Trend Analysis of Time Series of Temperature data for Lahore, Pakistan

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Introduction

According to fifth assessment report (AR5) of intergovernmental panel on climate change (IPCC) temperature (calculated by linear trend) has been increased by 0.72^{O}C (from 0.49 to 0.89^{o}C) and warming rate decreases up - 0.05^{O}C/decades during period of 53 years [1] [2]. This report continuously supporting forth report of assessment (AR4) that on a global scale, number of cold nights and days have been decreased while number of warm nights and days have been increased.

Now a days, Global warming is one of the biggest challenge. The continuous increase in emission of greenhouse gases affects the Earth's climate [3] which leads to global warming. During industries revolution 1700s-1800s, Earth's climate has been change by anthropogenic activities [4]. Global surface mean temperature has been increased up to 0.6^{o}C in the last century and it may increase further by 1.8^{o}C to 4^{o}C in 21st century, causing a serious threat to the socioeconomic sector worldwide. Variations in temperature, precipitation humidity as well as sea surface temperature are due to warming in atmosphere [5]. Due to shifting in mean temperature extreme events such as heat wave and cold spells occurs in some regions [6]. Due to warming of atmosphere variation in pattern of temperature, precipitation and humidity has been detected [7]. According to global climate models (GCMs), average temperature will be increased in the range 1.3-1.5^{o}C in 2020s, 2.5-2.8^{o}C in 2050s and 3.9-4.4^{o}C in 2080s (Climate change, 2012).

There is non-significant increasing trend in annul mean temperature in upper Indus basin [8], while north western Himalayan region, since 19th century there is increasing trend in annual mean temperature [9].

According to AR5 annual mean temperature has increased during past century in most of the region of Asia. The warming trend between November and March (cold season) was more strong in the period 1901 to 2009, with an increase of 2.4^{o}C in mid latitude semiarid area of Asia. The global temperature of 2009 rated among top 5 warmest decades since 1850, while the past few decades it warmest in the history [10].

The think tank "Germanwatch" graded Pakistan at 3 in the list of countries which are affected by the climate change [11]. During 1947-2000, Change in temperature is 5% per 50 years (calculated through linear trend) which shows that surface temperature of Pakistan is increasing [12] due to increase in population, emission of greenhouse gases and industrialization during last decades. It had been found that increase in temperature reduce the growing cycle of maize crop in Faisalabad [13].

At different time scale and regional level, many studies are present which investigated trends of temperature extremes. At local level, these studies have been basically focused on the major cities of the country: extreme temperatures variation (from 1961 to 2007) for major five cities has been studied by Sadiq and Qureshi [14]; Trends of maximum temperature, minimum temperature and mean temperature from 1947 to 2005 for Karachi had been studied by Sajjab et al. [12] and found that maximum temperature play significant role in increasing Karachi temperature than minimum temperature, mean temperature trends for Faisalabad (1945 to 2004) is studied by Cheema et al. (2006) [16] and diurnal temperature range (1979 to 2008) had been analyzed by Sadiq and Ahmed (2012) over Chaklala (Islamabad) [17]. Hussain et al. examined changes in climate of mountain region of Pakistan in winter and monsoon and its implications for water and agriculture [18]; Fowler and Archer (2006) and Khattak et al. (2011) examined trends of maximum and minimum temperature in the Upper Indus River Basin [19] [20] and Bochiola and Diolaiuti analyzed temperature trends of Karakoram and its possible effects on glaciers [21]. Ahmed et al. investigated long term metrological climate trends of middle and lower Indus basin of Pakistan [22] and Yaseen et al. tested the weather trends in maximum, minimum temperature and diurnal temperature range exist both annually and seasonally in the Mangla watershed [23]. Sheikh et al. did a complete study about climate profile and past changes in climate of Pakistan including trends in maximum and minimum temperature [24].

A number of studies has been carried on Pakistan but there is very few studies present on climate of Lahore. We are going to study trends of minimum and maximum temperature for last 32 years (1988 to 2019).

1. Data Assess

The data which is used for the analysis is downloaded from meteoblue Switzerland website (https://www.meteoblue.com/). The website provides weather information worldwide for location on land or sea in the world. Initially, Meteoblue was developed by university of Basel, Switzerland based on NOAA/NCEP.

1.1. Data processing and trend analysis

To examine linear trends of maximum and minimum temperatures Mann–Kendall (MK) test is used. Increasing and decreasing rate of temperatures is calculated by linear curve fitting (polynomial of degree.

To check annual trends of maximum and minimum temperatures we take mean of daily data of maximum and minimum temperatures for all the years. Statistical trend is significant over time which is detectable by parametric and non-parametric procedure. In this study statistical significant trend analysis is performed by using MK test.

1.1.1 Mann–Kendall Test

Mann-Kendall (MK) is statistical test which is used to check null hypothesis of no-trend verses alternative hypothesis of monotonic decreasing or increasing trend of hydro-climatic time series data.

Z-statistics is used for data with 10 or more data points. Trend in time series data can be assessed by Z value. Positive z value shows upward (increasing) trend while negative value of Z shows downward (decreasing) trend. Z is calculated by the following equation (Mann 1945; Kendall 1955).

$$Z = \begin{cases} \frac{S-1}{\sqrt{var(S)}} & if\ S > 0 \\ 0 & if\ \ S = 0 \\ \frac{s+1}{\sqrt{var(s)}} & if\ S < 0 \end{cases}$$

var(S) and S are

$$Var(S) = \frac{1}{18}\left\{n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p-1)(2t_p-5)\right\}$$

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} f(x_j - x_i)$$

Where, x_i and x_j are annual values of year i and j, j>i respectively, n is number of data points and $f(x_j - x_i)$ is calculated by:

$$f(x_j - x_i) = \begin{cases} 1 & if\ x_j - x_i > 0 \\ 0 & if\ \ x_j - x_i = 0 \\ -1 & if\ x_j - x_i < 0 \end{cases}$$

2 RESULTS AND DISCUSSIONS

Annual mean is calculated by taking mean of daily data for maximum and minimum temperature. Trends is examined by Mann-Kendall and slope is calculated by linear fit (polynomial of degree 1). The objective of this research it to evaluate temperature trends for Lahore, Pakistan.

2.1 Trends of Minimum Temperature

2.1.1 Linear Trend

Upward (increasing) trend has been found in minimum temperature from 1988 to 2019 as shown in figure (1). Minimum temperature has increase with the rate of 0.04782^{O}C/decades.

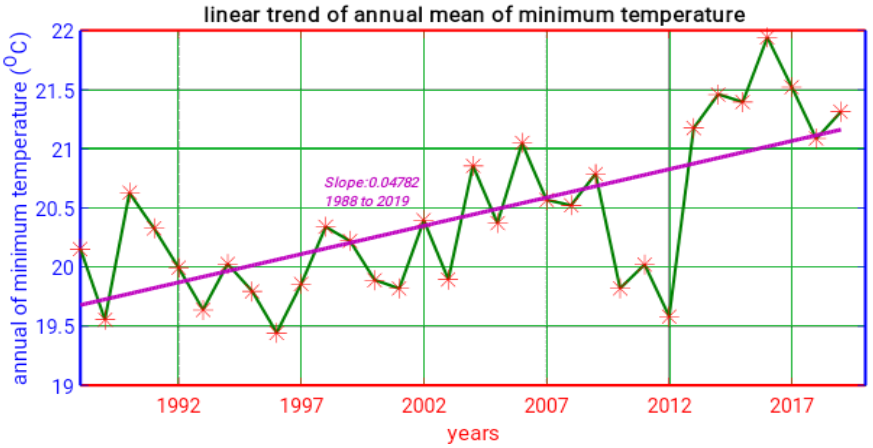


Fig. 1 Trend of minimum temperature (C^{O}) for the period from 1988 to 2019

When time series is divided into 2 time series such that each time series has 6 data points: 1988 to 2003, 2004 to 2019. From 1988 to 2003 no remarkable trend has been detected, it means that no significant increase or decrease in minimum temperature because slope is approximately equal to zero (Figure 2a, Table 1). But after from 2004 to 2019 minimum temperature increases because it has upward (increasing) trend. Increasing rate of minimum temperature during last six years (2004 to 2019) is 0.06877^{O}C/decades (figure 2a, Table 1)

If minimum temperature time series in divided into six time series: 1988 to 1992, 1993 to 1997, 1998 to 2002, 2003 to 2007, 2008 to 2012 and 2013 to 2019, each have 5 data points except last one which has 7 data points. Mix trends have been observed (figure 2b, Table 1).

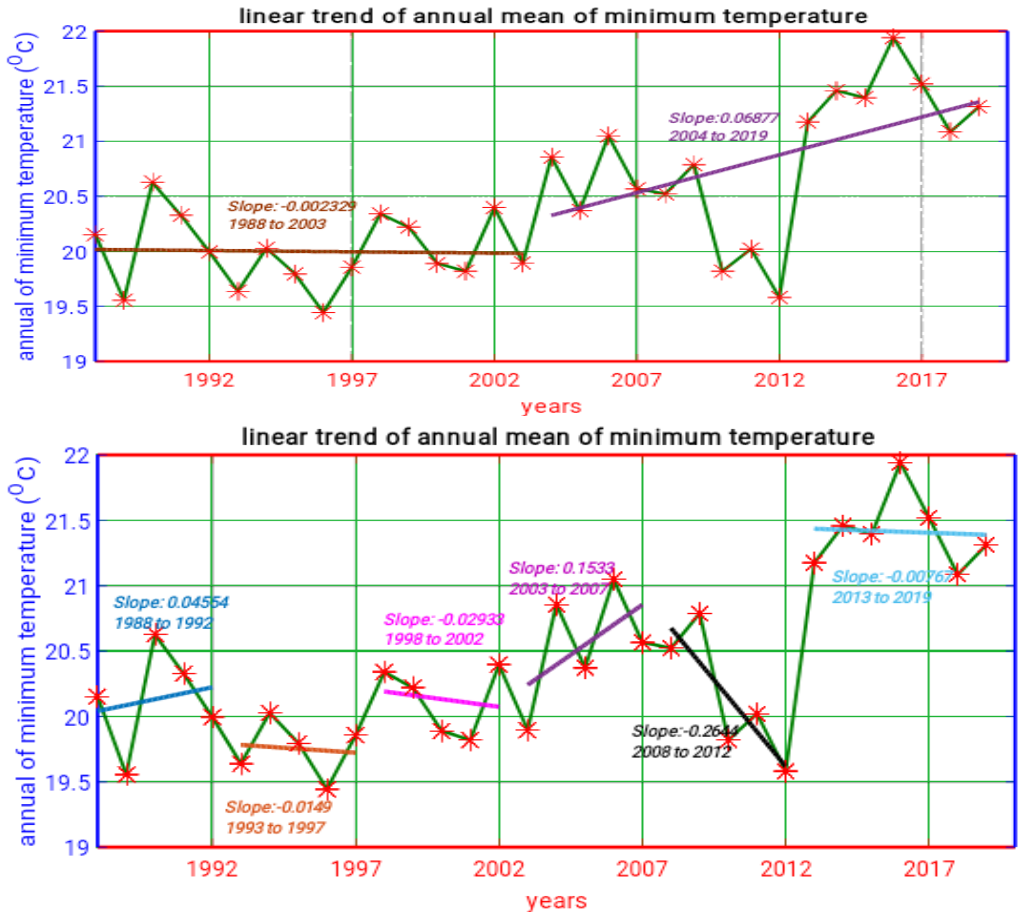


Fig. 2 Trends of Tmin (in ^{O}C) (a) when Tmin is divided into 2 time series (b) when Tmin is divided into 6 time series

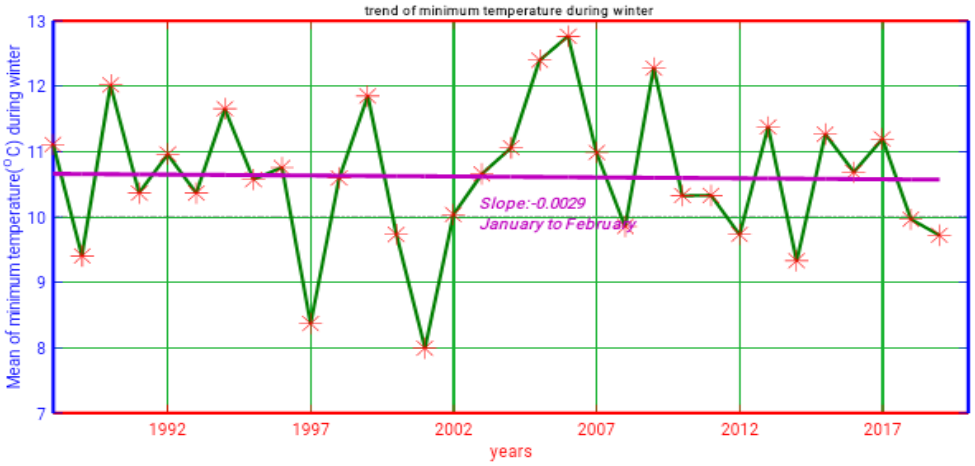
Table 1 Goodness of fit, null hypothesis (at alpha significance level 0.1) trend and slope of annual mean minimum temperature

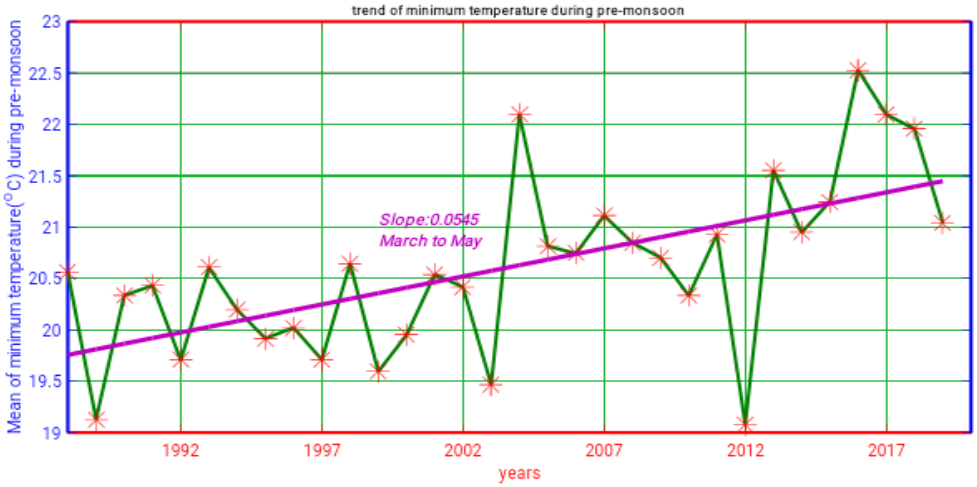
	1988 to 1992	1993 to 1997	1998 to 2002	2003 to 2007	2008 to 2012	2013 to 2019
goodness of fit	SSE: 0.6108 R-square: 0.03284 Adjusted R-square: -0.2895 RMSE: 0.4512	SSE: 0.193 R-square: 0.01137 Adjusted R-square: -0.3182 RMSE: 0.2537	SSE: 0.2672 R-square: 0.0312 Adjusted R-square: -0.2917 RMSE: 0.2984	SSE: 0.5639 R-square: 0.2941 Adjusted R-square: 0.0588 RMSE: 0.4336	SSE: 0.2931 R-square: 0.7046 Adjusted R-square: 0.6062 RMSE: 0.3126	SSE: 0.465 R-square: 0.00353 Adjusted R-square: -0.1958 RMSE: 0.3049
Slope	0.04554	-0.0149	-0.02933	0.1533	-0.2644	-0.00767
Trend	Increasing	Decreasing	Decreasing	Increasing	Decreasing	No remarkable decreasing trend
	1988 to 2003			2004 to 2019		

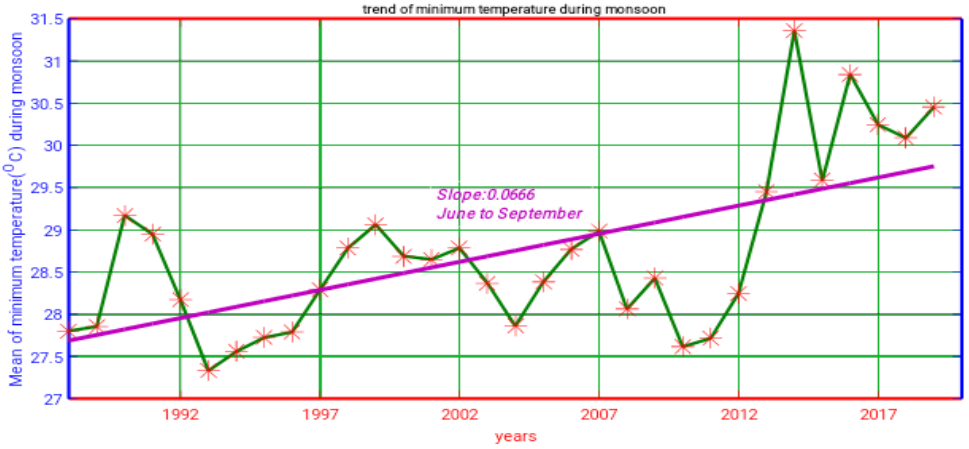
goodness of fit	SSE: 1.591 R-square: 0.001158 Adjusted R-square: -0.07019 RMSE: 0.3372	SSE: 4.884 R-square: 0.2477 Adjusted R-square: 0.1939 RMSE: 0.5906
Slope	-0.002329	0.06877
P-value	0.9641>0.1	0.0649<0.1
Null Hypothesis	Accepted	Rejected
Z	0	1.8459 (Positive)
Trend	No trend	Increasing
	1988 to 2019	
goodness of fit	SSE: 7.527 R-square: 0.4532 Adjusted R-square: 0.435 RMSE: 0.5009	
Slope	0.04782	
P-value	0.00023<0.1	
Null Hypothesis	Rejected	
Z	3.6811 (Positive)	
Trend	Increasing	

2.1.2 Seasonal Trends

It has been found that there is upward (increasing) trend in minimum temperature during pre-monsoon, monsoon and post-monsoon. Increasing rate of pre-monsoon, monsoon and post-monsoon are 0.05453^{O}C/decades, 0.06658^{O}C/decades and 0.04848^{O}C/decades respectively from 1988 to 2019. On the other hand there is no trend has been analyzed during winter because is almost zero (-0.002874^{O}C/decades). So, we can conclude that minimum temperature during winter is almost similar from 1988 to 2019 and during monsoon minimum temperature has increased with maximum rate 0.06658^{O}C/decades (figure 3, Table 2).


trend of minimum temperature during winter
Mean of minimum temperature(°C) during winter
13
12
11
10
9
8
7
1992
1997
2002
2007
2012
2017
years
Slope:-0.0029
January to February


trend of minimum temperature during pre-monsoon
Mean of minimum temperature(°C) during pre-monsoon
23
22.5
22
21.5
21
20.5
20
19.5
19
1992
1997
2002
2007
2012
2017
years
Slope:0.0545
March to May


trend of minimum temperature during monsoon
Mean of minimum temperature(°C) during monsoon
31.5
31
30.5
30
29.5
29
28.5
28
27.5
27
1992
1997
2002
2007
2012
2017
years
Slope:0.0666
June to September

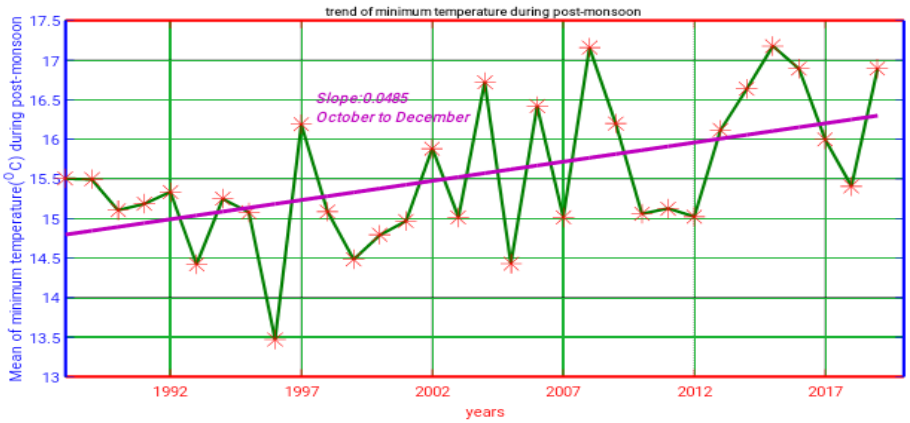


Fig. 3 Seasonal trends Tmin (in ^{O}C) (a) winter (January to February) (b) pre-monsoon (March to May) (c) monsoon (June to September) (d) post-monsoon (October to December)

Table 2 Seasonal trends, goodness of fit and slope of minimum temperature Tmin

	Winter	Pre-monsoon	Monsoon	Post-monsoon
goodness of fit	SSE: 36.19 R-square: 0.0006221 Adjusted R-square: -0.03269 RMSE: 1.098	SSE: 14.02 R-square: 0.3666 Adjusted R-square: 0.3454 RMSE: 0.6836	SSE: 19.46 R-square: 0.3833 Adjusted R-square: 0.3627 RMSE: 0.8054	SSE: 18.28 R-square: 0.2596 Adjusted R-square: 0.235 RMSE: 0.7806
Slope	-0.002874	0.05453	0.06658	0.04848
P-value	0.6615>0.1	$2.3220e^{-04}$<0.1	0.0027<0.1	0.0263<0.1
Null Hypothesis	Accepted	Rejected	Rejected	Rejected
Z	0	3.6811 (Positive)	3 (Positive)	2.2217(Positive)
Trend	No trend	Increasing	Increasing	Increasing

2.2 Trends of Maximum Temperature

2.2.1 Linear Trends

We have found downward (decreasing) trend of maximum temperature with decreasing rate which is -0.01905^{O}C/decades as shown in figure (5) and in table 3

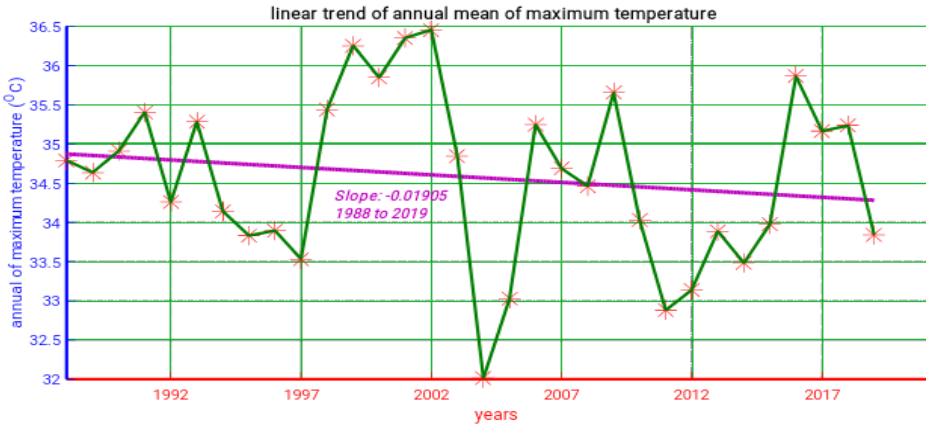


Fig. 5 Annual trend of maximum temperature (in ^{O}C) for the period from 1988 to 2019

Now we will check trend of maximum temperature by dividing into two time series 1. From 1988 to 2003 and 2. From 2004 to 2019. It has been found that there is upward (increasing) trend from 1988 to 2003 at the rate of 0.08426^{O}C/decades. Similarly, upward (increasing) trend from 2004 to 2019 has been observed and increasing rate is 0.07564^{O}C/decades (figure 6, Table 3)

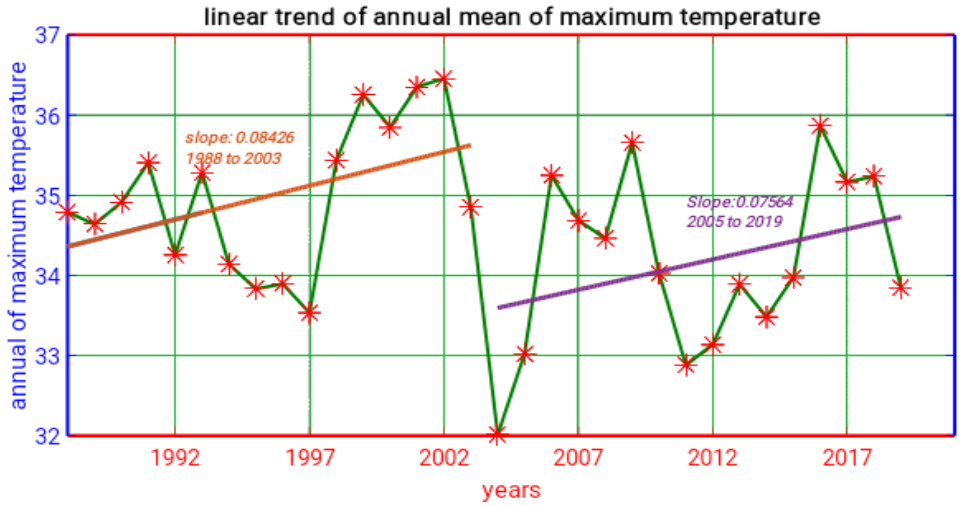


Fig. 6 Trend of Tmax (^{O}C), time series is divided into two parts: from 1989 to 2003 and from 2004 to 2019.

Now, trend of time series is checked by dividing temperature time series into 6 time series 1 (1988 to 1992), 2 (1993 to 1997), 3 (1998 to 2002), 4 (2003 to 2007), 5 (2008 to 2012), 6 (2013 to 2019). Upward (increasing) trend has been observed for time series 3, 4 and 6. In these time series, increasing rates are 0.2131^{O}C/decades, 0.2919^{O}C/decades and 0.1627^{O}C/decades respectively but increasing rate of maximum temperature from 2003 to 2007 (time series 4) has maximum value because it has maximum slope. While time series 6 (2013 to 2019) has minimum increasing rate because it has minimum positive slope among all. On the other hand, time series 1, 2 and 5 has downward (decreasing) trend. Decreasing rate of these time series are -0.2982^{O}C/decades, -0.375^{O}C/decades and -0.5418^{O}C/decades as shown in figure. Maximum temperature decrease with maximum rate during 2008 to 2012 because it has maximum slope (figure 7, Table 3).

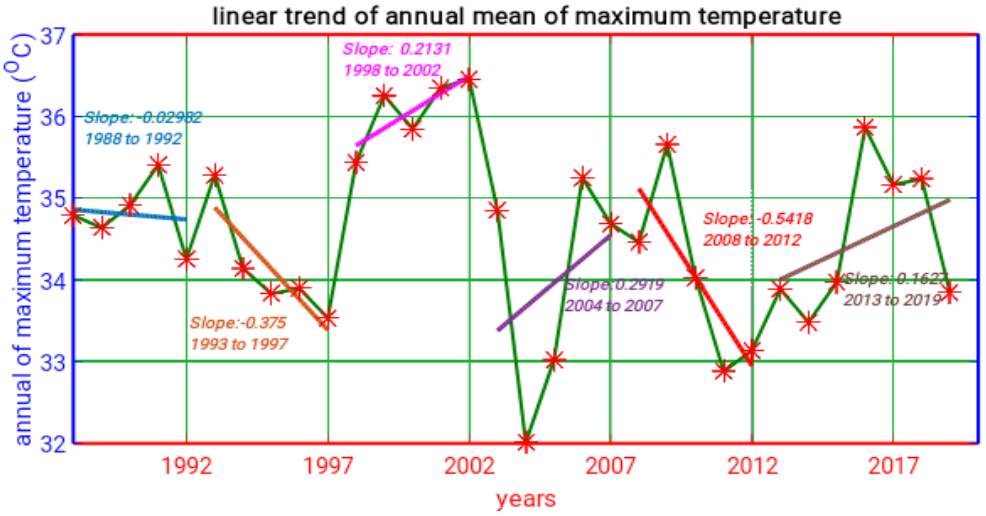


Fig. 7 Trend of Tmax (^{O}C) when time series is divided into six parts: time series.

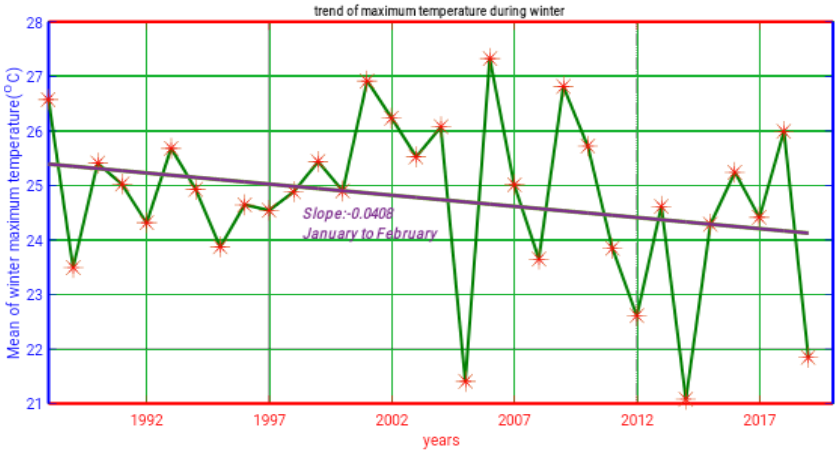
Table 3 Goodness of fit, null hypothesis (at alpha significance level 0.5), slope and trend of annual mean of maximum temperature

	1988 to 1992	1993 to 1997	1998 to 2002	2003 to 2007	2008 to 2012	2013 to 2019
goodness of fit	SSE: 0.6902 R-square: 0.01272 Adjusted R-square: -0.3164 RMSE: 0.4797	SSE: 0.4277 R-square: 0.7668 Adjusted R-square: 0.689 RMSE: 0.3776	SSE: 0.2553 R-square: 0.6402 Adjusted R-square: 0.5203 RMSE: 0.2917	SSE: 6.792 R-square: 0.1114 Adjusted R-square: -0.1848 RMSE: 1.505	SSE: 2.008 R-square: 0.5939 Adjusted R-square: 0.4585 RMSE: 0.818	SSE: 4.212 R-square: 0.1496 Adjusted R-square: -0.02049 RMSE: 0.9178
Slope	-0.02982	-0.375	0.2131	0.2919	-0.5418	0.1627
Trend	Decreasing	Decreasing	Increasing	Increasing	Decreasing	increasing
	1988 to 2003			2004 to 2019		
goodness of fit	SSE: 10.49 R-square: 0.1871 Adjusted R-square: 0.129 RMSE: 0.8656			SSE: 16.17 R-square: 0.1073 Adjusted R-square: 0.04359 RMSE: 1.075		

Slope	0.08426	0.07564
P-value	0.1628<0.5	0.3923<0.5
Null Hypothesis	Rejected	Rejected
Z	1.3957 (Positive)	1 (Positive)
Trend	Increasing	Increasing
	1988 to 2019	
goodness of fit	SSE: 35.55 R-square: 0.02708 Adjusted R-square: -0.005349 RMSE: 1.089	
Slope	-0.01905	
P-value	0.3553<0.5	
Null hypothesis	Rejected	
Z	-1 (negative)	
Trend	Decreasing	

2.2.2 Seasonal Trend

Seasonal has been classified as winter (January to February), pre monsoon (March to May), monsoon (June to September) and post-monsoon (October to December). It has been analyzed that there is downward (decreasing) trend in maximum temperature during winter, pre-monsoon, monsoon and post-monsoon with the rate of -0.0408^{O}C/decades, -0.0025^{O}C/decades, -0.007^{O}C/decades and -0.0213^{O}C/decades respectively from 1988 to 2019 (figure 8, Table 4).



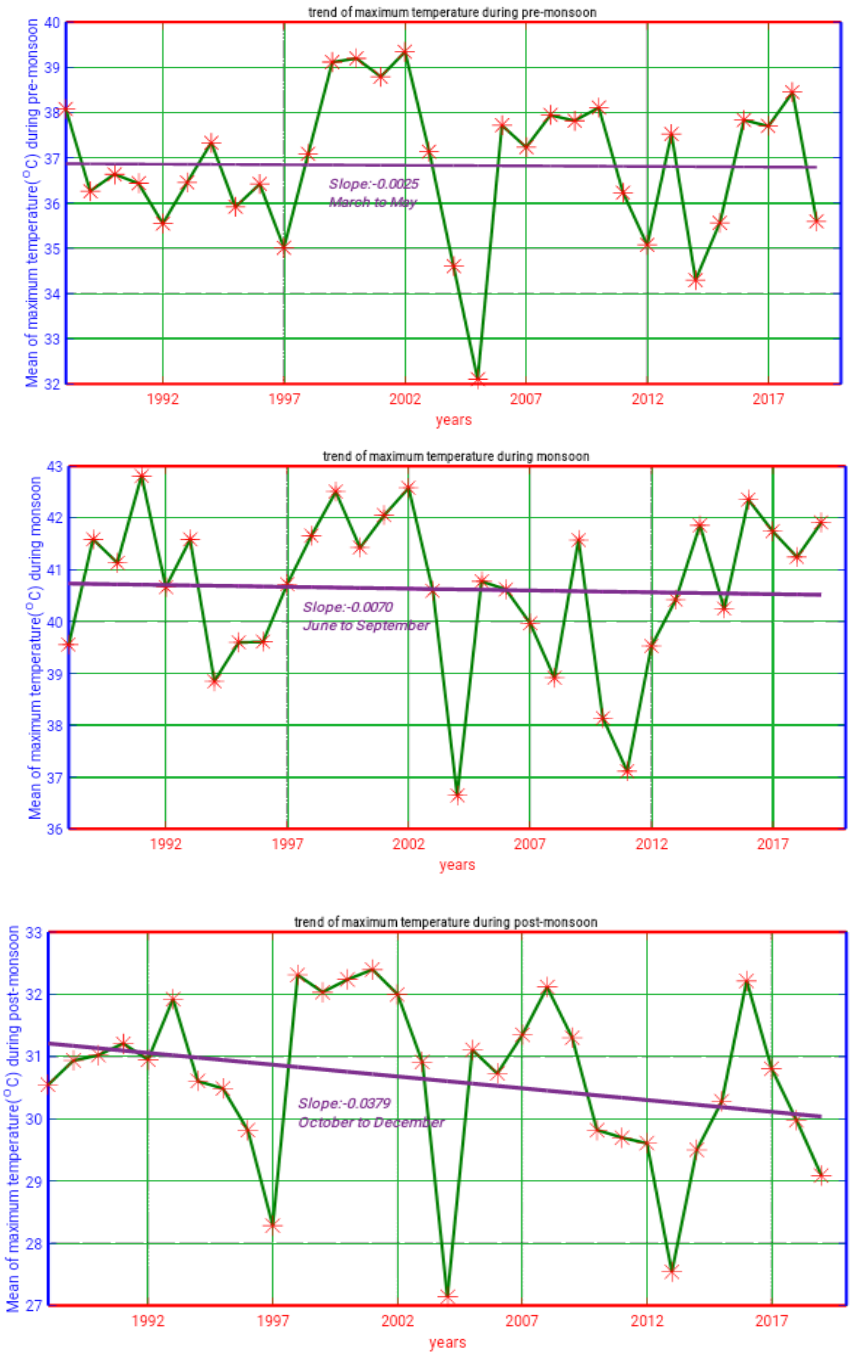


Fig. 8 Seasonal trends of Tmax (^{O}C) for (a) winter (January-February) (b) pre-monsoon (March-May) (c) monsoon (June-September) (d) post-monsoon (October-December)

Table 4 Seasonal trend, goodness of slope, null hypothesis (at alpha significance level 0.5) and slope of maximum temperature

	Winter	Pre-monsoon	Monsoon	Post-monsoon
goodness of fit	SSE: 66.27	SSE: 79.36	SSE: 71.98	SSE: 51.57

	R-square: 0.06427 Adjusted R-square: 0.03308 RMSE: 1.486	R-square: 0.0002137 Adjusted R-square: -0.03311 RMSE: 1.626	R-square: 0.001865 Adjusted R-square: -0.03141 RMSE: 1.549	R-square: 0.0705 Adjusted R-square: 0.03951 RMSE: 1.311
Slope	-0.04085	-0.002493	-0.007021	-0.03787
P-value	0.3724<0.5	0.8078>0.5	0.9871>0.5	0.1234<0.5
Null hypothesis	Rejected	Accepted	Accepted	Rejected
Z	-1 (negative)	0	0	-1.5406 (negative)
Trend	Decreasing	No trend	No trend	Decreasing

5 Conclusion

This paper is aim at to analysis the changes in maximum and minimum temperature in Lahore at annual and seasonal resolution using data provided by meteoblue from 1988 to 2019 and applying statistical tools. Trend of maximum and minimum temperature has been observed by statistical test called Mann-Kendall and slope is calculated by linear fit (Polynomial of degree 1).

Minimum temperature is increased at the rate of 0.04782^{O}C/decades while maximum temperature is decreased at the rate of -0.01905^{O}C/decades from 1988 to 2019. But when we analyzed minimum and maximum temperature into two parts, from 1988 to 2003 no significant trend has been observed in minimum temperature because its slope is approximately equal to zero but from 2004 to 2019 minimum temperature increased at the rate of 0.06877^{O}C/decades, on the other hand, maximum temperature has been increased at the rate of 0.08426^{O}C/decades and 0.07564^{O}C/decades from 1988 to 2003 and 2004 to 2019 respectively. Both increasing and decreasing trend has been found when minimum and maximum temperature is analyzed into six parts.

In the future we want to evaluate temperature data by applying nonlinear curve fitting such as some trigonometric function. It is to find out trends and periodicity in the temperature data

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