Arabian Journal of Geosciences (2022) 15:1747
https://doi.org/10.1007/s12517-022-11021-5

ORIGINAL PAPER

Point and regional analysis of drought in Northern Iran

Yagob Dinpashoh[1] · Seyed Mostafa Biazar[1] · Vahid Rahmani[2]

Received: 17 September 2021 / Accepted: 19 November 2022

Abstract
Here, daily precipitation depths in the period 2000–2018 were used in the 13 weather stations located in northern Iran. Three meteorological drought-related characteristics including severity (S_d), magnitude (M_d), and duration (L_d) were evaluated. The data were converted to the monthly scale by summation of the daily records for a given month. Five distinct truncation levels (*TL*) were selected. The maximum values of S_d, M_d, and L_d were calculated for each of the stations. Then, using the annual scale, the observed S_d and M_d series were subjected to frequency analysis. Regional droughts were analyzed using the cumulative annual precipitation depths in the stations. In each year, the area faced with drought was measured. In a monthly scale, after choosing the mean monthly precipitation ($\overline{x}$) as a *TL*, the observed maximum value of L_d was less than 15 months. As the return period (*Tr*) increases, each of the drought characteristics increased as well. When the mean annual precipitation (MAP) was selected as a *TL*, the ratio of S_d in a 10-year to 2-year return period varied between 2.39 and 3.82, among stations. Similarly, in the case of M_d, this ratio varied in the stations between 1.88 and 3.75. Larger values of S_d and M_d were observed in western parts of the region. In the years 2008, 2010, and 2017, the study area experienced very severe regional droughts. The findings of this study may help decision-makers in better management of water in the region.

Keywords Drought magnitude · Northern Iran · Point drought · Regional drought · Severity

Introduction

Drought is a natural phenomenon that usually starts by a precipitation deficit and gradually propagates in time and space (Hisdal and Tallaksen 2003; Livada and Assimakopulos 2007; Chen et al. 2009). It is known as a creeping phenomenon that can be conceived in any climate (e.g. Karavatiz et al. 2011; Todisco et al. 2013; Vrochidou et al. 2013). In general, drought can be classified into the four distinct classes of (i) meteorological drought, (ii) agricultural drought, (iii) hydrological drought, and (iv) economic and social drought (Wilhite and Glantz 1985). Among the mentioned types of drought, the meteorological drought perceives earlier in time compared to the others. It was shown that 2010 to 2019 was the hottest decade since record keeping began 140 years ago (https://www.nationalgeographic.com/science/2019/12). This report also revealed that 2019 was the second hottest year ever recorded. This report point to greenhouse gas emissions as the main source of global warming.

Numerous historical drought events were reported by investigators in literature. In October 2011, nearly 90% of the USA experienced severe drought (Mishra and Singh 2011). In the past few decades, the biggest drought in Europe affected people (Spinoni et al. 2015; Mishra and Singh 2011). In Asia, approximately 60 million people were affected by a prolonged severe drought that happened during 1999–2000 (Mishra and Singh 2011). According to the report of Berito et al. (2018), the most severe and prolonged drought occurred in the period 2011–2016 in the northeast of Brazil.

Many studies conducted on meteorological droughts in different regions over the globe. In a comprehensive study carried out by Santos (1983) in Portugal, the quantitative definitions of point and regional droughts were presented. Dracup et al. (1980) defined the four distinct issues which are required for the definition of drought. These items are (i) the nature of water, (ii) the basic time unit of the data, (iii) the truncation level (TL), and (iv) the selection of a

Responsible Editor: Amjad Kallel

✉ Yagob Dinpashoh
dinpashoh@yahoo.com

1 Department of Water Engineering, Faculty of Agriculture, University of Tabriz, Tabriz, Iran

2 Department of Biological and Agricultural Engineering, Kansas State University, Manhattan, KS 66503, USA

regionalization or standardization method. The latter is needed in regional drought studies with different areas. Such a standardization is useful and can be accomplished by calculating the ratio of the area confronted with drought to the whole area of the region. It is well known that each of the four drought classes needs different types of data. For example, in meteorological drought, the used data are typically cumulative precipitation depth in a certain time scale. The work of Eltahir (1992) in Sudan is a typical example of a meteorological drought. In hydrological droughts, the water table level in different observation wells may be used. Another type of data such as the stream flow records may be selected and used in hydrologic droughts (Sen 1980; Kendall and Dracup 1992).

In meteorological drought analysis, there is a need for the selection of a proper TL. It is needed for distinguishing the dry spells from the wet spells. In this regard, Griffiths (1990) selected the median of rainfall records as a TL in New Zealand. Dracup et al. (1980) suggest that there are two choices for TLs which are mean and median of the used data. They preferred the mean to the median due to the fact that the mean is highly sensitive to the extreme values. Eltahir (1992) used 0.6 times the mean to 1.0 times the mean in his study as the TLs, subjectively.

In Iran, occurrences of consecutive severe droughts in the past were reported by investigators (Raziei et al. 2009; Amirataee et al. 2018; Ekhtiari and Dinpashoh 2019; Bazrafshan et al. 2015). The works of Ghorbani-Aghdam et al. (2013), Amirataee et al. (2018) in the Urmia Lake basin, and Abolverdi and Khalili (2010) in the Tashk-Bakhteghan-Maharlo basin are noticeable in drought-related studies. Sayari et al. (2013) studied the effect of climate change on drought in the Kashafrood basin, located in NE of Iran. In a recently published paper, daily rainfalls of three stations having different climates were used for drought analysis (Ekhtiari and Dinpashoh 2019).

Based on our best knowledge, the previous drought studies in Iran were not used both the point and regional drought analysis, simultaneously. Moreover, the study area selected for the present work, i.e., Northern Iran, is not yet considered in the past studies. The coastal humid region in Northern Iran produces the main portion of cereal (rice, wheat, barley) of the country. Therefore, conducting this study by using the most recent data seems to be necessary. The two main objectives of this study are (i) identification of point drought characteristics (severity, magnitude, duration) in the selected stations in northern Iran using the monthly precipitation assuming five distinct TL values and (ii) quantification of regional drought using the annual precipitation records. The latter one is accomplished by taking a fixed proportion of MAP as TL. The propagation of meteorological drought in the region is studied.

Materials and methods

Study area

The area under study comprises the three adjacent provinces, namely Guilan, Mazandaran, and Golestan located in the coastal area of the Caspian Sea in Northern Iran. This area covers mainly by forest trees in hills and many plains mainly cultivated by rice and other cereals. The shape of the region is a narrow strip lying from west to east. The Caspian Sea is located in the north of the region. The coordinates of this region lie approximately between 36° 30′ to 38° 30′ N latitudes and 48° 00′ to 56° 00′ E longitudes (Fig. 1). Province of Guilan is located in the western part of the study area. The climate of this province is humid with hot summers and mild winters (Dinpashoh et al. 2019). Mazandaran province is located in the middle of the study area. Its climate is similar to Guilan. Rice (*Oriza sativa*) is the main crop cultivated by agriculturalists mainly in these two provinces. The eastern province namely Golestan is semi-humid with hot summers. It is known that the MAP of the region is decreased from west to east. All the rivers in the region originated from the summits of Alborz chain mountains lied from west to east. All of them discharge water into the Caspian Sea. The mentioned mountains act as a barrier to prevent vapor movement from the region. The main source of rain in the region is the Caspian Sea vapors. The north and south of the Alborz Mountains had different climates. The mean annual relative humidity (RH) in the north of the mentioned mountains is considerably more than in the southern parts. The maximum value for MAP reported to be more than 1800 mm that belonged to a station namely Anzali located in Guilan province (Dinpashoh et al. 2004). In this study, thirteen stations were selected from different parts of the three mentioned provinces (Fig. 1). Table 1 shows the geographical information of the selected stations.

The used data was acquired from the two sources: (i) Rasht Weather Office (located in Guilan province) and (ii) the Iran Water Resources Management Office (located in Tehran). The used data are originally in a daily scale. However, they converted to monthly and yearly time scale later as needed. The homogeneity of data is controlled by the run test (Peel et al. 2004) method. This test verified the annual precipitation depth series. The outliers were controlled by visual inspection of the time-series plots. This approach is simple and fast in the detection of high outliers. Furthermore, by this practice, it was assured for non-negative values of precipitation in addition to the appearance of very large values (say daily mean plus k times of standard deviation). In this regard, k is assumed to be 5 here. When the high outlier appears, the rainfall of a nearby station is inspected. If such a high rain on the same day is experienced in the nearby station, then such a high value is assumed to be true. Otherwise, it is substituted by the corresponding mean rain value on that day.

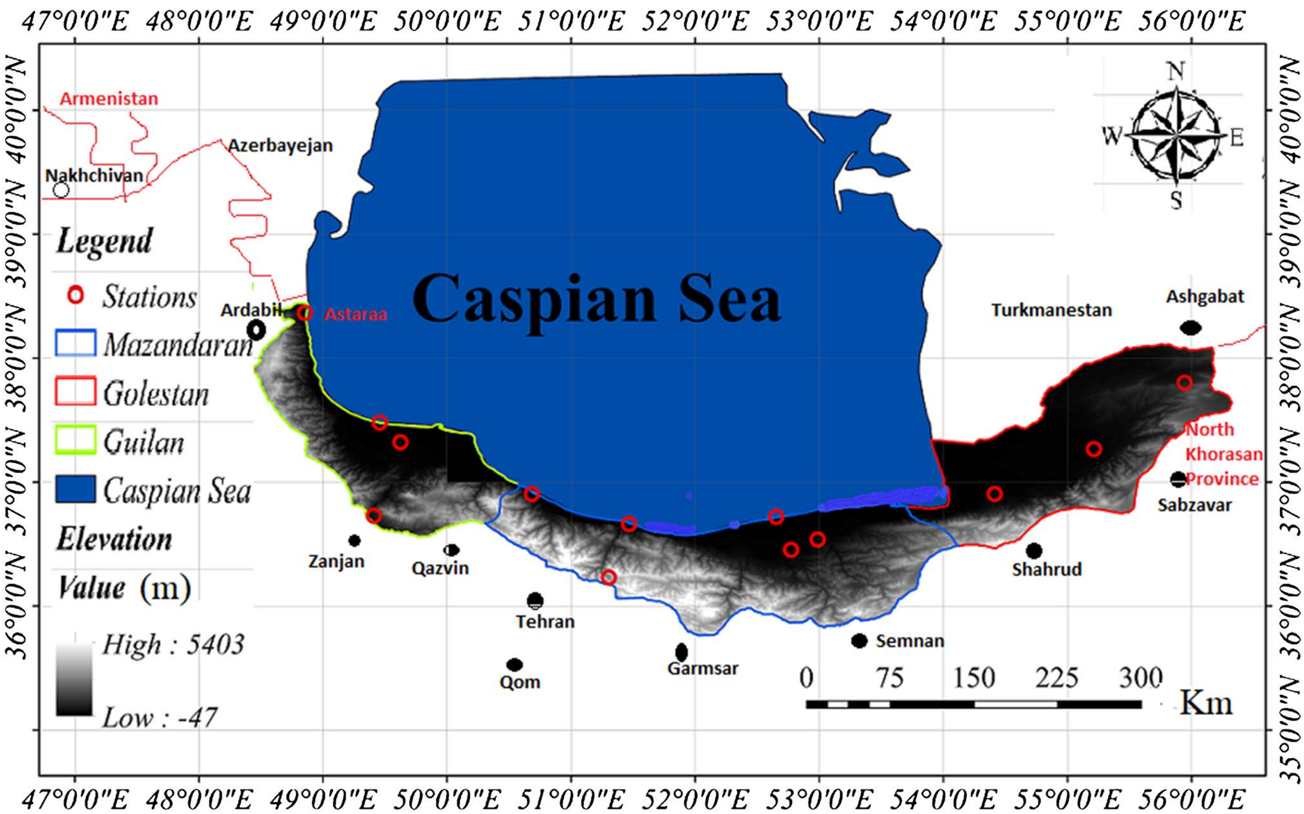

Fig. 1 Location of the study area and the selected stations

Table 1 Geographic information of the selected stations based on time period (2000–2018) in the study area

Station	Lat	Long	MAP (mm)	SD (mm)
Anzali	37° 48′	49° 46′	1705	342
Astara	38° 37′	48° 85′	1186	180
Manjil	36° 73′	49° 41′	192	44
Rasht	37° 32′	49° 62′	1185	212
Gondab-E-Kavous	37° 27′	55° 21′	405	80
Gorgan	36° 91′	54° 41′	431	99
Maravetappeh	37° 80′	55° 94′	295	64
Babolsar	36° 72′	52° 65′	821	160
Gharakil	36° 45′	52° 77′	601	139
Nowshahr	36° 66′	51° 47′	1163	234
Ramsar	36° 90′	50° 68′	1108	248
Sari	36° 54′	52° 99′	669	148
Siahbishe	36° 23′	51° 30′	498	91

MAP is the mean annual precipitation in mm, and SD is the standard deviation of annual precipitation time series in mm

Drought analyses

Drought is one of the natural disasters in Iran which affected many people compared to others. In 2000, about 37 million people were affected by drought in Iran. This fact can be considered a good reason for the conduction of this analysis.

Point drought

Drought is defined here as a time period of consecutive months in which the amount of monthly precipitation is less than the predefined TLs. In this study, the five distinct TLs were subjectively used for meteorological drought analysis at each of the selected stations. These TLs are as follows: (i) long-term mean monthly precipitation ($\overline{x}$) in every month, (ii) 0.9$\overline{x}$, (iii) 0.8$\overline{x}$, (iv) 0.7$\overline{x}$, and (v) 0.6$\overline{x}$. Drought severity for a distinct dry spell with the length of L_{d} in months is defined to be the sum of the absolute values of deviations of monthly precipitation from the assumed TL as follows:

$$S_d = \left\{ \begin{array}{ll} \sum_{i=1}^{L_d} \left| \left(x_i - c\overline{x}_i\right) \right| . \text{ if } x_i < \left(c\overline{x}_i\right). & \text{for } c \text{ from } 0.6 \text{ } to \text{ } 1 \text{ } (0.1) \\ 0. & \text{otherwise} \end{array} \right\} \tag{1}$$

where S_d is the severity of drought in mm during a given dry spell, $\overline{x}$ is the long-term mean of the monthly precipitation mm, x_i is observed precipitation in the i$^{\text{th}}$ month in a certain dry spell mm, $\overline{x}_i$ is the long-term mean of precipitation for the i$^{\text{th}}$ month mm, and L_d is the number of consecutive months that the amount of monthly precipitation is less than the predefined TL in a specific station. A similar definition was implemented in the study of Wijayaratne and Golube (1991); however, this is not a universal definition in the analysis of the point drought. For a given dry spell, the magnitude of the drought (M_d) is defined as the ratio of drought severity in mm during the dry spell to its length (L_d):

$$M_d = \frac{S_d}{L_d} \tag{2}$$

where M_d is the magnitude of drought in mm month^{-1}, varies from one dry spell to another one. Its unit depends on the used time scale. In the monthly scale, its unit is mm month^{-1}; however, it is mm year^{-1} in the yearly scale. In this stage of the study, (1) and (2) were used to calculate the point drought characteristics. In this stage, the monthly precipitation data were used. Therefore, based on an assumed TL, say $\bar{x}$, which varied from month to month, some historical dry spells were identified. Each spell had its own drought characteristics (i.e., S_d, L_d, and M_d). The number of dry spells may vary from site to site. Moreover, this number may be changed by using different TLs. The reason is behind in the nature of precipitation, which is a stochastic process. Once the point drought characteristics were evaluated for the selected sites, historical sets of (S_d), (M_d), and (L_d) in a given site were subjected to frequency analysis, separately. In this regard, some common statistical distributions were examined for the goodness of fit. The candidate statistical distributions selected here are (i) generalized extreme value (GEV), (ii) Pearson, (iii) Gamma, iv) (Gumbel, v) (Weibull, (vi) Wakeby, (vii) Log-Logistic (3p), (viii) Dagum (4p), and (ix) inverse Gaussian (3p). Among the mentioned distributions, the best one which fits well with the observed data is selected using the chi-square criterion at a 0.05 significant level. The details of this method are explained in Rao and Khaled (1999). Once the most suitable statistical distribution is selected, its parameters are estimated using the maximum likelihood estimation (MLE) method (Rao and Khaled 1999). This method is one of the most efficient parameter estimation methods (Chow et al. 1988). Therefore, for each set of the observed drought characteristics in a given station, the parameters of the distribution are estimated using the sample data (i.e., observed values). Therefore, quantile functions for each of the mentioned sets are obtained. Using the quantile function, the values of drought characteristics are estimated for different return periods (Tr) in a given site. The above-mentioned analysis of the drought characteristics was repeated for all of the chosen stations. Using the ArcGIS software, the resulting values were mapped for each of the drought characteristics in the region.

Regional drought

In order to analyze the regional drought, the annual precipitation records in the selected stations were used. In order to characterize the regional drought, the whole area of the region is assumed to be s. The number of stations was assumed to be m (here $m = 13$) in the region. By plotting the Thissen polygon (Chow et al. 1988), the representative area of k^{th} site was denoted by S_k ($k = 1, 2, \ldots, m$). The area was measured by ArcGIS here. At this stage, in order to analyze the regional drought, the four distinct TL values were used. Data used at this stage are the historical annual precipitation. The used TLs are (i) 10$^{\text{th}}$ percentile, (ii) 20$^{\text{th}}$ percentile, (iii) 30$^{\text{th}}$ percentile, and (iv) 40$^{\text{th}}$ percentile. In order to calculate them in a given station, the observed annual precipitation records are sorted in descending order. Then, the value positioned in the 10$^{\text{th}}$ percentile (from the bottom) was chosen to be the first TL. By the same way, the values positioned in the 20$^{\text{th}}$, 30$^{\text{th}}$, and 40$^{\text{th}}$ percentiles were considered to be the second, third, and fourth TL, respectively. These TL values varied from one station to another station. It is worth mentioning that these four used percentiles are not a unique choice, and one can use other options, subjectively. In a given year, the sum of areas of the stations which experienced drought is calculated. Then, it was divided into the whole region area to calculate the relative drought-prone area. This process is repeated for each year during the time period.

Assuming a certain TL value for a given station, the first year of the used time period is considered. Each of the recorded values during the period is compared with the TL. If the recorded annual precipitation was less than the TL, then the station was assumed to be in a drought state in that year. Otherwise, its state in that year is considered to be normal (or wet). This comparison was repeated for all of the selected sites. The sum of the relative representative area faced with drought in the first year is obtained. This process was repeated for all the years through the time period. The histogram of the relative areas prone with drought versus the years is plotted. Such a process is repeated for the other three TL values. In order to detect the years with drought, a subjective classification method is considered as follows. In the year t, the cumulative relative areas prone with drought are measured. After the multiplication of it by 100, it is denoted by A_s (t). This measure was evaluated for all the years during the time period. Then, the A_s (t) versus year (t) was plotted as a histogram in the region. Those years having A_s (t) which was more than 70% of the whole region are considered as the years with exceptional regional droughts. The 70% is a subjective choice here. If the measured A_s (t) was between 50 and 70%, then such a year is assumed to be faced with severe regional drought. Similarly, if A_s (t) was between 30 and 50%, then such a year is assumed to be faced with moderate regional drought. Finally, if A_s (t) was less than 30% of the total area, then the year t is considered a year with slight regional drought.

In regional drought analysis, the duration of a regional drought in a given dry spell is calculated from the following equation:

$$L_{rd} = t_e - t_0 + 1 \quad (3)$$

where L_{rd} is the length of regional drought spell in years, t_0 and t_e are the first year and the last year of the regional dry spell, respectively.

Results and discussion

Results of historical point drought

Table 2 shows the results of the point drought analysis. The first set of TL values used in this stage is the $\bar{x}$ (i.e., long-term mean of monthly precipitation). It changes from month to month. Furthermore, in a given month, it varies from site to site. As mentioned before, the other chosen four sets of TL values were $(0.9\bar{x})$, $(0.8\bar{x})$, $(0.7\bar{x})$, and $(0.6\bar{x})$, respectively. For a given station, monthly precipitation records, as well as the first set of TL, are considered. The cumulative rain of the first month in the time period (i.e., January 1985) was compared with the TL (i.e., long-term mean precipitation of January). If it was less than the TL, then the month is labeled as a dry month; otherwise, it is considered to be wet (or normal). Then, the precipitation of the second month (i.e., February 1985) was compared with the TL (i.e., long-term mean rain of February). It is labeled dry or wet month accordingly. Such a process is repeated for all the months during the used time period. A dry spell is defined as a month (or a sequence of consecutive months) having dry labels. Different dry spells can be detected in a given station, throughout the time period. Each dry spell had its own unique drought characteristics (i.e., severity, magnitude, and dry spell length). Here, the first aim of this study is to find the maximum of them in a given station. Then it is tried to calculate the point drought characteristics in different return periods. This approach is repeated for all of the selected TLs and chosen stations.

As can be seen from Table 2 that in the station Anzali, by applying different values for TL, different largest values of S_d were obtained. As c decreases from 1 to 0.6 with 0.1 steps, the largest S_d at this site was found to be 455, 382, 329, 276, and 223 mm, respectively. It can be concluded that in the mentioned station, as c decreases from 1 to 0.6, the maximum observed S_d decreases to 49%. The observed maximum M_d corresponds to the five selected TL values calculated from (2). In the mentioned site, by assuming TL equal to $\bar{x}$, $(0.9 \times \bar{x})$ $(0.8 \times \bar{x})$, $(0.7 \times \bar{x})$ and $(0.6 \times \bar{x})$, the highest M_d values were equal to 251, 220, 190, 160, and 129 mm month^{-1}, respectively. At the same time, the largest L_d was equal to 9, 6, 6, 5, and 5 months, respectively. This means that as the c decreases, the highest M_d and the largest L_d values decrease. It is true for other stations as can be seen in Table 2.

The largest value for the maximum S_d belonged to the station Nowshar. It was about 619 mm and using $\bar{x}$ as TL. The stations namely Anzali and Ramsar having the maximum observed S_d values equal to 455 and 392 mm are positioned in the 2nd and 3rd ranks, respectively. On the other hand, the largest value for the maximumt M_d belonged to the station Anzali having the 251 mm month^{-1} using the same TL. The stations namely Rasht and Ramsar having the maximum M_d values equal to 248 and 235 mm month^{-1} are positioned in the 2nd and 3rd ranks, respectively. The maximum L_d was observed in the station Manjil. It lasted about 15 months assuming $\bar{x}$ as TL. The stations namely Gharakil and Sari having the maximum observed L_d values equal to 14 and 12 months are positioned in the 2nd and 3rd ranks, respectively. It can be concluded that the largest observed values of the three drought characteristics do not belonged to a certain station. For example, assuming TL to be equal to $\bar{x}$, the maximum S_d belonged to the station Nowshar; however, in the case of M_d, it belonged to another station (Anzali for this case). At the same time, the maximum L_d belonged to the other third station namely Manjil. In essence, it can be claimed that in a certain station, as the TL decreases, the observed maximum values for each of the point drought characteristics (i.e., S_d, M_d, and L_d) decrease as well.

An example of calculation routine used here for drought characteristics in monthly scale is presented in supplementary material S1.

Results of frequency analysis in monthly scale

For each of the 13 selected stations and by employing each of the five TL values, the frequency analysis was carried out for S_d and M_d observations during the time period. The number of observed values during the used time period is small; therefore, to estimate them in long-return periods, such an analysis is needed. Therefore, in a given station, the frequency analysis is performed for the mentioned drought characteristics. This process was accomplished for each of the selected stations by employing the five TL values, separately. Here, three return periods which are 2-, 5-, and 10-year were considered. Table 2 shows the output of the frequency analysis in the selected stations. It is worthy to remember that in Table 2, the used time scale is yearly, and the $\bar{x}$ denotes the mean annual precipitation (MAP) in mm. The units of both M_d and L_d used in Table 2 are quite different from Table 3. The reason is behind the fact that the time scales used for these two tables are quite different. In Table 2, the time scale is monthly, whereas it was yearly in Table 3. Therefore, in Table 3, the unit of M_d is mm year^{-1}, whereas it is mm month^{-1} in Table 2. Similarly, the unit of L_d is years in Table 3; however, its unit is months in Table 2. Moreover, the units of S_d is mm during a given dry spell in both the tables. Because, the maximum S_d is the highest

Table 2 Maximum values of historical point drought characteristics using the five distinct truncation levels in monthly scale at the selected stations (2000–2018)

Station name	TL = ($\bar{x}$)			TL = (0.9 × $\bar{x}$)		TL = (0.8 × $\bar{x}$)			TL = (0.7 × $\bar{x}$)			TL = (0.6 × $\bar{x}$)			
	S_d (mm)	L_d (month)	M_d (mm/month)	S_d (mm)	L_d (month)	M_d (mm/month)	S_d (mm)	L_d (month)	M_d (mm/month)	S_d (mm)	L_d (month)	M_d (mm/month)	S_d (mm)	L_d (month)	M_d (mm/month)
Anzali	455	9	251	382	6	220	329	6	190	276	5	160	223	5	129
Astara	312	8	119	247	8	115	188	6	156	143	4	131	118	4	106
Manjil	92	15	34	71	15	22	54	15	19	46	7	16	38	7	13
Rasht	358	6	248	237	6	133	185	6	163	138	6	78	105	6	58
Gonbad-E-kavous	157	9	68	71	6	35	62	6	31	53	4	27	45	4	22
Gorgan	214	10	41	156	9	42	123	8	38	89	8	33	56	5	28
Mara-vetappeh	97	9	97	82	8	26	68	8	21	46	6	18	35	5	15
Babolsar	370	8	125	221	7	111	194	5	97	166	5	83	138	5	69
Gharakil	270	14	56	217	8	77	119	6	68	101	5	58	85	5	48
Nowshahr	619	7	197	530	7	171	441	6	145	352	6	119	268	5	93
Ramsar	392	7	235	331	7	210	281	6	184	210	5	159	165	4	134
Sari	287	12	72	244	8	83	202	8	73	159	8	62	73	7	52
Siahbishe	143	6	47	120	6	40	100	5	34	79	4	27	59	4	21

TL monthly truncation level, $\bar{x}$ mean monthly precipitation (mm), S_d severity of drought (mm), L_d length of dry period (months), M_d magnitude of drought (mm/month) cumulative rainfall deficit observed in different among the dry spells. The unit of S_d in either Table 2 or Table 3 is mm during a given dry spell. However, it has quite different meaning. In Table 3, S_d is the highest observed cumulative rainfall deficit during a given dry spell that was calculated in an annual time scale. However, the meaning of S_d in Table 2 is the highest observed cumulative rainfall deficit during a certain dry spell that was calculated in a monthly scale.

Results of frequency analysis in annual scale

Table 3 shows the results of the frequency analysis of the S_d and M_d series in an annual scale. The output of the frequency analysis is presented for the five distinct TL and the three distinct return periods (i.e., 2-, 5-, and 10-year).

As can be seen from Table 3, in the station Anzali, the estimated value of a 2-year S_d was equal to 102 mm, using $\bar{x}$ as TL. In Anzali, in a 2-year return period, as the TL decreases from $\bar{x}$ to $0.9\bar{x}$, $0.8\bar{x}$, $0.7\bar{x}$, and $0.6\bar{x}$, the corresponding S_d values reduce from 102 mm to 90, 70, 45, and 34 mm, respectively. Similarly, the calculated values of S_d in the mentioned site for a 5- and 10-year return period (corresponding to the non-exceedance probabilities of 0.8 and 0.9, respectively) were increased to 196 mm and 270 mm, respectively. All of the other selected stations showed a similar pattern. Therefore, it can be concluded that as the return period increases, the value of S_d increased. When MAP of the sites was used as TL, the ratio of 10- to 2-year value for S_d ranged between 2.39 (in Nowshar) and 3.82 (in Ramsar). Assuming 0.6MAP as TL, the mentioned ratio ranged from 2.22 (in Maravetapeh) to 3.67 (in Ramsar). For instance, in station Anzali, let MAP to be a TL, then the 10-year S_d is 2.65 times greater than the 2-year one.

Table 4 shows the name of the most appropriate fitted distributions for the S_d and M_d observations in the selected stations. As can be seen from Table 4, the S_d observations are not fitted well with a single distribution. For instance, in station Anzali and in the case of S_d, for TL = $\bar{x}$ and TL = $0.9\bar{x}$, GEV was found to be the most suitable distribution. However, it is Frechet for TL = $0.8\bar{x}$. On the other hand, no single distribution was appropriate to fit a certain drought characteristic in all the stations.

In the case of M_d as as the return period increases (for a certain TL), M_d increases as well (Table 3). For instance, in the station Anzali, assuming TL equal to MAP, the M_d values corresponding to return periods equal to 2-, 5-, and 10-years were found to be equal to 53, 101, and 133 mm year^{-1}, respectively. Therefore, at this site, the ratio of 10 years to the 2-year M_d is equal to 2.51. In other words, the magnitude of a 10-year drought is about 2.51 times of its mean. This ratio varies from site to site. It is true for other drought characteristics. By lowering the TL values (say from MAP to 0.9MAP), the mentioned ratios have been changed in the stations. When MAP used as TL, the range of the mentioned ratio for M_d is between 1.88 (in the station Gorgan) and 3.75 (in the station Gonbad-E-kavous). However, employing the 0.6MAP as TL, this range was between 2.29 (in the station Gonbad-E-kavous) and 4 (in the station Manjil).

Historical droughts in annual scale

Results indicated that using the $\bar{x}$ as TL, the number of dry spells vary between 4 and 8 in the selected stations. The range of the highest L_d was between 2 and 6 years. The 6-year drought spell (2013–2018) experienced in the couple of stations namely Babolsar and Gharakil. Furthermore, the range of maximum S_d was between 122 and 808 mm. The three stations having high values for S_d are Ramsar, Anzali, and Babolsar, with 808, 803, and 789 mm rain deficits during the dry spells, respectively. The range of the maximum M_d is between 63 and 563 mm year^{-1} in the selected stations. The three stations having the highest values for M_d are Nowshar with 563 mm year^{-1}, Anzali with 401 mm year^{-1}, and Ramsar with 389 mm year^{-1}, respectively.

Spatial pattern of drought severity in annual scale

Figure 2 shows the spatial pattern of S_d estimated for two return periods (Tr = 2- and Tr = 10-year) by using the two distinct truncation levels (TL = $\bar{x}$ and TL = 0.6 $\bar{x}$). Here, $\bar{x}$ is the long-term MAP in mm year^{-1} which varies from site to site. These maps were obtained using ArcGIS. As can be seen from Fig. 2a, for a certain TL (say $\bar{x}$), the S_d decreases from west to east (except for the two points located in high altitudes). The western province (i.e., Guilan) experienced severe water shortages during the dry periods compared to the eastern province (i.e., Golestan). Considering TL = $\bar{x}$ and Tr = 2 years, the S_d in the region varied between 15 mm in the east and 103 mm in the west (Fig. 2a). However, for a 10-year Tr, it is in the range of 44 and 270 mm (Fig. 2b). The pattern of S_d in Fig. 2b is very similar to that of Fig. 2a. According to Fig. 2b, it can be seen that the range of S_d is between 44 and 270 mm across the region. Low values of S_d were observed in the east; however, high values were experienced in the west. On the other hand, as can be seen from Fig. 3c for TL = $0.6\bar{x}$, the 2-year S_d varied between 4 mm in the east and 34 mm in the west. However, for the same TL, but for a 10-year Tr (Fig. 3d), this range is between 13 mm in the east and 104 mm in the west. It can be claimed that the western province (i.e., Guilan) had high values for S_d (and M_d) compared to the others. Guilan is positioned in the first rank for drought risk. The second and third ranks belonged to the Mazandaran and Golestan provinces, respectively. Figure 2 demonstrates that in a certain station, as Tr increases, the S_d increases. For example, in the station Rasht, assuming 0.8 $\bar{x}$ for TL, the S_d in a 2-year Tr is equal to

Table 3 Frequency analysis output of S_d and M_d in annual scale for the five TL and three distinct Tr (i.e., 2, 5 and 10 years) in the selected stations

Station name	Tr (years)	TL = $(\bar{x})$		TL = $(0.9 \times \bar{x})$		TL = $(0.8 \times \bar{x})$		TL = $(0.7 \times \bar{x})$		TL = $(0.6 \times \bar{x})$	
		S_d (mm)	M_d (mm/yr)	S_d (mm)	M_d (mm/yr)	S_d (mm)	M_d (mm/yr)	S_d (mm)	M_d (mm/yr)	S_d (mm)	M_d (mm/yr)
Anzali	2	102	53	90	48	70	43	45	31	34	25
	5	196	101	159	97	124	79	88	65	74	52
	10	270	133	210	131	164	108	131	97	103	81
Astara	2	61	30	46	24	40	25	35	21	26	17
	5	129	55	108	50	69	47	69	39	48	31
	10	187	73	162	70	92	66	96	55	69	43
Manjil	2	16	7	13	6	10	5	7	4	4	2
	5	33	13	25	11	20	9	15	7	10	6
	10	46	17	35	14	29	11	21	9	14	8
Rasht	2	92	40	59	30	45	27	39	25	31	21
	5	172	84	129	53	97	50	77	46	54	39
	10	236	122	168	71	129	69	101	58	69	47
Gonbad-E-kavous	2	24	12	20	12	16	11	13	9	10	7
	5	50	26	40	20	35	17	25	14	20	12
	10	66	45	53	25	44	20	34	18	26	16
Gorgan	2	23	16	21	14	17	12	13	9	9	7
	5	50	24	43	24	33	20	26	15	19	13
	10	77	30	62	30	47	26	36	20	27	17
Maravetapeh	2	17	10	14	9	17	7	11	6	9	5
	5	32	19	27	14	32	12	20	10	16	10
	10	45	29	36	18	44	15	26	13	20	12
Babolsar	2	46	25	38	23	21	21	22	17	16	13
	5	102	53	83	46	37	37	44	32	35	24
	10	147	73	118	63	49	49	65	43	51	34
Gharakil	2	30	18	23	15	17	11	14	6	12	8
	5	67	30	55	23	38	22	33	18	27	17
	10	98	36	82	29	56	33	47	26	38	24
Nowshahr	2	54	29	41	28	32	23	21	16	20	19
	5	97	58	72	50	56	43	44	34	37	34
	10	129	82	103	68	81	63	63	50	50	45
Ramsar	2	62	32	47	28	36	24	27	21	21	16
	5	145	57	117	53	82	46	62	39	47	32
	10	237	79	197	76	127	64	99	48	77	48
Sari	2	39	20	27	18	21	14	16	11	14	9
	5	88	31	62	30	48	23	38	21	31	16
	10	134	39	94	38	72	31	56	27	41	23

Table 3 (continued)

Station name	Tr (years)	TL = ($\bar{x}$)		TL = ($0.9\times\bar{x}$)		TL = ($0.8\times\bar{x}$)		TL = ($0.7\times\bar{x}$)		TL = ($0.6\times\bar{x}$)	
		S_d (mm)	M_d (mm/yr)	S_d (mm)	M_d (mm/yr)	S_d (mm)	M_d (mm/yr)	S_d (mm)	M_d (mm/yr)	S_d (mm)	M_d (mm/yr)
Siahbishe	2	23	14	22	12	16	10.54	12	8	8	6
	5	48	23	43	20	32	18	22	14	16	11
	10	73	29	61	25	47	23	32	18	23	15

Table 4 The names of the appropriate statistical distributions fitted for the S_d and M_d values using the five distinct TL values in the selected stations

	TL = $\bar{x}$		TL = $0.9\bar{x}$		TL = $0.8\bar{x}$		TL = $0.7\bar{x}$		TL = $0.6\bar{x}$	
Station name	S_d	M_d	S_d	M_d	S_d	M_d	S_d	M_d	S_d	M_d
Anzali	GEV	Wakeby	GEV	GPAR	Frechet	Dagum	LLogist3	LN3	Pearson 6	LLogist3
Astara	LN3	Wakeby	FL3	Johnson Sb	LN3	Wakeby	InvG3	Wakeby	Dagum	LGamma
Manjil	GEV	Dagum	GEV	Wakeby	GEV	Wakeby	GEV	Dagum	Dagum	Wakeby
Rasht	FL3	InvG3	Johnson Sb	Wakeby	Johnson Sb	Wakeby	GPAR	Johnson Sb	Wakeby	Kumaraswamy
Gonbad-E-kavous	Wakeby	LLogist3	Wakeby	Kumaraswamy	Johnson Sb	Normal	Gamma (3p)	GumMax	Pert	Phased Bi-Weibull
Gorgan	Wakeby	GLO	LN3	FL3	InvG3	FL3	LN3	InvG3	Wakeby	Dagum
Maravetappeh	Frechet (3p)	Burr (4p)	Wakeby	GLO	Dagum	GLO	GGamma4	Wakeby	Wakeby	Wakeby
Babolsar	FL3	Wibull	LPearson	Wakeby	Wakeby	Wakeby	LLogist3	Dagum	Wakeby	Frechet (3p)
Gharakil	Wakeby	Wakeby	Burr	Wakeby	Wakeby	LLogist3	Gamma	InvG3	Pearson 6	Pearson 6
Nowshahr	Wakeby	InvG3	Wakeby	GLO	Wakeby	LLogist3	Wakeby	LN3	Wakeby	Phased Bi- Weibull
Ramsar	LLogist3	GLO	LGamma	Wakeby	Freshet	Burr (4p)	Dagum	Wakeby	Burr (4p)	Burr (4p)
Sari	InvG3	Wakeby	Johnson Sb	Pearson 6 (4p)	GGamma4	Dagum	GPAR	Wakeby	Dagum	Wakeby
Siahbishe	Dagum	GumMax	Dagum	Wakeby	LLogist3	Wakeby	GLO	Dagum	GLO	LLogist3

GEV generalized extreme value, *LN3* log normal (3p), *GLO* generalized logistic, *GPAR* generalized pareto, *InvG3* inverse Gaussian (3p), *LLogist3* log logistic (3p), *GGamma4* generalized gamma (4P), *GumMax* Gumbel maximum, *LPearson* log-Pearson, *LGamma* log-Gamma, *FL3* fatigue life (3p), *TL* truncation level, S_d severity, M_d magnitude, $\bar{x}$ mean annual precipitation

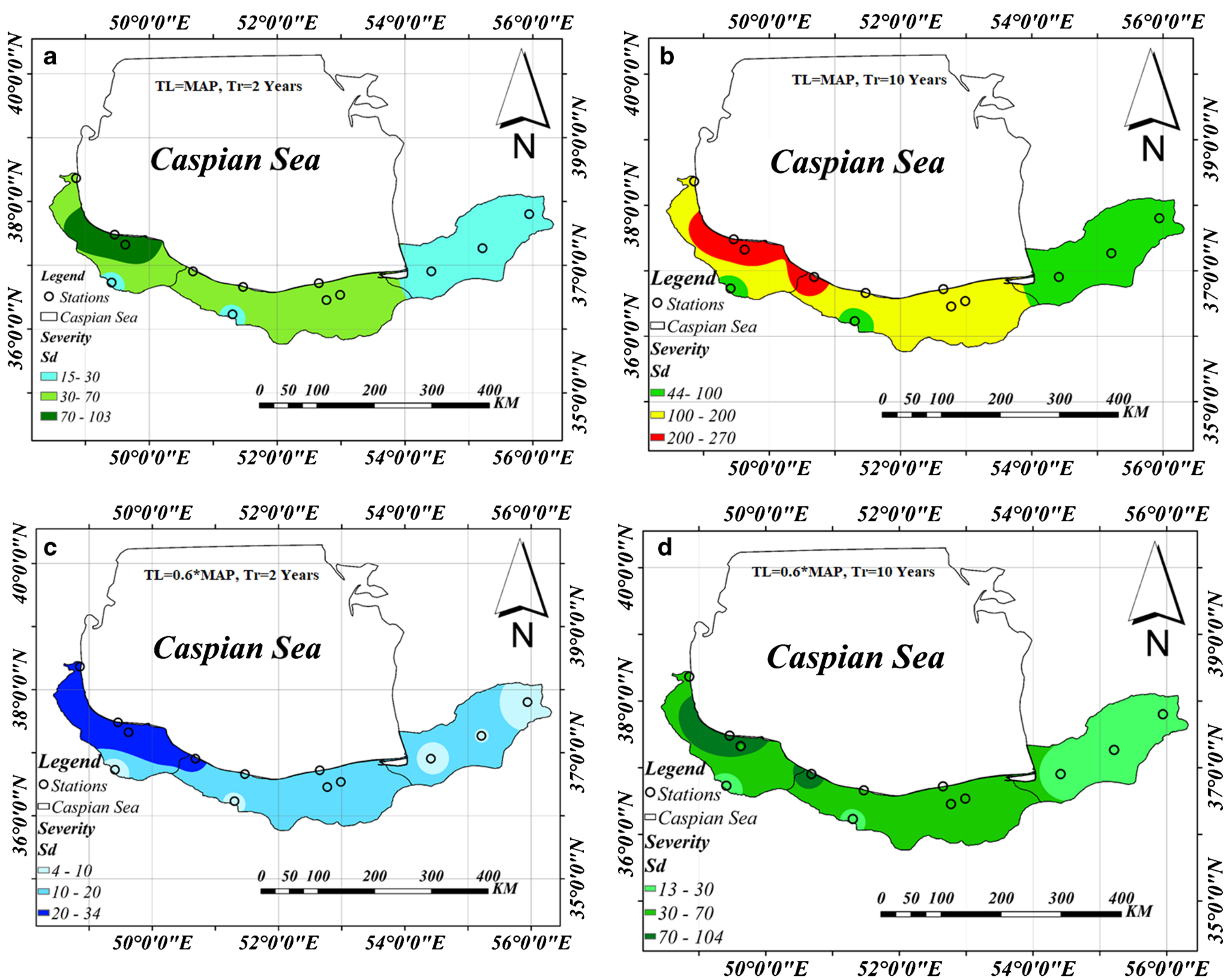

Fig. 2 The maps of S_d mm for the two distinct return periods (Tr) and for the two distinct truncation levels (TL) in the study area, **a** for Tr = 2 years and TL = MAP, **b** for Tr = 10 years and TL = MAP, **c** for Tr = 2 years and TL = 0.6MAP, and **d** for Tr = 10 years and TL = 0.6MAP

45 mm; however, it is increased to 149 mm for Tr = 10 years (Table 3). At this site, by assuming 0.8 $\bar{x}$ as TL, the observed value of the maximum S_d is equal to 185 mm. This means that the largest historical S_d had a Tr great than the 10 years.

Spatial pattern of drought magnitude in annual scale

Figure 3 shows the spatial pattern of M_d values across the study area. In Fig. 3a, this pattern is shown for TL = MAP and Tr = 2 years. As can be seen from Fig. 3a, in a 2-year return period, the north of the Guilan province experienced high M_d values (40–54 mm year^{-1}). A large portion of Guilan and Mazandaran provinces experienced moderate M_d values (20–40 mm year^{-1}). However, in the east of the study area, the whole of the Golestan province as well as some spars areas (mainly located in high altitude areas) experienced low values for M_d (7–20 mm year^{-1}). Therefore, it can be concluded that in the normal conditions (Tr = 2 years and TL = MAP), the M_d values in the west are about 3 times greater than the east. By increasing the Tr from 2 to 10 years, M_d increased to more than two times across the area (Fig. 3b). In the west of the region (i.e., Guilan), there is a small area having large M_d values (105–133 mm year^{-1}). The location of the mentioned area was not changed in Fig. 3b compared to Fig. 3a. The range of M_d values in this part of the area was increased from 40–54 (in Fig. 3a) to 105–133 mm year^{-1} (in Fig. 3b). The M_d values at the eastern part of the area comprising the whole province Golestan and some eastern parts of the province Mazandaran showed relatively low values of M_d compared to the other parts of the study area. It can be concluded that the pattern of the drought-affected areas was not changed considerably (Fig. 3 a and b); however, the values of M_d

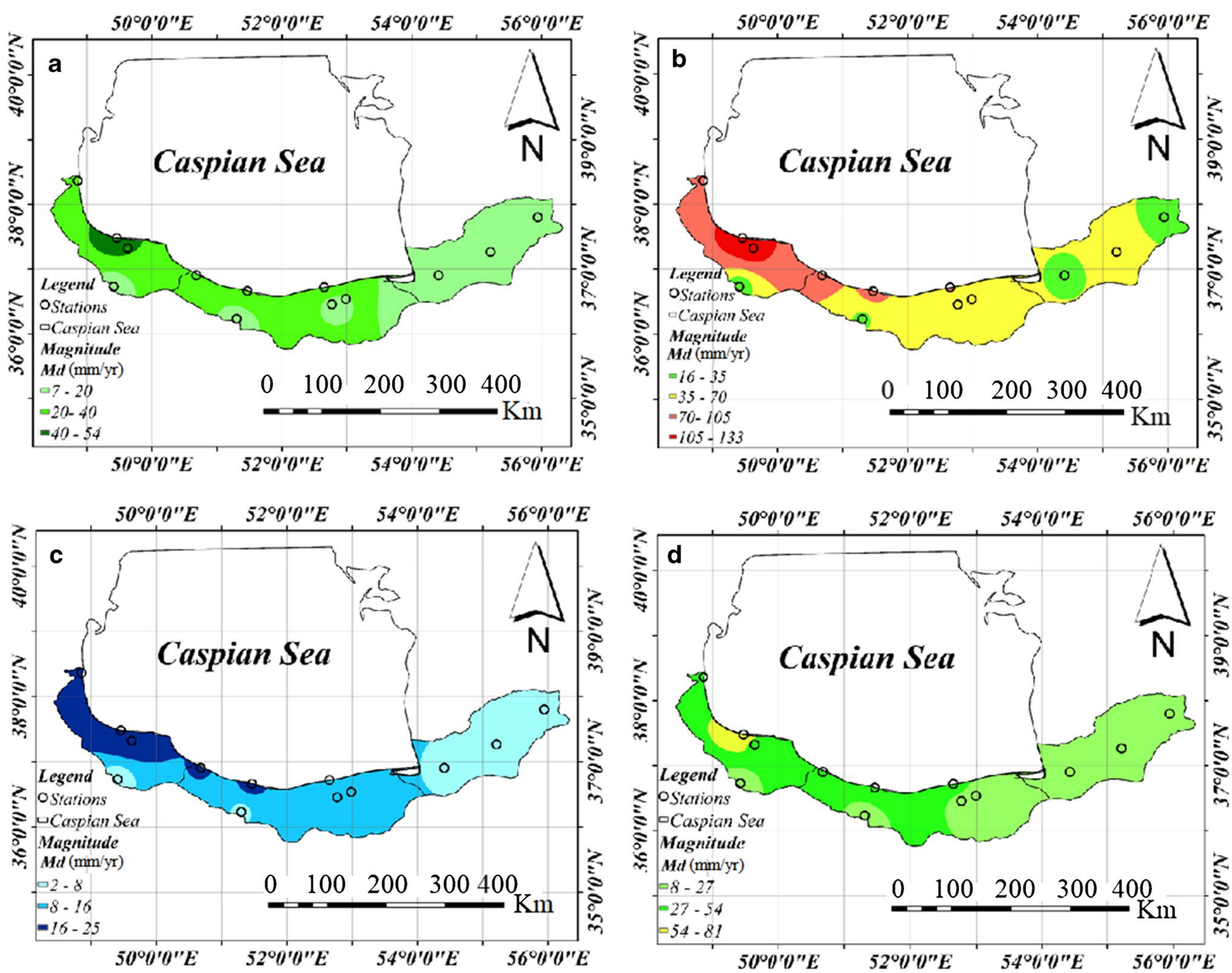

Fig. 3 The maps of M_d (mm year^{-1}) in annual scale and for the two distinct return periods (Tr) and two distinct truncation levels (TL) in the study area, **a** for Tr = 2 years and TL = MAP, **b** for Tr = 10 years and TL = MAP, **c** for Tr = 2 years and TL = 0.6MAP, and **d** for Tr = 10 years and TL = 0.6MAP

increase using the Tr = 10 years with respect to Tr = 2 years. For both of the return periods (i.e., 2 and 10 years), the low M_d values belonged to the east, and the high values belonged to the west. In Fig. 3c, the TL is equal to 0.6MAP, and the Tr is equal to 2 years. As can be seen from Fig. 3c, the values of M_d decreased concerning to Fig. 3a. This means that for the normal conditions (i.e., Tr = 2 years) as the TL declines from MAP to 0.6MAP, the M_d values decreases as well. The maximum value of M_d in both of Fig. 3 a and b belonged to the Guilan province; however, the largest value for TL = 0.6MAP is 25 mm year^{-1}, which is less than half of the corresponding value for TL = MAP. In Fig. 3d, the Tr = 10 years, and the Tl = 0.6MAP. As can be seen from Fig. 3d, the range of 10-year M_d values was between 8 and 81 mm year^{-1}. This range is at least three times greater than that of the 2-year M_d and the same TL (Fig. 3c). It can be concluded that for a same TL, as the return period increases, the values of M_d increase. Also, for the same return period, as the TL value declines, the M_d values decrease.

Regional pattern of drought using the annual scale

Figure 4 shows the histogram of drought prone areas (in %) during the time period in the study area. The four distinct truncation levels were used in plotting Fig. 4, which are (i) the 10th percentile of the annual precipitation, (ii) 20th percentile, (iii) 30th percentile, and (iv) 40th percentile. The coverage of drought prone area using the first TL is depicted in Fig. 4a. As can be seen from Fig. 4a, there are 2 years (2008 and 2010) in which drought coverage is more than 30% of the total area. In the year 2010, a severe regional drought covered more than 56% of the region. Furthermore, in the year 2008, moderate regional drought was experienced since the drought extent was more than 37% of the total area under study. There were some years with slight drought in the region that the drought extent is less than 30%. From these years, it can be referred to 2014 with A_s $(t)=16.5\%$. Using the second TL (i.e., 20th percentile), the number of years with regional drought increased. In addition, the values of A_s (t) in the years were increased comparing the 10th percentile used as TL (Fig. 4b). Assuming TL = 20th percentile, the year 2010 with A_s (t) greater than 99% experienced the exceptional drought. The year 2014 covering the drought-affected area close to 60% was known as the year with severe drought. The years 2008 and 2017, having the A_s (t) values, respectively equal to 38.3% and 34.7%, were known as the years with moderate drought (Fig. 4b). Some years with slight droughts occurred in the region too. The year 2007 with A_s $(t)=12.8\%$ is known to be the most noticeable one among the others. Figure 4c shows the similar histogram but for the 3rd TL (i.e., 30th percentile). As can be seen from Fig. 4c, the coverage of drought (i.e., A_s (t)) increased for all the years comparing the two first choices for TL (i.e., 10th and 20% percentiles). For example, assuming TL = 30th percentile, the year 2010 was found to be an exceptional drought that covered the 100% of the region. The years 2014 and 2017 had drought coverage equal to 68.4% and 75.5%, respectively, and experienced severe droughts in the region. Furthermore, in the years 2008 and 2015, the region under study covered moderate drought with A_s (t) values equal to 45.3% and 31.9%, respectively. Figure 4d shows the values of A_s (t) in different years through the time period assuming the 40th percentile as a TL. Three years were found to face with exceptional regional droughts, which are 2008, 2010, and 2017, having A_s (t) equal to 70.4%, 100%, and 91.1%, respectively. The region experienced severe drought in the year 2001 with A_s $(t)=67.1\%$. The 4 years that the region encountered with moderate droughts are 2001, 2006, 2015, and 2018, having the A_s (t) values equal to 32.2%, 42.4%, 43.6%, and 43.1%, respectively. It can be concluded that by increasing the TL value from the 10th to the 40th percentiles, both the number of years with regional drought and the coverage of regional drought increased. According to Fig. 4d, by assuming the 40th percentile as a TL, the longest time distance between the 2 years with exceptional regional droughts is equal to 8 years (i.e., the first one experienced in 2010 and the second one observed in 2017). This result is valid in this region even TL decreased from 40 to 30th percentile (see Fig. 4 d and c). With more declination of TL (i.e., using 20th percentile instead of 30th as TL), the number of years with exceptional regional drought (i.e., drought coverage of more than 70% of the whole area) reduces from two to one. This means that among all the 19 years throughout the time period (i.e., from 2000 to 2018) only 2010 had exceptional regional drought (Fig. 4b). When TL was raised to the 10th percentile, the year 2010 had drought coverage of about 57% which is less than the critical level for exceptional regional drought (i.e., less than 70%). Therefore, it can be claimed that the number of years with exceptional droughts (and other classes of regional droughts) decreases as the regional TL raise. Furthermore, the time distance between the two adjacent years with exceptional droughts increases as regional drought TL raise.

Discussion

One of the main common problems in drought-related studies is that there are a few dry spells in the historical time period. This issue was pointed out before in the work of

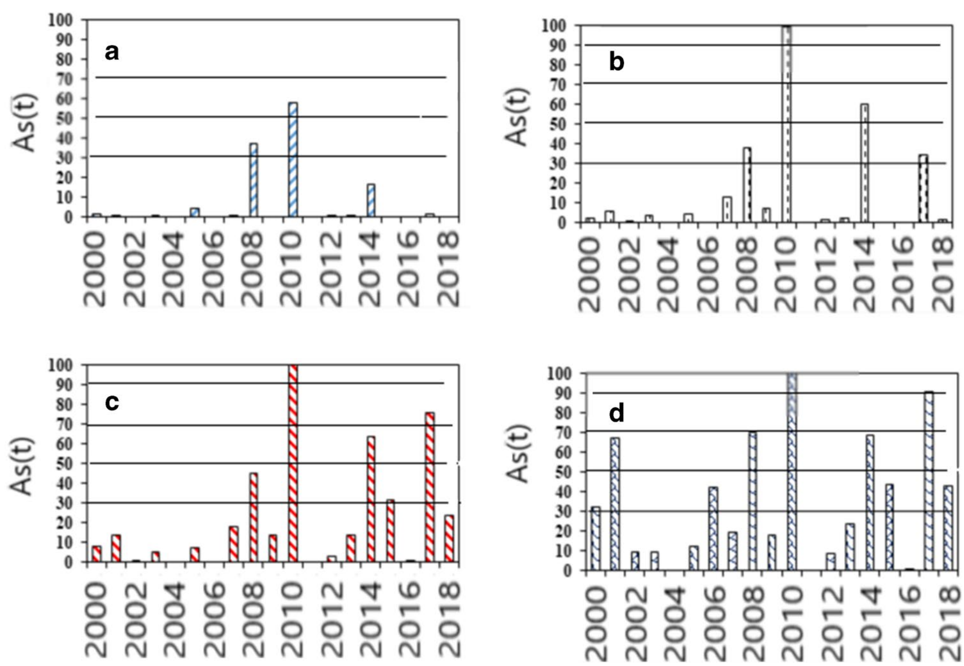

Fig. 4 Histograms of the areas (in percentages) faced with drought in annual scale during the time period for the four different truncation levels, **A** 10th percentile, **B** 20th percentile, **C** 30th percentile, and **D** 40th percentile

Mtilatila et al. (2020). Most of the stations in Iran had less than 30 years of precipitation records. By defining a fixed truncation level (say $\overline{x}$) for point drought analysis, the number of dry spells is not sufficient for reliable inference. This problem is intensified when a lower TL is selected for analysis. This is why the frequency analysis was used here for prediction of drought characteristics for different return periods. As each set of observed drought characteristics came from different statistical distributions, therefore, each set of data had their own parameters. In this regard, details of frequency analysis using the statistical distributions were described by Rao and Khaled (1999). In this study, the common statistical distributions were examined to fit the historical drought characteristics. Among the candidate distributions, the most suitable one was selected for each set of the drought characteristics. Parameters of the selected distributions are estimated using the maximum likelihood estimation (MLE) method. Once the parameters are estimated, the values of drought characteristics in different return periods are estimated for each of the stations. The used method is simple and applicable for other regions in annual scale. Specifically, this method is applicable for those climates in which all the months had rain less and more. By this method, it is also possible to compare the drought characteristics of two stations with different mean monthly rainfalls. Any fixed percentage value (say 20%) reduction in rainfall led to different rain depths. Therefore, it is easy to compare drought-prone areas in a large region, such as a country. Therefore, in a certain month (say January) when precipitation in one or more stations is less than the TL, it can be suggested that a drought occurs. This is important especially when the stations located in the region belonged to different climates. For example, assume the long-term means of January precipitation in the two stations namely “a” and “b” are equal to 300 and 50 mm, respectively. Then, by application of $TL = 0.2\ \overline{x}$, receiving 240 mm rain in the station “a” will have the same sense of drought in the station “b” with only 40 mm rain. Therefore, it can be suggested that the used method provides reliable comparison of drought in the stations with different climates.

However, in the case of two stations are from different climates, a problem with the monthly time scale might arise. It seems that this approach is not efficient for those stations having long dry summer times. As the mean monthly rainfall in summer months is zero (or close to zero), therefore, coming a little rain in a month may bisect a long dry spell into the two short ones. It is clear that such a little rain in a month would not be sufficient to compensate the experienced water scarcity in the previous months. Therefore, in such a condition, the used method seems to fail in discrimination of dry and wet spells. However, this problem never arises, if annual time scale was used instead of monthly scale. The other question that may arise here is, “What is the suitable TL in drought analysis?” It is well known that the agriculturalists (especially rain-fed farmers) are the first layer of society that percept droughts. Deficiency in rainfall during the crop growth period, especially during the grain filling time, affects the yield seriously. This situation affects rain-fed farmer’s income, adversely. However, other farmers who irrigate their farms are not affected immediately by such a shortage of rain. These farmers percept drought with a delay in time compared to the rain-fed farmers. This time lapse depends on availability of reserved water sources such as groundwater and/or water stored in the reservoirs. Obviously, the impact of drought on groundwater level is not perceivable immediately when dry spell is in its start phase. This is why different TL values were used in this study for drought analysis. It is noted that comparison of findings of this study with others is not a simple task because the same time period should be used for the works that contribute in comparison. It can be concluded that as the main aim of this research is to recognize the past drought characteristics (dry length, drought severity, and drought magnitude) in the chosen stations, therefore, available fresh water during the future dry periods can be better managed taking into account the present results. Li et al. (2020) who studied the meteorological drought in Luanhe River basin, located in China, reported that this method is recommendable for those sites which precipitation during the year is not concentrated in few rainy months. It seems that this is not the case when the used time scale is year. The used approach here ignored the effect of heat waves which exacerbate the destructive drought impacts in the region. In order to overcome this problem, one may use the precipitation and air temperature records simultaneously similar to the study of Spinoni et al. (2015). In the work of Khan et al. (2020), some indices were used for drought identification in a rain-fed area located in Punjab, Pakistan. They used SPI, SPEI, Vegetation Condition Index (VCI), Precipitation Condition Index (PCI), Soil Moisture Condition Index (SMCI), and Temperature Condition Index (TCI). They detected seven distinct years in the period 2000–2015 that experienced drought. Mtilatila et al. (2020) used two indices namely SPI and SPEI for analysis of meteorological drought in Lake Mallawi and Shire River basins. They showed that due to decrease in precipitation, trends in drought characteristics are upward. Also, as air temperature showed increasing trend, therefore, drought percept stronger than usual. They showed that at basin scale, there were only eight drought events in the period 1970–2013.

Conclusions

Drought is one of the most important hydrologic phenomenon, which is directly related to different activities of a society. Better management of available water in a dry spell needs to understand the drought characteristics occurred in the past. This study focused on the meteorological drought in Northern Iran in the period 2000–2018. Both point droughts and regional droughts were analyzed. Point droughts were analyzed using the five truncation levels (TL) selected subjectively. These TLs were $\overline{x}$, $0.9\overline{x}$, $0.8\overline{x}$, $0.7\overline{x}$, and $0.6\overline{x}$ in monthly time scale. In this study, $\overline{x}$ is the mean precipitation, which varies from month to month. For each month, the $\overline{x}$ is the average of all precipitation records during the time period. In a certain station, the TL varies from month to month. This study compared the mentioned five TL values to analyze the drought characteristics.

Different water users percept drought in different times. Dry farmers are the first group that percept drought effects. The most suitable TL for this group seems to be the $\overline{x}$. Those agriculturalists who use surface water for irrigation percept drought inverse effects later. Therefore, using a low TL for this group is recommended. Those water users who use groundwater percept later in time compared to the others. For this group of water users, a very low TL (such as $0.6 \times \overline{x}$) is preferable.

In each of the selected stations, drought severities were estimated in dry spells. The highest one is selected to report in the results using the five selected TLs. This approach was repeated for the drought magnitudes. In this way, the highest values of L_d, S_d, and M_d in the period 2000–2018 were obtained for each of the chosen stations. Then, frequency analysis was performed using the observed values of S_d and M_d in a given station. This process was repeated for each of the selected stations. Results indicated that as the return period (*Tr*) increases, the values of S_d and M_d increase as well. Regional drought was analyzed in the present study using the annual precipitation records. In regional analysis, four percentiles of annual precipitation time series were selected as TLs subjectively. These thresholds comprise the 10th, 20th, 30th, and 40th percentiles of mentioned time series. Bearing in mind that the 10th percentile level is lower than the 20th, and so on, results indicated that in a given station by choosing the lowest TL (i.e., 10th percentile here), the number of years experienced drought was minimum. In other words, in such a condition, the annual precipitation in the most of years was more than TL.

Plotting the histogram of drought coverage across the region versus the years showed that 2010 experienced the largest drought extent in the region. Both the severity and magnitude values were found to be large in the west part of the region (i.e., Guilan province), comparing the east. These results indicated that the provinces of Guilan, Mazandaran, and Golestan have faced different levels of drought during 2000–2018, which influences water availability and agricultural production. It seems that freshwater needs better management at this time. If water decision-makers do not pay attention, then fast evolving of water crises in the region would be inevitable.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12517-022-11021-5.

Acknowledgements Data used in this research was provided by the Islamic Republic of Iran Meteorological Organization (IRIMO) which is greatly appreciated. Also, special thanks to the editor in chief and anonymous reviewers for their valuable suggestions.

Author contribution Conducting the research and writing the manuscript are done equally by the authors.

Data availability Data and code will be available upon request.

Declarations

Ethical approval The authors have agreed on the submission of this article, and it is not currently under any consideration for publication in other journals.

Consent to participate The authors voluntarily agreed to participate in this research study.

Consent for publication The authors approved the publication of this study.

Conflict of interest The authors declare no competing interests.

References

Abolverdi J, Khalili D (2010) Probabilistic analysis of extreme regional meteorological droughts by L-moments in a semiarid environment. Theoret Appl Climatol 102:351–366

Amirataee B, Montaseri M, Rezaie H (2018) Regional analysis and derivation of copula-based drought Severity-Area-Frequency curve in Lake Urmia basin, Iran. J Environ Manag 20:134–144

Bazrafshan J, Nadi M, Ghorbani K (2015) Comparison of empirical copula-based joint deficit index (JDI) and multivariate standardized precipitation index (MSPI) for drought monitoring in Iran. Water Resour Manage 29(6):2027–2044

Berito SSB, Cunha APM, Cunningham CC, Alvalá RC, Marengo JA, Carvalho MA (2018) Frequency, duration and severity of drought in the Semiarid Northeast Brazil region. Int J Climatol 38(2):517–529

Chen ST, Kuo CC, Yu PS (2009) Historical trends and variability of meteorological droughts in Taiwan. Hydrol Sci J 54(3):430–441

Chow VT, Maidment DR, Mays LW (1988) Applied hydrology. McGraw-Hill, p 564

Dinpashoh Y, Fakheri-Fard A, Moghaddam M, Jahanbakhsh S, Mirnia M (2004) Selection of variables for the purpose of regionalization of Iran's precipitation climate using multivariate methods. J Hydrol 297:109–123

Dinpashoh Y, Singh VP, Biazar SM, Kavehkar S (2019) Impact of climate change on streamflow timing (case study: Guilan Province). Theoret Appl Climatol 138:65–76. https://doi.org/10.1007/s0070-4-019-02810-2

Dracup JA, Lee KS, Paulson EG (1980) On the definition of droughts. Water Resour Res 16(2):297–302

Ekhtiari S, Dinpashoh Y (2019) Application of effective drought index (EDI) in characterizing drought periods (case study: Tabriz, Bandar-e Anzali and Zahedan stations). Sustain Water Resour Manag 5:1723–1729. https://doi.org/10.1007/S40899-019-00315-4

Eltahir EA (1992) Drought frequency analysis of annual rainfall series in central and western Sudan. Hydrol Sci J 37(3–6):185–199

Ghorbani-Aghdam M, Dinpashoh Y, Mostafaeipour A (2013) Application of factor analysis in defining drought prone areas in Lake Urmia basin. Nat Hazards 69:267–277

Griffiths GA (1990) Rainfall deficits: distribution of monthly runs. J Hydrol 115:219–229

Hisdal H, Tallaksen ML (2003) Estimation of regional meteorological and hydrological drought characteristics: a case study for Denmark. J Hydrol 281:230–247

Karavatiz CA, Alexandris S, Demetrios ET, Athanasopoulos G (2011) Application of the standardized precipitation index (SPI) in Greece. Water 3(3):787–805

Kendall DR, Dracup JA (1992) On the generation of drought events using an alternating renewal-reward model. Stoch Hydrol Hydraul 6:55–68

Khan R, Gilani H, Iqbal N, Shahid I (2020) Satellite-based (2000–2015) drought hazard assessment with indices, mapping, and monitoring of Potohar plateau, Punjab, Pakistan. Environ Earth Sci 79(23):1–18. https://doi.org/10.1007/s12665-019-8751-9

Li J, Zhou K, Chen F (2020) Drought severity classification based on threshold level method and drought effects on NPP. Theoret Appl Climatol 142:675–686. https://doi.org/10.1007/s00704-020-03348-4

Livada I, Assimakopulos VD (2007) Spatial and temporal analysis of drought in Greece using the Standardization of Precipitation Index (SPI). Theoret Appl Climatol 89:143–153

Mishra AK, Singh VP (2011) A review of drought concept. J Hydrol 203:157–175

Mtilatila L, Bronstert A, Bürger G, Vormoor K (2020) Meteorological and hydrological drought assessment in Lake Malawi and Shire River basins (1970–2013). Hydrol Sci J 65(16):2750–2764. https://doi.org/10.1080/02626667.2020.1837384

Peel MC, Pegram GS, Mcmahon TA (2004) Global analysis of runs of annual precipitation and runoff equal to or below the median: run length. Int J Climatol 24(7):807–822

Rao AR, Khaled H (1999) Flood frequency analysis. CRC Press

Raziei T, Saghafian B, Ana A, Paulo AA, Pereira LS, Bordi I (2009) Spatial patterns and temporal variability of drought in western Iran. Water Resour Manage 23(3):439–455

Santos MA (1983) Regional droughts: a stochastic characterization. J Hydrol 66:183–211

Sayari N, Banayan M, Alizadeh A, Farid A (2013) Using drought indices to assess climate change impacts on drought conditions in the northeast of Iran (case study: Kashafrood basin). Meteorol Appl 20(1):115–127

Sen Z (1980) The numerical calculation of extreme wet and dry periods in hydrological time series. Hydrol Sci J 25(2–6):135–145

Spinoni J, Naumann G, Vogt JV, Barbosa P (2015) The biggest drought events in Europe from 1950 to 2012. J Hydrol: Reg Stud 3:509–524

Todisco F, Mannocchi F, Vergni L (2013) Severity-duration-frequency curves in the mitigation of drought impact: an agricultural case study. Nat Hazards 65:1863–1881

Vrochidou AK, Tsanis IK, Grillakis MG, Koutroulis AG (2013) The impact of climate change on hydrometeorological droughts at a basin scale. J Hydrol 476:290–301

Wijayaratne LH, Golube E (1991) Multiyear drought simulation. Water Resour Bull 27(3):387–395

Wilhite DA, Glantz MH (1985) Understanding the drought phenomenon, the role of definitions. Water Int 10(3):111–120