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Research Article

Investigation of The Effect of Climate Change on Extreme Precipitation: Tekirdağ Case

İklim Değişikliğinin Aşırı Yağış Üzerine Etkisinin Araştırılması: Tekirdağ Örneği

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Abstract

This study examines the potential impacts of climate change on extreme precipitation in a specific location, Tekirdağ, Turkey. Trends in rainfall extremes for (1963-2015 period) observed data of 5, 10, 15, 30 minutes and 1, 2, 3, 4, 5, 6, 8, 12, 18, 24 hours are determined by using 1:1 straight line method and Mann-Kendall trend test. Also, daily (24h) future projections for Tekirdağ region are assessed and bias corrected with Quantile Mapping method for the 2015-2050 period. Subsequently, observed and bias corrected daily (24h) time series are used for the Generalized Extreme Value analyses to quantify the potential changes with respect to observation period. Most of the observed time series show increasing trend tendency. Considering the projected data driven analyses results; for shorter return periods results show smaller variations while variability increase with the increasing return period. Depending on the models and Representative Concentration Pathways, there are different results for the future extreme rainfall; yet all results indicate an increasing extreme daily rainfall magnitude at Tekirdağ Province.
Keywords: *Climate change, extreme rainfall, quantile mapping, Mann-Kendall trend test*

Öz

Bu çalışma, belirli bir alanda, Türkiye Tekirdağ ilinde iklim değişikliğinin aşırı yağışlar üzerindeki potansiyel etkilerini incelemektedir Aşırı yağışlarda (1963-2015 dönemi) gözlemlenen 5, 10, 15, 30 dakika ve 1, 2, 3, 4, 5, 6, 8, 12, 18, 24 saatlik verilerin trendi 1:1 düz çizgi yöntemi ve Mann-Kendall trend testi kullanılarak belirlenmiştir. Ayrıca, 2015-2050 döneminde Tekirdağ ili için günlük (24 saat) gelecek dönem projeksiyonları değerlendirilmiş ve kantil haritalama yöntemi ile sapmalar düzeltilmiştir. Bunu takiben, günlük (24 saat) zaman serileri kullanılarak Genel Aşırı Değer analizleri ile gözlem periyoduna göre gelecek dönemdeki potansiyel değişimler hesaplanmıştır. Gözlemlenen zaman serilerinin çoğu artan trend eğilimi göstermektedir. Öngörülen veri odaklı analiz sonuçları dikkate alındığında; daha kısa geri dönüş periyotları için sonuçlar daha küçük farklılıklar gösterirken değişkenlik artan geri dönüş periyodu ile birlikte artmaktadır. Modellere ve Temsili Konsantrasyon Senaryolarına bağlı olarak, gelecekteki aşırı yağışlar için farklı sonuçlar görülse de, tüm sonuçlar Tekirdağ ilinde günlük aşırı yağış miktarında artışı işaret etmektedir.
Anahtar kelimeler: *İklim değişikliği, aşırı yağış, kantil haritalama, Mann-Kendall test*

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Introduction

By the end of the 21st century extreme rainfall events, such as extreme rainfalls, are expected under climate change conditions (Willems, 2013; IPCC, 2013; Liew et al., 2014; Pohl et al., 2017). There are several studies that indicate the effect of climate change on the rainfall regimes and trends. It is a common acceptance that water cycle and rainfall characteristics will be effected significantly by climate change (Osborn et al., 2015). Changes in the rainfall regimes, intensification of extreme rainfall or increasing frequency are expected in some regions as a consequence of climate change (Zhou, 2012; Papagiannaki et al., 2015).

Various urban infrastructure and flood control structures (e.g. dams, culverts, stormwater networks) are designed based on the characteristics of extreme rainfall that is reflected as intensity (depth)-duration-frequency (I(D)DF) curves (Peck et al., 2012; Hosseinzadehtalaei et al., 2017).

The IDF or DDF curves are used to quantify the intensity and its frequency of rainfall considering different durations (Willems et al., 2012) and traditionally the IDF/DDF curves are based on historical rainfall properties in general (Cheng & Aghakouchak, 2014). However, it is found that neglecting the changing frequency may result in the underestimation of obtained IDF/DDF curves (Cheng & Aghakouchak, 2014). Sarhadi et al. (2017) and Cheng and Aghakouchak (2014) also urge the need of updated extreme rainfall used in the infrastructure design process. In the IDF/DDF curve generations updating is important as new records become available because some natural effects may cause alterations in the frequency or the magnitude of rainfall events (Güçlü et al., 2018). Hence future changes became into consideration to obtain appropriate and futureproofing design.

In order to close the information gap regarding future climate, currently Global Climate Models (GCMs) are the most advanced tools. GCM data is widely used for the climate change studies however these raw GCM data is quite coarse for local scale studies and impact evaluations because of resolution problem, inconsistent physical processes, and regional patterns (Emami & Koch, 2018; Bedia et. al., 2020). Therefore, regional climate models (RCMs) is one of the methods that is used for regional assessment however GCM&RCM coupling outputs cannot be used directly at a local scale for the impact studies since RCMs keep coupled GCM biases, particularly for extreme events (Kara et al., 2016). Furthermore, complexity of rainfall processes also produces larger bias between observations and model results (Dai, 2006).

To overcome the model induced, bias various methods have been developed and are now being used for bias correction (BC). Quantile mapping (QM) method is one of the most widely used BC techniques (Themeßl et al., 2011; Cannon et al., 2015; Ngai et al., 2017). QM method is based on calibrating, CDF of the modeled data into the CDF of observed data by using a transfer function. Studies support that quantile mapping or CDF matching technique yields sufficient results for rainfall data (Piani et al., 2010; Gudmundsson et al., 2012; Chen et al., 2013; Trinh-Tuan et al., 2019; Mendez et al., 2020). Piani et al. (2010) reveal that QM is well represented the simulated daily rainfall across Europe. Gudmundsson et al. (2012) also present that QM is quiet well performed in reducing bias among other techniques. Moreover Chen et al. (2013) assessed BC methods and demonstrated the advantage of distribution-based methods, including QM, over mean-based methods. Coupling bias correction methods with GCM&RCM outputs provide necessary knowledge to further climate change impact studies.

Considering the climate change effects of on extreme rainfall properties can help to improve the several methodologies regarding flood risk and potential damages investigation in urban areas or can used to perform a better decision making approach for flood risk management and infrastructure design (Notaro et al., 2015).

The aim of this study is to explore the effects of changing climatic conditions on extreme rainfall and to urge the need to update IDF/DDF curves at Tekirdağ Station, Turkey. The reason for Tekirdağ being the center of attention in this study is being one of the major cities that are on the route of 324 km long Kınalı-Tekirdağ-Çanakkale-Savaştepe Motorway project in western Turkey which is one of the key KGM "Vision 2023" Projects. Moreover, the Project consists of many highway drainage infrastructures such as culverts and open channels which their design process is directly concerned with extreme rainfall patterns.

The approach used to achieve this goal includes 1) identify, if any, trends for observed rainfall extremes, 2) parametric and nonparametric transformation of projected daily time series 3) quantification of changes by using projected daily time series

Methodology

Data and Study Area

Study area.

Tekirdağ is in northwestern Turkey. It is one of three cities in Thrace, is also one of the six coastal provinces that have coasts of two different seas in Turkey. The province, with a surface area of 6.313 km² is between 0 and 200 m above sea level. The city is surrounded by Silivri and Çatalca Districts of İstanbul from the east, Vize, Lüleburgaz, Babaeski and Pehlivanköy Districts of Kırklareli from the north, the Marmara Sea and Gallipoli District of Çanakkale from the south (Figure 1). The Mediterranean climate is dominant in the Marmara Sea coasts. However, unlike the coasts of the Mediterranean Region, snowfall can be seen in the winter. In the inner parts of the city, the continental climate dominates the summers and cold winters. It has a coast of 1.5 km to the Black Sea from the northeast. Tekirdağ, the largest city in the southern part of the Ergene Basin, was established on the shore of a large bay where the roads from the southern Ergene region and the north reach the Sea of Marmara (URL 1).

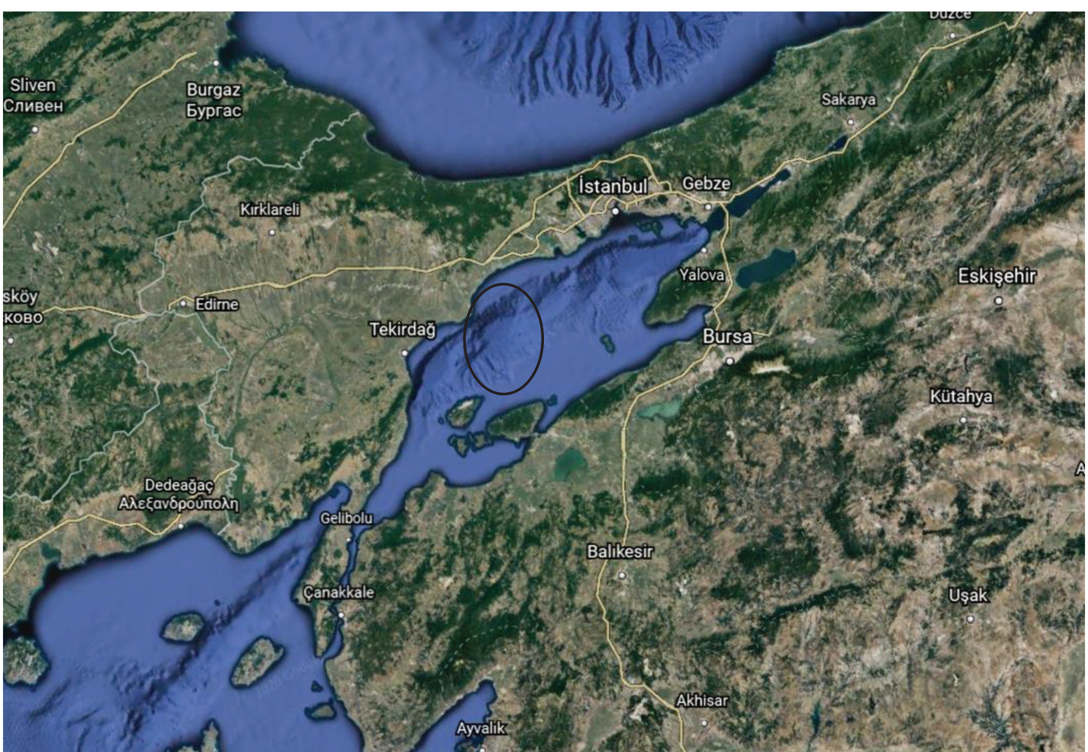


Figure 1. Map of Thrace Region and location of the stations.

Data

Observed station data.

The observed (1963-2015) annual maximum time series and daily (1940-2016) rainfall time series of Tekirdağ Station were acquired from State Meteorological Service. Daily observed time series are used for the bias adjustment of model data which then used to derive future annual maximum time series. Observed and simulated annual maximum time series are used for the extreme value analysis. Since the model data starts from 1971, 1971 and later are taken into consideration both for annual maximum and daily observed data.

Future projections.

Daily historical and future (1971-2100) rainfall projections from hydrological model E-HYPEv3.1.2 which is run by the Swedish Meteorological and Hydrological Institute (SMHI) (Hundecha et al., 2016) are used in this study. Daily projected rainfall data were obtained for the Catchment Sub-ID= 9761280, Lat: 40.98 and Lon: 27.51 that includes city of Tekirdağ. Catchments are defined as irregular catchment polygons and median catchment size is 215 km² (spatial resolution). The Hydrological Predictions for the Environment (HYPE) model is a semi-distributed, physically based catchment model (Lindström et al., 2010). The model and scenarios for the future projections can be seen from Table 1 while models and RCPs are entitled as in Table 2 and hereafter will be included in the text in this way.

Table 1

Simulations Used in This Study

RCM	Driving GCM	RCPs
CSC-REMO2009	MPI-ESM-LR	2.6, 4.5, 8.5
IPSL-WRF331F	IPSL-CM5A-MR	4.5
KNMI-RACMO22E	EC-EARTH	4.5, 8.5
SMHI-RCA4	EC-EARTH	2.6, 4.5, 8.5
SMHI-RCA4	HadGEM2-ES	4.5, 8.5

Table 2

Notation of RCM & GCM & RCP Combinations

Period	Model No	RCM & GCM & RCP Combinations
Historical	Model 1	CSC_REMO2009_MPI-ESM-LR
	Model 2	IPSL-IPSL-CM5A-MR
	Model 3	KNMI_RACMO22E_EC-EARTH
	Model 4	SMHI_RCA4_EC-EARTH
	Model 5	SMHI_RCA4_HadGEM2-ES
Future	Model 1	CSC_REMO2009_MPI-ESM-LR_rcp26
	Model 2	CSC_REMO2009_MPI-ESM-LR_rcp45
	Model 3	CSC_REMO2009_MPI-ESM-LR_rcp85
	Model 4	IPSL-IPSL-CM5A-MR_rcp45
	Model 5	KNMI_RACMO22E_EC-EARTH_rcp45
	Model 6	KNMI_RACMO22E_EC-EARTH_rcp85
	Model 7	SMHI_RCA4_EC-EARTH_rcp26
	Model 8	SMHI_RCA4_EC-EARTH_rcp45
	Model 9	SMHI_RCA4_EC-EARTH_rcp85
	Model 10	SMHI_RCA4_HadGEM2-ES_rcp45
	Model 11	SMHI_RCA4_HadGEM2-ES_rcp85

In this study the changing climatic conditions are assessed by using observed and projected daily extreme rainfall data (annual maximum). To capture any variations, trend tests are applied to the observed annual maximum time series. Observed and projected 24h annual maximum time series are used for the return level (rainfall depth in mm) calculations for 2-5-10-25-50-100-year return periods. Daily model time series data first adjusted using quantile mapping method. After that annual maximum time series are obtained from the projected data and added to the observed time series until 2050 to gain final time series for the extreme value analysis. Since historical model data covers 1971-2005 period, this period is used for calibration and validation process. The analyses period covers 1971-2050 period daily maximum time series (1971-2015 observed and 2016-2050 projected). Finally, obtained changes are used to quantify the impact of climate change over daily extreme rainfall for the area of interest that in this study is Tekirdağ.

Trend Analysis

In this study, 1:1 straight-line method (Şen, 2012), which has been awarded by American Society of Civil Engineers in 2014 as the best technical note and widely used Mann-Kendall trend test (Mann, 1945; Kendall, 1975; Gilbert, 1987) are used to trend detection.

For the 1:1 straight line method, time series are divided into two halves, sorted in ascending order. First half of the series is previous half and places on the horizontal (X) axis. Second half of the time series is latter half and places on the vertical (Y) axis. The existence of a trend is visually inspected by the position of scattered points relative to 1:1 line (Şen, 2012; Haktanir & Citakoglu, 2014; Güçlü et al., 2018; Ali et al., 2019; Alifujiang et. al., 2020).

Mann-Kendall (MK) test makes a statistical assessment of the existence of monotonic trend (upward or downward) for a chosen variable over time. A monotonic upward or downward trend indicates the consistently increase or decrease of the tested variable whether the increase (decrease) linearly or not.

The main equations of the MK test are given below (Mann, 1945; Kendall, 1975; Longobardi & Villani, 2010; Ahmad et al., 2015; Chen et al., 2016):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \quad (3.1)$$

in which S is the MK test statistic.

$$sgn(x_j - x_i) = \begin{cases} +1 & (x_j - x_i) > 0 \\ 0 & (x_j - x_i) = 0 \\ -1 & (x_j - x_i) < 0 \end{cases} \quad (3.2)$$

$$VAR(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \quad (3.3)$$

$$z = \frac{S-1}{\sqrt{VAR(S)}}, \quad \text{if } S>0 \qquad z = 0, \quad \text{if } S=0$$

(3.4)

$$z = \frac{S+1}{\sqrt{VAR(S)}}, \quad \text{if } S<0$$

The hypothesis, H0, that there is no trend is rejected when the absolute value of Z is greater than the critical value Z_α, at a chosen level of significance α and the alternative hypothesis, H1, is accepted. R package trend (Pohlert, 2020) was used for the MK test.

Distribution Fitting (Bias-correction Method)

In this study two methods of quantile mapping (QM) were used. Non-parametric quantile mapping (QM) using robust empirical quantiles (REQ) and quantile mapping using parametric transformations (PT) are used for bias correction. The QM non-parametric technique which has the additional advantage of not relying on any predetermined statistical distribution of the data, is used in this study (Gudmundsson et al., 2012; Trinh-Tuan et. al., 2019). However parametric transformation is also applied to figure out discrepancies and to validate the conformity of non-parametric method. According to QM method the distribution of observed data is preserved by the distribution of simulated data (Heo et.al., 2019). More detail about this procedure can be found in (Piani et al., 2010; Gudmundsson et al., 2012; Wuthiwongyothin et. al., 2020). The QM was conducted using the available qmap package in the R software (Gudmundsson, 2016).

Extreme Value Analysis

Extreme Value Analysis (EVA) is a tool used commonly for investigating meteorological extremes (Cheng et al., 2015; Vahedifard et al., 2017; Makkonen & Tikanmäki, 2019). Extreme value theory (EVT) is concerned with the statistical properties of the tails of distributions and by providing the necessary methods to estimate the distribution of the extremes of a time series (Umbricht et al., 2013). By this way quantification of the return level values (in this study rainfall depth in mm for the duration of interest, which in this study is 24-hour (daily) rainfall and return periods of extreme events become possible.

Extreme Value Theory (EVT) uses probabilistic distribution functions such as Generalised Extreme Value (GEV) or Generalised Logistic (GL) function fitted on a block of (in this study annual) maximum series, called Block Maxima (BM) approach or Generalised Pareto Distribution (GPD) function which is fitted to series over a selected threshold, called peak-over-threshold (POT) method (Collet et al., 2017). GEV distribution function is used in the present study to fit the observed and future rainfall data. The methodology is widely used in engineering applications that need an assessment of extreme environmental conditions (Coles, 2001; Coles & Sparks, 2006).

The aim of BM approach is to obtain the probability distribution of the maximums of a block. In the BM approach, equal length of blocks are selected and maximum values from each block are determined and subsequently the GEV distribution is fitted to the obtained maxima series to estimate the exceedance probability, calculate return period and its return level. The size of the block is important because the distribution of the maximum series of the parent distribution may not converge to the GEV distribution as expected for the block maxima approach because of small number of blocks and block size caused biases and errors (Cai & Hames, 2010; Umbricht et al., 2013; Wang et al., 2016). Yearly maximum time series generated from 1971 to 2050 provide time series that are relatively long enough in this study.

The generalized extreme value (GEV) distribution function is widely used to model block maxima of data with theoratical justification. The GEV df is given by (3.1);

$$G(z) = \exp[-\{1 + \xi\left(\frac{z-\mu}{\sigma}\right)\}_{+}^{-\frac{1}{\xi}}] \tag{3.5}$$

Depending on the sign of the shape parameter, ξ, Equation 3.5 covers three types of df's. Fréchet df with $\xi > 0$, Weibull df with $\xi < 0$ and Gumbel df by with limit as $\xi \rightarrow 0$. Maximum Likelihood Estimation (MLE) and L-Moments methods are preferred parameter estimation method of models in this study (Gilleland & Katz, 2016; Lazoglou & Anagnostopoulou, 2017).

Results and Discussions

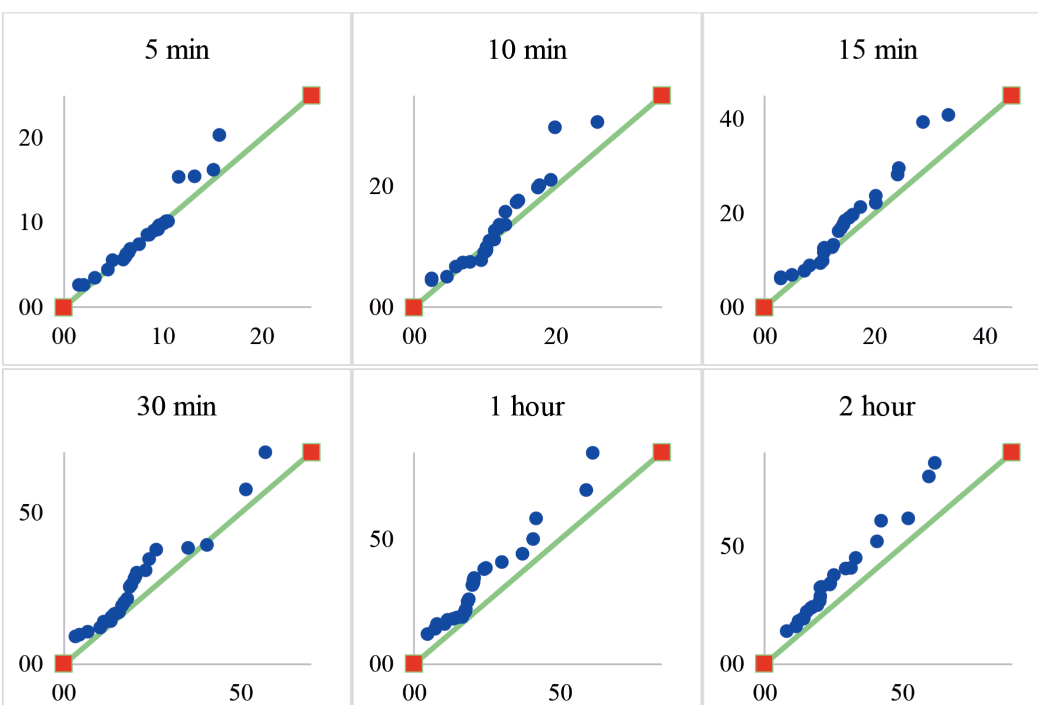


Figure 2. The results of the 1:1-line method (Şen, 2012) for annual maximum rainfall at the Tekirdağ station 1964–2015.

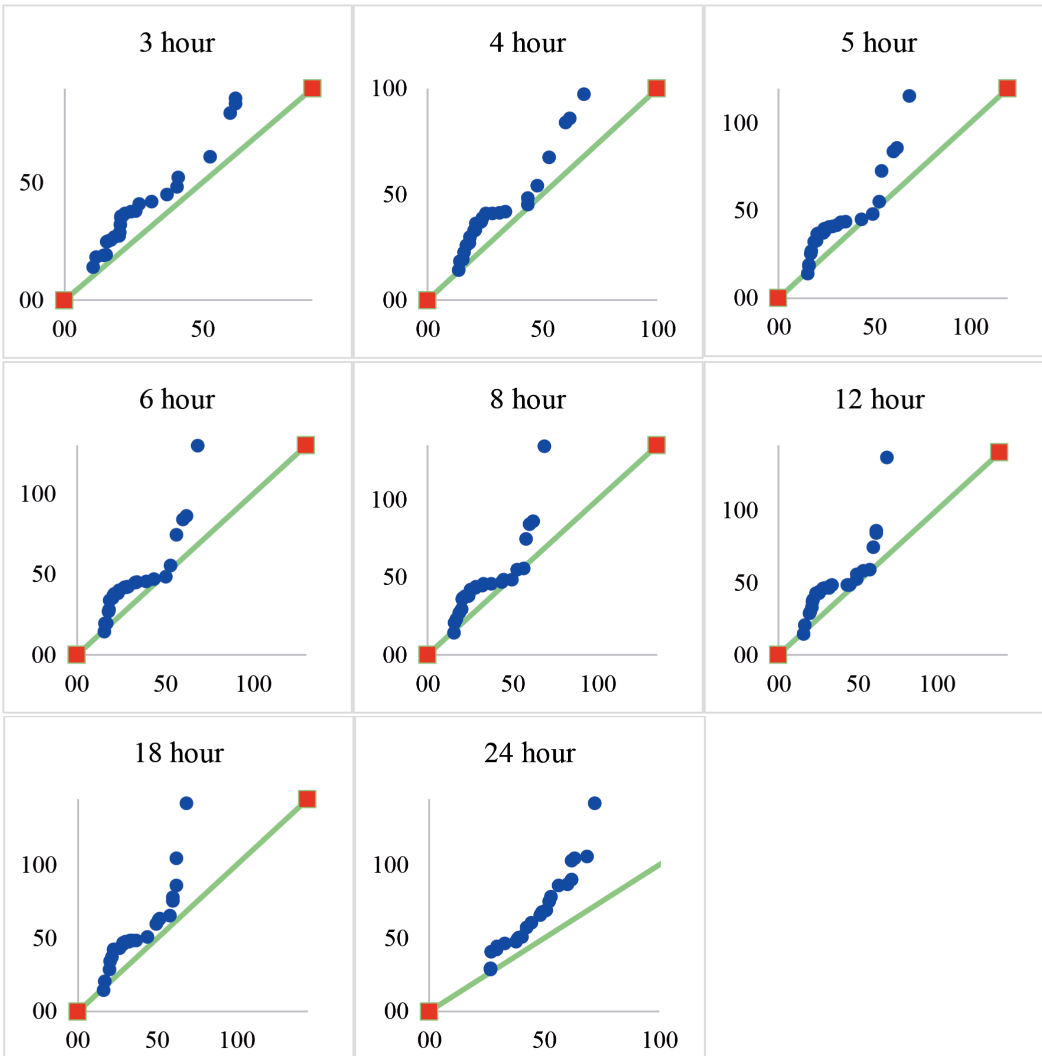


Figure 2. (continue) The results of the 1:1-line method (Şen, 2012) for annual maximum rainfall at the Tekirdağ station 1964–2015.

As mentioned in the methodology section, first (1964–1989 period) and the second (1990–2015 period) halves of the time series sorted in ascending order for the 1:1 line trend detection analysis. The trend conditions of annual maximum of 5-10-15-30 minutes and 1-2-3-4-5-6-812-18-24 hours storm durations can be seen from Figure 2 according to 1:1 straight line – Şen (2012) method. Although all storm durations show positive trend, 5-10-15 minutes data show smaller magnitudes in terms of trend tendencies when compared with the longer storm durations. With the increasing storm duration positive trend conditions become more dominant. It can be said that changing conditions over time effect both short and long duration annual maximum time series and the existence of this effect can be seen clearly from the Figure 2.

Table 3

MK Test Results of 14 Standart Duration Time Series

	5M	10M	15M	30M	1H	2H	3H	4H	5H	6H	8H	12H	18H	24H
Z value	0.952	1.189	1.488	1.757	2.347	2.424	2.769	2.578	2.662	2.647	2.478	2.370	2.624	2.685
P value	0.341	0.234	0.137	0.079	0.019	0.015	0.006	0.010	0.008	0.008	0.013	0.018	0.009	0.007

Moreover, MK trend test also applied to time series in order to support and to validate the visual inspection results of ITA method (Table 3). According to MK results, all extreme rainfall time series showed increasing trends while 30 minutes at 0,1 significance level, 1, 2, 8 and 12 hours at 0,05 significance level and, 3, 4, 5, 6, 18, 24 hours annual maximum rainfall series at 0,01 significance level show increasing trends. These results indicate consistent outcomes with the ITA analyses. Regarding annual maximum rainfall series, it can be said that the series are dominated by increasing trend tendency while hourly data is dominated with significant increasing trend compared to sub-hourly data.

Afterwards quantile mapping applied to bias correct the daily rainfall values obtained from the simulations. Because daily rainfall values of historical period (1971–2005) and future period (2006-2050) are containing catchment scale values these results it is necessary to corrected by PT and REQ approaches with observed daily rainfall results of Tekirdağ Station. Model biases were determined by computing the probability of exceedance curves and box plots between the raw model, adjusted and the observed annual daily maximum time series during the historical period. Five models are used for the historical period bias adjustment procedure.

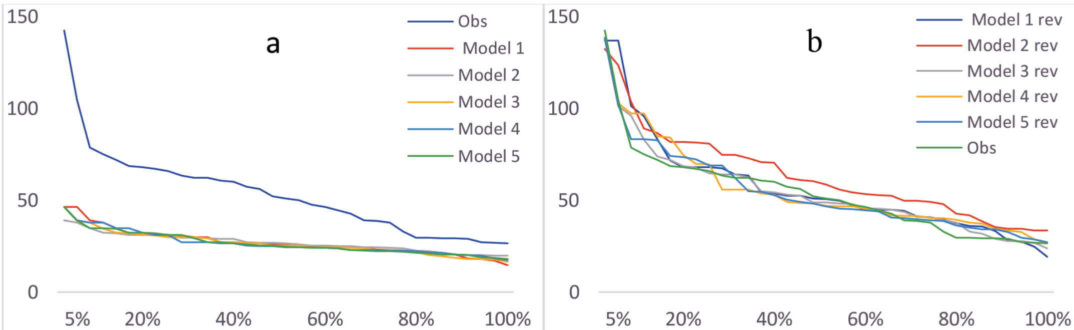


Figure 3. a) Raw model and observed annual daily maximum time series (1971-2005), b) PT bias corrected model results and observed annual daily maximum time series (1971-2005) (X-Axis is probability of exceedance in %, Y-Axis is daily annual maximum rainfall in mm).

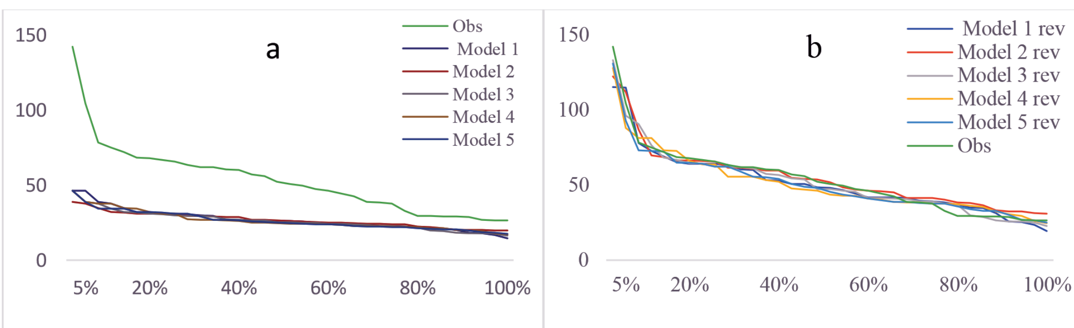


Figure 4. a) Raw model and observed annual daily maximum time series (1971-2005), b) REQ bias corrected model results and observed annual daily maximum time series (1971-2005) (X-Axis is probability of exceedance in %, Y-Axis is daily annual maximum rainfall in mm).

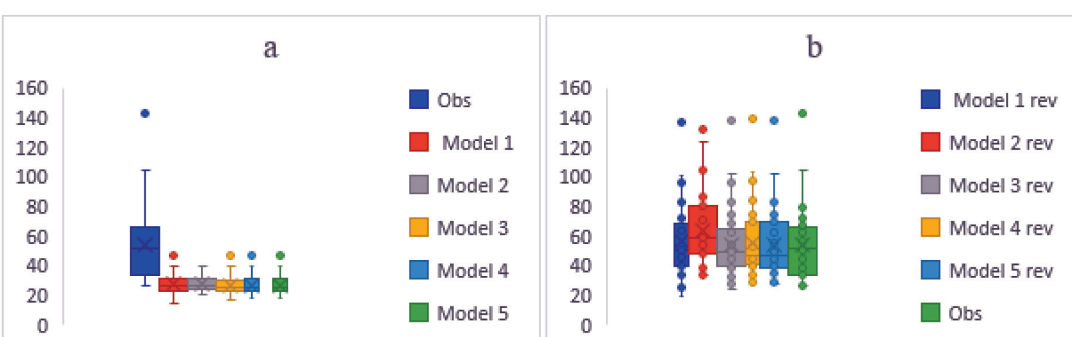


Figure 5. Boxplots showing a) raw model and observed annual daily maximum time series (1971-2005), b) PT bias corrected model results and observed annual daily maximum time series (1971-2005).

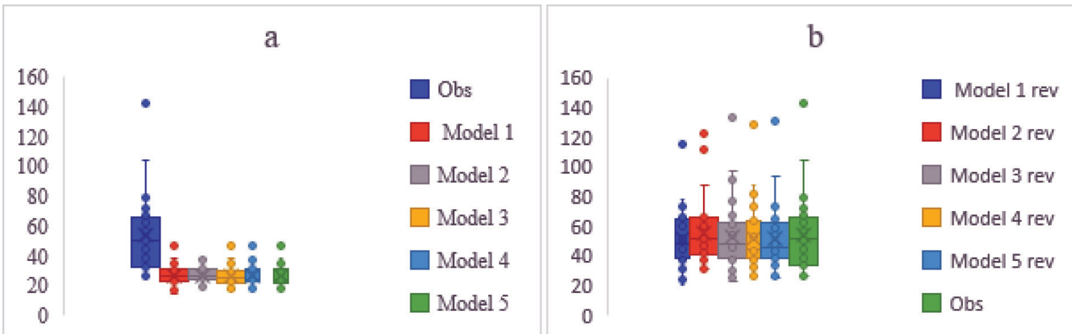


Figure 6. Boxplots showing a) raw model and observed annual daily maximum (mm) time series (1971-2005), b) REQ bias corrected model results and observed annual daily maximum (mm) time series (1971-2005).

Figures 5 and 6 show boxplots of raw model, bias corrected model, and observation results of daily annual maximum time series between 1971-2005. Bias corrected time series are constructed with PT and REQ methods can be seen. Both PT and REQ results show considerable performance however evaluating the box plot results together with probability of exceedance results that are shown in Figures 3 and 4 above, REQ model results are used for the rest of this study.

After obtaining final daily rainfall projections from bias correction procedure, it is possible to evaluate the variability amongst the different climate models and RCP combinations and observation. In total, 11 sets of rainfall projections were generated until 2050. Every data set then used to calculate the annual daily maximum time series to perform GEV analyses with BM approach. For each model GEV analyses with MLE and L-Moments methods are conducted, and 2-5-10-25-50-100-years return levels of annual daily maximum time series are calculated. Each 11 model, RCP2.6 model average, RCP4.5 model average and RCP8.5 model average and observed return level results are compared.

Results of the 11 model and observation period return level values are drawn for 2-5-10-25-50-100-years return periods. Frequency Depth Duration curves that are derived to capture the variations clearly. Estimation results are given in Figure 7 and their corresponding percent change values are given in Table 4. Rainfall depts are in mm and return periods are in years. All figures and tables are obtained for daily (24 hour) annual maximum rainfall data.

In general, all model results, both with MLE and L-Moments, yield grater return level values than observed ones. It can be easily seen that except model1 for

2 years and model 2 for 2-5-10-25 years return levels, observation-based return level values are smaller than projection results. These results also support the observation period trends that generally provide positive trends. It is apparent that results which are calculated with MLE approach produce greater return levels when compared to the results that are calculated with L-Moments approach. Furthermore, the difference between observation-based return levels and projected ones increases with the increasing return period. On the other hand, Model 1, Model 2 and Model 3 return level values revealed smaller and Model 5 and Model 6 revealed larger difference among other models. There is great variability among models in return level values on the other hand the sign of change is clearly indicated by all models.

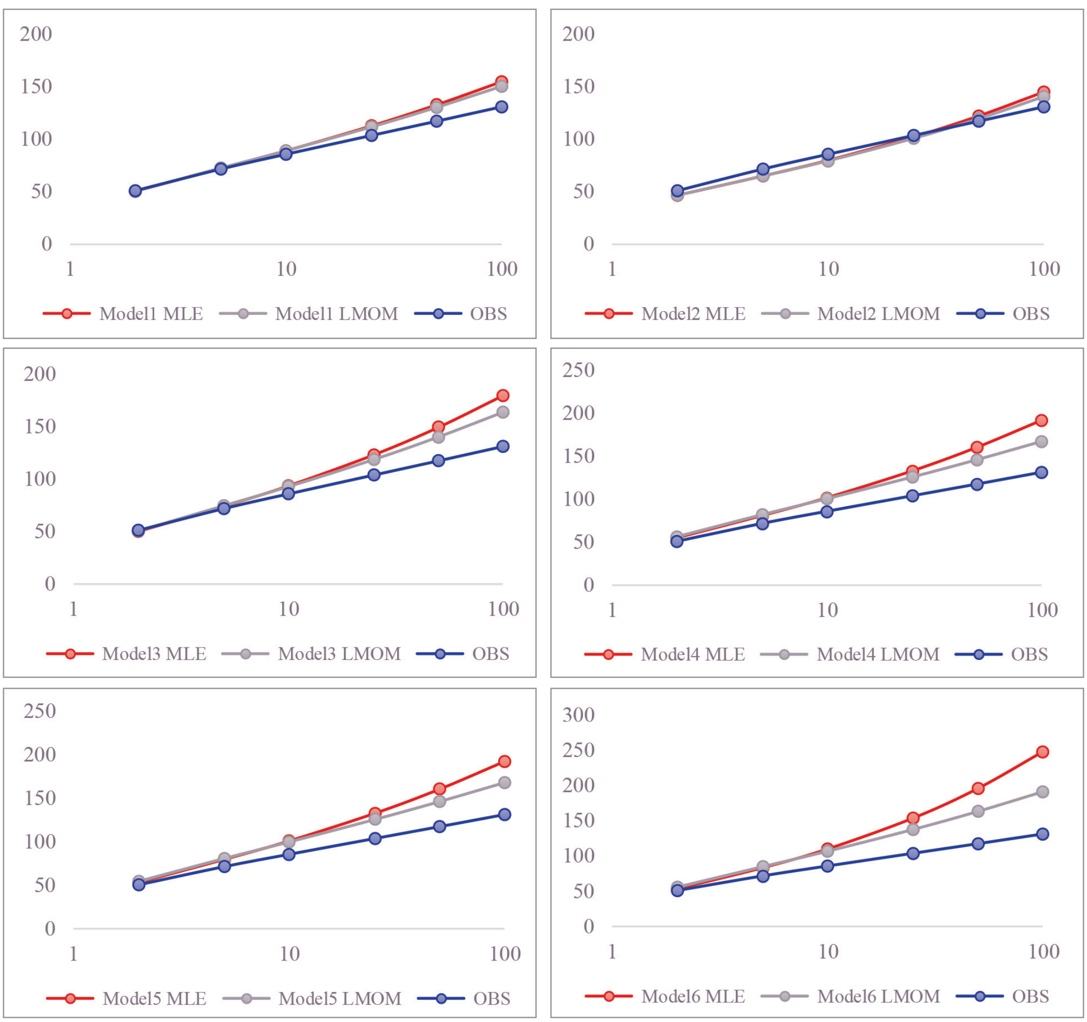
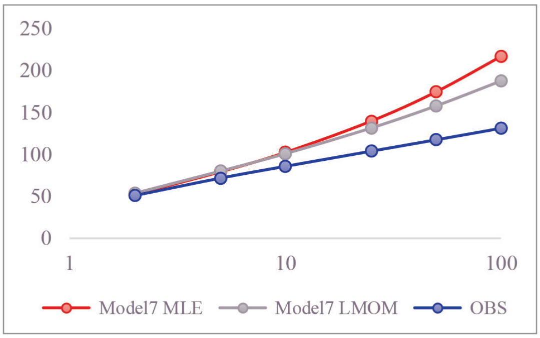
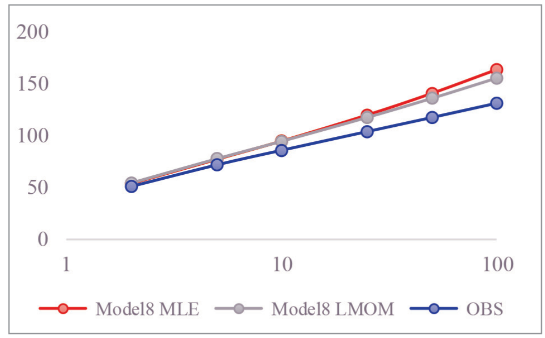
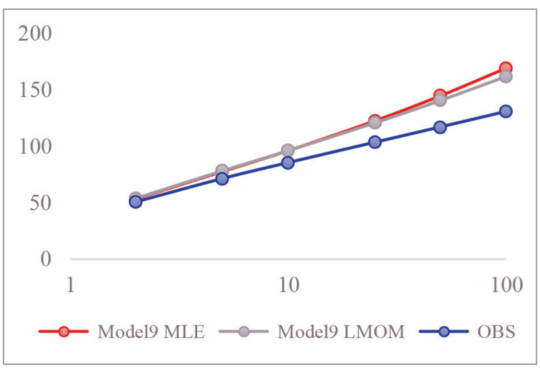
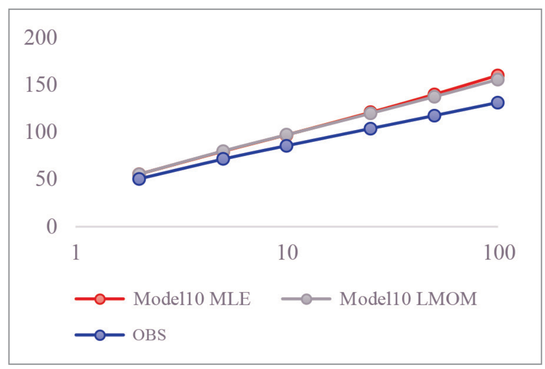


Figure 7. Depth Duration Frequency Curves of 24h data for single models - (X-Axis is return period in years, Y-Axis is return level in mm).









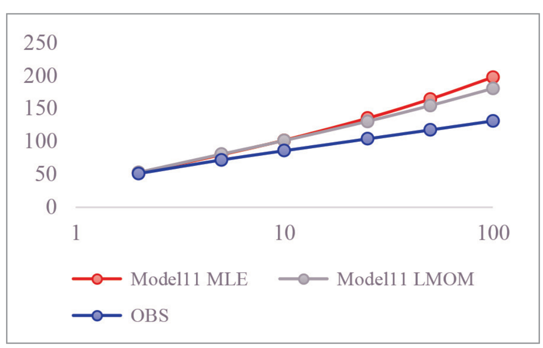


Figure 7. (continue) Depth Duration Frequency Curves of 24h data for single models - (X-Axis is return period in years, Y-Axis is return level in mm).

Table 4

Return Level Comparison (Percent Change) of Models Vs. Observation

	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
Model1 MLE	-2%	1%	4%	9%	13%	18%
Model1 LMOM	-1%	1%	4%	8%	11%	15%
Model2 MLE	-9%	-10%	-7%	-2%	4%	10%
Model2 LMOM	-9%	-10%	-7%	-3%	2%	7%
Model3 MLE	-2%	3%	9%	18%	27%	37%
Model3 LMOM	0%	4%	8%	14%	19%	25%
Model4 MLE	7%	12%	18%	28%	37%	46%
Model4 LMOM	10%	14%	17%	21%	24%	28%
Model5 MLE	5%	11%	18%	28%	37%	47%
Model5 LMOM	8%	13%	17%	21%	25%	28%
Model6 MLE	5%	16%	28%	48%	67%	89%
Model6 LMOM	10%	19%	25%	33%	39%	46%
Model7 MLE	3%	10%	19%	34%	49%	65%
Model7 LMOM	5%	12%	18%	27%	34%	43%
Model8 MLE	6%	8%	11%	16%	20%	25%
Model8 LMOM	7%	9%	10%	13%	16%	19%
Model9 MLE	6%	9%	13%	19%	24%	29%
Model9 LMOM	7%	10%	13%	17%	20%	24%
Model10 MLE	9%	11%	13%	17%	19%	22%
Model10 LMOM	10%	12%	14%	16%	17%	19%
Model11 MLE	1%	11%	19%	30%	40%	51%
Model11 LMOM	3%	12%	18%	26%	32%	38%

Figure 8 and Table 5 show differences between projected return level values of RCP scenarios and observation-based return levels for 2-5-10-25-50-100 years return periods. In general, RCP26, RCP45 and RCP85 scenario averages yield similar results with single model evaluations. 1–5 % increase for 2 years return period to 29-52% increase for 100 years return period. Comparing MLE and L-Moments results it can clearly be seen that all return level values are greater than the observation base ones. However, when two approaches compared with each other, it is the L-Moments results that yield greater values for shorter return periods whereas MLE results yield larger return level values after 25-years return periods. Considering the RCP scenarios RCP85 return level values show the larger difference between observation and projections. All models show smaller variations for the shorter return period values however RCP26 increases with return period duration and become larger than RCP45 results with increasing return period. The magnitude of change increases in accordance with the return period.

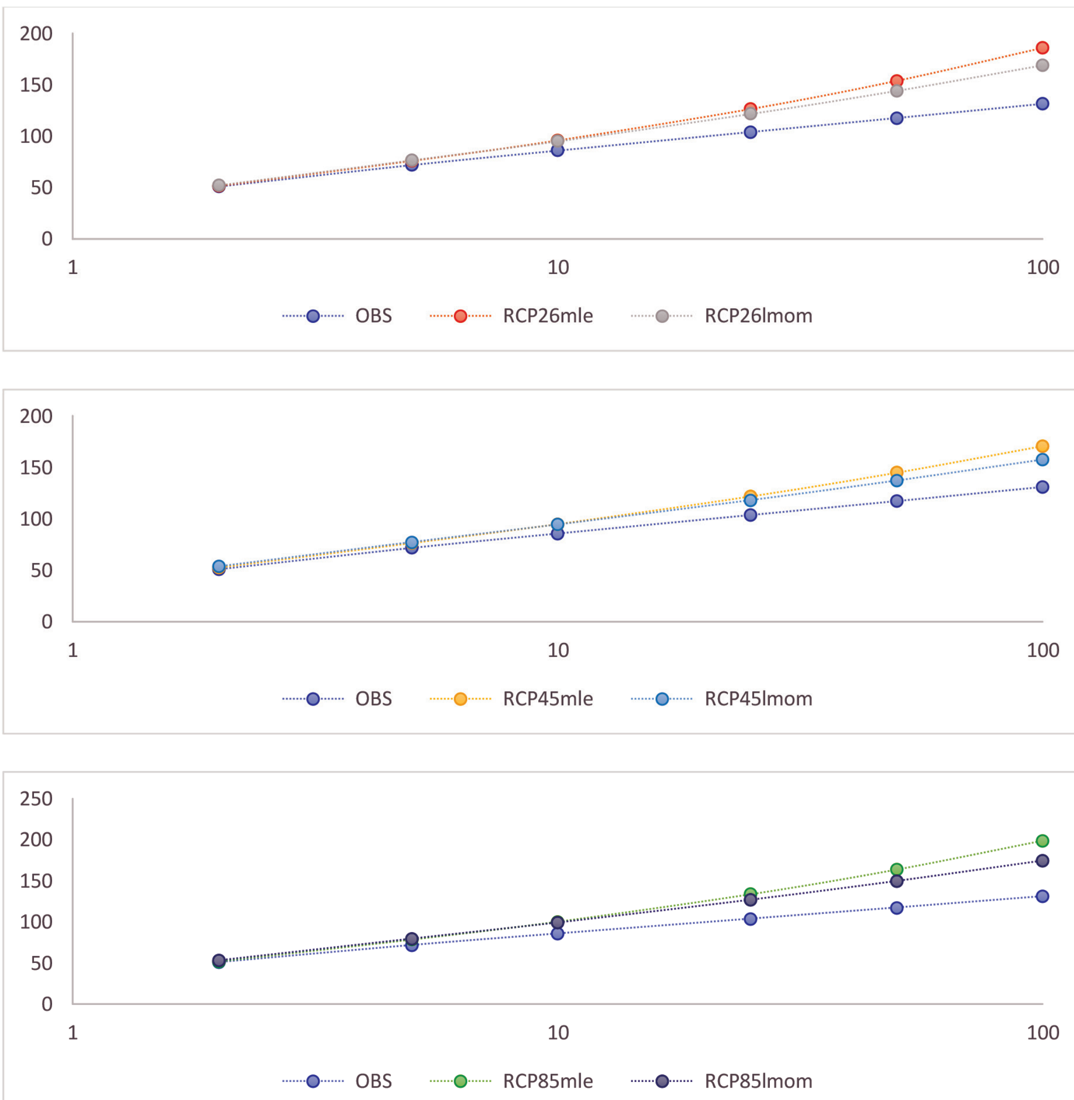


Figure 8. Depth Duration Frequency Curves for RCP averages and observation - (X-Axis is return period in years, Y-Axis is return level in mm).

Table 5

Return Level Comparison (Percent Change) of RCP Averages Vs. Observation

	2-Years	5-Years	10-Years	25-Years	50-Years	100-Years
RCP26MLE	1%	6%	12%	22%	31%	42%
RCP26LMOM	2%	6%	11%	17%	23%	29%
RCP45MLE	3%	7%	11%	17%	23%	30%
RCP45LMOM	5%	8%	10%	14%	17%	20%
RCP85MLE	2%	10%	17%	29%	39%	52%
RCP85LMOM	5%	11%	16%	22%	27%	33%

Discussion and Conclusions

In this study first trend of observed (1964-2015) annual maximum of 5-10-15-30 minutes and 1-3-6-24 hours storm durations time series of Tekirdağ province are examined by using 1:1 straight line method. Moreover, projected daily time series are used to capture the potential changes. Quantile mapping method applied, and bias corrected future time series are obtained up to 2050. After that, by using GEV analyses potential changes are quantified in terms of maximum daily (24h) rainfall for 2-5-10-25-50-100 years return periods at Tekirdağ station.

All storm durations show positive trends according to 1:1 straight line method. Both short duration and long duration time series show increasing trend while longer duration time series show higher magnitudes in terms of trend tendency. Bias corrected daily time series are used for the GEV analyses. These results reveal that future period 24h annual maximum values will probably increase based on the model results. On the other hand, variations among model results increase with the increasing return period. RCP averages are also calculated and used in comparison that reveal similar results with single model evaluation.

There are studies that cover precipitation properties of Tekirdağ region but many of these studies are not considering future extreme rainfall magnitudes with changing climatic conditions. Sirdas et al. (2016) investigated heavy precipitation at 23 meteorological observation stations in the Marmara region, including Tekirdağ, in terms of temperature, Arctic Oscillation Indices (AO) and North Atlantic Oscillation Indices (NAO) and revealed no significant relationship. Also, Gönençgil (2013) studied Thrace region and found significant dry conditions for annual precipitation series of Tekirdağ.

Considering the extreme conditions, Abbasnia & Toros (2018) indicated significant heavy precipitation trends for Rx1day and Rx5day for Edirne and Tekirdağ. In this study it is also found that annual maximum 24h rainfall have a potential increase according to model results. Considering the findings of Üstün Topal et al. (2016) that noticed the increasing rate of impervious land cover, the potential increase that is shown in this study urges to take attention in this issue. There is great variability among models in return level values on the other hand the sign of change is clearly indicated by all models.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

İklim Değişikliğinin Aşırı Yağış Üzerine Etkisinin Araştırılması: Tekirdağ Örneği

Küresel ısınmadan kaynaklanan değişiklikler, fırtınaların ve aşırı yağışlar gibi diğer ekstrem hava olayların görülme sıklığında ve şiddetinde bir artışa neden olabilecektir (IPCC, 2013). İklim değişikliğinin su döngüsü ve yağış rejimi üzerinde önemli etkileri olacağı yaygın bir görüş olarak ortaya çıkmaktadır (Osborn vd., 2015). Bazı bölgelerde, bu değişiklikler ile ekstrem yağışların görülme sıklığı ve şiddetinde artış olacaktır (Zhou, 2012; Papagiannaki vd., 2015). Diğer bir deyişle, ekstrem yağış olaylarının iklim değişikliğinin de etkisi ile 21. yüzyılın sonlarına doğru belirgin bir şekilde görülmesi beklenmekte olup bu etkiler bölgesel olarak farklılıklar gösterebilecektir (Willems, 2013; IPCC, 2013; Liew vd., 2014; Pohl vd., 2017; Seneviratne vd., 2012).

Bu çalışmanın amacı, değişen iklim koşullarının aşırı yağışlar üzerindeki etkilerini anlamak ve Tekirdağ İstasyonu'ndaki IDF / DDF eğrilerini güncelleme ihtiyacını ortaya koymaktır. Bu çalışmada Türkiye'nin batısında yer alan Tekirdağ ilinin seçilme nedeni, tasarım süreçleri doğrudan aşırı yağış düzenleriyle ilgili olan menfezler ve açık kanallar gibi birçok otoyol drenaj altyapısını barındıran 324 km uzunluğundaki Kınalı-Tekirdağ-Çanakkale-Savaştepe Otoyolu projesinin güzergahında yer alan şehirlerinden biri olmasıdır.

Çalışmada izlenen yol: 1) gözlem dönemi standart süreli yıllık maksimum yağışların trendlerinin belirlenmesi, 2) projeksiyon sonuçları elde edilmiş olan günlük zaman serilerinin parametrik ve parametrik olmayan yöntemler ile yanlılık düzeltmesinin yapılması, 3) projeksiyon ve gözlem dönemi günlük yağış serileri kullanılarak iki dönem arasındaki değişikliklerin belirlenmesidir.

Tekirdağ İstasyonunda gözlemlenen (1963-2015) standart süreli yıllık maksimum zaman serileri ve günlük (1940-2016) yağış zaman serileri Meteoroloji Genel Müdürlüğünden temin edilmiştir. Günlük gözlemlenen zaman serileri, daha sonra gelecekteki yıllık maksimum zaman serilerini türetmek için kullanılan model verilerinin yanlılık düzeltmesi için kullanılmıştır. Model verileri geçmiş dönemi içine alacak şekilde 1971 yılından itibaren mevcut olduğu için gözlem dönemi yağış serileri de 1971 ve sonrası itibari ile kullanılmıştır. Gelecek dönem analizleri için kullanılan veriler ise Tekirdağ şehrini (Enlem: 40.98 ve Boylam: 27.51) içeren alt havzaya ait günlük ölçekteki yağış projeksiyonlar olup (1971-2100), İsveç Meteoroloji ve Hidroloji Enstitüsü (SMHI) (Hundecha vd., 2016) tarafından işletilen hidrolojik model E-HYPE v3.1.2'den temin edilmiştir.

Gözlem ve projeksiyon dönemi günlük aşırı yağış verileri (yıllık maksimum) analiz edilerek değişen iklim koşullarının etkisi değerlendirilmiştir. Gözlem dönemi yağış serilerine ait trendler 1:1 düz çizgi yöntemi ve Mann-Kendall trend testi ile tespit edilmiştir. 2 - 5 - 10 - 25 - 50 - 100 yıllık geri dönüş periyotlarında mm olarak yağış yüksekliği hesaplamaları için gözlem ve projeksiyon dönemi 24 saatlik yıllık maksimum zaman serileri kullanılmıştır. Günlük ölçekte elde edilmiş model zaman serileri için önce kantil haritalama yöntemi kullanılarak yanlılık düzeltmeleri gerçekleştirilmiştir. Elde edilen sonuçlar karşılaştırmalı olarak incelenmiş ve düzeltme sonuçlarının yeterli performans gösterdiğine kanaat getirilmiştir. Daha sonra, projeksiyon verilerinden elde edilerek yanlılık düzeltmesi yapılan günlük yağış verilerinden yıllık maksimum yağışlar elde edilmiş ve gözlem dönemi zaman serilerine

eklenmek sureti ile 2050 yılına kadar olan yeni zaman serileri elde edilmiştir. Toplamda 11 adet farklı zaman serisi elde edilmiş ve analizlerde kullanılmıştır. Bu zaman serileri farklı genel iklim modeli, bölgesel iklim modeli ve temsili konsantrasyon senaryolarına göre belirlenmiştir. Geçmiş dönem model verileri 1971-2005 dönemini kapsadığından, bu süre gözlem verileri kullanılmak sureti ile kalibrasyon ve doğrulama işlemi için kullanılmıştır. Analiz dönemi 1971-2050 günlük maksimum zaman serilerini kapsamaktadır (1971-2015 gözlemlenen ve 2016-2050 projekte edilen yağış verileri olmak üzere). Son olarak, yeni günlük maksimum yağış serileri kullanılarak Genel Aşırı Değer analizleri yapılmış ve 2 - 5 - 10 - 25 - 50 - 100 yıllık geri dönüş periyotları için yağış yükseklikleri elde edilmiş ve gözlem dönemi verileri ile karşılaştırılmıştır. Genel aşırı değer analizi yapılırken blok maksimum yöntemi kullanılmıştır. Söz konusu yöntemde zaman serileri için seçilen bloklara (bu çalışmada yıl) ait maksimum değerler elde edilmek sureti ile hesaplamalar gerçekleştirilmiştir.

Elde edilen sonuçlara göre gözlem dönemine ait tüm yağış süreleri 1:1 düz çizgi yöntemine ve Mann-Kendall trend testi sonuçlarına göre artan trend eğilimleri göstermektedir. Hem kısa süreli hem de uzun süreli zaman serileri artış eğilimi gösterirken, daha uzun süreli zaman serileri incelendiğinde (örn. 1 saat, 3 saat, 24 saat) artış eğiliminin bu serilerde daha belirgin olduğu görülmektedir. Genel aşırı değer analizleri için yanlılık düzeltilmesi yapılmış günlük zaman serileri kullanılarak yapılan analizler sonucunda; gelecek dönemde 24 saat süreli yıllık maksimum değerleri göz önüne alındığında model sonuçlarına göre bu değerlerde muhtemel bir artış beklenmektedir. Öte yandan, artan geri dönüş periyodu ile model sonuçları arasındaki farklılıklar da artış göstermektedir. Ayrı ayrı model sonuçlarının yanında temsili konsantrasyon senaryolarına göre ortalama değerler de hesaplanmış ve bu ortalama sonuçlarına göre model değerlendirmelerine benzer sonuçların ortaya çıktığı görülmüştür, gözlem dönemi değerlerinin temsili konsantrasyon senaryolarına göre ortalama değerlerden daha düşük olduğu tespit edilmiştir. Modellere ve Temsili Konsantrasyon Senaryolarına (TKS) bağlı olarak, gelecekteki aşırı yağışlar için farklı sonuçlar görülse de, tüm sonuçlar Tekirdağ ilinde günlük aşırı yağış miktarında artışı işaret etmektedir.