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ORIGINAL PAPER

Spatial and temporal characterization of standard duration-maximum precipitation over Black Sea Region in Turkey

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Abstract
This study characterises the spatial and temporal behaviours of maximum precipitation over the Black Sea Region in northern Turkey. Maximum precipitation data of 14 standard durations changing from 5 min to 24 h were used from 21 meteorological stations in the region with record lengths ranging from 25 to 71 years. In line with the objective of the study, tests for the detection of outliers, homogeneity, and trend were applied in order to reveal the structural characteristics of the data set. Tests detected no outlier, and the homogeneity analysis found only three stations fully homogeneous, all others being inhomogeneous. Change points identified in the data set by the homogeneity tests were linked to the local characteristics of meteorological stations. Trend analysis revealed that slightly more than half of the meteorological stations are exposed to a positive trend in the maximum precipitation of one standard duration at a minimum. The main conclusion is that maximum precipitation is subject to change over the Black Sea Region in Turkey.

Keywords Black Sea Region · Change-point · Homogeneity · Maximum precipitation · Trend analysis · Turkey

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1 Introduction

It is important that hydraulic structures such as dams, culverts, and bridges function properly under flood conditions for which maximum precipitation is commonly used to estimate the peak discharge or water level in a given cross section of the stream. Therefore, analysis of the maximum precipitation data is essential for the planning, design, management and risk analysis of hydraulic structures. A detailed analysis is needed in achieving tangible results for the extreme precipitation. However, basic statistical analysis such as the outlier detection, homogeneity and trend tests may help the users to identify the general structural characteristics of maximum precipitation time series prior to any advanced analysis is made with which the frequency or return period of maximum precipitation is determined. This has made understanding the general or region-specific structural characteristics of precipitation a very attractive issue to study all over the world (Koutsoyiannis and Baloutsos 2000; Dahamsheh and Aksoy 2007; Sun et al. 2013; Vaheddoost and Aksoy 2017; Fagnant et al. 2020).

Hydraulic structures are designed based on country- or region-specific design codes using inputs estimated from the past records of hydrometeorological variables, e.g. precipitation. Estimation techniques usually work under the stationarity condition. Yet, hydrometeorological variables such as precipitation are subject to change in their characteristics indicating that the stationarity in time does not exist anymore. In this context, the non-stationarity issue is of great importance in areas where hydrological extremes overwhelm. The issue has greater importance due to the fact that hydrological extremes including floods (especially flash floods) and droughts intensify as regards to climate change in many parts of the World (IPCC 2007, 2013). Flash floods are much more problematic for hydraulic structures as well as for urban areas particularly for large cities where the infrastructure can easily be overtopped.

Climate models are useful tools to estimate trend in precipitation due to climate change after which regional models have shown an increase in precipitation over the Black Sea Basin (Gao et al. 2006; Bozkurt et al. 2008; Onol and Semazzi 2009). Increase in precipitation is attributed to the strengthening of high pressure over the Mediterranean Basin and subsequently to the change of the path of cyclones to the North (Giorgi and Lionello 2008). Croitoru et al. (2013) studied change in precipitation by using indices on the western coast of the Black Sea, i.e. the coastline of Bulgaria, Romania and partially Ukraine and showed that a positive trend exists over the region. Another significant variation is the rise in the sea surface temperature of the Black Sea for which Shaltout and Omstedt (2014) found a strong upward trend of 0.51 C^0/decade. Observation-based evidence and atmospheric modelling studies indicate that the Black Sea region is under the impact of climate change and variability.

Mediterranean countries (e.g. Turkey) are prone to flash floods. As such, the Black Sea region in the northern part of Turkey is vulnerable to flood due to its topography, proximity to the Black Sea, and synoptic weather patterns. In this regard, flood-related deaths have been on the increase lately. Over the last 90 years, 644 people have lost their lives during 59 floods and landslides in the Eastern Black Sea region (URL-1). On 11 August 2021 (when this study was under review), a flood occurred after a heavy rainfall in Kastamonu, the western Black Sea region, leaving 78 people dead behind (URL-2). Another catastrophic flood in the Central Black Sea region caused 59 people to die in provinces Corum, Amasya and Tokat on 30 August 1979 (Aksoy 2020). The flood-oriented annual economic loss in Turkey is about 100 million USD (Uskay and Aksu 2002). In turn, increase in the

magnitude and duration of precipitation directly affects the loss of life and property in the country.

Due to its vulnerability to flood, the Black Sea region has been studied widely in Turkey. For example; Haktanir and Citakoglu (2014), among many others, conducted tests for the trend, independence, stationarity and homogeneity in maximum precipitation of the 24-h standard duration for several meteorological stations. Almost 90% of annual maximum precipitation time series in Turkey were found trend-free, stationary, and homogeneous at 5% significance level, while the likely changes in the maximum precipitation in the Black Sea region were pointed, and further research was suggested. The Black Sea region shows unique climatological characteristics compared to other climatic regions in Turkey. It, in turn, gains much more attention than other regions in terms of precipitation characteristics. Studies on the Black Sea region in Turkey have been focusing on trends in precipitation (Eris and Agiralioglu 2012; Tonkaz and Bostan 2016; Tosunoglu 2017), weather extremes (Abbasnia and Toros 2020; Aksu 2021), intensity–duration–frequency of maximum precipitation (Korkmaz et al. 2019) and modelling monthly maximum precipitation (Yozgatligil and Turkes 2018). Focusing on the Black Sea region, Ay (2020) tested the homogeneity and trend in the monthly mean temperature and monthly total precipitation. There are also streamflow modelling studies conducted for the region. For example; Usul and Turan (2006) performed a GIS-supported flood analysis for the Ulus River Basin in the Western Black Sea region.

There exist quite high number of studies mainly focusing on the trend analysis of various hydrometeorological variables for different parts of the Black Sea Region. However, besides its clear importance for the flood prediction and management practice, no comprehensive characterization study has so far been performed for the maximum precipitation data of standard durations for the entire Black Sea Region. The primary objective of this study is therefore to identify structural characteristics of maximum precipitation time series of standard durations over the region. It can be anticipated that we will be less exposed to flood hazard by better understanding the structural characteristics of maximum precipitation (Mondal and Daniel 2019).

2 Study area

The Black Sea Region is the third largest of the seven geographical regions in Turkey. It extends from the eastern part of the Sakarya plain in the west to Georgia in the east for 1400 km in the East–West direction with a width from 100 to 200 km in the North–South direction. The total area of the region is 143.537 km^2 (URL-3). In the region, a rainy and temperate climate prevails over the coastal part while a continental climate dominates the inland as the mountains lie parallel to the coastal line and prevents air moisture to move behind the mountains. The region is divided into three geographical sub-regions. The maximum annual precipitation is, on average, in the range 2000–2500 mm over the eastern sub-region, whereas it is 1000–1500 mm in the western sub-region, and 1000–1200 mm in the central sub-region. The substantial difference in the precipitation is related to the elevation, which is the highest in the east.

There are large river basins such as Yesilirmak, Kizilirmak and Coruh in the Black Sea Region. Therefore, it is one of the most vulnerable regions of Turkey in terms of flooding due also to its heavy rainfall characteristics and topographical structure. Flood events occurred substantially in the coastal parts of the Black Sea region; and they are mostly

caused by cyclones coming from the Black Sea, except for some local events (Celik et al. 2007). Many observations or modelling studies showed increasing trends of extreme meteorological events over the region (Aziz et al. 2020; Oruc 2021; Drobinski et al. 2018; Aksu et al. 2021). Based on the topographical and hydrological characteristics, the Black Sea region was selected to study here (Fig. 1).

3 Data

Depending on the diverse precipitation climatology changing from one region to another, countries use different standard durations for their precipitation inventory. The Turkish State Meteorological Service uses 14 standard durations which are 5-, 10-, 15-, 30-min, 1-, 2-, 3-, 4-, 5-, 6-, 8-, 12-, 18-, and 24-h. Maximum precipitation time series of the standard durations were acquired from the Meteorological Service. An aggregation methodology is used by the Meteorological Service to detect the maximum value of the overlapping moving window of the interested standard duration in each day. Then, the maximum of each year is extracted to construct the annual block maximum precipitation time series of the given standard duration. Thus, the annual block maximum precipitation time series of each standard duration has the same length as the record period of the meteorological station. This is the data set we used. The block maximum precipitation data of the 14 standard durations were acquired from the Meteorological Service. Additionally, the monthly maximum precipitation data together with the date they are observed were provided. The latter data set is needed for further analysis of the timing of extreme precipitation characteristics over the study area.

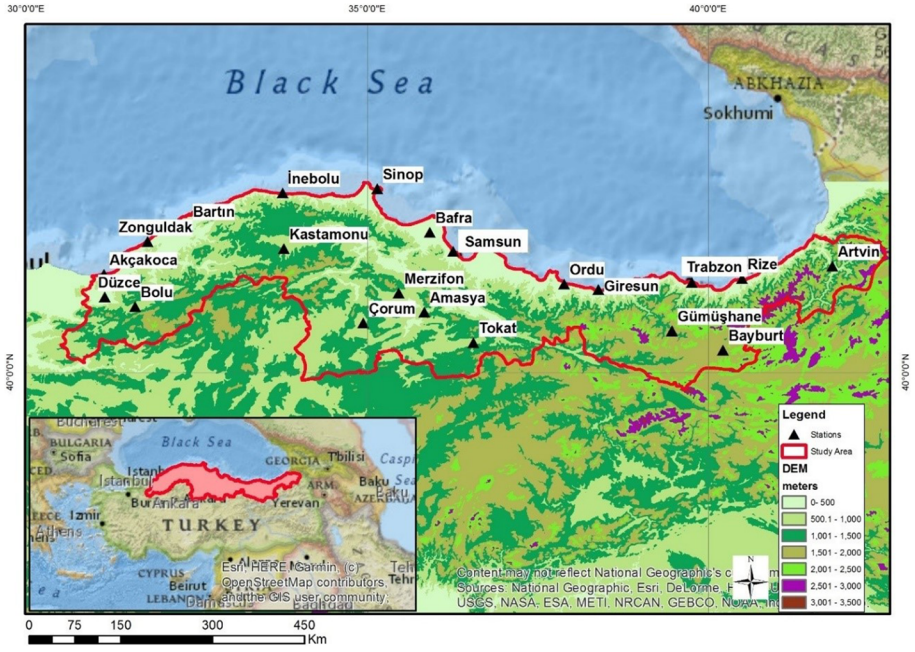


Fig. 1 Study area and spatial distribution of meteorological stations

In total, we selected 21 meteorological stations to study the entire Black Sea region. Descriptive statistics for the 5-min, 4-h and 24-h maximum precipitation time series are given in Table 1 along with the name and location of the meteorological stations distributed over the region (Fig. 1). Elevation of the meteorological stations ranges from 4 to 1584 m increasing substantially with the less proximity to the Black Sea coast. Record lengths of the meteorological stations changes from 25 to 71 years. All meteorological stations have records of longer than 30 years, most being longer than 40 years, except for Artvin, which is the shortest record lenght (25-year) existing in the eastern part of the region. This meteorological station was particularly covered in the study for the sake of a homogeneous spatial distribution of meteorological stations over the study area. None of the selected meteorological stations has a gap in their records. Therefore, no data filling procedure was used taking into account the potential of data filling errors that could be detrimental in the extreme precipitation. Additional remarks indicated that the location of six meteorological stations was altered (Table 1), and the measurement equipment was modernized in the recent 20 years. Mainly syphon type precipitation measurement devices were used in parallel with pluviometers in the past while tipping-bucket type pluviographs were deployed to all meteorological stations in the last twenty years.

All the data sets were quality checked before they were used. No disaggregation procedure was applied. Characteristics of the maximum precipitation data of standard durations were investigated by using the homogeneity and trend analysis techniques. Basic statistical homogeneity tests and trend analyses were implemented using relevant packages in the R programming language (Hothorn et al. 2015; Gama 2016; Pohlert et al. 2016; Wuertz et al. 2017). Details of the tests are given in the following section.

4 Statistical analysis

4.1 Homogeneity analysis

Time series of meteorological data is formed of records, which might show deviations from the real value due to systematic or non-systematic errors. This might be because of the malfunctioning of the measurement system, change in the vicinity of the measurement site, or human-induced effects as well as natural changes on the measured variable itself (Wijngaard et al. 2003). Therefore, any substantial change in the location of meteorological stations, urbanization around them and alteration in the measurement devices were considered in this study as potential reasons for the inhomogeneity. Clearly, statistical analysis of non-homogeneous data may cause erroneous results. This gives a particular importance to the homogeneity analyses of maximum precipitation data for each standard duration before they are used for the design of hydraulic structures such as dams and spillways, sluice gates, culverts, bridges, diversion dams, weirs, flumes.

Homogeneity of the dataset was given particular importance in this study by applying four absolute homogeneity tests, namely the Standard Normal Homogeneity Test, Buishand Test, Pettitt Test and von Neumann Test. The reason for the utilization of the absolute homogeneity tests stems from the difficulties in finding homogeneous regions and time series with common observation period in the study area. Also, the relative methodology may mislead the homogeneity test when a signal exists in the time series because of climate change. The tests are explained below briefly.

Table 1 General information of meteorological stations and descriptive statistics for 5-min, 4-h, and 24-h maximum precipitation time series. Meteorological stations are ordered alphabetically. Coordinates are in decimal degrees, and precipitation in mm (*Cv* Coefficient of variation, *Ck* Coefficient of kurtosis, *Cs* Coefficient of skewness, *r1* Lag-one auto-correlation coefficient)

Station no.	Station name	Recording period	Date of change in location	Long.	Lat.	Altitude (m)	Duration	Median (mm)	Mean (mm)	Standard error of the mean (mm)	Min. (mm)	Max. (mm)	St. Dev (mm)	Cv	Cs	Ck	*r*1
1	Akçakoca	1968–2015 ($n=48$ years)	–	31.14	41.09	10	5-min	8.80	8.85	0.39	4.00	17.6	2.7	0.31	0.62	0.59	−0.077
							4-h	40.65	48.26	3.69	17.7	126.8	25.57	0.53	1.55	1.8	0.007
							24-h	75.6	84.45	5.55	35.1	218	38.44	0.46	1.75	3.42	−0.144
2	Amasya	1965–2015 ($n=51$ years)	–	35.84	40.67	412	5-min	5.5	5.6	0.35	1.5	15	2.5	0.45	1.19	2.39	0.12
							4-h	20.1	21.27	1.27	8.6	60.2	9.06	0.43	1.74	4.75	−0.049
							24-h	33.8	36.19	1.99	19.3	109.4	14.21	0.39	2.83	11.57	−0.174
3	Artvin	1991–2015 ($n=25$ years)	1983	41.82	41.18	597	5-min	4.1	5.13	0.4	2.4	10.5	2.01	0.39	0.68	−0.27	−0.184
							4-h	21.1	22.05	1.89	11.7	47.8	9.44	0.43	1.34	1.37	−0.098
							24-h	52.6	51.89	3.89	23.8	108.5	19.47	0.38	0.74	0.69	−0.09
4	Bafra	1965–2010 ($n=46$ years)	–	35.92	41.55	20	5-min	7.15	7.61	0.56	2.4	20.4	3.82	0.50	0.81	0.72	−0.248
							4-h	28.85	34.4	2.63	13.6	86	17.83	0.52	1.14	0.37	0.065-
							24-h	58	57.76	2.7	24.8	111.8	18.34	0.32	0.47	0.05	0.101
5	Bartin	1966–2015 ($n=50$ years)	–	32.36	41.62	30	5-min	7.6	7.53	0.3	3.2	11.6	2.13	0.28	−0.11	−0.96	0.118
							4-h	38.6	41.7	2.28	17.7	82.9	16.14	0.39	0.76	−0.08	0.011
							24-h	76.6	80.07	4.26	28	174.9	30.12	0.38	0.81	1.07	−0.191
6	Bayburt	1966–2015 ($n=50$ years)	–	40.22	40.25	1584	5-min	5	5.14	0.35	2	13.2	2.46	0.48	0.99	0.8	−0.117
							4-h	17.15	18.62	0.93	9.2	39.3	6.6	0.35	0.91	0.43	−0.157
							24-h	27.75	28.3	1	17.4	53.2	7.06	0.25	1	1.35	−0.046
7	Bolu	1958–2015 ($n=56$ years)	–	31.60	40.73	742	5-min	5.2	5.58	0.33	1.2	14.4	2.5	0.45	1.03	1.48	0.055-
							4-h	17.7	20.19	1.08	10.6	50.7	8.19	0.41	1.37	2.23	0.047
							24-h	32.05	35.05	1.48	17.4	59.5	11.26	0.32	0.62	−0.71	0.112

Table 1 (continued)

Station no.	Station name	Recording period	Date of change in location	Long.	Lat.	Altitude (m)	Duration	Median (mm)	Mean (mm)	Standard error of the mean (mm)	Min. (mm)	Max. (mm)	St. Dev (mm)	Cv	Cs	Ck	*r*1
8	Corum	1958–2015 ($n=58$ years)	1983	34.94	40.55	837	5-min	7.05	7.68	0.52	2.2	24	3.99	0.52	1.42	3.27	−0.213
							4-h	20.95	24.98	1.62	8.3	56.3	12.33	0.49	0.84	−0.16	−0.111
							24-h	33.3	34.14	1.55	14	62.5	11.81	0.35	0.69	−0.23	−0.167
9	Duzce	1965–2015 ($n=51$ years)	–	31.15	40.84	146	5-min	7	7	0.46	1.7	15.5	3.27	0.47	0.4	−0.27	0.109
							4-h	25	25	1.67	12.7	66.8	11.91	0.48	1.03	0.71	0.070
							24-h	53.1	56.12	3.19	26.6	125.8	22.75	0.41	1.31	1.38	0.020
10	Giresun	1966–2010 ($n=45$ years)	–	38.39	40.92	38	5-min	8.9	8.78	0.5	3	19.2	3.36	0.38	0.54	0.3	−0.180
							4-h	45	53.68	3.97	21.1	130.5	26.63	0.50	1.19	0.77	0.015
							24-h	70.8	78.43	4	47.4	160.9	26.81	0.34	1.42	1.64	−0.186
11	Gumushane	1966–2015 ($n=50$ years)	–	39.47	40.46	1219	5-min	3.95	4.46	0.35	0.8	12.4	2.44	0.55	1.24	1.4	−0.205
							4-h	15.2	15.92	0.78	6.5	34.7	5.51	0.35	1.1	1.63	0.054
							24-h	29.35	30.5	1.29	16.7	51.7	9.09	0.30	0.6	−0.48	0.012
12	Inebolu	1959–2015 ($n=57$ years)	–	33.76	41.98	58	5-min	7	7.85	0.42	3.2	20.4	3.16	0.40	1.36	2.66	0.172
							4-h	34.5	38.32	2.26	14.5	97.5	17.03	0.44	1.49	2.37	0.318
							24-h	67.5	71.24	3	34.3	135.9	22.62	0.32	0.68	0.34	0.255
13	Kastamonu	1985–2015 ($n=31$ years)	–	33.78	41.37	800	5-min	6.6	7.73	0.73	2.5	17	4.06	0.53	0.76	−0.4	0.096
							4-h	23.4	26.7	2.65	9	73.5	14.76	0.55	1.81	3.24	−0.161
							24-h	33.9	39.44	2.91	17.3	81.2	16.2	0.41	1.04	0.41	0.145
14	Merzifon	1955–2010 ($n=56$ years)	–	35.46	40.88	759	5-min	6.5	7.17	0.43	1.4	20.7	3.25	0.45	1.3	3.53	−0.107
							4-h	18.3	20.52	1.05	8.4	44.3	7.86	0.38	0.97	0.47	0.120
							24-h	28.6	31.32	1.27	15.2	56.1	9.49	0.30	0.61	−0.24	0.068

Table 1 (continued)

Station no.	Station name	Recording period	Date of change in location	Long.	Lat.	Altitude (m)	Duration	Median (mm)	Mean (mm)	Standard error of the mean (mm)	Min. (mm)	Max. (mm)	St. Dev (mm)	Cv	Cs	Ck	*r*1
15	Ordu	1965–2015 ($n=51$ years)	–	37.89	40.98	4	5-min	6.7	7.09	0.35	2	11.7	2.48	0.35	0.11	−0.89	−0.073
							4-h	34.5	40.21	2.57	12.5	88.6	18.35	0.46	0.87	−0.05	−0.167
							24-h	65.5	73.15	4.22	28.3	171.3	30.14	0.41	1.47	1.68	0.013
16	Rize	1952–2015 ($n=64$ years)	–	40.50	41.04	4	5-min	9.9	10.39	0.44	4.9	24.4	3.48	0.33	1.49	3.04	−0.089
							4-h	61.8	71.08	3.79	32.9	174	30.3	0.43	1.23	1.23	0.139
							24-h	102.05	112.75	4.1	66.3	228	32.79	0.29	1.22	1.47	0.065-
17	Samsun	1957–2015 ($n=59$ years)	1973	36.26	41.34	4	5-min	7.4	8.48	0.57	3.1	24.3	4.41	0.52	1.51	2.39	−0.093
							4-h	31.8	41.7	3.53	14.4	130	27.08	0.65	1.58	1.89	0.167
							24-h	54.5	65	5.09	22	244.2	39.09	0.60	3.21	11.4	0.187
18	Sinop	1965–2015 ($n=56$ years)	–	35.15	42.03	36	5-min	6.6	7.58	0.51	2.5	20.4	3.66	0.48	1.24	1.86	0.177
							4-h	25.6	31.31	2.23	10.9	67.1	15.9	0.51	0.78	−0.74	0.003
							24-h	46.3	52.96	3.72	20.1	148.1	26.55	0.50	1.78	4.01	0.114
19	Tokat	1966–2015 ($n=51$ years)	–	36.56	40.33	608	5-min	4.95	5.56	0.4	1.8	17.5	2.81	0.51	1.82	4.77	−0.156
							4-h	17.2	17.54	0.69	10.7	32.6	4.86	0.28	0.79	0.34	−0.375
							24-h	29.8	29.88	1.09	17.6	52.5	7.69	0.26	0.81	0.56	−0.079
20	Trabzon	1957–2010 ($n=54$ years)	2005	39.76	41.00	30	5-min	6.3	7.04	0.41	2	18.7	2.99	0.42	1.47	3.18	−0.137
							4-h	31	32.44	1.92	15.8	92.7	14.12	0.44	2.38	7.3	0.033
							24-h	54.1	57.48	2.28	34.2	116.6	16.78	0.29	1.45	2.58	−0.088
21	Zonguldak	1945–2015 ($n=71$ years)	1950	31.78	41.45	42	5-min	9	9.35	0.38	3.9	22	3.18	0.34	1.5	3.05	0.028
							4-h	42.8	49.41	3.01	20.7	180.1	25.4	0.51	2.33	8.36	0.054
							24-h	81.1	91.04	6.04	37.4	438.8	50.9	0.56	4.53	27.94	0.067

4.1.1 Standard normal homogeneity test

The Standard Normal Homogeneity Test (SNHT) was developed by Alexandersson (1986) to detect breaks (change points), which represent sudden changes in the mean of the time series. The SNHT statistics is

$$T(k) = k\bar{z}_1^2 + (n-k)\bar{z}_2^2 \quad 1 \le k \le n \tag{1}$$

$$T_0 = \max T(k) \quad 1 \le k \le n \tag{2}$$

$$\bar{z}_1 = \frac{1}{k}\sum_{i=1}^{k}\frac{\left(Y_i - \overline{Y}\right)}{S} \tag{3a}$$

$$\bar{z}_2 = \frac{1}{n-k}\sum_{i=k+1}^{n}\frac{\left(Y_i - \overline{Y}\right)}{S} \tag{3b}$$

$T(k)$ in Eq. (1) compares the mean value of the first k years of the record with that of the last $n-k$ years. In Eqs. (3a–b), Y_i is the ith value of observation, $\overline{Y}$ is the mean, and S is the standard deviation of the time series. The SNHT statistics (T_0) is compared with the sample size-dependent critical values to decide if the null hypothesis that the time series is homogeneous is rejected or accepted.

4.1.2 Buishand test

The test is based on the normality assumption (Buishand 1982); i.e. it is a parametric test. The null hypothesis is that the time series is made of an independent and identically distributed variable, while its alternative assumes that the time series have a jump-like shift (break). The test statistics is the adjusted partial sums defined as follows:

$$S_0^* = 0 \tag{4a}$$

$$S_k^* = \sum_{i=1}^{k}\left(Y_i - \overline{Y}\right) \quad 1 \le k \le n \tag{4b}$$

in which Y_i is the ith element of the time-series and $\overline{Y}$ stands for mean value. In the case of a homogeneous time-series, the values of S_k^* fluctuate around zero because of no systematic deviation of Y_i around their mean. When a break exists in the year K, then S_k^* reaches a maximum (negative shift) or minimum (positive shift) near the year $k = K$. The significance of a shift can be checked by comparing the rescaled adjusted range (R), defined as follows:

$$R = \frac{\max S_k^* - \min S_k^*}{S} \quad 0 \le k \le n \tag{5}$$

with the critical values of $R/\sqrt{n}$ which depend on sample size.

4.1.3 Petttitt test

The Petttitt Test is a nonparametric rank test commonly used to determine a single change-point in a time series (Pettitt 1979). The ranks $r_1, \ldots, r_n$ of $Y_1, \ldots, Y_n$ observations are used to calculate the test statistics as follows:

$$X_k = 2\sum_{i=1}^{k} r_i - k(n+1) \quad 1 \le k \le n \tag{6}$$

The test statistics is assessed for the whole sequence of the time series from which the most significant change point is selected where $|X_k|$ is the largest:

$$X_K = max|X_k| \quad 1 \le k \le n \tag{7}$$

This indicates that a break occurs in year K as the statistics is either maximal or minimal around the year K in the time series. The significance of the change point is decided by using the critical values.

4.1.4 von Neumann ratio test

The von Neumann Ratio Test (VNRT) is a nonparametric test with the null hypothesis that the data are composed of independent and uniformly distributed random values (von Neumann 1941). The VNRT statistics is defined as follows:

$$N = \frac{\sum_{i=1}^{n-1}\left(Y_i - Y_{i+1}\right)^2}{\sum_{i=1}^{n}\left(Y_i - \overline{Y}\right)^2} \tag{8}$$

When the sample is homogeneous, the expected value of N is 2. If the time series under consideration contains a break, the value of N tends to be lower than 2 (Buishand 1982). If the sample has rapid variations in the mean $\overline{Y}$, the value of N tends to get values larger than 2 (Bingham and Nelson 1981). However, the test gives no information about the location of the shift. In this study, we followed the method proposed by Wijngaard et al. (2003) who classified precipitation data "*homogeneous*" when one single test, at maximum, rejects the homogeneity; "*suspect*" when two tests reject the homogeneity, and "*doubtful*" when three tests, at minimum, reject the homogeneity; the same classification procedure was adopted by taking the significance level at 5%.

4.2 Trend analysis

4.2.1 Durbin–Watson test

A trend refers to a gradual but continuous change in a time series; it can be either linear or nonlinear (Maity 2018). A significant autocorrelation in a time series may cause to over- or underestimate the trend. Therefore, it is necessary to reveal the presence of autocorrelation in the time series before the trend analysis is applied. The existence of the autocorrelation was investigated by the Durbin-Watson test (Durbin and Watson

1951). The test classifies the time series into three groups in terms of autocorrelation: "*positive*", "*negative*" and "*none*". The test statistics is calculated as

$$d = \frac{\sum_{t=2}^{n} \left(e_t - e_{t-1}\right)^2}{\sum_{t=1}^{n} e_t^2} \tag{9}$$

where e stands for residuals. Small values of d are the indication of the existence of autocorrelation. The null hypothesis that the residuals are independent are rejected in favour of autocorrelation when $d < dL$ which is tabulated in text books (e.g. Helsel and Hirsch 1992).

4.2.2 Mann–Kendall test

Mann–Kendall test is a nonparametric test, i.e. it is independent of the probability distribution of the random variable and commonly used in trend detection (Mann 1945; Kendall 1975), and it does not require data to be normally distributed. This procedure checks for the existence of a trend without specifying whether or not the trend is linear (Libiseller and Grimvall 2002; Helsel and Hirsch 1992; Birsan et al. 2005). However, this method is robust for detecting trends in precipitation data due to the influence of extremes and the fit of applications with skewed variables (Gilbert 1987; Yue et al. 2002a, b; Hamed 2008). The test statistics Z is calculated as

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn\left(x_j - x_k\right) \tag{10}$$

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{p=1}^{g} t_p\left(t_p - 1\right)\left(2t_p + 5\right)}{18} \tag{11}$$

where sgn stands for signum function, n is the number of data points, g is the number of tied groups (a tied group is a set of sample data having the same value), and t_p is the number of data points in the pth group. The Z statistics which has a normal distribution is defined as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & S > 0 \\ 0, & S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, & S < 0 \end{cases} \tag{12}$$

Positive and negative values of Z are signals for upward (positive) and downward (negative) trends, respectively. To test whether the trend is downward or upward, and its significance, a two-tailed test is applied at a given significance level (Mondal and Daniel 2019).

4.2.3 Sen's slope estimator

Sen's slope estimator (Sen 1968) was applied to determine the magnitude of the trend in the precipitation data for the period considered. This is a nonparametric method that can calculate the change per unit time (direction and volume). Sen's method uses a linear

model to estimate the slope of the trend, and the variance of residuals should be constant in time (da Silva et al. 2015). In this procedure, firstly, the slope estimates were calculated as follows:

$$\beta_n = Median\left(\frac{x_i - x_j}{i-j}\right) \forall j < i, j = 1, \ldots, (n-1), i = 2, 3, \ldots, n \tag{13}$$

where x_i and x_j are annual precipitation values for years i and j, respectively, and n is the number of data points (Yue et al. 2002a, b). This method is powerful for estimating the magnitude of the trend. In the case of missing values or gaps in the data set, De Lima et al. (2005) noted that this estimator prevails as it is not affected by outliers or gross error.

4.3 Frequency analysis

Fitting a probability distribution function is useful for the statistical modelling, forecasting, risk management, etc. The best-fit probability distribution function can be determined by using a goodness-of-fit test. In this study, we used the Anderson–Darling test (Anderson and Darling 1952) as it gives more weight to the tails than does the Kolmogorov–Smirnov test. The test statistic is defined as follows:

$$A^2 = -n - S \tag{14}$$

where n is the sample size and

$$S = \sum_{i}^{n} \frac{2i-1}{n}\left[\ln F\left(Y_i\right) + \ln\left(1 - F\left(Y_{n+1-i}\right)\right)\right] \tag{15}$$

In Eq. (15), F is the cumulative function of the specified distribution and Y is the ordered data. The best-fit probability distributions of the standard duration maximum precipitation time series were checked.

Taking into account the dominance of the GEV distribution together with the extreme value theorem, we decided to apply the GEV probability distribution function to the maximum precipitation data at all standard durations for the entire study area. The GEV probability distribution function is given as follows:

$$GEV(x) = \exp\left\{-\left[1 + \xi((x-\mu)/\sigma)\right]^{-1/\xi}\right\} \tag{16}$$

on $\left\{x|1 + \frac{\xi(x-\mu)}{\sigma} > 0\right\}$, where $\mu \in [-\infty, +\infty]$, $\sigma \in (0, +\infty]$ and $\xi \in [-\infty, +\infty]$ refer to the location, scale, and shape parameters, respectively (Coles 2001).

Before the frequency analysis, we used a simple detrending technique introduced by Sherwood et al. (2007). It is formulated as follows:

$$P_i = \frac{P_i'}{1 + r(i)}\left(1 + r\left(Y_T\right) - 1\right) \tag{17}$$

where P is maximum precipitation adjusted to current conditions, i.e. detrended precipitation, P' is the trend-affected maximum precipitation, i denotes the sequence number,

Y_T is total number of years, and r is the annual trend rate expressed in decimal (not in percentage).

The standard model checks such as the quantile plots, probability plots, return level plots (Coles 2001) were also applied in this study to check the goodness-of-fit of the probability distribution function selected.

5 Results and discussion

5.1 General characteristics of maximum precipitation series

Since maximum values of extreme events may have significant importance in frequency analysis, outliers in the precipitation time series were detected first for further investigation. In this study, a value was considered an outlier if it is larger than the sum of the third quartile and the threefold of the interquartile range (Trenberth and Paolino 1980). Personal communication with meteorology experts who are responsible for the data observation and collection system at the Turkish State Meteorological Service revealed that we were not able to conclude whether the values determined in this study are indeed outliers or not;

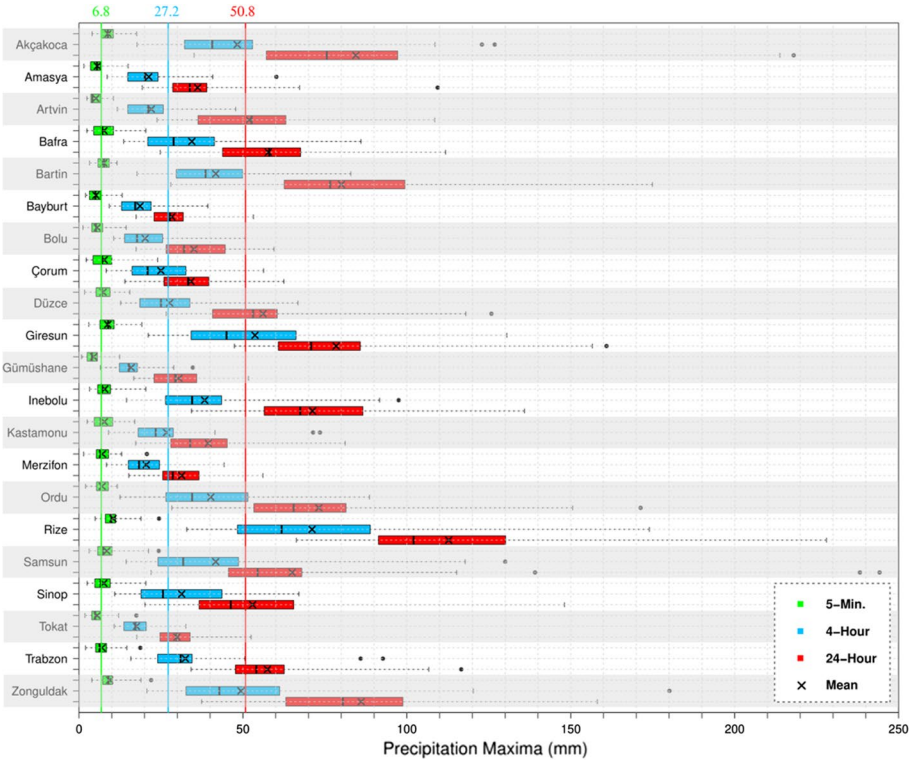


Fig. 2 Boxplots of maximum precipitation data. Vertical lines (green, blue and red) indicate regional medians of maximum precipitation for 5-min, 4-h and 24-h standard durations, respectively. The most extreme value (438.8 mm) in Zonguldak meteorological station was excluded from the graph for better visualization of the horizontal axis

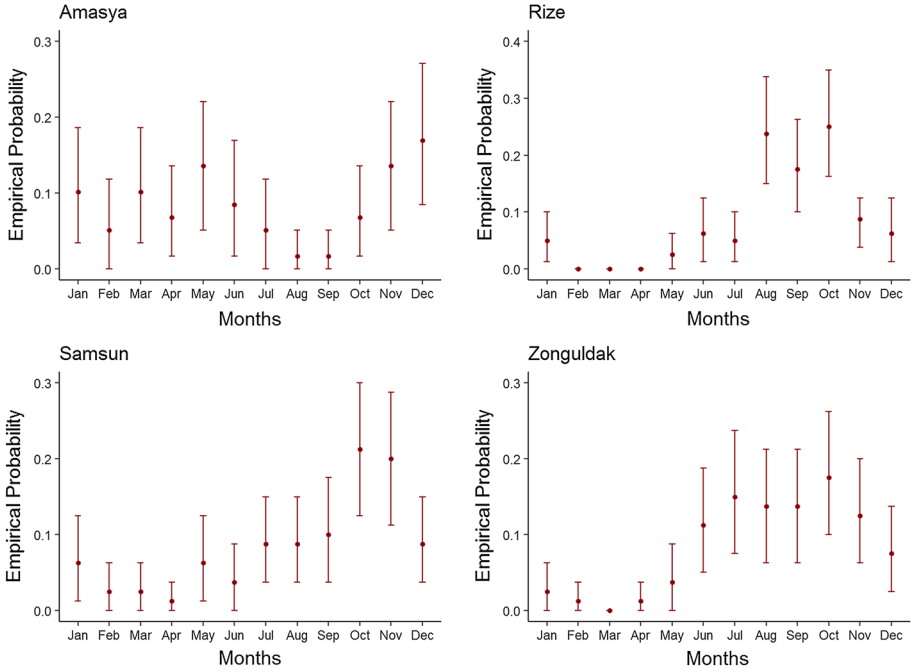


Fig. 3 Occurrence probability (dots) of the 24-h maximum precipitation in each month and the 95% confidence limits (vertical lines) for Amasya, Rize, Samsun and Zonguldak stations

therefore, we kept them in the time series for further analysis. Singular points located outside the whiskers of the boxplots of the 5-min, 4-h and 24-h standard duration maximum precipitations might be considered outliers, or be considered suspicious data in case they are not confirmed by the outlier test (Fig. 2). Maximum precipitation of 4-h and 24-h is significantly higher at stations close to the sea. This clarifies that the average and standard deviation of precipitation are greatly influenced by the proximity of the station to the sea. Stations in the inner part of the region such as Bolu, Kastamonu, Merzifon and Bayburt get remarkably lower precipitation for all standard durations. It can be concluded that mountains extending parallel to the sea, which is a distinctive feature of the region's geography, prevent the air moisture coming from the sea from moving into the inland part of the region; thus they reduce the effect of the sea on precipitation over the inner part of the region; i.e. air moisture coming from the sea cannot be added to the extreme precipitation generating system in the inland part of the region.

The empirical occurrence probability of maximum precipitation in each month was determined at 95% confidence level by using data from 1940 to 2019 (Fig. 3). Confidence level was estimated by the binomial distribution considering the non-normal distribution of occurrence times of maximum precipitation. For Amasya meteorological station, located in the inland part of the Central Black Sea region, maximum precipitation events mostly occur in the winter season (between November and May) while very few events occur in August and September. In Samsun meteorological station located at the coast in the Central Black Sea Region, a clear periodicity is observed with the highest probability in October and November. However, it is remarkable that May has the highest probability in spring.

Table 2 Homogeneity test classification of each station (1 = useful, 2 = doubtful, 3 = suspect)

Stations	Standard Durations													
	5-min	10-min	15-min	30-min	1-h	2-h	3-h	4-h	5-h	6-h	8-h	12-h	18-h	24-h
Akçakoca	1	1	1	1	1	2	2	2	1	1	1	1	1	2
Amasya	1	1	1	1	2	2	2	1	1	1	1	1	1	1
Artvin	1	1	1	1	1	1	1	1	1	1	1	1	2	2
Bafra	1	1	1	1	1	1	1	1	1	1	2	1	1	1
Bartın	1	1	1	1	1	3	3	3	3	3	3	3	3	2
Bayburt	1	2	2	2	2	1	1	1	1	1	1	1	1	1
Bolu	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Çorum	1	1	1	1	1	2	2	2	2	2	2	2	1	1
Düzce	1	1	1	1	2	1	1	1	1	1	1	1	1	1
Giresun	1	1	1	1	1	2	2	2	2	2	2	3	2	2
Gümüşhane	1	1	1	1	2	1	1	1	1	1	1	1	1	1
İnebolu	1	1	1	1	1	1	2	2	2	2	2	2	2	2
Kastamonu	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Merzifon	1	1	1	1	2	2	2	2	2	2	2	2	1	2
Ordu	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Rize	1	1	1	2	1	2	2	2	2	2	2	2	3	1
Samsun	1	1	2	2	2	2	1	1	1	1	1	1	1	1
Sinop	1	1	1	1	3	3	3	3	2	2	2	2	2	2
Tokat	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Trabzon	2	1	1	2	2	2	2	2	2	2	2	2	3	1
Zonguldak	2	1	1	1	1	1	1	1	1	1	1	1	1	1

On the other hand, Zonguldak meteorological station which is located at the proximity to the sea in the western part of the region receives most of the maximum precipitation from June to November. Meteorological stations close to the sea display similar characteristics as regards to the most probable time of occurrence of maximum precipitation over time. The second-highest occurrence probability of maximum precipitation in Rize, in the eastern part of the region, occurs in August. Floods, one of the important problems of the region, are expected to occur during months when the maximum precipitation is high. For this reason, months with a high probability of maximum precipitation should be considered the most critical periods in terms of flood practice in the eastern part of the Black Sea region.

5.2 Homogeneity

Results of the four absolute homogeneity tests conducted for the standard duration maximum precipitation data of the meteorological stations were examined and evaluated using the classification method proposed by Wijngaard et al. (2003) (Table 2). Number of the tests rejecting the homogeneity was counted each time. If either none or only one of the four tests rejected the homogeneity, the time series was classified as Class 1 (*useful*). If two tests rejected the homogeneity, it was classified as Class 2 (*doubtful*), and if three or four tests rejected the homogeneity, the time series was classified as Class 3 (*suspect*). Results of the homogeneity classification based on the test as applied by Wijngaard et al. (2003) were given for each standard duration maximum precipitation of all stations (Table 2).

As an example; for Corum meteorological station, the Pettitt test indicates that precipitation is non-homogeneous for seven standard durations while the VNRT shows that precipitation is non-homogeneous at all standard durations. A change point was detected by the Pettitt test in 1984 for seven standard durations. This is one year after the location of Corum meteorological station was changed in 1983 (Table 1). Homogeneity tests showed that any change in the location of the station is of great importance. In our case, the change in station location caused non-homogeneity in the data as soon as a year after the change. For Trabzon meteorological station in the east, all tests indicate the non-homogeneity of the 18-h precipitation while the Pettitt and VNRT tests show that precipitation of other standard durations could also exhibit a non-homogeneous structure. Looking at the test results for the 18-h standard duration, the SNHT, Pettitt and Buishand tests identify a change point in 1989 well before the location of this particular station has changed in 2005. The meteorology station in Samsun was shifted from its original location in 1973. The Pettitt test detected a change point in 1988 for four standard durations, while the SNHT identified a change point in 2011 for three standard durations. The VNRT found the non-homogeneity in nine standard durations without detecting a change point. Although the location of Artvin meteorological station has been changed in 1983, the SNRT showed the non-homogeneity in the time series of two standard durations (18 and 24 h) only, and the change point located in 2014 for both. The VNRT also shows the non-homogeneity for all standard durations without giving a change-point due to the nature of the test. Again the VNRT shows that Zonguldak meteorological station has non-homogeneous precipitation data for all standard durations. Finally, it should be emphasized that only the Pettitt test showed a change point in 1987 for the 5-min standard duration while other tests detected no change in the time series for this particular station although its location has been changed in 1950. When the whole region is considered, no clear relation was found between the date of the location change and the change point detected by the tests. Minor changes in the locations are not expected to have as much impact on precipitation as it does on temperature. Therefore, any non-homogeneity in the time series can be considered as a signal of change in the extreme precipitation characteristics rather than the effect of the change in the location of the meteorology station. Only four stations (Bolu, Kastamonu, Ordu and Tokat) have fully homogeneous maximum precipitation time series, whereas data of all other meteorology stations (17 out of 21) were found either "*suspect*" or "*doubtful*" in terms of homogeneity.

5.3 Trend analysis

The above-explained inhomogeneity can probably be associated with the trends in extreme precipitation. The maximum precipitation series of all standard durations at each weather station was subjected to autocorrelation analysis before being analyzed by the Mann–Kendall trend test. A statistically significant autocorrelation was detected in only five meteorological stations (Samsun, Bartin, Inebolu, Tokat, Bolu), and only 5% of the time series were found significantly autocorrelated ($\alpha = 0.05$) when all standard durations for all stations were counted.

The Mann–Kendall test results indicated no negative or downward trend in any standard duration of maximum precipitation time series at 5% significance level. All statistically significant trends in the time series were found positive, i.e. upward increase in time. Results for the 24-h maximum precipitation time series of Merzifon meteorological station are given in Fig. 4 as an example, and meteorological stations with a positive trend in at least one standard duration are listed in Table 3 and shown in Fig. 5. Meteorological

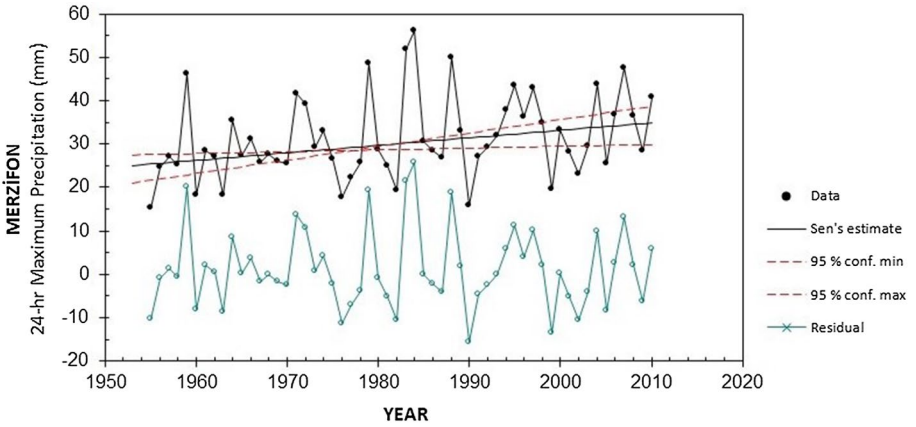


Fig. 4 Mann–Kendall trend test for the 24-h maximum precipitation series in Merzifon meteorological station

Table 3 Trends in maximum precipitation of standard durations

Stations	Standard durations with a positive trend of maximum precipitation series
Akçakoca	24-h
Bartin	2-h, 3-h, 4-h, 5-h, 6-h, 8-h, 12-h, 18-h, 24-h
Bayburt	15-min, 30-min, 1-h
Bolu	1-h
Corum	5-h, 6-h, 8-h, 12-h
Inebolu	2-h, 3-h, 4-h, 5-h, 6-h, 8-h, 12-h, 18-h, 24-h
Merzifon	1-h, 2-h, 3-h, 4-h, 5-h, 6-h, 8-h, 12-h, 18-h, 24-h
Rize	4-h, 5-h, 6-h, 8-h, 12-h, 18-h
Samsun	2-h, 4-h, 5-h, 6-h, 8-h
Sinop	2-h, 8-h,12-h, 18-h, 24-h
Trabzon	5-min, 15-min, 30-min, 1-h, 2-h, 3-h, 4-h, 5-h, 6-h

stations with trend-free data are located mainly in the central part of the study area between Amasya and Gumushane. In the eastern part of the study area, there are only two stations (Artvin and Gumushane) with trend-free data. The number of stations with trend-free data is three (Zonguldak, Kastamonu and Duzce) in the western part of the Black Sea region. Apart from the Mann–Kendall trend test, Sen's slope values were found to be positive for 90% of the stations with a maximum value of 0.66 mm per year and a minimum of -0.076 mm per year. Estimated Sen's slopes are listed in Table 4 for all standard durations of each station**.**

Balkanian cyclones encounter high mountain ranges of the Western Black Sea Region, and as a result of the orographic lifting mechanism, most of the precipitation occurs over the western parts. This general characteristic of maximum precipitation in the Black Sea Region displays itself as an increasing trend in maximum precipitation time series in the proximity of the coastal line, while no trend has been detected behind the range of mountains. The trend in the maximum precipitation data in the eastern part



Fig. 5 Meteorology stations having at least one positive (upward) trend in maximum precipitation series of 14 standard durations

of the Black Sea can be explained by similar reasoning as the western part; i.e. the mountain chain is effective in the trend existence in the proximity of the coast. Studies show that the sea surface temperature has been rising (Shaltout and Omsteld 2014), and this significantly contributes to the water vapour content of weather systems. Considering also that most of the maximum precipitation occurs by the systems formed over the Black Sea, increasing sea surface temperatures lead to an increase in water vapour content of the weather systems and interact with the high mountainous ranges.

Results in this study were found compatible with the outputs of Haktanir and Citakoglu (2014) who analysed only one standard duration maximum precipitation time series, the 24-h maximum precipitation, of meteorological stations located in the Black Sea Region. Haktanir and Citakoglu (2014) detected a positive trend in 15% of 26 stations. Here, we found a higher percentage of stations for which a positive trend is detected; i.e. 24% of stations has an increasing trend in the 24-h maximum precipitation data. It is important to emphasize that we investigated not only one but all of the available 14 standard durations in this study. Only five of the stations showed no trend in the 24-h precipitation, while an upward (positive) trend was detected in their precipitation data with a shorter standard duration. The main reason for the slight difference between this study and Haktanir and Citakoglu (2014) might be attributed to the longer data sets we used here, indicating the importance of the record length in the maximum precipitation analysis. In the present study, the data are up to 2015 in which several extreme events were recorded in both precipitation and temperature data between 2010 and 2015, a period not covered by Haktanir and Citakoglu (2014). The outputs show also that 52.4% of the stations have a positive trend in their maximum precipitation at least for one of the standard durations. Positive (upward) trends were detected in 1-h standard duration

Table 4 Sen's slope trend analysis results ($\alpha = 0.05$, Values of Sen's slope are in mm per year)

Station	Duration →	5-min	10-min	15-min	30-min	1-h	2-h	3-h	4-h	5-h	6-h	8-h	12-h	18-h	24-h
Akçakoca	Trend	No	No	No	No	No	No	No	No	No	No	No	No	No	**Up**
	Sen's slope	0	0.064	0.094	0.14	0.182	0.258	0.267	0.294	0.282	0.259	0.294	0.264	0.423	0.658
Amasya	Trend	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Sen's slope	0.025	0.037	0.005	0.044	0.063	0.083	0.081	0.086	0.092	0.071	0.048	0.044	0.074	0.078
Artvin	Trend	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Sen's slope	0.018	0	0.015	0.05	0.048	0.185	0.121	0.082	0.056	0.088	0.122	0.126	0.162	0.57
Bafta	Trend	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Sen's slope	0	0.025	0.038	0.103	0.137	0.132	0.09	0.123	0.111	0.093	0.033	0.033	0.096	0.068
Bartin	Trend	No	No	No	No	No	**Up**	**Up**	**Up**	**Up**	**Up**	**Up**	**Up**	**Up**	**Up**
	Sen's slope	0.013	0.006	0.022	0.075	0.189	0.325	0.381	0.444	0.545	0.578	0.663	0.753	0.86	0.654
Bayburt	Trend	No	No	**Up**	**Up**	**Up**	No	No	No	No	No	No	No	No	No
	Sen's slope	0.006	0.051	0.083	0.136	0.137	0.089	0.029	0.007	0.013	0.024	0.018	0.047	0.048	0.038
Bolu	Trend	No	No	No	No	**Up**	No	No	No	No	No	No	No	No	No
	Sen's slope	0.011	0.011	0.025	0.076	0.106	0.05	0.06	0.058	0.044	0.057	0.05	0.049	0.016	0.01
Corum	Trend	No	No	No	No	No	No	No	No	**Up**	**Up**	**Up**	**Up**	No	No
	Sen's slope	0	0.018	0.03	0.118	0.127	0.151	0.155	0.156	0.184	0.18	0.176	0.167	0.142	0.114
Duzce	Trend	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Sen's slope	0.053	0.076	0.054	0	0.01	0.038	0.055	0.082	0.1	0.067	0.1	0.092	0.117	0.109
Giresun	Trend	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Sen's slope	0.016	0.03	0.036	0.005	0.043	0.163	0.228	0.316	0.362	0.355	0.35	0.538	0.55	0.55
Gumushane	Trend	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Sen's slope	0.013	0	0.02	0.044	0.05	0.05	0.036	0.04	0.013	0.013	0.007	0	0.008	0.045
Inebolu	Trend	No	No	No	No	No	**Up**	**Up**	**Up**	**Up**	**Up**	**Up**	**Up**	**Up**	**Up**
	Sen's slope	0	0.008	0.011	0.088	0.106	0.187	0.21	0.276	0.314	0.358	0.397	0.447	0.556	0.614
Kastamonu	Trend	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Sen's slope	0.033	0.033	0.088	0.05	0.075	0.048	0.084	0.133	0.119	0.083	0.04	0.003	0.1	0.2

Table 4 (continued)

Station	Duration →	5-min	10-min	15-min	30-min	1-h	2-h	3-h	4-h	5-h	6-h	8-h	12-h	18-h	24-h
Merzifon	Trend	No	No	No	No	**Up**	**Up**	**Up**	**Up**	**Up**	**Up**	**Up**	**Up**	**Up**	**Up**
	Sen's slope	0.033	0.004	0.014	0.063	0.106	0.155	0.151	0.16	0.161	0.172	0.153	0.146	0.17	0.173
Ordu	Trend	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Sen's slope	0.013	0.002	0.031	0.07	0.086	0.078	0.075	0.077	0.123	0.115	0.136	0.085	0.009	0.041
Rize	Trend	No	No	No	No	No	No	No	**Up**	**Up**	**Up**	**Up**	**Up**	**Up**	No
	Sen's slope	0.029	0.046	0.052	0.116	0.145	0.2	0.272	0.34	0.39	0.435	0.437	0.473	0.514	0.278
Samsun	Trend	No	No	No	No	No	**Up**	No	**Up**	**Up**	**Up**	**Up**	No	No	No
	Sen's slope	0.045	0.055	0.055	0.1	0.192	0.21	0.225	0.246	0.246	0.262	0.266	0.191	0.153	0.087
Sinop	Trend	No	No	No	No	No	**Up**	No	No	No	No	**Up**	**Up**	**Up**	**Up**
	Sen's slope	0.043	0.047	0.027	0.1	0.154	0.233	0.2	0.216	0.221	0.25	0.3	0.294	0.392	0.442
Tokat	Trend	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Sen's slope	0.023	0.035	0.056	0.078	0.073	0.067	0.036	0.04	0.033	0.035	0.057	0.039	0.015	0.015
Trabzon	Trend	**Up**	No	**Up**	**Up**	**Up**	**Up**	**Up**	**Up**	**Up**	**Up**	No	No	No	No
	Sen's slope	0.05	0.035	0.077	0.125	0.148	0.162	0.178	0.196	0.231	0.23	0.197	0.164	0.133	0.118
Zonguldak	Trend	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Sen's slope	0.025	0.009	0.007	0.037	0.03	0.04	0.028	0.064	0.094	0.115	0.073	0.065	0.131	0.082

Bold indicates Significance level at 0.05

or longer at all meteorological stations except for two stations (Trabzon and Bayburt) in the east part of the region.

5.4 Frequency analysis

Statistically significant trend components in maximum precipitation series of standard durations were removed from the time series before the frequency analysis is applied for the identification of the best-fit probability distribution function. Frequency analysis was conducted on the maximum precipitation of the 5-min, 4-h and 24-h standard durations. The GEV probability distribution function was mostly found the best-fit probability distribution with a few exceptions only. This is in accordance with the hydrological extreme practice in which GEV has quite common use. In turn, parameters of the GEV probability distribution were estimated by the L-moments and given in Table 5. The quantile plot, probability plot, density plot and return level have shown how good the GEV probability distribution fits to the data (Fig. 6). In order to assure the stationarity in the parameters, a de-trending technique was applied to the data. Comparison of the original and de-trended intensity–duration–frequency (IDF) curves in Merzifon meteorological station for 10- and 100-year return periods shows that the de-trended estimates of the maximum precipitation are 10–33% higher than the original data with the trend component (Fig. 7). Results led

Table 5 Parameters of GEV probability distribution function for standard durations of 5-min, 4-h and 24-h

Station name	Standard durations								
	5-min			4-h			24-h		
	ξ	μ	σ	ξ	μ	σ	ξ	μ	σ
Akçakoca	−0.1517	2.4642	7.7531	0.2693	13.6180	35.5160	0.1993	22.5230	65.9840
Amasya	−0.0199	1.9604	4.5044	0.1109	6.0238	17.0580	0.1895	7.7577	29.9400
Artvin	0.0082	1.6055	4.1922	0.1677	5.9731	17.4240	−0.1106	17.2220	43.6640
Bafra	−0.0539	3.2344	5.9104	0.21469	10.8120	25.273	−0.1591	16.9120	50.3250
Bartin	−0.3608	2.2599	6.8458	0.0115	12.8160	34.1530	−0.0960	25.8820	67.3880
Bayburt	0.0489	1.8651	3.9689	0.0491	5.0190	15.4700	−0.0063	5.6274	25.0910
Bolu	0.0170	1.9288	4.4381	0.1335	5.4591	16.2180	0.00259	9.1153	29.7670
Corum	0.0431	2.9248	5.8666	0.06244	9.2799	19.016	−0.0164	9.6172	28.7450
Duzce	−0.1558	3.0289	5.9948	0.09133	8.608	21.85	0.1349	14.9530	45.2010
Giresun	−0.1628	3.1095	7.4179	0.17913	16.972	40.27	0.2072	16.0290	65.0890
Gumushane	0.1212	1.6607	3.2810	0.00535	4.2472	13.448	−0.0387	7.7004	26.3380
Inebolu	0.0897	2.2195	6.3497	0.1616	10.7570	30.0810	−0.0792	19.5130	61.3990
Kastamonu	0.0596	3.0967	5.7515	0.2394	8.0260	19.6070	0.1198	11.2390	31.4490
Merzifon	−0.0339	2.5704	5.7678	0.07775	5.7634	16.712	−0.0240	7.8210	26.9890
Ordu	−0.0339	2.5704	5.7678	0.09711	13.256	31.161	0.2406	16.9130	58.1710
Rize	0.0879	2.3726	8.7949	0.14505	20.1270	56.125	0.1090	22.6850	96.9360
Samsun	0.1658	2.7656	6.3494	0.29543	13.8090	28.1030	0.42923	12.713	48.4080
Sinop	0.0691	2.6542	5.8526	0.13506	10.978	23.2920	0.1455	16.6960	40.5430
Tokat	0.1542	1.7535	4.2392	−0.0197	3.9983	15.3070	0.08686	11.5580	49.729
Trabzon	0.0912	2.0476	5.6532	0.1769	7.9706	26.1690	0.0869	11.5580	49.7290
Zonguldak	0.0939	2.1721	7.8760	0.1982	14.4740	37.5600	0.2501	22.4360	70.8050

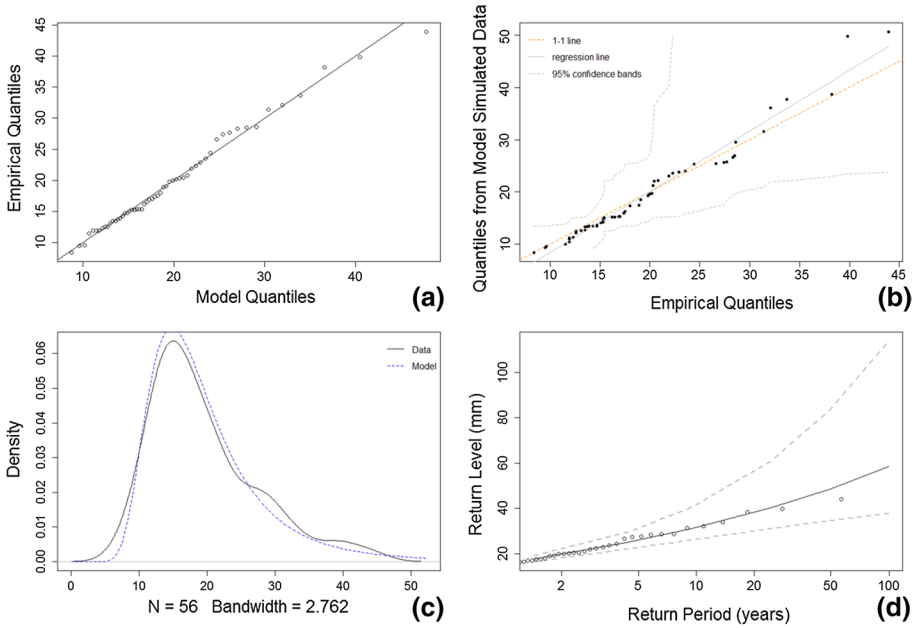


Fig. 6 Standard best-fit checks with **a** quantile plot, **b** probability plot, **c** density plot, and **d** return level for maximum precipitation series of 3-h duration in Merzifon station

us to conclude that if the non-stationarity in the meteorological data sets is not considered in the frequency analysis or estimation process, this may most probably cause a failure in hydraulic structures in the future due to the underestimation of the design precipitation.

6 Conclusions

The Black Sea region of Turkey has been exposed to serious floods with heavy rainfall in recent years; therefore, floods emerge as one of the most important problems of the region. Moreover, regional climate models show that precipitation in the Black Sea Region will increase in the future with the effect of climate change. Understanding the extreme precipitation characteristics of the region is important for flood risk management and water resources planning, as well as the design of water structures. The main objective of this study has therefore been the characterisation of maximum precipitation time series of the Black Sea region in terms of spatial and temporal behaviour.

Characterisation of 14 standard duration-maximum precipitation of the Black Sea region in Turkey in terms of spatial and temporal behaviour through several tests by using data from twenty-one meteorological stations provides the following conclusions:

1. Autocorrelation coefficients of maximum precipitation were found statistically significant for 5% of the time series analysed, which lead us to adopt more reliable trend estimation techniques.

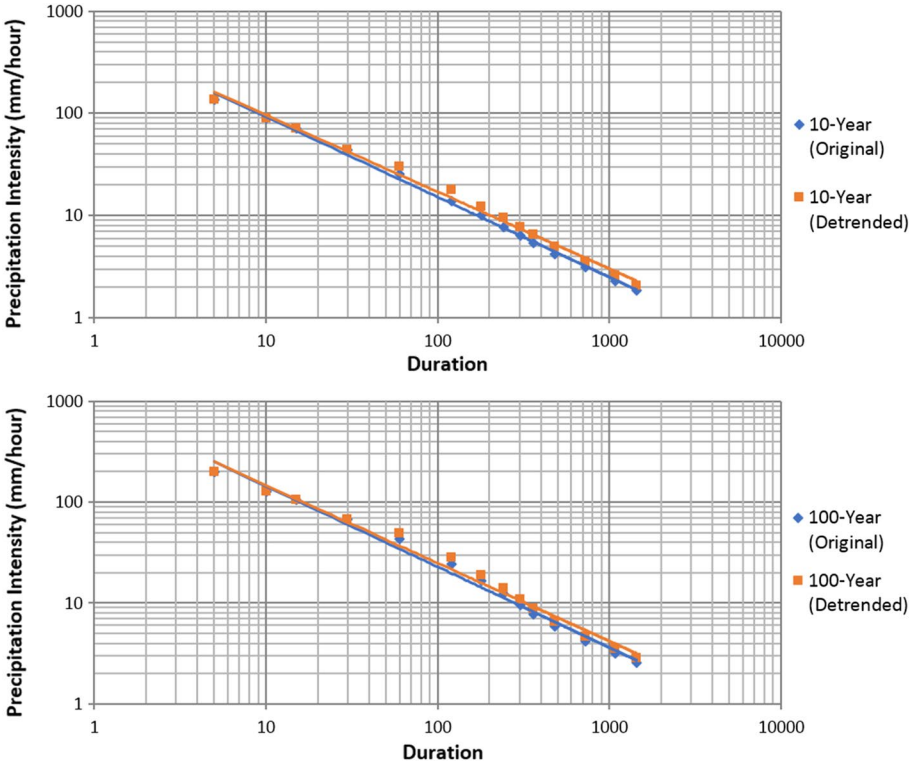


Fig. 7 Impact of de-trending process on the maximum precipitation intensity–duration–frequency (IDF) curves of Merzifon meteorological station

2. Meteorological stations in the proximity to the Black Sea have higher variability in the maximum precipitation and the variability increases in time.
3. Timing of annual maximum precipitation changes over the Black Sea Region; it occurs in winter over the stations in the inland part of the region, whereas it is seen in a period from June to November (summer and autumn) over the coastal stations. This indicates the spatio-temporal aspects of the maximum precipitation over the region.
4. Only four stations have fully homogeneous maximum precipitation while other meteorology stations were found either "*suspect*" or "*doubtful*" in terms of homogeneity.
5. Regional inhomogeneity can stem from climate change over the Mediterranean region. This was supported by the trend test which revealed that slightly more than half (52.4%) of meteorological stations were exposed to a positive trend in the maximum precipitation events of one standard duration at minimum.
6. A change in the location of any meteorological station does not necessarily create non-homogeneity in the maximum precipitation time series. In turn, change points in the data set could therefore be linked to the local characteristics of the meteorology station.
7. The Mann–Kendall test revealed upward trends in maximum precipitation. Trend component in the maximum precipitation is a source of the non-stationarity issue in the data. Meteorology stations with no significant trend are located mainly in the central

part of the Black Sea Region extending from Amasya in the central part of the region to Gumushane in the east.

8. Frequency analysis results led us to conclude that the best-fit probability distribution function is mainly the Generalized Extreme Value (GEV) for the Black Sea Region of Turkey.
9. Frequency analysis of maximum precipitation time series in Merzifon meteorological station showed that the design precipitation of the 100-year return period is underestimated if the non-stationarity is not taken into account. Consequently, it is important to take the nonstationary character of maximum precipitation into consideration over the Black Sea Region regarding its significant effect on return levels.

As a more general statement, we may conclude that severity of maximum precipitation has a tendency to increase with time over the Black Sea region. Results have been compatible with the observed data and climate modelling studies. Detected trends may be attributed to an increase in the sea surface temperature and change in the atmospheric circulation patterns as a result of radiative forcing that have been experienced all over the globe. Since the flood, a major problem of the region, is strongly linked to both duration and magnitude of maximum precipitation events, further studies on the issue seem crucial for taking steps for the flood prediction and protection.

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Authors' contributions All authors provided critical feedback and helped shape the research, analysis and manuscript. The authors confirm contribution to the paper as follows: HA, MC, HA contributed to study conception and design; SGY, IY, GK contributed to analysis and interpretation of results; HA and IY contributed to draft manuscript preparation. All authors reviewed the results and approved the final version of the manuscript.

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Availability of data and material The data that support the findings of this study are available from State Meteorology Office of Turkey upon official request.

Declarations

Conflict of interest The authors declare that there is no conflict of interest.

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