



Analysis of Temperature Data Using the Innovative Trend Pivot Analysis Method and Trend Polygon Star Concept: A Case Study of Soan River Basin, Potohar, Pakistan

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Abstract—The trend analysis approach is used to estimate changing climate and its impact on the environment, agriculture and water resources. Innovative polygonal trend analyses are qualitative methods applied to detect changes in the environment. In this study, the Innovative Trend Pivot Analysis Method (ITPAM) and Trend Polygon Star Concept Method were applied for temperature trend detection in Soan River Basin (SRB), Potohar region, Pakistan. The average monthly temperature data (1995–2020) for 11 stations were used to create polygon graphics. Trend length and slope were calculated separately for arithmetic mean and standard deviation. The innovative methods produced useful scientific information, with the identification of monthly shifts and trend behaviors of temperature data at different stations. Some stations showed an increasing trend and others showed decreasing behavior. This increasing and decreasing variability is the result of climate change. The winter season temperature is increasing, and the months of December to February are getting warmer. Summer is expanding and pushing autumn towards winter, swallowing the early period of the cold season. The monthly polygonal trends with risk graphs depicted a clear picture of climate change in the Potohar region of Pakistan. The phenomena of observed average temperature changes, indicated by both qualitative methods, are interesting and have the potential to aid water managers' understanding of the cropping system of the Potohar region.

Keywords: Temperature, ITPAM, trend polygon star concept, climate change.

1. Introduction

The Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) provides an unprecedented degree of clarity about global warming, revealing that the annual mean temperature (1850–2020) of land and oceans is 1.1 °C higher than it was in the nineteenth century. It is unequivocal that observed temperature change is mainly due to emissions from human influence, which is called greenhouse gas warming, partly masked by aerosol cooling (Allan, 2021). The impacts of climate change are now widespread, pervasive, intensifying and unprecedented in thousands of years in terms of floods, heat waves, drought, hurricanes, wildfires and loss of glacial ice. Climate change has emerged as one of the most important nontraditional security challenges. According to our interpretation of AR6, we are in a situation of climate emergency, and we should fight now rather than waiting for the end of this century. This is a wake-up call to take action over the near term to prevent or reduce the effects of climate change. It is recommended that measures be taken at the national, regional and local scale by calculating and predicting changes in average conditions of temperature and weather patterns (Aktaş, 2020). Trend analysis is one of the most widely adopted methodological approaches for predicting and identifying possible climate change impacts at a small scale (Şen, 2021). Trend analysis is a data processing approach used to detect,

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identify and interpret changes in observed hydrometeorological time series data to make future predictions. It also addresses visible and hidden issues in environmental changes such as the climate change impacts on the water cycle.

The trend is the direction of the general tendency in time series data in an increase (upward), decrease (downward) or stable (neutral) way. Any systematic and continuous increase or decrease along the time axis is referred to as a temporal trend, which may be in linear or nonlinear forms. A book written by Zekai Şen entitled *Innovative trend methodologies in science and engineering* (Şen, 2017a) covered trend analysis literature review and innovative trend identification and detection procedures. This book highlights the importance of time series analysis in many disciplines including water resources planning and management and new issues of sustainable management, where innovative trend analysis techniques are ready to pave objective ways for logical interpretation and quantitative calculations. In general, trends are systematic changes in natural, social and artificial events over relatively long periods, preferably with at least 30 or more samples. The application of trend analysis on hydrometeorological time series data for climate change detection has accelerated over the last 30 years after Mann's (1945) and Kendall's (1975) work, known as the Mann–Kendal (MK) trend test. For instance, trends have important implications for the planning and management of water resources in the future (Change, 2007).

In the literature, there are numerous applications of the well-known MK test with the Theil–Sen approach (Theil, 2011; Sen, 1968) for the assessment of time series trend components and variability changes around the world (Hussain et al., 2021). Cui et al. (2017) estimated seasonal and annual temperature trends using the Mann–Kendall test and Sen's slope estimator in the Yangtze River Basin, China. Both methods have been used in the Godavari River Basin of India to estimate seasonal and annual temperature trends by Jhajahria et al., 2014. Other literature studies include the applied Mann–Kendall test and Sen's slope estimator for trend detection of temperature that Tabari et al. (2011) applied in the west, south and southwest of Iran; Mahmood and Jia (2017) in the Jhelum River basin, Ahmad et al. (2020) in the Chitral River Basin

and Nawaz et al. (2019) in Punjab province of Pakistan; Khatiwada et al. (2016) in the Karnali River Basin of Nepal; Dabanli et al. (2016) in the Ergene Drainage Basin of Turkey; Chattopadhyay and Edwards (2016) in Kentucky, USA; Birara et al. (2018) in the Tana Basin of Ethiopia. The context of literature studies indicates that the detection of historical variations in climate indicators such as temperature is highly important for countries where agriculture is the backbone of the economy, such as Pakistan. According to a German watch report, Pakistan is the fifth most vulnerable country to climate change, and the rate of change was 0.74 °C for the period 1961–2018 (Chaudhry, 2017). MK trend analysis with Sen's slope estimator was used in the Soan River Basin (SRB) of the Potohar region of Pakistan by various authors, such as Hussain et al. (2021) for rainfall and Shahid et al. (2018) for hydro-climatic data. Classical MK trend analysis with Sen's slope estimator was used for holistic trend identification (monotonic trend) and statistical quantification for given time series intercept and slope. The serious drawbacks of the MK test are the set of basic assumptions such as sample size, the serial independence of the given time series, normal (Gaussian) probability distribution functions (pdf), pre-whitening, normality of the data and nonexistence of serial comparison among different sections of the same record. The validity of the classical approach is possible under a set of restrictive assumptions such as the independent structure of the time series, normality of the distribution and length of data. It is also not possible to calculate trend magnitude (slope) except through the regression approach, which brings additional assumptions for the theoretical validation in practical applications. In the past, hydrometeorological time series were often assumed as stationary or weakly stationary stochastic processes for simulation purposes. Because of anthropogenic (human disturbance) effects on climate, environment, drainage basins and atmosphere, such an assumption is no longer valid (Şen, 2017b).

Trend analysis is continuously on the research and application agenda, and scientific studies show the development of innovative methodologies or even modification of existing approaches for trend analysis. Recently, the most common trend analysis methods used in academic studies are innovative

trend analysis (ITA), Sen's innovation method, innovative triangular trend analysis (ITTA), and innovative polygon trend analysis (IPTA) (Ceribasi et al., 2021a). Şen (2012, 2014) proposed a robust trend identification procedure, ITA, independent of any restrictive assumption such as serial correlation, non-normality, or sample number. Innovative trend analysis is a modern, simple, easy-to-interpret and effective trend analysis procedure that incorporates first visual inspection for identification of the trend type as increasing, decreasing, or no trend, and then provides a numerical calculation for the trend slope again by a very simple formulation. The ITA method depends on the 1:1 (45°) straight line on a Cartesian coordinate system, where it corresponds to a trend-free case, and any deviation from this line indicates the existence of a trend; the closer the plot is to the 1:1 (45°) straight line, the smaller the trend slope. This non-parametric ITA approach has been analyzed by many researchers in several scientific studies around the world (Singh et al., 2021; Wang et al., 2020; Alifujiang et al., 2020; Almazroui et al., 2019; Dabanli & Şen, 2018; Alashan, 2018; Güçlü, 2018; Wu & Qian, 2017; Mohorji et al., 2017; Tabari et al., 2017; Şen, 2014, 2017b; Elouissi et al., 2016; Sonali & Nagesh Kumar, 2013). To explore trend possibilities in monthly hydrometeorological record series, the IPTA methodology was introduced by Şen et al. (2019). IPTA is a non-parametric approach to identifying the trends and trend transitions between successive sections of the two equal segments from the original hydrometeorological time series, leading to a 12-sided irregular trend polygon, which provides a productive basis for finer interpretation with linguistic and numerical interpretations and inferences from a given time series. This method does not require any assumptions and can be applied directly, leading to empirical inferences and interpretations. A few studies in the literature have used the IPTA method for the analysis of hydrometeorological time series data (Achite et al., 2021; Ahmed et al., 2022; Akçay et al., 2022; Ceribasi & Ceyhunlu, 2021; Ceribasi et al., 2021b; Hirca et al., 2022; Şan et al., 2021; Şen, 2021; Şen et al., 2019).

The Innovative Trend Pivot Analysis Method (ITPAM) and Trend Polygon Star Concept Method are new trend tests, and only three studies have been reported that used both methods for temperature and precipitation trend analysis (Ceribasi et al., 2021a, 2021b; Hussain et al., 2022). The ITPAM determines risk classes by establishing a relationship between data (Ceribasi et al., 2021a). The Trend Polygon Star Concept Method was proposed by Sen (2021). Ceribasi et al. (2021b) analyzed 22 years of monthly average temperature data (1996–2017) from six stations in Susurluk Basin, Turkey, with innovative polygon trend analysis and trend polygon star concept methods. Ceribasi et al. (2021a) analyzed Susurluk Basin's total monthly precipitation data (2006–2017) using ITPAM and determined the degree of trend risk. Hussain et al. (2022) analyzed precipitation data from SRB, Potohar, Pakistan, using ITPAM and the Trend Polygon Star Concept Method. In the present study, the same methodology of ITPAM and Trend Polygon Star Concept Method has been applied to analyze SRB average monthly temperature data and further strengthen the adaptability and applicability of both newest methods in academics. Hussain et al. (2022) analyzed the qualitative trends of rainfall data using ITPAM and trend polygon star concept method in the selected study area of SRB Potohar region in Pakistan, and in the present study, we further want to analyze the degree of trend risk and observe climate change using ITPAM based on average monthly temperature data.

According to our understanding, all the parametric and non-parametric methods of trend analysis establish a relationship between data and made definitions such as increasing, decreasing, low, medium, and high, while ITPAM categorizes the risk classes showing changes between available data sets. ITPAM is a modified version of the IPTA method used to determine five risk classes of average monthly temperature data of 11 stations of SRB (Hussain et al., 2022). Moreover, the increasing and decreasing trend regions are divided into five classes for a clear understanding of this method. Furthermore, star graphs are generated using Trend Polygon Star Concept Method to determine the transition distance from one month to another and the slopes of these transitions. The analysis is performed based on the

arithmetic mean and standard deviation of temperature data because the trend approach provides physical aspects of mean and standard deviation seasonal variations that are essential and refined parts hidden in holistic annual trend behaviors (Sen et al., 2019). Moreover, the analysis of hydrometeorological data based on the mean and standard deviation is very important for the effective planning of different human activities such as agricultural activities (irrigation practices, groundwater recharge), water supply and hydroelectric power generation (Ceribasi et al., 2021a).

2. Materials and Methods

2.1. Study Area and Data Descriptions

Soan River Basin (9994 km²; Fig. 1) is located in the Potohar region with an elevation of 222–2261 m above mean sea level. This semi-arid to sub-humid

climatic zone area falls under the administrative control of Islamabad, Rawalpindi, Attock and Chakwal districts. Overall, the northern part of the basin is dominated by humid and sub-humid climates, while the central and southern parts are dominated by arid and semi-arid climates, respectively. The northern boundary of SRB is surrounded by the Margalla Hills and the Murree Hills, while the southern boundary is covered by a salt range (Hussain et al., 2022). The climate is continental and subtropical, with hot summers and relatively cold winters. December is the coldest month, with a mean temperature of 9 °C, and June is the hottest with an average temperature of 31 °C. The 35-year (1981–2016) mean annual rainfall ranges from 400 mm in the plains to about 1710 mm in the mountainous terrain, of which about two thirds occurs during the monsoon period from June to September (Hussain et al., 2021). The major crops grown under rain-fed conditions are wheat, chickpeas, groundnuts, millet, sorghum, oilseeds and

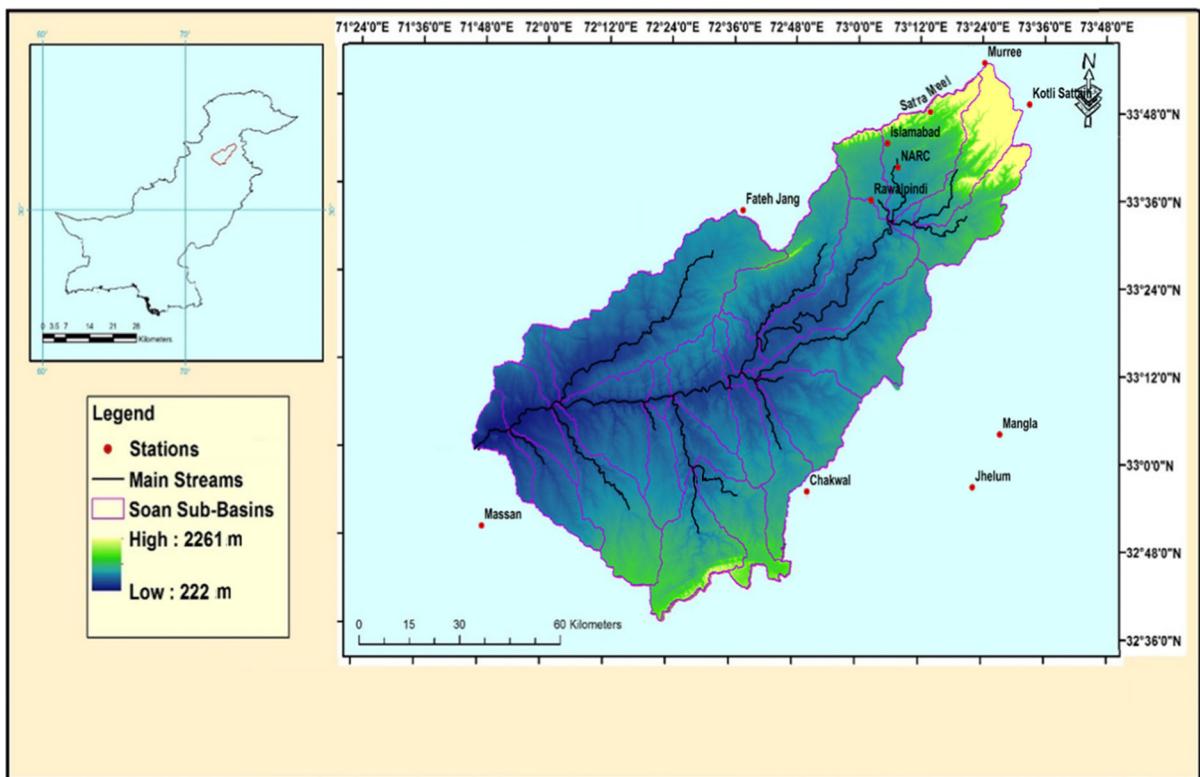


Figure 1

Soan River Basin (SRB), Pakistan, map with meteorological stations and elevation range (Hussain et al., 2022)

Table 1

Meteorological stations in SRB with information on data availability and source of data

Stations	Longitude	Latitude	Altitude (m)	Data range	Source of data
Murree	73°24'3.148" E	33°54'58.847" N	2025	(1995–2020)	PMD
Kotli Sattain	73°32'39.24" E	33°49'18.942" N	1352	(1991–2016)	PMD
Satra Meel	73°14'3.118" E	33°48'16.042" N	715	(1995–2020)	PMD
Islamabad	73°5'42.464" E	33°43'50.202" N	569	(1991–2016)	PMD
Rawalpindi	73°2'50.035" E	33°35'41.506" N	540	(1995–2020)	PMD
NARC	73°7'44.157" E	33°40'23.056" N	551	(1995–2020)	NARC
Mangla	73°28'6.65" E	33°3'54.357" N	283	(1995–2020)	PMD
Jhelum	73°22'30.283" E	32°56'40.575" N	287	(1995–2020)	PMD
Fatehjang	72°38'14.979" E	33°33'58.479" N	514	(1990–2015)	SAWCRI
Chakwal	72°51'14.452" E	32°55'48.639" N	522	(1991–2016)	SAWCRI
Massan	71°49'26.733" E	32°49'39.852" N	335	(1995–2020)	WAPDA

fodder. Agriculture is dependent on the rainfall and perennial flows stored through small/mini dams (Nabi et al., 2020).

Hussain et al. (2021) divided the SRB into three different zones based on the elevation and location of the stations. Murree, Satra Meel, Kotli Sattain, Islamabad, NARC and Rawalpindi are highland stations within 540–2025-m elevation. Fatehjang and Jhelum are midland stations within the 283–529 m elevation range. Chakwal and Massan are lowland stations within 218–522-m elevation from mean sea level. The study area faces four climatological seasons in a year, i.e. winter (December to February or DJF), spring or pre-monsoon (March to May or MAM), summer or monsoon (June to September or JJAS), and fall or post-monsoon (October to December or OND). For the analysis of temperature data using ITPAM and the Trend Polygon Star Concept Method, the historical monthly time series records of 11 stations over the different periods according to data availability (Table 1) in SRB was collected from the Pakistan Meteorological Department (PMD), Soil and Water Conservation Research Institute (SAWCRI), National Agricultural Research Centre (NARC) and Water and Power Development Authority (WAPDA) in Pakistan. The detailed description of 11 stations, data availability and source of data are presented in Table 1.

2.2. Innovative Trend Pivot Analysis Method (ITPAM)

ITPAM (Ceribasi et al., 2021a) is an extended version of Innovative Polygon Trend Analysis (IPTA; Hussain et al., 2022; Şen et al., 2019). In ITPAM, the increasing or decreasing trend regions are categorized into five different classifications as (1) very high degree, (2) high degree, (3) medium degree, (4) low degree and (5) very low degree. This classification is used to define the risk range by establishing a relationship between the data being analyzed wherein the very-high-degree class represents the first-degree risk range, and the very-low-degree class represents the fifth-degree risk range. ITPAM is hypothetically explained in Fig. 2 based on monthly data.

Figure 2a is a modified form of the IPTA graph with increasing and decreasing trend regions. The point on the 1:1 (45°) line is called the no-trend class. This Cartesian graph (Fig. 2a) is attained by dividing the data length into five equal parts of both axes, which are combined via the 1:1 line. This combination is represented by a different color scheme for identification and better interpretation of results obtained via the IPTA method.

Figure 2b is the main output of ITPAM (risk graph) obtained by following the given sequence (Fig. 3).

Tabulation (Table 2) of extracted information is recommended for a clear understanding of ITPAM graphics. For example, the information can be denoted as follows: a monthly point in Fig. 1a is a medium-degree increasing trend, while this point in

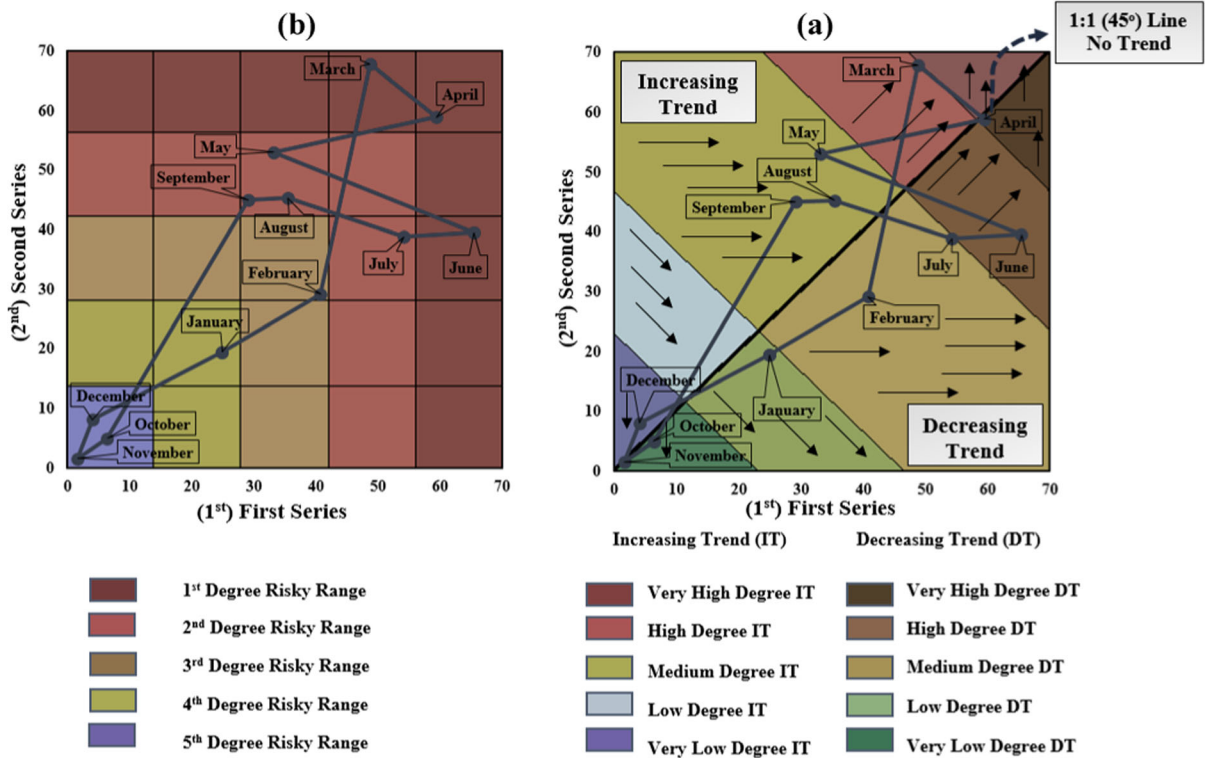


Figure 2

Hypothetical ITPAM template for monthly data: **a** improved form of IPTA graph representing increasing and decreasing trend regions with degree classification; **b** ITPAM risk graph with classification

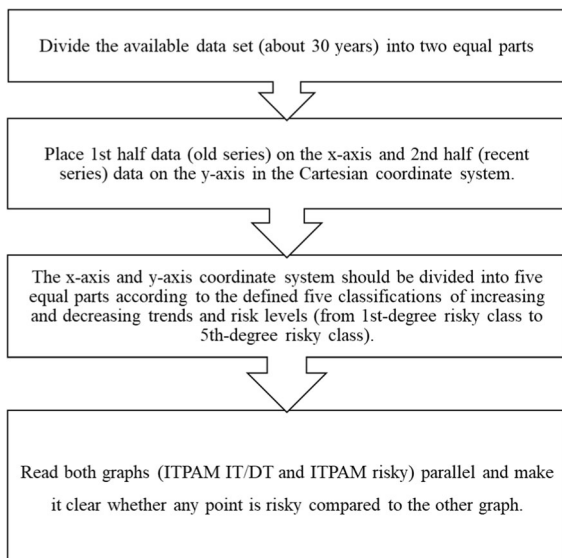


Figure 3
ITPAM risk graph flowchart

Fig. 1b may be in the first-degree risk class. This position demonstrated considerable variation of this point between the first and second data sets.

Table 2 contains the information of Fig. 2 graphs and can be explained as 7 months (Jan, Feb, Apr, Jun, Jul, Oct and Nov) that are in the decreasing trend region. April showed no trend. October and November showed a very-low-degree trend class, with the fifth-degree risk class. The trend class of January is low degree and the risk class is fourth degree. The February and July trend class is of medium degree, while the risk class analysis indicated that February is in the third-degree and July is in the second-degree risk class. June showed a high-degree decreasing trend in the first-degree risk class. The other five months (Mar, May, Aug, Sep and Dec) are in an increasing trend region. December showed a very-low-degree trend class and fifth-degree risk class. The

Table 2

Tabulation of extracted information of hypothetical ITPAM graphics based on Fig. 2

Months	Trend region	Trend class	Trend symbology	Risk class	Risk range	
January	DT	LD		4th DRC	14–28	
February		MD		3rd DRC	28–42	
April		VHD		1st DRC	56–70	
June		HD		1st DRC	56–70	
July		MD		2nd DRC	42–56	
October		VLD		5th DRC	0–14	
November		VLD		5th DRC	0–14	
March		IT	HD		1st DRC	56–70
May			MD		2nd DRC	42–56
August			MD		2nd DRC	42–56
September	MD			2nd DRC	42–56	
December	VLD			5th DRC	0–14	

DT, decreasing trend; IT, increasing trend; LD, low degree; MD, medium degree; VHD, very high degree; HD, high degree; VLD, very low degree; DRC, degree risk class

trend class for May, August and September is of medium degree, and these months are in the second-degree risk class. March showed a high-degree increasing trend with first-degree risk class. The hypothetical results in Table 2 show that some months are in a low degree in the ITPAM graph while showing a high risk class in the risk graph. For example, May, August and September are in the medium-degree increasing trend class in the developed ITPAM graph, and they are in the second-degree risk class in the risk graph. This indicates that there is a significant change between the first and second data sets for these months.

2.3. Trend Polygon Star Concept

The Trend Polygon Star Concept (Sen, 2021) exemplifies the distance between two succeeding months that reflects the temporal duration and slope of a trend line (Hussain et al., 2022). The Trend Polygon Star Concept of Fig. 2 is shown in Fig. 4. In this method, the graph area is divided into four regions, with arrows originating from the origin (0, 0). The first half of the data set is presented on the X-axis and the second half on the Y-axis. The following information can be extracted from the trend star graph based on Sen (2021) and Ceribasi et al. (2021b):

1. The arrows are drawn according to the transition line between two months. Each arrow length gives the amount of the respective monthly data set in terms of the amount that the trend polygon side extends from one month to the next. The greater the length of the arrow line, the greater transition between two months.
2. The values on the horizontal axis of arrows correspond to the monthly change in the data set during the first half and the values on the vertical axis display the amount of monthly change during the second half. The difference between horizontal and vertical amounts indicates the monthly climate change.
3. Region I (III) shows that both projections are positive (negative), which represents an increasing (decreasing) trend in the first and second halves in both axes.
4. If the direction of an arrow is in region II (IV) represents an increase (decrease) in the first (second) half time duration.
5. The ratio of the vertical projection to the horizontal is the trend slope of the polygon side.

3. Results

In this study, innovative trend methods (ITPAM and Trend Polygon Star Concept) based on two

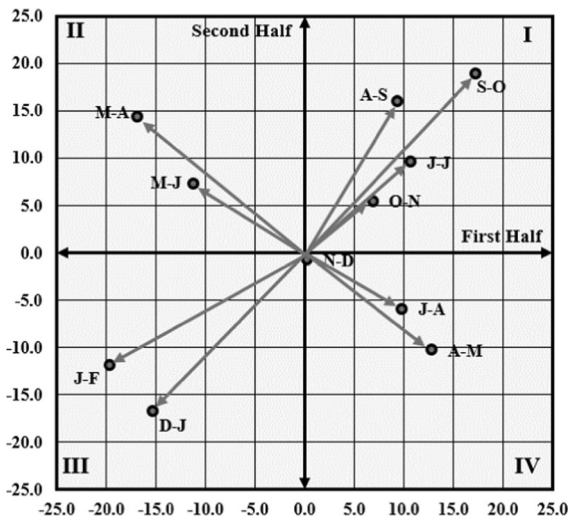


Figure 4

Hypothetical Trend Polygon Star Concept for monthly data. In region I, four corresponding months (J–J, June–July; A–S, August–September; S–O, September–October; O–N, October–November) showed an increasing trend while in region III two corresponding months (J–F, January–February; D–J, December–January) representing decreasing trends between both axes of the data set. The months in region II (IV), M–A, March–April; M–J, May–June (A–M, April–May; J–A, July–August; N–D, November–December), represent an increase (decrease) in the first (second) half of the time duration

statistical parameters (arithmetic mean and standard deviation) were applied to monthly average temperature data for the SRB, Potohar region, Pakistan. The arithmetic mean analysis results of mean monthly temperature data for each station are given in Fig. 5 using the ITPAM method. The arithmetic mean analysis results are summarized in Table 3 for each station of Fig. 5, and the following findings were extracted.

According to ITPAM analysis results (Fig. 5), there is no single polygon formed at any station, indicating that monthly average temperature data are not homogeneous.

1. For Massan station, which is located downstream of the SRB, five months (February, May, June, July and September) showed no trend, indicating that the monthly average temperature is the same in the first and second data sets. August, November, December and January are in decreasing trend regions with very-high- to medium- to very-low-degree trend class,

respectively. The risk class also varies from the first DRC, fourth DRC and fifth DRC for August, November, December and January, respectively. March, April and October showed a medium-degree increasing trend in the fourth- and second-degree risk classes. The first- and second-degree risk classes show a significant change between the first and second data sets, indicating that the second monthly data set has a higher temperature than the first data set in April and October. The deviating pattern in August may be due to some unknown errors during data collection.

2. For Chakwal station, November to March showed no trend, while April to October showed a medium- to high-degree decreasing trend. June showed a first-degree risk classification.
3. All months except March and April showed no trend for Fatehjang station, and these two months are in a medium-degree increasing trend with third- and second-degree risk class, respectively.
4. Jhelum station showed similar behavior as Fatehjang, namely that March, April and October are in a medium-degree increasing trend with third- and second-degree risk class, respectively.
5. For Mangla station, September and October are in the increasing trend region with medium- to high-degree trend class, respectively. Looking at the risk graph, both are in the second-degree risk class.
6. For Rawalpindi station, February, March, April, September and October are in an increasing trend with very-low-, low-, medium-, high- and medium-degree trend class, respectively. Looking at the risk graph, September is only in the second-degree risk class, while the others have lower-degree risk.
7. All months except March showed no trend for Islamabad station, indicating that the monthly average temperature is the same in the first and second data sets. March is in a medium-degree increasing trend region with a third-degree risk class.
8. For NARC station, February to May are in an increasing trend and the trend class is low to high degree, respectively. May is in the second-degree risk class according to risk analysis.

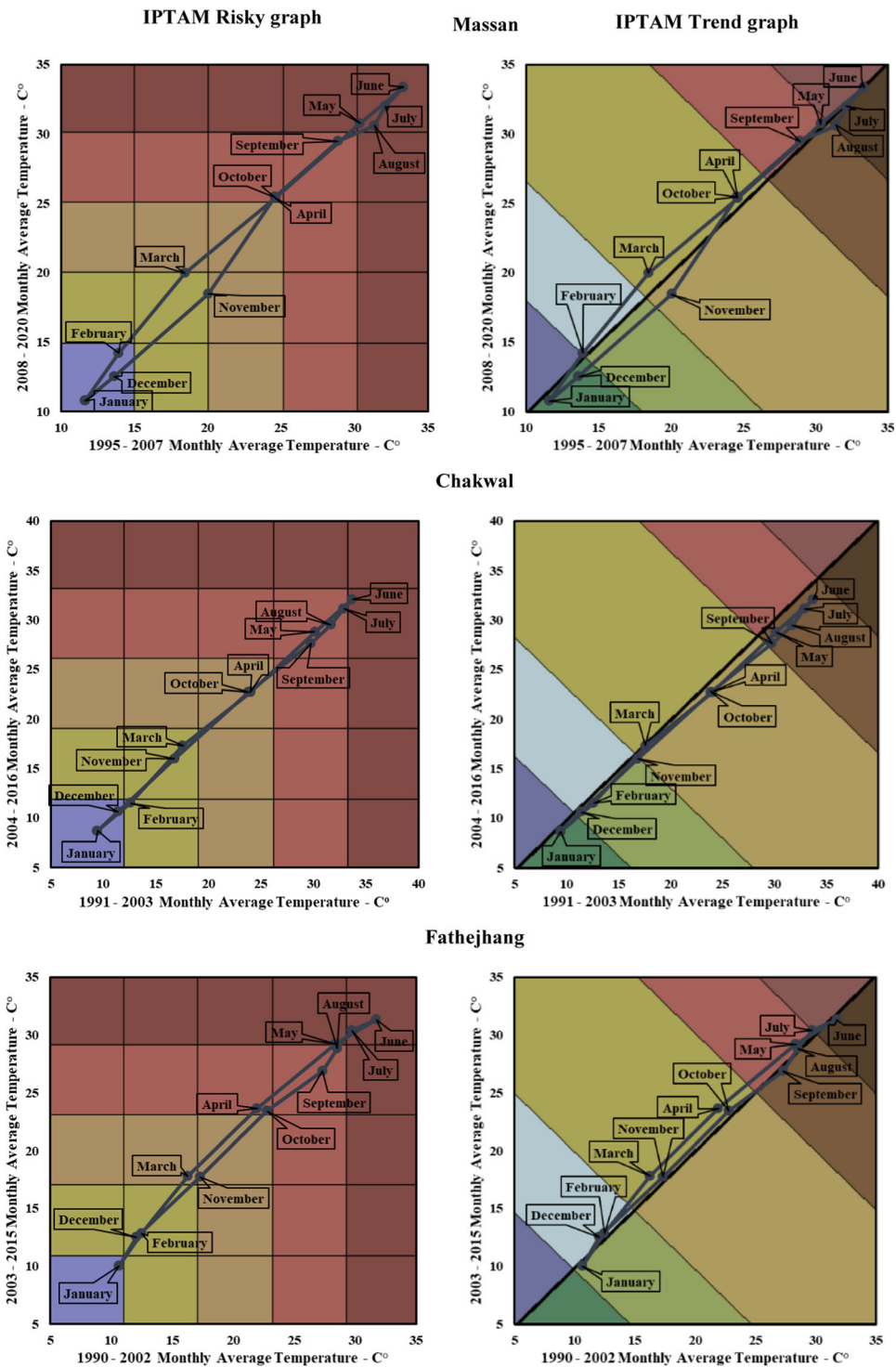
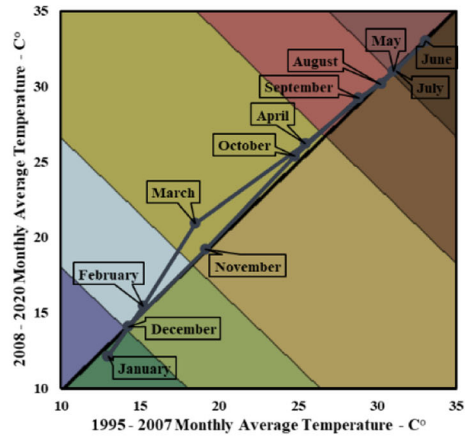
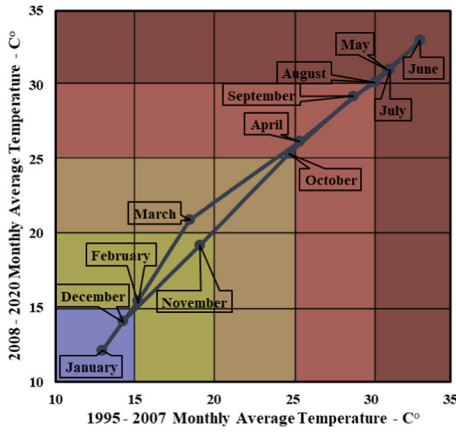
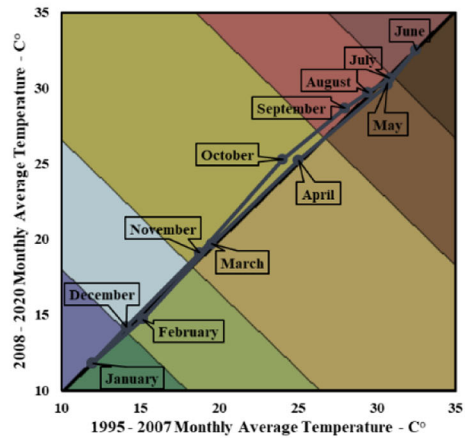
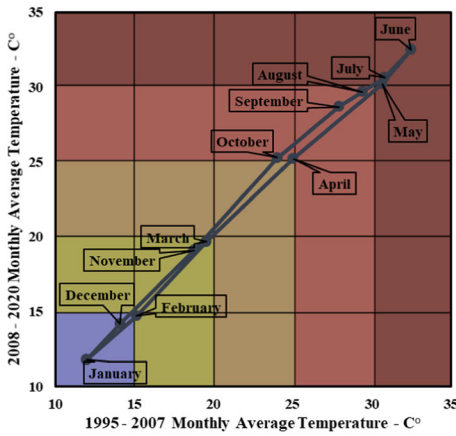


Figure 5
 ITPAM analysis results of mean monthly temperature data based on the arithmetic mean parameter for each station of Soan River Basin, Potohar region, Pakistan

Jhelum



Mangla



Rawalpindi

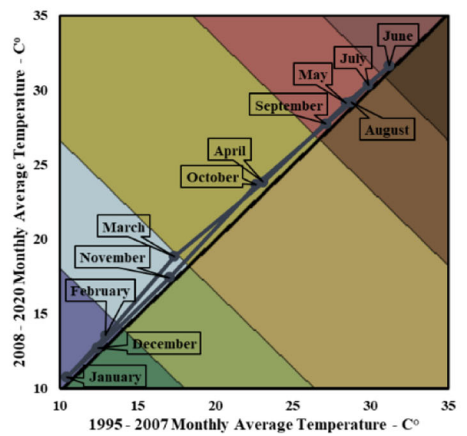
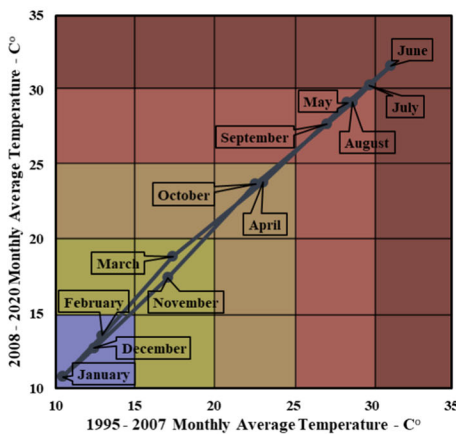
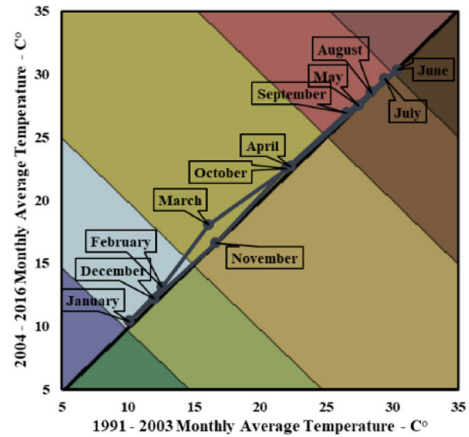
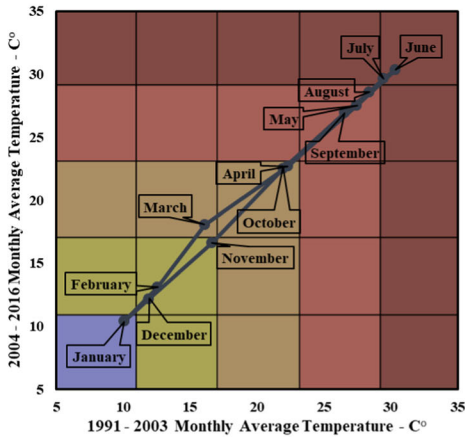
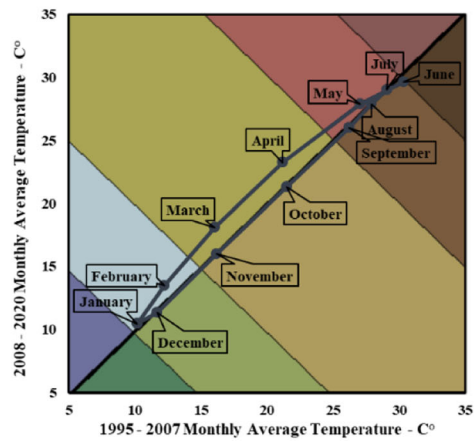
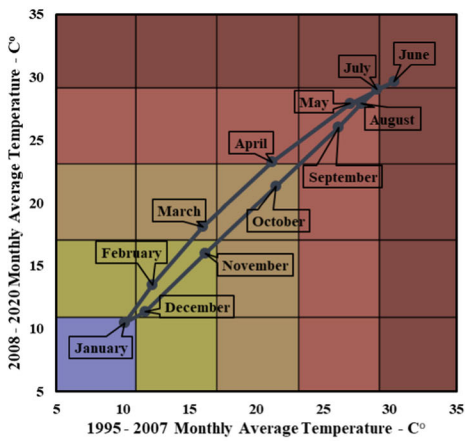


Figure 5 continued

Islamabad



NARC



Satra Meel

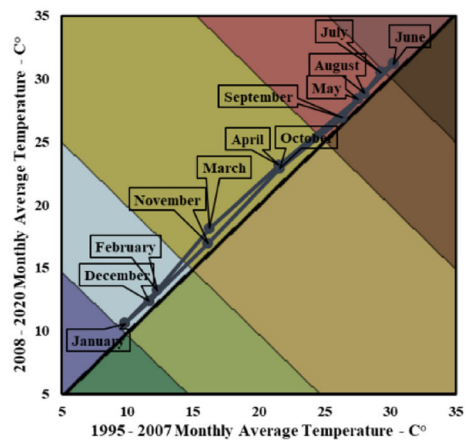
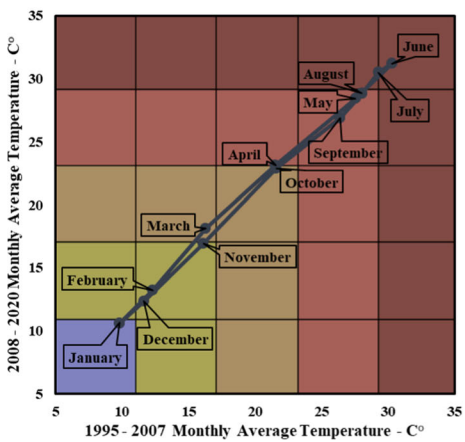
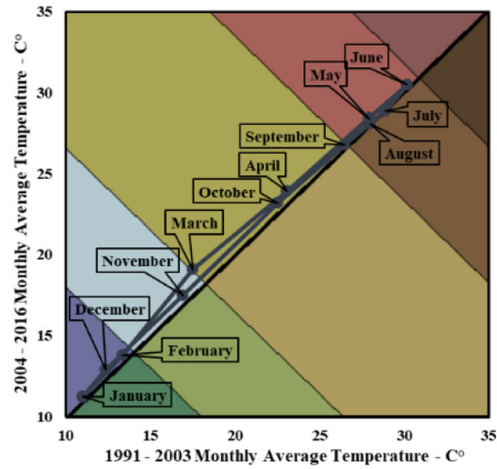
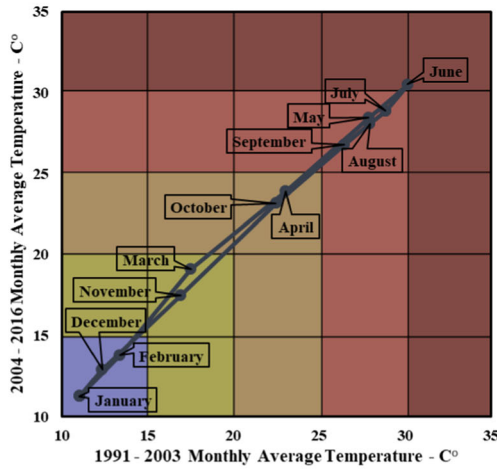


Figure 5 continued

Kotli Sattain



Murree

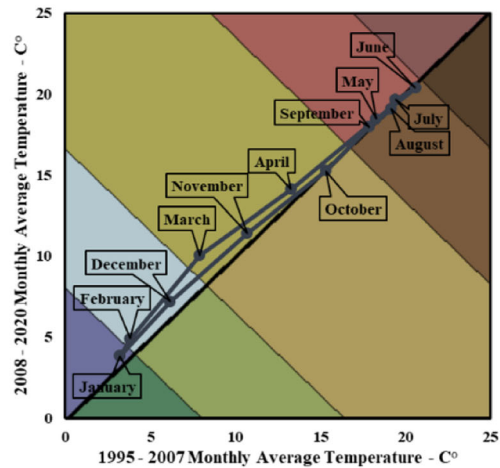
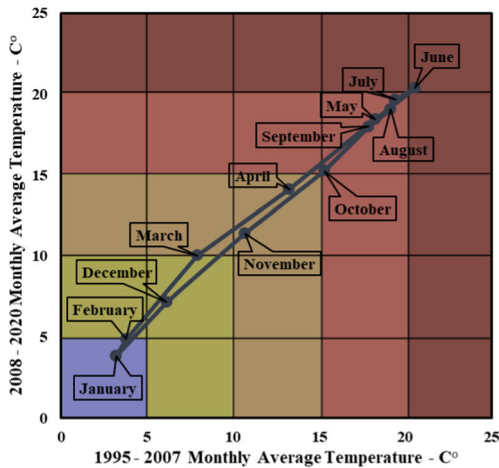


Figure 5 continued

9. For Satra Meel station, all months are in an increasing trend region with low-, medium-, high- to very-high-degree trend class. It was found that June and July are in the first-degree risk class. This result shows a significant change between the first and second data sets in June and July.
10. For Murree station, October to April indicate an increasing trend but the trend class is low to medium, while looking at the risk graph, these months are in the third- to fourth-degree risk

- class and only October is in the second-degree risk class.
11. For Kotli Sattain station, the increasing trend is in March, April and October with a medium-degree trend class. April and October are in the third-degree risk class.

Based on the examination of results, it was found that March and April at four stations (Massan, Fatehjang, Jhelum and Mangla) showed increasing changes in temperature between the first and second data sets. The temperature for March continuously

Table 3

Evaluation of arithmetic mean analysis results of temperature data of each station in Soan River Basin

Stations	Months											
	January	February	March	April	May	June	July	August	September	October	November	December
Massan												
Trend (region-class)	DT-VLD	NT	IT-MD	IT-MD	NT	NT	NT	DT-VHD	NT	IT-MD	DT-MD	DT-VLD
Trend symbol	↓	—	→	→	—	—	—	↑	—	→	→	↓
Risk class	5th DRC	5th DRC	4th DRC	2nd DRC	1st DRC	1st DRC	1st DRC	1st DRC	2nd DRC	2nd DRC	4th DRC	5th DRC
Chakwal												
Trend (region-class)	NT	NT	NT	DT-MD	DT-HD	DT-HD	DT-HD	DT-HD	DT-HD	DT-MD	NT	NT
Trend symbol	—	—	—	→	↗	↗	↗	↗	↗	→	—	—
Risk class	5th DRC	4th DRC	4th DRC	3rd DRC	2nd DRC	1st DRC	2nd DRC	2nd DRC	2nd DRC	3rd DRC	4th DRC	5th DRC
Fatehjang												
Trend (region-class)	NT	NT	IT-MD	IT-MD	NT	NT	NT	NT	NT	NT	NT	NT
Trend symbol	—	—	→	→	—	—	—	—	—	—	—	—
Risk class	5th DRC	4th DRC	3rd DRC	2nd DRC	2nd DRC	1st DRC	1st DRC	2nd DRC	2nd DRC	2nd DRC	3rd DRC	4th DRC
Jhelum												
Trend (region-class)	DT-VLD	NT	IT-MD	IT-MD	NT	NT	NT	NT	NT	IT-MD	NT	NT
Trend symbol	↓	—	→	→	—	—	—	—	—	→	—	—
Risk class	5th DRC	4th DRC	3rd DRC	2nd DRC	1st DRC	1st DRC	1st DRC	1st DRC	2nd DRC	2nd DRC	4th DRC	5th DRC
Mangla												
Trend (region-class)	NT	NT	NT	NT	NT	NT	NT	NT	IT-MD	IT-HD	NT	NT
Trend symbol	—	—	—	—	—	—	—	—	→	↗	—	—
Risk class	5th DRC	4th DRC	4th DRC	2nd DRC	1st DRC	1st DRC	1st DRC	2nd DRC	2nd DRC	2nd DRC	4th DRC	5th DRC
Rawalpindi												
Trend (region-class)	NT	IT-VLD	IT-LD	IT-MD	NT	NT	NT	NT	IT-HD	IT-MD	NT	NT
Trend symbol	—	↓	↘	→	—	—	—	—	↗	→	—	—
Risk class	5th DRC	5th DRC	4th DRC	3rd DRC	1st DRC	1st DRC	1st DRC	1st DRC	2nd DRC	3rd DRC	4th DRC	5th DRC
Islamabad												
Trend (region-class)	NT	NT	IT-MD	NT	NT	NT	NT	NT	NT	NT	NT	NT
Trend symbol	—	—	→	—	—	—	—	—	—	—	—	—
Risk class	5th DRC	4th DRC	3rd DRC	3rd DRC	2nd DRC	1st DRC	1st DRC	2nd DRC	2nd DRC	3rd DRC	4th DRC	4th DRC
NARC												
Trend (region-class)	NT	IT-LD	IT-MD	IT-MD	IT-HD	NT	NT	NT	NT	NT	NT	NT
Trend symbol	—	↘	→	→	↗	—	—	—	—	—	—	—
Risk class	5th DRC	4th DRC	3rd DRC	2nd DRC	2nd DRC	1st DRC	1st DRC	2nd DRC	2nd DRC	3rd DRC	4th DRC	4th DRC
Satra Meel												
Trend (region-class)	IT-LD	IT-LD	IT-MD	IT-MD	IT-HD	IT-VHD	IT-HD	IT-HD	IT-HD	IT-MD	IT-MD	IT-LD
Trend symbol	↘	↘	→	→	↗	↑	↗	↗	↗	→	→	↘
Risk class	5th DRC	4th DRC	3rd DRC	3rd DRC	2nd DRC	1st DRC	1st DRC	2nd DRC	2nd DRC	3rd DRC	4th DRC	4th DRC
Murree												
Trend (region-class)	IT-VLD	IT-LD	IT-MD	IT-MD	NT	NT	NT	NT	NT	IT-MD	IT-MD	IT-LD
Trend symbol	↓	↘	→	→	—	—	—	—	—	→	→	↘
Risk class	5th DRC	4th DRC	3rd DRC	3rd DRC	2nd DRC	1st DRC	2nd DRC	2nd DRC	2nd DRC	2nd DRC	3rd DRC	4th DRC
Kotli Sattain												
Trend (region-class)	NT	NT	IT-LD	IT-MD	NT	NT	NT	NT	NT	IT-MD	NT	NT
Trend symbol	—	—	↘	→	—	—	—	—	—	→	—	—
Risk class	5th DRC	5th DRC	4th DRC	3rd DRC	2nd DRC	1st DRC	2nd DRC	2nd DRC	2nd DRC	3rd DRC	4th DRC	5th DRC

increased and became relatively significant in April. This trend implies monthly climate change in the spring season. At other stations (Rawalpindi, NARC, Satra Meel, Murree and Kotli Sattain) this change starts in February and continues to April. The temperature in September and October is also in an increasing trend region at Massan, Jhelum, Mangla,

Rawalpindi, Satra Meel, Murree and Kotli Sattain stations, with third- to second-degree risk class, indicating climate change from the late monsoon period to the early post-monsoon period. The analysis also indicates that the downstream stations (such as Massan, Fatehjang, Jhelum and Mangla) in April and October are undergoing significant change, with

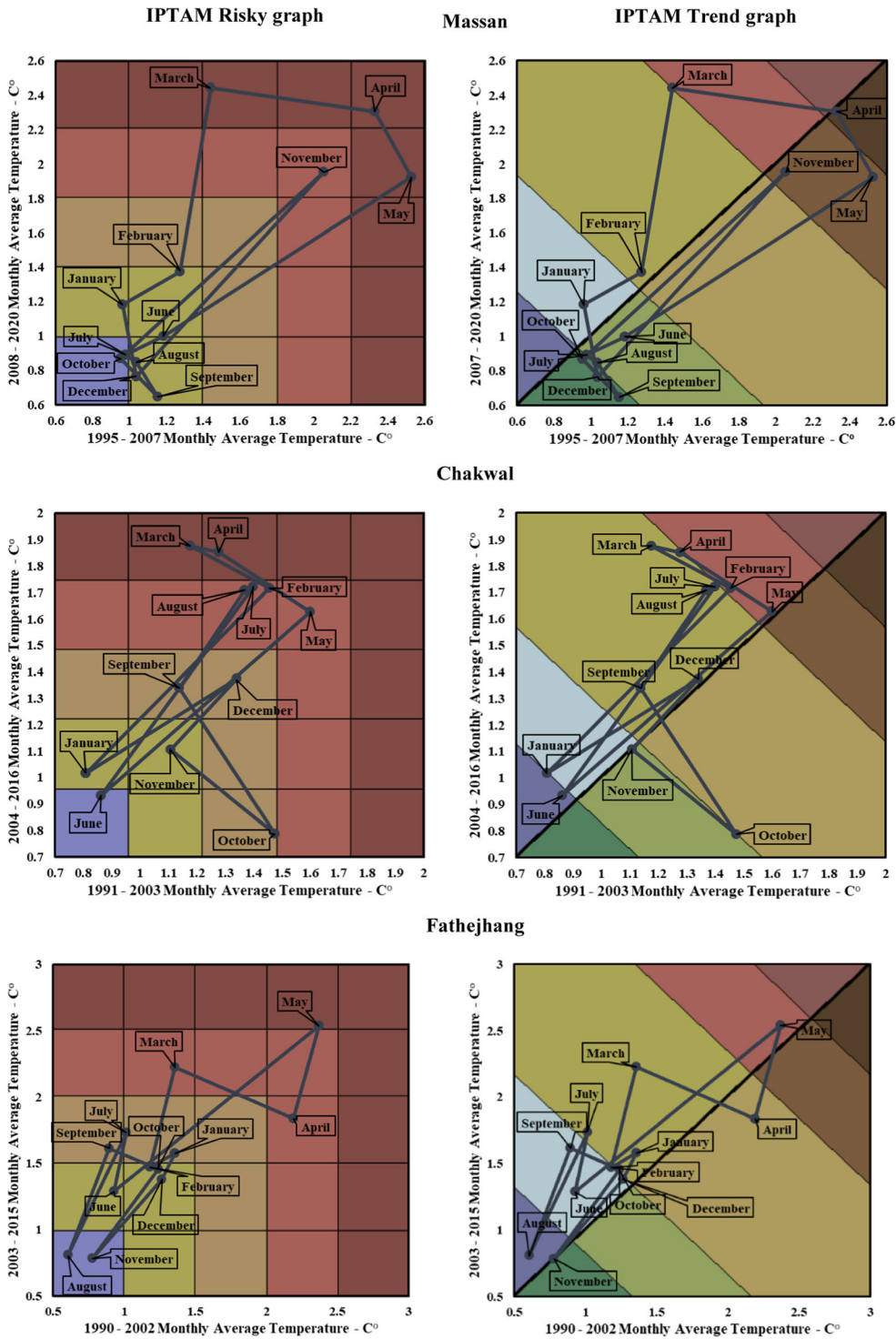
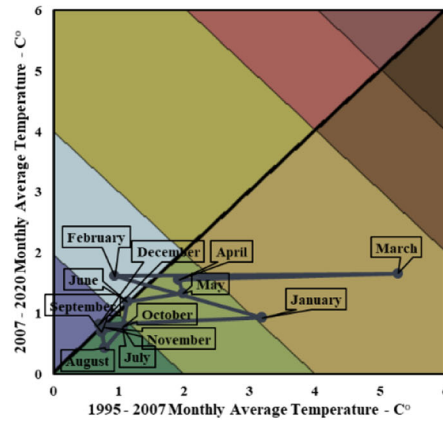
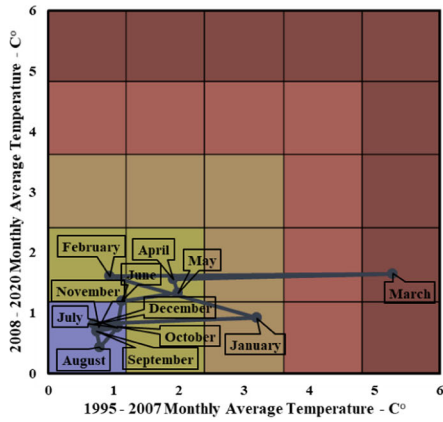
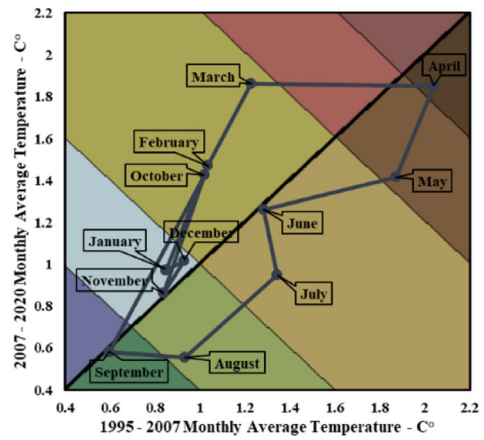
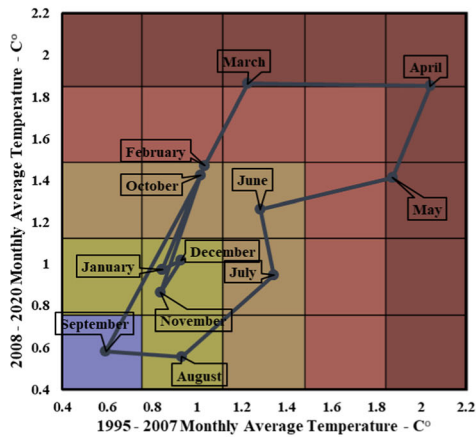


Figure 6
ITPAM analysis results of monthly temperature data based on the standard deviation for each station of Soan River Basin, Potohar region, Pakistan

Jhelum



Mangla



Rawalpindi

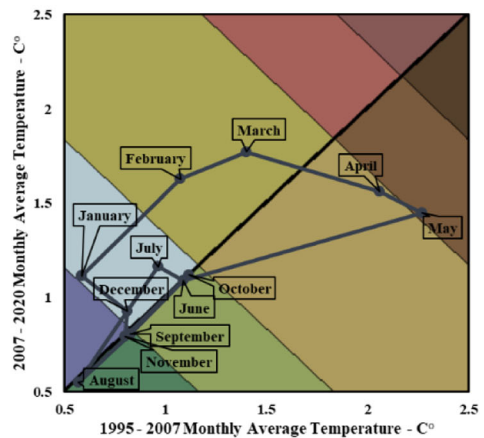
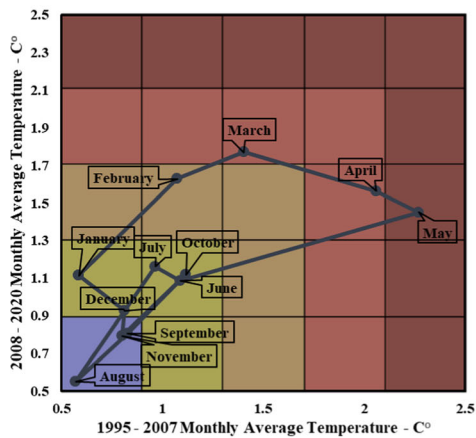
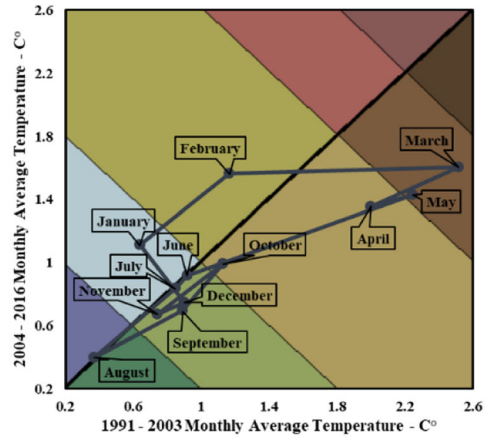
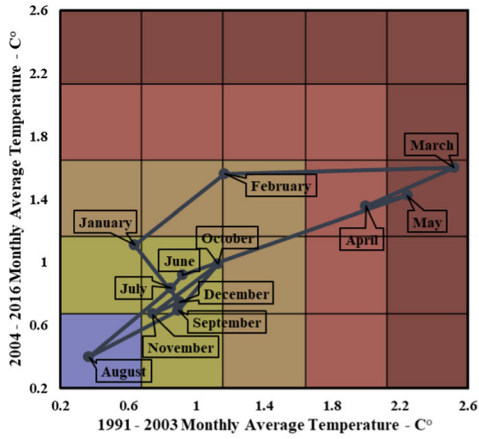
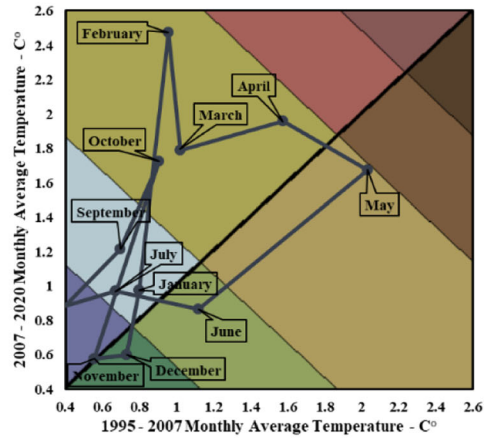
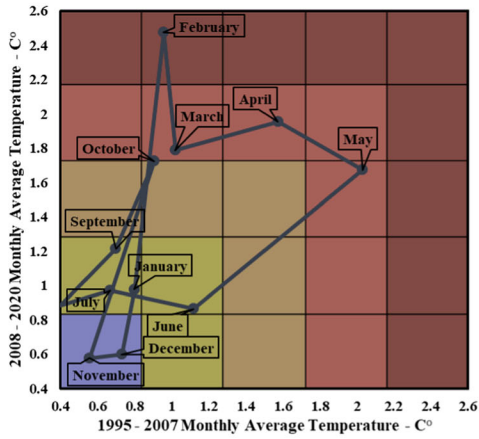


Figure 6 continued

Islamabad



NARC



Satra Meel

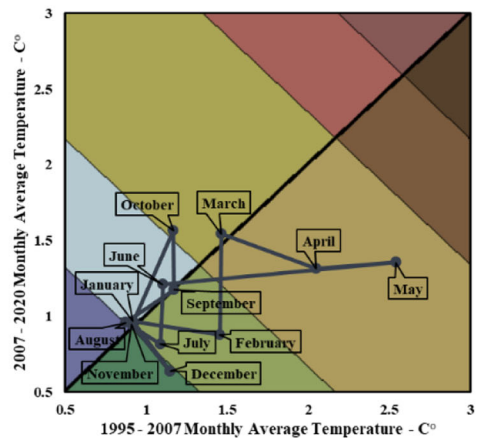
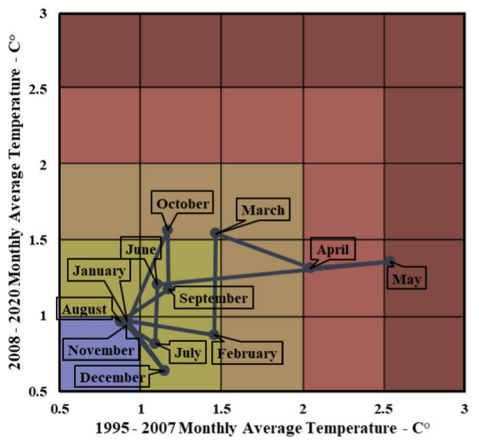
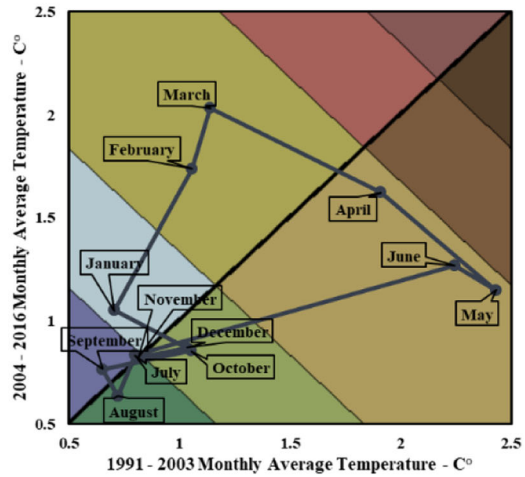
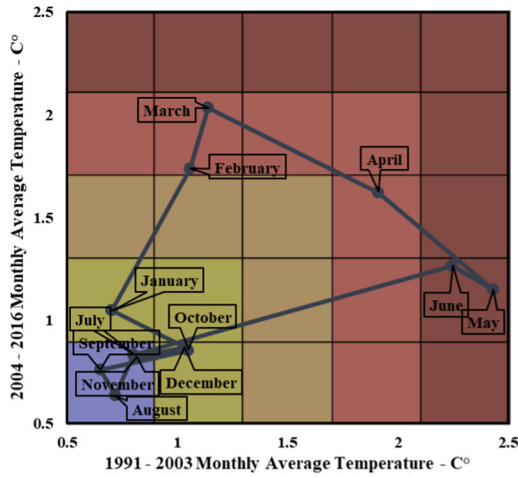


Figure 6 continued

Kotli Sattain



Murree

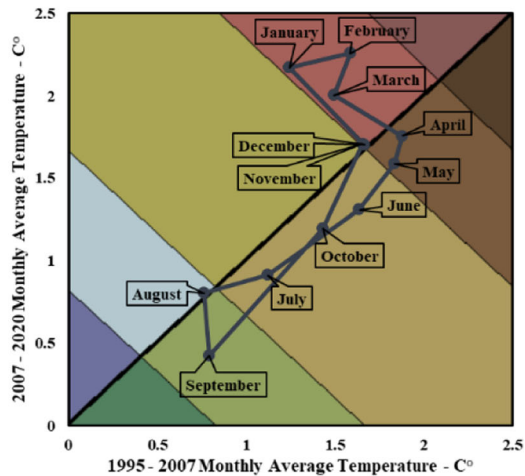
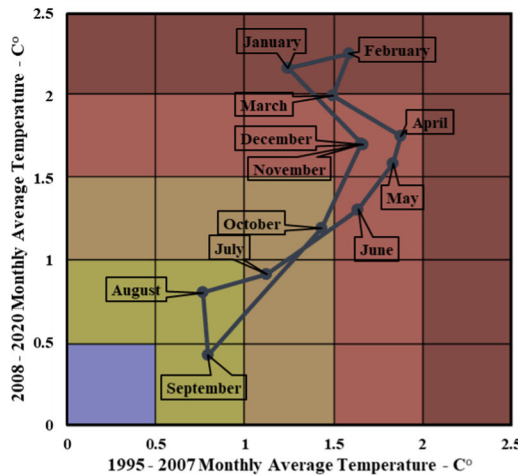


Figure 6 continued

second-degree risk class, while upstream stations such as Rawalpindi, NARC, Murree, Satra Meel and Kotli Sattain are in a low-degree risk class, indicating that low-elevation stations have a high degree of climate change compared to higher-elevation stations. There is monthly climate change in April and October of the SRB with a high degrees in low-lying areas compared to high-elevation areas. May to August are in a no-trend region, indicating that the monthly average temperature is the same in the first and second data sets.

ITPAM graphics of standard deviation analysis results of mean monthly temperature data for each station are given in Fig. 6. Standard deviation is the measure of variation/dispersion of data sets. It determines whether the data values are generally near or far from the mean temperature data. In Fig. 6, more complex polygons emerge from standard deviation graphs compared to arithmetic mean graphs. The information on standard deviation analysis results is summarized in Table 4 for each station of Fig. 6 and the following findings were extracted.

Table 4

Evaluation of standard deviation analysis results of monthly temperature data of each station in the Soan River Basin

Stations	Months											
	January	February	March	April	May	June	July	August	September	October	November	December
Massan												
Trend (region-class)	IT-LD	IT-MD	IT-HD	NT	DT-HD	DT-LD	DT-LD	DT-LD	DT-VLD	DT-VLD	DT-HD	DT-VLD
Trend symbol	↘	→	↗	—	↗	↘	↘	↘	↓	↓	↗	↓
Risk class	4th DRC	4th DRC	1st DRC	1st DRC	1st DRC	4th DRC	5th DRC	4th DRC	4th DRC	5th DRC	2nd DRC	5th DRC
Chakwal												
Trend (region-class)	IT-LD	IT-HD	IT-MD	IT-MD	NT	IT-VLD	IT-MD	IT-MD	IT-MD	DT-LD	NT	NT
Trend symbol	↘	↗	→	→	—	↓	→	→	→	↘	—	—
Risk class	4th DRC	2nd DRC	1st DRC	1st DRC	2nd DRC	5th DRC	2nd DRC	2nd DRC	3rd DRC	3rd DRC	4th DRC	3rd DRC
Fathejhang												
Trend (region-class)	IT-MD	IT-MD	IT-MD	DT-MD	IT-HD	IT-LD	IT-MD	IT-VLD	IT-LD	IT-LD	NT	IT-LD
Trend symbol	→	→	→	→	↗	↘	→	↓	↘	↘	—	↘
Risk class	3rd DRC	4th DRC	2nd DRC	2nd DRC	1st DRC	4th DRC	3rd DRC	5th DRC	3rd DRC	4th DRC	5th DRC	4th DRC
Jhelum												
Trend (region-class)	DT-MD	IT-LD	DT-MD	DT-LD	DT-LD	NT	DT-VLD	DT-VLD	NT	DT-VLD	NT	NT
Trend symbol	→	↘	→	↘	↘	—	↓	↓	—	↓	—	—
Risk class	3rd DRC	4th DRC	1st DRC	4th DRC	4th DRC	4th DRC	5th DRC	5th DRC	4th DRC	4th DRC	4th DRC	4th DRC
Mangla												
Trend (region-class)	IT-LD	IT-MD	IT-MD	DT-VHD	DT-HD	NT	DT-MD	DT-LD	NT	IT-MD	NT	IT-LD
Trend symbol	↘	→	→	↑	↗	—	→	↘	—	→	—	↘
Risk class	4th DRC	3rd DRC	1st DRC	1st DRC	1st DRC	3rd DRC	3rd DRC	4th DRC	5th DRC	3rd DRC	4th DRC	4th DRC
Rawalpindi												
Trend (region-class)	IT-LD	IT-MD	IT-MD	DT-MD	DT-MD	NT	IT-LD	NT	NT	NT	NT	IT-LD
Trend symbol	↘	→	→	→	→	—	↘	—	—	—	—	↘
Risk class	4th DRC	3rd DRC	2nd DRC	2nd DRC	1st DRC	4th DRC	4th DRC	5th DRC	5th DRC	4th DRC	5th DRC	4th DRC
Islamabad												
Trend (region-class)	IT-LD	IT-MD	DT-HD	DT-MD	DT-HD	NT	NT	NT	DT-LD	DT-MD	DT-LD	DT-LD
Trend symbol	↘	→	↗	→	↗	—	—	—	↘	→	↘	↘
Risk class	4th DRC	3rd DRC	1st DRC	2nd DRC	1st DRC	4th DRC	4th DRC	5th DRC	4th DRC	4th DRC	4th DRC	4th DRC
NARC												
Trend (region-class)	IT-LD	IT-MD	IT-MD	IT-MD	DT-MD	DT-LD	IT-LD	IT-VLD	IT-LD	IT-MD	NT	DT-VLD
Trend symbol	↘	→	→	→	→	↘	↘	↘	↘	→	—	↓
Risk class	4th DRC	1st DRC	2nd DRC	2nd DRC	2nd DRC	4th DRC	4th DRC	4th DRC	4th DRC	3rd DRC	5th DRC	5th DRC
Satra Meel												
Trend (region-class)	IT-LD	DT-LD	IT-MD	DT-MD	DT-MD	IT-LD	DT-LD	IT-LD	NT	IT-MD	NT	DT-VLD
Trend symbol	↘	↘	→	→	→	↘	↘	↘	—	→	—	↓
Risk class	5th DRC	4th DRC	3rd DRC	2nd DRC	1st DRC	4th DRC	4th DRC	5th DRC	4th DRC	3rd DRC	5th DRC	4th DRC
Murree												
Trend (region-class)	IT-HD	IT-HD	IT-HD	DT-HD	DT-HD	DT-MD	DT-MD	NT	DT-LD	DT-MD	NT	NT
Trend symbol	↗	↗	↗	↗	↗	→	→	—	↘	→	—	—
Risk class	1st DRC	1st DRC	1st DRC	2nd DRC	2nd DRC	2nd DRC	3rd DRC	4th DRC	4th DRC	3rd DRC	2nd DRC	2nd DRC
Kotli Sattian												
Trend (region-class)	IT-LD	IT-MD	IT-MD	DT-MD	DT-MD	DT-MD	NT	DT-VLD	IT-VLD	DT-LD	NT	NT
Trend symbol	↘	→	→	→	→	→	—	↓	↓	↘	—	—
Risk class	4th DRC	2nd DRC	2nd DRC	2nd DRC	1st DRC	1st DRC	4th DRC	5th DRC	5th DRC	4th DRC	5th DRC	4th DRC

1. For Massan station, March is in the increasing trend region while May is in the decreasing trend region, and the trend class is of high degree. Looking at the risk graph, these are in the first-degree risk class. These results show a significant change between the first data set and the second data set in March and May.
2. For Chakwal station, March and April are in a medium-degree increasing trend region with

first-degree risk class, while July and August are also in a medium-degree increasing trend region with second-degree risk class. February is in an increasing trend region and the trend class is of high degree. Looking at the risk graph, it is in the second-degree risk class. These results indicate that the temperature is increasing in months of late winter to early spring, which is evidence of climate change in the SRB. It also

shows that the winter temperature increased from 1 to 1.8 °C from 2004 to 2016.

3. For Fatehjang station, a high-degree increasing trend with first-degree risk class was observed in May, while the other months (except April) are also in increasing trend regions with medium- to low-degree trend and third- and fourth-degree risk class, indicating a nonsignificant change in the second data set.
4. For Jhelum station, March is in the decreasing trend region and the trending class is of high degree. Looking at the risk graph, these are in the first-degree risk class.
5. For Mangla station, March is in the increasing trend region and April and May are in the decreasing trend region. The trend class is medium degree, very high degree and high degree, respectively. Looking at the risk graph, these are in the first-degree risk class. These results show a significant change between the first data set and the second data set in March, April and May.
6. For Rawalpindi station, May is in a decreasing trend region and the trending class is of medium degree. Looking at the risk graph, it is in the first-degree risk class.
7. For Islamabad station, March and May are in a high-degree decreasing trend region with first-degree risk class.
8. For the NARC station, February is in the increasing trend region and the trend is of medium degree. Looking at the risk graph, it is in the first-degree risk class.
9. For Satra Meel station, May is in a medium-degree decreasing trend region with first-degree risk class.
10. For Murree station, January, February and March are in the increasing trend region, and the trending class is of high degree with first-degree risk class.
11. For Kotli Sattian station, May and June are in a decreasing trend region with a medium-degree trend and first-degree risk class.

Based on the standard deviation analysis results, a significant change is observed between the first data set and the second data set of March, April and May at many stations. It was found that most of the points

have a medium-degree trend class of the ITPAM graph, while this point is in the first-degree risk class in the risk graph. This result reveals the importance of ITPAM analysis. Almost all stations of the SRB showed an increasing temperature trend in winter months, indicating that the severity of the cold lessened during the second data set. Looking at the risk graph, the high-altitude station (Murree) is in the first-degree risk class in winter. The spring months of March and April show the complex nature of behavior around the study region. All stations except Jhelum and Islamabad showed an increasing temperature trend, with first- and second-degree risk class in March, while all stations except Chakwal and NARC showed a decreasing temperature trend with first- and second-degree risk class. The summer season temperature is also decreasing around the study region except at Chakwal and Fatehjang stations. A significant change is observed in May and June with the first- and second-degree risk classes.

The analysis based on standard deviation clarified the climate change and global warming effects in the Potohar region of Pakistan, as it was observed that the winter season temperature is increasing and the months of December to February are getting warmer. Summer is expanding and pushing autumn towards winter, swallowing the early period of the cold season. The spring season is also getting effects by changing the temperature of the summer season as the late-April temperature is decreasing. The phenomena of global warming and observed changes in temperature of the study area indicate that there is a need to understand the cropping system according to temperature variation because in the study region Rabi (winter season) wheat crop is sensitive to temperature and needs both cold and warm temperature to produce maximum yield.

Table 5 consists of statistical values of temperature analyzed by the IPTA method in the SRB. The maximum transition value between two months based on the arithmetic mean and standard deviation are shown in bold in Table 5. The transition is examined in terms of trend length and trend slope. For example, for the Rawalpindi station, the statistical results indicated that the maximum trend length is between October and November for the arithmetic mean and between May and June for standard deviation. The

Table 5

Statistical results of IPTA method of monthly temperature data for each station in the Soan River Basin

Stations		Months											
		Jan– Feb	Feb– Mar	Mar– Apr	Apr– May	May– Jun	Jun– Jul	Jul– Aug	Aug– Sep	Sep– Oct	Oct– Nov	Nov– Dec	Dec– Jan
Massan													
Arithmetic mean	Trend length (mm)	4.11	7.36	8.21	7.87	3.94	1.83	1.57	2.71	5.91	8.35	8.74	2.65
	Trend slope	1.49	1.28	0.88	0.94	0.87	1.12	1.84	0.46	0.93	1.55	0.93	0.86
Standard deviation	Trend length (mm)	0.37	1.08	0.90	0.43	1.63	0.23	0.07	0.23	0.30	1.10	1.02	0.43
	Trend slope	0.61	6.44	−0.16	−1.92	0.69	0.52	−0.79	−1.69	−1.09	−0.02	0.08	−5.61
Chakwal													
Arithmetic mean	Trend length (mm)	4.22	7.67	8.41	8.62	4.83	1.26	2.04	2.68	7.65	9.75	7.64	2.73
	Trend slope	0.89	1.17	0.84	0.99	0.92	1.16	1.36	0.97	0.83	0.96	0.99	0.99
Standard deviation	Trend length (mm)	0.95	0.32	0.10	0.39	1.01	0.95	0.03	0.43	0.65	0.50	0.34	0.64
	Trend slope	1.08	−0.58	−0.24	−0.70	0.94	1.47	0.43	1.61	−1.65	−0.93	1.05	0.67
Fatehjang													
Arithmetic mean	Trend length (mm)	3.38	6.25	8.13	8.51	3.99	2.22	1.98	2.27	5.73	7.91	7.39	2.89
	Trend slope	1.54	1.30	1.03	0.87	0.63	0.46	1.28	1.64	0.77	1.04	0.99	1.74
Standard deviation	Trend length (mm)	0.21	0.78	0.92	0.73	1.91	0.46	1.01	0.86	0.38	0.79	0.75	0.22
	Trend slope	0.62	4.31	−0.47	3.94	0.87	5.11	2.28	2.79	−0.47	1.40	1.17	2.18
Jhelum													
Arithmetic mean	Trend length (mm)	3.99	6.41	8.73	7.37	2.83	2.71	1.28	1.68	5.59	8.38	7.06	2.35
	Trend slope	1.48	1.68	0.76	0.87	0.98	1.05	0.93	0.66	0.95	1.10	1.06	1.50
Standard Deviation	Trend length (mm)	2.36	4.34	3.36	0.24	0.87	0.45	0.42	0.26	0.34	0.30	0.13	2.50
	Trend slope	−0.31	0.01	0.03	−3.35	0.15	6.12	1.21	−5.00	0.26	0.24	−1.56	0.04
Mangla													
Arithmetic mean	Trend length (mm)	4.30	6.63	7.80	7.54	2.93	2.50	1.69	1.79	5.19	8.12	6.77	3.20
	Trend slope	0.91	1.14	1.00	0.89	1.24	1.10	0.69	0.68	0.87	1.18	1.05	1.13
Standard deviation	Trend length (mm)	0.53	0.44	0.81	0.47	0.61	0.32	0.57	0.34	0.94	0.42	0.09	0.09
	Trend slope	2.64	2.04	−0.01	2.61	0.26	−5.24	0.96	−0.08	1.99	2.13	−0.25	0.54
Rawalpindi													
Arithmetic mean	Trend length (mm)	3.72	6.91	7.59	7.55	3.70	1.86	1.57	2.20	6.05	8.36	6.63	2.77
	Trend slope	1.11	1.19	0.88	1.00	0.90	0.97	1.02	0.90	0.90	1.13	1.01	0.97
Standard deviation	Trend length (mm)	0.71	0.36	0.69	0.24	1.24	0.14	0.73	0.36	0.43	0.52	0.22	0.29
	Trend slope	1.05	0.43	−0.31	−0.54	0.31	−0.62	1.55	0.99	1.08	1.29	15.13	−0.83
Islamabad													
Arithmetic mean	Trend length (mm)	3.70	6.06	7.72	7.09	4.07	1.18	1.47	2.49	6.39	7.91	6.50	2.55
	Trend slope	1.10	1.41	0.74	0.95	0.97	0.79	1.01	0.88	0.96	1.11	0.96	0.95
Standard deviation	Trend length (mm)	0.70	1.35	0.57	0.25	1.42	0.11	0.65	0.60	0.38	0.49	0.17	0.45
	Trend slope	0.85	0.03	0.48	0.29	0.38	1.23	0.91	0.57	1.27	0.80	0.39	−1.39
NARC													
Arithmetic mean	Trend length (mm)	3.67	5.97	7.28	7.53	3.70	1.43	1.64	2.51	6.66	7.52	6.45	1.76
	Trend slope	1.47	1.22	0.99	0.80	0.53	0.49	0.98	1.10	1.00	1.00	1.03	0.62

Table 5 *continued*

Stations		Months											
		Jan–Feb	Feb–Mar	Mar–Apr	Apr–May	May–Jun	Jun–Jul	Jul–Aug	Aug–Sep	Sep–Oct	Oct–Nov	Nov–Dec	Dec–Jan
Standard deviation	Trend length (mm)	1.51	0.69	0.58	0.54	1.22	0.46	0.28	0.45	0.55	0.74	0.51	0.38
	Trend slope	9.54	-10.79	0.30	-0.62	0.89	-0.24	0.32	1.10	2.46	1.86	-2.76	5.58
Satra Meel Arithmetic mean	Trend length (mm)	3.61	6.35	7.27	8.01	3.87	1.19	2.08	2.55	6.27	8.08	6.37	2.58
	Trend slope	1.07	1.24	0.95	0.88	1.02	0.69	1.31	1.18	0.85	1.08	1.02	0.98
Standard deviation	Trend length (mm)	0.54	0.67	0.63	0.49	1.45	0.39	0.26	0.37	0.39	0.75	0.32	0.40
	Trend slope	-0.17	66.36	-0.39	0.09	0.10	26.88	-0.68	0.72	-69.21	2.76	-0.93	-1.43
Murree Arithmetic mean	Trend length (mm)	1.22	6.59	6.73	6.63	3.01	1.39	0.61	1.70	3.76	5.99	6.22	4.46
	Trend slope	1.80	1.25	0.76	0.87	0.83	0.63	2.23	0.85	1.08	0.83	0.93	1.14
Standard deviation	Trend length (mm)	0.35	0.27	0.46	0.17	0.34	0.65	0.38	0.38	1.00	0.31	0.29	0.63
	Trend slope	0.26	2.78	-0.64	3.78	1.42	0.77	0.31	-14.14	1.20	0.98	23.74	-1.10
Kotli Sattian Arithmetic mean	Trend length (mm)	3.45	6.73	7.38	6.62	3.07	2.09	1.20	1.99	5.37	7.96	6.50	2.10
	Trend slope	1.08	1.28	0.87	0.93	0.91	1.26	0.86	0.86	0.92	1.02	1.00	1.22
Standard deviation	Trend length (mm)	0.77	0.31	0.87	0.70	0.22	1.51	0.21	0.15	0.41	0.45	0.45	0.38
	Trend slope	1.95	3.54	-0.53	-0.91	-0.64	0.30	2.50	-1.91	0.23	1.61	1.81	-0.55

maximum trend slope shows that the arithmetic mean is between February and March and the standard deviation between November and December.

The Trend Polygon Star Concept Method graphics of arithmetic mean and standard deviation analysis results for mean monthly temperature data for each station are given in Fig. 7. All station arrow directions are in regions I and III (except Chakwal, based on the standard deviation), showing a transition between both consecutive months for all stations. Examination of Fig. 7 reveals the following information.

1. For Chakwal station, the arithmetic mean arrows showing transitions between the first five months (J–F, F–M, M–A, A–M and M–J) are in region III (decreasing trend). Arrows showing transitions between the other seven months (J–J, J–A, A–S, S–O, O–N, N–D and D–J) are in region I (increasing trend). The highest transition was observed in A–M (April–May; highly decreasing)

and O–N (October–November; highly increasing) between two months. The standard deviation arrows showing the transition between both months are in four regions. The longest arrow direction of S–O (O–N) in region II (IV) represents an increase (decrease) in the first (second) half time duration.

2. For all other ten stations (Massan, Fatehjang, Jhelum, Mangla, Rawalpindi, Islamabad, NARC, Satra Meel, Murree and Kotli Sattain) arrows showing transitions between the first five months (J–F, F–M, M–A, A–M and M–J) are in region III. Arrows showing transitions between the other seven months (J–J, J–A, A–S, S–O, O–N, N–D and D–J) are in region I. While months in region I show an increasing trend, months in region III show a decreasing trend. The longest arrow indicates the highest transition, and it was observed that M–A (March–April) in region III and N–D (November–December) in region I show

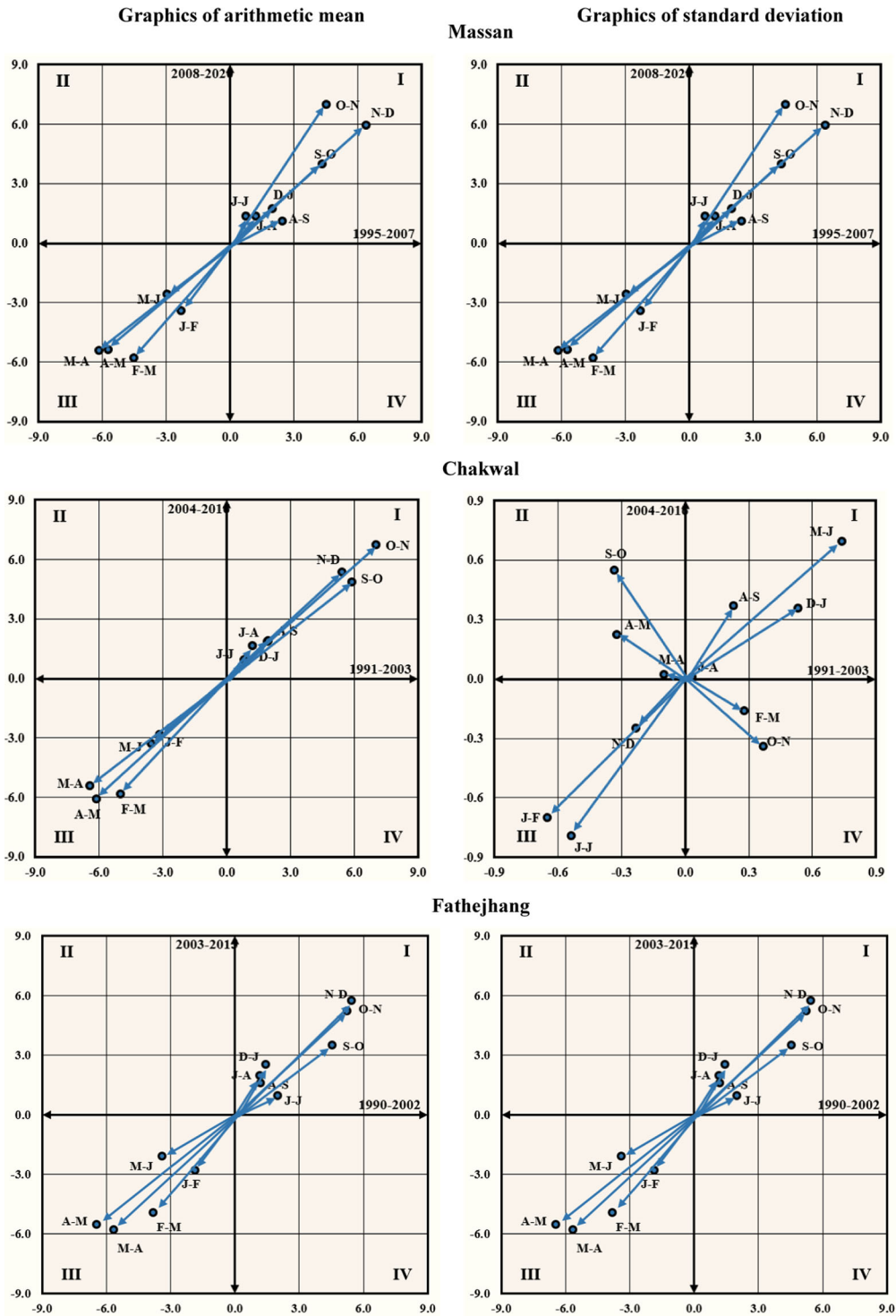
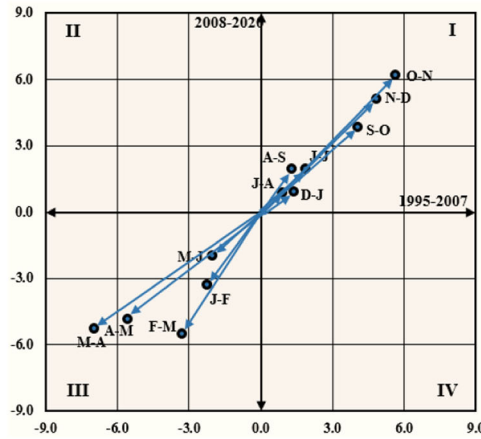
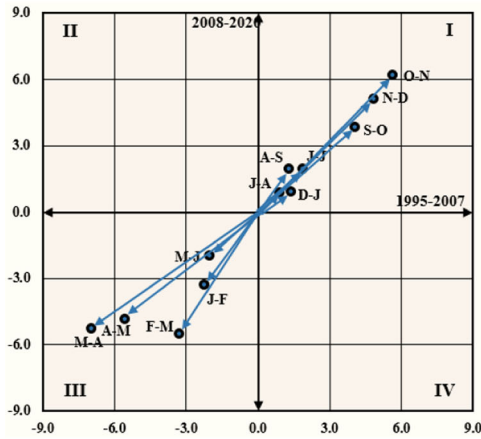


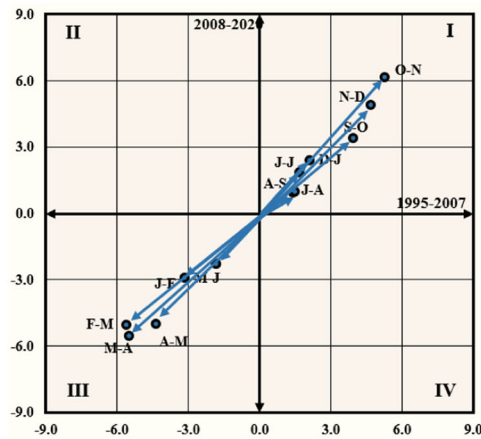
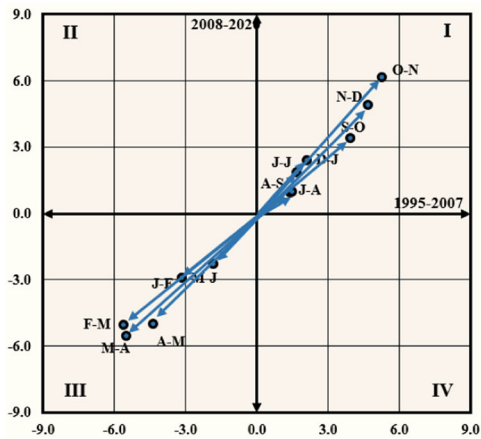
Figure 7

Trend Polygon Star Concept graphics of arithmetic mean and standard deviation analysis results of monthly temperature data for each station of Soan River Basin, Pothwar region, Pakistan

Jhelum



Mangla



Rawalpindi

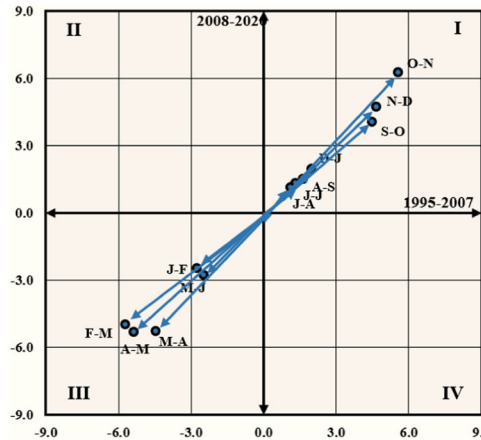
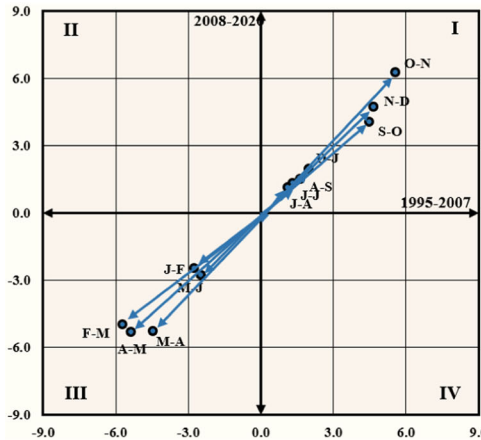
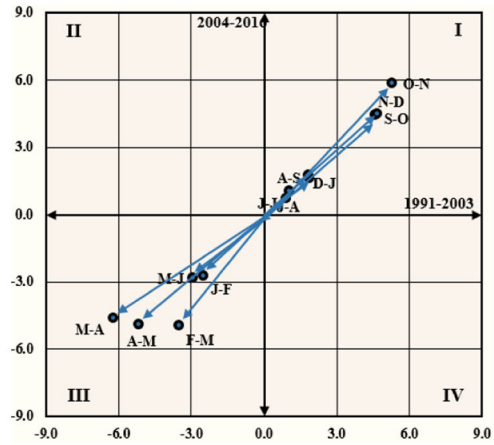
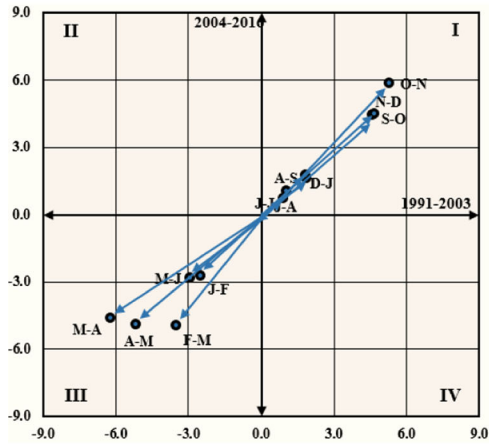
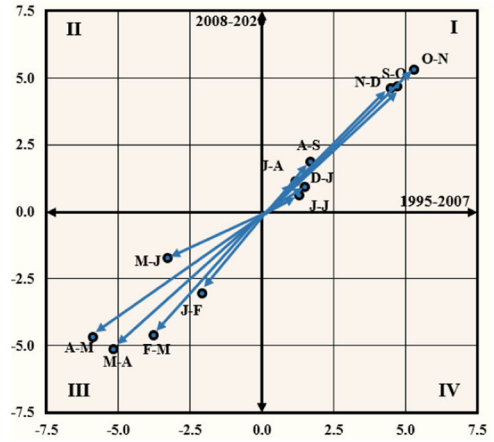
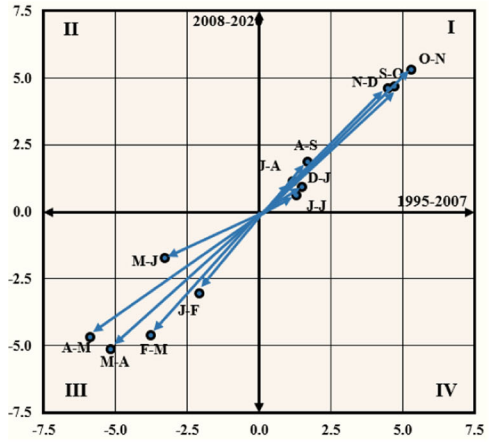


Figure 7 continued

Islamabad



NARC



Satra Meel

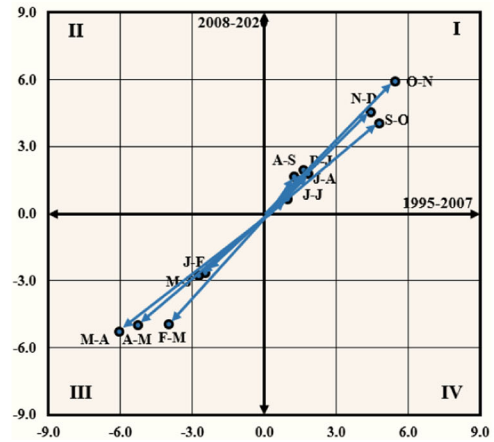
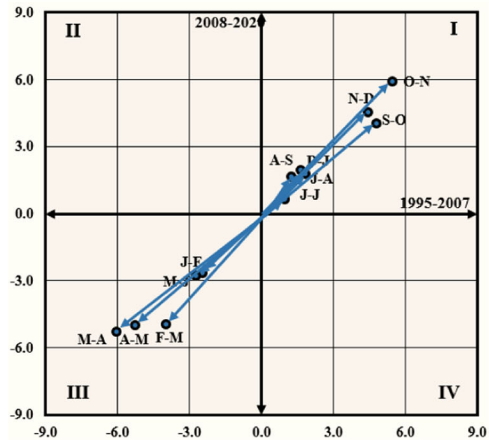
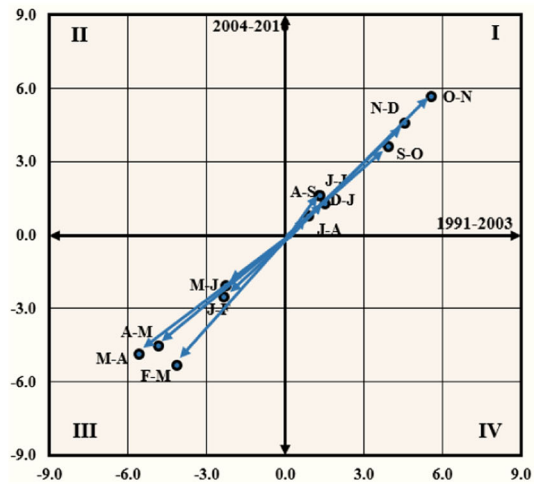
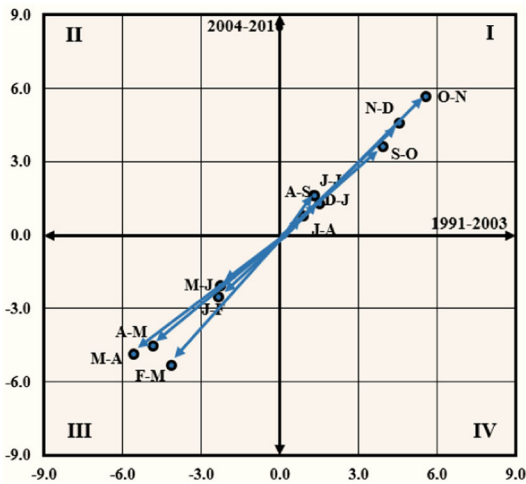


Figure 7 continued

Kotli Sattain



Murree

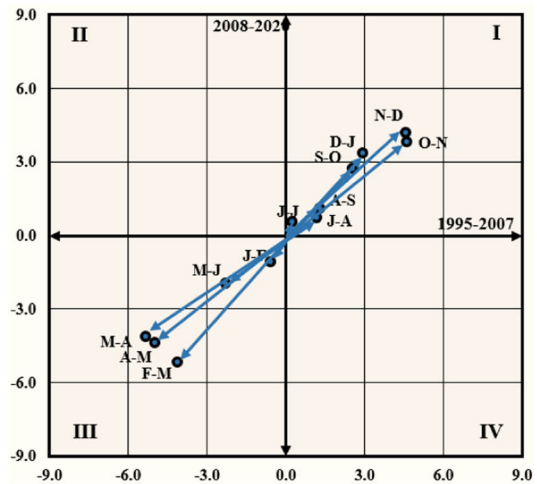
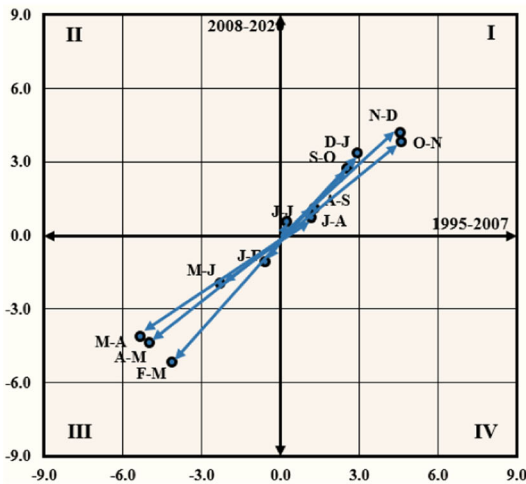


Figure 7 continued

the longest arrow, which turns out to be a highly decreasing and increasing trend in transition between the two months, respectively, in all these ten stations.

Statistical values for 11 stations of the Trend Polygon Star Concept method are given in Table 6. The bold values show the maximum transition between two months. For example, for the Rawalpindi station, the statistical results show maximum horizontal is between March and April for the arithmetic mean and between May and June for standard

deviation. The maximum vertical shows that it is between October and November for both the arithmetic mean and between June and July for standard deviation.

4. Discussion

Temperature is a key indicator of a changing climate. A trivial change in temperature can result in significant changes in weather patterns, with severe repercussions on the environmental conditions of an

Table 6

Statistical results of trend polygon star concept method of mean monthly temperature data of each station in the Soan River Basin

Stations		Months												
		Jan– Feb	Feb– Mar	Mar– Apr	Apr– May	May– Jun	Jun– Jul	Jul– Aug	Aug– Sep	Sep– Oct	Oct– Nov	Nov– Dec	Dec– Jan	
Massan	Arithmetic mean	Horizontal (mm)	–2.29	–4.53	–6.18	–5.75	–2.97	1.22	0.75	2.46	4.34	4.53	6.41	2.01
	Vertical (mm)	–3.41	–5.80	–5.41	–5.38	–2.58	1.36	1.38	1.14	4.01	7.01	5.95	1.73	
Standard deviation	Horizontal (mm)	–0.31	–0.17	–0.89	–0.20	1.34	0.20	–0.06	–0.12	0.20	–1.10	1.02	0.07	
	Vertical (mm)	–0.19	–1.07	0.14	0.38	0.93	0.11	0.04	0.20	–0.22	0.02	0.08	–0.42	
Chakwal	Arithmetic mean	Horizontal (mm)	–3.15	–4.99	–6.44	–6.12	–3.55	0.82	1.21	1.92	5.89	7.04	5.42	1.95
	Vertical (mm)	–2.81	–5.82	–5.41	–6.07	–3.27	0.95	1.65	1.86	4.88	6.75	5.38	1.92	
Standard deviation	Horizontal (mm)	–0.65	0.28	–0.10	–0.32	0.74	–0.54	0.03	0.23	–0.34	0.37	–0.23	0.53	
	Vertical (mm)	–0.70	–0.16	0.02	0.22	0.70	–0.79	0.01	0.37	0.55	–0.34	–0.25	0.36	
Fatehjang	Arithmetic mean	Horizontal (mm)	–1.84	–3.81	–5.65	–6.44	–3.38	2.02	1.22	1.18	4.55	5.47	5.24	1.44
	Vertical (mm)	–2.83	–4.95	–5.84	–5.57	–2.13	0.93	1.56	1.94	3.48	5.71	5.20	2.50	
Standard deviation	Horizontal (mm)	0.18	–0.18	–0.83	–0.18	1.44	–0.09	0.41	–0.29	–0.34	0.46	–0.49	–0.09	
	Vertical (mm)	0.11	–0.76	0.39	–0.70	1.25	–0.45	0.93	–0.81	0.16	0.64	–0.57	–0.20	
Jhelum	Arithmetic mean	Horizontal (mm)	–2.23	–3.28	–6.97	–5.57	–2.02	1.88	0.93	1.40	4.05	5.65	4.85	1.30
	Vertical (mm)	–3.31	–5.50	–5.27	–4.82	–1.98	1.96	0.87	0.93	3.85	6.19	5.13	1.95	
Standard deviation	Horizontal (mm)	2.26	–4.34	3.36	–0.07	0.86	0.07	0.27	0.05	–0.33	0.30	0.07	–2.50	
	Vertical (mm)	–0.69	–0.04	0.09	0.23	0.13	0.44	0.33	–0.26	–0.09	0.07	–0.11	–0.11	
Mangla	Arithmetic mean	Horizontal (mm)	–3.18	–4.37	–5.51	–5.62	–1.85	1.68	1.39	1.48	3.92	5.26	4.67	2.12
	Vertical (mm)	–2.90	–4.98	–5.53	–5.03	–2.28	1.85	0.96	1.01	3.40	6.19	4.90	2.40	
Standard deviation	Horizontal (mm)	–0.19	–0.19	–0.81	0.17	0.59	–0.06	0.41	0.34	–0.42	0.18	–0.09	0.08	
	Vertical (mm)	–0.50	–0.39	0.01	0.44	0.15	0.31	0.39	–0.03	–0.84	0.38	0.02	0.05	
Rawalpindi	Arithmetic mean	Horizontal (mm)	–2.49	–4.45	–5.71	–5.35	–2.75	1.33	1.10	1.63	4.48	5.55	4.65	1.98
	Vertical (mm)	–2.77	–5.29	–5.00	–5.33	–2.48	1.30	1.13	1.48	4.06	6.25	4.72	1.93	

Table 6 *continued*

Stations		Months											
		Jan– Feb	Feb– Mar	Mar– Apr	Apr– May	May– Jun	Jun– Jul	Jul– Aug	Aug– Sep	Sep– Oct	Oct– Nov	Nov– Dec	Dec– Jan
Standard deviation	Horizontal (mm)	-0.49	-0.33	-0.66	-0.21	1.18	0.12	0.40	-0.26	-0.29	0.32	-0.01	0.23
	Vertical (mm)	-0.51	-0.14	0.21	0.11	0.36	-0.08	0.61	-0.26	-0.31	0.41	-0.22	-0.19
Islamabad Arithmetic mean	Horizontal (mm)	-2.49	-3.50	-6.20	-5.15	-2.93	0.93	1.03	1.87	4.60	5.30	4.69	1.85
	Vertical (mm)	-2.73	-4.95	-4.60	-4.88	-2.83	0.73	1.05	1.65	4.44	5.87	4.50	1.76
Standard deviation	Horizontal (mm)	-0.53	-1.35	0.52	-0.24	1.33	0.07	0.48	-0.52	-0.23	0.38	-0.16	0.26
	Vertical (mm)	-0.45	-0.04	0.25	-0.07	0.51	0.08	0.44	-0.30	-0.30	0.31	-0.06	-0.37
NARC Arithmetic mean	Horizontal (mm)	-2.06	-3.78	-5.16	-5.89	-3.27	1.29	1.17	1.69	4.72	5.31	4.50	1.49
	Vertical (mm)	-3.03	-4.62	-5.13	-4.69	-1.73	0.62	1.15	1.86	4.71	5.32	4.63	0.92
Standard deviation	Horizontal (mm)	-0.16	-0.06	-0.55	-0.46	0.91	0.45	0.27	-0.30	-0.21	0.35	-0.17	-0.07
	Vertical (mm)	-1.50	0.68	-0.17	0.28	0.81	-0.11	0.09	-0.33	-0.51	0.65	0.48	-0.38
Satra Meel Arithmetic mean	Horizontal (mm)	-2.47	-3.98	-5.28	-6.03	-2.72	0.98	1.26	1.65	4.79	5.48	4.46	1.85
	Vertical (mm)	-2.63	-4.94	-5.00	-5.28	-2.76	0.68	1.66	1.94	4.05	5.94	4.54	1.80
Standard deviation	Horizontal (mm)	-0.53	-0.01	-0.59	-0.49	1.44	0.01	0.21	-0.30	0.01	0.26	-0.24	0.23
	Vertical (mm)	0.09	-0.67	0.23	-0.04	0.15	0.39	-0.14	-0.22	-0.39	0.71	0.22	-0.33
Murree Arithmetic mean	Horizontal (mm)	-0.59	-4.12	-5.35	-5.01	-2.32	1.18	0.25	1.30	2.55	4.61	4.56	2.93
	Vertical (mm)	-1.07	-5.14	-4.09	-4.35	-1.93	0.74	0.56	1.10	2.76	3.83	4.23	3.36
Standard deviation	Horizontal (mm)	-0.34	0.09	-0.38	0.04	0.20	0.51	0.36	-0.03	-0.64	-0.22	-0.01	0.42
	Vertical (mm)	-0.09	0.26	0.25	0.17	0.28	0.39	0.11	0.38	-0.77	-0.22	-0.29	-0.47
Kotli Sattian Arithmetic mean	Horizontal (mm)	-2.34	-4.15	-5.57	-4.84	-2.27	1.30	0.91	1.51	3.95	5.58	4.58	1.33
	Vertical (mm)	-2.53	-5.30	-4.85	-4.52	-2.07	1.63	0.78	1.30	3.64	5.68	4.60	1.63
Standard deviation	Horizontal (mm)	-0.35	-0.08	-0.77	-0.52	0.19	1.45	0.08	0.07	-0.40	0.24	-0.22	0.33
	Vertical (mm)	-0.69	-0.29	0.41	0.47	-0.12	0.44	0.20	-0.13	-0.09	0.38	-0.39	-0.18

area (Safdar et al., 2021). Trend analysis is a globally acknowledged approach in research for changing climate estimation based on temperature data sets. It was observed that the innovation and modification in trend analysis has accelerated over the last 30 years. The innovative trend analysis (ITA) methodology was proposed by Şen (2012, 2014) and applied in different studies around the world using different climatological data (Elouissi et al., 2016; Tabari et al., 2017; Wu & Qian, 2017; Mohorji et al., 2017; Alashan, 2018; Güçlü, 2018; Dabanli and Şen, 2018; Almazroui et al., 2019; Alifujiang et al., 2020; Wang et al., 2020; Singh et al., 2021). Sen et al. (2019) developed the innovative polygonal trend analysis (IPTA) methodology and Ceribasi et al. (2021a) modified the IPTA, known as the Innovative Trend Pivot Analysis Method (ITPAM), while the Trend Polygon Star Concept Method was proposed by Sen (2021). In the literature, a few studies have applied these new trend tests for the analysis of hydrometeorological data (Achite et al., 2021; Ahmed et al., 2022; Ceribasi & Ceyhunlu, 2021; Ceribasi et al., 2021a, 2021b, 2022; Hirca et al., 2022; Hussain et al., 2022; Şan et al., 2021; Şen, 2021; Şen et al., 2019).

The ITPAM and Trend Polygon Star Concept Method are graphical methods and are used as alternatives to classical statistical trend approaches (Mann–Kendall and Theil–Sen tests). The innovative methods are qualitative rather than quantitative analysis, and therefore do not provide any numerical value for the trend as in the classical test. The other limitations are as follows. (1) In the ITPAM method, data sets must be double. Single data series cannot be analyzed with ITPAM methods. This is because the data should be divided into two equal series. For example, you can analyze the data set between 1991 and 2020 with the ITPAM method, but ITPAM cannot be used for the years 1990–2020. Since this interval is single, the analysis will be made from 1991 or will be completed in 2019. (2) Although ITPAM can analyze daily, monthly or annual data, it is seen that the most appropriate annual data is analyzed in terms of reading and understanding the graphics. For example, in monthly data, the cycle will consist of 29–31 days. Therefore, the graph will be complex and the loop will not be fixed-interval. At least 30 years of data are needed to analyze climate data

while ITPAM is out for such a limit. However, if the selected station does not have 30 years of climate data, then the existing data set can be analyzed using the ITPAM method. It can also analyze data sets under 30 years (Achite et al., 2021; Ceribasi et al., 2022).

There is no doubt that there are many applications for classical trend methods, but they also have serious drawbacks as described in the introduction section. To our knowledge, there are few studies that have applied classical trend tests for hydrometeorological data analysis in the selected study area of the SRB, Potohar region, Pakistan. Shahid et al. (2018) applied the Mann–Kendall test to determine the trends and change point in hydro-climatic variables during the period 1983–2012. Hussain et al. (2021) analyzed the monthly and annual temporal trends of rainfall data using the Mann–Kendall (MK) trend test and Sen's slope estimator in the SRB, Potohar region, Pakistan. Hussain et al. (2022) is the only study that applied ITPAM and Trend Polygon Star Concept to precipitation data in the selected study area of the SRB, and no study was found in which temperature data were analyzed by applying these innovative methods. In this present study, these graphical methods (ITPAM and Trend Polygon Star Concept) indicated the existence of both decreasing and increasing trends of temperature data in different periods in the SRB, which indicates the irregular behavior of climatic variable (average temperature) and requires an integrated approach to managing available water resources for agricultural practices. Moreover, these newest methods provided information on the degree of risk and trend class with the interpretation of monthly and seasonal shifts in temperature in terms of standard deviation and arithmetic mean graphs. These indicators are helpful tools for decision-makers to manage water resources in the SRB. During the analysis, it was observed that there is a shifting pattern of temperature on a monthly basis in the SRB, and our results are in line with previous studies indicating a shifting of temperature in regions of Pakistan (Khan et al., 2022; Nawaz et al., 2019; Abbas et al., 2018; Afzaal et al., 2009; Yaseen et al., 2014). For example, del Río et al. (2013) revealed the shifting temperature trend using Sen's slope and Mann–Kendall tests in Pakistan at monthly, seasonal

and annual time scales over the past few decades and the mean annual temperature increased around $0.36\text{ }^{\circ}\text{C}/\text{decade}$. Similarly, Safdar et al. (2021) revealed that, overall, Pakistan's maximum temperature increased by $0.026\text{ }^{\circ}\text{C}/\text{year}$ with a maximum increase of $0.05\text{ }^{\circ}\text{C}/\text{year}$ during pre-monsoon, and the minimum temperature increased by $0.027\text{ }^{\circ}\text{C}/\text{year}$. Other relevant literature studies also indicate that significant climatic changes have been observed with respect to temperature (maximum and minimum) fluctuations at rates of $0.12\text{--}0.29$ and $0.10\text{--}0.37\text{ }^{\circ}\text{C}/\text{decade}$, respectively (Khan et al., 2019; Qasim et al., 2014). Pakistan's temperature is increasing due to global warming as indicated by a number of studies with classical trend tests (Islam et al., 2009; Zahid & Rasul 2011; Ríó et al., 2013; Iqbal et al., 2016; Jahangir et al., 2016; Abbas et al., 2018; Aslam et al., 2017). Both temperatures (T_{max} and T_{min}) are increasing in Punjab, Pakistan, with a rate of $0.10\text{ }^{\circ}\text{C}$ and $0.04\text{ }^{\circ}\text{C}$ per year, respectively, from 1981 to 2018 (Nawaz et al., 2019; Yaseen et al., 2014), while in the Kanshi catchment, Potohar region, the increasing rate is $0.0134\text{ }^{\circ}\text{C}$ and $0.0334\text{ }^{\circ}\text{C}$ per year for T_{max} and T_{min} , respectively (Khattak et al., 2011; Shirazi et al., 2020).

With this literature, knowledge and findings of the present study related to the shifting patterns of temperature all over Pakistan and the study area are essential for the development of effective climate change adaptation policies (Wang et al., 2016; Shahid et al., 2016). According to literature studies, a major impact of increasing temperature is the reduction of agricultural productivity (Asseng et al., 2013) because crop growth is sensitive to the required optimum temperatures, i.e. the optimum temperature for maximum wheat growth is $25\text{ }^{\circ}\text{C}$ and its growth stops above $30\text{--}32\text{ }^{\circ}\text{C}$ and below $0\text{--}5\text{ }^{\circ}\text{C}$ (Rashid & Ayaz, 2015). It has been demonstrated in the study conducted by Aslam et al. (2017) that a $1\text{ }^{\circ}\text{C}$ increase may cause a decrease of $4.1\text{--}6.4\%$ in wheat yields. Zhao et al. (2017) also reported similar findings. The importance of temperature analysis can be highlighted by the relationship between crop growth and temperature variations. For example, spring or winter wheat heading is delayed until the plant experiences a period of cold winter temperatures ($0\text{--}5\text{ }^{\circ}\text{C}$) (Curtis et al., 2002), while wheat grown in countries such as

Pakistan is usually planted in the spring and requires high temperatures at heading. Another important factor is the availability of optimum soil moisture for seed germination in the Potohar rain-fed region while climate variability causes a reduction in soil moisture leading to significant changes in the growth pattern of crops by reducing growth stage durations (Asseng et al., 2011). Considering the impact of temperature increase on moisture availability, i.e. increased temperature favors more evaporation of water from the soil to the atmosphere and depletes soil moisture and photosynthesis at much more rapid rates (Turnbull et al., 2001). This shortage in moisture during crop growth may cause complete crop failure, and supplemental water availability should be managed in the future. Moreover, the decrease in the amount of moisture available during planting time and during crop growth cycles causes a decrease in water use efficiency. Therefore, it is important to understand changing patterns of temperature. The current manuscript would be very useful for the agriculture sector to predict the future irregular trends of climate change in the Potohar region of Pakistan. Moreover, current findings can be an important tool for the management of climatic change issues to formulate future strategies for improving crop growth in arid and semi-arid regions of Pakistan. Based on the aforementioned trends in temperature, we can forecast increasing water demands for crops in the future, and should adopt effective water resources management techniques such as harvesting rainwater and building small and mini dams to meet crop water demand and to recharge aquifers.

5. Conclusions

The Innovative Trend Pivot Analysis Method (ITPAM) and Trend Polygon Star Concept Method were applied to the average monthly temperature data for 11 stations in the Soan River Basin (SRB), Potohar region, Pakistan. Two different graphs, the developed innovative polygonal trend analysis (IPTA) graph and the risk graph, and trend lengths and slopes of temperature data were calculated based on the arithmetic mean and standard deviation. It was found that while a month in the developed IPTA

graph is not in a high class, it is in the first-degree risk class in the risk graph. This kind of result indicates a significant change between the first data set for that month and the second data set. Therefore, the risk factor is high in the month in which that point is indicated. It was also found that most of the points have a medium-degree trend class of the ITPAM graph while this point is in first-degree risk class in the risk graph. These results indicate the importance of ITPAM in such studies. Moreover, the maximum trend lengths and trend slopes of temperature data show that the transition between two months is severe. Based upon the Trend Polygon Star Concept Method, arrows showing transitions between the first five months (J–F, F–M, M–A, A–M, and M–J) are in region III (decreasing trend), and arrows showing transitions between the other seven months (J–J, J–A, A–S, S–O, O–N, N–D and D–J) are in region I (increasing trend) for all stations. A significant change is observed between the first data set and the second data set for March, April and May at most of the stations.

The monthly polygonal trends with risk graphs depicted a clear picture of climate change and global warming effects in the Potohar region of Pakistan, as it was observed that the winter season temperature is increasing, and the months of December to February are getting warmer. Summer is expanding and pushing autumn towards winter, swallowing the early period of the cold season. The spring season is also affected by changing temperatures of the summer season, as the late April temperature is decreasing. The phenomena of global warming and observed changes in temperature in the study area indicate that there is a need to design the cropping system according to temperature variation, because in the study region, the Rabi (winter season) wheat crop is sensitive to temperature and needs both cold and warm temperatures to produce maximum yield. There exist both increasing and decreasing trends in different periods, with evidence of seasonal variations that will cause irregular behavior in the water resources and agricultural sectors.

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Data availability

The data presented in this study are available on request.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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