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ORIGINAL PAPER

Detection and attribution of climate change at regional scale: case study of Karkheh river basin in the west of Iran

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Abstract This research aims at providing a statistical framework for detection and attribution of climate variability and change at regional scale when at least 30 years of observation data are available. While extensive research has been done on detecting significant observed trends in hydroclimate variables and attribution to anthropogenic greenhouse gas emissions in large continents, less attention has been paid for regional scale analysis. The latter is mainly important for adaptation to climate change in different sectors including but not limited to energy, agriculture, and water resources planning and management, and it is still an open discussion in many countries including the West Asian ones. In the absence of regional climate models, an informative framework is suggested providing useful insights for policymakers. It benefits from general flexibility, not being computationally expensive, and applying several trend tests to analyze temporal variations in temperature and precipitation (gradual and step changes). The framework is implemented for a very important river basin in the west of Iran. In general, some increasing and decreasing trends of the interannual precipitation and temperature have been detected. For precipitation annual time series, a reducing step was seen around 1996 compared with the gradual change in most of the stations, which have not experience a dramatical change. The range of natural forcing is found to be ±76 % for precipitation and ±1.4 °C for temperature considering a two-dimensional diagram of precipitation and temperature anomalies from 1000-year control run of global climate model (GCM). Findings out of applying the proposed framework may provide useful insights into how to approach structural and non-structural climate change adaptation strategies from central governments.

Keywords Statistical analysis · Regional climate variability and change · Detection and attribution · CGCM3 · Karkheh Basin · Iran

1 Introduction

According to IPCC's fifth assessment report (AR5), there is a 99 % probability that more than half of the observed increase in global mean surface temperature (from 1951 to 2010) was as a result of human activity (IPCC 2014). This contribution of anthropogenic activities is mainly because of combustion of fossil fuels in addition to landuse change leading to an increase greenhouse gas emissions particularly CO_2. Detection and attribution to climate variability and change are mainly important as existence of any past trends can provide valuable insights for impact studies and policy adaptation strategies relevant to agriculture, environment, infrastructures, and ecosystems.

Many studies have analyzed large-scale general pattern of climatic changes at global and continental scales based on the observation/simulation of the past. Recently, extensive research has been done on detection of changes in the trend of

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hydroclimatic variables (Zhai et al. 1999; Kaiser and Qian 2002; del Río et al. 2005, 2007; Zhang et al. 2007; Wang et al. 2008; Liu et al. 2012; Fu et al. 2013; Rutgersson et al. 2014; Nilesh et al. 2014), and attribution of changes in climatic variables to human-made activities has been studied in many parts of the earth (Barnett and Schlesinger 1987; Kazadi and Kaoru 1996; Meehl and Washington 1996; Crowley 2000; Stott 2000; Seung et al. 2005; Hegerl et al. 2007; Milly et al. 2008; Sridhar and Nayak 2010; Stott et al. 2010; Pall et al. 2011; Zhang et al. 2013). As far as Asian countries are concerned, Afzaal et al. (2009) showed that after 1993, there was a sharp rise in temperature trends in Pakistan which lasted up to 2007. The observed trend in temperature raised 0.53 °C per decade in this period. Also in Turkey, Tayanç et al. (2009) analyzed daily temperature data. The result from this study shows an apparent increase in the temperature during the 1990s when a filtered moving average (MA) approach has been applied on the records, although a decrease in temperature has been detected in the period of 1971–1993. In the south western part of China (SWC), Ding and Dai (1994) reported a decreasing trend of annual mean temperature during 1951–1990. In another study over SWC, precipitation variability and its trend was studied from 1951 to 1995 (Dong and Duan 1998). The conclusion was that annual and seasonal (spring, summer, and autumn) precipitation variability showed an overall negative trend, and that the number of stations having a negative trend are more than those having positive. Temperature and precipitation changes have also been studied from a detection perspective across Iran. In many cases, results have suggested increasing trends of temperature in addition to some significant precipitation changes on a network of stations (Rahimzadeh and Asgari 2004; Modarres and da Silva 2007; Modarres and Sarhadi 2009; Sohrabi et al. 2009; Varshavian et al. 2010; Yazdani et al. 2011; Tabari et al. 2011a, 2011b; Abghari et al. 2012; Massah Bavani et al. 2012; Fathian and Morid 2013; Kousari et al. 2013; Tabari and Hosseinzadeh Talaee 2013; Azarakhshi et al. 2013; Massah Bavani et al. 2013;, Fathian et al. 2015). Any detected trend in hydroclimate variables might have been as a result of natural or anthropogenic forcings (especially by considering increased temperature), and controversies are still over the contribution of internal variability at regional scale. From place to place, one should consider that existence of a trend in climatic variables cannot be simply attributed only to climate change (Massah Bavani et al. 2013).

Detection and attribution studies for hydroclimate variables (e.g., streamflow, precipitation, temperature) are important at all spatiotemporal scales as any observed trends is as an alert for managing all sectors including but not limited to water resources, agriculture, and energy. However, there are few studies conducting both detection and attribution to climate change at regional scale. This research provides a statistical framework based on at least 30 years of observational data to analyze observed changes and its attribution to climate variability and change. The proposed framework provides useful insights for policymakers and benefits from general flexibility and not being computationally expensive compared to that of the dynamical approach, and is informative in the absence of regional climate model analysis and taking advantage of applying several trend analysis tests including in order to analyze temporal variations in temperature and precipitation in terms of gradual and step changes. The framework is applied for a very geographically strategic case study in west of Iran, Karkheh river basin as an illustration.

The outline of this paper is presented below: after this part, major characteristics of the case study will be presented in "Case study and data" section. "Methodology" section investigates the trend of variations in temperature and precipitation in different parts of Karkheh river basin, located in the west of Iran. In addition, a methodology is described for determining the domain of influence of changes in climatic variables when interannual and interdecadal windows are concern. Main results are discussed in "Results and discussion" section followed by conclusion remarks at the last section.

2 Case study and data

Six main hydrologic divisions are recognized by the Iranian Ministry of Energy (MOE). Karkheh river basin is located in the middle and southwestern regions of Zagros Mountain, a part of Persian Gulf division, with an approximate area of 51,643 km^2 in the west of Iran. The climatic condition of the Karkheh river basin is influenced by three properties including wide latitude, altitude, and being located in the western Zagros. It has been faced a significant change in precipitation, similar to many other parts of the country. Such variability has also resulted in some restrictions in terms of developing new water resources projects. The basin faces serious hydro-energy and agricultural related challenges in recent years ending with significant decrease in renewable water resources in recent years. Such variability has also resulted in some restrictions in terms of developing new water resources projects. In addition to this, recent studies suggests that high human-induced water demand is unsustainable (Ashraf et al. 2015), very likely to raise inter-province conflicts under climate change future projections (Najafi 2015). Therefore, policymakers have been interested to see how the observed

Table 1 General characteristics of the stations in the Karkheh river basin

Station	Elevation (m)	Longitude	Latitude	Type of station
Kermanshah	1318.6	46° 17′	38° 05′	Synoptic
Hamedan[a]	1741.5	47° 04′	38° 26′	Synoptic
Khorramabad	1147.8	45° 40′	38° 45′	Synoptic
Ahvaz	22.5	44° 36′	38° 05′	Synoptic
Dezful	143	47° 42′	37° 20′	Synoptic
Aghajanbolaghi	1830	48° 03′	34° 50′	Rain gauge
Holilan	703	46° 39′	33° 44′	Evaporation gauge
Kanal vorayneh	1760	48° 24′	34° 4.56′	Evaporation gauge
Dehnoud	1770	48° 47′	33° 31′	Evaporation gauge

[a] Precipitation data was not available for this station

trends in precipitation and temperature at the first hand are attributed to climate variability and change.

In this study, data from five synoptic stations are available from the Meteorological Organization of Islamic Republic of Iran (MOIRI). Aside from these stations, the remaining data (rain gauge as well as evaporation) have been provided by the Iran Water Resources Management Company and Khuzestan Water and Power Authority (KWPA). Since the sources of data are not provided by a single responsible authority having different years of record, we did a preliminary assessment ensuring that data are quality controlled in several aspects including the measurement uncertainties, consistencies in

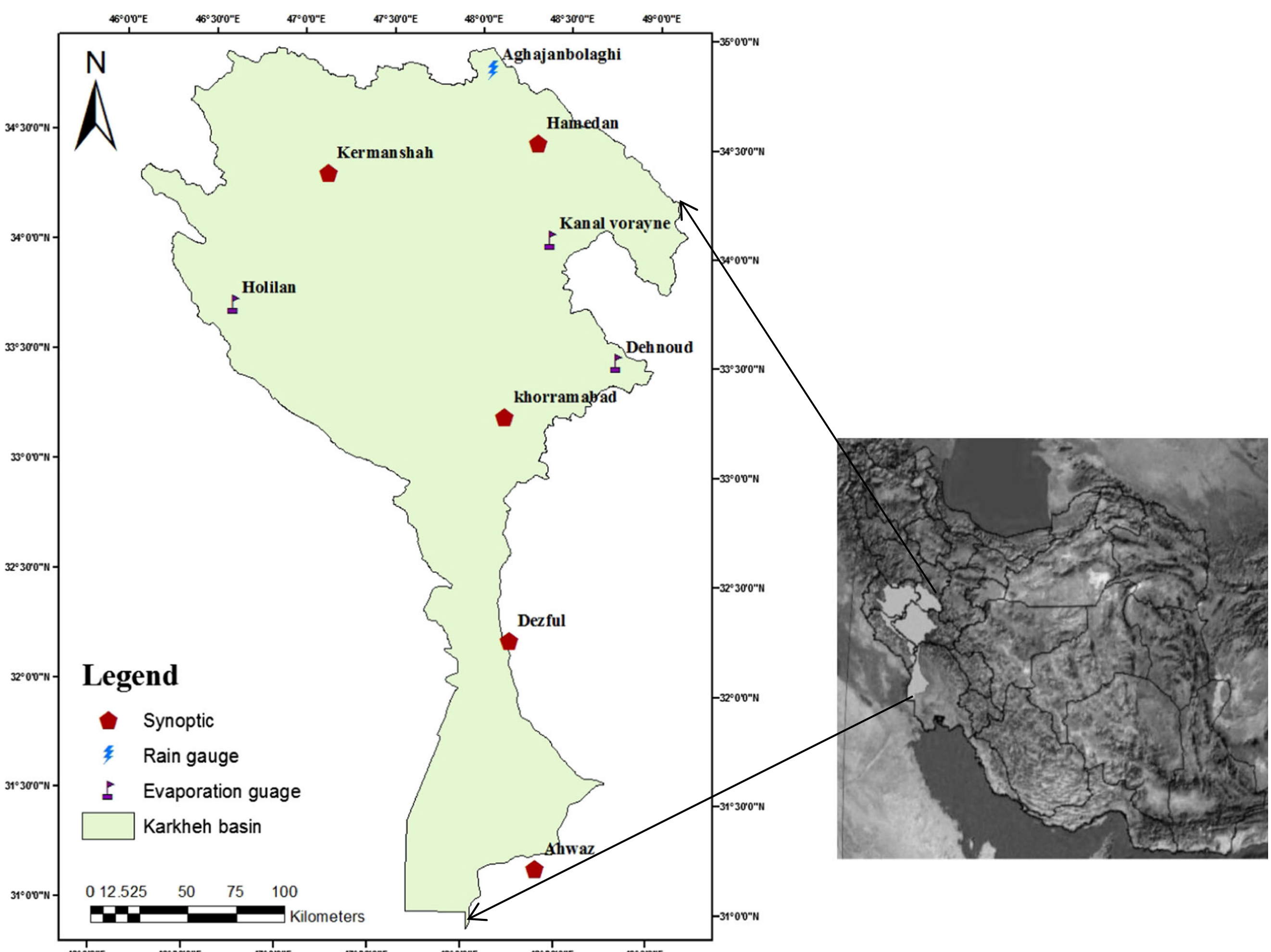

Fig. 1 Location of the meteorological stations in the study area

addition to the homogenization of data. Out of 24 stations in total, only nine hold a common data period of 40 years "1971–2011". Detailed information on the stations and their main characteristics including geographical location is presented in Table 1 and Fig. 1, respectively.

3 Methodology

3.1 Trend detection in temperature and precipitation data

3.1.1 Standardized departures analysis

First, standardized departures of the annual temperature and precipitation for each station were computed. As shown by Eq. 1, standardized departures are calculated in two steps: the initial step is to subtract the respective long- term mean from the data series. Then, it is divided by the respective standard deviation for each station (McCabe and Wolock 2002).

$$St_{Di} = \frac{X_i - \overline{X}}{\sigma}, \quad (1)$$

where,

X_i Climate variable values in each year
$\overline{X}$ The average annual time series of the climate variable
σ The standard deviation of annual time series

3.1.2 Student's t test

This test is most commonly applied when the test statistics follow a normal distribution, if the value of a scaling term were known (Yue and Pilon 2004), and if two sets of data are significantly different from each other. In this paper, Student's *t* test is used to evaluate the mean in two different periods (1971–1990 and 1991–2011). It can be used to determine.

3.1.3 Mann–Kendall test

Changes in precipitation and temperature are not only examined based on gradual changes but also according to step changes. While the former is mainly characterized by commonly used statistical tests, the latter is distinguishable when multiple tests are also applied to the observed

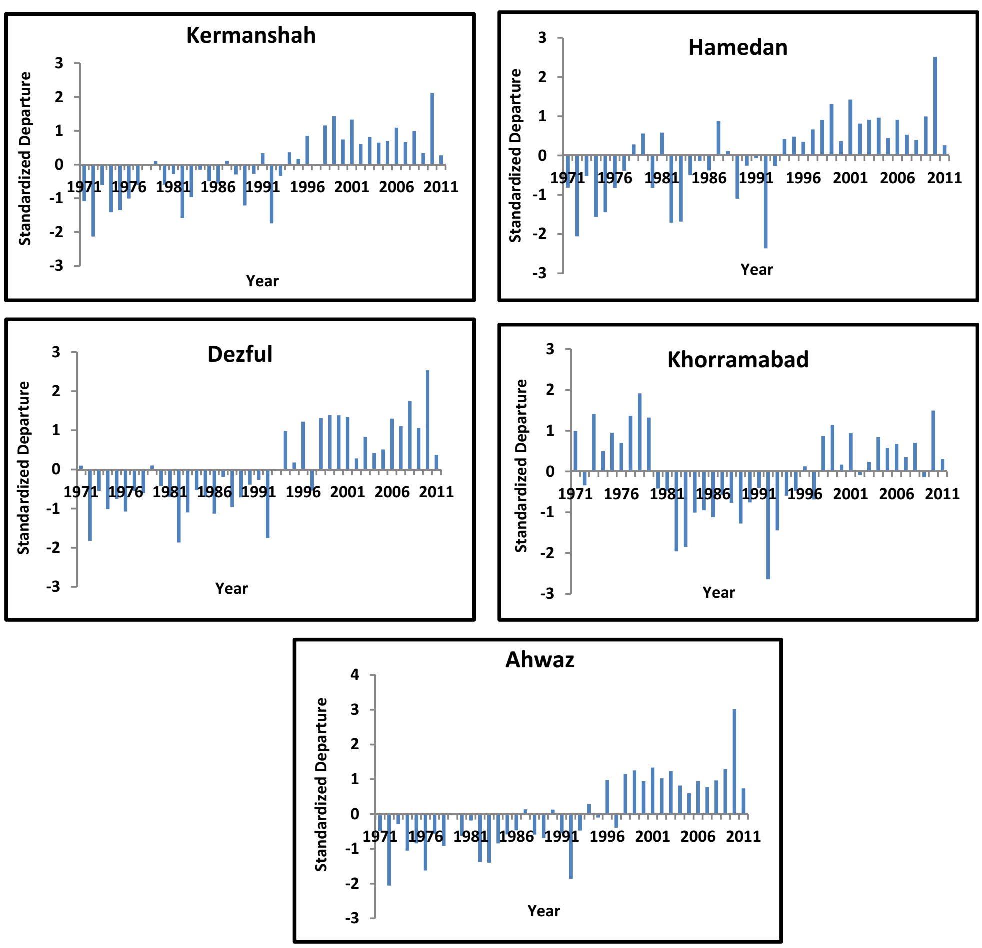

Fig. 2 Standardized departures of the mean annual temperature for selected stations of study area from 1971 to 2011

data. In order to analyze the nature of temporal changes in temperature and precipitation, the methodology suggested by McCabe and Wolock (2002) is followed. The Mann–Kendall test (multiple trend analysis) (Mann 1945; Kendall 1975) has been applied to all observational data in this research. To eliminate the effect of serial correlation, the pre-whitening (Von storch 1995) is also applied beforehand. The methodology requires two sequential 5-year time periods (equal to 10 years) of data as a start of the analysis at each round. The starting year will be kept constant at the first round with a 5-year window added to the ending period. In other words, the second trend analysis will be applied to the first 10 years plus an additional 5 years (Zohrbi et al. 2011b).

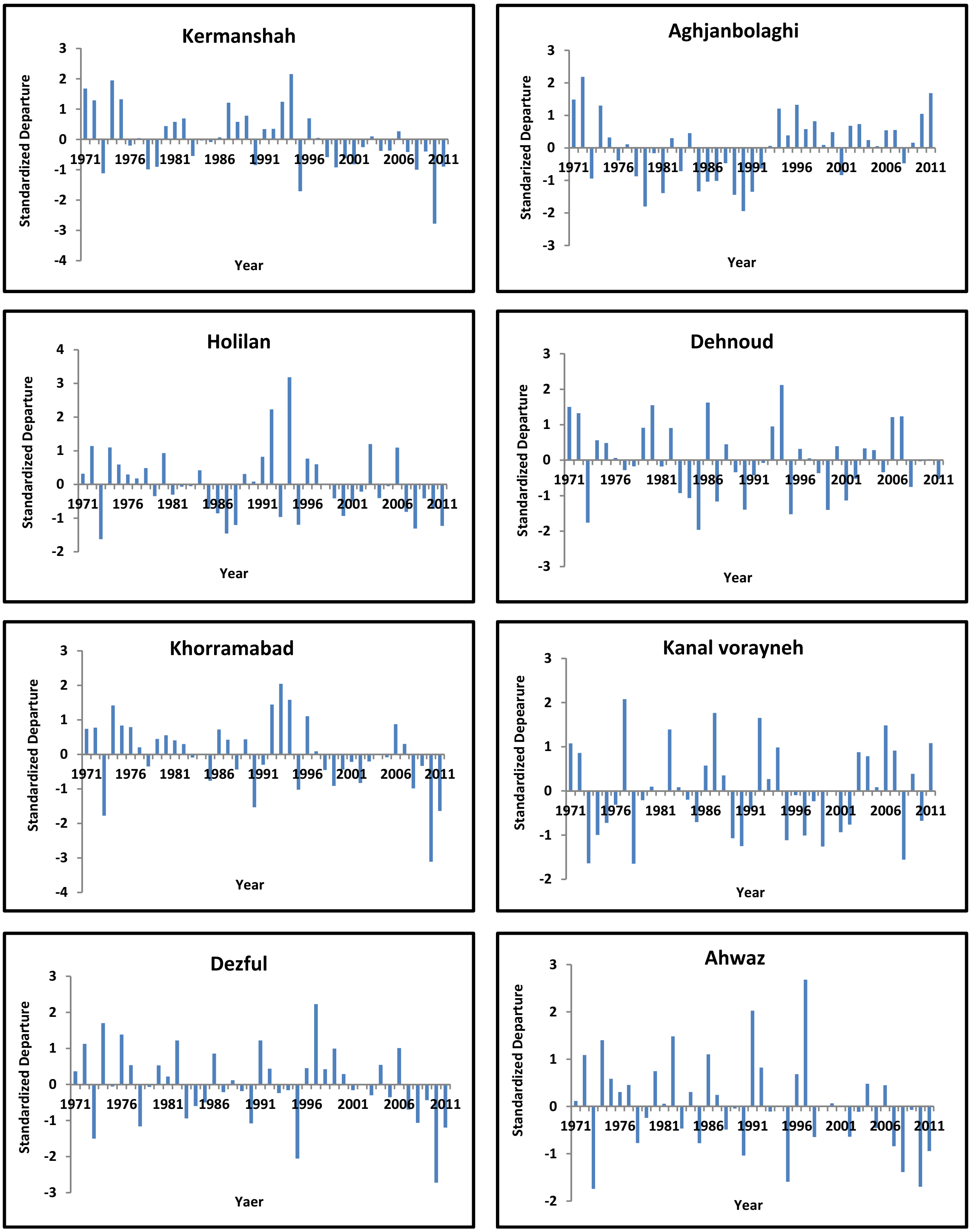

Fig. 3 Mean standardized departures of the mean annual precipitation for selected stations of study area from 1971 to 2011

In the case of this paper, the first period of the first round is from 1971 to 1981. Considering this duration, it is imminent how adding an additional 5 years can alter trend analysis at the subsequent step (1971–1986). Trend analysis for the first round is continued until the entire period covered (1971–2011). The last step of the first round is in fact the gradual common test of Mann–Kendall. After the first round is finished (a total of nine trends), the initiation year for the next round being shifted (5 years added to the first year which has been incorporated into the duration at the previous round). In this case, it will be commenced needed to last for a 10-year period (1976 to 1986). This procedure will be continued until the last trend is covered (final round), which should also have a minimum of 10 years (2001 to 2011). The (+) and (−) trends are drawn in each period and for each station at different significant levels.

3.2 Internal climate variability

A proper understanding of internal climate variability has been stated as one of the most difficult geophysical problems in the twenty-first century (Ghil 2001). To evaluate the range of internal variability of the climate system, 1000-year temperature and precipitation time series data from coupled global climate model (CGCM3 model) (Kim et al. 2002; 2003) control run were used. For the case under study, the range for internal climate variability is determined by two-dimensional graphs for temperature (horizontal axis) and precipitation (vertical axis) based on a two-variant normal distribution proposed by Von Storch and Zwiers 2002 (Eq. 2):

$$\frac{1}{1-\rho^2}\left\{\frac{T'^2}{\sigma_T^2} - 2\rho\frac{T'}{\sigma_T}\frac{P'}{\sigma_P} + \frac{P'^2}{\sigma_P^2}\right\} = \chi^2 \qquad (2)$$

T' Temperature anomaly
σ_T Standard deviation of temperature
P' Precipitation anomaly
σ_P Standard deviation of precipitation
ρ Correlation between temperature and precipitation anomalies

The amount of χ^2 is determined by square distribution of χ^2 with two degrees of freedom, which is extracted from the given reference tables at 95 % confidence level (df ¼ 2, 95 %/X^2 ¼ 5.99). By plotting (Eq. 2) for 95 % confidence level, elliptic circuits whose internal area indicates the internal climate variability range for temperature and precipitation are obtained. The external area represents the variability related to other factors (including greenhouse gases) (Zohrabi et al. 2014).

4 Results and discussion

4.1 Standardized departure analysis on temperature and precipitation

With respect to temporal variability of mean annual temperatures, the visual pattern reveals a dramatic increase around 1993 compared with a gradual increase during the record under study (Fig. 2). The visual pattern of temporal variability (Fig. 3) illustrates a dramatic decrease in the annual precipitation around 1996 compared with the gradual reduction present during the period in most studied stations. To investigate the significance of differences in mean values of mean annual temperature and precipitation, the statistical period was divided into two periods each having a 20-year period (before and after 1991) for which Student's *t* test was used (Tables 2 and 3).

According to Table 2, it is observed that in almost all of the synoptic stations, differences are significant at the level of 1 and 5 % in the mean annual temperature between 1971 and 1990 and thereafter, from 1991 to 2011, where the average of the second period (1991–2011) is more than that of the first. However, one cannot come to a same conclusion for precipitation since analyses show significant changes in precipitation for only two stations out of the eight (an increase observed for Aghajanbolaghi and for Kermanshah having a decrease one) considering the long-term average for the second period (1971–2011).

Table 2 Results of the Student's test for mean annual temperature in Karkheh river basin over the period 1971–2011

Station	*t* test	Significant level	Mean annual temperature (°C)	
			1971–1990	1991–2011
Kermanshah	−4.257	S (0.01)	13.97	15.3
Hamedan	−3.701	S (0.01)	10.61	11.77
Khorramabad	−0.611	NS	16.69	16.88
Ahvaz	−3.563	S (0.01)	25.12	26.23
Dezful	−3.342	S (0.01)	23.57	24.61

S significant, *NS* non significant

Table 3 Results of the Student's test for mean annual precipitation in Karkheh river basin over the period 1971–2011

Station	*t* test	Significant level	Mean annual precipitation (mm)	
			1971–1990	1991–2011
Kermanshah	1.852	S (0.1)	468.325	395.419
Khorramabad	0.966	NS	506.985	464.743
Ahvaz	0.597	NS	239.145	223.1
Dezful	0.553	NS	400.75	376.2
Aghajanbolaghi	−2.301	S (0.05)	257.39	367.405
Holilan	−0.235	NS	320.746	329.2
Kanal vorayneh	−0.152	NS	523.693	529.707
Dehnoud	0.046	NS	459.59	457.957

S significant, *NS* non significant

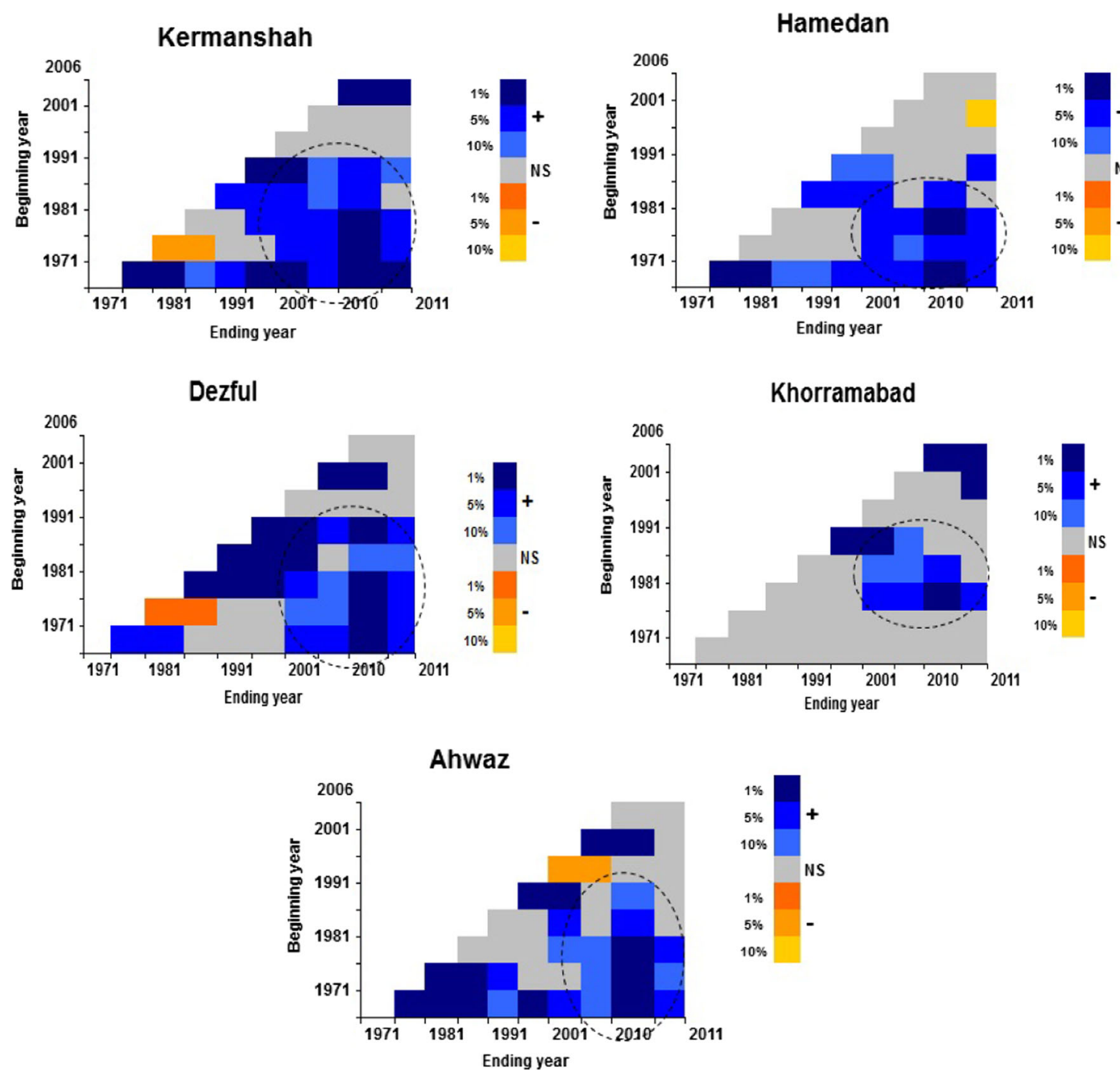

Fig. 4 Multiple-trend analysis at the 1, 5, and 10 % local significance levels increasing trends in the mean annual temperature series in the study area during the 1971–2011

4.2 Analysis of multiple trend in mean annual temperature and precipitation

Figures 4 and 5 demonstrate multiple-trend analysis of the mean annual temperature and precipitation time series at different significant levels in the selected stations of Karkheh basin.

Results that have been found based on the multiple-trend analysis for almost all stations show increasing trends at 1 % significance levels in terms of mean annual temperature series from around 1991 to recent years (Fig. 4). This finding is also in support of global warming. Unlike temperature, for precipitation variability, there was no increasing trend. The results based on multiple-trend analysis for

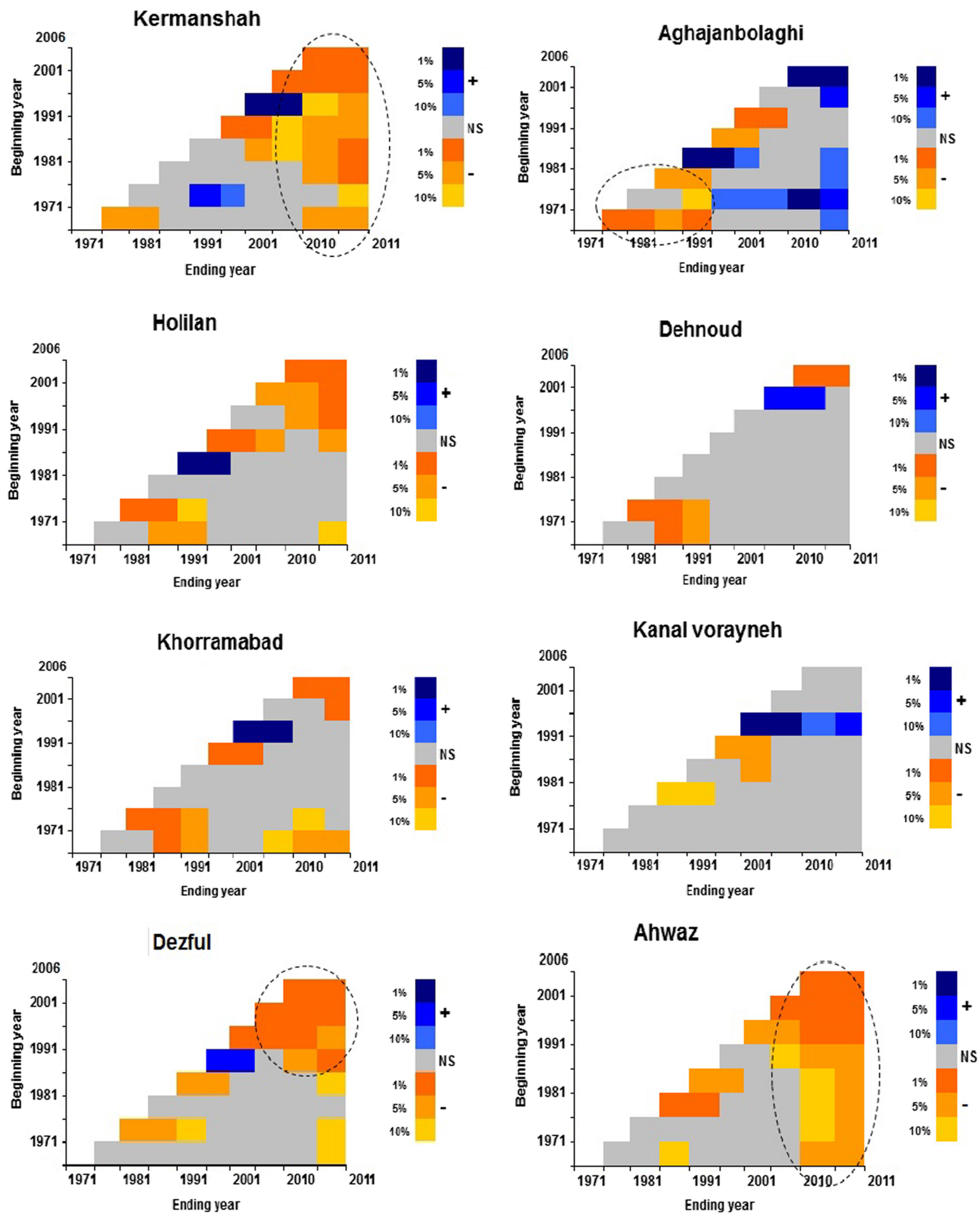

Fig. 5 Multiple-trend analysis at the 1, 5, and 10 % local significance levels decreasing trends in the mean annual precipitation series in the study area in length during 1971–2011

mean annual precipitation in this research reveal that a decreasing trend in precipitation almost since 1995–1996 significant at (1 and 5 %) levels in most of studied stations within the Karkheh basin (Fig. 5). This trend has continued up to the recent years, and it is more evident in the southern part of the basin. However, due to local general circulation patterns, some cycles of an ascending precipitation trend where observed considering the beginning of each period. The visual pattern of decreased precipitation in the late years was observed at significant levels (1 and 5 %) in most of the studied stations particularly in Kermanshah and Ahvaz stations.

4.3 Internal climate variability and attribution of temperature and precipitation trends to greenhouse gas emissions

The CGCM3 control run output is evaluated over the study area for the baseline period 1971–2000. This preliminary analysis may elaborate how well the CGCM3 simulates annual cycle of the general climate in Karkheh river basin. The result of this assessment is shown for precipitation and temperature in Fig. 6a, b, respectively. It is shown that the model captures annual cycles of precipitation and temperature reasonably well compared to the observed station data in the region under study.

To start the analysis, first, the precipitation and temperature anomalies for 1000-year control run with respect to the base period (1971–2000) are calculated for the study area (1000 points displayed in Fig. 6). Then, the two-variant

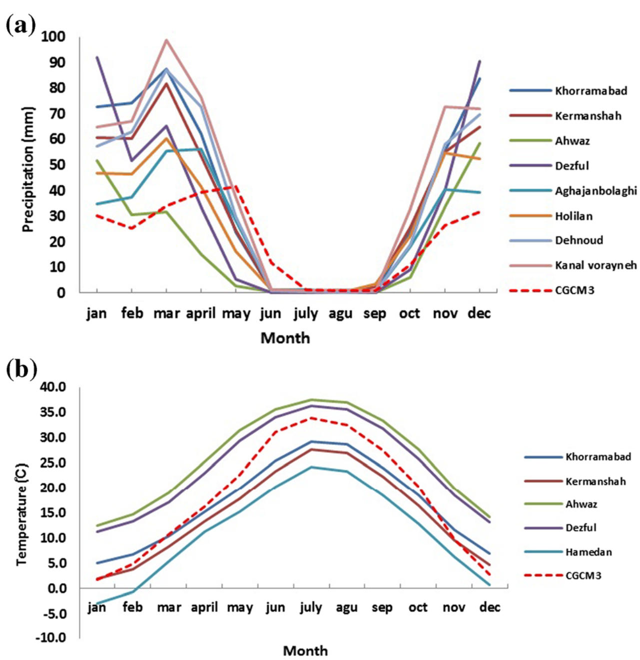

Fig. 6 Average annual cycles of station data and the CGCM3 control run for precipitation (**a**) and temperature (**b**) for the baseline period (1971–2000) over Karkheh river basin

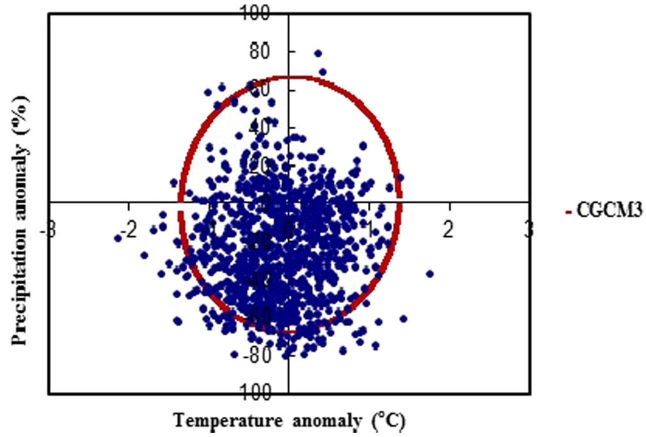

Fig. 7 Internal variability for temperature–precipitation anomalies in the Karkheh river basin

normal distribution of precipitation and temperature is fitted on the data to provide the range of internal variability from a statistical point of view. Figure 7 shows the internal variability in 95 % confidence level for temperature (*x* axis horizontal) and precipitation (*y* axis). Considering 95 % probability, therefore, the range of internal variability for bivariate temperature–precipitation anomalies is drawn that is ±1.4 °C and ±76 %, respectively. Note the results obtained are in agreement with the recent studies (particularly for temperature), which have been conducted in the relevant regions of Iran (Zohrabi et al. 2013, 2014).

After determining the range of internal climate variability, the observed annual anomaly of temperature and precipitation is compared with internal variability to analyze the attribution of climate change (Fig. 8).

For more accurate results, the study area was divided into different parts of the north and the northeastern, northwestern and west, east, central, and southern. As Fig. 8 demonstrates the investigation of the anomaly of temperature and precipitation observed in north and northeastern of Karkheh basin, the growth of temperature in the late years is strongly evident compared with previous years. The changes in the amount of precipitation in the late years are still within positive variations confirming the results of the detection section for the Aghajanbolaghi station. The same conditions are applicable to the northeastern part of Karkheh basin. In the eastern part of Karkheh basin, the precipitation variations did not have a significant decreasing trend compared with previous years, while the increase of temperature is evident. In other parts of the Karkheh basin, the position *A* (the starting point) and *Z* (the ending point) in the diagrams of variability indicate an increase and a decrease in temperature and precipitation, respectively, in later years. As we move toward, from north to south, the precipitation anomaly exhibits a greater reduction in later years. According to Fig. 7, the investigation over the last 10 years of the record at hand

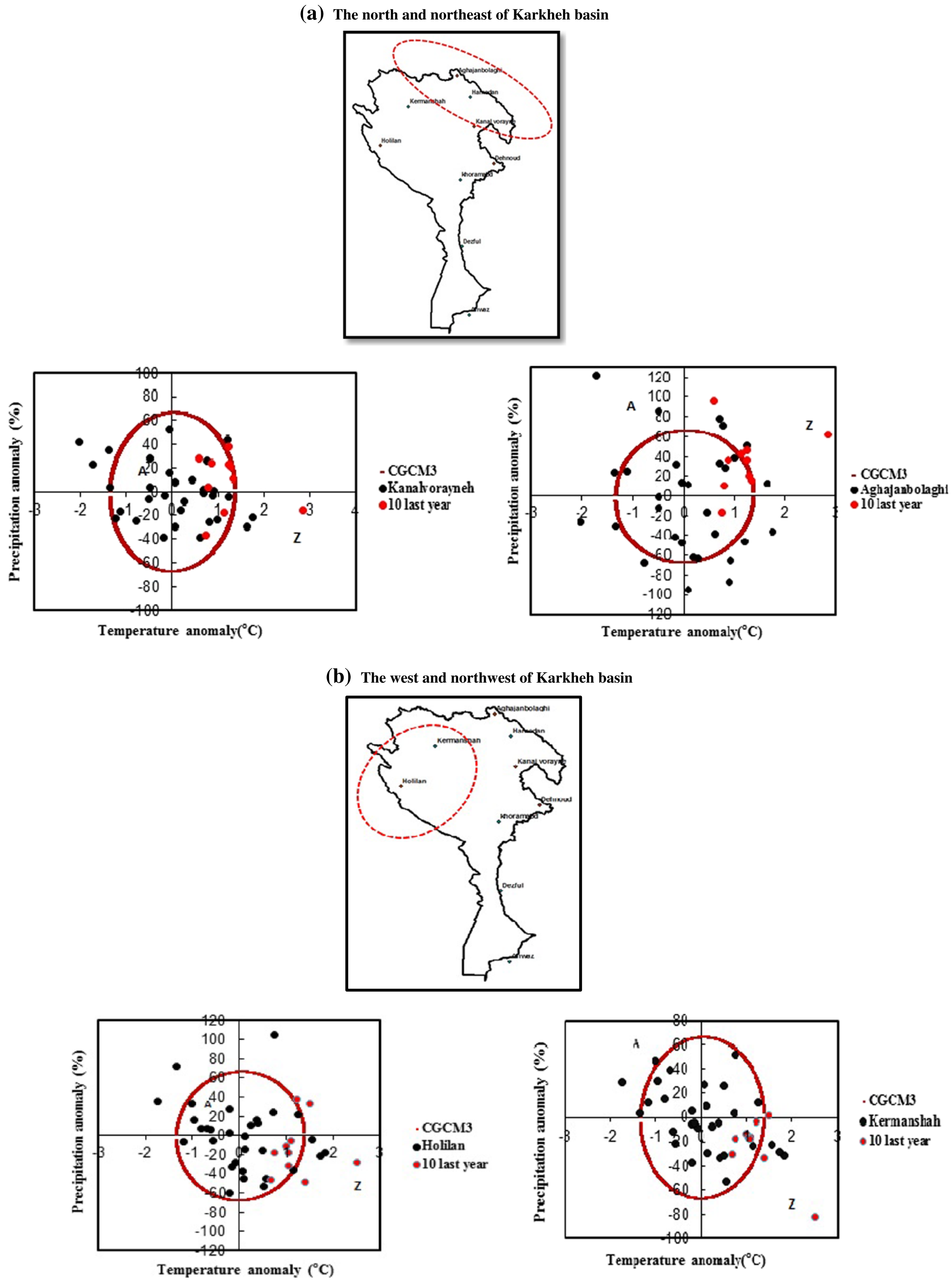

Fig. 8 Two-dimensional trend for temperature–precipitation anomalies over 1971–2000 in the Karkheh river basin (**a**–**e**)

indicates that variations in temperature and precipitation have been outside the internal variability as much as 40–45 % in the north and northeast, 30 % in the west and northwest, 10 % in the east and in the middle, and around 30 % in the south of basin on average. As far as internal variability is concern, two-variant normal distributions have been drawn for each station

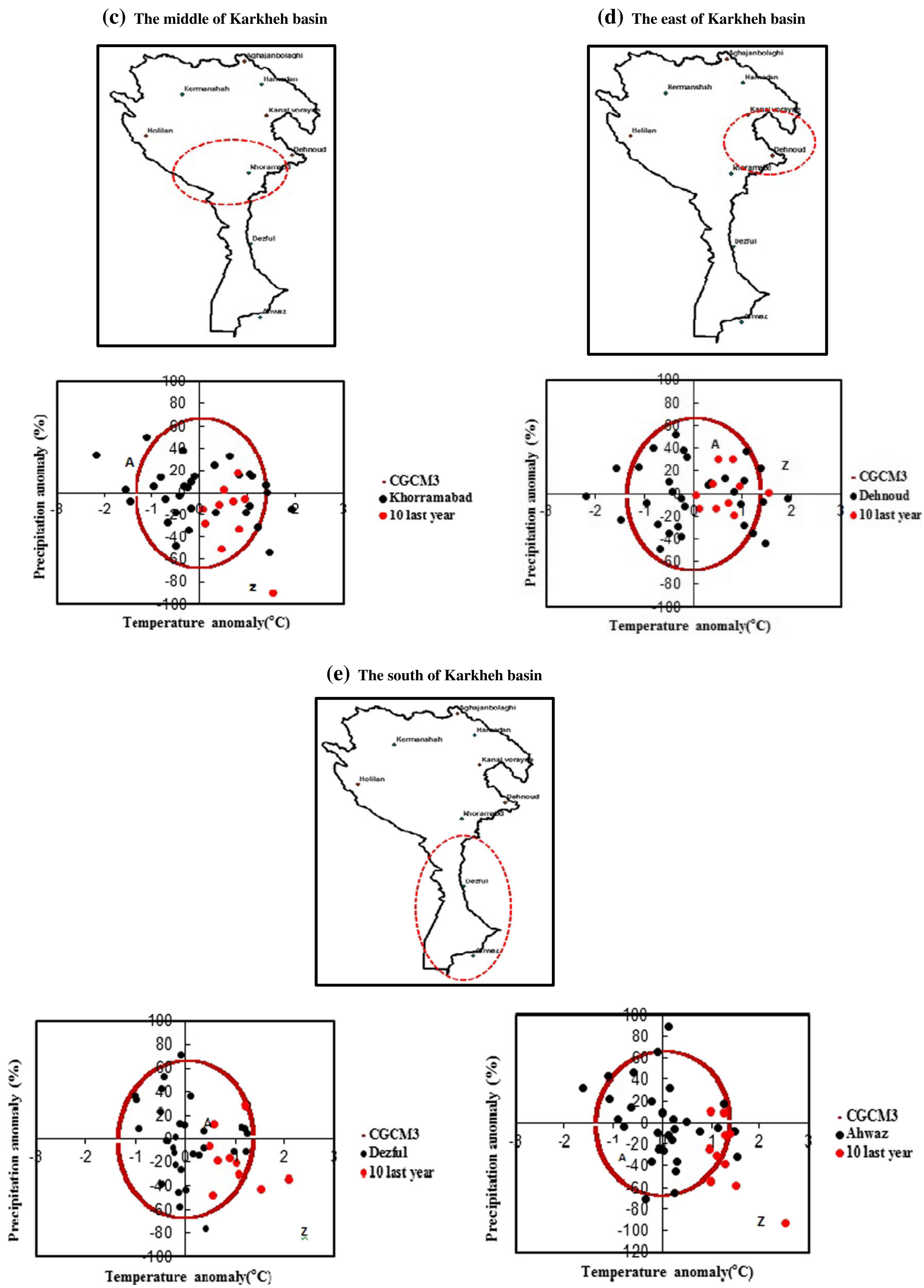

Fig. 8 (continued)

reflecting that temperature and precipitation anomalies out of the range of ±1.4° C and ±76 % cannot simply be attributed to natural climate system variability with regard to CGCM3 1000-year control run.

5 Conclusion

According to the latest IPCC's report (IPCC, 2014), global warming is most likely due to anthropogenic activities in the global scale. It is required to see how such similar patterns are likely to be detected in regional scales as well. Almost all research studies have been done to analyze absence/presence of any trends in hydroclimate observed data. While this is of utmost importance, this study goes one step further providing a chain of analysis in terms of a framework. Both statistical as well as dynamic approaches are needed in detection and attribution studies to analyze interannual and decadal changes. Here, we propose a framework from a statistical point of view, which benefits from major features including minimum level of data, being flexible to be applied for all regions around the world and not being computationally expensive. We hope that these characteristics make the framework popular where there are at least 30 years of station data. The proposed trend analysis in this study is based on every 5-year moving window rather than providing a single trend over the whole observed period. Therefore, it is a great tool to see interannual as well as decadal changes at regional scale. In addition, the framework includes approaches to determine range of internal variability from a statistical point of view. Based on 1000-year control run of general circulation models (GCMs), one can evaluate whether observed changes are found to be in the range of natural forcing at regional scale. This framework can broaden the view of policymakers to answer "What have been the driving forces of observed changes at spatiotemporal scale?" and "To which extend observed changes are significant and that whether they could be attributed to climate change?". The paper then illustrates the application of the proposed methodology (framework) for a case study in Iran. Many studies have recently reported a number of factors leading to unsustainable developments at the studied area during the past three decades including but not limited to excessive landuse change in terms of urbanization, deforestation as well as significant agricultural development projects (see e.g., discussion provided by Kousari et al. 2013). Any increasing trend of temperature may have a significant impact on evapotranspiration and finally, agricultural productivity. Statistical analysis suggests that at least for precipitation, one cannot make a firm judgment to attribute the observed changes mainly to climate change. In general, the investigation of attribution of hydrocliatme changes to internal climate factors in other studies for Iran confirms variations in temperature, precipitation, evapotranspiration, and stream flow in many stations (e.g., see Tabari and Marofi 2011; Tabari and Hosseinzadeh Talaee 2011a, b; Tabari et al. 2011a, 2011b; Tabari and Hosseinzadeh Talaee 2011a, 2011b; Zohrabi et al. 2011a; Zohrabi et al. 2014).

Other main results can be summarized as follows:

1. Standardized departure analysis as well as multiple-trend test were used to prove the presence of trends over the aforementioned basin. Standardized departure analysis for 42 years of data, time series for mean annual temperature from 1971 to 2011, shows that almost all synoptic stations of Karkheh basin have a variation between 1993 and 1994 from an initial negative to positive departure. For precipitation annual time series, a reducing step was seen around 1996 compared with the gradual change in most of the stations. According to Student's t test, the analysis over average precipitation does not show a dramatical change in about 75 % of the stations under study. Only two stations out of eight have shown significant trends.
2. The analysis of multiple-trend test reveals some increasing and decreasing trends of the interannual temperature and precipitation. The trends in temperature and precipitation have been confirmed at different significant levels (1, 5, and 10 %). The present work confirms the findings of the former studies being conducted in different parts of the country (Modarres and Sarhadi 2009; Tabari et al. 2011a; Tabari and Hosseinzadeh Talaee 2011a, b; Zohrabi et al. 2011b).
3. Analysis based on a two-variant normal distribution show that temperature and precipitation anomalies between the range of ±1.4 °C and ±76 % can be considered as natural climate variability. While temperature anomalies falls out of the climate variability and the observed changes in last years are very likely to be attributed to anthropogenic activities, one cannot conclude similarly for precipitation.

The authors imply that any robust judgment for policymaking requires complementary analysis based on a physical understanding of any observed changes at regional scale. Further studies should also concentrate on the added value of applying both approaches so that useful insights can be provided to decision makers in a broad context. While detection studies can provide useful insights, lack of any plan for conducting studies on climate change impact assessments and adaptation strategies can have irreversible outcomes in the future considering sustainability of resources. Given these regional changes in recent years, hydroclimate trend analysis followed by attributing temporal changes to human-related emissions and natural causes (Isaksen et al. 2009) can provide useful insights for future adaptation strategies.

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