International Journal of Applied Environmental Sciences
ISSN 0973-6077 Volume 19, Number 1 (2024), pp. 19-49

http://www.ripublication.com/ijaes.htm

An Analysis of Temperature Trends of Five Metro Cities in India

Upendra Kumar Sahoo* **and Tirthankar Ghosh**

Department of Statistics, Visva-Bharati University, Santiniketan, 731235

Abstract

The issue of climate change is pivotal in today's world. Greenhouse gases have a predominantly warming effect on the atmosphere. Among the climatic elements, temperature is a primary determinant in identifying climate change resulting from urbanization and industrialization. This manuscript discusses the trends in temperature over five metro cities, Kolkata, New Delhi, Mumbai, Bhubaneswar, and Bangalore in India from 1951 to 2020. The long-term temperature change was evaluated using a linear trend and the Mann-Kendall test. Analysis was performed on both average maximum and minimum temperatrures by annual, decade and season parttern. The analysis results show a significant upword trend in the average maximum and minimum temperatures of considered five cities. Although a few are not significant.

Keywords: Climate change, linear trend, Mann-Kendall test, Temperature

1.INTRODUCTION

The climate of a region is the average weather over a 30-year time period. In climate study, the principal parameters of interest are temperature, rainfall, humidity, Sea surface temperature (SST) etc. Global warming is a reality, and climate change is a concerning phenomenon affecting all spheres of the World. Temperature plays a crucial role in the study of global climate study. The changes, like the temperature pattern of a region over a considerable period of time, indicate changes in general climatic conditions. Therefore, the trend (long-term upward/downward movement) analysis of the temperature of a region over the years is also important to understand if there is any departure from the long-term average or not. The 2023 IPCC (Intergovernmental Panel on Climate Change) indicates that the global average surface air temperature rose by 1.1 ^{0} Celsius between 2011 and 2020 (2023). The report also highlights global mean surface temperature fluctuations across different time periods and geographical locations. Assessing the change in climatic behavior over a small region like a metro

city or an important economic hub is necessary for policy making. Several investigations have been carried out to determine the influence of climate change on temperature over different regions, including urban areas. Pramanik and Jagannathan (1954) pointed out the vital role of temperature changes and their relationship with climate, underscoring their importance in predicting future climate trends. The primary focus of their study was on assessing the secular trends of mean maximum and minimum temperatures across India from 1876 to 1950. However, their conclusion was that the maximum temperature trend was increasing for some cities (Alipore, Bangalore, Bombay, Karwar, Kozhikode, and Patna). However, a few cities (Aurangabad, Madras, Tiruchirapalli, and Visakhapatnam) also showed a decreasing trend. For other places, there were no significant trends in maximum temperature. Regarding the trend of minimum temperature, they found a consistent upward trend across all the meteorological stations except (Jalpaiguri, Nagpur Visakhapatnam, and Sambalpur(decreasing trend)). Jagannathan and Parthasarathy (1972) analyzed the series of annual temperature averages recorded at 8 stations over time, i.e., Fort Cochin, Bangalore, Madras, Hyderabad, Mumbai, Nagpur, Kolkata, and Allahabad, from 1875 to 1968. They found an ongoing upward movement in Kolkata and Bombay's average annual temperature and a downward trend in Fort Cochin. Sarker and Thapliyal (1988) studied India's rainfall and temperature data from 1890 to 1970. They found a slight increasing trend in air temperature, with no change in rainfall. In their investigation of decadal temperature trends across India from 1900 to 1990, Srivastava et al.(1992) revealed that the maximum temperature showed a greater upward trend than the minimum temperature across most meteorological stations. They also found that, the minimum temperature is decreasing over most areas of Northern India (23^{0} N). According to their analysis, an increase of 0.35^{0}C occurred in the mean maximum temperature over most parts of southern India (23^{0} S). Rup Kumar et al. (1988) have analysed 121 stations of temperature data at 121 stations in all over India during 1901-87. Their study revealed an increase of 0.6^{0}C in the average maximum temperature and a 0.1^{0}C rise in the average minimal temperature. However, the decrease in minimum temperature is not statistically significant. In their study, Kothawale and Rupa Kumar (2005) analyzed the surface temperature trends in India from 1901 to 2003. It was observed that the mean annual temperature showed a 0.22^{0} C increase every 10 years. The annual and seasonal average temperatures were considered across 30 sub-divisions and 7 regions in over India for 107 years during 1901-2007 by Mondal et al.(2015). They observed that, temperature (mean,maximum and minimum) increased significantly particularly in winter and post-monsoon time in their study. Radhakrishnan et al.(2017) provided insights into climate change trends in India by analyzing temperature and rainfall data. They conducted an analysis of maximum and minimum temperature data from 36 meteorological subdivisions spanning the years 1901 to 2014. Their findings revealed an upward trend in mean annual temperature by 0.86^{0} C. Alaka Gadgil et al.(2005) focused on temporal variation over Pune city of India from 1901 to 2000. The study indicated that the decline in standard annual and maximum temperature is more noticeable during winter. The evidence points towards a downward trend within the local region. Bhavin Ram et al.(2015) focused on temperature trends of Junagarh of Gujurat during 1980-2011. They found a declining

trend of the maximum temperature during summer. Therefore, it may be said that most of the previous studies revealed an increasing temperature trend at all India level. However, in smaller regions like in cities, consideration showed a mixed temperature trend. In a few cities, there is a declining trend in temperature. Therefore, it is pertinent to concentrate on studying temperature movements over the years at city levels, especially for metros. Because population densities in metros are generally higher, and consistent changes in temperature affect a large number of people. Knowing about metros' temperature pattern change would help city administrators and other government agencies make appropriate policy decisions. Hence, this study focuses on assessing the temperature trends for a few important metro cities in India, namely Bhubaneswar, Bangalore, Delhi, Kolkata, and Mumbai. The present study analyses the temperature pattern of the five metropolitan cities of India over 7 decades.

The layout of the work is as follows. The details of study locations are given in section 2. Materials and methods are focused in section 3. In section 4, results are described. Section 5 concludes the study.

2.STUDY AREA

The present study is concentrated on the Indian cities of Bhubaneswar, Bangalore, Delhi, Kolkata, and Mumbai. The locations of the five cities of India undertaken in this study are depicted in Fig 1. Bhubaneswar is the capital of Odisha. It is known as the temple city of India. Bhubaneswar city is located between latitudes 20.27 ^{0} N and longitudes 85. 84 ^{0} E, 148 feet from mean sea level. The Daya River also bounds the city, the Kuakhai River, and the Mahanadi River in the south, east, and southeast directions. Chandaka Wildlife Sanctuary and Nandan Kanan Zoo are, respectively, on the western and northern sides of the city. As per the Koppen climate classification, Bhubaneswar has a tropical savanna climate. Generally, in summer, the temperature reaches beyond 40^0 C. During winter, the temperature typically reaches a maximum of around 18^0C. The city frequently experiences heatwaves, rainfall, and tropical cyclones (2020,2014,2014) during summer.

Bangalore, the bustling capital of the Indian state of Karnataka is celebrated for its pleasant climate and lifestyle. It is one of India’s significant cities and is treated as the IT capital. Bangalore is located between latitudes 12.59^0 N and longitudes 77.57^0 E, 2953 feet from the mean sea level. It is the heart of the Mysore plateau. There are no such rivers running through the city. As per the Koppen climate classification, it has also a savanna climate. The climate of Bangalore is moderate, with maximum temperature ranging from 35 to 38^0 C during summer and minimum temperature around 10^0 C in winter.

Delhi is the Capital of India. It is between the latitudes 28.61^0 N and longitudes 77.23^0 E, 1000 feet from mean sea level. This city is completely bounded by land. The city is bounded by the states Haryana in the northern, western, and southern directions and UP in the east. As per Koppen climate classification, Delhi has a dry winter humid subtropical climate. The average max temperatures are 39^0 and 20^0 C during summer and winter, respectively.

Kolkata (22.35^0 N and 88.30^0 E) is honoured the Capital of the Indian state of West Bengal. This city is known as the cultural capital of India. This is situated on the eastern river banks of the Hooghly River. The total covered area by the city is 71 square miles or 185 km^2 . An average height 17 feet above the sea level, the city's proximity to the Bay of Bengal is notable. Its shore line is located around 60 kms to the south. The Sundarban National Park sits at a distance of 100 km from the city. It has a tropical climate. During summer, the maximum temperature occasionally surpasses 40^0 C, while the minimum temperature can reach upto 30^0 C. During winter , the minimum temperature fluctuates between 9 to 11^0 C .

Mumbai, the capital of Maharastra, is located between the latitude 19.08^0 N and longitudes 72.89^0 E and 33 feet from mean sea level. Mumbai is recognized as the business hub of India. The Arabian Sea forms the western boundary of Mumbai. According to the Koppen climate classification, Mumbai experiences an extreme tropical wet and dry. The average maximum and minimum temperatures are around 35^0C and 20^0C, respectively.

3. DATA AND METHODOLOGY

3.1 Data Sources

In the study, Daily maximum and minimum temperatures data is employed in the analysis. The data were collected from the IMD(India Meteorological Department) **https://www.imdpune.gov.in**. The considered data period ranges from 1951 to 2020 (70 years). There is no missing value in the data. The data were statistically processed and reduced to monthly values for further analysis. Trend analysis of a time series consists of determining the trend magnitude and also finding the statistical significance of the trend.

3.2 Linear Regression Analysis

Linear regression (LR) expresses the relationship between two or more variables with a causal link. It is used for trend analysis also. If the regression coefficient, commonly known as beta, is significant, then the linear trend may be said to be significant. LR method is more powerful than a non-parametric approach for the normally distributed variables. It detects trends and quantifies the change in data over time. The linear relationship and trend between variables were analyzed with a 95% confidence interval (1989,2009,2015). In trend analysis, the Null Hypothesis (H_0) states that of no trend and it is tested against the alternative hypothesis (H_1) ,which suggest either an increasing or decreasing trend. In the LR method, a random variable (Temperature) over time is estimated from the following equation

$$Y = a + bX \quad \textbf{(1)}$$

where Y indicates the Dependent variable(temperature), X indicates the Independent variable (time), and a and b are intercepts and slope of the regression coefficients, respectively. The significance of the slope is tested with a 95% confidence interval by

Student t-test (1989,2014). If the coefficient *b* is statistically significant, we can say the trend is statistically significant.

3.3 Mann-Kendall Test

The MK (Mann-Kendall) trend test, is applied to examine time-series data for persistent upward or downward trends (monotonic) in temperature values (Y) (1948,1945). As a non-parametric test, it works for all the distributions if the data set does not conform to a normal distribution. A simple linear regression is fitted if the data follow a normal distribution.

Trends in data can be detected using either parametric or non-parametric methodologies. Both methods have seen widespread adoption for trend identification in recent times. The MK test tests whether to reject the null hypothesis(H_0) and accept the alternative hypothesis(H_1), where H_0:No monotonic trend is present and H_1:Monotonic trend is present.

$$sign(y_j - y_k) = 1, if\ y_j - y_k > 0 \quad \textbf{(2)}$$

$$sign(y_j - y_k) = 0, if\ y_j - y_k = 0 \quad \textbf{(3)}$$

$$sign(y_j - y_k) = -1, if\ y_j - y_k < 0 \quad \textbf{(4)}$$

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(y_j - y_k) \quad \textbf{(5)}$$

Where, n is the number of data points y_j and and y_k are the values of time series at the time points i and j respectively. The sign function determines the trend direction between each pair of observations. If y_j is greater than y_k , it is a downward trend and resulting a negative trend to S and vice versa. The calculated result of the test is directly compared with the table value ($t_{ctitical}$) of the 95% confidence interval in the Student-t distribution.

4. RESULTS

4.1 Analysis of Annual Temperature

Analysis of annual monthly trends in both average minimum and maximum temperatures was meticulously conducted for the period covering 1951-2020. The details of average minimum temperature anomalies for five cities in India is shown in Fig 2.

The results of statistically significant at a 5% level of significance are shown in Table 1. In January, the minimum temperature in Bangalore, Delhi, and Mumbai increased except in Bhubaneswar and Kolkata. It is also increasing in all the cities except Bhubaneswar for the Month of February. This month's minimum temperature

significantly increases in Delhi, Kolkata, and Mumbai. In March, the minimum temperature of all the cities is increasing. In Bhubaneswar, the average minimum temperature decreases in all months of the year except for March, November, and December. The average minimum temperature of Bangalore is significantly increasing except in January and February. The average minimum temperature in Mumbai registered a significant rise in all months except January, March, and April. Delhi experiences a steady average maximum temperature throughout the year, except for June. The same increase trend in average minimum temperature is found for Kolkata. Thus, it can be concluded that, across all the metro cities analyzed here, the average minimum temperature has shown a significant rise almost every month of the year, with only a few instances to the contrary. Hence, this may taken as an indication of climate change at the city level. The average maximum temperature is also considered here.

The annual average maximum temperature anomalies of five Indian metro cities are illustrated in Fig 3. The statistical significance level is displayed in Table 2. There is an increase in the average maximum temperature at Bhubaneswar for each month of the year, as well as in Bangalore and Mumbai. Whereas in the case of Delhi, there is a decreasing trend of maximum temperature in Jan, Feb, Mar, May, and Jun. For the other months, an increasing trend was observed. In Kolkata, the average maximum temperature has a rising trend for the first five months. However, the average maximum temperature displayed an upward trend for the remaining months of the year. Therefore, looking at the above results, it may be said that the average monthly maximum temperature also has a significantly increasing trend for all the cities considered here, except for a couple of months for a few cities. The temperature trends in the metropolitan cities were assessed by analyzing the decadal temperature values.

4.2 Analysis of Decadal Temperature

The decadal average minimum temperature anomalies are depicted in Fig 4. The test of significance at 5% level results of both minimum and maximum temperatures are highlighted in Table 2. The decadal average minimum temperature has decreased in all the months except for March, November, and December in Bhubaneswar. Interestingly, the decadal average of minimum temperature has increased for all the months of the year in Bangalore and Mumbai. Apart from June, all the months in Delhi observed an upward trend in decadal averages of minimum temperature. The average maximum temperature in Kolkata has risen continuously from June through November.

The decadal maximum temperature anomalies are presented in the Fig 5. It has increased in each month of the year in Bhubaneswar, Bangalore, and Mumbai. However, in Bangalore, the deacadal average of maximum temperature has increased significantly. In the months of April, July, August, September and November, it has increased for Delhi, and in other months, it has decreased. The average maximum temperature has increased from June through November at Kolkata.

4.3 Analysis of Seasonal Temperature

In the section, average minimum and maximum temperatures are analyzed seasonally.

The months of the year are classified into four Seasons. They are Winter (December, January and February), Pre-monsoon (March, April and May), Monsoon (Jun, July and August), and Post-monsoon (September, October and December). The average minimum and maximum temperature anomalies are depicted in Fig 6 and Fig 7, respectively. The average minimum and maximum test of significance results are shown in Table 3. In Bangalore and Mumbai, the average minimum temperature has shown an increasing trend for each season of the year. But in Bhubaneswar, it has decreased in all the seasons except Post-monsoon. In Kolkata, the Monsoon and Post-monsoon seasons have seen a significant upward trend in temperature, unlike the other seasons. Significantly, the minimum temperature increases are observed in Delhi in all the seasons apart from Monsoon season. The average maximum temperature showed a rising trend across all seasons in the cities of Bhubaneswar, Bangalore, and Mumbai. It has increased in the Pre-monsoon season but not significantly in Mumbai. In the Monsoon and Post-monsoon seasons, the maximum temperature has increased for Kolkata but has significantly decreased in the Winter and Pre-monsoon seasons. In Delhi, the average maximum has dropped in the Winter, Pre-monsoon, and monsoon seasons and increased in Post-monsoon.

CONCLUSION

In the study, we investigated the both trend of minimum and maximum temperatures in five metro cities in India from 1951 to 2020. The data are analyzed as annual, decadal, and seasonal. The average minimum and maximum temperature trends are statistically significant, with a 5% significance level in the considered cities' months and seasons. The increase in temperature for a few months is non-significant. However, there is no increasing trend of minimum temperature in Bhubaneswar. The temperature data indicated a general warming trend in Bangalore, Delhi, Kolkata, and Mumbai. Most months have shown an increasing trend in minimum and maximum temperatures. This may be taken as a visible sign of climate change. Therefore, policymakers should consider the above facts in order to plan appropriately for city planning.

REFERENCES

[1] Lee H, Romero J. 2023.*Synthesis Report.*Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change , IPCC, Geneva, Switzerland , pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001.

[2] Pramanik S.K, Jagannathan P. 1954.Climatic changes in India–(ii) temperature. MAUSAM, 5(1):29–47.

[3] P Jagannathan P and Parthasarathy B. 1972. Fluctuations in the seasonal oscillations of temperature in india. MAUSAM, 23(1):15–22.

[4] Sarker R.P and Thapliyal V. Climatic change and variability. Mausam 1988; 39(2):127–138.

[5] Srivastava H.N, Dewan B.N, Dikshit S.K, Rao G.S.P, Singh S.S, Rao K.R. 1992. Decadal trends in climate over india. Mausam, 43(1):7–20.

[6] Rupa Kumar K, and Hingane L. S. 1988. Long-term variations of surface air temperature at major industrial cities of india. Climatic Change, 13(3):287–307.

[7] Kothawale D.R and Kumar K. 2005. On the recent changes in surface temperature trends over india. Geophysical Research Letters, 32(18).

[8] Mondal A, Khare D, Kundu S. 2015. Spatial and temporal analysis of rainfall and temperature trend of india. Theoretical and applied climatology, 122:143–158.

[9] Radhakrishnan K, Sivaraman I, Jena S.K, Sarkar S, Adhikari S. 2017. A climate trend analysis of temperature and rainfall in india. Climate Change and Environmental Sustainability, 5(2):146–153.

[10] Gadgil A and Dhorde A. 2005. Temperature trends in twentieth century at pune, india. Atmospheric environment, 39(35):6550–6556.

[11] Ram B, Chinchorkar S.S, Khardiwar M.S, Sayyad F.G. 2015. A study of maximum and minimum temperatures trends at junagadh (saurashtra region) of gujarat, india. Curr. World Environ, 10(1):321–329.

[12] Gupta K. 2020. Challenges in developing urban flood resilience in india. Philosophical Transactions of the Royal Society A, 378(2168):20190211.

[13] Mohanty U.C, Mohapatra M, Singh O.P, Bandyopadhyay B.K, Rathore L. S. 2014. Monitoring and prediction of tropical cyclones in the Indian Ocean and climate change. Springer Science & Business Media.

[14] Panda D.K, Mishra A, Kumar A, Mandal K.G, Thakur A.K, Srivastava R.C. 2014. Spatiotemporal patterns in the mean and extreme temperature indices of india, 1971–2005. International Journal of Climatology, 34(13):3585–3603.

[15] Haan. CT.1989. Parametric uncertainty in hydrologic modeling. Transactions of the ASAE, 32(1):137–0146.

[16] Hamdi M.R, Abu-Allaban M, Elshaieb A, Jaber M, Momani M. N. 2009. Climate change in jordan: a comprehensive examination approach. American Journal of Environmental Sciences , 5(1):740– 750.

[17] Singh D, Gupta R.D, Jain S.K. 2015. Study of daily extreme temperature indices over sutlej basin, nw himalayan region, india. Global Nest J, 17(2):301–311.

[18] Sneyers R. et al. 2014. On the statistical analysis of series of observations. America journal of climate change 2014;

[19] Kendall M.G. 1948. Rank correlation methods.

[20] Mann H.B. 1945. Nonparametric tests against trend. Econometrica: Journal of the econometric society, pages 245–259.

[21] Dash S.K, Jenamani R.K, Kalsi S.R, Panda S.K. 2007. Some evidence of climate change in twentieth-century India.Climate change, 85(3):299-321.

TABLES

Table 1: The slope coefficients of linear regression are in percentage of decadal ave. minimum (TMIN) and ave. maximum temperature (TMAX) of Bhubaneswar (BHU), Bangalore (BANG), Delhi (DEL), Kolkata (KOL) and Mumbai (MUM) *Significance at 5% level

Month	TMIN					TMAX				
	BHU	BANG	DEL	KOL	MUM	BHU	BANG	DEL	KOL	MUM
January	-0.8	0.8	0.7	-0.6	0.8	0.4	2.1*	-3.1*	-1.9*	0.3
February	-0.04	0.5	1.6*	1.1*	1.4*	1.1	1.9*	-0.9	-0.2	0.5
March	0.3	1.0*	0.9	1.1*	0.6	1.2*	1.8*	-0.6	-0.3	1.1*
April	-0.7	1.03*	1.3*	0.2	0.6	1.1*	1.9*	0.9	1.0	1.6*
May	-1.3*	1.1*	0.4	-0.5	1.1*	0.2	1.9*	-0.5	-1.5*	1.5*
June	-0.7	1.1*	-1.1*	0.7*	1.0*	0.2	1.5*	-2.1*	0.5	0.7
July	-0.4	1.1*	0.6	0.9*	1.03*	1.5*	2.4*	0.01	1.3*	0.7*
August	-0.6*	0.9*	1.1*	0.6*	0.9*	1.3*	1.5*	1.2*	1.3*	1.09*
September	-0.3	1.1*	1.02*	0.7*	1.1*	1.6*	1.6*	0.3	1.3*	1.2*
October	-0.4	0.6*	0.9*	0.5	1.2*	1.6*	1.8*	0.2	1.1*	1.2*
November	1.03	1.2*	2.2*	1.9*	1.8*	2.03*	1.5*	0.4	1.1*	1.2*
December	0.2	1.2*	1.1*	1.03*	0.8*	0.7*	1.8*	1.5*	1.05*	0.7*

Table 2: The slope coefficients of linear regression are in percentage of decadal ave. minimum (TMIN) and ave. maximum temperature (TMAX) of Bhubaneswar (BHU), Bangalore (BANG), Delhi (DEL), Kolkata (KOL) and Mumbai (MUM) *Significance at 5% level

	TMIN					TMAX				
	BHU	BANG	DEL	KOL	MUM	BHU	BANG	DEL	KOL	MUM
January	-0.9	0.8	0.6	-0.7	0.5	0.3	2.08*	-3.25*	-2.1*	0.2
February	-0.1	0.5	1.5	1.04	1.3	1.1	1.9*	-1.05	-0.3	0.4
March	0.3	0.9	0.9	1.08	0.6	1.2*	1.8*	-0.5	-0.3	1.1*
April	-0.7	1.01*	1.2	0.08	0.5	0.9*	1.8*	0.6	-1.1*	1.4*
May	-1.3	1.1*	0.4	-0.5	1.07	0.2	2.0*	-0.5	-1.5*	1.4*
June	-0.7	1.1*	-1.08	0.5	1.06*	0.2	1.4*	-2.1*	0.4	0.7
July	-0.4	1.1*	0.7	0.8	1.01*	1.5*	2.4*	0.1	1.2*	0.7*
August	-0.7	0.9*	1.1*	0.6	0.9*	1.2*	1.4*	1.1*	1.2*	1.08*
September	-0.4	1.1*	0.9	0.7	1.09*	1.5*	1.6*	0.3	1.3*	1.2*
October	-0.5	0.6	2.1*	1.7*	1.5*	1.9*	1.5*	-0.4*	1.05	1.2*
November	1.03	1.2*	2.2*	1.9*	1.8*	2.03*	1.5*	0.4	1.1*	1.2*
December	0.1	1.09	1.1	0.9	0.7	0.7	1.8*	-1.6*	-1.1	0.7

Table 3: The slope coefficients of linear regression are in percentage of seasonal ave minimum (TMIN) and ave. maximum temperature (TMAX) of Bhubaneswar (BHU), Bangalore (BANG), Delhi (DEL), Kolkata (KOL) and Mumbai (MUM) *Significant at 5% level

Season	TMIN					TMAX				
	BHU	BANG	DEL	KOL	MUM	BHU	BANG	DEL	KOL	MUM
Winter	-0.2	0.8*	1.1*	0.5	1.01*	0.7*	1.9*	-1.8*	-1.1*	0.5*
Pre-monsoon	-0.5	1.04*	0.8*	0.2	0.7*	0.8*	1.9*	-0.04	-0.9*	1.3
Monsoon	-0.5*	1.05*	0.2	0.7*	1.0*	1.02*	1.8*	-0.2	1.05*	0.8*
Post-monsoon	0.05	1.02*	1.4*	1.06*	1.4*	1.7*	1.6*	0.07	1.2*	1.2*

FIGURES

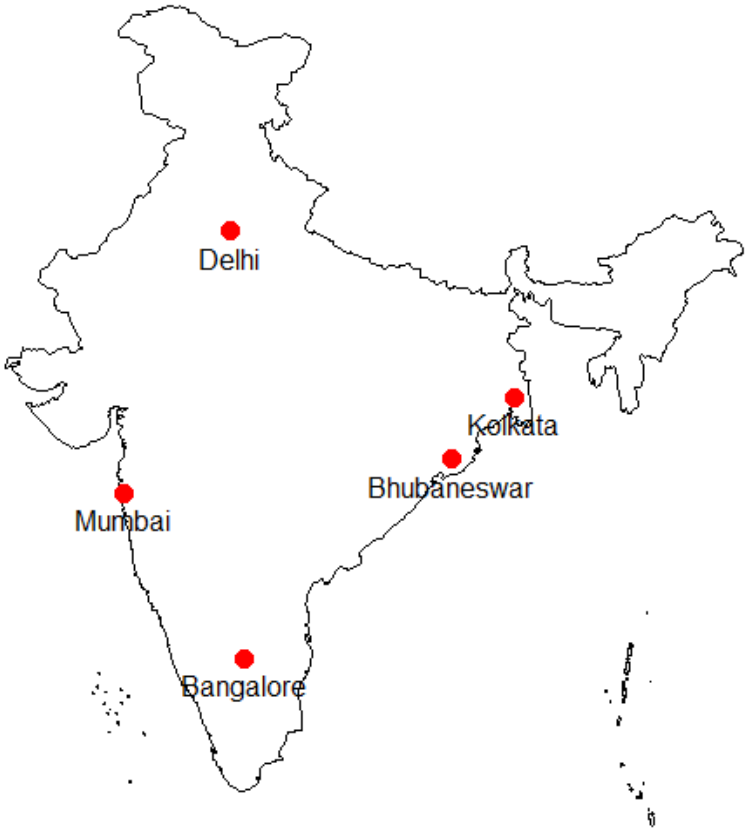
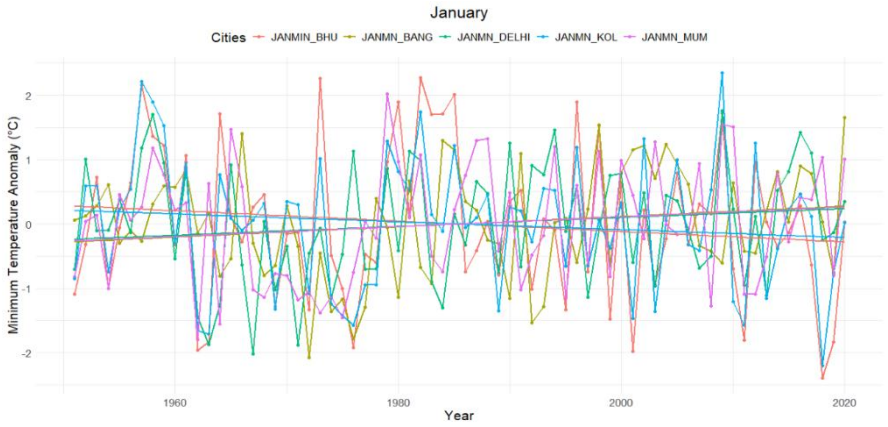
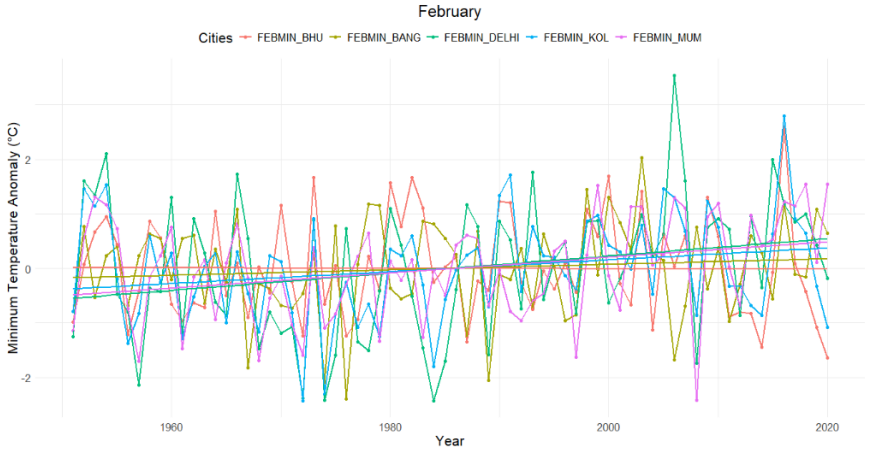


Figure 1: Cities included in this study

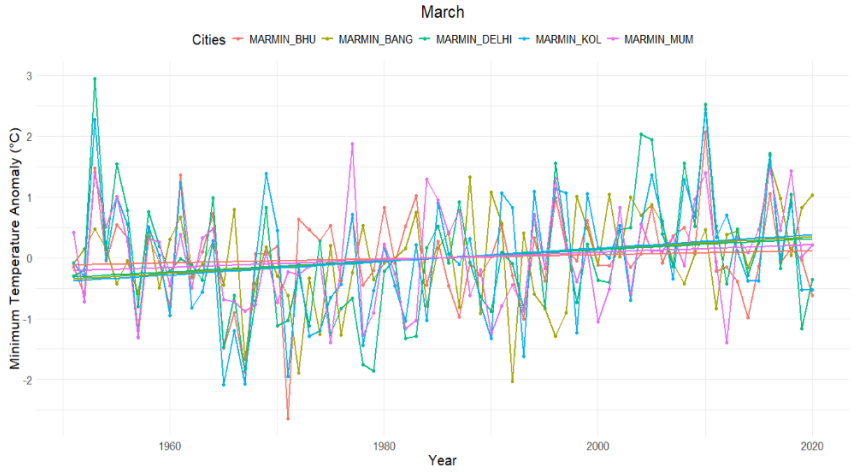
(a)


January
Cities JANMIN_BHU JANMN_BANG JANMN_DELHI JANMN_KOL JANMN_MUM
Minimum Temperature Anomaly (°C)
2
1
0
-1
-2
1960
1980
2000
2020
Year

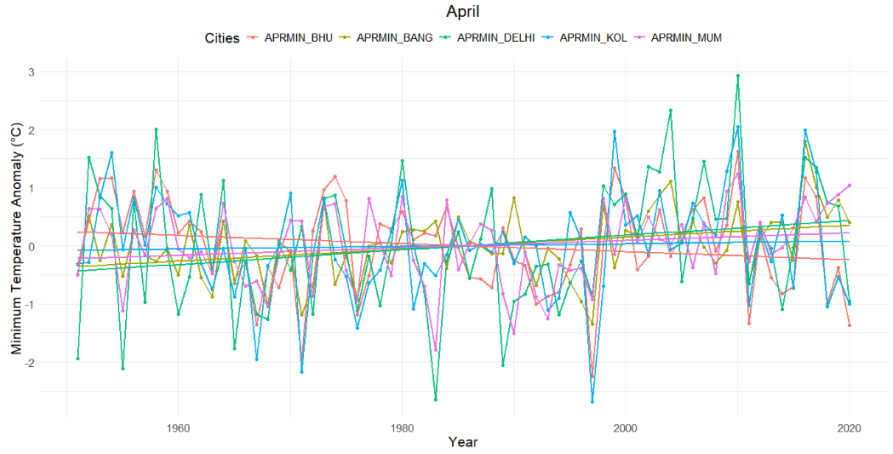
(b)


February
Cities FEBMIN_BHU FEBMIN_BANG FEBMIN_DELHI FEBMIN_KOL FEBMIN_MUM
Minimum Temperature Anomaly (°C)
2
0
-2
1960
1980
2000
2020
Year

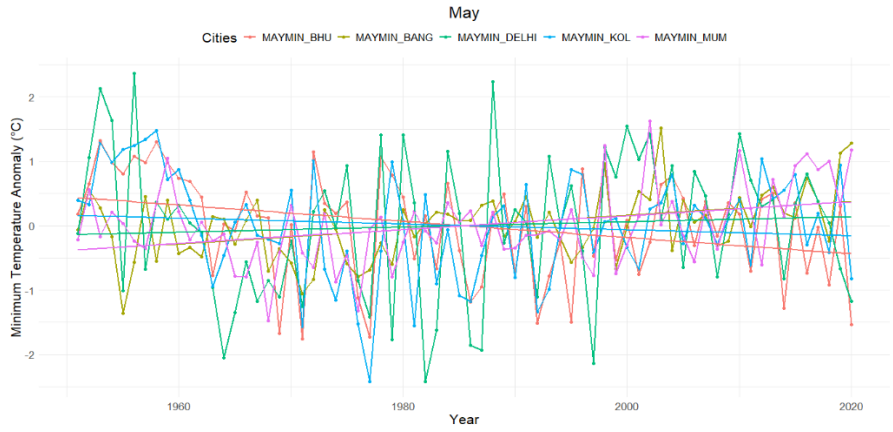
(c)


March
Cities MARMIN_BHU MARMIN_BANG MARMIN_DELHI MARMIN_KOL MARMIN_MUM
Minimum Temperature Anomaly (°C)
3
2
1
0
-1
-2
1960
1980
2000
2020
Year

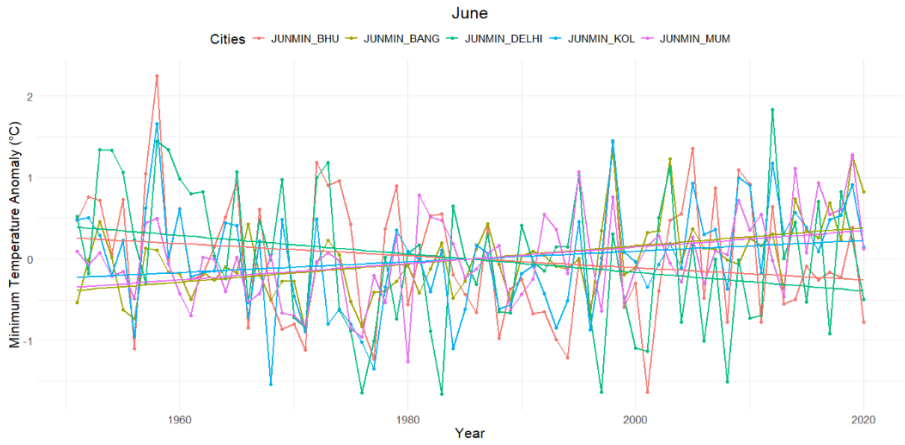
(d)


April
Cities APRMIN_BHU APRMIN_BANG APRMIN_DELHI APRMIN_KOL APRMIN_MUM
Minimum Temperature Anomaly (°C)
3
2
1
0
-1
-2
1960
1980
2000
2020
Year

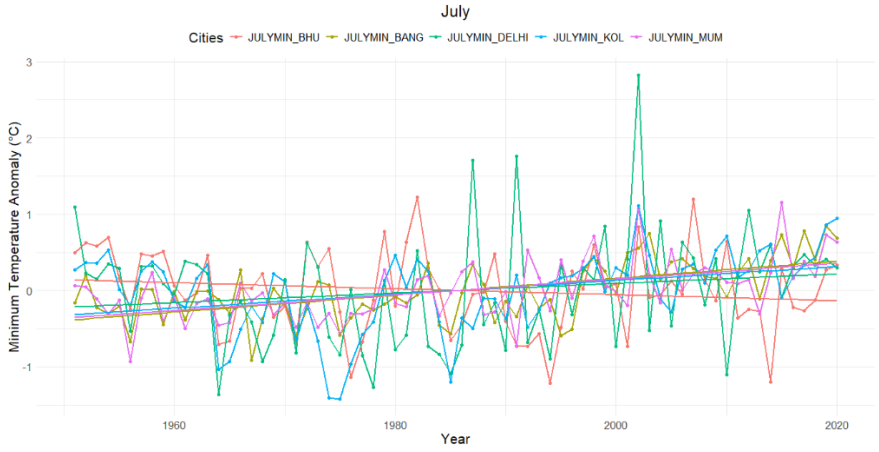
(e)


May
Cities MAYMIN_BHU MAYMIN_BANG MAYMIN_DELHI MAYMIN_KOL MAYMIN_MUM
Minimum Temperature Anomaly (°C)
2
1
0
-1
-2
1960
1980
2000
2020
Year

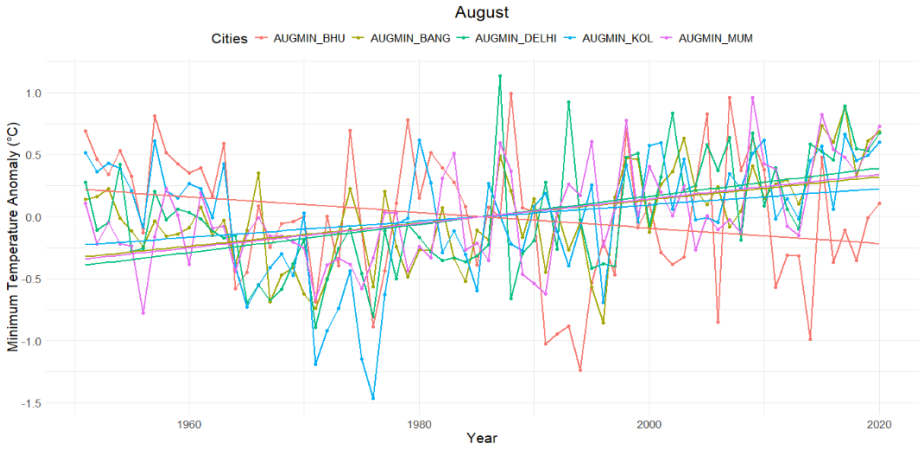
(f)


June
Cities JUNMIN_BHU JUNMIN_BANG JUNMIN_DELHI JUNMIN_KOL JUNMIN_MUM
Minimum Temperature Anomaly (°C)
2
1
0
-1
1960
1980
2000
2020
Year

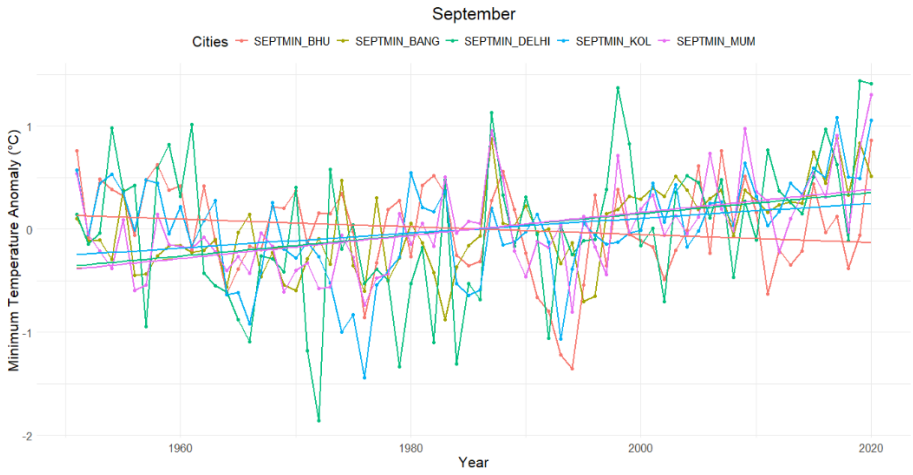
(g)


July
Cities JULYMIN_BHU JULYMIN_BANG JULYMIN_DELHI JULYMIN_KOL JULYMIN_MUM
Minimum Temperature Anomaly (°C)
3
2
1
0
-1
1960
1980
2000
2020
Year

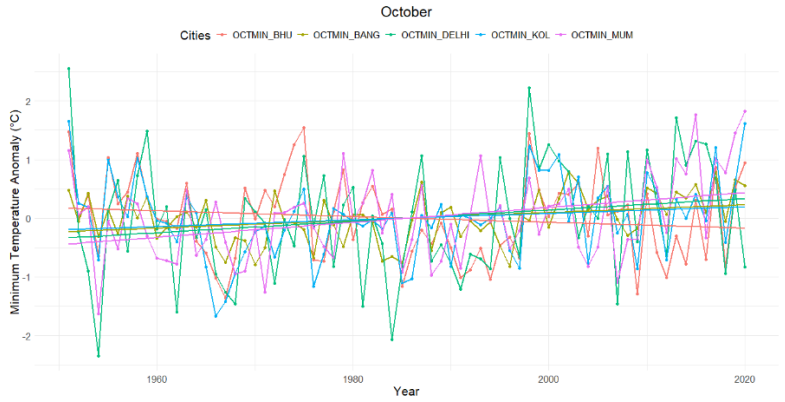
(h)


August
Cities AUGMIN_BHU AUGMIN_BANG AUGMIN_DELHI AUGMIN_KOL AUGMIN_MUM
Minimum Temperature Anomaly (°C)
1.0
0.5
0.0
-0.5
-1.0
-1.5
1960
1980
2000
2020
Year

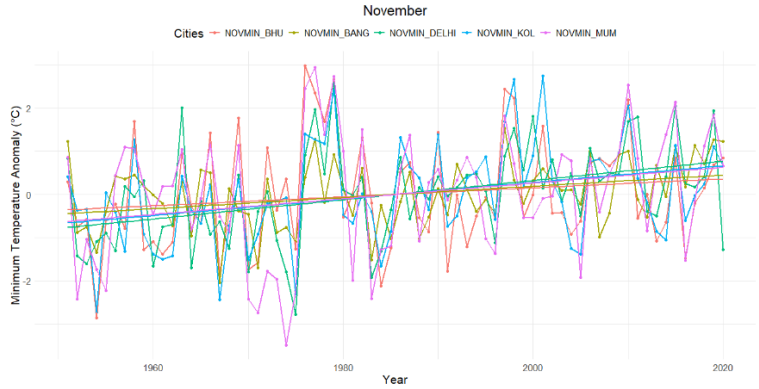
(i)


September
Cities SEPTMIN_BHU SEPTMIN_BANG SEPTMIN_DELHI SEPTMIN_KOL SEPTMIN_MUM
Minimum Temperature Anomaly (°C)
1
0
-1
-2
1960
1980
2000
2020
Year

(j)



(k)



(l)

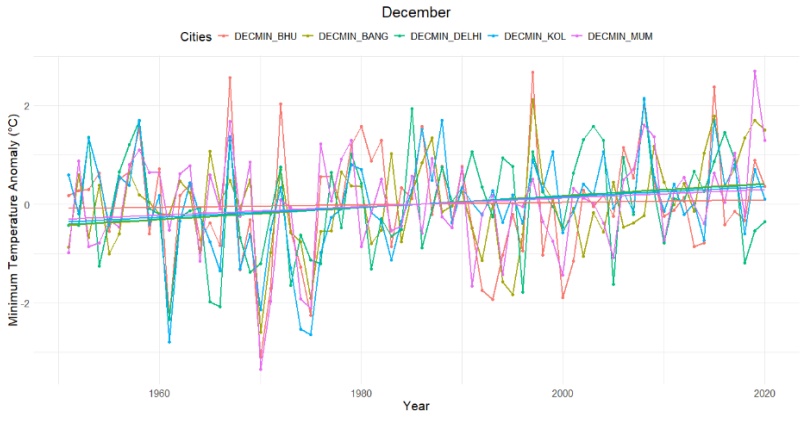
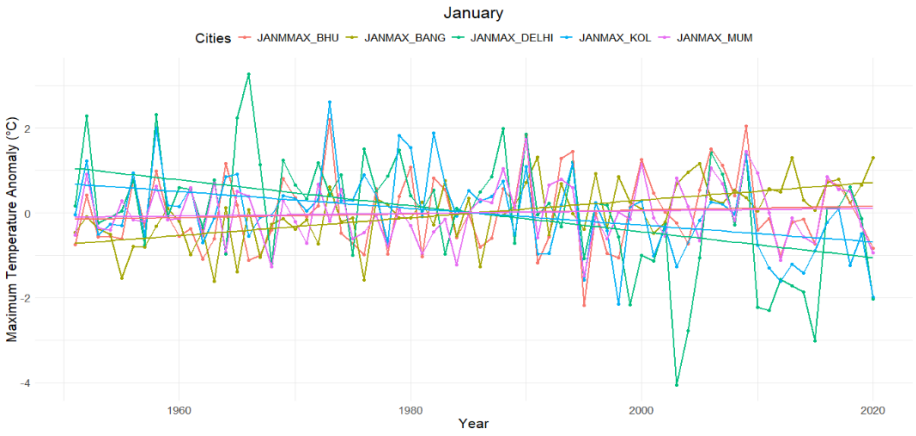
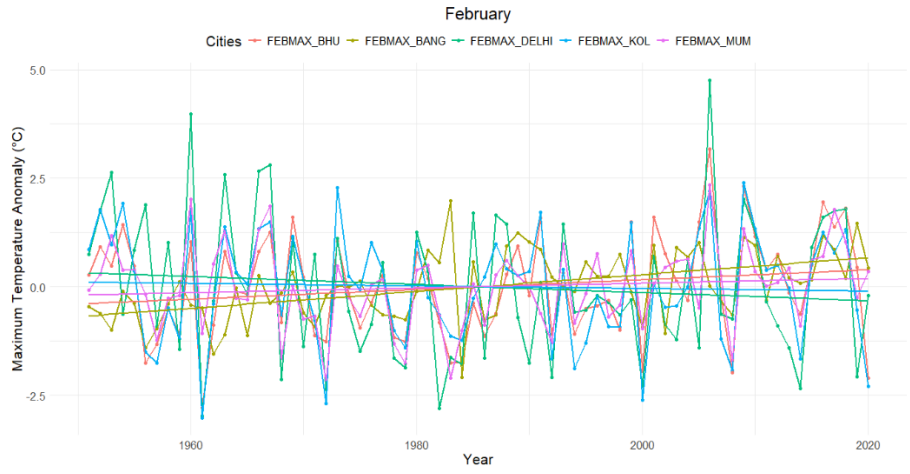


Figure 2: Anomalies of annual ave min temp (^{0} C) during the months of five metro cities of India over the period 1951-2020

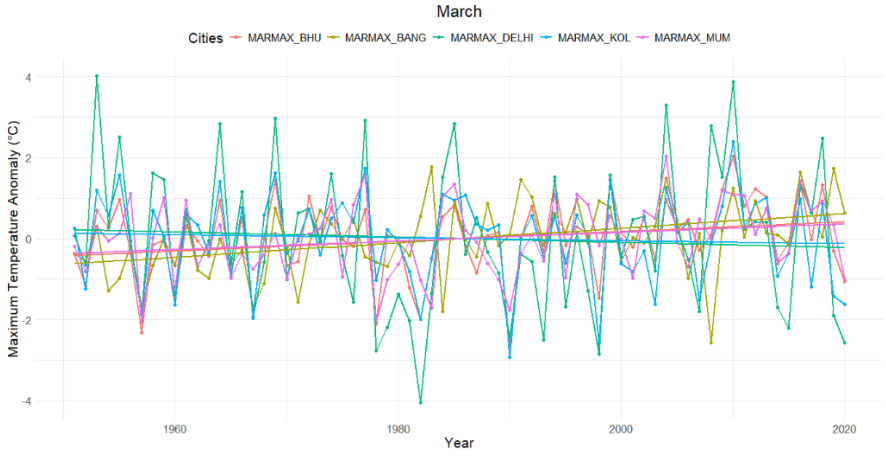
(a)


January
Cities JANMMAX_BHU JANMAX_BANG JANMAX_DELHI JANMAX_KOL JANMAX_MUM
Maximum Temperature Anomaly (°C)
2
0
-2
-4
1960
1980
2000
2020
Year

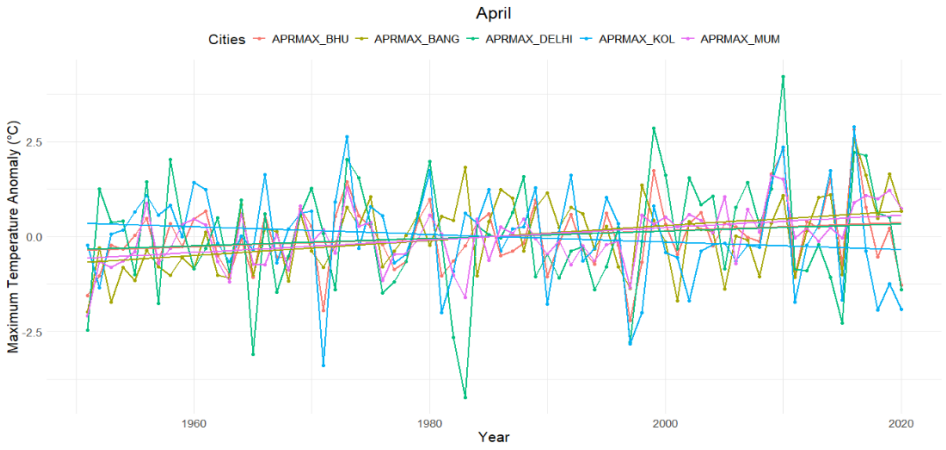
(b)


February
Cities FEBMAX_BHU FEBMAX_BANG FEBMAX_DELHI FEBMAX_KOL FEBMAX_MUM
Maximum Temperature Anomaly (°C)
5.0
2.5
0.0
-2.5
1960
1980
2000
2020
Year

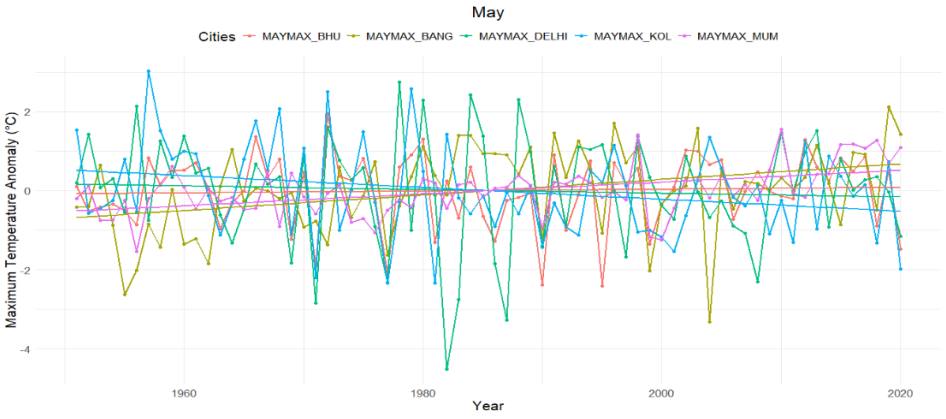
(c)


March
Cities MARMAX_BHU MARMAX_BANG MARMAX_DELHI MARMAX_KOL MARMAX_MUM
Maximum Temperature Anomaly (°C)
4
2
0
-2
-4
1960
1980
2000
2020
Year

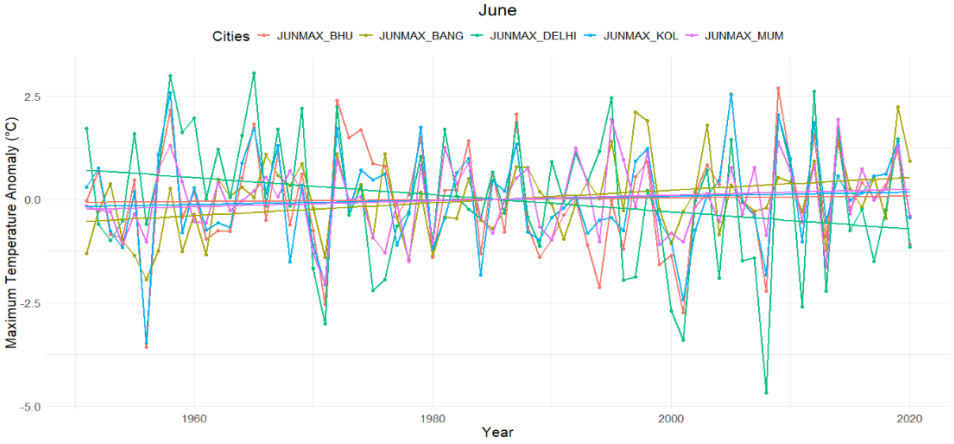
(d)


April
Cities APRMAX_BHU APRMAX_BANG APRMAX_DELHI APRMAX_KOL APRMAX_MUM
Maximum Temperature Anomaly (°C)
2.5
0.0
-2.5
1960
1980
2000
2020
Year

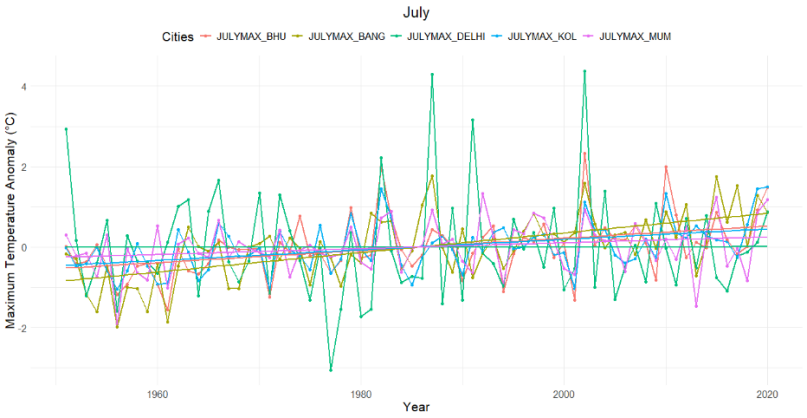
(e)


May
Cities MAYMAX_BHU MAYMAX_BANG MAYMAX_DELHI MAYMAX_KOL MAYMAX_MUM
Maximum Temperature Anomaly (°C)
2
0
-2
-4
1960
1980
2000
2020
Year

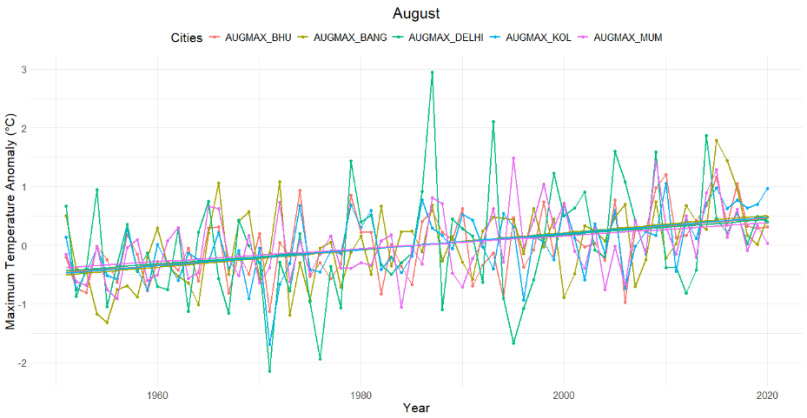
(f)


June
Cities JUNMAX_BHU JUNMAX_BANG JUNMAX_DELHI JUNMAX_KOL JUNMAX_MUM
Maximum Temperature Anomaly (°C)
2.5
0.0
-2.5
-5.0
1960
1980
2000
2020
Year

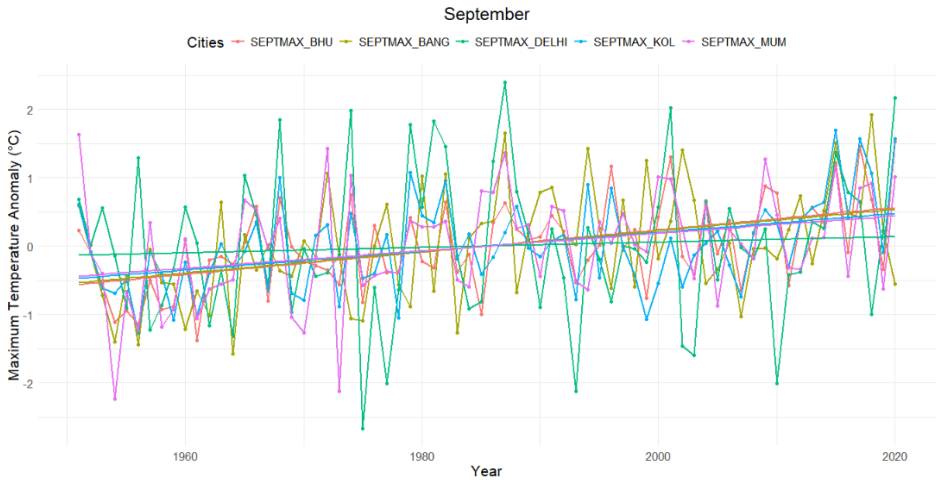
(g)


July
Cities JULYMAX_BHU JULYMAX_BANG JULYMAX_DELHI JULYMAX_KOL JULYMAX_MUM
Maximum Temperature Anomaly (°C)
4
2
0
-2
1960
1980
2000
2020
Year

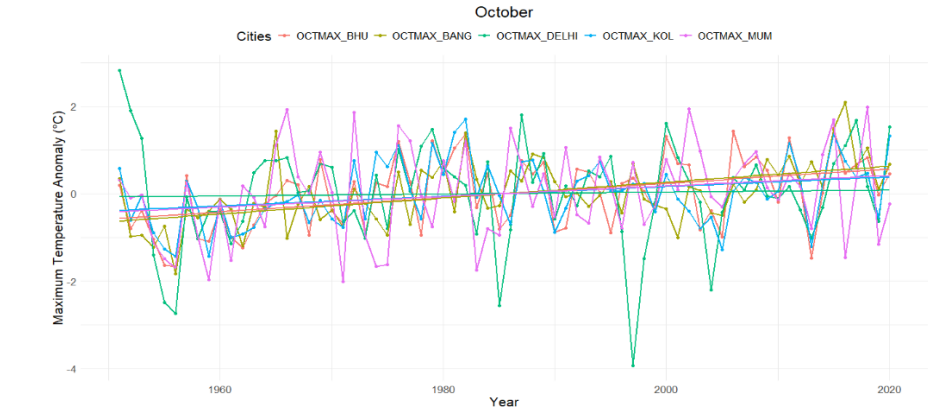
(h)


August
Cities AUGMAX_BHU AUGMAX_BANG AUGMAX_DELHI AUGMAX_KOL AUGMAX_MUM
Maximum Temperature Anomaly (°C)
3
2
1
0
-1
-2
1960
1980
2000
2020
Year

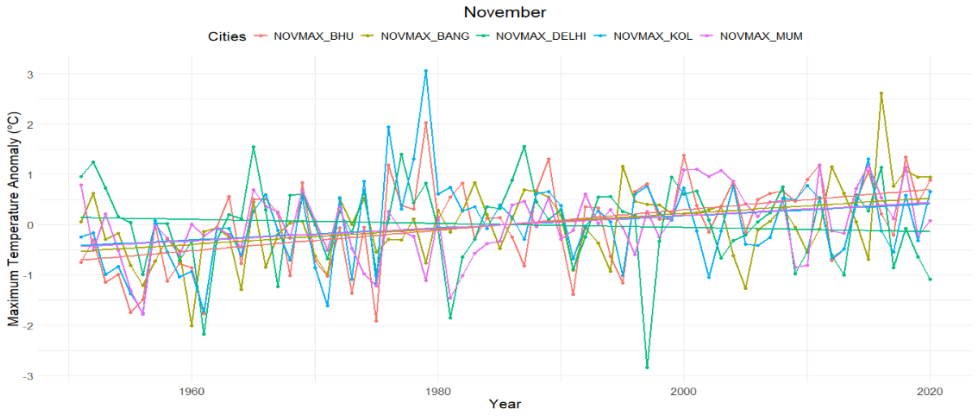
(i)


September
Cities SEPTMAX_BHU SEPTMAX_BANG SEPTMAX_DELHI SEPTMAX_KOL SEPTMAX_MUM
Maximum Temperature Anomaly (°C)
2
1
0
-1
-2
1960
1980
2000
2020
Year

(j)



(k)



(l)

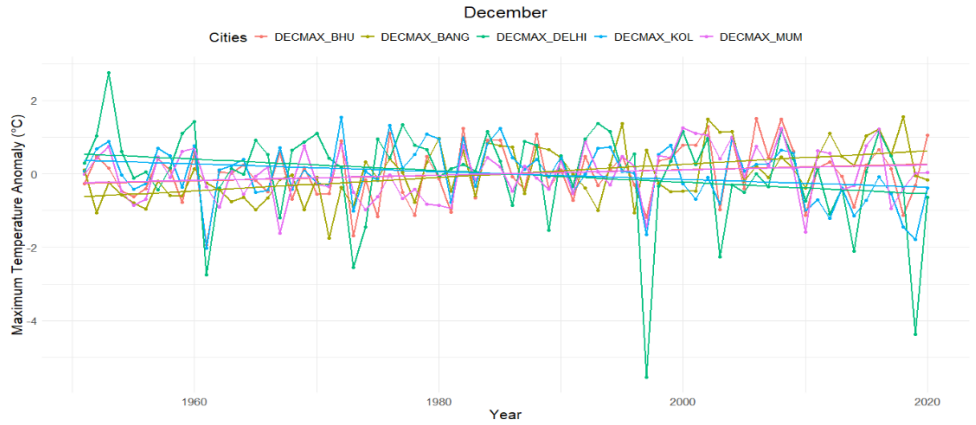
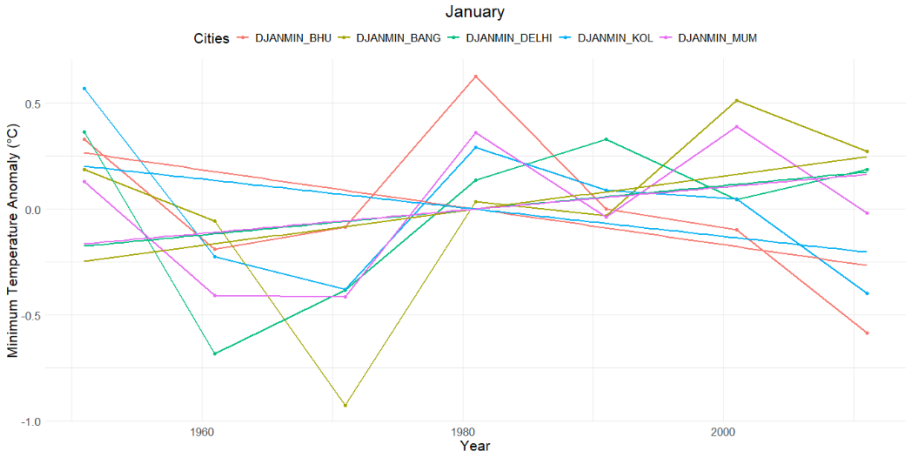
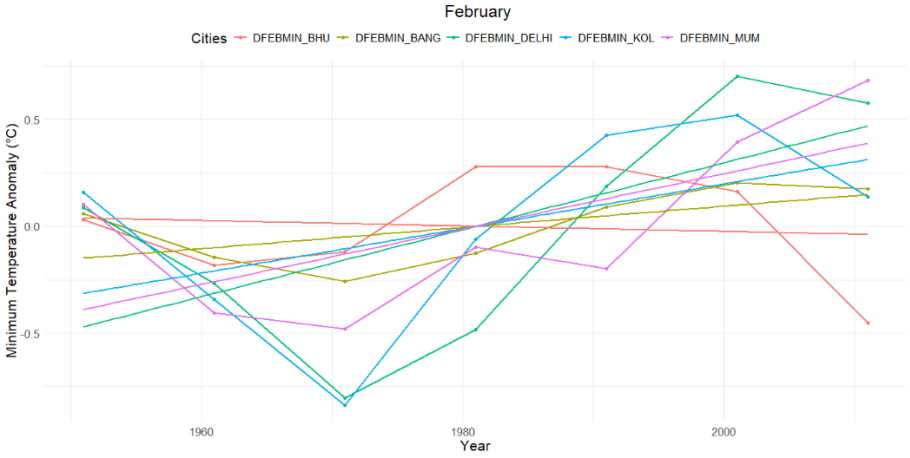


Figure 3: Anomalies of annual Ave max temp (^{0} C) during the months of five metro cities of India over the period 1951-2020

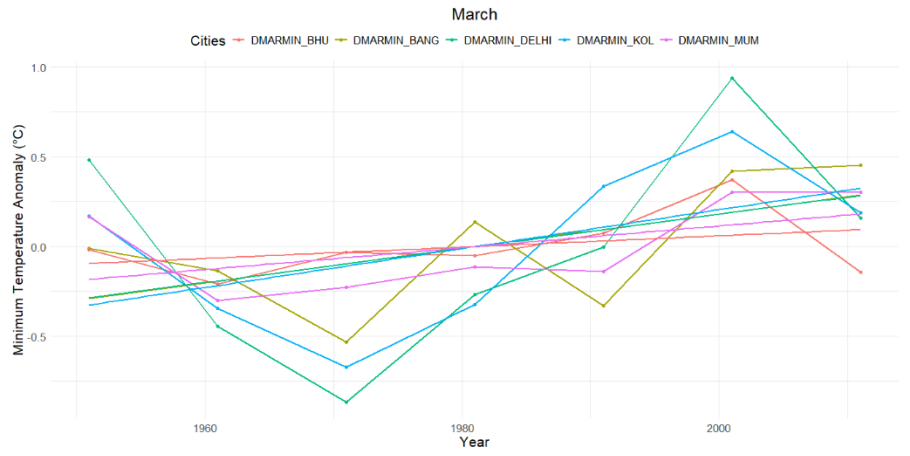
(a)


January
Cities DJANMIN_BHU DJANMIN_BANG DJANMIN_DELHI DJANMIN_KOL DJANMIN_MUM
Minimum Temperature Anomaly (°C)
0.5
0.0
-0.5
-1.0
1960
1980
2000
Year

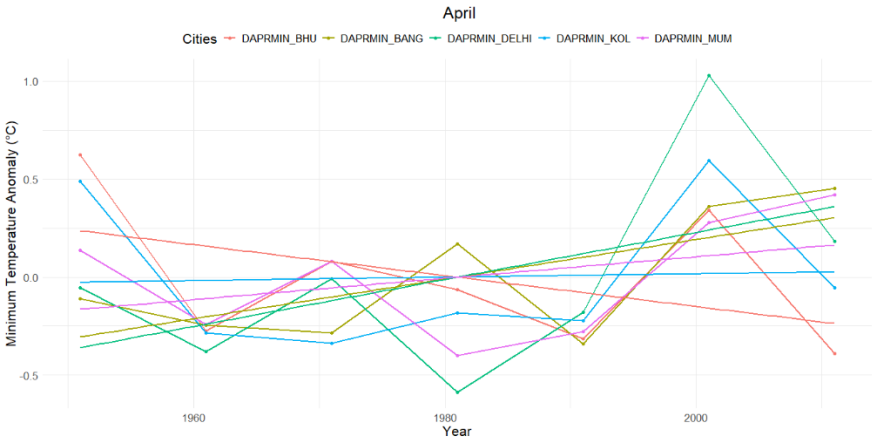
(b)


February
Cities DFEBMIN_BHU DFEBMIN_BANG DFEBMIN_DELHI DFEBMIN_KOL DFEBMIN_MUM
Minimum Temperature Anomaly (°C)
0.5
0.0
-0.5
1960
1980
2000
Year

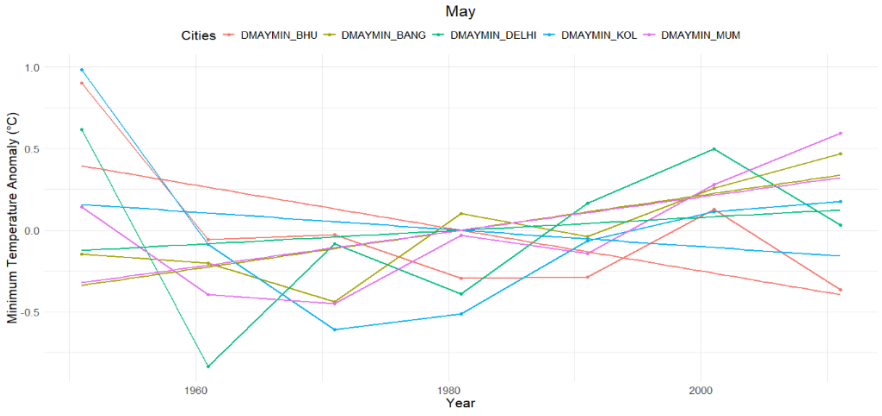
(c)


March
Cities DMARMIN_BHU DMARMIN_BANG DMARMIN_DELHI DMARMIN_KOL DMARMIN_MUM
Minimum Temperature Anomaly (°C)
1.0
0.5
0.0
-0.5
1960
1980
2000
Year

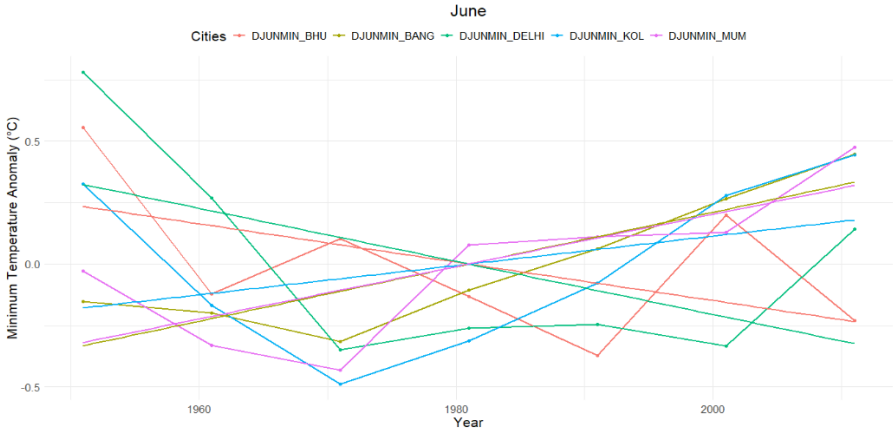
(d)


April
Cities DAPRMIN_BHU DAPRMIN_BANG DAPRMIN_DELHI DAPRMIN_KOL DAPRMIN_MUM
Minimum Temperature Anomaly (°C)
1.0
0.5
0.0
-0.5
1960
1980
2000
Year

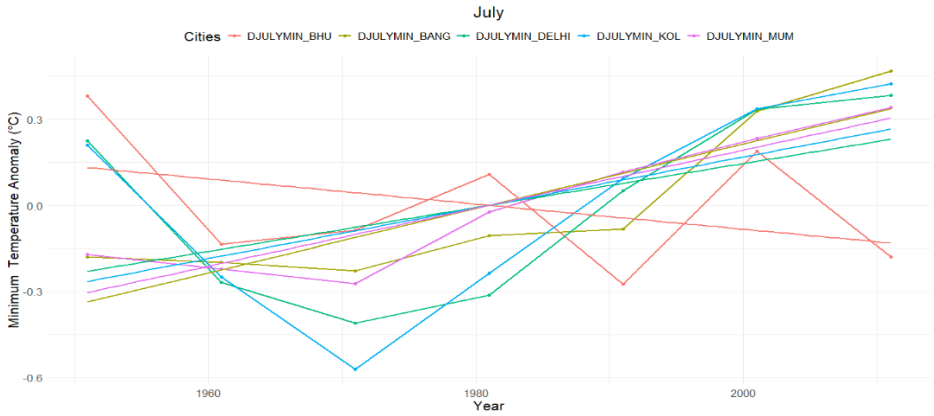
(e)


May
Cities DMAYMIN_BHU DMAYMIN_BANG DMAYMIN_DELHI DMAYMIN_KOL DMAYMIN_MUM
Minimum Temperature Anomaly (°C)
1.0
0.5
0.0
-0.5
1960
1980
2000
Year

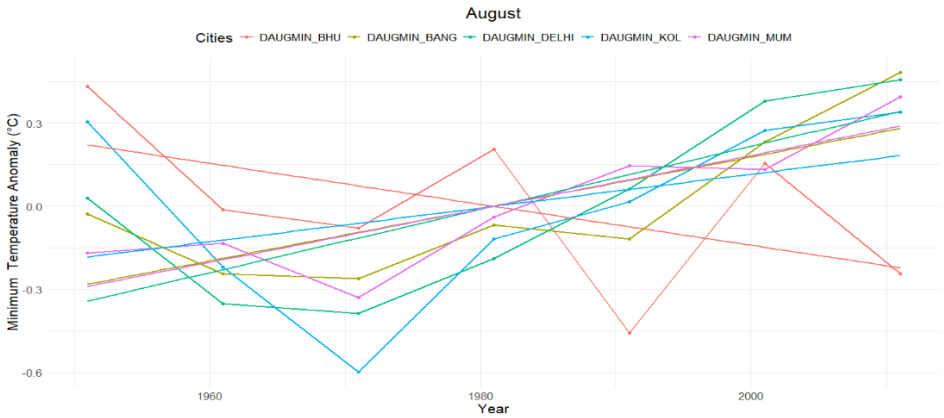
(f)


June
Cities DJUNMIN_BHU DJUNMIN_BANG DJUNMIN_DELHI DJUNMIN_KOL DJUNMIN_MUM
Minimum Temperature Anomaly (°C)
0.5
0.0
-0.5
1960
1980
2000
Year

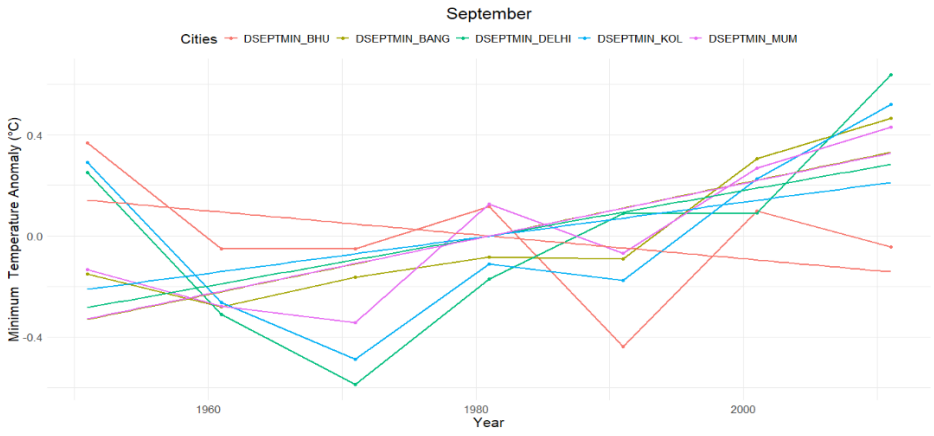
(g)


July
Cities DJULYMIN_BHU DJULYMIN_BANG DJULYMIN_DELHI DJULYMIN_KOL DJULYMIN_MUM
Minimum Temperature Anomaly (°C)
0.3
0.0
-0.3
-0.6
1960
1980
2000
Year

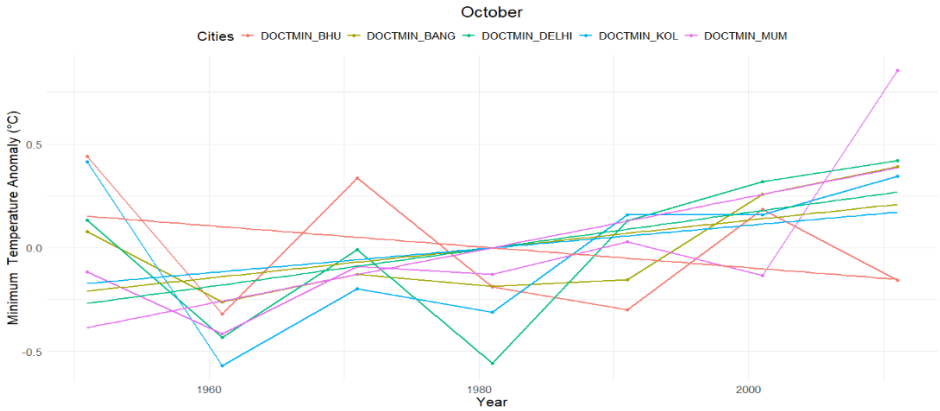
(h)


August
Cities DAUGMIN_BHU DAUGMIN_BANG DAUGMIN_DELHI DAUGMIN_KOL DAUGMIN_MUM
Minimum Temperature Anomaly (°C)
0.3
0.0
-0.3
-0.6
1960
1980
2000
Year

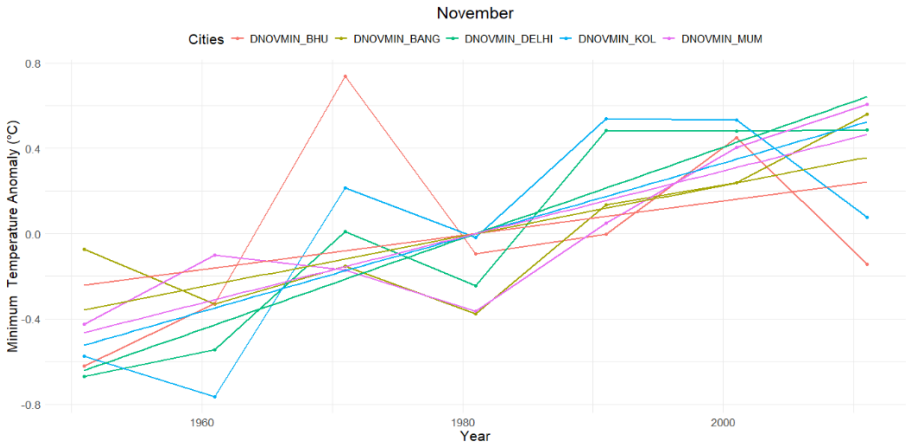
(i)


September
Cities DSEPTMIN_BHU DSEPTMIN_BANG DSEPTMIN_DELHI DSEPTMIN_KOL DSEPTMIN_MUM
Minimum Temperature Anomaly (°C)
0.4
0.0
-0.4
1960
1980
2000
Year

(j)



(k)



(l)

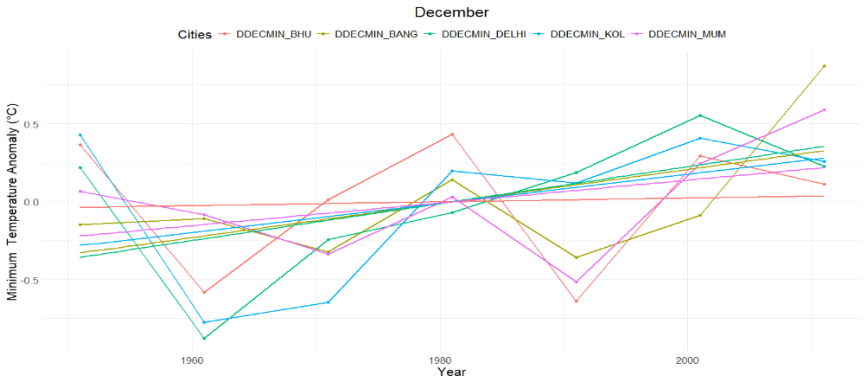
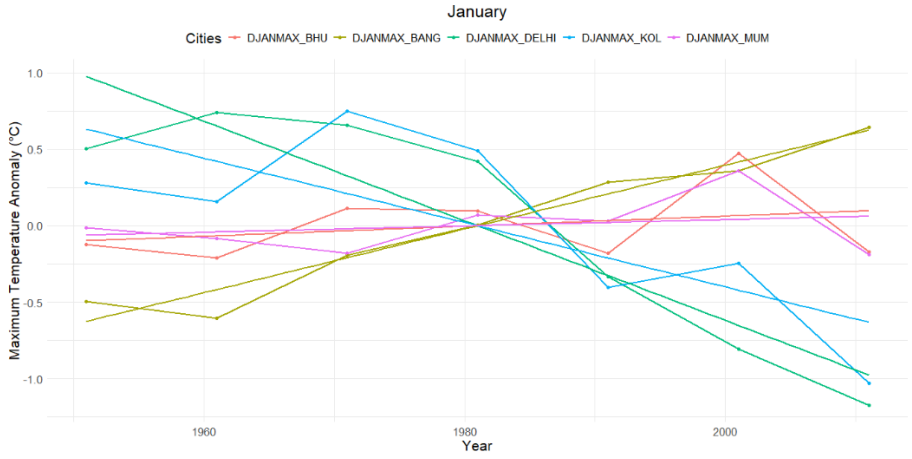
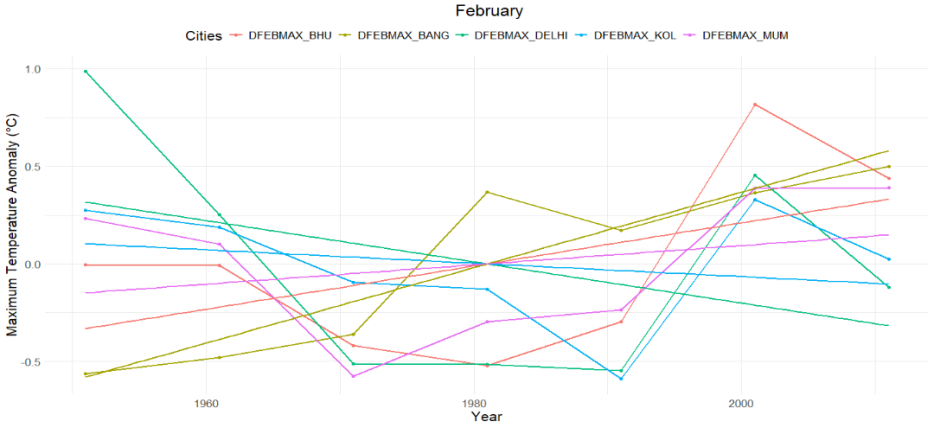


Figure 4: Anomalies of decadal ave min temp (^{0} C) during the months of five metro cities of India over the period 1951-2020

(a)

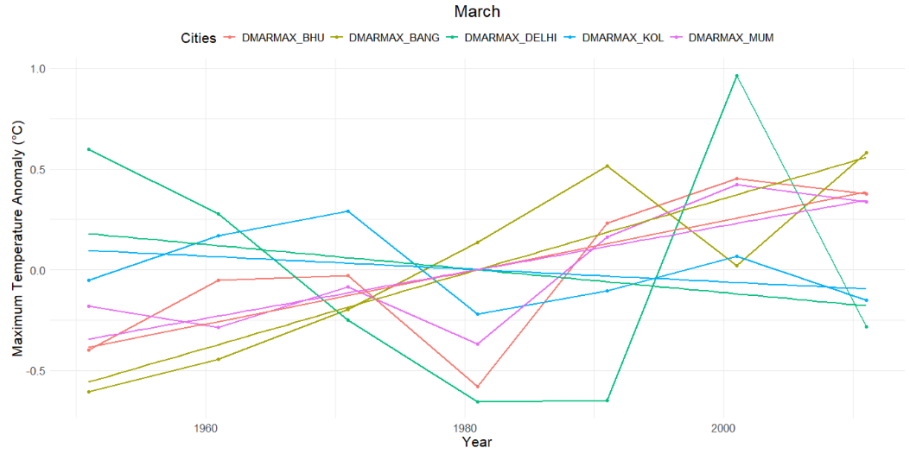

January
Cities DJANMAX_BHU DJANMAX_BANG DJANMAX_DELHI DJANMAX_KOL DJANMAX_MUM
Maximum Temperature Anomaly (°C)
1.0
0.5
0.0
-0.5
-1.0
1960
1980
2000
Year

(b)

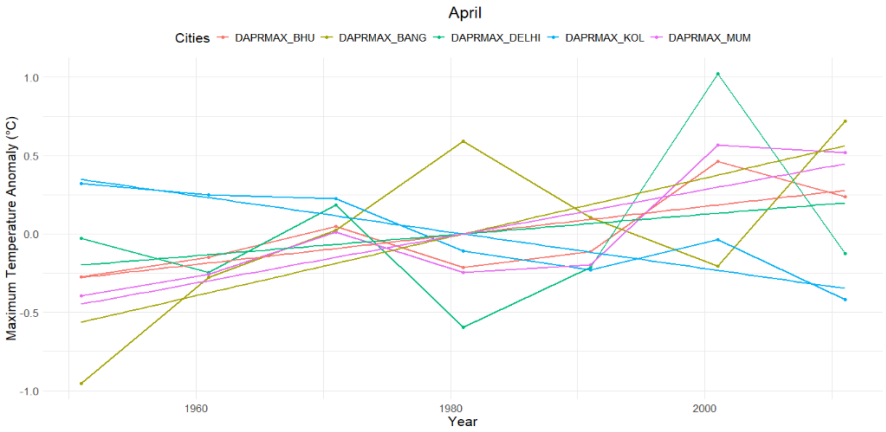

February
Cities DFEBMAX_BHU DFEBMAX_BANG DFEBMAX_DELHI DFEBMAX_KOL DFEBMAX_MUM
Maximum Temperature Anomaly (°C)
1.0
0.5
0.0
-0.5
1960
1980
2000
Year

s

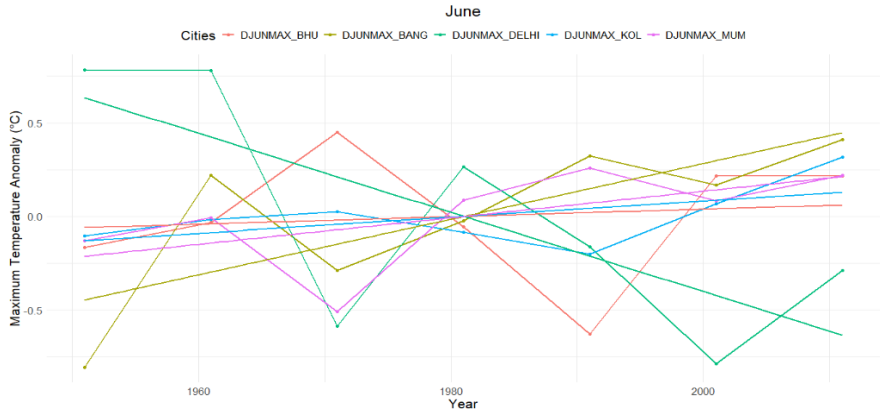
(c)


March
Cities DMARMAX_BHU DMARMAX_BANG DMARMAX_DELHI DMARMAX_KOL DMARMAX_MUM
Maximum Temperature Anomaly (°C)
1.0
0.5
0.0
-0.5
1960
1980
2000
Year

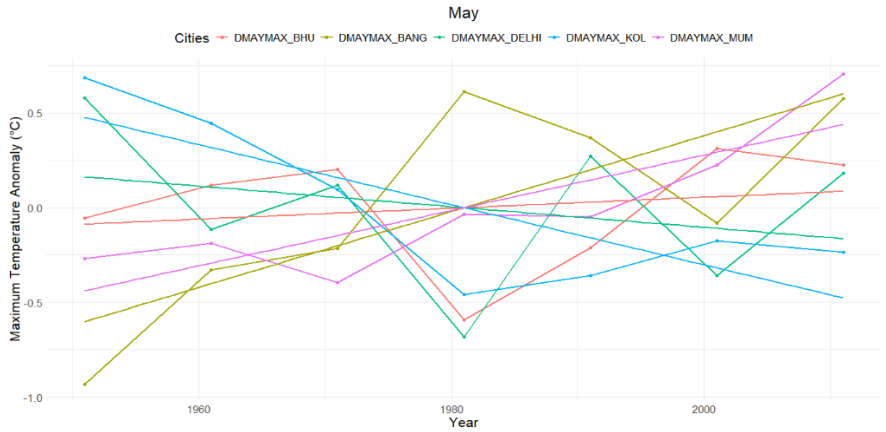
(d)


April
Cities DAPRMAX_BHU DAPRMAX_BANG DAPRMAX_DELHI DAPRMAX_KOL DAPRMAX_MUM
Maximum Temperature Anomaly (°C)
1.0
0.5
0.0
-0.5
-1.0
1960
1980
2000
Year

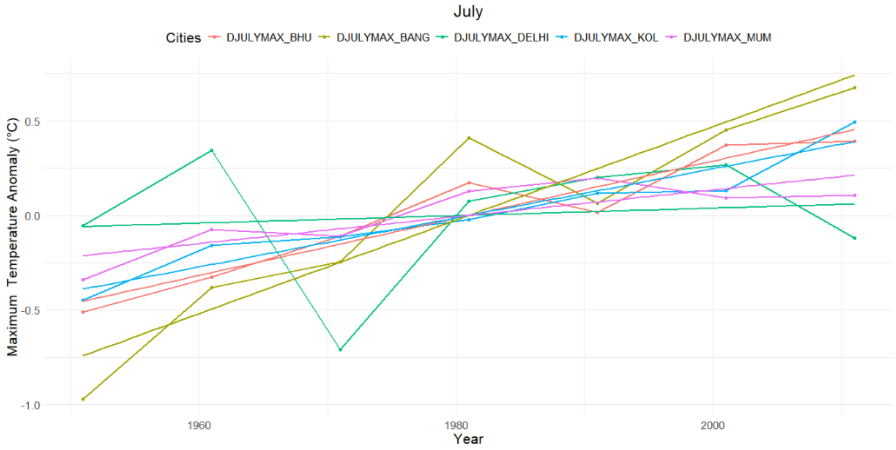
(e)


June
Cities DJUNMAX_BHU DJUNMAX_BANG DJUNMAX_DELHI DJUNMAX_KOL DJUNMAX_MUM
Maximum Temperature Anomaly (°C)
0.5
0.0
-0.5
1960
1980
2000
Year

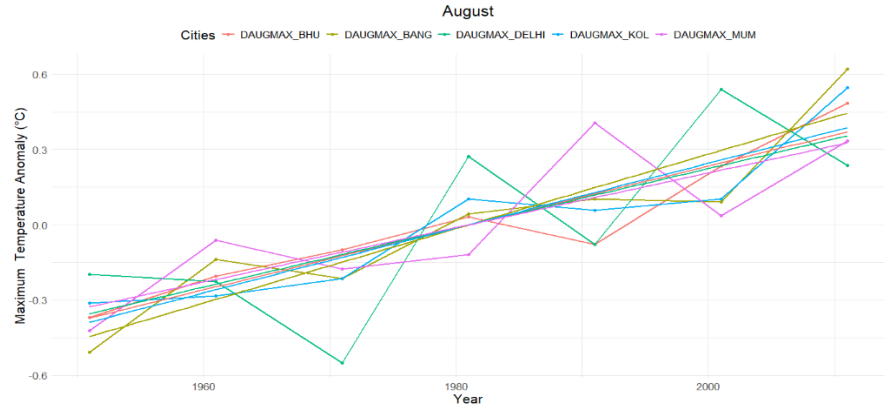
(f)


May
Cities DMAYMAX_BHU DMAYMAX_BANG DMAYMAX_DELHI DMAYMAX_KOL DMAYMAX_MUM
Maximum Temperature Anomaly (°C)
0.5
0.0
-0.5
-1.0
1960
1980
2000
Year

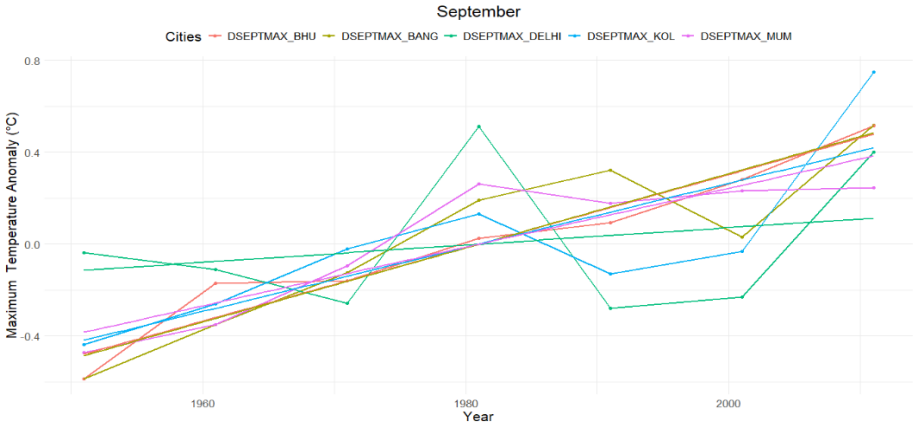
(g)


July
Cities DJULYMAX_BHU DJULYMAX_BANG DJULYMAX_DELHI DJULYMAX_KOL DJULYMAX_MUM
Maximum Temperature Anomaly (°C)
0.5
0.0
-0.5
-1.0
1960
1980
2000
Year

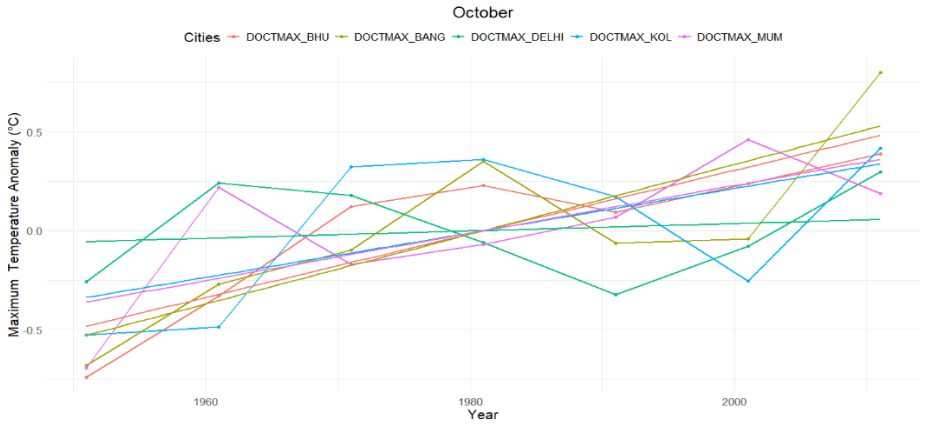
(h)


August
Cities DAUGMAX_BHU DAUGMAX_BANG DAUGMAX_DELHI DAUGMAX_KOL DAUGMAX_MUM
Maximum Temperature Anomaly (°C)
0.6
0.3
0.0
-0.3
-0.6
1960
1980
2000
Year

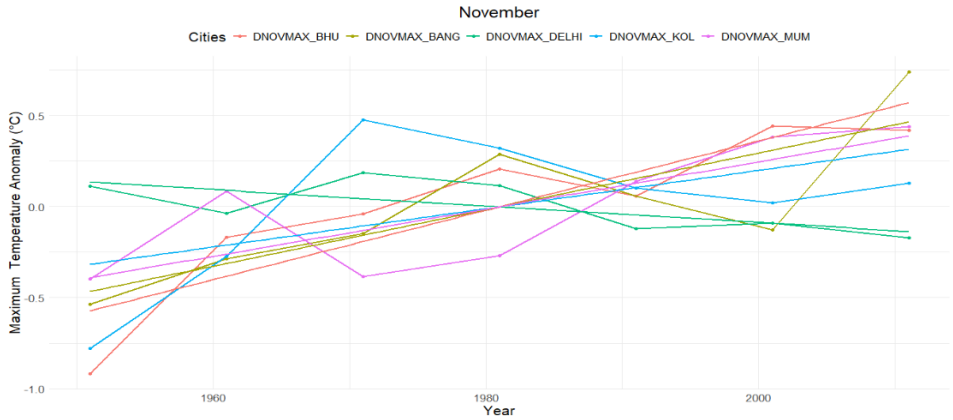
(i)


September
Cities DSEPTMAX_BHU DSEPTMAX_BANG DSEPTMAX_DELHI DSEPTMAX_KOL DSEPTMAX_MUM
Maximum Temperature Anomaly (°C)
0.8
0.4
0.0
-0.4
1960
1980
2000
Year

(j)



(k)



(l)

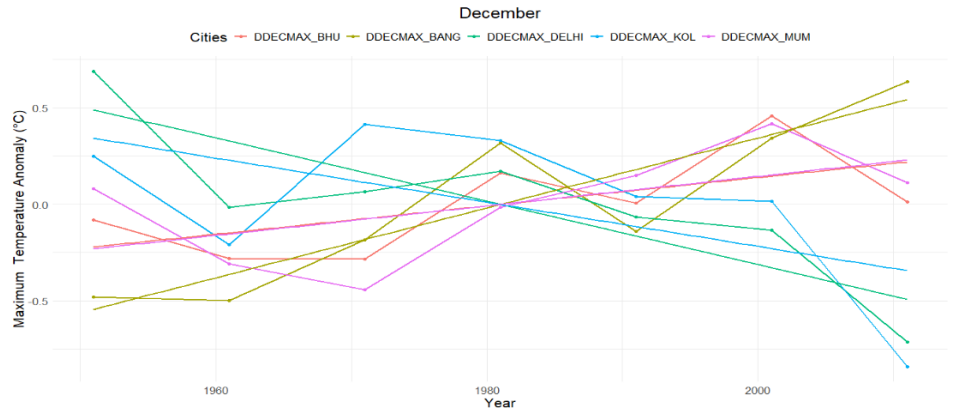
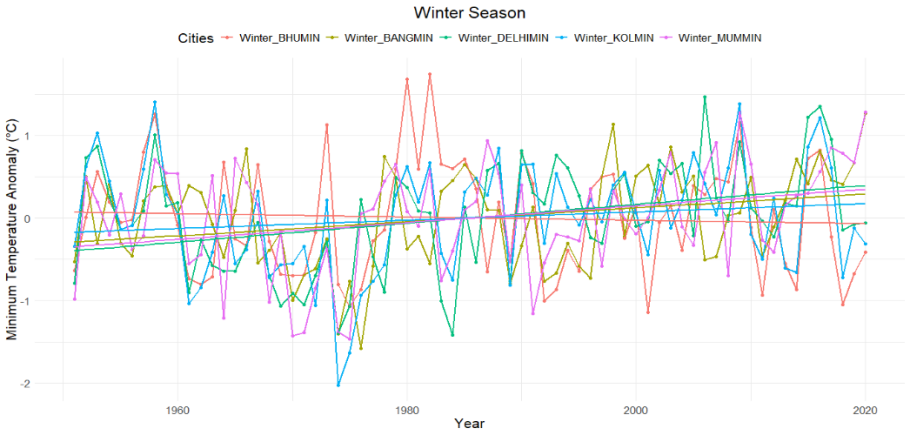
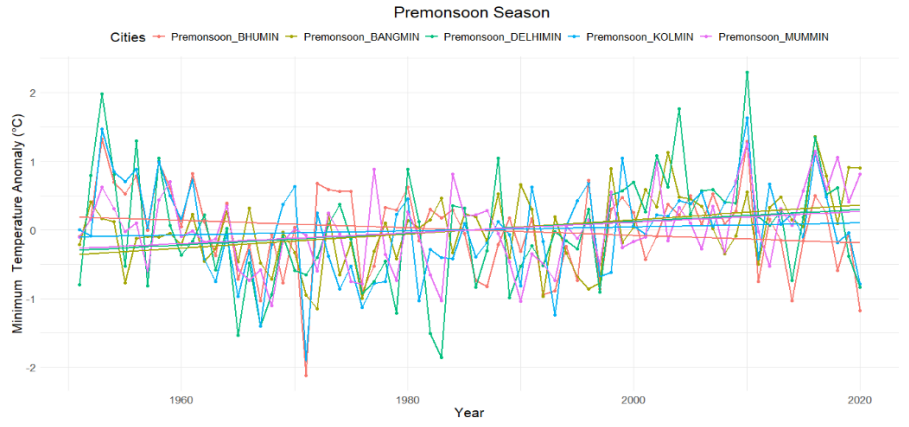


Figure 5: Anomalies of decadal ave max temp (^{0} C) during the months of five metro cities of India over the period 1951-2020

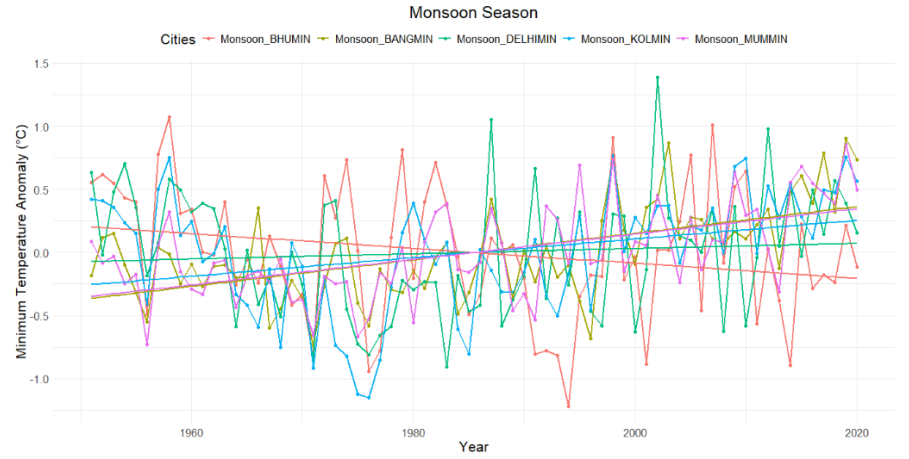
(a)


Winter Season
Cities Winter_BHUMIN Winter_BANGMIN Winter_DELHIMIN Winter_KOLMIN Winter_MUMMIN
Minimum Temperature Anomaly (°C)
1
0
-1
-2
1960
1980
2000
2020
Year

(b)


Premonsoon Season
Cities Premonsoon_BHUMIN Premonsoon_BANGMIN Premonsoon_DELHIMIN Premonsoon_KOLMIN Premonsoon_MUMMIN
Minimum Temperature Anomaly (°C)
2
1
0
-1
-2
1960
1980
2000
2020
Year

(c)


Monsoon Season
Cities Monsoon_BHUMIN Monsoon_BANGMIN Monsoon_DELHIMIN Monsoon_KOLMIN Monsoon_MUMMIN
Minimum Temperature Anomaly (°C)
1.5
1.0
0.5
0.0
-0.5
-1.0
1960
1980
2000
2020
Year

(d)

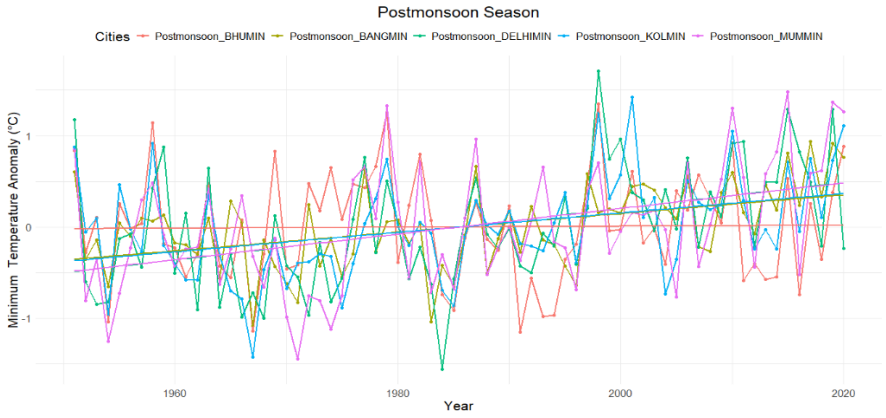
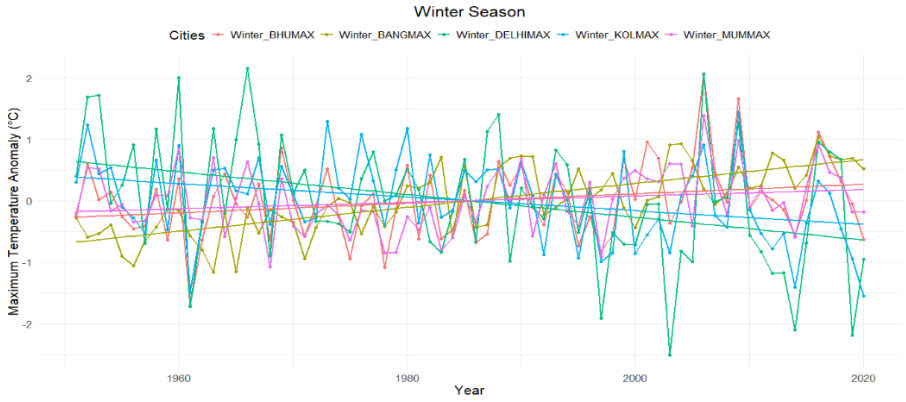
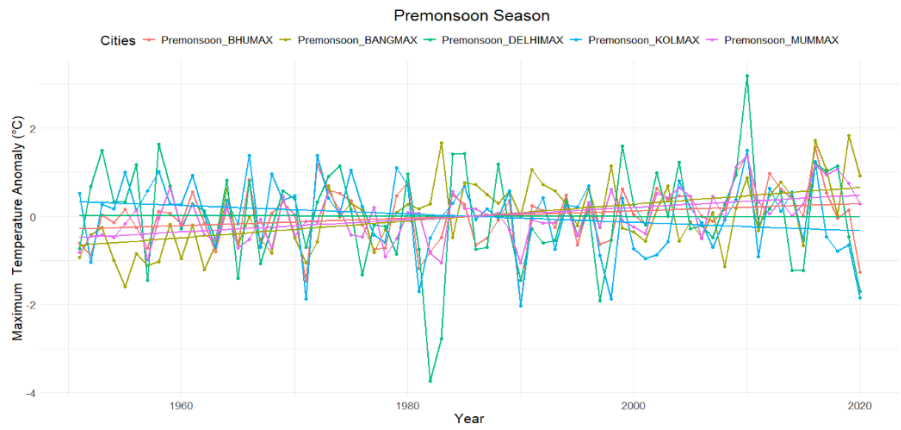


Figure 6: Anomalies of the ave min temp (^{0} C) of five metro cities of India for the seasons (a) Winter, (b) Pre-Monsoon, (c) Monsoon and (d) Post-Monsoon during 1951-2020

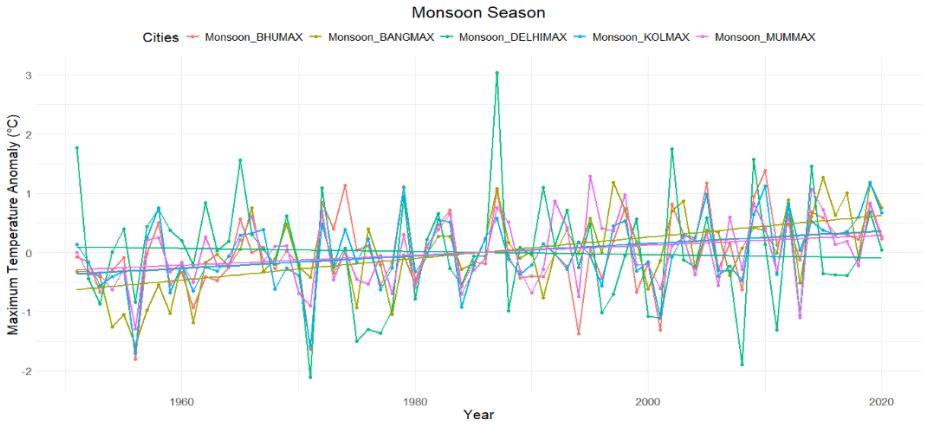
(a)



(b)



(c)



(d)

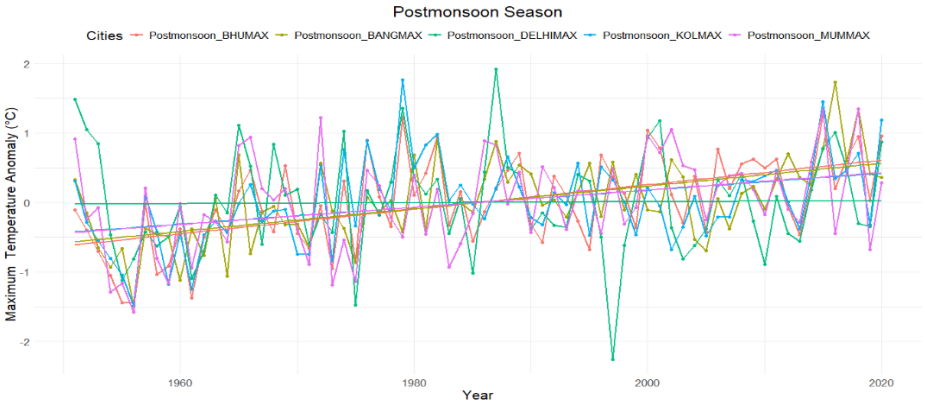


Figure 7: Anomalies of the ave max temp (^{0} C) of five metro cities of India for the seasons (a) Winter, (b) Pre-Monsoon, (c) Monsoon and (d) Post-Monsoon during 1951-2020

ABBREVIATIONS

SST: Sea Surface Temperature

IIPC: Intergovernmental Panel on Climate Change

IMD: India Meteorological Department

LR: Linear Regression

MK Test: Mann Kendall Test

TMIN: Minimum Temperature

TMAX: Maximum Temperature

BHU: Bhubaneswar

BANG: Bangalore

DEL: Delhi

KOL: Kolkata

MUM: Mumbai

JAN: January

FEB: February

MAR; March

APR: April

JUN; June

JUL: July

AUG: August

SEP: September

OCT: October

NOV: November

DEC: December

ACKNOWLEDGMENT

I am grateful to the University Grant Commission, New Delhi, for providing a Non-Net fellowship for this work.

CONFLICT OF INTEREST

The author declares no conflict of interest.

FUNDING SOURCES

The author has received a Non-Net fellowship from Visva Bharati University for this work (Memo No: Aca/149/2021-22/).