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Scrutinization of Potential Concern in Estimating Hydrological Design Parameter in Changing Climate Conditions

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Abstract: Traditional approaches considered in estimating the design parameters of hydraulic structures assume that the data to be used in the analysis is stationary. However, the assumption of stationary has lost its validity, as the normal functioning of the hydrological cycle is deteriorated by climate change. Furthermore, the estimation of the required design parameter for hydraulic structures under non-stationary conditions would be evidence of failure for the structure in question. The aim of the study was to come up with what the regional frequency distribution characteristic of maximum rainfall with 2-h duration for the Euphrates-Tigris river basin would differ under non-stationary conditions. For this purpose, ITA and PITA approaches were used. Trends were detected in approximately 83% of the maximum rainfall series, with increasing variation in 80% of this amount. In order to reveal the variability in the regional frequency distribution of all rainfall series, the L-moments algorithm was applied to the data series of the first halve and second halve formed by the ITA method. It was found that remarkable differences were detected in the quantiles obtained for some risk levels.

Keywords: Euphrates-Tigris basin, frequency analysis, maximum rainfall

Değişen İklim Koşullarında Hidrolojik Tasarım Parametresinin Tahmininde Potansiyel Endişenin İncelenmesi

Öz: Hidrolik yapıların tasarım parametrelerinin tahmininde dikkate alınan geleneksel yaklaşımlar, analizde kullanılacak verilerin durağan olduğunu varsaymaktadır. Ancak, hidrolojik döngünün normal işleyişi iklim değişikliği nedeniyle bozulduğu için durağanlık varsayımı geçerliliğini yitirmiştir. Daha da ötesi, durağan olmayan koşullar altında hidrolik yapılar için gerekli tasarım parametresinin tahmini, söz konusu yapı için başarısızlığın kanıtı olacaktır. Çalışmanın amacı, Fırat-Dicle nehir havzası için 2 saat süreli maksimum yağışın bölgesel frekans dağılım özelliğinin durağan olmayan koşullarda ne gibi farklılık göstereceğini ortaya çıkarmaktır. Bu amaç için ITA ve PITA yaklaşımları kullanıldı. Maksimum yağmur serilerinin yaklaşık %83'ünde trend tespit edildi, bu miktarında %80'inde artan değişim bulundu. Tüm yağış serilerinin bölgesel frekans dağılımındaki değişkenliği ortaya çıkarmak için ITA yöntemiyle oluşturulan birinci yarı ve ikinci yarının veri serilerine L-momentler algoritması uygulanmıştır. Bazı risk seviyeleri için elde edilen niceliklerde dikkate değer farklılıklar tespit edildi.

Anahtar Kelimeler: Fırat-Dicle Havzası, Frekans Analizi, Maksimum Yağmur

1. Introduction

The IPCC (2013) highlighted that the variability in the global climate system was an indisputable fact. Under this reality of human intervention, the deterioration of the natural functioning of the hydrological cycle has allowed the experience of the changes in the amount and frequency of rainfall (Fotovatikhah et al. 2018; Li et al. 2018). The studies conducted on the climate of Turkey emphasized that there would be remarkable decreases in rainfalls and streamflows (Hemming et al. 2010; IPCC, 2007; Kitoh et al. 2008). Research on rainfall extremes, which have a considerable impact on the ecosystem, has increased recently (Cheng et al. 2015; Whang et al. 2012). In this context, a successful estimation of the design rainfall amount in the terms of planning, management, and cost of water-related structures, which are considered to be built in order to minimize the damage caused by maximum rainfalls, is also a necessity. On the other hand, it is assumed that the data to be used in the estimation of the design rainfall value based on the frequency analysis is provided under stationary climatic conditions. However, this assumption has lost its validity due to the reality of global climate change. The existence of trends in the rainfall datasets points out that its frequency distribution is inconstant over time. From this perspective, the stationarity of the relevant data should be satisfied to clear possible doubt while carrying out its frequency analysis. Hosking and Wallis (1997) underlined that performing a successful frequency analysis was based on reliable observations, also, that the assumption dealing with having analogous characteristics of frequency distributions belonging to the past and future observations would be ceased where there was an upward or downward change in a given data over time.

Şen-Innovative Trend Analysis (ITA) has recently become a considerable tool to scrutinize variation in the meteorological data sequences (Şen, 2017). The distinctions of the approach from the others are that it does not expect to fit a certain distribution for the data to be analyzed, as well as it does not deals with the length of the data and serial dependence between observations. Şen (2020) proposed a new approach (PITA) to detect the change in frequency distribution behavior of past and future observations. In line with the above, the reliability of the data to be subjected to frequency analysis for the design rainfall value should be checked. Accordingly, the basic objectives of the study were a- to statistically evaluate variability in the maximum rainfalls with the ITA approach, b- to realize regional frequency analysis based on PITA (Probabilistic Innovative Trend Analysis) methodology and to reveal the difference in the frequency distributions of the past and future observations.

2. Materials and Methods

The materials and methods used in the study are given in the following subtitles.

2.1. Basin and Data

The Euphrates and Tigris rivers, which are the transboundary rivers of Turkey, merge within Iraq territory and flow into the Persian Gulf in Shatt al-Arab. The part of the basin within Turkey is 185.000 square kilometers. As of the geographical location of the basin belonging to these rivers, both rivers are vitally important water resources for Turkey and the Middle East. Therefore, the dispute regarding water allocation of the rivers among the riparian countries has been proceeding for a long time. Turkey has been claiming the demand for using more water due to the upstream position. Approximately 40 % of the mean annual streamflow to the Tigris River is supplied by the part of the basin in Turkey. The contribution to the Euphrates River by Turkey's territory is about 90 % (Daoudy, 2004; Kibaroglu and Unver, 2000). Approximately 28% of our country's water needs are supplied by the two rivers. The arid and semi-arid climate characteristics in the basin of these rivers are dominant. Precipitation falling in the basin of these rivers substantially occurs in the winter period (from October to April). A notable part of the precipitation during the period in question falls in the form of snow. Therefore, snowmelt from the highlands forms a considerable part of the river streamflows (Altınbilek, 2004; Ozdogan, 2011). Furthermore, the fact that the part in Turkey of the basin covers the GAP region, in which was planned 13 groups of irrigation and energy projects within the scope of the Southeastern Anatolian Project (GAP), has further increased its importance. The GAP has a critical role in the context of regional development and irrigation.

The annual average rainfall in the basin varied between 378 mm (Malatya Station) and 1234 mm (Bitlis station). This implies that the distribution of precipitation in the basin has a highly variable structure (Yurekli, 2015). In the northern and eastern parts of the basin, the altitude reaches up to 4,000 m. However, towards the south of the basin, the topography changes rapidly and the height decreases to 300 m. In the southern parts of the basin, evaporation is high as well as less precipitation.

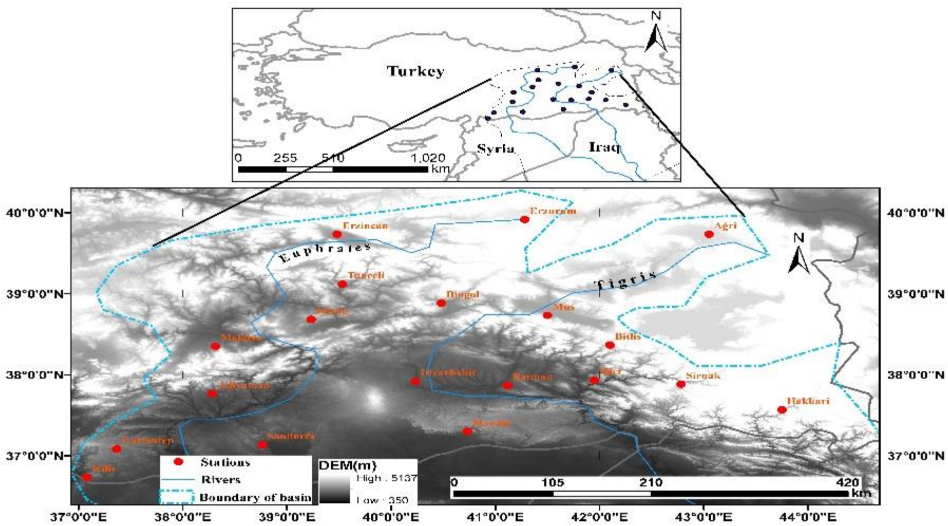

Figure 1. Geographic positions of the stations in the study
Şekil 1. *Çalışmadaki istasyonların coğrafik konumları*

The maximum rainfall data sequences with the duration of 2-h from 18 rainfall gauging stations in the upper Euphrates- Tigris basin were used as materials in the study to scrutinize variability in them. The missing maximum rainfall amounts with the duration of 2-h at any station in the study area were completed with the normal-ratio method. Some defining characteristics regarding the stations are presented in Table 1, and their geographic positions are available in Figure 1.

2.2. Şen-ITA Approach

The essence of this approach is based on splitting the original data into two equal parts and analyzing the scattering of two split data sets (first halve and second halve) against each other around the 1:1 line (with a slope of 45°). Based on this approach, the judgment on the trend is determined by the positioning of the data of the two halves according to the 1:1 line. The cases where the points corresponding to each pair of observations are above, below, or on the line with a slope of 45° point out an upward, downward trend or no change, respectively. In this state, a visual analysis is allowed, but it cannot be done statistically. But, the statistical significance test in the study conducted by Şen (2017) was brought to the literature. The statistical significance test is on the comparison of means averages belonging to the first (FH) and second (SH) halve series. The null hypothesis is accepted when the calculated slope (Scal) is smaller than the critical slope value, Scrit. Analysis details of this test are available in Yurekli (2021). The calculated test statistic and the confidence interval (CI) based on the critical test value were formulated in the following relationships.

$$S_{cal} = \frac{2(\bar{y}_2 - \bar{y}_1)}{n} \quad (1)$$

$$CI_{(1-\alpha)} = 0 \pm S_{crit}\sigma_S \quad (2)$$

$$\sigma_S = \frac{2\sqrt{2}}{n\sqrt{n}}\sigma\sqrt{1-\rho_{\bar{y}_1\bar{y}_2}} \quad (3)$$

Where $\bar{y}_1$ and $\bar{y}_2$ are the averages associated with the first and second halves; $\rho_{\bar{y}_1\bar{y}_2}$ is cross-correlation coefficient; σ is standard deviation of the full data; n is the number of observations in the full data.

The S_{crit} value (±1.960) is obtained based on the Standard Normal Distribution for the 5% (α) significance level.

2.3. Regional Frequency Analysis based on PITA Approach

The PITA approach is concerned with the probabilistic behavior of two equal datasets (FH and SH) split according to the ITA method. Pettitt (1979) underlined that the fact that parts of a time series had different frequency distributions indicated the existence of a change point in that series. The PITA approach was also based on this reference. Regional frequency analysis was performed with the L-moments algorithm using data sets of both halves for 18 stations in the basin. Thus, the regional variability in the probabilistic behavior of the data sequences belonging to both halves would be revealed. In the regionalization process, the L-moment algorithm is carried out in the stages described below (Hosking and Wallis, 1997).

First, the L-moments statistics, namely the measure of location, the coefficient of L-variation, the coefficient of L-skewness, and the coefficient of L-kurtosis (λ_1, L-CV, L-CS, and L-CK), of the data series of the two halves belonging to each station are calculated. In the next step, the discordancy (Di) between the stations in the tentatively formed region is tested by considering the L-moments statistics. With the detection of discordant station(s), it is decided to divide the relevant region into sub-regions as an alternative. This process continues until no discordant stations are found. Then, after it was found that none of the stations in the formed regions were discordant, the homogeneity of the region is tested with the H measure. If this measure is H<1 for a region, that region is judged to be acceptably homogeneous. In the last step, the regional distribution is determined among the candidate distributions depending on the goodness-of-fit measure (Z^{DIST}). The distributions satisfying the condition of the $\left|Z^{DIST}\right| \leq$ 1.64 are accepted as regional distributions. The details on how to perform these analyzes are available (Hosking and Wallis, 1997). The Generalized Logistic (GLOG), Generalized Extreme Values (GEV), Generalized Normal (GNO), Pearson Type III (PIII), and Generalized Pareto (GPA) distributions were considered as candidate distributions in the study. The implementation of the above-mentioned L-moments algorithm was achieved by the Fortran routines developed by Hosking (1996).

The quantile estimation at a given return period is fulfilled according to the index-storm approach of Dalrymple (1960). The mathematical relationship of the approach for site i is as follows;

$$Q_i(F) = \mu_i q(F) \quad (4)$$

Where Q(F) and μ_i are respectively the quantile and index rainfall value for the site i, and q(F) is the value dealing with the growth factor. F is the level of probability.

3. Results and Discussion

The study was conducted to detect how the temporal variability in the maximum rainfall data sets with the duration of 2-h belonging to 18 rainfall stations of the basin would influence their probabilistic behavior. Firstly, the analysis of variability in the maximum rainfalls was scrutinized by the ITA approach. In line with this goal, after the full data set was divided into the first halve (FH) and second halve (SH), their calculated slope values (Scal) were compared with the critical slope value (Scrit). The ITA results for the stations in question are available in Table 1. Statistically, insignificant trend was detected in only three (Ağri, Erzurum, and Mus) of them out of all stations, while a statistically significant downward was also found in the three stations (Malatya, Mardin, Sanliurfa). On the other hand, the remaining stations had a statistically significant increasing change. The results highlighted that all rainfall series (excluding the three data) were subjected to statistically significant variability over time. In fact, this finding pointed out that it was imperative to perform frequency analyzes under the existing non-stationary conditions. The following findings are regionally in line with this basis, considering Şen (2020)'s proposal (PITA) for station-based.

Table 1. Geographic features and ITA results for the stations
Çizelge 1. *İstasyonların coğrafik özellikleri ve ITA sonuçları*

Rainfall Stations	Elevation (Meter)	Mean (mm)	ITA Results	Rainfall Stations	Elevation (Meter)	Mean (mm)	ITA Results
Adiyaman	669	713	0.034	Gaziantep	840	554	0.168
Agri	1640	526	**-0.037**	Hakkari	1720	783	0.098
Batman	550	492	0.118	Kilis	680	498	0.030
Bingol	1177	953	0.149	Malatya	977	377	-0.075
Bitlis	1545	1234	0.157	Mardin	1150	678	-0.108
Diyarbakir	677	487	0.063	Mus	1300	765	**0.022**
Elazig	1015	410	0.072	Siirt	895	718	0.042
Erzincan	1214	380	0.047	Sanliurfa	547	453	-0.078
Erzurum	1893	434	**-0.005**	Tunceli	914	884	0.093

*The bolded ones denote statistically insignificant trend.

In the study, the regional frequency analysis was applied to the FH and SH data sequences of all stations as the first attempt. It was found that not all of the regionalization steps described above were satisfied for the FH and SH data sets. Therefore, the possibility of evaluating all stations as a single region has been eliminated. Therefore, the process of forming sub-regions, in which all the regionalization phases would be achieved, was started. At first, efforts were made to divide the basin into two sub-regions. In the effort of two sub-regions for the FH, all stages of the regionalization process were able to be achieved when the Mus station was left out of action. On the other hand, the SH data of all stations were used for the aforementioned trial, and the regionalization process was completed. But, although two sub-regions were formed for the two halves, the stations assigned to their sub-regions showed no similarity in terms of numbers and names. The results of regionalization for both halve data sets are in Table 2. It was found that all of the candidate distributions considered in the study could be used as a regional distribution for the first sub-region (SR1) of the FH, while there were three candidate distributions (GLOG, GEV, GNO) for the first sub-region of the SH. But, for the second sub-regions (SR2) of the FH and SH, the same candidate distributions (GEV, GNO, PIII) were chosen as the regional distribution. Among the distributions found suitable based on the Z DIST value, the distribution having the smallest value for the sub-regions was chosen as the best fit (Table 2). These findings support the idea of Pettitt (1979). The first sub-regions of FH and SH indicate a different probabilistic structure. On the other hand, although the second sub-regions of these two halves have the same distribution characteristic, the differences in the stations in the region should not be overlooked.

Table 2. Heterogeneity and Goodness-of-Fit results for two halves
***Çizelge 2**. İki yarı için Heterojenlik ve Uyum iyiliği testi*

Regionalization Tests	First Halve		Second Halve	
	$2FH\text{-}_{SR1}$	$2FH\text{-}_{SR2}$	$2SH\text{-}_{SR1}$	$2SH\text{-}_{SR2}$
H measure	0.41	-0.39	-0.96	0.69
Z^{DIST} measure	GEV (0.06)	PIII (-0.34)	GLOG (0.09)	PIII (-0.26)

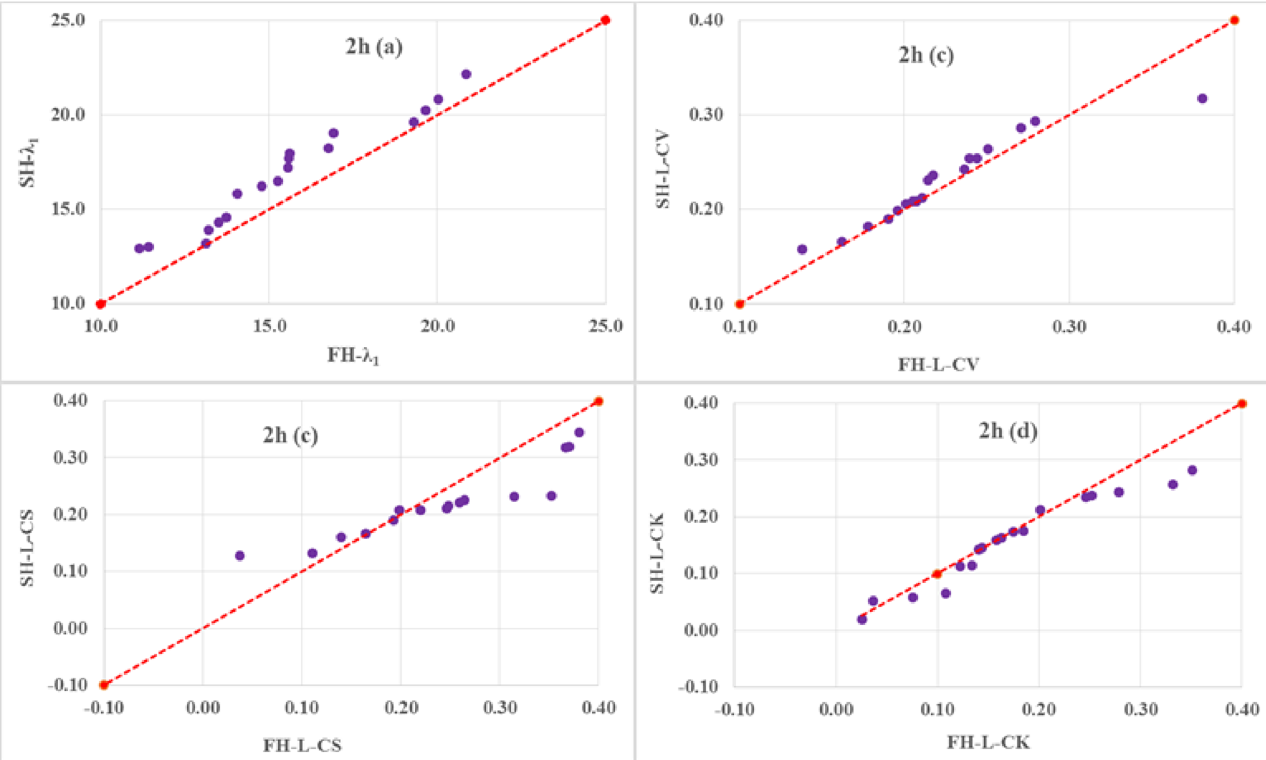

Figure 2. Variability in the L-moment statistics of the FH and SH rainfall series
***Şekil 2**. FH ve SH yağmur serilerinin L-moment istatistiklerindeki değişim*

The first L-Moment and L-moment ratios of the rainfall data sequences with 2-h duration of the FH and SH were positioned according to the 1:1 line within the ITA mentality to visually reveal the change in these statistics (Figure 2). An increase was detected in the λ1 statistic of the Maximum rainfall data series with the 2-h duration. This detection determines that the maximum rainfall amounts of the FH are smaller than that of the SH. When analyzed in terms of L-CV statistics, it is seen in Figure 2b that there is a partial increase. In other words, this L-moment ratio showed no significant change in the region. In terms of the region, it is noteworthy that there is a significant decrease especially in large L-CS values (Figure 2c). On the other hand, the L-CK statistic is scattered around the 1:1 line in a structure similar to the L-CS. The change detected in these L-moment statistics was clear evidence that the data used in performing the regional frequency analysis was not obtained under stationary conditions. In the regionalization process, the variability in these statistical parameters, which have great importance in defining the regional distribution, would obstacle the decision of the distribution best fit to the region.

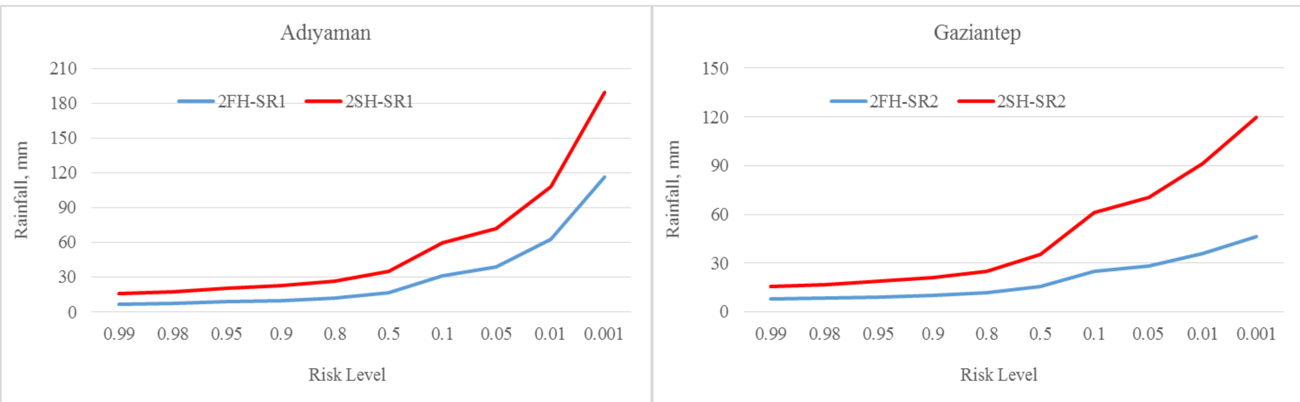

Figure 3. Variation of the quantiles estimates for risk levels
***Şekil 3.** Risk seviyeleri için nicelik tahminlerinin değişimi*

One of the main objectives in the current study was to come up with the change between the quantiles estimated regionally, but the assignments of the different stations to the sub-regions of the first and second halves was an obstacle to reaching the intended target. However, instead of this goal, the station-based quantile estimates for the FH and SH data sets regarding the stations selected, namely Adiyaman and Gaziantep, were performed based on the method of Dalrymple (1960). The relevant results are in Figure 3. The fact that there was an upward trend in the maximum rain series at these stations has caused an increase in the quantile estimates. The difference between the large quantile estimates for both halves also increased significantly.

4. Conclusion

The prevalent assumption in traditional practices to the frequency analysis of hydro-meteorological data sequences is that the hydrological variable has stationary over time. With the reality of global climate change, the fulfillment of the expectations from a hydraulic structure constructed based on executing frequency analysis under the assumption of stationarity would be insufficient. This study was conducted to detect how variability in climate conditions affects regional frequency analysis regarding rainfall series with the 2-h duration. The goal was achieved by the L-moments algorithm considering the PITA approach. With the ITA approach, statistically significant changes were detected in approximately 83% of the maximum rainfall series. This finding indicated that the frequency distributions of the rainfall series of two halves (FH and SH) split according to the ITA mentality would be different. The regionalization results based on the FH and SH rainfall series showed that the best fit regional distributions representing each halve series were different. Besides, the $\lambda 1$, L-CV, L-CS, and L-CK statistics were compared to each other within the ITA procedure in order to come up with the variation in the regional frequency distribution behavior. In this respect, significant changes were detected. Additionally, the station-based quantile estimates at different risk levels for the first halve and second halve data sequences were carried out based on the procedure of Dalrymple (1960). In particular, the differences between large quantile estimates were greater.

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