



Trend analysis of hydro-climatic variables in the north of Iran

E. Nikzad Tehrani¹ · H. Sahour² · M. J. Booij³

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Abstract

Trend analysis of climate variables such as streamflow, precipitation, and temperature provides useful information for understanding the hydrological changes associated with climate change. In this study, a nonparametric Mann-Kendall test was employed to evaluate annual, seasonal, and monthly trends of precipitation and streamflow for the Neka basin in the north of Iran over a 44-year period (1972 to 2015). In addition, the Inverse Distance Weight (IDW) method was used for annual seasonal, monthly, and daily precipitation trends in order to investigate the spatial correlation between precipitation and streamflow trends in the study area. Results showed a downward trend in annual and winter precipitation ($Z < -1.96$) and an upward trend in annual maximum daily precipitation. Annual and monthly mean flows for most of the months in the Neka basin decreased by 14% significantly, but the annual maximum daily flow increased by 118%. Results for the trend analysis of streamflow and climatic variables showed that there are statistically significant relationships between precipitation and streamflow (p value < 0.05). Correlation coefficients for Kendall, Spearman's rank and linear regression are 0.43, 0.61, and 0.67, respectively. The spatial presentation of the detected precipitation and streamflow trends showed a downward trend for the mean annual precipitation observed in the upstream part of the study area which is consistent with the streamflow trend. Also, there is a good correlation between monthly and seasonal precipitation and streamflow for all sub-basins (Sefidchah, Gelvard, Abelu). In general, from a hydro-climatic point of view, the results showed that the study area is moving towards a situation with more severe drought events.

Keywords Climate change · Streamflow trend · Precipitation trend · Mann-Kendal test · Spatial patterns

1 Introduction

Global increases in greenhouse gases in the atmosphere are expected to be the major cause for changes in various climate variables such as temperature and precipitation (e.g., IPCC 2013). Evaluation of climate change impacts on the hydrological cycle is a key component for any long-term water resources utilization and management program. Assessment of climate change helps to build resilience to its possible impact through enhanced institutional flexibility and consideration of climate-related risks in the planning process (Buishand et al.

2013; Gocic and Trajkovic 2013; Kundzewicz and Robson 2004; Obot et al. 2010; Wang and Li 2015). Therefore, it is important to investigate the impacts of climate change patterns on water resources and to implement appropriate adaptation strategies. Analysis of hydro-climatic time series (e.g., precipitation, temperature, and river discharge) in different parts of the world for detecting climate change has been frequently reported in international studies during the last decade (Shaban 2008; Novotny and Stefan, 2007; Wue et al. 2007; Zhang and Lu, 2009; Tian et al. 2012; Hubbart and Zell, 2013; Yeh et al. 2015; Zamani et al. 2016; Gholami et al. 2017). Temperature plays an important role in evaporation, transpiration, and water demand, and thus significantly affects both water requirements and strategies to assure its availability. Many decision makers believe that the effects of global warming are already being felt (Capparelli et al. 2013). Temperature changes, as a cause of alterations to precipitation patterns, are crucial for the management of water resources and water-related natural hazards (Zhang et al. 2013). Several studies have been carried out on trend analysis of temperature in Iran and neighboring regions in recent years (Soltani et al.

✉ H. Sahour
hossein.sahour@wmich.edu

¹ Mazandaran Regional Water Company, Sari, Iran

² Department of Geological and Environmental Sciences, Western Michigan University, Kalamazoo, MI 49008, USA

³ Water Engineering and Management Group, Faculty of Engineering Technology, University of Twente, Enschede, Netherlands

2015, Saboohi et al. 2012 and Tabari and Hosseinzadeh Talae (2011a). Kousari et al. (2013) detected meaningful trends in maximum air temperature during warm months (April, June, July, August, and September) over the period 1960–2005. Ghasemi (2015) evaluated trends in maximum, minimum, and mean temperatures over the period 1961–2010 using the Mann-Kendall test. The study showed a general dominating warming trend over most parts of Iran. Dinpashoh et al. (2011) investigated trends in reference crop evapotranspiration on monthly and annual scales in Iran. They concluded that the upward trends in reference crop evapotranspiration were more pronounced than the downward trends on an annual scale. On a monthly scale, there was a larger number of upward trends than the number of downward trends in most of the warm months. Jhajharia et al. (2012) reported a significantly decreasing trend for reference crop evapotranspiration on annual and seasonal scales for 6 sites in NE India and NE India as a whole during the last 22 years. Jhajharia et al. (2014) showed that about 60% (45%) of the stations exhibited increasing trends in the maximum temperature (minimum temperature) for different durations.

Precipitation is the most important hydro-climatic variable to be investigated as a key for flood and drought events and mitigation assessments (Groisman et al. 2001; McCabe and Wolock, 2002; Esmaeli Gholzom and Gholami 2012). In recent years, several studies have been carried out on trend analyses of precipitation in the area of interest (Irannezhad et al. 2014, 2015)

and the Middle East (Tabari and Hosseinzadeh Talae (2011b) and Soltani et al. 2012). In Iran, Farhangi et al. (2016) analyzed the rainfall trends in the west of Iran and concluded that most stations experienced a downward trend. Minaei and Irannezhad (2016) used a nonparametric Mann-Kendall test to analyze the spatiotemporal trends of climate variables in the northeast of Iran. They observed a significantly increasing trend in monthly precipitation for 19% of the stations and a significantly increasing trend in annual precipitation for 13% of the stations. Abolverdi et al. (2014) identified no significant trends in precipitation over the Maharlo watershed in the south of Iran. Soltani et al. (2015) investigated extreme climate indices at 50 meteorological stations during 1975–2010 and identified significant trends for less than 15% of the stations. Partal and Kahya (2006) used nonparametric methods (i.e., the Mann-Kendall and Sen's slope estimator tests) to determine trends in the long-term annual, mean, and monthly precipitation series. They presented a significant decrease in the annual mean precipitation mostly in western and southern Turkey, as well as along the coasts of the Black Sea.

Streamflow integrates the impact of atmospheric variables over a basin. If consistent changes are observed in precipitation and temperature, these should also be reflected to some degree in streamflow at the basin scale (Kliment et al. 2011). There are numerous studies focusing on this topic around the world; in Iran, Masih et al. (2011) used the Spearman rank test for the detection of trends. They revealed a number of

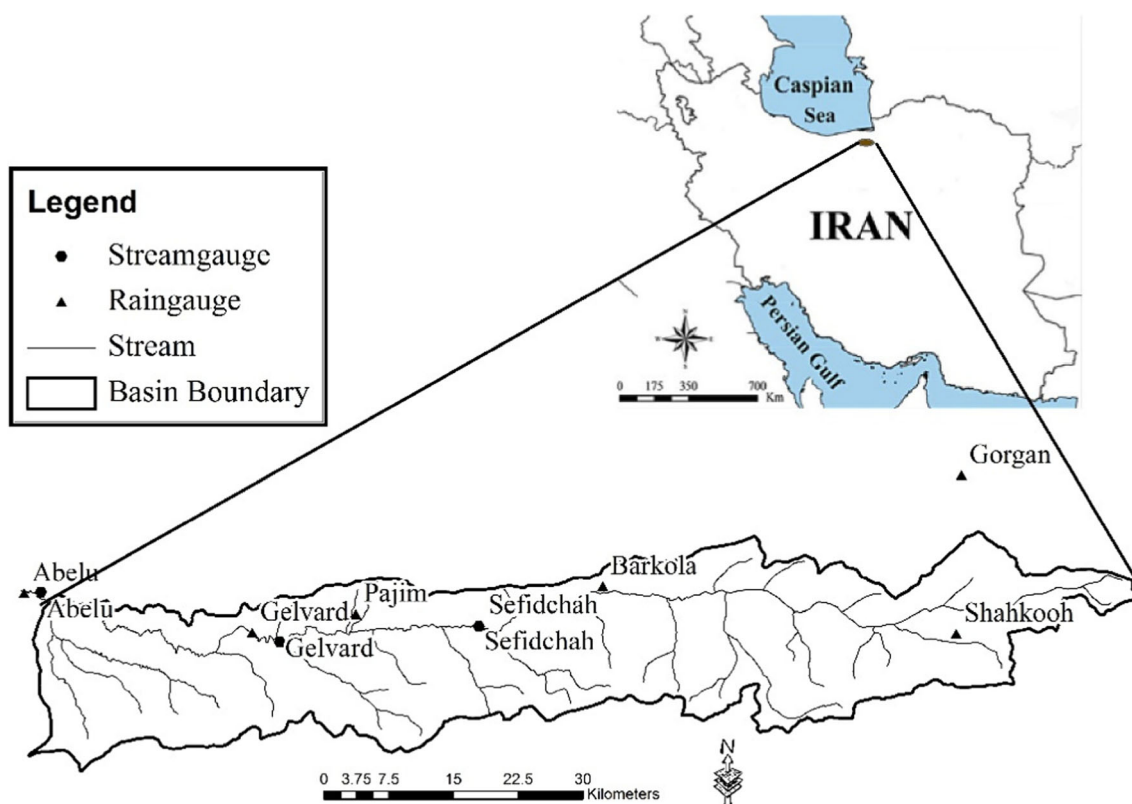


Fig. 1 Neka basin, stream network, and location of streamflow and rain gauge stations

Table 1 Characteristics of rain gauge stations located in or around Neka basin

Station	Station code	Gauge elevation (m)	Record since	ρ	P_{mean} (mm)	$P_{\text{max}}^{\text{day}}$ (mm)
Pajim*	13-007	1250	1973	0.113	775.6	49.63
Sefidchah*	13-005	1040	1968	0.133	428.62	39.22
Gorgan	40,738	13	1952	0.005	581.66	49.47
Gelvard*	13-009	660	1981	0.168	883.14	57.83
Barkola*	13-001	1430	1972	0.228	514.75	46.74
Abelu*	13-013	50	1970	0.091	720.4	55.47
Shahkooh*	13-002	2500	1970	0.260	350.03	29.37

*Stations which are located in Neka basin. Thiessen weights (ρ) are areal weights assigned to each station based on the Thiessen polygon method. The end of the period for all gauges to compute the mean annual precipitation (P_{mean}) is 2015. $P_{\text{max}}^{\text{day}}$ is the maximum daily precipitation

significant trends in streamflow variables, both increasing (e.g., December flows) and decreasing (e.g., May flows) for all stations. In another study in Iran, Fathian et al. (2015) used three nonparametric statistical tests, the Mann-Kendall, Spearman rho, and Sen's slope estimator, to estimate the trends in the annual and seasonal time series of streamflow at 95 stations throughout the basin. The tests showed a general decreasing trend in basin streamflow that was more pronounced for the downstream stations. In Turkey, Kahya and Kalaycı (2004) used four nonparametric trend tests to detect streamflow trends in Turkey. They found significantly downward trends in western and southeastern Turkey.

In the northern part of Iran, previous studies on climate and streamflow variables are rare. Thus, there is an obvious need for more research in this area to provide a comprehensive overview of trends on streamflow and climate variables. No comprehensive study has yet been conducted in this region for spatial pattern analysis of hydro-climatic variables. The objective of the present study is to explore temporal and spatial trends in the time series of temperature, precipitation, and streamflow in the northern part of Iran using a nonparametric statistical technique, namely the Mann-Kendall test. The main objectives of this study are to (1) assess the trends in precipitation, temperature, and streamflow for the stations studied; (2) determine basin-scale relations between the hydro-meteorological time series using the Kendall, Spearman rank and linear regression tests; and (3) to present a spatial visualization of the detected precipitation, temperature, and streamflow trends in order to compare the variables.

2 Material and methods

2.1 Study area and data

The study area is the Neka River basin located in Mazandaran province, in the northern part of Iran. The area is approximately 1992 km² extending from 53 20' to 54 50'E and 36 27' to 36 40'

N. The elevation in the Neka River basin varies from -27 m at the outlet to 3400 m upstream. The length of the main stream is approximately 175 km. The main land use in the basin consists of rangeland in the upstream area, forest in the middle of the basin, and urban areas downstream. Geological formations mostly consist of limestone and dolomitized limestone layers. The river is characterized by perennial flow conditions. The hydro-climate data were obtained from the Mazandaran Regional Water Company (MRWC) and the Iran Meteorological Organization (IMO). The data were acquired for stations lying in a quadrangle that covered the entire watershed. Within the quadrangle, seven stations were working in 2015 and had sufficiently long records (at least 44 years). The locations of the stations are shown in Fig. 1. Table 1 shows the details of the rain gauge stations. Six stations are located inside the Neka basin. The data from three stations with continuous records of daily streamflow (Sefidchah, Gelvard, Abelu) are used in this analysis and locations are shown in Fig. 1 as well. These gauges are currently in operation (Table 2).

2.2 Methodology

The systematic method that was employed in this study to detect the significance and comparison of the trends in streamflow, precipitation and temperature can be summarized through the following steps:

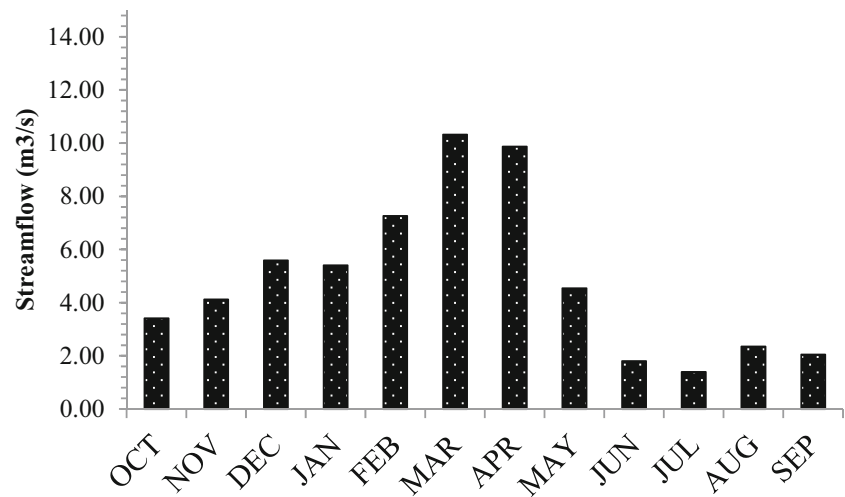
- Selection of the variables for trend analysis. Streamflow, precipitation, and temperature were used given their key role in the hydrological cycle.

Table 2 Characteristics of stream gauge stations located in Neka basin

Station	Station code	$H_{(m)}$	$A_{(km^2)}$	Record period	$Q_{(m^3/s)}$
Sefidchah	13-005	1040	1040	1972-2016	1.12
Gelvard	13-009	600	1405	1978-2016	3.58
Abelu	13-013	50	1900	1973-2016	4.76

* H gauge elevation, A contributing drainage area, Q mean annual discharge

Fig. 2 Distribution of mean monthly streamflow in Neka basin (Abelu station)



- Identification of trends in the time series data. This was done using the Mann-Kendall nonparametric test.
- Applying Sen's slope estimator and determine the temporal correlation between the variables using the Kendall, Spearman Rank, and linear regression tests.
- Spatial visualization of the detected precipitation, temperature, and streamflow trends in order to compare the variables.

2.2.1 Selection of hydro-climatic variables

Numerous studies have suggested analyzing different variables to investigate the changes in hydro-climatic regimes (Monlar and Ramirez 2001, Burn and Hag Elnur, 2002 and Burn and Cunderlik 2004). The procedure adopted is to select a collection of variables comprising the components of the hydrologic and meteorological regime. Monthly, annual, and seasonal precipitation; temperature; and streamflow were computed from daily data. Analysis of streamflow, temperature, and precipitation was conducted for a period of 44 years from 1972 to 2015 using water years (from October 1 to September 30). Annual maximum daily precipitation and streamflow were selected to analyze the extreme events in the Neka basin.

2.2.2 Statistical test for detection of trends and serial correlation

Testing for trends was conducted using the nonparametric Mann-Kendall test (Kendall 1938), which is commonly used for hydrologic data analysis (Hirsch and Slack 1984; Helsel and Hirsch 1992; Hirsch and Slack, 1982). It is a rank-based procedure especially suitable for non-normally distributed data, censored data, data containing outliers, and nonlinear trends. Detailed explanation of the Mann-Kendall test can be found in Helsel and Hirsch (1992). The Mann-Kendall approach requires the data to be serially independent. If the data are positively serially correlated, then the Mann-Kendall approach tends to overestimate the significance of a trend. If,

on the other hand, the data have a negative serial correlation, then the significance of the trend is underestimated. To investigate serial correlation in time series, the Watson-Durbin test can be used (Durbin and Watson, 1971). This statistic ranges from 0 to 4. If the correlation between successive observations does not exist, the Durbin-Watson statistic is close to 2. If this statistic is close to zero, it shows a negative strong

Table 3 Monthly, seasonal, and annual streamflow trends with $p = 0.95$ for the common period*

Station Variables	Sefidchah	Gelvard	Abelu
October mean flow	-2.98	-2.40	-0.08
November mean flow	-4.85	-2.84	-1.64
December mean flow	-4.05	-1.00	-0.85
January mean flow	-3.43	-1.26	-1.12
February mean flow	-3.35	-0.52	-0.85
March mean flow	-2.40	-1.34	-1.75
April mean flow	-3.81	-1.90	-2.07
May mean flow	-4.19	-3.14	-1.40
Jun mean flow	-2.59	-3.48	-2.89
July mean flow	-2.82	-3.67	-2.50
August mean flow	-2.33	-3.43	-2.63
September mean flow	-0.59	-2.71	-0.26
Fall mean flow	-4.40	-2.03	-0.83
Winter mean flow	-3.18	-1.07	-1.36
Spring mean flow	-4.15	-2.73	-2.20
Summer mean flow	-1.43	-3.65	-1.69
Annual mean flow	-4.29	-2.81	-1.52
Annual maximum daily flow	-0.03	1.77	1.06

* The column of each station shows the Z statistic of the trend test. The sign of Z indicates the trend direction. Statistically significant trends at the 95% confidence level are shown in bold. Fall includes October, November, and December; winter includes January, February, and March; spring includes April, May, and Jun; and summer includes July, August, and September

correlation among successive observations. In general, if the statistic is between 1.5 and 2.5 it can be concluded that there is no correlation between successive observations. Successive correlation has a slight effect on the Mann-Kendall statistic when the number of samples is more than 50 (Yue and Wang, 2002). As the study period is 44 years, all time series have been tested using this method. There are few series with serial correlation, minimizing the effect on the results of this research. To correct the serial correlation in the data, the Trend-Free Pre-Whitening (TFPW) procedure was used. A more detailed description of the methodology can be found in Yue and Pilon (2003). This method has been used in other streamflow analyses by Burn and Hag Elnur (2002), Burn and Cunderlik, (2004a, 2004), and Abdul Aziz and Burn (2006) as well.

2.2.3 Basin-scale relations between trends in climatic variables and streamflow

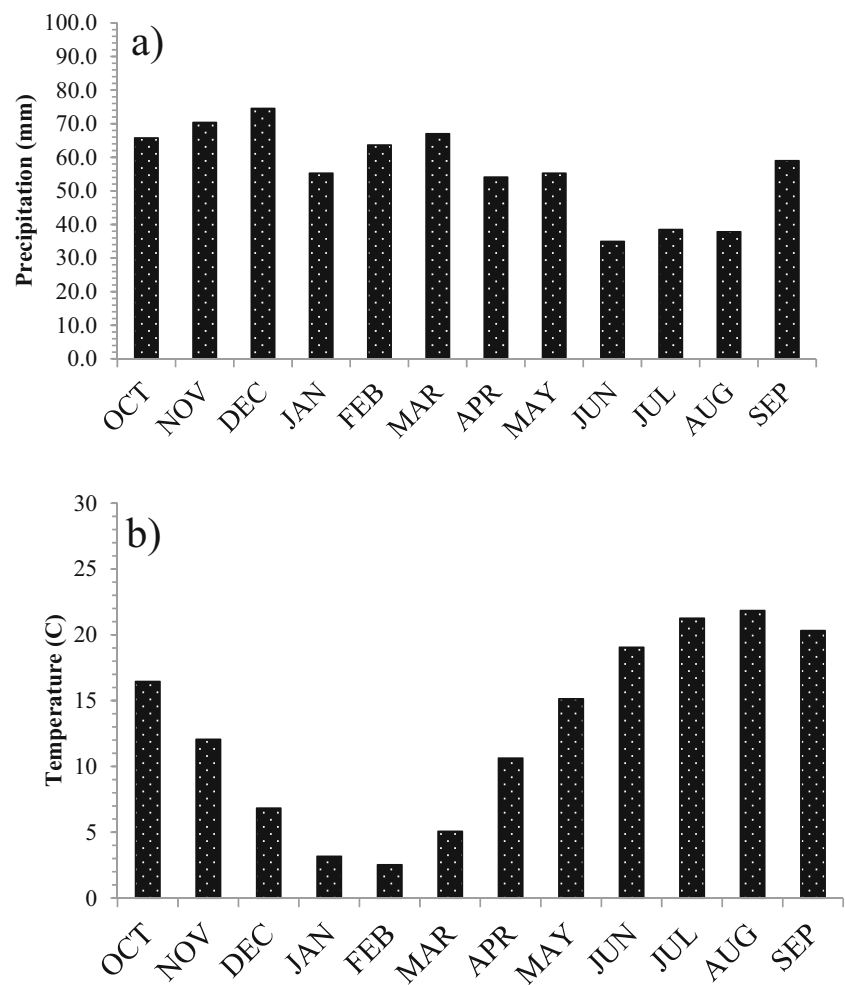
The relationship between trends in streamflow and climatic variables was assessed by performing parametric and non-parametric tests. The parametric linear regression test and

nonparametric Spearman's Rank (SR) and Kendall correlation coefficients were examined to study correlation between streamflow and climatic variables. Each method has its own strength and weakness and the results of these different tests can complement each other. For the simple linear regression method, the parametric t test is powerful to test the significance of the long-term linear trend, while the Kendall and Spearman's Rank (SR) tests can show detailed trends of different periods over the analyzed time series and do not require the data to have a normal distribution. A detailed explanation of these tests is presented in McCuen (2003).

2.2.4 Spatial relations between trends in precipitation and streamflow

A spatial presentation of the detected precipitation trends gives us insight for a better understanding of climatic changes or variations in the study area within the last 44 years, especially in terms of the spatial distribution of precipitation trends. The spatial distribution of precipitation trends (Z -statistics) was determined using the Inverse Distance

Fig. 3 Distribution of **a** mean monthly precipitation and **b** mean monthly temperature



Weighting (IDW) interpolation method. IDW is a kind of multivariate interpolation in which the assigned values to unknown points are calculated with a weighted average of the values available at the known points. In the IDW method, the weight assigned to cells in a raster is a function of the distance between the input point and the output cell location (Gemmer et al. 2004).

3 Results and discussion

The main results are reported in four sections. First, trends in streamflow were analyzed for monthly, seasonal, annual, and annual maximum daily time series. Second, trends in precipitation and air temperature were analyzed and their connections with streamflow were investigated. Third, temporal relationships between trends in streamflow, precipitation, and air temperature were investigated. Fourth, spatial relationships between trends in streamflow and precipitation were explored.

3.1 Streamflow trends

The monthly distribution of mean streamflow in the Neka basin is shown in Fig. 2. On average, most of the streamflow occurs in late winter and spring. March is commonly the

month with the highest observed streamflow in the basin. However, the highest precipitation occurs in fall. This time delay is due to snow melt and base flow from the mountainous regions in the eastern part of the basin.

Results of the trend analysis for monthly streamflow using the nonparametric tests are presented in Table 3. First, there is a statistically significant downward trend for all months in Sefidchah sub-basin except for September. Seven months show statistically significant decreasing trends in the Gelvard sub-basin, while the other months experienced downward trends which are not statistically significant. April, June, July, and August have experienced significant downward trends in the Abelu sub-basin.

At the seasonal timescale, there is a statistically significant downward trend in streamflow in winter, spring, and fall in the Sefidchah sub-basin (Table 3). In the Gelvard sub-basin, fall, spring, and summer have experienced a significant downward trend ($Z < -1.96$). The streamflow trend in spring is significantly downward for the Abelu sub-basin.

The annual trend in the Sefidchah and Gelvard sub-basins are downward (statistically significant), and in the Abelu sub-basin there is a downward trend which is not significant. In contrast, Minaei and Irannezhad (2016) found no clear trend in annual streamflow in the northeast of Iran, but Abghari et al. (2013) reported significant changes in mean annual

Table 4 Monthly, seasonal, and annual precipitation trends with $p = 0.95$ for the common period

Station Variables	Sefidchah	Pajim	Abelu	Barkola	Gelvard	Shahkooh	Gorgan	Neka basin								
OCT	43.9	0.79	77.4	0.23	80.7	0.51	55.7	1.02	85.8	0.31	18.9	-0.80	55.4	-0.92	65.8	-0.01
NOV	47.4	-0.19	77.0	1.35	93.1	0.74	51.8	-0.27	90.0	0.04	21.5	0.70	67.2	-0.50	70.4	-0.43
DEC	50.9	1.19	92.4	-1.24	93.7	-0.17	51.9	1.79	98.6	-0.26	39.8	-2.69	56.0	-2.87	74.5	-0.91
JAN	34.1	-3.19	60.9	-1.57	65.6	-0.75	39.3	-0.41	65.7	-1.15	31.4	-4.04	51.9	-0.98	55.3	-2.41
FEB	45.5	-0.12	71.3	-1.41	77.2	-0.98	43.7	1.88	74.7	0.16	35.7	-2.99	57.5	-2.68	63.7	-1.88
MAR	36.3	1.16	69.0	-1.12	74.5	0.04	44.4	0.45	83.8	-0.18	38.5	-0.99	70.0	0.71	67.0	-0.83
APR	34.7	-0.37	56.8	-0.20	50.9	-0.11	39.7	-0.09	61.6	-0.13	48.8	-1.12	44.4	-0.48	54.1	-0.69
MAY	36.0	-2.65	58.8	-2.84	41.7	-1.13	43.7	-1.57	67.3	-1.74	40.6	-2.36	49.3	0.72	55.3	-2.08
JUN	21.1	-1.25	41.2	-1.13	25.4	-0.15	30.0	-0.54	42.2	-0.35	25.5	-0.55	28.9	-0.12	35.0	-0.61
JUL	23.3	-0.54	50.7	0.20	31.4	-0.58	35.5	1.54	57.0	-1.18	22.3	-1.16	21.9	0.75	38.5	0.16
AUG	20.2	-0.60	53.7	-2.36	29.6	-3.11	33.1	-0.83	61.2	-1.53	10.2	-0.88	28.2	-1.27	37.8	-2.51
SEP	35.4	1.29	66.5	1.00	56.7	-0.16	45.8	2.24	95.4	-0.85	16.7	0.43	50.9	0.10	59.0	0.95
Fall	142.2	1.51	246.7	0.35	267.5	0.41	159.5	1.76	274.3	0.73	80.1	-1.66	162.3	-1.73	174.6	-1.36
Winter	115.9	-1.42	201.2	-2.11	217.3	-0.88	127.5	1.33	224.2	-0.40	105.7	-3.68	163.1	-1.75	153.3	-1.27
Spring	91.8	-2.03	156.9	-1.99	118.0	-0.69	113.4	-1.08	171.1	-0.93	114.9	-2.67	111.5	0.28	125.9	-0.51
Summer	78.9	1.06	170.8	-1.27	117.7	-2.09	114.3	2.12	213.6	-1.55	49.3	-1.40	91.9	-0.23	116.0	-1.36
Annual	428.6	-0.64	775.6	-1.78	720.4	-1.05	510.8	1.50	883.1	-1.00	350.0	-3.64	581.7	-1.24	570.9	-1.96
Annual max daily prec.	39.2	2.94	49.6	-0.91	55.5	0.20	46.7	2.61	57.8	1.04	29.4	-3.54	49.5	1.66	44.2	-0.51

The first column of each station is the mean precipitation (mm). The second column of each station shows the Z statistic of the trend test. The sign of Z indicates the trend direction. Statistically significant trends at the 95% confidence level are shown in bold

streamflow in some parts of western Iran. Kahya and Kalaycı (2004) found significant downward trends in western and southeastern Turkey with a similar latitude as the study area. The peak flows seem to have upward tendency in the Gelvard and Abelu sub-basins.

3.2 Precipitation and temperature trends

The mean annual precipitation in the Neka basin was estimated using the Thiessen polygon method. The weights and mean annual precipitation of each station are given in

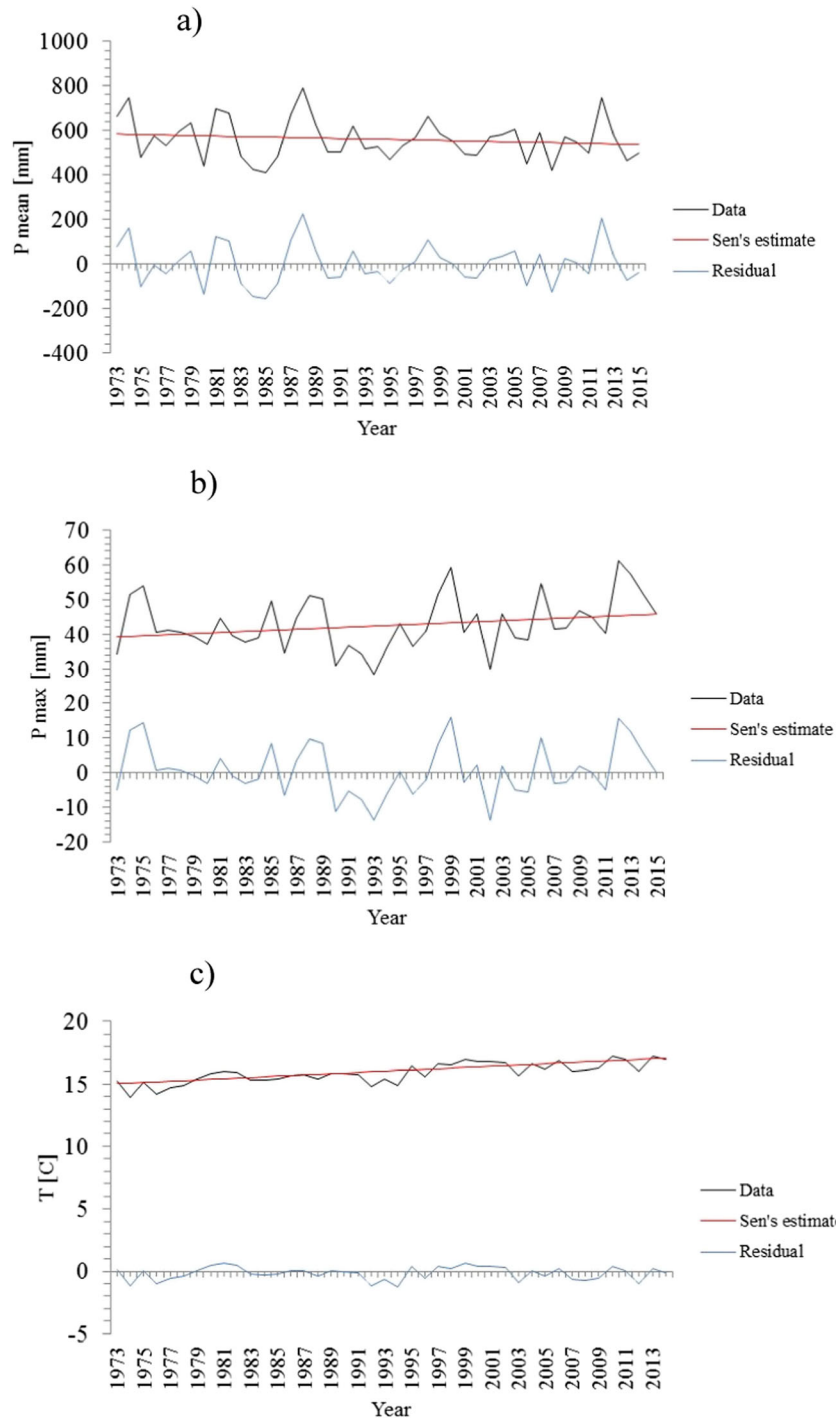


Fig. 4 Sen's slope estimator: **a** Time series for the period 1972–2015 of mean annual precipitation over the Neka basin with linearly decreasing trend. **b** Time series of annual maximum daily precipitation over the Neka basin with significant linearly increasing trend. **c** Time series of mean annual temperature for Sefidchah station with significant linearly

increasing trend. **d** Time series of mean annual streamflow for Abelu station with linearly decreasing trend. **e** Time series of annual maximum daily streamflow for Abelu station with linearly increasing trend

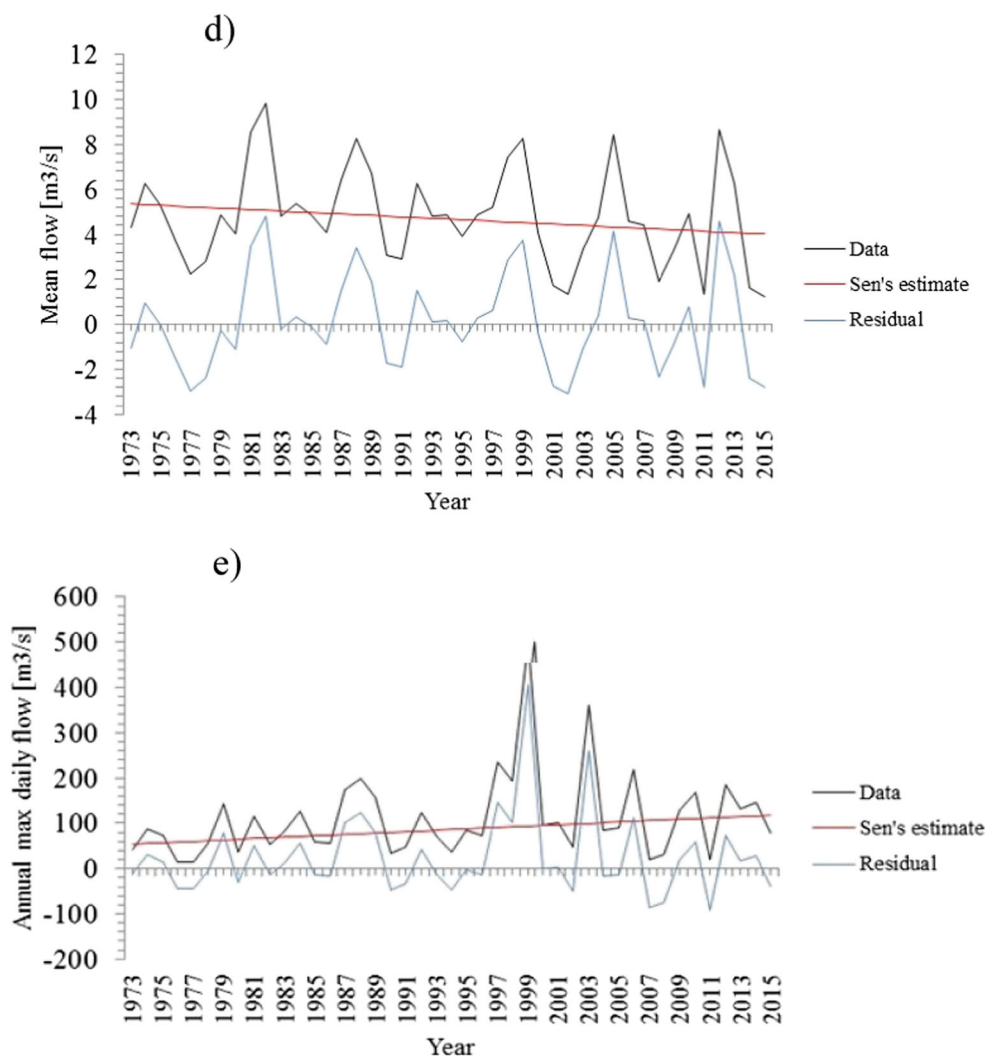


Fig. 4 (continued)

Table 1. Estimated mean annual precipitation in the Neka basin from 1972 to 2015 was 570.9 mm. Seasonal distributions of the precipitation and temperature are shown in Fig. 3. Figure 3a shows the distribution of mean monthly precipitation. The highest rate of precipitation occurs in December. On average, winter (January–March) precipitation is 27% of total annual precipitation and this is 22, 20, and 31% for spring (April–June), summer (July–September), and fall (October–December), respectively. The highest and the lowest annual precipitation occurred in Pajim station (883 mm year⁻¹) and Sefidchah station (429 mm year⁻¹) respectively. In general, precipitation amounts in the western part of the Neka basin are larger than in the central and eastern parts (semi-arid region) throughout the year. To understand the hydrological behavior of the study area, the seasonal distribution of the mean temperature for the Neka basin is shown in Fig. 3b. The highest and the lowest temperature occur in the summer (August) and February, respectively.

Trend analysis was conducted on mean monthly precipitation data for the period 1972–2015. The Z statistic for precipitation trends is shown in Table 4. The trend for monthly mean precipitation in the Neka basin is downward and significant for January, May, and August ($Z < -1.96$).

Shahkooh station located in the upstream area has experienced significant downward trends in 4 months (December, January, February, and May). Overall, monthly precipitation trends for stations are in the downward direction. These results agree with the findings of Minaei and Irannezhad (2016) who identified a negative trend in monthly precipitation for the northeast of Iran (Gorgan station).

Trend analysis was also conducted on seasonal precipitation data in the Neka basin. All four seasons show a downward trend but not significant. In winter and spring, two stations (Pajim and Shahkooh) have downward and significant trends ($Z < -1.96$). Shifteh Some'e et al. (2012) reported significant decreases in seasonal precipitation in the northeast of Iran by investigating precipitation records at Gorgan station.

The mean annual precipitation trends for each station are shown in Table 4 as well. The only significant downward trend is found for Shahkooch station ($Z < -1.96$). Other stations generally experienced downward trends except for Barkola station. These results agree with the findings of Tabari and Talaei (2011b) who identified negative trends in annual precipitation at 60% of the stations, particularly in the northwest of Iran. Partal and Kahya (2006) found a significant downward trend in the annual mean precipitation in western and southern Turkey, as well as along the coasts of the Black Sea.

Annual maximum daily precipitation shows significant upward trends with the exception of Shahkooch and Pajim stations (Table 4). Considering the upward trend in annual maximum daily precipitation and convective storms which occur in spring and summer, upward trends in these seasons are important due to their contribution to destructive flood events.

Trend analysis was also conducted on monthly, seasonal, and annual temperature data for the period 1972–2015 (Table 5). For monthly mean temperature, the four stations in the study area showed warming trends with a significant upward direction for all stations in August. The temperature trend in the Neka basin is significantly upward for most months. Minaei and Irannezhad (2016) also found significant increases in monthly temperature for Gorgan station.

For seasonal mean temperature, fall, winter, and summer have experienced significant positive trends. The temperature trend in spring is upward, but not statistically significant ($Z < 1.96$) at the basin scale. The seasonal analysis of temperature showed a significant upward trend for all stations. No single downward trend was detected in any of the stations. Also, a statistically significant upward trend was detected for the mean annual temperature.

These results are in agreement with the findings of Tabari and Hosseinzadeh Talaei, 2011a) and Minaei and Irannezhad (2016) reporting a significantly warmer climate over some parts of Iran including the northeastern parts.

3.3 Basin-scale relations between trends in streamflow and climatic variables

Sen's slope estimator, following the Mann-Kendall test, was employed to determine the change per year of the trends in the hydro-climatic time series. The results are presented in Fig. 4. On an annual basis, mean precipitation has a decreasing tendency for the Neka basin by 1.1 mm/year (Fig. 4a). The annual maximum daily precipitation shows a statistically significant upward trend of 0.2 mm/year (Fig. 4b). As shown in Fig. 4b, variations in recent years are greater than in the early years of the study period. Increases in extreme precipitation caused several destructive flood events for the study

region in recent years (Neka Disaster Taskforce, 2010). Temperature shows a statistically significant increasing trend of approximately 0.05 °C/year (Fig. 4c). The downward trend of streamflow at Abelu station corresponds with the mean annual precipitation trend (Fig. 4d). Annual maximum daily streamflow is linearly increasing in the same direction as the annual maximum daily precipitation trend (Fig. 4).

To better understand the relationship between the climatic variables and streamflow, three statistical tests were used for the period 1972–2015 (Table 5). The Kendall correlation coefficient, Spearman's rank coefficient, and the parametric linear regression test revealed a statistically significant relationship between streamflow and precipitation trends (p value < 0.05) in the Neka basin. The p value and correlation coefficient for each test are shown in Table 6. The correlation coefficients for Kendall, Spearman's rank, and linear regression are 0.43, 0.61, and 0.67, respectively. The relationship between temperature and streamflow is not significant (p value > 0.05) and correlations are low.

3.4 Spatial relations between trends in streamflow and precipitation

Spatial visualization of precipitation and streamflow can help us to identify the relationship and correlation between them. Figure 5a, c shows the interpolated trends (Z-Statistics) using

Table 5 Monthly, seasonal, and annual mean temperature trend with $p = 0.95$ for the common period

Station Variables	Abeloo	Sefidchah	Pajim	Gorgan	Basin
OCT	3.27	3.90	4.01	1.48	3.76
NOV	2.06	1.95	1.76	-0.25	2.05
DEC	0.33	1.28	0.52	-0.51	0.70
JAN	1.80	3.17	1.52	0.73	2.46
FEB	1.69	4.64	2.74	1.25	3.15
MAR	2.99	5.02	3.87	1.86	4.09
APR	0.73	2.17	1.62	-1.74	0.89
MAY	0.94	2.27	0.88	0.95	1.60
JUN	1.83	2.64	2.77	1.77	3.04
JUL	1.35	2.36	2.46	1.48	2.15
AUG	2.98	3.70	3.04	3.29	3.75
SEP	3.46	3.01	3.15	1.88	3.82
Autumn	2.67	2.69	2.99	0.95	2.56
Winter	3.40	5.43	3.72	2.02	4.74
Spring	1.51	2.37	2.34	0.45	1.94
Summer	3.47	3.85	3.81	3.07	4.34
Annual	4.43	5.23	4.61	3.07	5.62

The column of each station shows the Z statistic of the trend test. The sign of Z indicates the trend direction. Statistically significant trends at the 95% confidence level are shown in bold

Table 6 *p* value and correlation coefficient between annual streamflow and climatic variables

Variables	Linear regression		Spearman		Kendall	
	<i>R</i>	<i>p</i> value	<i>R</i>	<i>p</i> value	<i>R</i>	<i>p</i> value
Precipitation	0.67	0.00	0.61	0.00	0.43	0.00
Temperature	-0.11	0.47	-0.14	0.37	-0.11	0.32

IDW for annual mean and annual maximum daily precipitation. As can be seen in the figures, the spatial presentation of the detected precipitation trends enables us to have a better understanding of climatic changes and their relation with streamflow in the study area within the last 44 years. The

trends in mean annual and annual maximum daily streamflow are shown in Fig. 5b, d to compare with the precipitation trend. According to Fig. 5a, the downward trend for the mean annual precipitation observed in the upstream part of the Neka basin is consistent with the downward trend for streamflow in Sefidchah and Gelvard sub-basins. Abelou station seems to have a decreasing tendency (*Z*-value > -1.96).

According to Fig. 5, there is a spatial relationship between annual maximum daily precipitation and annual maximum daily streamflow. The annual maximum daily streamflow of the Neka basin (Abelou) shows an upward trend and also the annual maximum daily precipitation has an upward trend in the center and downstream part of the basin. The upward trend in the central area of the basin is significant. The mean *Z*-statistics extracted from Fig. 5

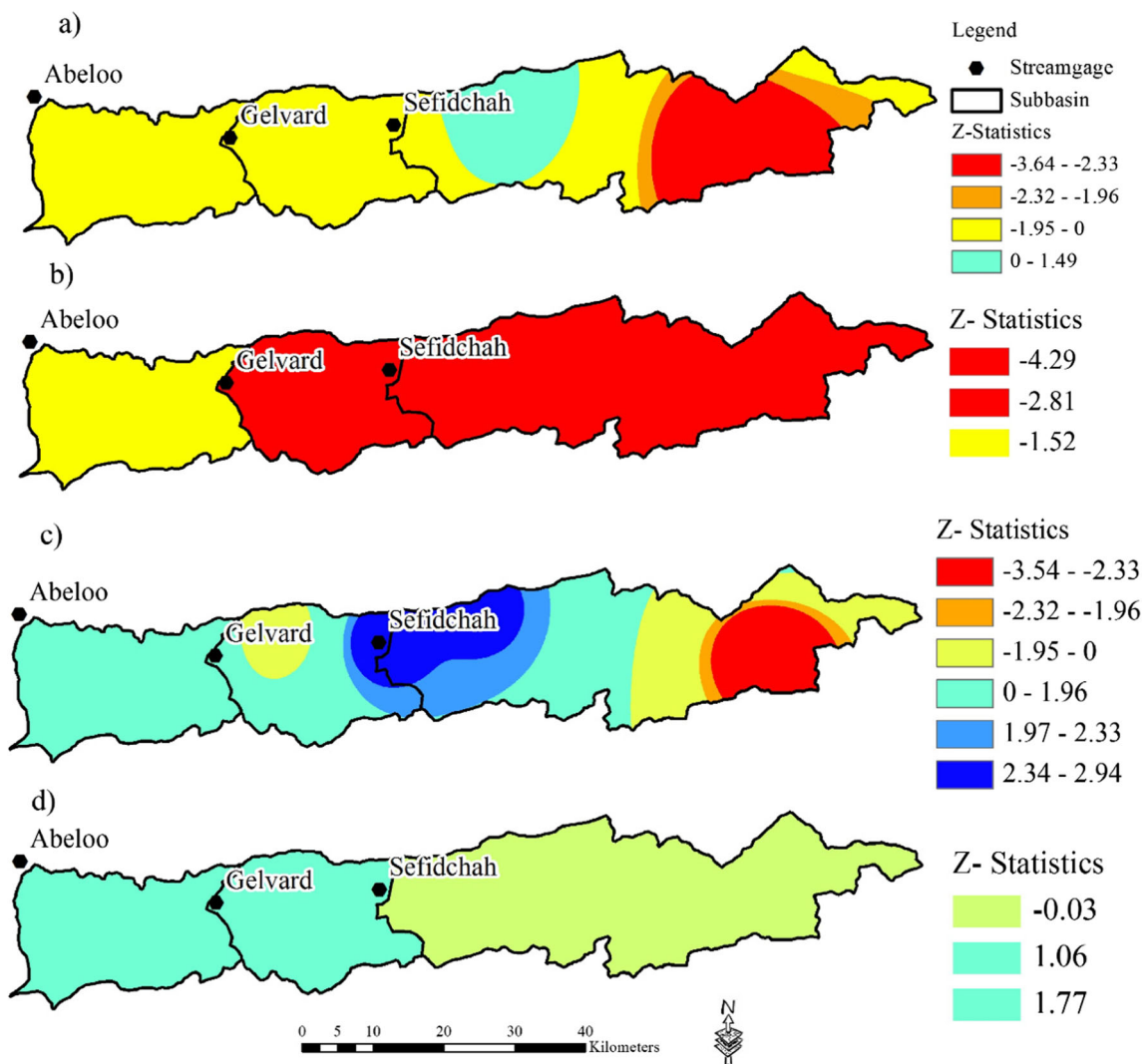
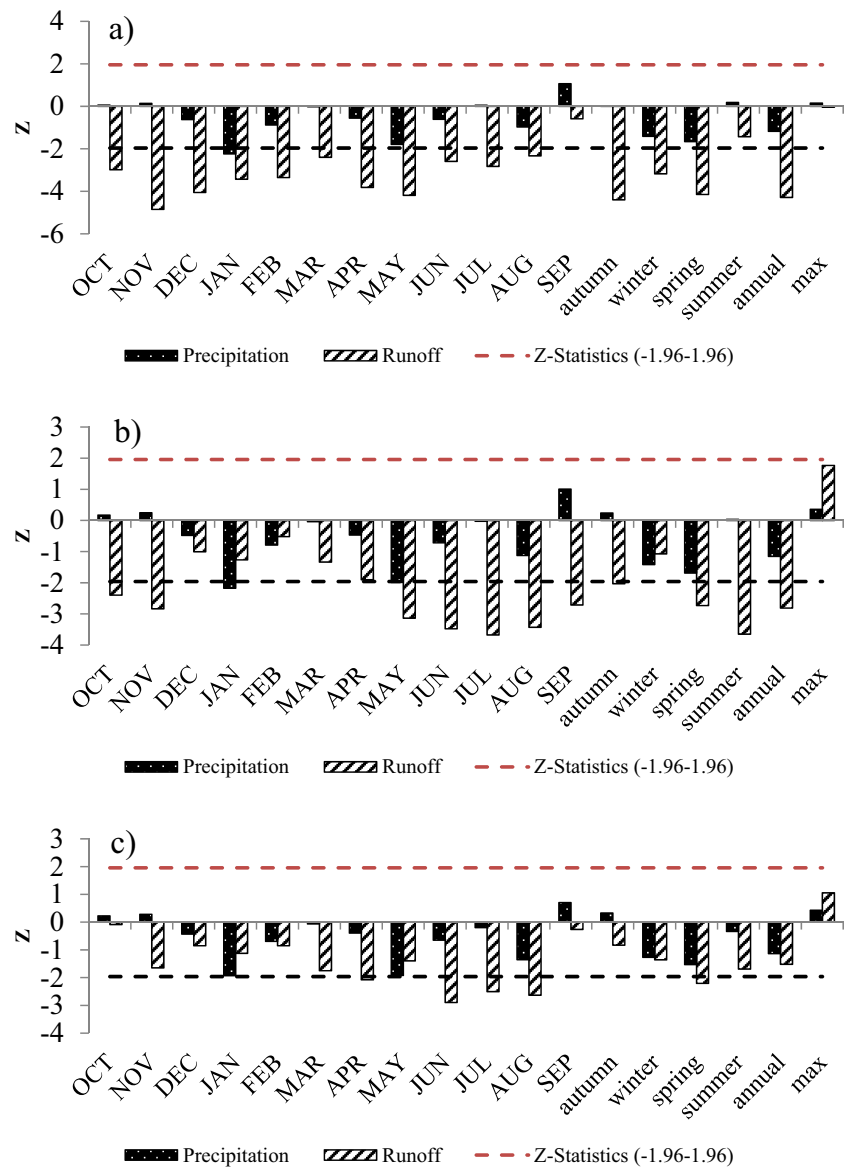


Fig. 5 Spatial trends in *Z*-statistics (from Mann-Kendal test) for annual mean and annual maximum daily precipitation and streamflow using the IDW method. **a** Observed mean annual precipitation trends, **b** observed mean annual flow trends, **c** observed annual maximum daily precipitation trends, and **d** observed annual maximum daily flow trends in the Neka

basin. The sign of *Z* indicates trend direction. $Z > 2.33$ or $Z < -2.33$ denotes that trends are statistically significant at the 99% confidence level, $Z > 1.96$ or $Z < -1.96$ denotes that trends are statistically significant at the 95% confidence level, and $Z < 1.96$ or $Z > -1.96$ denotes that trends are not significant

Fig. 6 Comparison of monthly and seasonal precipitation and streamflow variables for the Neka basin using the IDW method. **a** Sefidchah station. **b** Gelvard station. **c** Abelu station



for each basin were compared to the Z-statistics in Sefidchah, Gelvard and Abelu sub-basins which are shown in Fig. 6. A good correlation between the annual maximum daily precipitation and annual maximum daily streamflow trends in the Gelvard and Abelu sub-basins was observed (Fig. 6). The upward trends for both sub-basins are not significant.

Also, monthly and seasonal precipitation Z-statistics were interpolated using the IDW method for the Neka basin. The most severe downward trends occur in winter in the upstream part of the basin ($Z < -1.96$) at the seasonal time-scale. The most severe upward trends occur in summer in the central part of the basin ($Z > 1.96$). For the monthly time-scale, most of the months (except November) have negative trends ($Z < -1.96$). The central part of the basin has upward trends but not significant in most of the months except September.

4 Conclusions

Trend analysis of climatic variables in the Neka basin gave us a good overview of the behavior of the climatic variables in this part of the world. At an annual timescale, a decreasing trend in precipitation in the basin was detected during the 1972–2015 period. A decreasing trend was also observed in the streamflow data. Analysis of seasonal precipitation showed that the constant decrease of annual precipitation is a result of a decrease in winter and fall precipitation.

Trend analysis using the Mann-Kendall test and geostatistical methods showed that the upstream part of the Neka basin is affected by decreasing precipitation which can be observed in Sefidchah sub-basin. The results of interpolation show a relationship between annual maximum daily precipitation and annual maximum daily streamflow in the study

area. Unlike the downward trend of the mean annual and monthly precipitation, the annual maximum daily precipitation has experienced an upward trend in most stations. Increases in the annual maximum daily precipitation caused several destructive flood events within the Neka basin in the past. Analysis of the results in the study generally represents downward trends in hydrological variables which means that the study region is going towards more severe drought events. Further trend analysis of hydro-climatic variables in other basins in the north of Iran will provide more insight about the impact of climate change in this region.

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