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Ghafoor and Nawaz, 2020. 22(3): 23-33. J. Environ. Agric. Sci. (ISSN: 2313-8629)

Changes in Climatic Parameters in Metropolitan City of Lahore, Pakistan

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Received
July 24, 2020

Accepted
September 14, 2020

Published Online
September 28, 2020

Abstract: Anthropogenic activities have offset the balance of the earth's energy resulting in changing climatic conditions. Climate change is a relatively new concept and is directly related to our livelihoods and needs to be studied to form mitigation and adaptation policies. This study was conducted to assess climatic changes in the Metropolitan City of Lahore, Pakistan. A thirty-one year data (1985-2015) of daily minimum and daily maximum temperatures and daily rainfall was collected from Regional Meteorological Center (RMC), Lahore. Statistical analysis was done using MS-excel and different values like mean, standard deviation, diurnal temperature range (DTR), and anomaly were estimated. Results showed that Lahore was getting more rainfall and the rainy season had widened. The months of June and September had gone wetter. The hottest year recorded was 2009, when the mean temperature was 25.54°C. A reduction of -1.32 °C in DTR and a 52 mm increase in rainfall has been witnessed.

Keywords: Diurnal Temperature; Precipitation; Seasons; Climate Change; Atmospheric Science.
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Cite this article as Ghafoor, A. and R. Nawaz. 2020. **Changes in climatic parameters in metropolitan city of Lahore, Pakistan**. Journal of Environmental and Agricultural Sciences. 22(3):23-33.

1. Introduction

Climate change is a global phenomenon and poses diverse implications in form and type for different ecologies (Comer et al., 2019; Fawzy et al., 2020; Kling et al., 2020; McLaren and Markusson. 2020). Anomalies in rainfall intensity, duration, and pattern could result in floods or droughts, causing a direct threat to regional and global food security (Mujumdar et al., 2020; Nkurunziza et al., 2019). Furthermore, the shortening or lengthening of the seasons causes ecological changes that adversely affect the agricultural outputs and habitat (Bates et al., 2008; Murali and Afifi. 2014; Rehmani et al., 2014; Savo et al., 2016). The variation in the season intensities and lengths undermines the crops' maturation cycle and a significant reduction in crop yields (Vikas, 2012; Zhang et al., 2015). Several African countries are suffering from decreased crop yields due to the increased frequency of floods (Borokini et al., 2014). Due to seasonal variability in California, USA wheat production is under threat (Frank and Elizabeth, 2010). Climate change also accounts for increased incidents of hurricanes and tsunamis, changes in pattern and frequency of rainfall (Darand et al., 2017; Maarten, 2006). The rise in the global mean temperatures is causing faster melting of glaciers, with higher risks of floods (Sujatha and Sudhir, 2015). The year 2014 has been recorded as the hottest year since man has started keeping records (Stein, 2015). Climate change is predicted, to intensify in the future and further aggravation and variability of these natural factors could be seen (IPCC, 2014).

Pakistan is facing serious consequences of erratic climate change, and it is globally listed as one of the most vulnerable countries to climate change (Fahad and Wang, 2020; UNEP, 2013; GOP, 2013). The climate variability manifests multifaceted problems for Pakistan. Floods are the major cause of damages and are increasing due to climate change. The recent incidents of the floods have put Pakistan's economy under tremendous pressure. The flood of 2014 caused even more devastation by submerging 17 districts of Punjab and drowning 3083 villages, destroying

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100,000 houses and resulting in a death toll of 367 (NDMA, 2014).

The Metropolitan City of Lahore is a fast-growing city of Pakistan with a bulging population growth rate of 3.73 percent/annum, and the present scenario of climate change impedes the city's future development. Megacity needs proactive climate change mitigation regimes at multilevel, from the provincial government, local bodies, organizations to individuals. The international indices and models show climate change on a large spatial grid. The cities globally accommodate more than 50% of the population, are major consumers of energy, and produce 70% of the global greenhouse gases (Sharifi, 2020). This study was done to assess changes in different climatic parameters including minimum temperature, maximum temperature, diurnal temperature range, and rainfall in the Metropolitan City of Lahore, Pakistan.

2. Methodology

2.1. Study area

Lahore is the capital of the Province of Punjab, Pakistan, and has a population of 12,642,423 (World Population Review, 2020). It is one of the fastest-growing cities in the world and ranked as the 34th populated city (Khan et al., 2011). The latitude and the longitudes of Lahore are 31.5546° N, 74.3572° E, respectively and it sits 217m above sea level. The weather of Lahore is arid to semi-arid with the occurrence of maximum rainfall in July and August, the monsoon months. During the winter months, the minimum temperatures range from 1 ºC to 7 ºC and it has a long summer starting from May to mid of October when temperatures remain in the high 40's during the days. Lahore has four seasons and with winter starting from 15th December to 15th February and a long summer starting from 15th May to 15th October. It also receives some winter rain in the months of December-February (Chaudhry et al., 2009).

2.2. Meteorological Parameters

Short-term atmospheric conditions including temperature, precipitation, relative humidity, and winds of a region is described as weather and average weather over a longer time period (30 years, as described by WMO) is defined as climate (Knight et al., 1991; Said and Kadry, 1994). The precipitation and temperature have been used in various methods to assess and predict climate change. Norman Phillips devised the basic statistical tool to predict climatic trends in 1956 and by 1980s, in the US, a community atmospheric model was built by National Center for Atmospheric Research. In mid-1980s, World Meteorological Organization (WMO) initiated the project called CLICOM (CLImate COMputing) that included over 100 countries to support and collect the climatic data (Stuber et al., 2011).

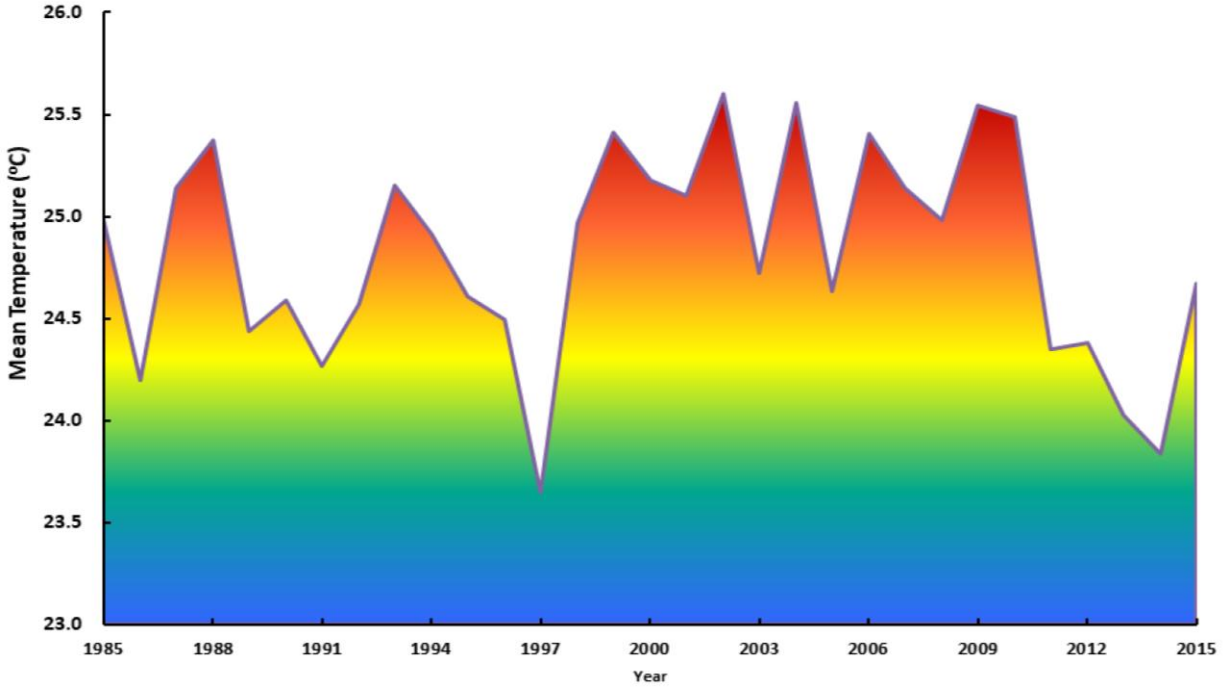

Fig.1: Annual mean temperature in Lahore (1985-2015)

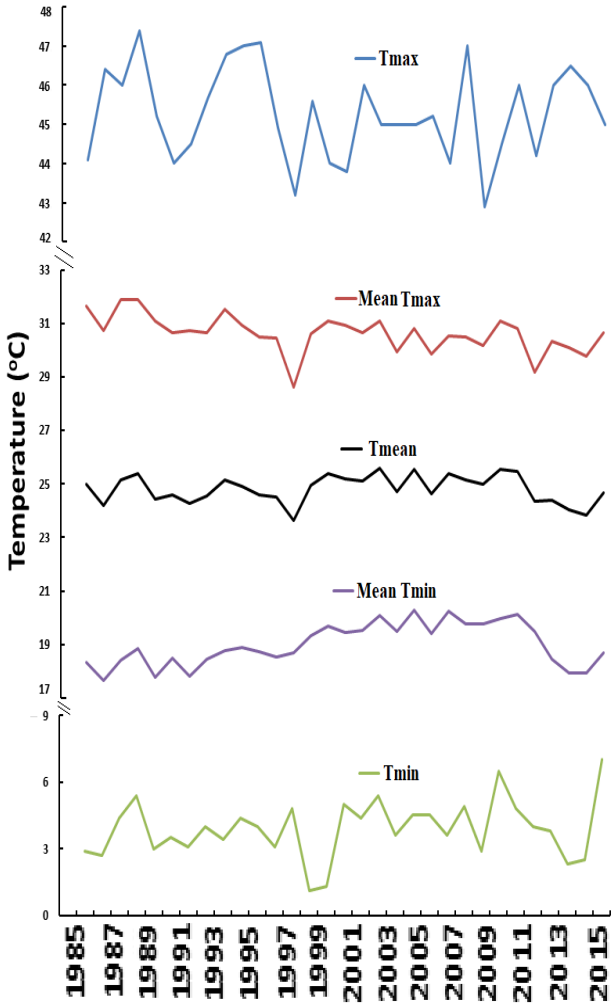

Fig.2: Annual Min, Max, Mean Temperatures °C (1985-2015) Lahore

Daily minimum and maximum temperatures of Lahore were looked at as one of the variables. The temperature variation was then employed to trace any signs of warming up of the City of Lahore. The temperatures are gauged by thermometers placed so that the sunlight does not fall directly onto the meter whereas, the mercury moves through the heat transferred by the air.

A record of daily precipitation levels was acquired as the other variable to find the changes in the climate of Lahore. The variations and the anomalies in the precipitation during the said time period were observed to detect climate change. A bottle type gauge is used to measure the precipitation and it's all done manually.

Thirty-one years (1985 to 2015) data of various climatic variables was collected from the Pakistan Meteorological Department (PMD). The said secondary data set was collected from the Regional Meteorological Center (RMC), Lahore of PMD. The RMC office is situated in the of Lahore city i.e. Shadman Colony. The study deployed Microsoft Excel to prepare different graphs, trends and compute the statistical values like mean, standard deviation and anomaly. Diurnal Temperature Range (DTR) was measured as the difference of annual maximum and minimum temperatures of a given year.

3. Results and Discussion

Annual mean temperature of Lahore from 1985 to 2015 (31 years period), (Fig. 1), indicated insignificant changes in the mean temperatures for the period from 1985 to 1997. The year 1997 was recorded as the coolest year in the studied period, with an annual mean temperature of 23.64 °C. Then a temperature rise is observed from 1998 (mean temperature was 24.97 °C), to 2009, the hottest year recorded (mean temperature of 25.55 °C). A downward trend in the mean temperature has been observed from 2011 to 2015, with the mean temperature of 24.67 °C for 2015. A study conducted by Bhatla et al. (2020) also mentions that a decrease of 0.5-1.0 degrees centigrade has been observed in Central and Southern India between the periods of 1951-2010.

Mean, maximum and minimum temperatures during the study period are presented in Fig. 2. The mean temperatures reading may suggest that there is no significant global warming for Lahore or if there was any it's returning back no normality. Importantly, the mean temperature encompasses both minimum and maximum temperatures, and does not offer any information about the inter-variability in the maximum or minimum temperatures. This study reveals that the maximum temperatures are getting lower whereas the minimum temperatures are getting higher, consequently having a nullifying each other's effect on the mean temperature calculation.

Results showed a downward trend in maximum temperatures. The first temperature reading, corresponding to the year 1985, is 31.65 °C which dropped sharply to 28.61 °C in the year 1997 and kept on dropping till 2015, when the mean maximum recorded temperature was 30.67 °C; a drop of 0.98 °C has been observed. There is an upward trend recorded from 1985 to 2010 where the temperature reached 20.14 °C, and then it dropped down till 2013-2014 and again it started to rise in the year 2015 with the mean minimum temperature of 18.67 °C.

Table 1. Yearly Temperature Extreme and Maximum Rainfall observations in Lahore (1985-2015)

Date (D/M/Y)	Annual Maximum TMax (ºC)	Date (D/M/Y)	Annual Minimum TMin (ºC)	Date (D/M/Y)	Max. Rainfall (mm)
21/05/1985	44.1	11/12/1985	2.9	09/10/1985	117.4
20/06/1986	46.4	18/12/1986	2.7	08/07/1986	65.3
08/06/1987	46.0	03/01/1987	4.4	12/06/1987	59.1
31/05/1988	**47.4**	26/01/1988	5.4	25/09/1988	76.9
17/05/1989	45. 2	13/01/1989	3.0	30/07/1989	123.1
19/06/1990	44.0	01/12/1990	3.5	14/08/1990	83.1
31/07/1991	44.5	03/01/1991	3.1	11/06/1991	75.7
18/06/1992	45.7	01/01/1992	4.0	10/09/1992	69.6
11/06/1993	46.8	22/01/1993	3.4	16/07/1993	55.1
31/05/1994	45.2	31/12/1994	4.4	31/06/1994	49.4
09/06/1995	47.1	23/01/1995	4.0	06/08/1995	76.8
04/06/1996	44.9	11/12/1996	3.1	**23/08/1996**	**189.7**
17/06/1997	43.2	14/01/1997	4.8	27/08/1997	151.1
26/05/1998	45.6	**25/01/1998**	**1.1**	08/08/1998	59.0
01/05/1999	44.0	06/01/1999	1.3	13/08/1999	88.2
22/05/2000	43.8	16/01/2000	5.0	24/06/2000	110.0
13/05/2001	46.0	18/01/2001	4.4	25/06/2001	87.0
13/05/2002	45.0	03/01/2002	5.4	03/09/2002	29.4
08/05/2003	45.4	13/01/2003	3.6	18/06/2003	84.2
22/05/2004	45.0	04/01/2004	4.5	16/06/2004	58.0
24/06/2005	45.2	15/12/2005	4.5	02/06/2005	136
14/05/2006	44.0	08/01/2006	3.6	03/09/2006	114.6
10/06/2007	47.0	31/12/2007	4.9	29/06/2007	49.2
10/05/2008	42.9	24/01/2008	2.9	13/08/2008	80.7
20/05/2009	44.3	02/01/2009	6.5	12/08/2009	49.7
27/05/2010	46.0	12/01/2010	4.8	22/07/2010	122.0
20/05/2011	44.2	18/01/2011	4.0	13/08/2011	86.0
31/05/2012	46.0	29/12/2012	3.8	05/08/2012	110.0
24/05/2013	46.5	29/12/2013	2.3	15/08/2013	113.1
09/06/2014	46.0	02/01/2014	2.5	04/09/2014	177.0
23/05/2015	44.0	25/12/2015	3.0	11/08/2015	74.5

The annual mean temperature showed a continuous increase in the mean temperatures from 1998 to 2010 with 2009 being the hottest year with a mean temperature of 25.545 ºC. Subsequntly there was a drop in the mean temperatures (24.67 ºC), slightly cooler years. Table 1 also shows maximum precipitation for each year of the study period.

The 10-year moving average anomaly provided a trending photo and it showed a rising trend of annual mean temperature from 1998, when the recorded average anomaly was -0.2545, in 2010, when the average anomaly recorded as 0.398 ºC. Then the temperatures started dropping and in 2015 the average moving anomaly reduced to only -0.0375 ºC (Fig. 3 a).

Anomalies of annual mean maximum temperature, over Lahore Metropolitan City, for the years 1985-2015, are presented in Fig. 3 b. Figure described the mean maximum temperature anomaly with a ten years moving average trend of 10 years. The first moving average plotted was of year 1994 where the anomaly was of -0.0565 ºC, it dropped sharply in the year 1997 to 0.075 ºC and stayed steady till 2010 when the anomaly of -0.072 was recorded, then it started dropping back again and reached -0.307 by the year 2015. Observed increase in temperature is consistent with other studies (Wilgen et al. 2016).

Anomalies of annual mean minimum temperature, over Lahore for the years 1985-2015, is presented in Fig. 3 c. It is evident that the anomaly was on the rise from the first reading and it reached to its highest value of 0.87 ºC in the year 2010, as temperatures were at their highest mean value in the year 2010.

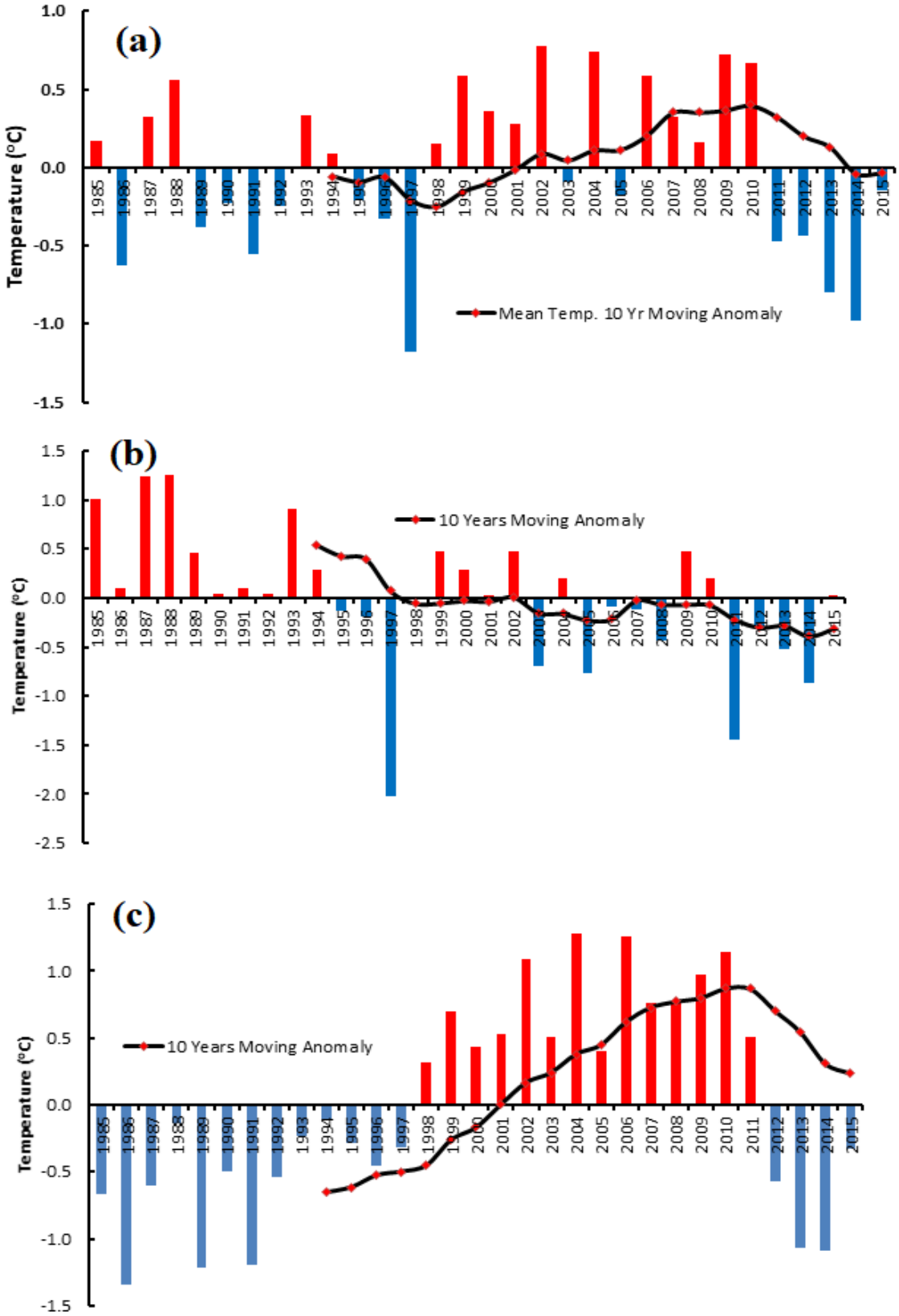

Fig. 3. Annual temperature anomalies (1985-2015) (a) mean temperature (b)mean maximum temperature (c) mean minimum temperature, in Lahore

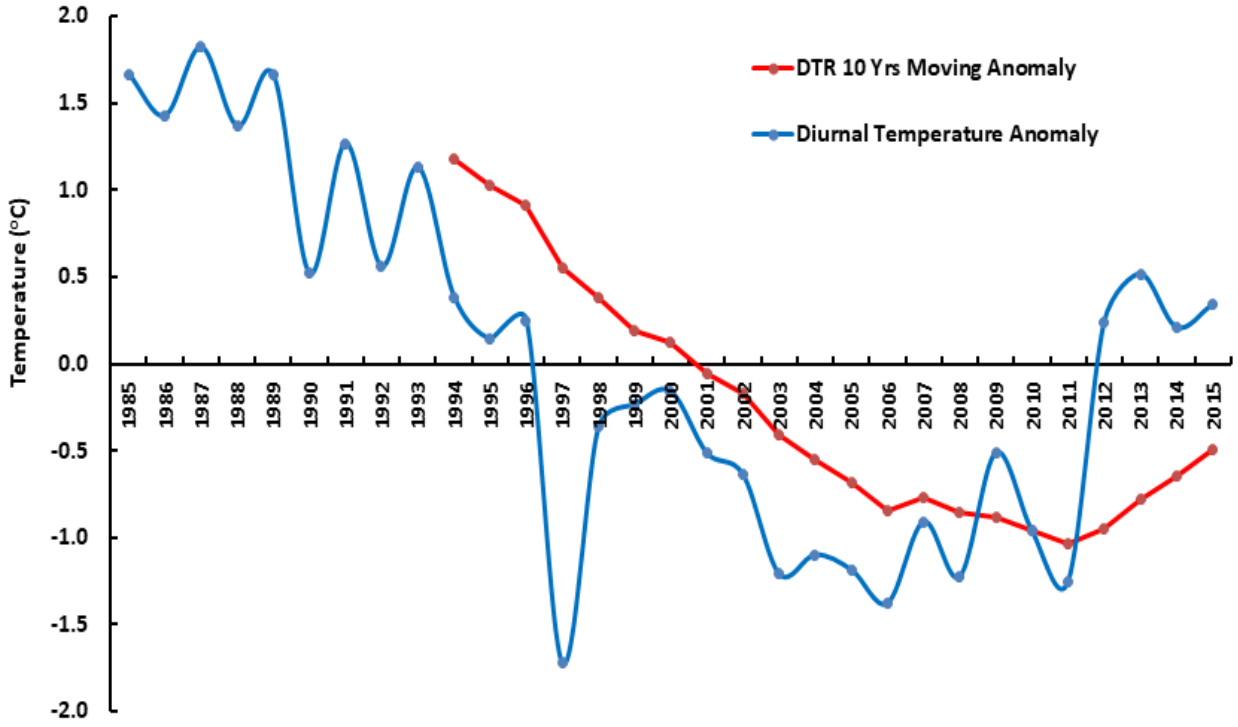

Fig. 4. Diurnal temperature range anomaly (DTR, 1985-2015), in Lahore

Diurnal temperature range (DTR) is changing across the globe, especially in the plans of the northern hemisphere the DTRs are decreasing (Chaudhry et al., 2009; Ongoma eal., 2020; Sun et al., 2019). It is evident from the figure that the DTR of Lahore was also decreasing. In 1985 the anomaly was 1.67 °C and it continuously dropped down to -0.1.24 °C by the year 2011 and rose back and in 2015 it was recorded at 0.35 °C; a difference of -1. 32 °C or -0.43/decade is seen (Fig. 4). A more recent study by Khan et al. (2020) also confirms a − 0.15 to − 0.08 °C/ decade DTR change in some regions of Pakistan.

The results stated above reveal a warming cycle for the most part of the time period analyzed and since 2011 the annual mean temperatures are returning back to normality. The annual mean temperatures 10 years moving anomaly in 1994 is -0.0565, slightly under the zero mark, it drops down to -0.2545 by 1998 and then for the next 12 years it rose to its maximum at 0.398 making a total of 0.45 °C rise in the mean temperatures by the year 2008. The downward trend started in 2011 when the moving average anomaly dropped to 0.323 and in the year 2015, it was recorded at -0.0375, about a 2% of a celsius degree change. Year 2009 was recorded as the hottest year (mean temperature were 25.545 °C).

Annual mean temperatures encompass both the maximum and the minimum temperatures, and gives an average number of temperatures around the year hence, the variations within the minimum and the cumulative score overshadows maximum temperatures. This study reveals that the maximum temperatures are getting lower and the minimum temperatures are getting higher. A significant climate change is evident in analyzing mean temperatures. The mean maximum temperature anomaly adopts a downwards trend with some small episodes of warming up but ending up to fall down.

There had been a decline in mean maximum temperatures during the studied period, highest value (31.65 °C) of mean maximum temperature was recorded in the year 1985, and fell 0.98 °C by 2015 to get to 30.67 °C. The minimum temperatures have been on the upward curve for most of the observed years and it starts returning in 2011.

The average ten years moving average minimum temperature anomaly of 1994 was -0.655 and rose to 0.868 by 2011 and fell back to -0.33 by 2015. A total warming up of 0.325 °C was observed in the mean minimum temperatures. The coolest year of the tenure was 1986 with the annual mean minimum temperature of 17.65 °C.

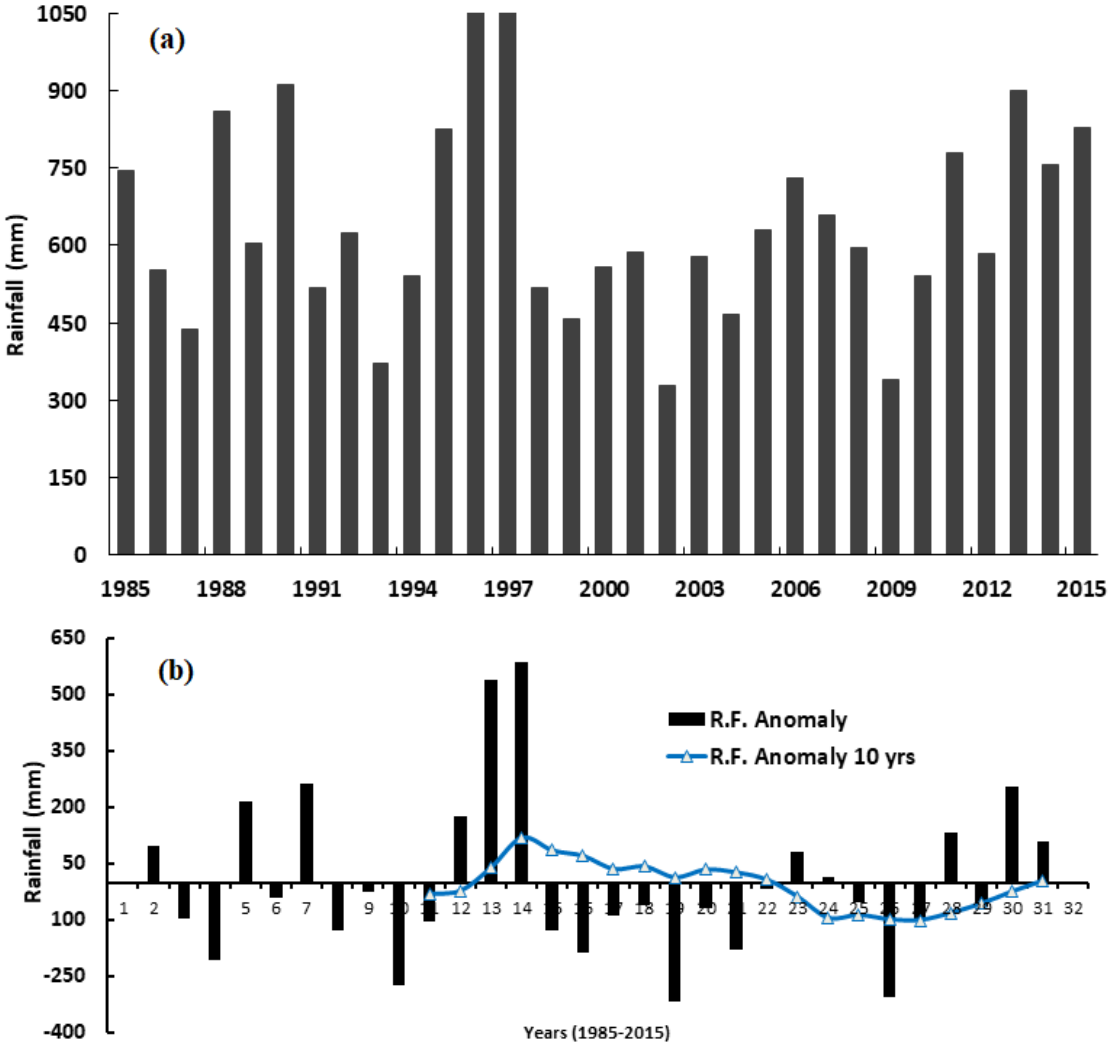

Fig. 5. Annual rainfall (1985-2015) Lahore (a), rainfall anomaly (b).

Rainfall trends in Lahore for 31-year period is presented in Fig. 5 (a). There had been only three instances, 1993, 2002 and 2009 when the total rainfall has been less than 400 mm and two years of 1996 and 1997 when it exceeded 1000mm mark with receiving 1185mm and 1232mm, respectively. Otherwise, there was an upward, slight though, trend in the rainfall. In 1985 Lahore received 774mm and 829mm in 2015. Figure 5(b), shows the trend of precipitation of the 31 year period of Lahore weather. The average moving anomaly states a slight overall upwards trend, where for two consecutive years 1996-1997 the city received more than 1100mm rainfall in a year. The moving average dropped after these two exceptional years. In the overall picture, the rainfall anomaly (ten years moving average) increased from -0.36.64 mm (1994) to 18.06 mm (2015) depicting an overall increase of 52 mm rainfall between the years 1994 to 2015.

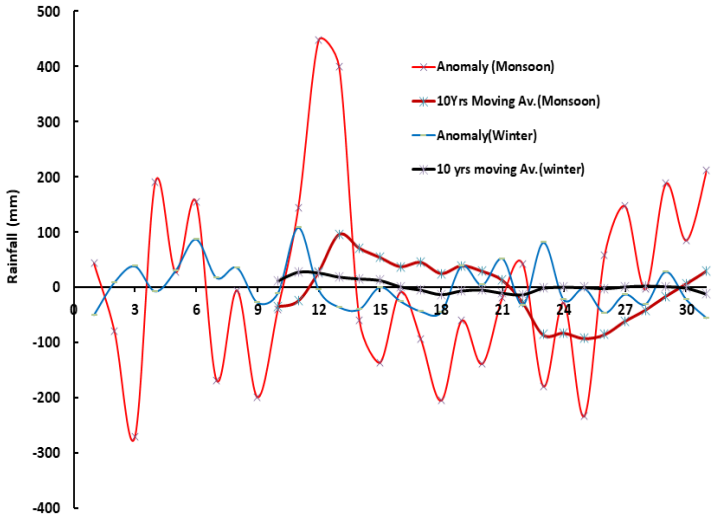

Fig.6: Seasonal rainfall anomaly for monsoon and winter seasons (1985-2015)

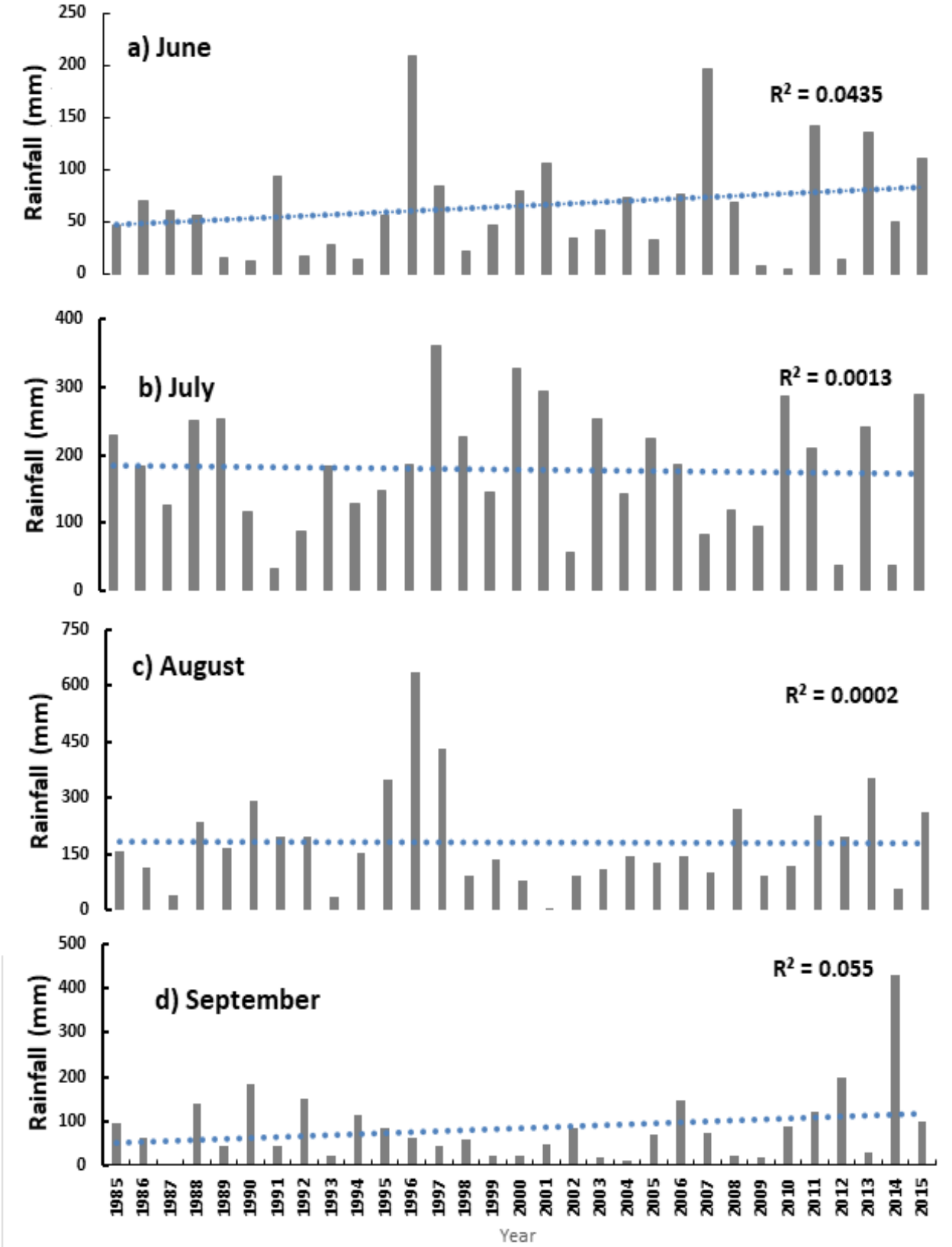

Fig. 7. Monthly rainfall in June (a), July(b), August (c) and September (d) from 1985-2015

Lahore gets two wet seasons in the year, one during the summer also known as the monsoon season and the other in the winter season. Monsoon comprises the months of July to September and is the major rainy season that brings the most water to the region. An upward trend was seen in the Monsoon rains whereas; the change in winter rainfall was insignificant (Fig. 6). The ten years moving anomaly started in 1994, when the anomaly -34.61mm and in 2015 it reached 28.86mm, a total gain of about 62mm. The result is in harmony with the study conducted by Athar (2020) for Punjab, according to which the rainfall contribution towards water supply for irrigation has an increase from 7.6 mm to 291.8 mm between the years 1982-2015. Table 1 shows maximum precipitation for each year of the study period.

Figure 7 displays the annual rainfall for the months of June, July, August and September for the years 1985-2015. Traditionally the month of August would get more rain as compared to the month of July, whereas, past 1995 we see that either June is getting more wetter or matching up with the rain volumes of August. Also the rain activity has picked up in the month of September. Seasonal monsoon shifting in the region is affecting the rainfall variability and the onset of monsoon (Loo et al. 2015; Zhisheng et al. 2015).

4. Conclusion

The present research was carried out to identify the potential occurrence of climate change in the Metropolitan city of Lahore. In the first decade 1985-1997, there was an insignificant change in the mean temperatures and from 1997 onwards there was a gradual rise in the mean temperatures and the year 2009 being the hottest with the annual mean temperature of 25.54 ^{o}C. The temperatures remained hotter till 2011 and then gradually fell down to the temperature range of 1985. It is concluded that the warming was insignificant in the study area of Lahore. Although the mean temperatures have changed slightly. There was a significant change in the mean maximum and mean minimum temperatures as the maximum temperatures were getting lower and minimum temperatures were getting higher. This fact is evident from the diurnal temperature range (DTR) with a reduction of 1.32 ^{o}C in the 31 years period. Lahore is getting more rainfall. It is clear that the rainy season has widened and the months of June and September have gone wetter, especially past 2010, expanding the active monsoon season. It is therefore concluded that Lahore is experiencing a climate change in terms of precipitation as well. The drainage systems need serious attention as they are a few and are mostly choked due to wastes being dumped in them by the public. A public awareness campaign needs to be launched. The capacity and capabilities of the local disaster risk reduction organizations need to be built and the provincial and federal governments are recommended to provide enough resources for such programs. Future development plans should incorporate environmental issues right from the inception phase.

Competing Interest Statement: All the authors declare that they have no competing interests.

Author's Contribution: Mr. Abdul Ghafoor: collected and analysed data, and prepared paper draft. Dr. Rab Nawaz: Supervised the entire research work, manuscript revision and imporovement.

Acknowledgments: Thanks are extended to Regional Meteorological Center (RMC) Lahore for provision of monitoring data and guidelines for the present research work. This manuscript has been prepared from M.Phil. thesis of the first author. It is certified that there is no competing interest for this paper with any individual or organization.

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