

Spatiotemporal variability of precipitation concentration in western Turkey

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Abstract This paper addressed the spatial and temporal variations of precipitation concentration across western Turkey, by analyzing daily and monthly precipitation time series recorded at 28 stations over the period 1966–2011. Four indices: daily precipitation concentration index (DPCI), monthly precipitation concentration index (MPCI), precipitation concentration degree (PCD) and precipitation concentration period (PCP) were used. The results showed higher values of DPCI in northwestern and southern parts and lower values in western-central, central, eastern and northeastern parts, and the southern part was the most critical part of the study area, with the highest values of DPCI, MPCI, PCD and annual total precipitation, but the lowest number of rainy days. MPCI and PCD values showed a seasonal precipitation regime over the whole study area and exhibited a pattern decreasing from southwest to northeast, which implies a more uniform distribution of monthly rainfall in a year toward the northeast. PCP values showed that annual precipitation mainly falls in December and January. Trend analysis demonstrated mostly non-significant decreasing trends for all indices, implying a very slight tendency toward a more regular precipitation distribution in a year and a slightly earlier occurrence of precipitation over western Turkey.

Keywords Precipitation concentration · Spatiotemporal variation · Trend analysis · Turkey

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1 Introduction

Global warming associated with the increase in greenhouse gases in the atmosphere is the most widespread and important environmental problem which the Earth is faced with today. Besides temperature, precipitation is also an important climatic variable which has been widely examined under the changing climate because it leads to opposite phenomena such as drought and flood (Coscarelli and Caloiero 2012). Precipitation patterns are expected to change spatially and temporally throughout the world due to an increase in the water-holding capacity of the air, which in turn results in an acceleration of the hydrological cycle and affects the spatiotemporal characteristics of precipitation (Fowler and Hennessy 1995; Mishra and Singh 2010).

Climate change can lead to changes not only in the total amount of precipitation but also in extreme precipitation events (Cubasch et al. 2013). Changes in the intensity, amount and pattern of precipitation would cause extreme events such as droughts and floods to occur more frequently (Li et al. 2011; Coscarelli and Caloiero 2012). These extreme events may have an influence on erosion, agriculture, water supply, storm water drainage, energy production, etc. (Caloiero 2014). Therefore, information on changing patterns of precipitation is important for the accurate assessment of water resources, drought and flood control, efficient water management and the understanding of climate change (Huang et al. 2013).

In order to understand and evaluate spatial and temporal variabilities of extreme precipitation events under changing climate, various methods such as frequency analysis of precipitation series and precipitation homogeneity indices can be used (Shi et al. 2014). Two types of precipitation concentration index have been widely used to quantify precipitation homogeneity in a year, based on either daily or monthly precipitation totals. For the quantification of daily precipitation homogeneity, Martin-Vide (2004) proposed a concentration index (abbreviated hereafter as DPCI which stands for daily precipitation concentration index) to assess the contribution of days with the greatest rainfall to the total amount. This index is a measure of irregularities in precipitation distribution in that a higher concentration index indicates a more heterogeneous precipitation distribution and a lower index indicates a more homogeneous distribution (Shi et al. 2013). The other index to evaluate monthly precipitation homogeneity in a year is the precipitation concentration index (abbreviated hereafter as MPCCI which stands for monthly precipitation concentration index) proposed originally by Oliver (1980) and modified by De Luis et al. (1997). This index allows the quantification of the relative distribution of the precipitation pattern and calculation of the seasonality of precipitation (Coscarelli and Caloiero 2012). In addition, Zhang and Qian (2003) proposed two indices to evaluate the concentration characteristics of precipitation: precipitation concentration degree (PCD) and precipitation concentration period (PCP). PCD depicts the degree to which total annual precipitation is distributed over 12 months, whereas PCP represents the period (month) in which total annual precipitation concentrates (Li et al. 2011).

Numerous studies have been conducted to explore the spatial and temporal characteristics of precipitation concentration using the indices DPCI, MPCCI, PCD or PCP on regional and subregional scales. Martin-Vide (2004) computed DPCI in peninsular Spain over the period 1951–1990 and analyzed its spatial variation, dividing the area into two regions: an eastern façade showing high concentration and the rest of the country showing more regular daily amounts. Coscarelli and Caloiero (2012) analyzed spatial and temporal variations of both DPCI and MPCCI in the Calabria region in southern Italy. They found that

the study area could be divided into two parts: the western side with the lowest values of DPCI and the eastern side with relatively higher values of DPCI. For precipitation seasonality throughout the year, they detected more marked seasonality on the eastern side. Coscarelli and Caloiero (2012) also detected no significant trend in DPCI at a majority of rainfall series, but decreasing trends in MPCCI at about half of series, meaning a tendency toward a more uniform distribution through the year. Cortesi et al. (2012) investigated spatiotemporal variability of DPCI across Europe based on 530 daily rainfall series over the period 1971–2010. They observed a northwest to southeast gradient on annual, winter, spring and autumn scales, but a north- to south-oriented gradient in summer. However, they detected no clear signal or spatial pattern of trends in DPCI on annual and seasonal scales. Razinei et al. (2014) analyzed precipitation homogeneity using MPCCI in Iran. They found a more regular distribution over the year in northern areas of Iran and a more concentrated distribution in the south. Cannarozzo et al. (2006) studied temporal variation of MPCCI in Sicily (Italy) and found mostly non-significant trends with exceptional decreasing trends at a few stations in the northern part. Vyshkvarokva and Voskresenskaya (2014) found that annual and seasonal DPCI values increased from northeast and northwest to the south of Ukraine, and that decreasing DPCI trends were dominant in all seasons over the country. De Luís et al. (2011) detected lower annual MPCCI values in the north and higher values in the south and along the Mediterranean coast in Spain, and also significant changes between two subperiods, 1945–1975 and 1976–2005.

In Turkey, Apaydin et al. (2006) detected a moderate precipitation seasonality in the southeastern part of Turkey. To the best of our knowledge, however, there has been no other comprehensive study of precipitation concentration changes, either spatially or temporally, in Turkey. Therefore, the objective of this paper was to investigate spatial and temporal patterns of daily precipitation concentration index (DPCI), monthly precipitation concentration index (MPCCI), precipitation concentration degree (PCD) and precipitation concentration period (PCP) in western Turkey using a high-quality daily and monthly precipitation data set. The results of this study may provide important valuable information on water management and environmental problems for western Turkey.

2 Materials and methods

2.1 Study area

The study area covers, completely or partially, 12 provinces in western Turkey and is about 120,000 km² in area (Fig. 1). It extends from the Marmara Sea in the north to the Mediterranean Sea in the south and from the Aegean Sea in the west to other provinces not included in the study in the east. The study area is mainly characterized by a Mediterranean climate, with hot and dry summers and mild and rainy winters. As in the greater part of Turkey, the spatial pattern of rainfall occurrence, amount and regimes in western Turkey is largely determined by physical factors, such as topography, proximity to large water bodies and elevation, and by atmospheric features such as the movement of air masses and regional circulation systems (Sönmez and Kömüscü 2011). Tropical and maritime polar air masses during the rainy season from October to April and a tropical air mass during the dry season from May to September are dominant (Cukur 2011). Deep valleys extending from west to east allow the frontal cyclones to enter the inner parts of the area toward the east, releasing abundant rainfall (Türkeş 1996).

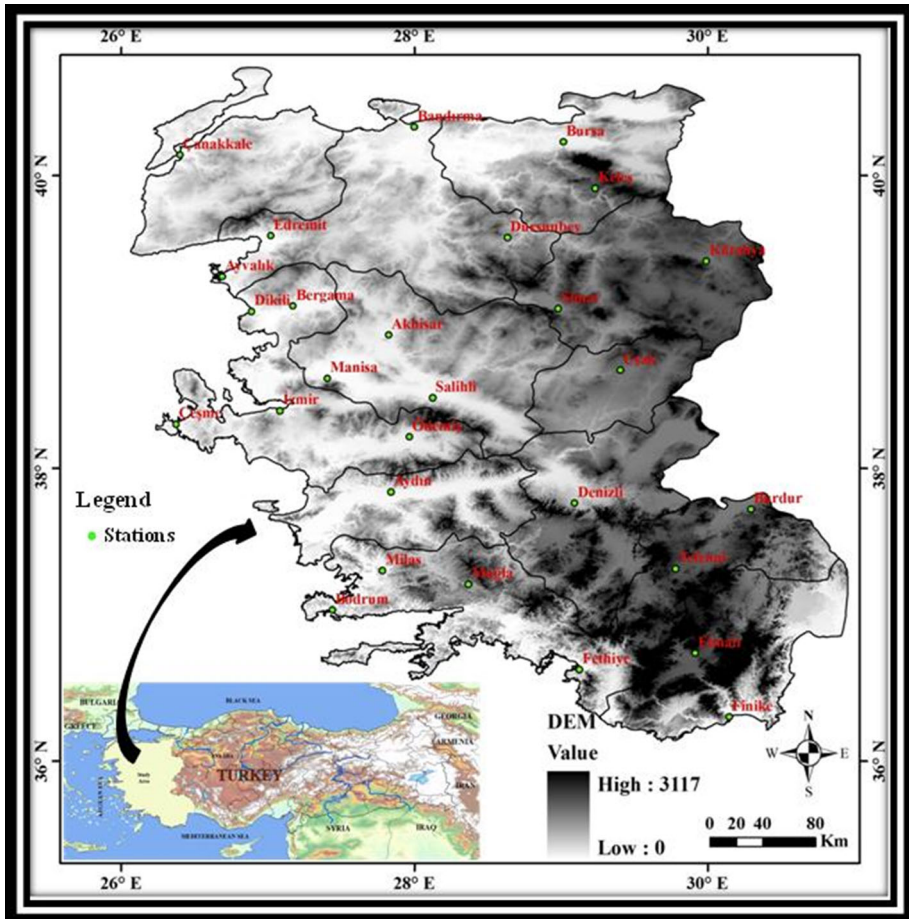


Fig. 1 Study area and locations of the stations

2.2 Data

The daily precipitation data of 28 weather stations located in western Turkey were provided by the State Meteorological Service of Turkey (MGM). The precipitation series cover the period from 1966 to 2011. Of the 28 stations, 25 stations had no days or 1 day of missing data, and the other three stations had 2, 3 and 7 days of missing data in which the missing dates were non-consecutive days. The missing precipitation values (all in the dry season) were filled by averaging the values of neighboring days (Li et al. 2011). The consistency of the data was checked by using the double-mass curve method (Zhang et al. 2012), and the results of the analysis showed that all of the data used were consistent. Detailed information on the stations and data sets is given in Table 1, and the geographical locations of all stations used in this study are presented in Fig. 1.

3 Methods

Four indices: daily precipitation concentration index (DPCI), monthly precipitation concentration index (MPCI), precipitation concentration degree (PCD) and precipitation concentration period (PCP) were used in this study to characterize the spatial and temporal variabilities of precipitation concentration.

The use of DPCI to assess the contribution of the days of highest rainfall to the total amount of rainfall is based on the fact that the distribution of precipitation frequencies follows a negative exponential distribution (Martin-Vide 2004; Li et al. 2011; Wang et al. 2013). In a given location within a data record period, the probability of large daily amounts of precipitation is lower than that of small daily amounts of precipitation (Wang et al. 2013). However, these very few large daily amounts may contribute a significant percentage of the total amount (Martin-Vide 2004; Wang et al. 2013). An exponential

Table 1 Basic characteristics of the stations: geographical coordinates; precipitation mean (*P*); and standard deviation (SD)

Station name	Station no.	Latitude (°N)	Longitude (°E)	Elevation (m.a.s.l.)	<i>P</i> (mm)	SD (mm)
Akhisar	17184	39.91	27.82	92	559.4	127.4
Aydın	17234	37.84	27.84	56	621.8	145.2
Ayvalık	17175	39.31	26.69	4	634.3	148.7
Bandırma	17114	40.33	28.00	63	713.6	149.3
Bergama	17742	39.11	27.17	53	650.2	166.6
Bodrum	17290	37.03	27.44	26	692.6	177.6
Burdur	17238	37.72	30.29	957	424.1	89.8
Bursa	17116	40.23	29.01	100	696.5	135.9
Çanakkale	17112	40.14	26.40	6	601.5	140.7
Çeşme	17221	38.30	26.37	5	562.5	145.7
Denizli	17237	37.76	29.09	425	557.8	115.8
Dikili	17180	39.07	26.89	3	587.7	150.0
Dursunbey	17700	39.58	28.63	637	559.9	91.2
Edremit	17145	39.59	27.02	21	684.4	171.1
Elmalı	17952	36.74	29.91	1095	487.1	125.1
Fethiye	17296	36.63	29.12	3	843.3	217.7
Finike	17375	36.30	30.15	2	967.0	300.1
İzmir	17220	38.39	27.08	29	686.4	182.7
Keleş	17695	39.92	29.23	1063	751.7	135.2
Kütahya	17155	39.42	29.99	969	552.1	96.8
Manisa	17186	38.62	27.40	71	715.8	168.6
Milas	17884	37.30	27.78	57	709.0	165.4
Muğla	17292	37.21	28.37	646	1154.9	277.9
Ödemiş	17822	38.22	27.96	111	576.6	122.1
Salihli	17792	38.48	28.12	111	488.4	85.5
Simav	17748	39.09	28.98	809	800.6	195.4
Tefenni	17892	37.32	29.78	1142	469.1	115.3
Uşak	17188	38.67	29.40	919	539.0	94.8

curve showing the relationship between the accumulated percentage of precipitation (Y) contributed by the accumulated percentages of days (X) during the occurrence of Y can be expressed as follows (Li et al. 2011; Coscarelli and Caloiero 2012):

$$Y = aX \exp(bX) \quad (1)$$

where a and b are constants. Equation (1) produces a polygonal line. Once these constants are predicted, then the precipitation concentration index can be calculated as:

$$\text{DPCI} = S/5000 \quad (2)$$

where S is the area enclosed by the bisector of the quadrant and the polygonal line (Wang et al. 2013). It can be calculated as follows:

$$S = 5000 - \int_0^{100} ax \exp(bx) dx \quad (3)$$

DPCI value is the fraction of S to the surface area of the lower triangle, and a greater DPCI value indicates that precipitation is more concentrated in a few rainy days during the year (Martin-Vide 2004; Li et al. 2011; Wang et al. 2013). In this study, DPCI values were computed not only for the entire period (1966–2011) for each station in order to reveal its spatial structure over western Turkey, but also for each year at each station, thus obtaining a time series, to analyze possible temporal characteristics.

Additionally, it was useful to analyze the homogeneity of the annual total precipitation among the months. This was accomplished by two methods. One was the modified version of Oliver's (1980) precipitation concentration index (MPCI), and the other was the precipitation concentration degree (PCD) proposed by Zhang and Qian (2003).

MPCI is calculated as:

$$\text{MPCI} = 100 \frac{\sum_{i=1}^{12} p_i^2}{\left(\sum_{i=1}^{12} p_i\right)^2} \quad (4)$$

where p_i is the amount of rainfall of the i th month. This index was calculated for each year at each station to detect the temporal variation of MPCI. Also, the long-term mean of this index was estimated by averaging over the study period (i.e., 1966–2011) in order to reveal its spatial distribution over the study area. MPCI values lower than 10 indicate a uniform rainfall distribution over the year, whereas values between 11 and 20 denote seasonality, and finally values greater than 20 indicate a strong irregularity throughout the year (Oliver 1980; Coscarelli and Caloiero 2012).

Zhang and Qian (2003) also proposed another index called precipitation concentration period (PCP). PCP represents the month in which total precipitation in a year concentrates (Li et al. 2011; Wang et al. 2013). The basic idea behind PCD and PCP is that the monthly total precipitation is a vectoral quantity having both magnitude and direction (Li et al. 2011; Wang et al. 2013). The magnitudes are the total precipitation of each month, and the directions are the angles assigned to each month in 30° increments, all of which comprise a circle (360°) for a year (Table 2). The procedure in this study to calculate PCP and PCD is as follows (Zhang and Qian 2003; Li et al. 2011):

$$R_i = \sum r_{ij} \quad (5)$$

Table 2 Angles assigned to each month in calculating PCP and PCD [adapted from Zhang and Qian (2003)]

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep
Degree	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°

$$R_{xi} = \sum r_{ij} \cdot \cos \theta_j \tag{6}$$

$$R_{yi} = \sum r_{ij} \cdot \sin \theta_j \tag{7}$$

$$PCP_i = \arctan(R_{xi}/R_{yi}) \tag{8}$$

$$PCD_i = \sqrt{R_{xi}^2 + R_{yi}^2}/R_i \tag{9}$$

where i is the year and j is the month in a year. θ_j is the angle assigned to the month j . For each station in the study area, PCD and PCP values were calculated for each year, and the time series obtained were assessed to depict their temporal changes over the period 1966–2011, and also yearly values of PCD and PCP were averaged over the years of the study period to obtain their long-term means. The spline interpolation method was used to obtain spatial distribution of indices over the study area.

The Mann–Kendall test was used to assess the significance of trends of the indices (Tabari and Hosseinzadeh Talaee 2013; Huang et al. 2013). This test was done with use of the Excel template MAKESENS (Salmi et al. 2002). In this test, the null hypothesis (H_0) states that the observations x_j are randomly distributed through time. However, the alternative hypothesis (H_1) is that there exists an upward or downward linear trend. The test statistic S is calculated using the following equation:

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

where x_j and x_k are the values in sequential years j and k , respectively, and

$$\text{sgn}(x_j - x_k) = \begin{cases} 1, & \text{if } x_j - x_k > 0 \\ 0, & \text{if } x_j - x_k = 0 \\ -1, & \text{if } x_j - x_k < 0 \end{cases} \tag{11}$$

If the number of observations in the series (n) is less than 10, the absolute value of S is compared with the theoretical distribution of S (Gilbert 1987). If n is equal to or more than 10, then the normal approximation test is used. To do so, the variance of S is first of all calculated using Eq. (12) taking the ties into account, if they exist,

$$\text{VAR}(S) = \frac{1}{18} \left[n(n-1)(2n+5) - \sum_{p=1}^q t_p(t_p-1)(2t_p+5) \right] \tag{12}$$

where q refers to the number of tied groups and t_p refers to the number of data in the p th group. Then, the test statistic Z is calculated using S and $\text{VAR}(S)$ as given below:

$$Z = \begin{cases} \frac{S - 1}{\sqrt{\text{VAR}(S)}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \frac{S + 1}{\sqrt{\text{VAR}(S)}}, & \text{if } S < 0 \end{cases} \quad (13)$$

The Z value is used to evaluate whether a statistically significant trend exists. If Z is positive, it indicates an increasing trend, while a negative value indicates a decreasing trend. At the α level of significance, if the absolute value of Z is greater than $Z_{1-\alpha/2}$, the null hypothesis is rejected, where $Z_{1-\alpha/2}$ is taken from tables of the standard normal cumulative distribution. In this study, the significance level of $\alpha = 0.05$ was used.

In order to apply the Mann–Kendall test, no significant serial correlation must exist in the time series (Yue et al. 2002; Yeşilırmak 2014). If there exists a significant serial correlation, a procedure known as trend-free prewhitening (TFPW) could be applied (Yue et al. 2002). In this procedure, according to Yue et al. (2002), the monotonic trend is first removed from the series; then, lag-1 serial correlation (r_1) is checked within the detrended series. If r_1 is not statistically significant, then trend analysis is applied to the original series. Otherwise, the serial correlation is removed and a prewhitened series is obtained. The removed trend is then added to the prewhitened series, and a new series is obtained. Trend analysis is applied to this new (TFPW-procedure-applied) series.

4 Results and discussion

4.1 Spatial variations of indices

DPCI values and the percentage of precipitation contributed by the 25 % rainiest days (P25) were estimated for each site covering all data over the period 1966–2011. The spatial distributions of DPCI and P25 over the study area are shown in Figs. 2 and 3, respectively.

DPCI values ranged from a minimum of 0.581 at Uşak (located in the central-east part of the study area) to a maximum of 0.657 at Finike (located in the southeastern part of the study area). On the other hand, P25 varied from 67.8 % (corresponding to the minimum value of DPCI at Uşak) to 75.2 % (corresponding to the maximum value of DPCI at Finike) with a variation of 7.4 %, which shows a considerably similar behavior between regular and concentrated rainfall areas in the study area. Among nearby countries, in Iran, DPCI values range from 0.59 to 0.73 and the highest values are found on the coasts of the Persian Gulf and Caspian Sea (Alijani et al. 2008). In Ukraine, the range between the highest and the lowest DPCIs is relatively narrow (from 0.64 to 0.58), and the highest values occur in the coastal regions of the Black Sea and the Sea of Azov (Vyshkvarkova and Voskresenskaya 2014).

In Fig. 2, it is clearly shown that higher values of DPCI were detected in northwestern and southern parts and lower values in western-central, central, eastern and northeastern parts. The spatial variation over the study area displayed two gradients: one increasing from the central part to the northwest and the other increasing from the central part to the south. However, the gradient from the central part to the south was stronger than the other one. The spatial variation also shows that the study area could be divided into three parts: the central part, which extends from the Aegean Sea coast in the west toward the east and northeast, assuming the lowest values (between 0.58 and 0.62) with exceptionally higher

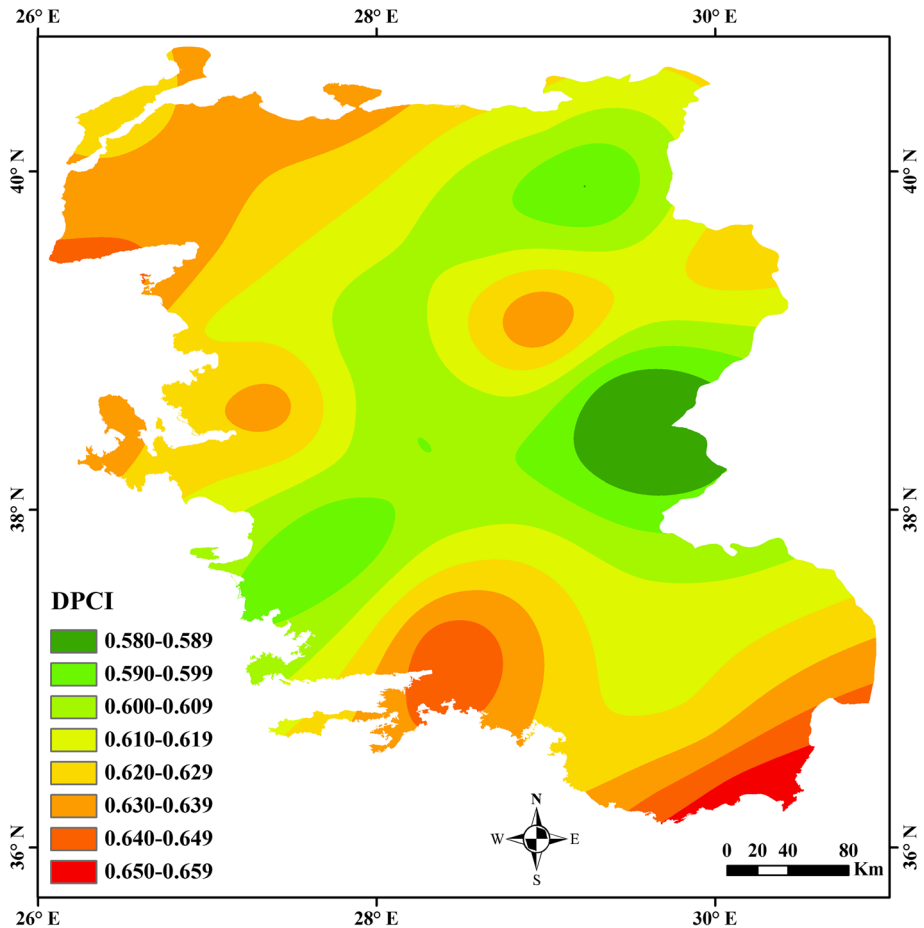


Fig. 2 Spatial distribution of DPCI in the study area

values at Kütahya and Simav; the northwestern part with relatively higher values in the range of 0.62–0.64; and finally the southern part with values of DPCI between 0.62 and 0.66. The central part is characterized as the area of most regular rainfall, whereas the southern part is characterized as the area of most concentrated rainfall.

The concentration of rain in a few rainy days is expected to be larger in places with low annual precipitation (Martin-Vide 2004). Similarly, Li et al. (2011) and Coscarelli and Caloiero (2012) reported that DPCI values were higher in places where annual precipitation and number of rainy days were lower in Xinjiang (China) and eastern Calabria (southern Italy). On the other hand, Martin-Vide (2004) found a non-significant negative correlation between DPCI and annual total precipitation but a significant negative correlation between DPCI and the annual number of rainy days in Spain. In this study, however, DPCI had a significant positive correlation with annual total precipitation ($r = 0.529, p < 0.01$), but a non-significant negative correlation with the annual number of rainy days ($r = -0.187$). Furthermore, the southern part where the highest values of DPCI occurred was the area with the highest values of P and the lowest values of N (Figs. 4, 5).

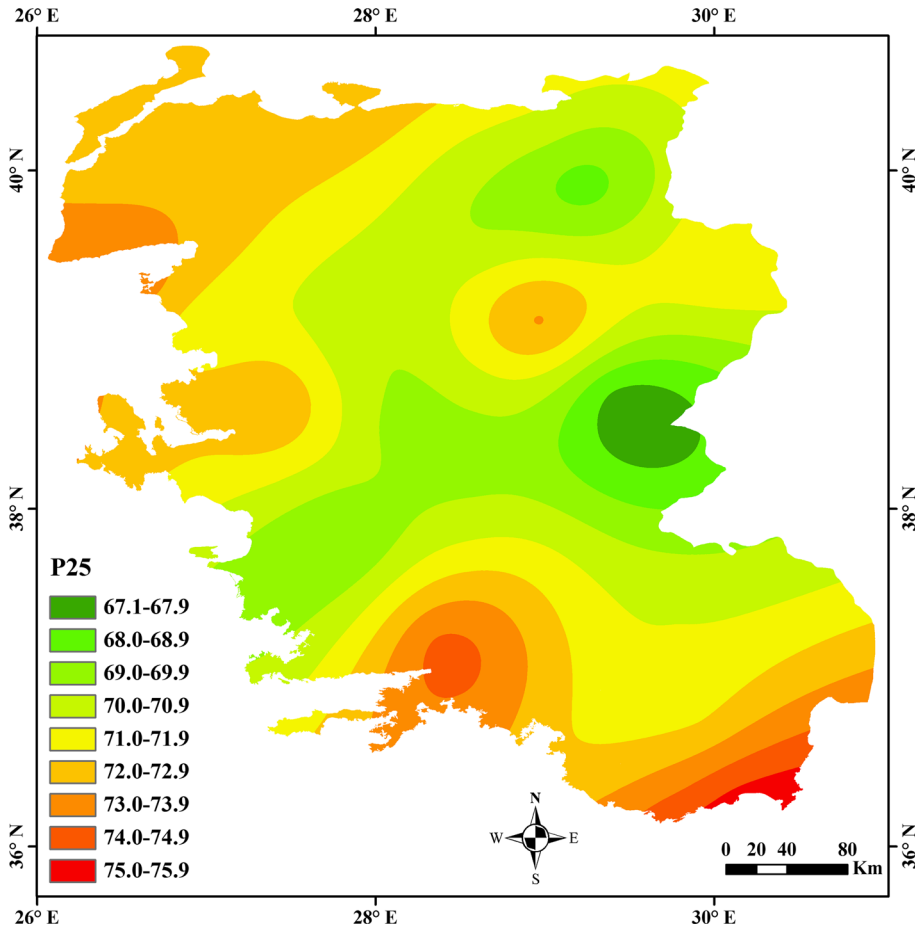


Fig. 3 Spatial distribution of P25 in the study area

Temporal distributions of precipitation throughout a year using monthly precipitation data were examined by MPCl and PCD which were calculated for each year and then averaged over the observation period for each site. Figures 6 and 7 illustrate the spatial distributions of MPCl and PCD, respectively, over the study area. MPCl values ranged from a minimum of 13.1 at Bursa and Kütahya to a maximum of 20.9 at Çeşme and Finike. There were 25 stations with a mean MPCl value of between 11 and 20, which denotes a seasonal precipitation regime, while three stations had a mean MPCl value slightly greater than 20, which corresponds to substantial monthly precipitation variability. Similarly, the lowest and the highest PCDs were detected at Kütahya and Finike with 0.31 and 0.66, respectively. In general, higher values of both MPCl and PCD (>18 and >0.55, respectively) were detected along the Aegean Sea and Mediterranean Sea coastline in the west and south, while lower values (<14 and <0.4, respectively) were found in inland parts in the east, hence exhibiting a gradient decreasing from the southwest toward the northeast. These results indicate that the annual precipitation concentration in several months in a

year decreases from the southwest to the northeast, implying a more uniform monthly precipitation distribution in a year toward the northeast.

Zhang and Qian (2003) reported that the length of the rainy season or the number of rainy days is inversely related to the PCD value. In this study, as shown in Fig. 5, the mean number of annual rainy days (N) assumed the lowest values (approximately 70 days) on the coastline in the south and west where the highest PCDs occurred, and increased toward the northeast, reaching about 120 days, where PCD took the lowest values. Besides, there was a strong negative correlation between N and PCD ($r = -0.766, p < 0.01$). This shows that annual precipitation occurs in a more limited number of days on the southern and western coasts, implying a higher probability of flood events than in other parts of the study area.

The precipitation concentration period (PCP) proposed by Zhang and Qian (2003) represents the month in a year in which total precipitation concentrates. The spatial distribution of PCP values is displayed in Fig. 8. Mean PCP ranged from a minimum of 74.3° at Bandırma to a maximum of 106.5° at Kütahya, which implies that annual precipitation mainly falls in December and January. A gradient increasing from the coastlines to inland

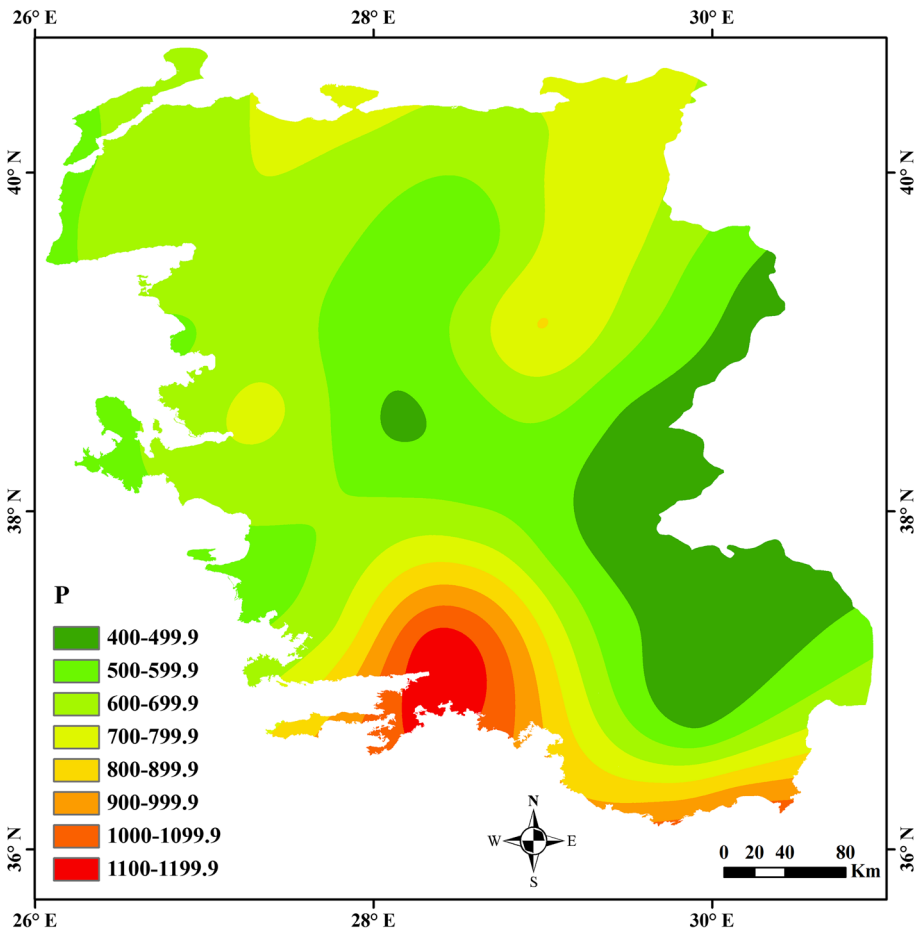


Fig. 4 Spatial distribution of P in the study area

observed from the spatial distribution of PCP values indicates that the rainy season arrives earlier on the coastlines than inland.

All the results given above show that the southern part is the most critical part of the study area, where the highest values of DPCI and annual total precipitation and the lowest numbers of rainy days are observed. Moreover, the southern part has the highest values of MPCD and PCD, indicating strong monthly precipitation irregularity. This part, which is bordered on the south and southwest by the Mediterranean Sea, is under the influence of frontal Mediterranean cyclones associated with southwesterly air flows in late autumn and early winter, and this creates favorable conditions for heavy precipitation and thunderstorms; also, orographic lifting affects precipitation intensity (Ceylan et al. 2007). These weather currents and topographic characteristics of the southern part (high mountains) seem to be the main causes of short and heavy precipitation and thereby of high DPCI and P25. Hence, this part is more prone to flood events in comparison with the rest of the study area, as also indicated by Kömüçü and Ceylan (2007).

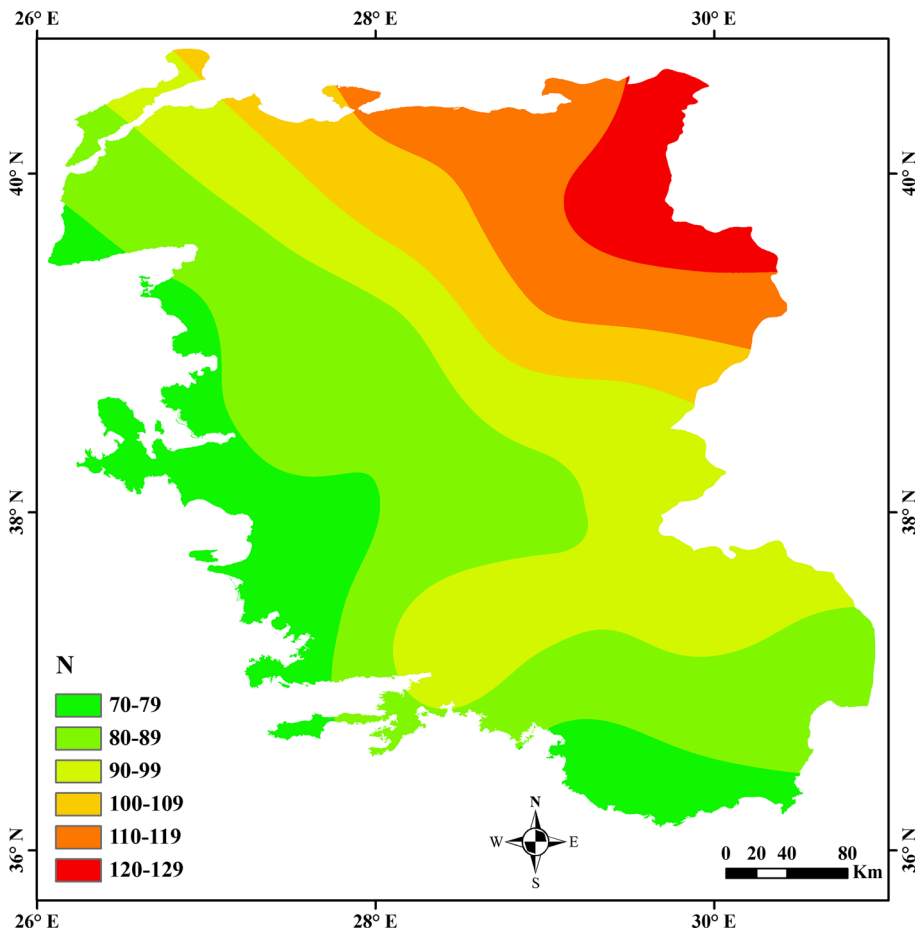


Fig. 5 Spatial distribution of N in the study area

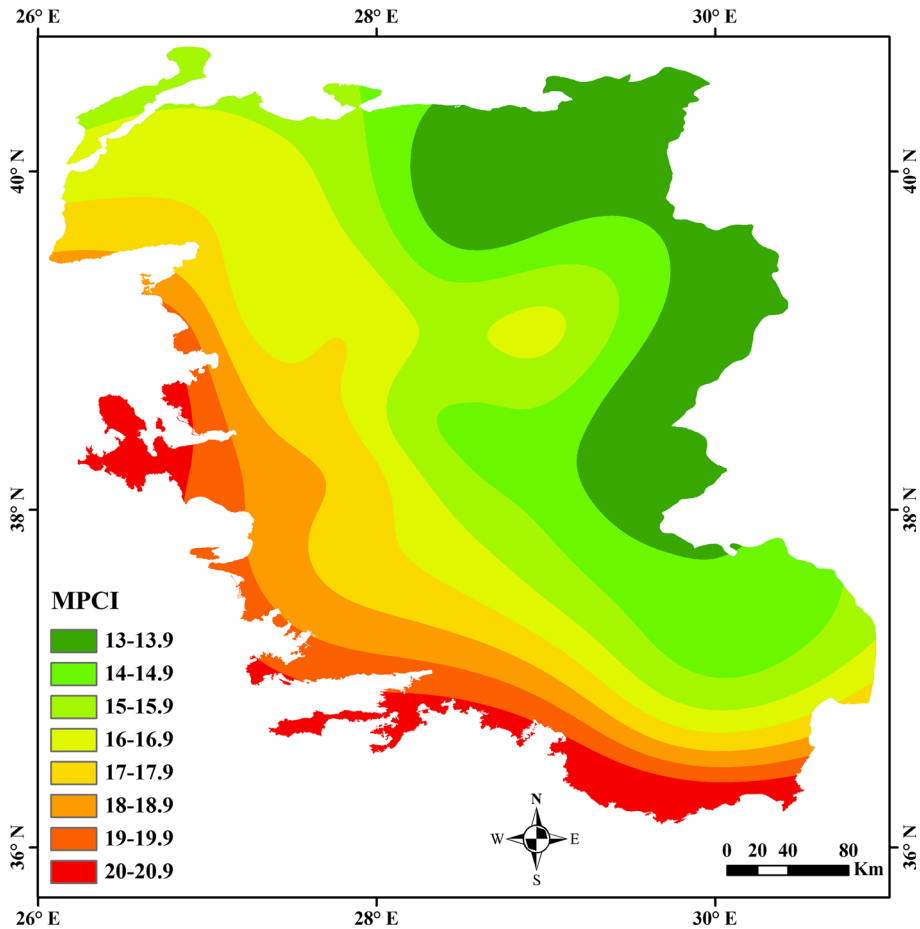


Fig. 6 Spatial distribution of MPCI in the study area

4.2 Temporal variations of indices

DPCI was calculated for each year, obtaining a time series at each station, and then, the possible trends were investigated using the Mann–Kendall test. Only one DPCI series (İzmir) required the TFPW procedure. Figure 9 shows the spatial distribution of trend directions across western Turkey. Figure 9 indicates that the number of stations with decreasing trends of DPCI was greater than that of those with increasing trends (16 vs. 12). Among the stations with decreasing trends, only four stations showed significant trends at 95 % level. These stations were Dikili, Keleş, Manisa and Simav, which are scattered over the central or northern parts of the study area. Similarly, non-significant trends of annual DPCI dominated over the study areas in the Calabria region of southern Italy (Coscarelli and Caloiero 2012), the Xinjiang region of Northwest China (Li et al. 2011), the Pearl River Basin of Southern China (Zhang et al. 2009), the Lancang River Basin of Southwestern China (Shi et al. 2013), Europe (Cortesi et al. 2012), the Jiangxi region of Southeast China (Huang et al. 2013), and the Hunan region of Central South China (Huang

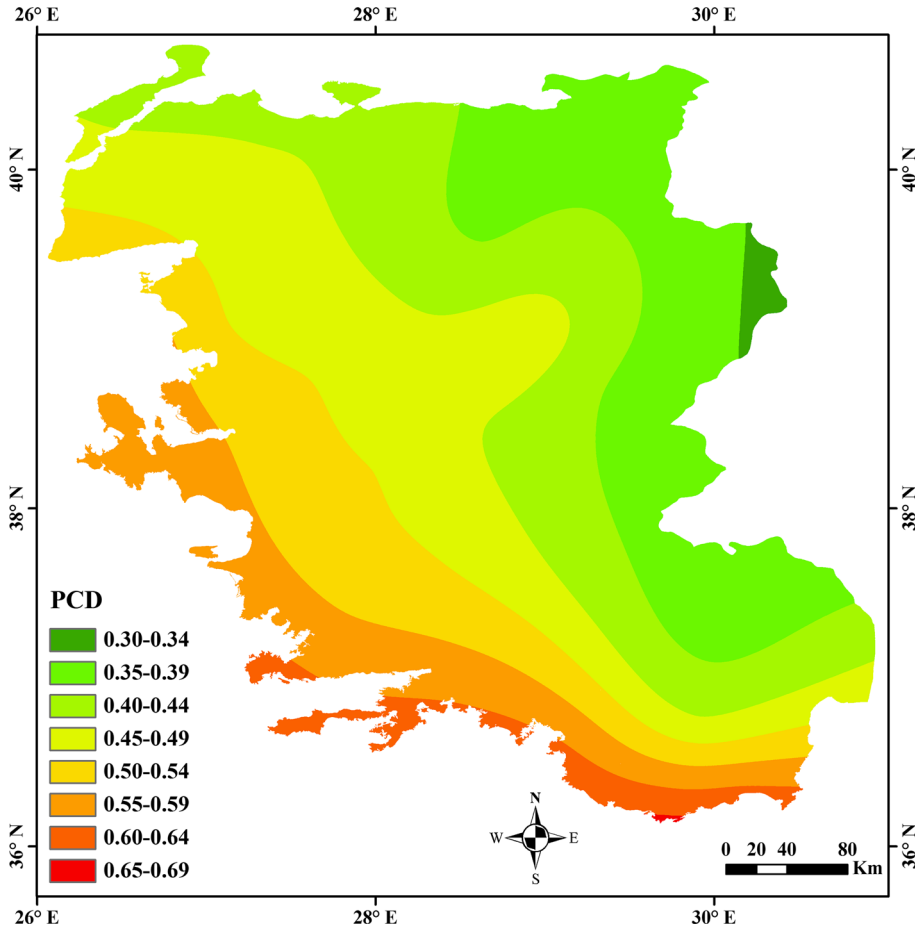


Fig. 7 Spatial distribution of PCD in the study area

et al. 2014). On the other hand, Caloiero (2014) detected non-significant trends for annual DPCI at approximately one-fourth of rain gauges in New Zealand.

The spatial distributions of trend directions of PCD and MPCPI over the study area are shown in Fig. 9. TFPW procedure was applied to the PCD series in Finike and Keleş and the MPCPI series in Finike. All sites except Dikili showed non-significant decreasing trends for PCD. Dikili had a significant decreasing trend at 95 % level. On the other hand, the number of sites with decreasing trends of MPCPI was greater than the number of those with an increasing trend (16 vs. 12), all of which were non-significant at 95 % level. These results indicate that, in general, there was no significant change in monthly total precipitation distribution in a year, and hence in flood risk, across western Turkey over the period 1966–2011.

When PCP trends were considered, 23 stations out of 28 showed decreasing trends, with only two sites (Bandırma and Finike) being significant at 95 % level. This indicates that the rainy season in western Turkey as a whole exhibited a very slight temporal change in a

decreasing direction over the period 1966–2011, implying a slightly earlier occurrence of precipitation.

The mostly non-significant decreasing trends found in this study for the indices DPCI, PCD and MPCPI are in good agreement with the results of a number of studies examining extreme precipitation indices in and around Turkey. For example, Zhang et al. (2005) analyzed the trends of various extreme precipitation indices such as the maximum 1-day precipitation amount, the annual number of days with precipitation greater than or equal to 10 mm and a simple daily intensity index (annual total precipitation divided by the number of wet days in a year) recorded at many stations in various Middle East countries (Armenia, Azerbaijan, Cyprus, Georgia, Iran, Iraq, Israel, Jordan, Oman, Saudi Arabia, Syria and Turkey) over the period 1950–2003. They found no significant trend in any of the precipitation indices. Another study is the one conducted by Kostopoulou and Jones (2005). They examined the trends of various extreme precipitation indices (e.g., simple daily intensity index, maximum 5-day precipitation total, 90th percentile of wet day amounts) for a number of stations located in 10 countries covering the European side of the

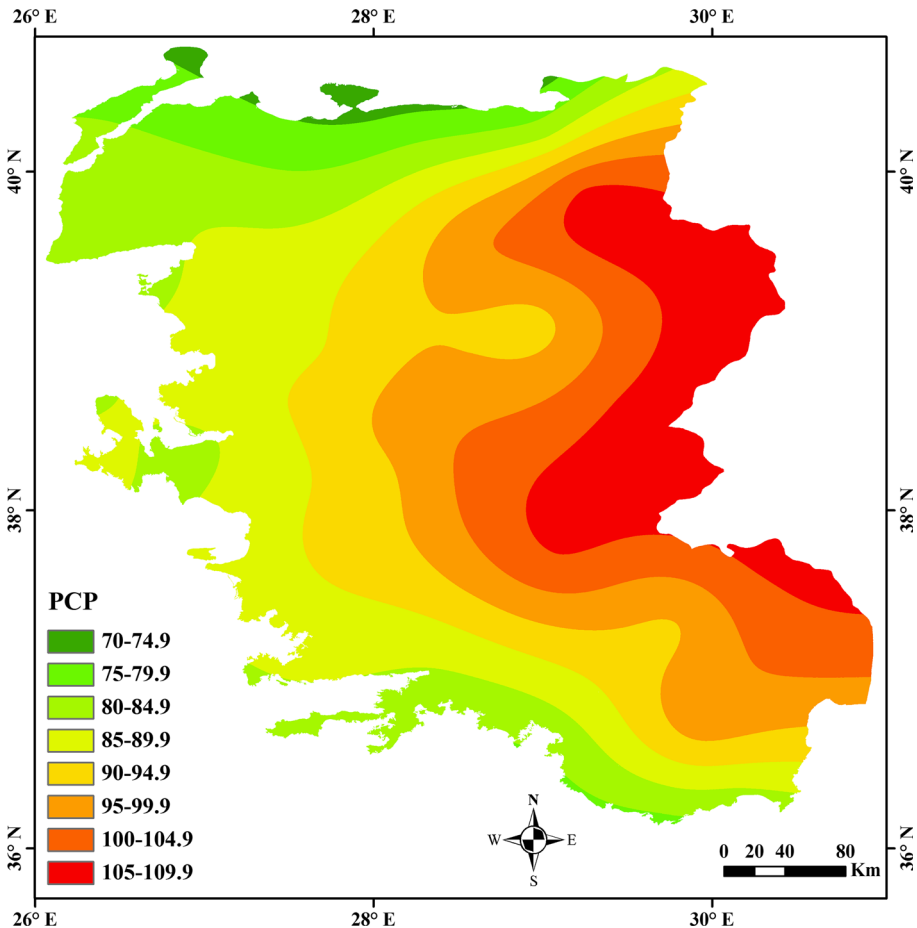


Fig. 8 Spatial distribution of PCP in the study area

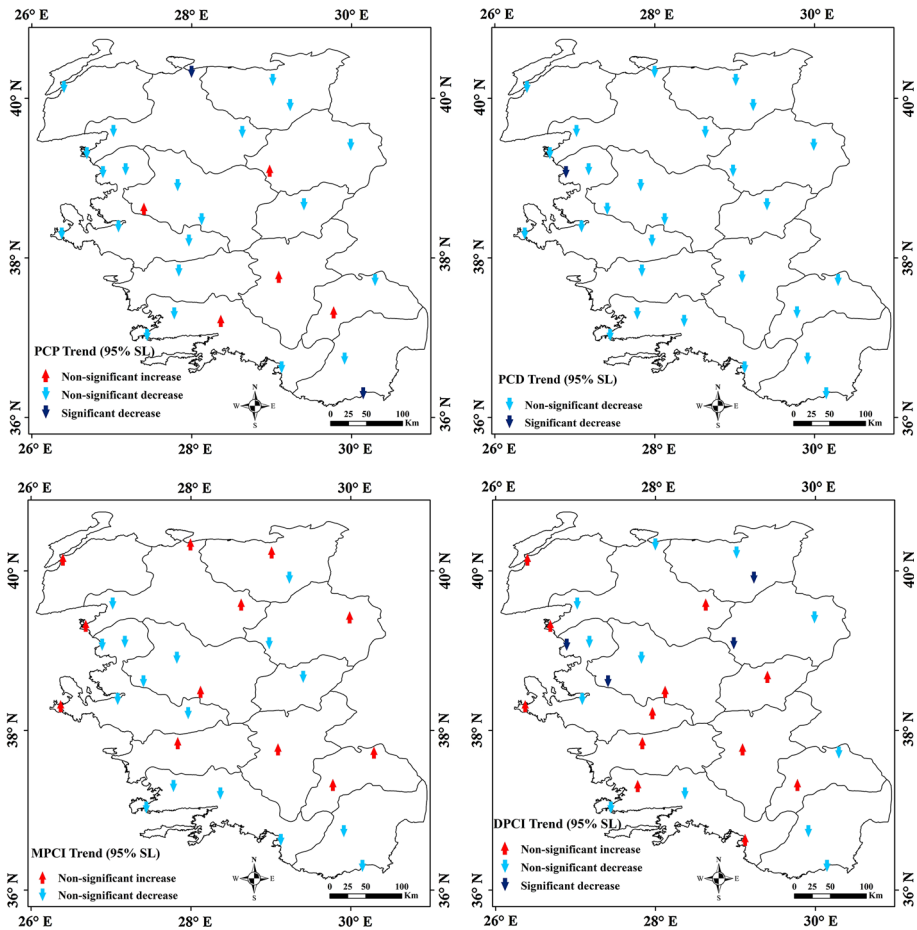


Fig. 9 Spatial distribution of the observed PCP, PCD, MPCI and DPCI trends over the study area

eastern Mediterranean Sea, which includes the Italian Peninsula, the Balkan Peninsula, western Turkey and Cyprus. They detected negative trends in all precipitation indices in the eastern half of the study area.

5 Conclusions

This study examined spatial and temporal changes of precipitation irregularity in a year using various indices with the use of daily and monthly precipitation totals for western Turkey. The main contribution of the results to present knowledge is twofold: (1) the long-term average pattern of precipitation irregularity in a year over the study area, which allows the characterization of the most flood-prone areas and (2) long-term trends which might contribute to a global database on how precipitation irregularity in a year has changed in recent decades under a changing climate.

The southern part of the study area is characterized as the most critical area, with the highest values of DPCI, P25, MPCI, PCD and P and with the lowest values of N, suggesting that this part is more prone to flooding events than the other parts of the study area. Therefore, sufficient measures should be taken for flood and drought control and for efficient water management in this part. A further study, preferably including seasonal values of indices, for other regions of Turkey or the whole of Turkey would make a substantial contribution to available research, providing a scientific basis for characterizing the flood-risk areas and for understanding how flood risk has changed.

The trend analysis showed that the study area is characterized by mostly non-significant decreasing trends for all indices, exhibiting a very slight tendency toward a more regular precipitation distribution throughout the year. This is in agreement with other studies conducted in Europe and China. Further research should investigate the physical mechanisms behind this variation considering global warming.

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References

- Alijani B, O'Brien J, Yarnal B (2008) Spatial analysis of precipitation intensity and concentration in Iran. *Theor Appl Climatol* 94:107–124
- Apaydin H, Erpul G, Bayramin İ, Gabriels D (2006) Evaluation of indices for characterizing the distribution and concentration of precipitation: a case for the region of Southeastern Anatolia Project, Turkey. *J Hydrol* 328:726–732
- Caloiero T (2014) Analysis of daily rainfall concentration in New Zealand. *Nat Hazards* 72:389–404
- Cannarozzo M, Noto LV, Viola F (2006) Spatial distribution of rainfall trends in Sicily (1921–2000). *Phys Chem Earth* 31:1201–1211
- Ceylan A, Alan İ, Uğurlu A (2007) Causes and effects of flood hazards in Turkey. *International Congress on River Basin Management*, pp 416–423, 22–24 March 2007, Antalya, Turkey
- Cortesi N, Gonzales-Hidalgo JC, Brunetti M, Martin-Vide J (2012) Daily precipitation concentration across Europe 1971–2010. *Nat Hazard Earth Syst* 12:2799–2810
- Coscarelli R, Caloiero T (2012) Analysis of daily and monthly rainfall concentration in Southern Italy (Calabria region). *J Hydrol* 416–417:145–156
- Cubasch U, Wuebbles D, Chen D, Facchini MC, Frame D, Mahowald N, Winther J-G (2013) Introduction. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge
- Cukur H (2011) Daily precipitation variations of selected meteorological stations in Turkey. *Procedia Social Behav Sci* 19:617–626
- De Luís M, González-Hidalgo JC, Raventós J, Sánchez JR, Cortina J (1997) Distribución espacial de la concentración y agresividad de la lluvia en el territorio de la Comunidad Valenciana. *Cuatrernario y Geomorfología* 11:33–44
- De Luís M, González-Hidalgo JC, Brunetti M, Longares LA (2011) Precipitation concentration changes in Spain 1946–2005. *Nat Hazard Earth Sys* 11:1259–1265
- Fowler AM, Hennessy KJ (1995) Potential impacts of global warming on the frequency and magnitude of heavy precipitation. *Nat Hazards* 11:283–303
- Gilbert RO (1987) *Statistical methods for environmental pollution monitoring*. Van Nostrand Reinhold Company, New York
- Huang J, Sun S, Zhang J (2013) Detection of trends in precipitation during 1960–2008 in Jiangxi province, southeast China. *Theor Appl Climatol* 114:237–251
- Huang J, Sun S, Xue Y, Zhang J (2014) Spatial and temporal variability of precipitation indices during 1961–2010 in Hunan Province, central south China. *Theor Appl Climatol* 118:581–595

- Kömüşçü AÜ, Ceylan A (2007) An evaluation of determining flood prone areas in Turkey based on maximum severe rainfall data. 5. National Hydrology Congress, pp 163–171, 5–7 September 2007, Ankara, Turkey (In Turkish)
- Kostopoulou E, Jones PD (2005) Assessment of climate extremes in the Eastern Mediterranean. *Meteorol Atmos Phys* 89:69–85. doi:[10.1007/s00703-005-0122-2](https://doi.org/10.1007/s00703-005-0122-2)
- Li X, Jiang F, Li L, Wang G (2011) Spatial and temporal variability of precipitation concentration index, concentration degree and concentration period in Xinjiang, China. *Int J Climatol* 31:1679–1693
- Martin-Vide J (2004) Spatial distribution of a daily precipitation concentration index in peninsular Spain. *Int J Climatol* 24:959–971
- Mishra AK, Singh VP (2010) Changes in extreme precipitation in Texas. *J Geophys Res* 115:D14106
- Oliver JE (1980) Monthly precipitation distribution: a comparative index. *Prof Geogr* 32:300–309
- Raziei T, Daryabari J, Bordi I, Pereira LS (2014) Spatial patterns and temporal trends of precipitation in Iran. *Theor Appl Climatol* 115:531–540
- Salmi T, Maata A, Antilla P, Ruoho-Airola T, Amnell T (2002) Detecting trends of annual values of atmospheric pollutants by the Mann–Kendall test and Sen’s slope estimates—the Excel template application Makesens. Finnish Meteorological Institute, Helsinki
- Shi W, Yu X, Liao W, Wang Y, Jia B (2013) Spatial and temporal variability of daily precipitation concentration in the Lancang River basin, China. *J Hydrol* 495:197–207
- Shi P, Qiao X, Chen X, Zhou M, Qu S, Ma X, Zhang Z (2014) Spatial distribution and temporal trends in daily and monthly precipitation concentration indices in the upper reaches of the Huai River, China. *Stoch Environ Res Risk Assess* 28:201–212
- Sönmez İ, Kömüşçü AÜ (2011) Reclassification of rainfall regions of Turkey by K-means methodology and their temporal variability in relation to North Atlantic Oscillation (NAO). *Theor Appl Climatol* 106:499–510
- Tabari H, Hosseinzadeh Talaei P (2013) Moisture index for Iran: spatial and temporal analyses. *Global Planet Change* 100:11–19
- Türkeş M (1996) Spatial and temporal analysis of annual rainfall variations in Turkey. *Int J Climatol* 16:1057–1076
- Vyshkvarikova E, Voskresenskaya E (2014) Precipitation inequality over Ukraine. *J Sci Res Rep* 3:384–396
- Wang W, Xing W, Yang T, Shao Q, Peng S, Yu Z, Yong B (2013) Characterizing the changing behaviours of precipitation concentration in the Yangtze River Basin, China. *Hydrol Process* 27:3375–3393
- Yeşilirmak E (2014) Soil temperature trends in Büyük Menderes Basin, Turkey. *Meteorol Appl* 21:859–866
- Yue S, Pilon P, Phinney B, Cavadias G (2002) The influence of autocorrelation on the ability to detect trend in hydrological series. *Hydrol Process* 16:1807–1829
- Zhang L, Qian Y (2003) Annual distribution features of precipitation in China and their interannual variations. *Acta Meteorol Sin* 17:146–163
- Zhang XB, Aguilar E, Sensoy S, Melkonyan H, Tagiyeva U, Ahmed N, Kotaladze N, Rahimzadeh F, Taghipour A, Hantosh TH, Albert P, Semawi M, Karam Ali M, Said Al-Shabibi MH, Al-Oulan Z, Zafari T, Al Dean Khelet I, Hamoud S, Sagir R, Demircan M, Eken M, Adiguzel M, Alexander LV, Peterson TC, Wallis T (2005) Trends in Middle East climate extreme indices from 1950 to 2003. *J Geophys Res* 110:D22104. doi:[10.1029/2005JD006181](https://doi.org/10.1029/2005JD006181)
- Zhang Q, Xu C-Y, Gemmer M, Chen YD, Liu C (2009) Changing properties of precipitation concentration in the Pearl River Basin, China. *Stoch Environ Res Risk Assess* 23:377–385
- Zhang Q, Zhou Y, Singh VP, Li J (2012) Scaling and clustering effects of extreme precipitation distributions. *J Hydrol* 454–455:187–194