ORIGINAL PAPER

Impact of climate change on streamflow timing (case study: Guilan Province)

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Abstract

The timing of streamflow characteristics is important for water resources management and agricultural irrigation. Using daily discharge data from 37 gaging stations, located in Guilan Province, Iran, for the period 2002–2016, this study investigated nine streamflow timing measures and tested their trends by the Mann-Kendall non-parametric test at the 90% significance level. The nine measures included Q5%, Q10%, Q50%, Q90%, and Q95%, date corresponding to the center of fall volume, and dates corresponding to centers of spring and winter volumes. Results revealed that the median values of low flow timing slopes (Q5% and Q10%) had significant negative trends. Q5% had the steepest downward trends, implying that low flows originating from groundwater occurred earlier than in the past. In contrast, high flow timings (Q90% and Q95%) showed upward trends. Also, Q50% exhibited upward trends for all 37 stations. The trends suggest that climate change has altered the river flow regime. Among the nine measures, the date corresponding to the center of fall volume (FCV) and the dates corresponding to the centers of winter/spring volumes (WSCV) had the most significant downward trends. Trends in the spring freshet were mainly significantly negative in the northwest. However, trends in the pulse date were negative mainly in the west. The occurrence of low flows became earlier in time, and the length of dry periods within a year became longer.

1 Introduction

In recent years, streamflows of most rivers have altered, perhaps due to climate change and global warming. One of the important changes in streamflow characteristics is the change in the timings of streamflow measures, such as the Julian date on which streamflow reaches its largest value in the year. Water resources management decisions depend on the timings of runoff characteristics. The timing of runoff, especially in mountainous catchments where snowmelt represents the largest portion of total runoff volume, is important, because these catchments are highly susceptible to climate change. In recent years,

such catchments in Canada have experienced large earlier runoff as a result of increasing spring air temperature (Burn 2008). Understanding the timing of runoff is therefore important for the overall management of quantity and quality of water resources, especially for environmental health and human consumption (Dettinger and Cayan 1995; Dudley et al. 2017). The earlier occurrence of runoff can decrease the availability of water in the warm season, impacting agriculture, ecosystems, and frequency and occurrence of wild fires (Hall et al. 2015).

Climate change impacts all of the components of hydrologic cycle at both temporal and spatial scales (Milly et al. 2008). In regions with large snow accumulation, increasing air temperature can result in changes in the magnitude and timing of peak discharge during the snowmelt season and low runoff occurrence in the dry season (Kang et al. 2016). Seasonal changes in air temperature and timing of runoff can affect many water-related activities and ecological communities (Goulding et al. 2009). Other effects from this type of change are (i) deficit in available water resources, especially in arid regions in warm seasons (Hodgkins and Dudley 2006); (ii) change in the starting time of spring during the year (Cayan et al.

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2001); and (iii) changes in peak streamflow magnitude and its timing which decrease the fish survival rate (Hare et al. 2016; Crecco and Savoy 1985). The rates and magnitudes of these changes will depend on the topography of region.

In recent years, several studies on the timing of runoff have been conducted in different countries. For example, Burn (1994) studied the timing of runoff in west Central Canada and Westmacott and Burn (1997) in the Churchill-Nelson River basin. Cayan et al. (2001) investigated the changes in the date of onset of spring runoff. The starting dates of streamflow peaks in spring were surveyed in Canada and Liard River basin, respectively (Zhang et al. 2001, Burn et al. 2004).

The timings of streamflows were investigated by Hodgkins et al. (2003) in New England, by Stewart et al. (2005) in western North America, by Hodgkins and Dudley (2006) in eastern North America, by Morán-Tejeda et al. (2014) in Spain, by Ryberg et al. (2016) in the United States, and by Dudley et al. (2017) in eastern North America during 1913–2002. Winter-spring streamflows have been reported to occur earlier

in the North Central U.S.A (Kam et al. 2018). Roberts et al. (2018) investigated streamflow timing as a determinant of lake flows and found a proportional decrease, ranging from approximately 50% in snow years to nearly 90% in dry years. Their findings suggested that climate change may be the cause of increased evidence of flow loads in the ecological dynamic coastal zone of high residence time of lake streamflow. Shen et al. (2018) assessed trends in streamflow timing in four mountainous basins in southern Tian Shan Mountains and found streamflow trends by the Mann-Kendall (MK) test. Results showed that annual streamflow increased significantly, especially in spring and winter months.

The objective of this study therefore was to investigate trends in the timings of runoff characteristics, using daily discharge data from 37 stations located in Guilan Province, Iran. Trend magnitudes were regionalized using the inverse distance weighted (IDW) method. Results of this study may help water resources management decisions. It may be mentioned that no such study has been done in this area.
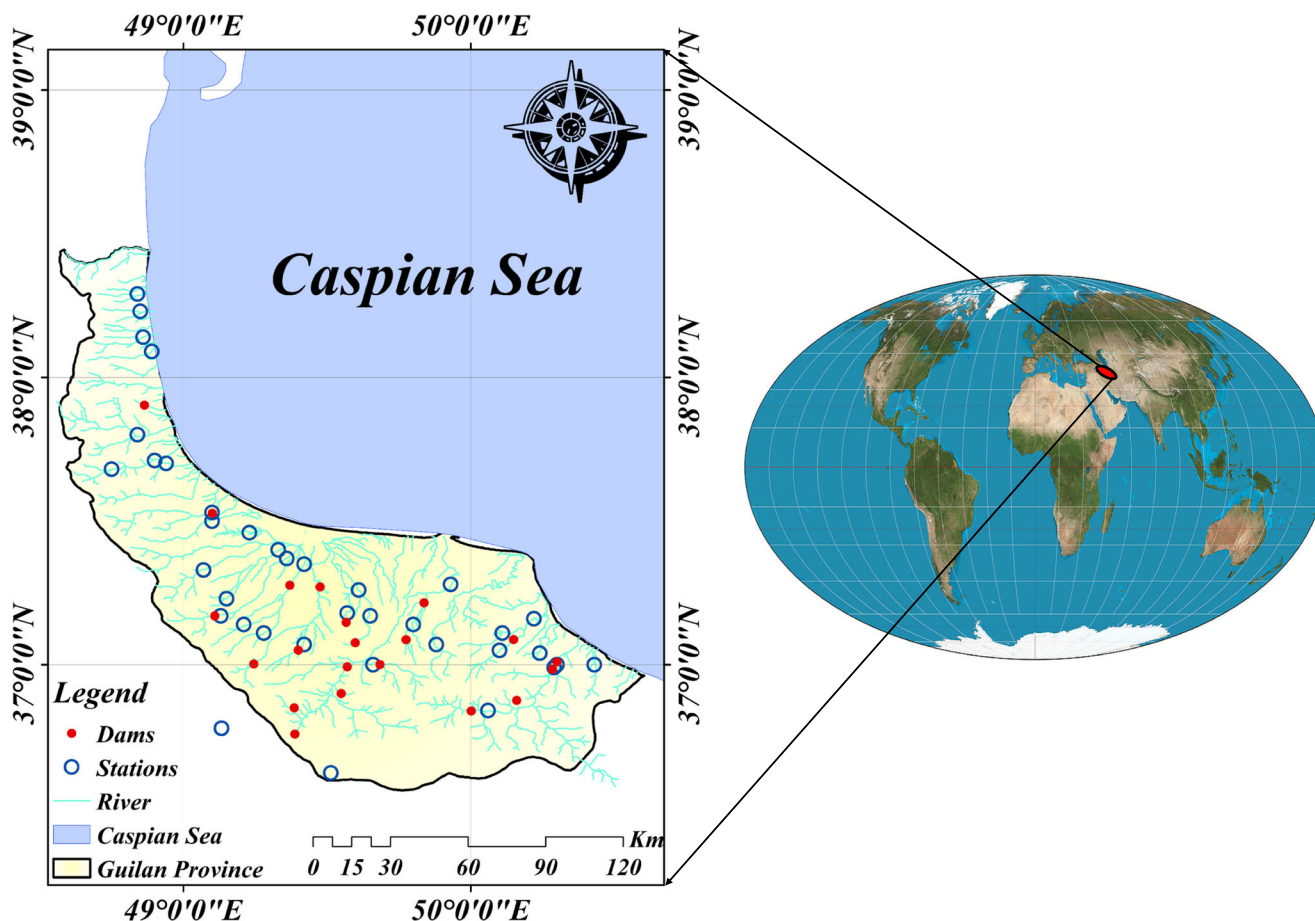

Fig. 1 Location of the study area and the selected stations

2 Material and methods

2.1 Study area

This study selected Guilan Province (northern Iran) which is a coastal province located between 48° 32′ N to 50° 36′ N and 36° 33′ E to 38° 27′ E. The climate is mainly humid in most of the area but is semi-arid in high altitude areas in southeast Guilan (called Manjil and Rudbar). This region is mostly covered by tall forest trees. The mean annual precipitation and mean annual pan evaporation are 1506 mm and 1306 mm, respectively (Isazadeh et al. 2017). The mean monthly temperature is 29.8 °C in hot months and declines to 6.3 °C in cold months (Isazadeh et al. 2017). Figure 1 shows the

Table 1 the geographical coordination of the stations and some useful statistics of discharges (m³/s) in the region

Stations	Longitude			Latitude			Min (m³/s)	Max (m³/s)	Average (m³/s)	Altitude (m)
	Degrees	Minutes	Seconds	Degrees	Minutes	Seconds				
Agha-Mahalleh	49	14	2	37	27	40	0	49.4	1.66	− 15
Astaneh	49	56	2	37	16	41	0.002	792	49.8	− 7
bajigovar	50	26	4	37	0	10	0	143	2.07	110
Behdan	49	38	52	37	10	14	0	112	1.59	35
Ghaleroodkhan	49	16	35	37	6	26	0.002	101	3.65	150
Ghorbanali-Mahalleh	48	50	43	38	13	40	0.001	53.8	1.78	50
Gilavan	49	7	58	36	46	42	0	904	44.2	311
Haratbar	50	18	11	36	59	53	0.015	69.3	2.36	105
Chomaskhal	49	21	52	37	22	23	0	75.2	4.71	− 13
Kolchal	50	6	11	37	3	11	0	83.1	2.88	155
Kolsar	49	19	30	37	23	43	0	105	6.29	− 20
Kalesara	48	56	17	37	42	8	0.02	57	1.44	55
Khalyan	48	45	13	37	40	48	0.157	38.2	2.13	740
Khan-Hayati	48	50	16	38	17	7	0	67.7	2.17	30
Kharjegil	48	53	44	37	42	41	1.15	46.3	4.17	140
Komadol	49	7	46	37	10	30	0.1	96	4.5	260
Lakan	49	34	3	37	10	48	0.001	20.9	0.72	40
Laksar	49	25	17	37	21	12	0	266	9.93	− 12
Loshan	49	30	48	36	37	23	0.25	317	19.31	342
Mashinkhaneh	48	50	11	37	47	42	0.169	101	6.65	155
Masjed-Pish	49	9	4	37	13	57	0.004	20.9	1.1	140
Mobarak-Abad	49	24	59	37	4	9	0	112	4.1	87
Moosa-Kelaye	50	3	49	36	50	22	0	60	2.52	1010
Oostaghasem-Mahalleh	48	53	10	38	5	9	0	45.1	1.17	55
Otaghvar	50	6	51	37	6	50	0	94.6	2.72	50
Pashaki	49	47	53	37	8	16	0.001	206	3.8	40
Pirsara	49	12	34	37	8	6	0.009	48.4	2.44	210
Poonel	49	6	8	37	31	47	0.615	62.8	4.67	85
Roodbarsara	49	5	52	37	30	15	0.014	22.4	1.74	120
Safar-Mahalleh	48	51	37	38	8	24	0.001	105	2.58	60
Sazmane-Ab	49	36	46	37	15	28	0.06	86.2	5.01	5
Shabkhooslat	50	14	21	37	2	37	0	58.9	1.43	50
Shahrebijar	49	39	22	37	0	5	0.064	142	6.35	100
Shalman	50	13	3	37	9	39	0	251	6.78	− 14
Taskooh	49	4	27	37	19	57	0.005	46.5	4.6	150
Toolelat	50	17	30	36	59	41	0.055	362	15.09	110
Tootaki	49	52	33	37	3	56	0	70	3.43	200

location of the study area and the positions of 37 selected hydrometric stations.

2.2 Data

Daily discharge data from 37 selected hydrometric stations were obtained for the period 2002–2016 from the Regional Water Company of Guilan Province, Iran (http://www.glrw.ir). The quality of data was carefully checked by drawing the discharge time series of each station and visually inspecting the data for outliers. The homogeneity of data was checked using the run test method. No missing data existed in the time series. Table 1 presents the geographical information of the selected stations. Useful statistical measures of observed discharges are also summarized in Table 1.

2.3 Timing measures

In this study, nine streamflow timing measures were used for the selected stations, which are explained in what follows:

2.3.1 Streamflow percentiles

Five out of the nine timing measures are related to streamflow percentiles, calculated based on the Julian day of each calendar year. These indices were defined as a date on which a constant percentage of annual (calendar year) runoff volume passes through the basin outlet (i.e., the given station). Figure 2 represents these measures based on the rating curve of a given site. The 5 percentile date, denoted by Q5%, is the Julian day for a given year by which 5% of the annual streamflow volume passed from the basin outlet. Likewise the 10, 50, 90, and 95 percentile

dates were defined (Fig. 2). The 5% and 10% dates were considered with the intention to consider changes in the onset of spring freshet–related runoff, and the 50% date is an overall measure of the timing of runoff, while the 90 and 95 percentile dates explore changes in how late in the year a runoff occurs (Burn 2008).

2.3.2 Pulse date

The pulse date was determined as the Julian day for which the departure of runoff from the average streamflow for the year was most negative (Burn 2008). According to Cayan et al. (2001), this is equivalent to detecting the date after which most of the runoff is above the average for the year.

2.3.3 Spring freshet

The spring freshet date was obtained by manually examining the annual hydrograph and selecting the date on which the first rise of the spring freshet occurred. Operationally, this was performed by calculating the average streamflow in the first 60 days of the spring season (from the 80th Julian day until the 140th Julian day in each year) and then checking if the daily discharge in these 60 days was greater than or equal to 1.5 times the mean value. The date at which discharge occurred was defined as spring freshet. Some investigators have considered 16 days instead of 60 days for spring freshet definition. However, in this study, based on our experience, we considered it to be 60 days. Past experience indicates that with some practice, this measure is reproducible (Burn 1994, 2008).

Fig. 2 Rating curve for the representative station, namely Agha-Mahalleh, showing the location of Q5%(days/year), Q10%(days/year), Q50%(days/year), Q90%(days/year), and Q95%(days/year)
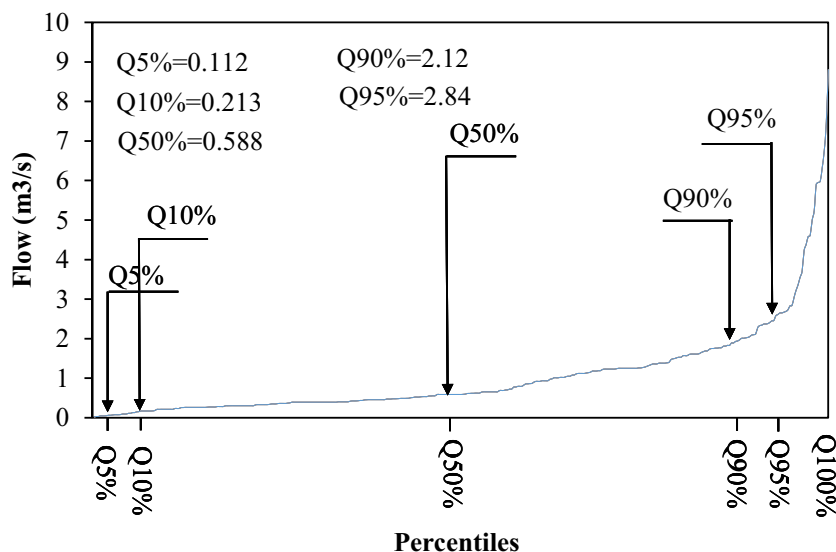
2.3.4 Winter/spring center of volume date (WSCV)

The final two measures are variations of the center of volume date (Hodgkins et al. 2003; Hodgkins and Dudley 2006; Burn 2008). The date corresponding to the center of winter/spring volume (WSCV) is the Julian day by which 50% of the volume for the winter/spring period (January1–June 30) has occurred.

2.3.5 Fall center of volume date (FCV)

The date corresponding to the center of fall volume (FCV) is the Julian day by which 50% of the volume for the fall period (October 1–December 31) has occurred (Burn 2008).

2.4 Trend analysis

The non-parametric Mann-Kendall (MK) method (Mann 1945; Kendall 1975) was applied to the nine time series. One of the main problems in testing a trend in a given data set is the effect of serial dependence. The modified version of the MK test, introduced by Yue et al. (2002), removes the effect of lag-1 serial correlation (r_1) in the data. If there is a positive consecutive correlation in the time series, then the non-parametric test will propose a significant trend in a time series that, in fact, is random more than determined with the significance test (Zhang et al. 2001). Therefore, to eliminate the effect of serial correlation from data series, the significance of r_1 for all time series at the 10% significance level was evaluated. For this purpose, the absolute value of r_1 was compared with the critical threshold, which depends on the number of data and significance level. If the absolute value of r_1 was greater than the critical value at a certain significance level (here 90% level), then the null hypothesis of no significant r_1 was rejected, and the alternative hypothesis (i.e., r_1 is statistically significant at 90% level) was accepted. Otherwise, the null hypothesis was accepted, and the alternative hypothesis was rejected. The effect of consecutive correlation was eliminated from the time series with pre-whitening before applying the MK test. For more information, one can refer to Dinpashoh et al. (2011) and Yue and Wang (2004).

2.5 Theil-Sen's estimator

Sen's slope estimator is a non-parametric method and is closely related to MK test (Tabari et al. 2012). The slope of n couples of data points was computed using this approach (Sen 1968; Dinpashoh et al. 2011) which is given by the following relationship:

$$\beta = Median\left(\frac{x_j - x_l}{j - l}\right) \quad \forall 1 < l < j \tag{1}$$

3 Results and discussion

Figure 3 shows the box plots of trend line slopes for each of the timing measures obtained using the 14 years of data. It is seen from the figure that the median slopes for Q5% and Q10% were negative but were positive in the case of Q50%, Q90%, and Q95%. The median values for Q5% and Q10% were equal to −2.143 and −1.8 (days/year), respectively. However, the median values for Q50%, Q90%, and Q95% were equal to 1, 0.435, and 1.5 (days/year), respectively. This implies that low flows were occurring earlier in time, however, the flood events occurred with delay in time compared with the past years.

It can also be seen from Fig. 3 that all of the trend line slopes for FCV and WSCV were negative. The median values of these two indices were equal to −1.545 and −1 (days/year), respectively. This means that the fall center of volume date occurred earlier in time. This was true in the case of winter/spring center of volume date. It is worth mentioning that most of the trends of FCV and WSCV were statistically significant at the selected stations. The median value of spring freshet dates was negative (Fig. 3d) which was equal to −0.364. This implies that the date on which the first rise of spring freshet occurred was earlier. The median of the pulse date trend line slopes was positive, equal to 0.5 (Fig. 3a).

The spatial distribution of trends of the nine indices are shown in Fig. 4. As can be seen from Fig. 4a, except for the four stations, the pulse date trends were often non-significant. These sites having significant decreasing trends were Lakan, Roodbarsara, and Sazman-Ab located in the center of province. A single station, namely Haratbar, located east of province, exhibited a significant increasing trend for the pulse date. Figure 4b shows that all the stations had decreasing trends in the case of WSCV dates. Twelve out of 37 stations mainly located near the sea had significant decreasing trends in the case of WSCV.

The spatial distribution of trends for FCV is depicted in Fig. 4c which shows that barring two stations, namely Khalyan and Moosa-Kelaye, all other stations showed decreasing trends for FCV. Twenty-seven out of the 37 stations had significant decreasing trends, most of them were located in the east and center of the area under study. Figure 4d shows that excepting four stations, all other stations showed decreasing trends in the case of spring freshet date. Among the 32 stations having decreasing trends in spring freshet dates, four stations exhibited decreasing significant trends.
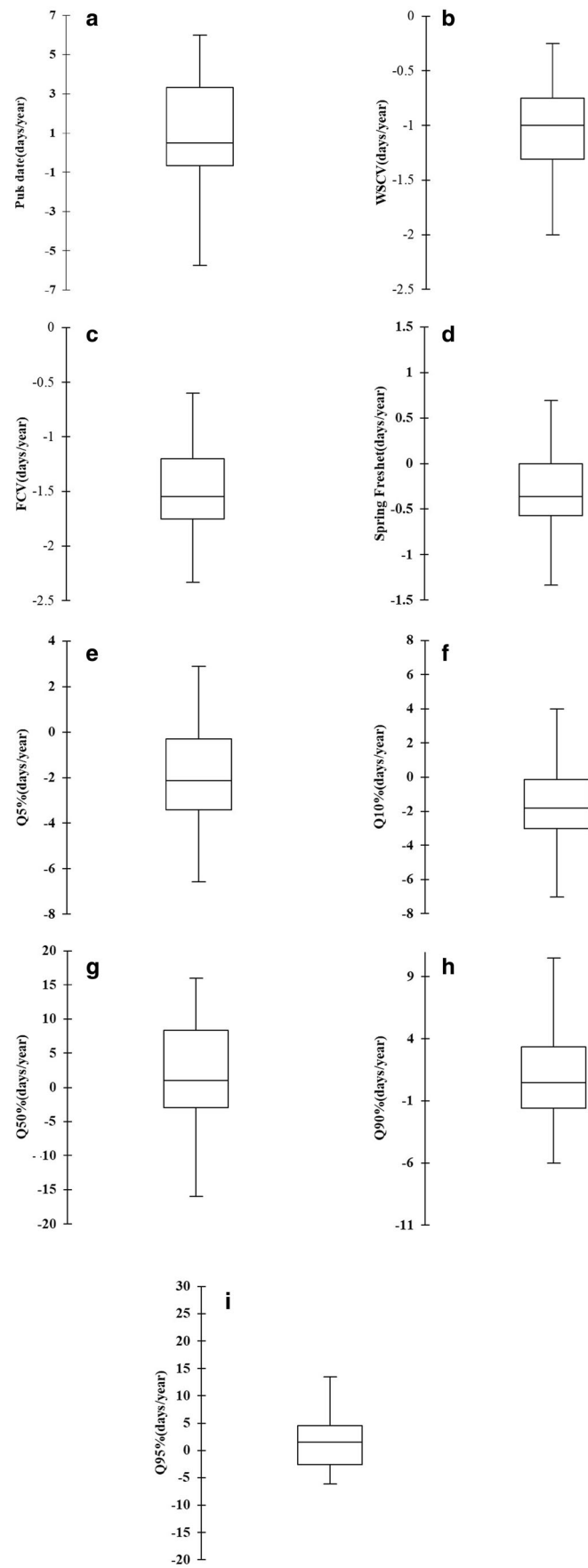
Fig. 3 Box plots of trend slopes for the timing measures. The lower and upper ends of the box define the 25 and 75 percentile values, the line inside the box demonstrates the median, and the whiskers show 5 and 95 percentile values. **a** Pulse date (days/year), **b** WSCV (days/year), **c** FCV (days/year), **d** spring freshet date, **e** 5 percentile date (days/year), **f** 10 percentile date (days/year), **g** 50 percentile date (days/year), **h** 90 percentile date (days/year), and **i** 95 percentile date (days/year)

The spatial distribution of trends for the Q5% dates are displayed in Fig. 4e which shows that except for nine stations, all other stations showed decreasing trends in the case of Q5% dates. Among the nine stations having increasing trends, only one of them exhibited an increasing significant trend. Seven out of 25 stations having decreasing trends in Q5% dates exhibited significant decreasing trends. In the case of Q10% dates, most of the stations had decreasing trends (Fig. 4f). Twenty-seven out of the 37 stations had decreasing trends for the Q10% measure. Among the 27 stations having decreasing trends, two of them exhibited significant decreasing trends. Among the seven remaining stations having increasing trends, only one of them (namely Haratbar) exhibited a significant increasing trend.

The spatial distribution for Q50% is depicted in Fig. 4g which shows that 13 stations had decreasing trends. Among the 13 stations having decreasing trends, two of them (namely Pirsara and Toolelat) exhibited statistically significant decreasing trends. The other 18 stations exhibited increasing trends five of which were significant. The spatial distribution of trends for Q90% is illustrated in Fig. 4h which shows that among all the stations, 19 stations had increasing trends, of which only Pirsara had a statistically significant trend. Also, five out of 15 stations exhibited significant decreasing trends in the case of Q90%. Finally, as can be seen from Fig. 4i, four out of the 37 stations had statistically significant trends in the case of Q95%. Two of them (namely Safar-Mahalleh and Kharjegil) had upward trends, whereas the other two (namely Mobarak-Abad and Otaghvar) had downward significant trends.

Figure 5 shows the spatial distribution of trend line slopes of the nine indices for runoff timing in Guilan Province. In this figure, red color shows a negative trend line slope, whereas green color shows a positive (upwards) trend line slope. The pulse date trend line slopes changed between 13.5 and −6 (days/year) (Fig. 5a). The maximum positive and the minimum negative values belonged to the stations, namely Kharjegil and Roodbarsara, respectively (located in the west of the region, namely Talesh plain). Generally, the pulse date trend line slopes in the west were positive. However, the area which had green color is less than that of red color. Therefore, it can be concluded that the day of the cumulative departure of streamflow from the long-term mean occurs early in time (red color in Fig. 5a) compared with the past. The green color shows the reverse slope of pulse date. Such areas show the day on which the cumulative departure of streamflow from the long-term mean occurs late in time compared with the past.

The slopes of the WSCV date trend lines changed between −0.3 and −2.7 values (days/year) (see Fig. 5b). The maximum positive and minimum negative values of WSCV belonged to the stations, namely Masjed-Pish and Pashaki (located in the Foumanat plain), respectively. The values of this measure were negative for the whole study area. A similar feature of Fig. 5a existed in Fig. 5b. Such differences in the slopes of the WSCV measure can be seen at a few nearby sites. These differences can be attributed to the nature of topography as well as the anthropogenic factors influencing streamflows. However, errors in data records may be the other source of differences.

The slopes of the FCV date trend lines are depicted in Fig. 5c which shows that the maximum positive and minimum negative values belonged to the stations, namely Moosa-Kelaye and Laksar stations, located in the Lahijan-Chaboksar and Foumanat plains, respectively. Generally, the values of FCV date trend line slopes in the high-altitude areas in the southern province were positive which are shown by green color in Fig. 5c. However, the FCV slopes in the middle part of the province were negative, which are shown by red color in Fig. 5c. The positive maximum slopes of the spring freshet date trend lines and the negative minimum of this measure were equal to 0.691 and −1.5, respectively. These values belonged to stations, namely, Shahrebijar and Bajigovar located in the Astaneh-Kouchesfehan and Lahijan-Chaboksar plains, respectively. Indeed, it can be seen from Fig. 5d that the eastern and southern parts of the study area had positive trend line slopes. Such areas have extreme differences in slopes of spring freshet at few nearby stations too. The possible origins of such inconsistencies are discussed later.

Figure 5e shows the Q5% date trend line slopes varied between −7 and 3 (days/year). The maximum positive and minimum negative values belonged to the stations, namely Mobarak-Abad and Kalesara, respectively (located in the Foumanat and Talesh plains, respectively). The few nearby sites had similar inconsistencies in the slopes of trend lines. Possible origins of these differences are discussed later.

Fig. 5f shows that the Q10% date trend line slopes changed between −7 and 15.1 (days/year). The maximum positive and minimum negative values belonged to Sazmane-Ab and Komadol stations (located in the Foumanat plain), respectively. These results indicate that the trend line slopes in the south part of the area were negative (Fig. 5f). The Q50% date index trend line slopes changed between −16 and 16 (days/year) (Fig. 5g). The maximum positive and negative minimum values belonged to Roodbarsara and Loshan stations, respectively (located in the Talesh and Taleghan-Alamout plains, respectively). Indeed, the southeastern part and points near the sea stations had negative and positive trend line slopes, respectively (Fig. 5g).

The Q90% dates trend line slopes changed between −10 and 14 (days/year) (Fig. 5h). The maximum positive and
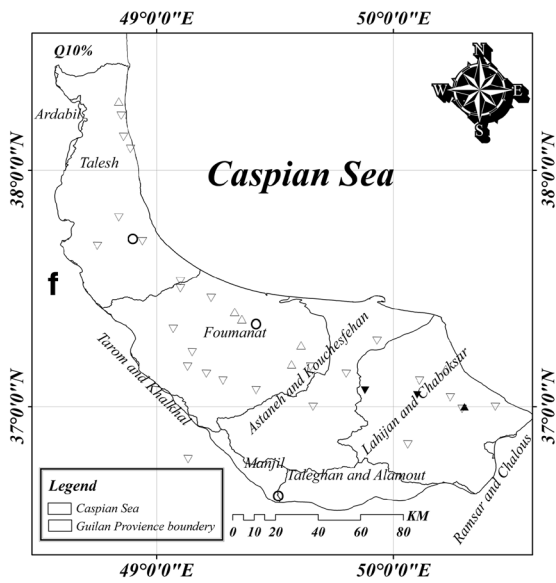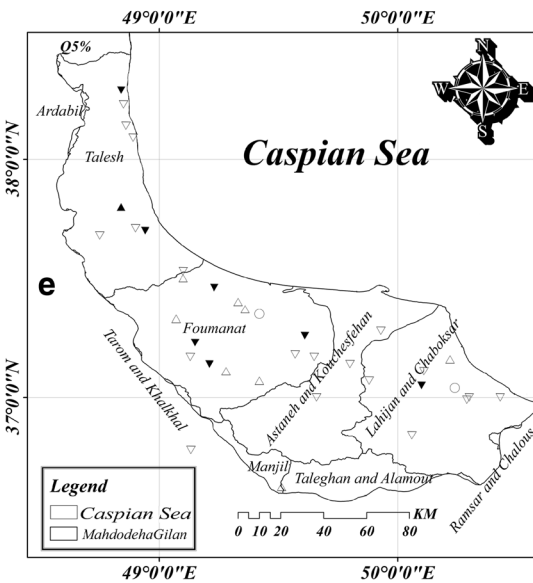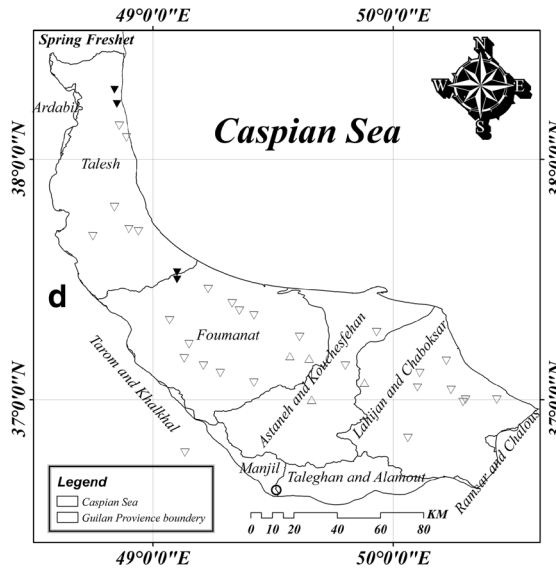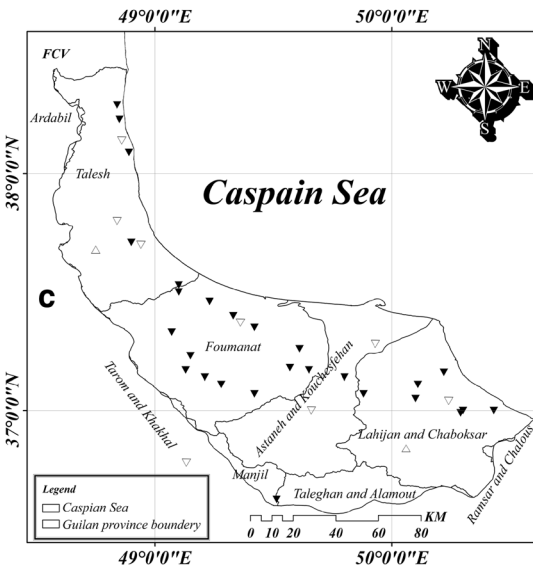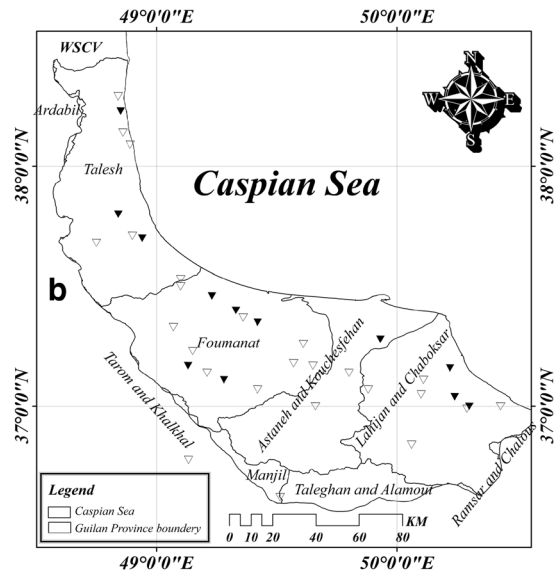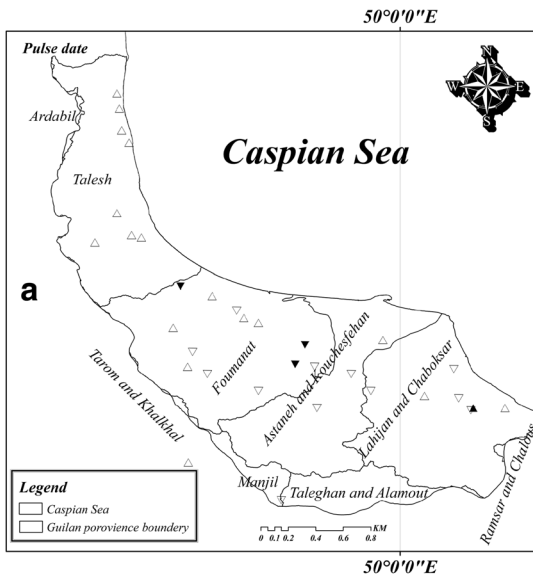
◀ **Fig. 4** Spatial distribution of trend results for **a** pulse date, **b** WSCV, **c** FCV, **d** spring freshet, **e** Q5% f) Q10%, **g** Q50%, **h** Q90%, and **i** Q95% for the period (2003–2016) for the Guilan Province. Downward (upward) pointing hollow triangles indicate the location of stations with decreasing (increasing) trend, and the downward (upward) pointing black-filled triangles indicate the location of stations with decreasing (increasing) trend (both at the 90% significance level). The open circles indicate the location of stations with zero Z statistics (i.e., no significant trend in any significance level)

minimum negative values belonged to Ghaleroodkhan and Taskooh stations (located in the Foumanat plain), respectively. As can be seen, the middle part of the area had positive trend line slopes which are shown by green color in Fig. 5h. Finally,

the domain of Q95% date trend line slopes changed between − 17 and 25 (days/year) (Fig. 5i). The maximum positive and minimum negative values belonged to Pashaki and Otaghvar stations, located in the Astaneh-Kouchesfehan and Lahijan-Chaboksar plains, respectively. Perhaps the reason of a few nearby stations having extreme differences is the topography of area. In the west of the province, the area is mountainous and the land is covered by tall trees. Such topography traps snow in the high-altitude forest regions which thaws late in spring. In contrast, the nearby station (in Fig. 5a, b, d, e) is located in the plain in which snow is not the main source of streamflow. On the other hand, anthropogenic factors as well as the possible errors in recorded data might be the other sources of differences in the figure.
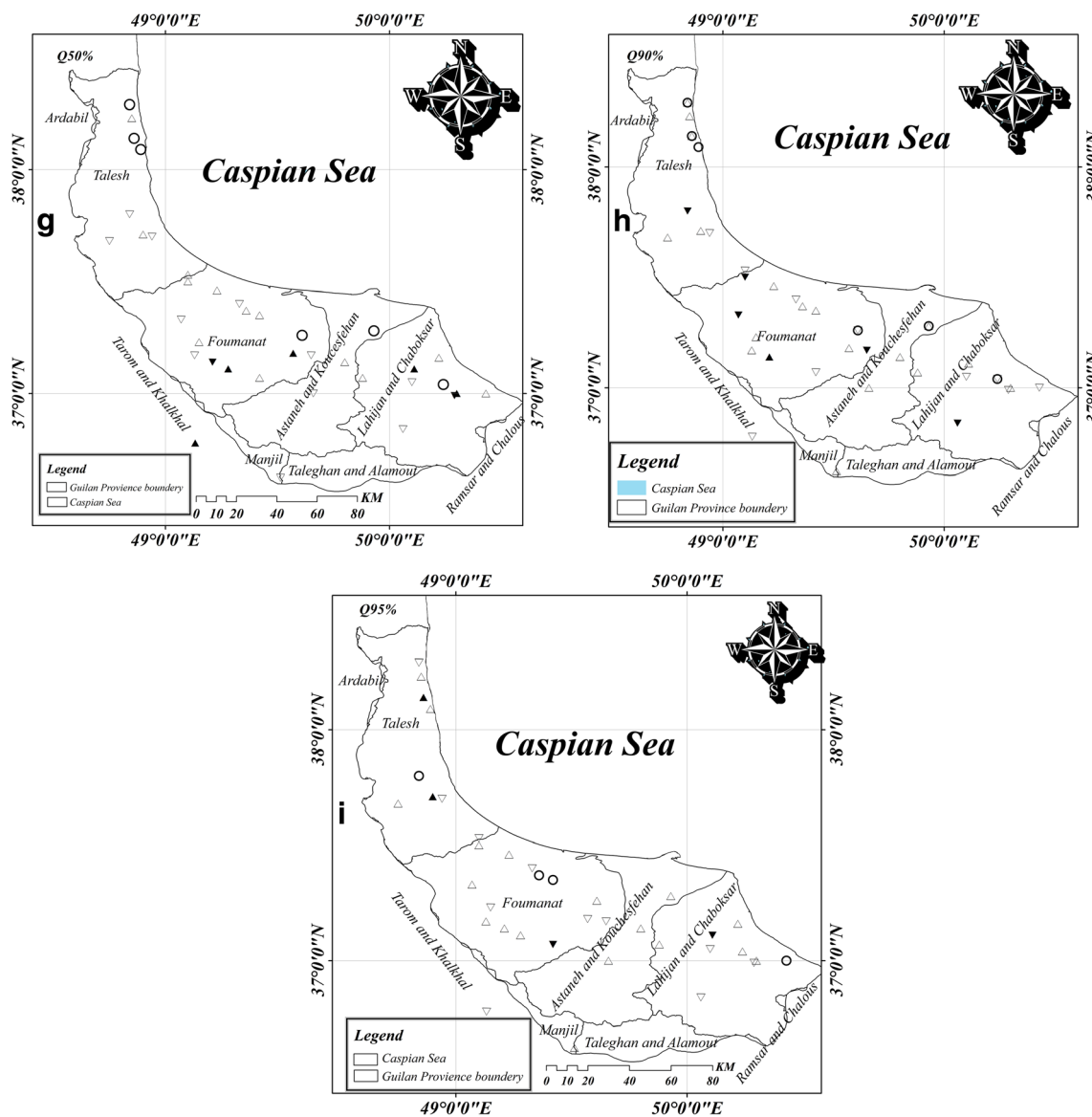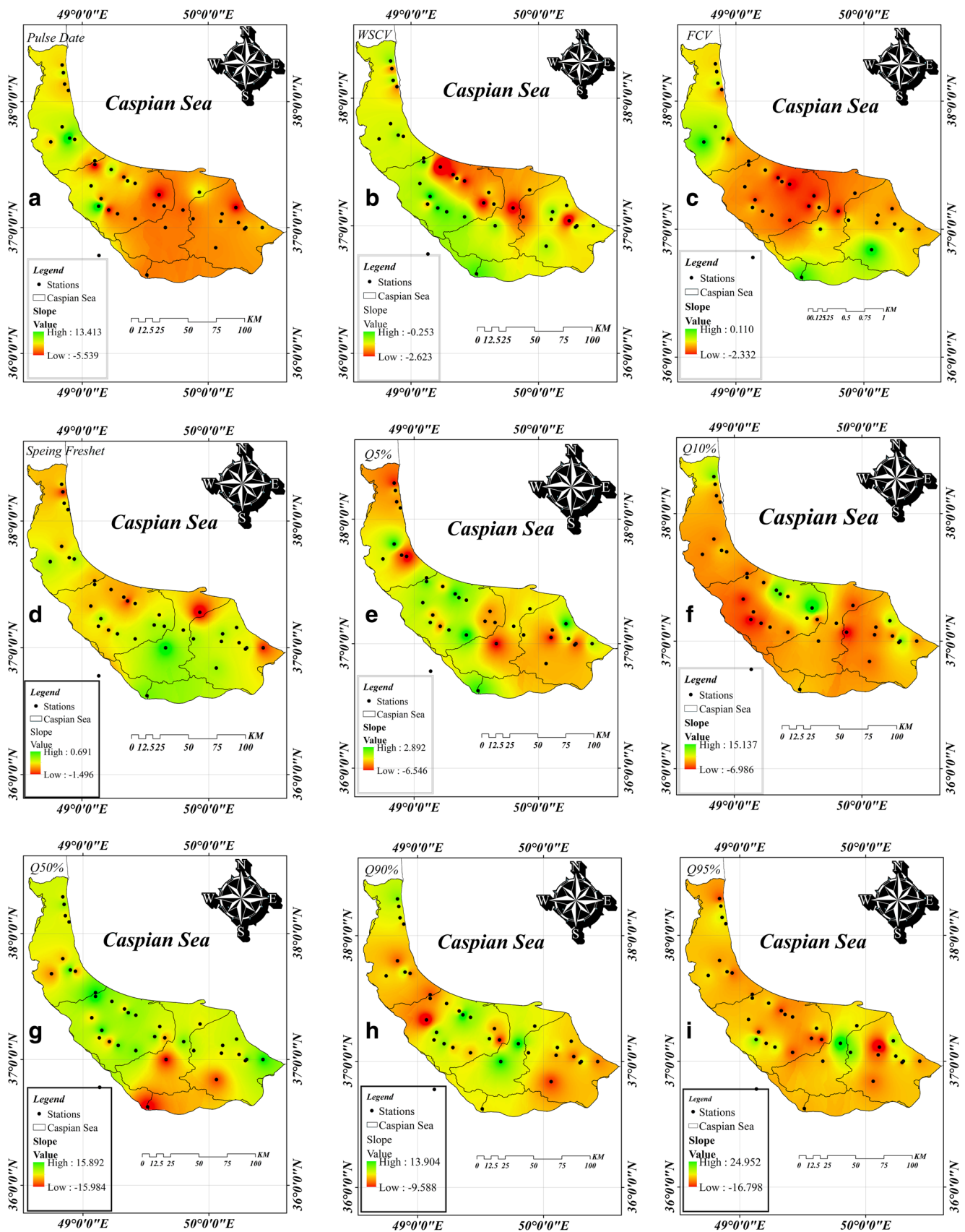

Fig. 4 continued.

Fig. 5 Spatial distribution of trend slopes for the **a** pulse date (days/year), **b** WSCV (days/year), **c** FCV (days/year), **d** spring freshet (days/year), **e** Q5%(days/year), **f** Q10%(days/year), **g** Q50% (days/year), **h** Q90%(days/year), and **i** Q95%(days/year) for 14 years (2003–2016)

4 Conclusion

Nine timing measures of streamflow at 37 gaging stations in a humid climate area of Guilan, Iran, were used and their trends were assessed. The effect of climate change on streamflow timing characteristics was investigated using (i) the MK method and (ii) Sen's estimator method. The median slopes of trend lines for low flow timing dates (Q5% and Q10%) were negative. The time series of the starting time of Q5% showed the steepest median of trend line slopes (among all the other eight quantiles and used measures) for the stations, implying that low flows originating from the groundwater leakage into the rivers occurred earlier than in the past. This means that the dry periods at the stations are becoming longer. Therefore, in water resources management, caution should be exercised for this important result. In contrast, the median slopes for high flow timing dates (Q90% and Q95%) were upward. On the other hand, the median of time series for Q50% was upward for all 37 selected stations, implying that the climate change impact on the median of Q50% time series is that such median discharges in this region arose late compared with the past years. Among all the nine measures, the FCV and WSCV dates had the most significant trends in the downward direction, implying that half of the runoff volume for the selected stations occurred earlier in time compared with the past, which in turn, implies longer dry spells in a year. Trends in spring freshet were mainly negative and were significant in the northwest. However, trends in the pulse date were negative mainly in the west. In general, it can be concluded that the timing of runoff in the study area changed due to climate change. The occurrence of low flow became earlier, and the length of dry periods in a year became longer. As is well known, the air temperature is rising and low flows are occurring earlier in time; hence, it can be anticipated that the planting date of cereals (especially rice which is the main type of cereal planting in the province) should be early. Medians of Q50%, Q90%, and Q95% were found to be positive which means that severe flash floods might occur late in time which should be taken into account in the preparedness of rural and urban communities to lessen flood hazards.

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