogeneity in the ETo data of both stations, the method used in the present study revealed that there was variability at the Amasya station. This contradiction is probably related to the power of these methods to capture variability.

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