MAUSAM, **73**, 1 (January 2022), 193-202

L E T T E R S

551.583 (540.33)

VARIATIONS IN RAINFALL, TEMPERATURES AND THUNDERSTORM OVER KOLKATA (INDIA) IN RECENT DECADES

1. Climate is usually defined as the long-term average of Weather. In a broader sense, it is the statistical description in terms of mean and variability of relevant quantities over a period ranging from months to millions of years (IPCC 2007). Climate change is one of the major challenges in the 21st century around the world. According to scientists' rapid industrialization, urbanization, population explosion and greenhouse gas concentration in the atmosphere are mainly responsible for significant changes in the climatic parameters such as temperature, rainfall, atmospheric pressure, humidity, etc. Among the climatic parameters, temperature and rainfall are the two most important variables to detect the impact of climate change in a region (Cannarozzo *et al*., 2006). Temperature drives the hydrological cycle by influencing hydrological processes directly or indirectly. A warmer climate leads to the intensification of the hydrological cycle resulting in higher rates of evaporation and liquid precipitation, these processes, in association with a shifting pattern of precipitation, will affect the spatial and temporal distribution of runoff, soil moisture, groundwater reserves and increase the frequency of droughts and floods (Arora *et al*., 2005). Therefore the study of temperature and rainfall of a region over a long period and detection of any significant change in these parameters are of particular importance. Various scientists have observed that due climate change in recent years there is a significant rise in extreme events around the world. Scientists have also observed that around the globe large cities are also being affected by the rise of temperature, water scarcity, pollution, etc. In our country, there are a large number of urban agglomerates and which are also facing a similar kind of problem. Urban locations are becoming increasingly vulnerable due to natural hazards related to weather and climate (De *et al*., 2001).

Surface temperature over a region shows a variety of trends in seasonal and annual patterns and is greatly modified by altitude, sea proximity and topographical features (Arora *et al*., 2005). Several studies have been conducted earlier to find the impact of climate change on temperature over urban areas. Among them (Tayanc *et al*., 1997; Chung *et al*., 2004b; Chung *et al*., 2004a; Trusilova *et al*., 2008) found that the increase in annual temperature over urban areas is higher than rural and maritime areas. (Jeganathan *et al*., 2013) reported that there is a rise in maximum, minimum and mean annual temperature over Chennai city due to climate change, overpopulation and industrialization, (Gadgil *et al*., 2005) observed a decrease in mean annual temperature over Pune due to the increase in the amount of Suspended Particulate Matter (SPM) in the ambient air, (Dhodre *et al*., 2009) observed a rise in the annual maximum temperature over Mumbai and Kolkata, (Hingane, 1996) estimated rising trends of mean annual temperature over Kolkata and Mumbai, (Jagannathan *et al*., 1973) reported an increase in mean annual temperature over Kolkata, Mumbai, Bangalore and Allahabad, (Tigga *et al*., 2011) found rising annual mean maximum temperature, lowering annual mean minimum temperature over Ranchi city.

The rainfall received over an area is an important factor in determining the amount of water available to meet various demands such as agricultural, industrial, domestic water supply and hydroelectric generation (Panda *et al*., 2019). Summer monsoon in India gives almost 80% of the total rainfall but monsoon rainfall in India is very erratic and highly unpredictable. Many studies over different parts of India have been conducted to study the Indian Summer Monsoon Rainfall (ISMR) and particularly to detect trends in monsoon rainfall. (Sarker *et al*., 1988; Thapliyal *et al*., 1991; Lal, 2001; Sinha Ray *et al*., 2003) concluded that at the all-India level there is no apparent trend of increase or decrease in average annual rainfall. (Koteswaram *et al*., 1969; Jagannathan *et al*., 1973; Raghavendra, 1974; Dash *et al*., 2007; Bhutiyani *et al*., 2010) observed significant fluctuations in long-term rainfall over certain pockets in India. (Panda *et al*., 2019) showed an increasing trend of annual rainfall over the Kalahandi, Koraput and Bolangir districts. (Ghosh, 2018) showed that Gangetic West Bengal (GWB) shows an overall increase in mean annual rainfall and an insequential increase in summer monsoon rainfall.

Most of the above studies are mainly focused on a country scale or regional scale but not at a local scale. The present study aims to find out the climate change impacts on temperature and rainfall at a local scale which is more relevant to devise specific development and adaptation plans to mitigate the negative effects of climate change.

This study is focused on the metro city Kolkata. This city is the home of 14617882 people according to the census 2011. There are many small and large industries surrounding this city. This city is growing rapidly and new constructions are in full swing. Over the years this city has witnessed many changes and it may or may not affect the climatic parameters of this city, therefore this study was undertaken to introspect the changes in climatic parameters. In this study besides studying the variations in temperature and rainfall, variations in the number of thunderstorm days have also been observed.

2. *Study area and data* : The study area is Kolkata, the capital of West Bengal, situated in the eastern part of India as pointed in Fig. 1. To study the temperature, rainfall and thunderstorm variability, daily maximum, minimum temperature, rainfall and thunderstorm data of Alipore Observatory (Lat. = 22°32', Long. = 88°20') for the period 1969-2020 have collected from National Data Centre (NDC) Pune (IMD) and Regional Meteorological Centre (RMC) Kolkata (IMD). Also the same has been collected from nearby two meteorological stations namely Canning (Lat. = 22°18', Long. = 88°39') and Diamond Harbour (Lat = 22°11', Long = 88°10') for the period 1982-2018 for comparison purposes. From maximum and minimum temperature mean, standard deviations (SV) and coefficient of variations (CV) have been calculated. The daily mean temperature has been calculated by taking the averages of daily maximum and minimum temperatures. Data for the Spatio-temporal land-use and land-cover pattern of Kolkata for the period 1991-2018 have been taken from the work of (Mandal *et al*., 2019).

2.1. *Man Kendall test* : To detect trends in temperature, rainfall and thunderstorm, the M-K test has been used. This test was suggested by (Mann, 1945). This is commonly used to detect monotonic trends in a time series. This is a non-parametric trend detection method and does not require the data to be normally distributed. This test has low sensitivity to abrupt breaks due to inhomogeneous time series. The equation of the M-K test is :

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(X_j - X_i\right) \quad (1)$$

where, n is the number of data points, x_i and x_j are the data values in the time series, i and j ($I < j$), respectively and sgn (x_j-x_i) is the sign function as:

$$\operatorname{sgn}\left(X_j - X_i\right) = \begin{cases} +1 \text{ if } \left(X_i - X_j\right) > 0 \\ 0 \text{ if } \left(X_i - X_j\right) = 0 \\ +1 \text{ if } \left(X_i - X_j\right) < 0 \end{cases} \quad (2)$$

A high positive value of S signifies an increasing trend and a negative value signifies a decreasing trend.

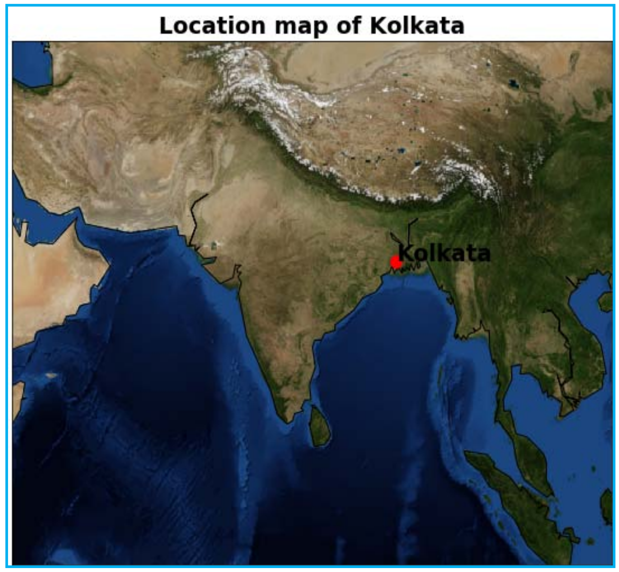


Fig. 1. Location map of Kolkata

The variance is computed as :

$$\operatorname{Var}(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=1}^{p} t_i(t_i - 1)(2t_i + 5)\right] \quad (3)$$

where, n is the number of data points, P is the number of tied groups, the summary sign (k) indicates the summation over all tied groups, t_i is the number of data values in the P^{th} group. A tied group is a set of sample data having the same value. In cases where the sample size is n > 30, the test statistic Z is calculated by using:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\operatorname{VAR}(S)}} & \text{for } S > 0 \\ 0 & \text{for } S = 0 \\ \dfrac{S+1}{\sqrt{\operatorname{VAR}(S)}} & \text{for } S < 0 \end{cases} \quad (4)$$

Positive values of Z indicate an increasing trend while negative values indicate decreasing trends.

2.2. *Sen's slope estimator* : The slope of n pair of data points has been estimated using Sen's slope estimator (Sen, 2012) which is calculated as:

$$Q_i \frac{x_j - x_k}{j - k}, \text{ for } i = 1 \ldots N \quad (5)$$

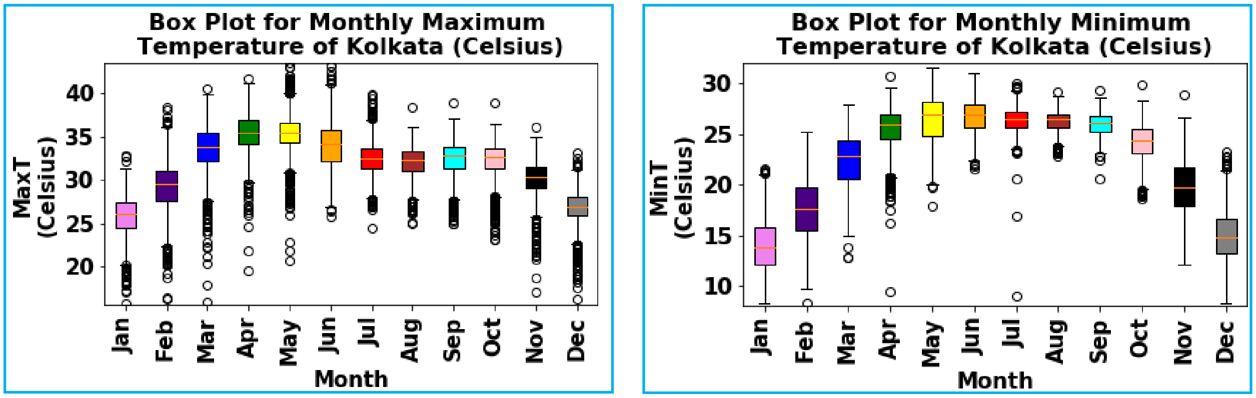


Fig. 2. Month wise maximum and minimum temperatures over Kolkata

TABLE 1

Monthly mean maximum (Max*T*), minimum (Min*T*), mean temperature (Mean Temp) and corresponding standard deviation (SD), coefficient of variation (CV)

Month	Max*T* (°C)	Min*T* (°C)	Mean*T* (°C)	Standard Deviation (SD)			Coefficient of Variation (CV)		
				Max*T*	Min*T*	Mean*T*	Max*T*	Min*T*	Mean*T*
January	25.86	14.06	19.96	2.32	2.47	2.12	8.97	17.57	10.61
February	29.27	17.59	23.43	2.87	3.06	2.71	9.82	17.41	11.58
March	33.62	22.36	27.99	2.61	2.82	2.39	7.75	12.6	8.52
April	35.42	25.45	30.43	2.38	2.30	2.01	6.70	9.05	6.62
May	35.46	26.38	30.92	2.30	2.45	2.05	6.49	9.29	6.61
June	34.03	26.81	30.42	2.61	1.86	1.89	7.65	6.95	6.22
July	32.44	26.43	29.44	1.89	1.31	1.37	5.83	4.96	4.64
August	32.17	26.38	29.27	1.80	1.06	1.22	5.59	4.01	4.17
September	32.45	26.03	29.24	2.08	1.06	1.39	6.40	4.09	4.71
October	32.28	24.17	28.22	1.98	1.91	1.58	6.13	7.89	5.61
November	30.19	19.83	25.01	1.91	4.19	2.49	6.31	21.11	9.94
December	26.84	14.98	20.91	1.98	2.34	1.86	7.39	15.58	8.87

where, x_j nad x_k are data values at time *s*, *j* and *k* respectively. The median of these *N* values of Q_i is Sen's estimator of the slope. The Sen's estimator is calculated as:

$$Sen's estimator = \begin{cases} Q_{\frac{N+1}{2}} \text{ when } N \text{ is odd} \\ \frac{1}{2}\left(Q_{\frac{N}{2}} + Q_{\frac{N+2}{2}}\right) \text{ when } N \text{ is even} \end{cases} \quad 6)$$

3. *Temperature trend* : Box-Whisker plots of monthly maximum and minimum temperatures which depict the monthly variations of maximum and minimum temperatures have been shown in Fig. 2. The compact nature of Box-Whisker plots assists side-by-side assessments of multiple datasets, which can otherwise be difficult to interpret using more complete representations such as histograms (Panda *et al.*, 2019). These plots graphically describe the statistical distribution of maximum, minimum temperature data of this study in a more comprehendible way. From Fig. 2 it is clear that maximum and minimum temperature data for each month is normally distributed and the degree of skewness is small. It is seen that the highest maximum temperature is observed in May and there are many days when May maximum temperatures have risen above 40 °C. The highest maximum May temperature observed during the period of study is 43 °C. January witnesses the lowest minimum temperatures with the lowest 8.4 °C during the last 51 years.

Monthly mean maximum, mean minimum, mean temperatures have been shown in Table 1, which shows that the average mean temperature of Kolkata remains

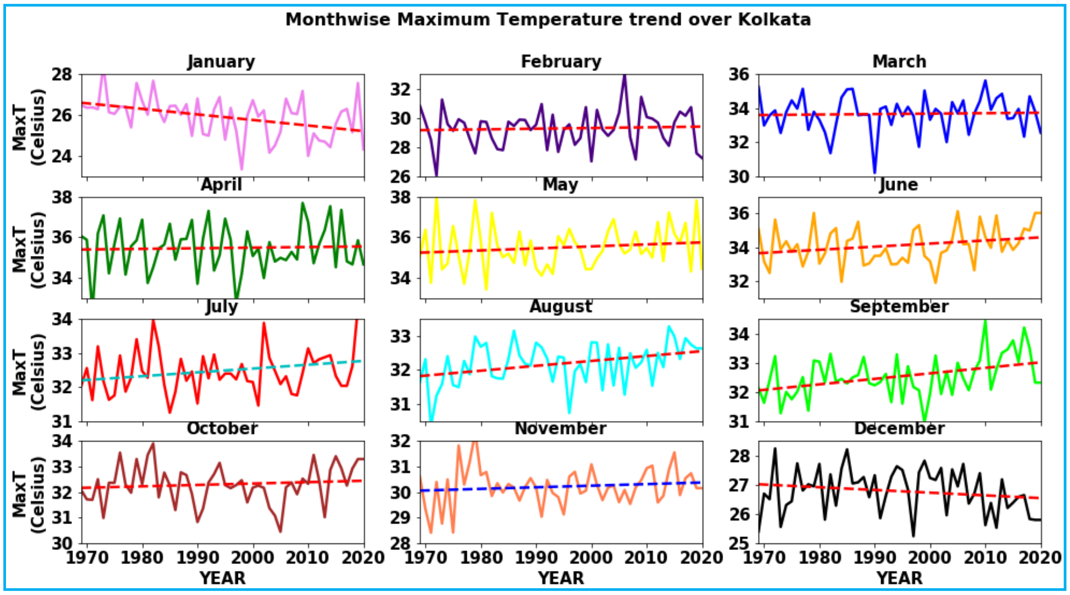


Fig. 3. Month wise maximum temperature trend over Kolkata

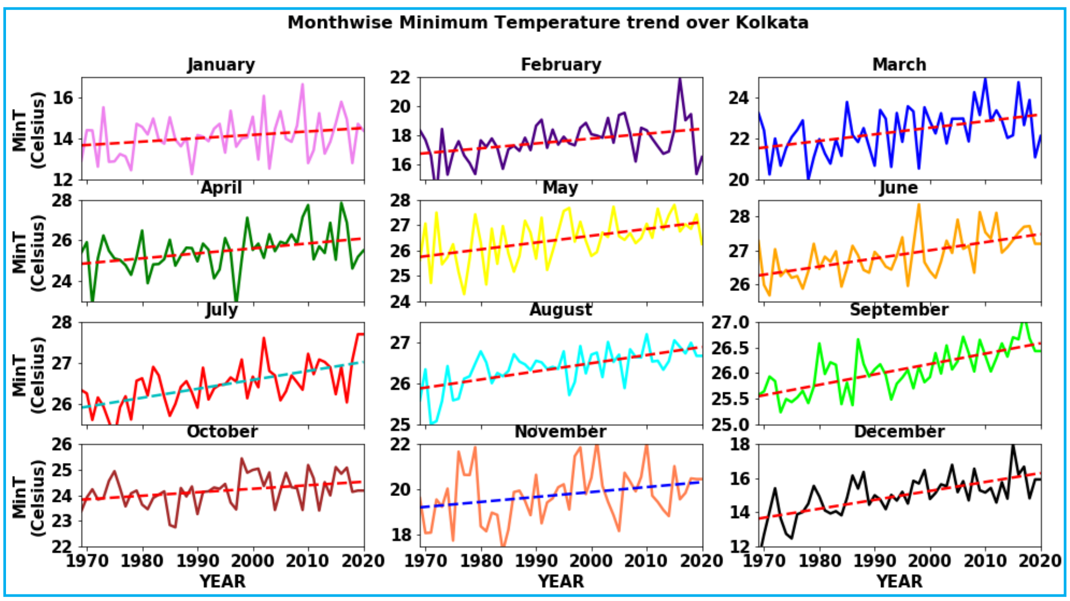


Fig. 4. Month wise minimum temperature trend over Kolkata

within 19.96-30.92 °C, the average minimum temperature of this city lies between 14.06-26.81 °C and the average maximum temperature of this location ranges 25.86-35.46 °C. The standard deviation and coefficient of variation of T_{max}, T_{min} and T_{mean} are also shown in Table 1. It is seen that for T_{max}, CV does not vary much with months. The highest variation is seen in February. This may be due to the transition from winter to summer. For T_{min} variation of CV is maximum and it varies from 17.57 in January to 15.58 in December with a maximum of 21.11 in November and a minimum of 4.01 in August. CV for T_{min} for June, July, August and September are smaller this means the daily minimum temperature is homogenous during these monsoon months whereas daily minimum temperature is erratic during November, December, January and February. Like T_{min}, Mean T shows a similar variation of CV.

Trends in maximum temperature and minimum temperature for each month have been shown in Figs. 3&4 respectively. M-K test statistics corresponding to the trend of each month have been calculated and test results of

TABLE 2

Result of Mann-Kendall rank statistics for monthly maximum and minimum temperatures of Kolkata

Month	Trend		p		τ		Slope	
	Max*T*	Min*T*	Max*T*	Min*T*	Max*T*	Min*T*	Max*T*	Min*T*
January	Decreasing	No trend	0.004**	0.111	-0.277	0.153	-0.025	0.019
February	No trend	Increasing	0.728	0.006**	0.034	0.263	0.003	0.032
March	No trend	Increasing	0.681	0.006**	0.040	0.260	0.004	0.031
April	No trend	Increasing	0.740	0.018*	-0.032	0.228	-0.004	0.019
May	No trend	Increasing	0.283	0.001**	0.103	0.327	0.013	0.029
June	Increasing	Increasing	0.043*	0**	0.194	0.426	0.022	0.025
July	No trend	Increasing	0.146	0**	0.140	0.439	0.009	0.022
August	Increasing	Increasing	0.021*	0**	0.222	0.461	0.014	0.017
September	Increasing	Increasing	0.008**	0**	0.254	0.520	0.019	0.021
October	No trend	Increasing	0.301	0.011*	0.100	0.241	0.006	0.014
November	No trend	Increasing	0.752	0.034*	0.031	0.203	0.003	0.023
December	No trend	Increasing	0.221	0**	-0.118	0.488	0.010	0.483

TABLE 3

Result of Mann-Kendall rank statistics for annual temperatures of Kolkata, Canning and Diamond Harbour

Parameters	Trend			p			τ			slope		
	Canning	Diamond Harbour	Kolkata	Canning	Diamond Harbour	Kolkata	Canning	Diamond Harbour	Kolkata	Canning	Diamond Harbour	Kolkata
Annual maximum temperature	No trend	Increasing	No trend	0.647	0**	0.641	0.054	0.405	0.045	0.002	0.046	0.001
Annual minimum temperature	No trend	No trend	Increasing	0.119	0.513	0**	0.180	-0.077	0.612	0.009	0.005	0.028
Annual mean temperature	No trend	Increasing	Increasing	0.295	0.015*	0**	0.122	0.279	0.449	0.005	0.021	0.015

*denotes 95% confidence level, **denotes 99% confidence level

individual months have been shown in Table 2. It is seen that maximum temperature shows a decreasing trend for January, an increasing trend for June, August and September and no trend for the rest of the months whereas minimum temperature shows an increasing trend for all the months except January which shows no trend. The decreasing trend of maximum temperature for January and increasing trend of maximum temperature for June, August and September are significant at 99% (p = 0.004), 95% (0.043), 95% (p=0.021) and 99% (p = 0.008) respectively. The magnitude of Sen slopes and τ for these months are -0.025, 0.022, 0.014, 0.019 and -0.277, 0.194, 0.222, 0.254 respectively which support these decreasing and increasing trends. The rest of the months show no trend for maximum temperature. But this 'no trend' results for maximum temperature are not significant as the p values corresponding to these are more than the level of significance.

The minimum temperature for all months except January shows an increasing trend. These trends are significant as their p values are less than the level of confidence. The decreasing trend for minimum temperature for January is not significant as (p = 0.111 < 0.05) and magnitude of the Sen's slope is positive.

For the sake of comparison, the M-K statistics for annual mean maximum, annual mean minimum and annual mean temperatures for rural town Canning, suburban town Diamond Harbour and metro city Kolkata have been calculated and shown in Table 3 and trend lines

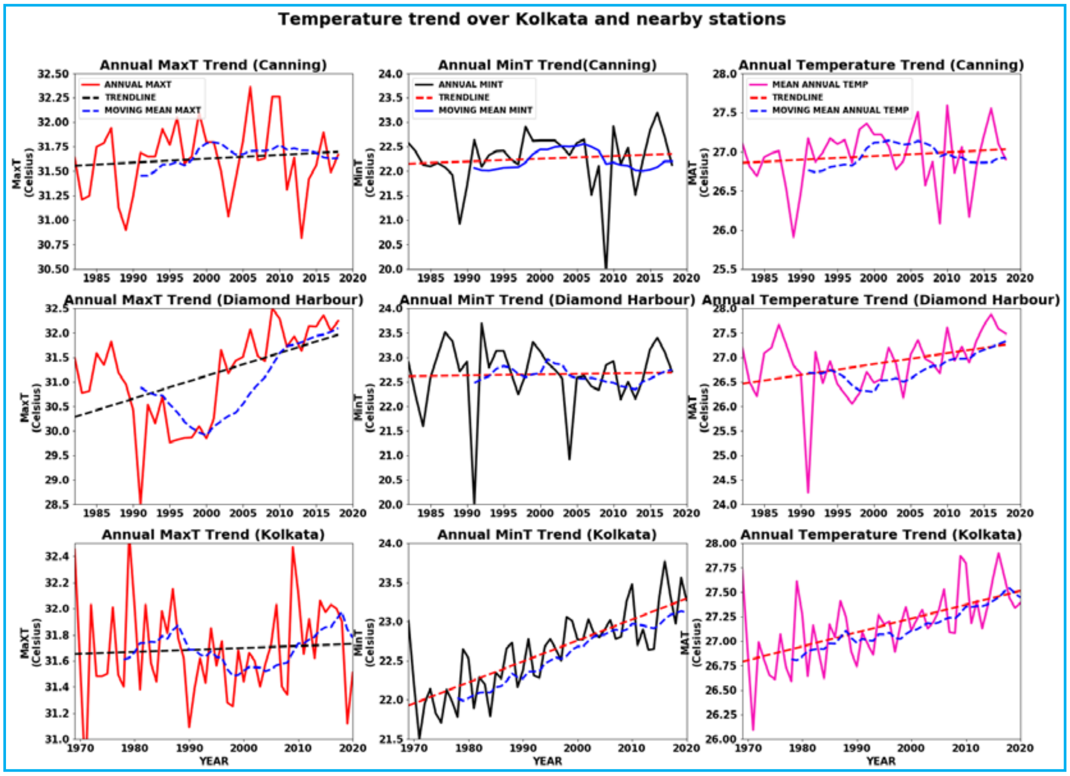


Fig. 5. Annual temperature trend over Kolkata and nearby meteorological stations

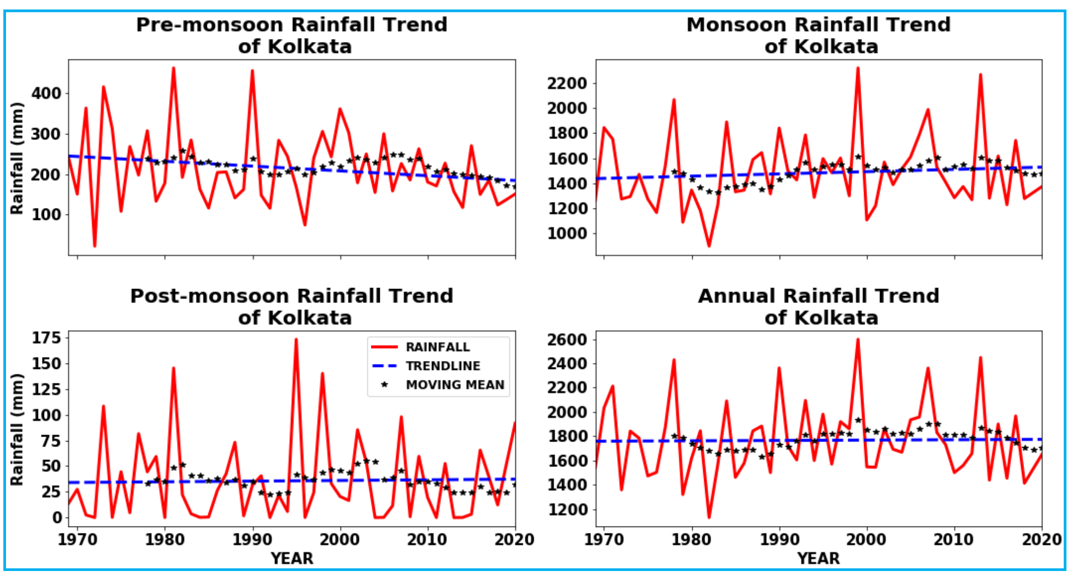


Fig. 6. Trends of annual and seasonal rainfall over Kolkata

with ten-year moving mean corresponding to each station have been shown in Fig. 5. It is clear from the above table and figures that for Canning annual mean maximum temperature, annual mean minimum temperature and annual mean temperature do not show any trend. For Diamond Harbour annual mean minimum temperature does not show any trend but the annual mean maximum and annual mean temperature show significant (p = 0, p = 0.015) increasing trend with Sen's slope magnitude 0.046 and 0.021 respectively. The increasing trend in annual mean temperature is due to the increasing trend in annual mean maximum temperature. But the reason for

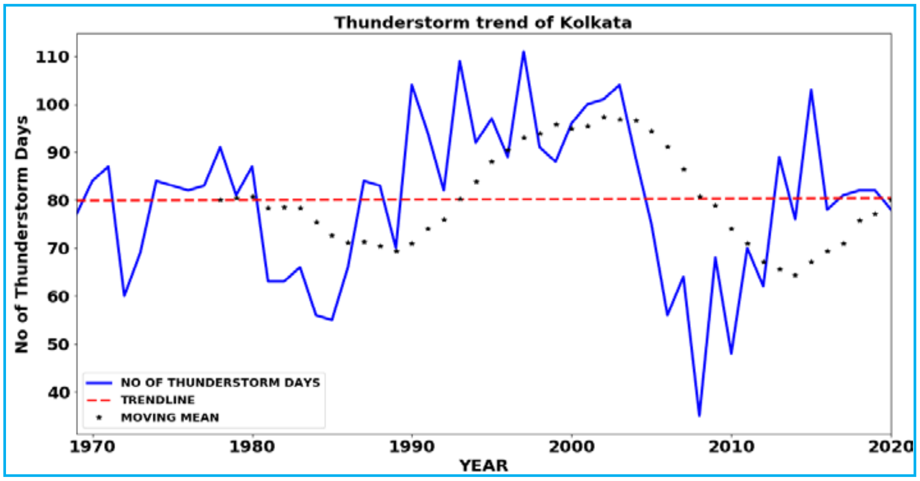
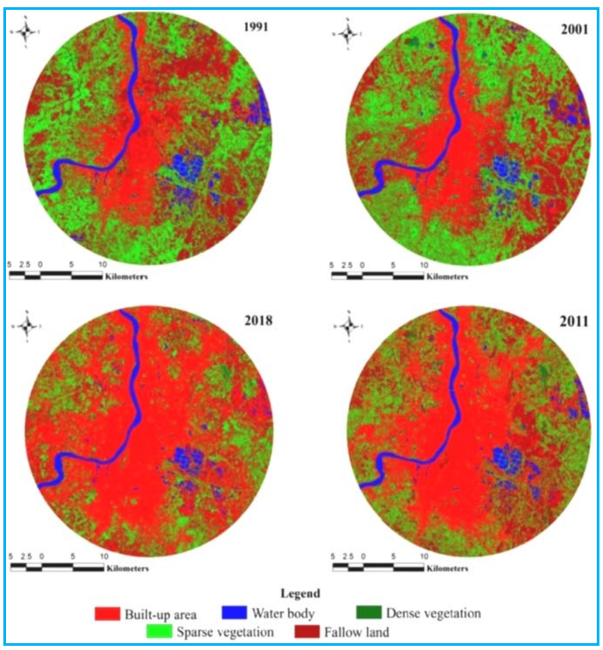
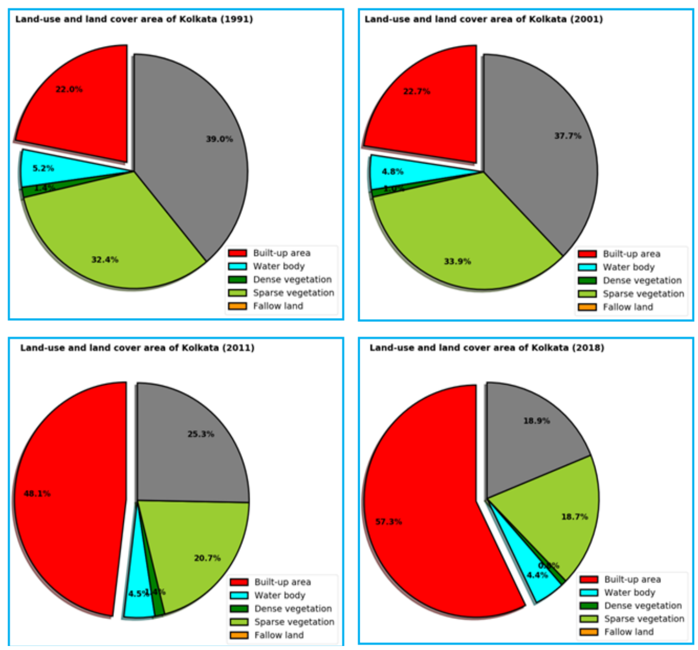


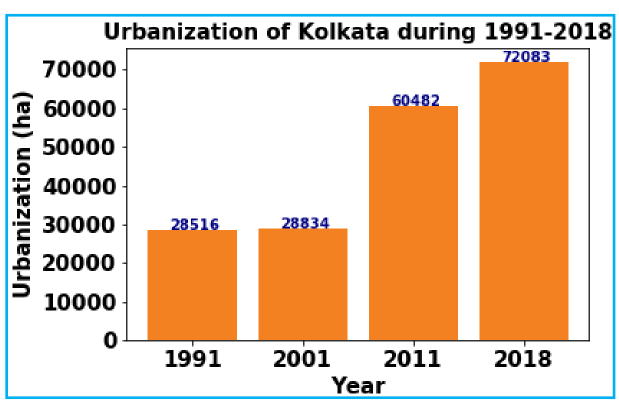
Fig. 7. Trends of annual thunderstorm over Kolkata



(a)



(b)



(c)

Figs. 8(a-c). (a) Spatio-temoral land use pattern of Kolkata during (*Source* : Mandal *et al*., 2019), (b) Pie diagram of change in land use pattern of Kolkata and (c) Growth in built up area of Kolkata the increasing trend in the annual mean maximum temperature of Diamond Harbour is not clear. For Kolkata, the annual mean maximum temperature does not show any trend whereas the annual mean minimum temperature and annual mean temperature show significant (p = 0, p = 0) increasing trend with Sen's slope magnitudes 0.028 and 0.015 respectively. The increasing trend of annual mean temperature is due to the increasing trend of annual mean minimum temperature.

The reason for this increasing trend of annual mean minimum temperature may be due to the urban heat island effect. Minimum temperature over this city is generally attained early in the morning. The rise in minimum temperature means that the city is not getting cooled enough till morning. Generally in a large metropolis city, built-up areas such as streets, monuments, high-rise buildings, etc. are made of materials that have high heat capacities and absorb more heat during daytime and release slowly at night. As a result, the city becomes comparatively warmer than the suburban and rural surroundings (Khan *et al*., 2016; Oke, 1982; Mehrotra *et al*., 2018). Over the years Kolkata has witnessed the growth of urbanization and the pace of this growth of urbanization has become rapid during recent decades (1991-2020). (Sahana *et al*., 2018; Mandal *et al*., 2019; Ramachandra *et al*., 2014) have analyzed and shown this rapid Spatio-temporal growth of urbanization and the land use pattern of this city. In the study, the Spatio-temporal land use pattern and growth of urbanization of Kolkata during 1991-2018 is shown in Fig. 8. Fig. 8(a) shows the Spatio-temporal land use pattern. It is seen that the built-up area has increased rapidly during 2001-2018. Fig. 8(b) shows the percentage change of this land-use pattern during 1991-2018. It is observed that the built-up area has increased from 22% in 1991 to 57.3% in 2018. This increase is rapid during 2001-2018 (22.7%-57.3%). This rapid increase of built-up area is mainly at the expense of a rapid decrease of fallow land (37.7%-18.9%) and sparse vegetation (33.9%-18.7%). Fig. 8(c) shows the growth of the built-up area/urbanization of Kolkata. It is seen that the built area has increased from 28516 Hectares in 1991 to 72083 Hectares in 2018. It is also seen that there is a jump in the built-up area from 28834 Hectares in 2001 to 72083 Hectares in 2018. This shows that during recent decades Kolkata has witnessed rapid urbanization. Surprisingly after 2000, we can also see the upward spikes in the annual mean minimum temperature and annual mean temperature of Kolkata.

3.1. *Rainfall trend* : According to Köppen's climate classification, Kolkata falls in the category of tropical savanna with high temperature throughout the year and high precipitation during monsoon. The monsoon rainfall is the main contributor to the overall precipitation of this city, though some appreciable amount of rainfall is received during pre-monsoon and post-monsoon seasons. June, July, August and September (JJAS) are considered as the Monsoon period, March, April, May (MAM) as the pre-monsoon period and October, November, December, January, February (ONDJF) as the post-monsoon season. Fig. 6 shows the annual and seasonal rainfall trends along with 10 years of rolling average rainfall. It is seen that seasonal rainfall as well as annual rainfall are very erratic and do not show any mentionable pattern. The maximum, minimum and average rainfall received in the pre-monsoon season during the study period are 462.2, 22.4 and 214.6 mm respectively. The maximum, minimum and average rainfall in the monsoon season is 2321.3, 897.5 and 1482.9 mm respectively. The same for the post-monsoon season is 173.2, 0 and 35.7 respectively. The overall annual rainfall varies from 1132 mm (in 1982) to 2597 mm (in 1999) with a mean of 1767 mm. The M-K test statistics results corresponding to the trend of pre-monsoon, monsoon, post-monsoon and annual rainfall are shown in Table 4. It is observed that annual and seasonal rainfall does not show any trend during the study period though there are ups and downs in the annual and seasonal rainfall.

TABLE 4

Result of Mann-Kendall rank statistics for rainfall and thunderstorm over Kolkata

Parameters	Trend	p	τ	slope
Pre-monsoon rainfall	No trend	0.167	-0.133	-1.085
Monsoon rainfall	No trend	0.518	0.063	1.276
Post monsoon rainfall	No trend	0.887	0.014	0.001
Annual rainfall	No trend	1.000	-0.001	-0.015
Thunderstorm	No trend	0.651	0.045	0.080

3.2. *Thunderstorm trend* : Annual thunderstorm days along with ten years moving average value for Kolkata have been shown in Fig. 7. The Mann-Kendall trend statistics for thunderstorm days have been shown in Table 4. It is seen that the average number of thunderstorm days in a year in Kolkata is 80. The maximum number of thunderstorm days (111) was observed in the year 1997 and the minimum number of thunderstorm days (35) was observed in the year 2008. M-K statistics in Table 4 suggest that there is no trend in the total number of thunderstorm days in a year. But a close inspection of the decadal thunderstorm trend reveals that during the period 1990-2002, the number of thunderstorm days in a year had increased significantly and during 2003-2008 the same had decreased sharply.

4. While analyzing the rainfall, temperature and thunderstorm data of Kolkata it has been observed that during the period of study there is no trend in maximum temperature, rainfall and the number of thunderstorm days. Though there are ups and downs in the maximum temperature, rainfall and thunderstorm days in this period those do not bring any changes in the overall trend of these parameters. It has also been observed that during the study period there is a significant rise in the monthly as well as the yearly minimum temperature. Particularly in the last two decades annual mean minimum temperature and annual mean temperature show sharp upward spikes. The rise in annual mean temperature is mainly due to the rise in annual mean minimum temperature in this city. The minimum temperature in this city is attained early in the morning. When there is a rise in the minimum temperature it seems that up to the early morning the city is not getting cooled enough at the normal rate, this can happen when the city is unable to fully release the heat which was trapped at the daytime by the built-up area/ man-made constructions. As a result, the city becomes warmer than its urban and suburban surroundings. From the analysis of section 3, it is seen that urbanization over Kolkata has grown over the years and particularly in the last two decades Kolkata witnessed rapid urbanization. The minimum temperature of the city has shown a steady increase during the study period with upward spikes in the last two decades. But the neighboring rural town canning and suburban town Diamond Harbour do not show any rise in the minimum temperatures. Hence it may be concluded that the rise in minimum temperature and annual temperature of Kolkata is solely due to the urban heat island effect and not due the climate change. Climate change has less to nil impact on the temperature, rainfall and thunderstorm of this city.

5. I gratefully acknowledge IMD for encouraging and supporting to carryout this work and RMC Kolkata for supplying meteorological data.

Disclaimer

The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

References

Arora, A., Goel, A. K. and Singh, P., 2005, "Evaluation of temperature trends over India", *Hydrol. Sci. J.*, **50**, 81-93.

Bhutiyani, M. R., Kale, V. S. and Pawar, N. J., 2010, "Climate change and the precipitation variations in the northwestern Himalaya : 1866-2006", *Int. J. Climatol.*, **30**, 535-548.

Cannarozzo, M., Noto, L. V. and Viola, F., 2006, "Spatial distribution of rainfall trends in Sicily (1921-2000)", *Phys Chem Earth*, **31**, 1201-1211.

Chung, U., Choi, J. and Yun, J. I., 2004b, "Urbanizatio effect on the observed change in mean monthly temperature between 1951-1980 and 1971-2000 in Korea", *Climatic Change*, **66**, 127-136.

Chung, Y. S., Yoon, M. B. and Kim, H. S., 2004a, "On climate variations and changes observed in South Korea", *Climatic Change*, **66**, 151-161.

Dash, S. K. and Hunt, J. C. R., 2007, "Variability of climate change", *Curr. Sci.*, **96**, 782-788.

De, U. S. and Dandekar, M. M., 2001, "Natural disasters in urban areas", *Deccan Geographer*, **39**, 1-12.

Dhodre, A., Dhodre, A. and Gadgil, A. S., 2009, "Long term temperature trends at four largest cities of India during the twentieth century", *J. Indian Geophys. Union.*, **13**, 85-97.

Gadgil, A. and Dhodre, A., 2005, "Temperature trends in twentieth century at Pune, India", *Atmosheric Environment*, **39**, 6550-6556.

Ghosh, K. G., 2018, "Analysis of rainfall trends and its spatial patterns during the last century over Gangetic West Bengal, Eastern India, *J. geovis. Spat. Anal*, **2:15.**

Hingane, L. S., 1996, "Is a signature of socio-economic impact written on the climate?", *Climatic Change*, **32**, 91-102.

IPCC 2007 Climate change, 2007, "Climate change impacts, adaptation and vulnerability", Working Group II Contribution to the Intergovernmental Panel on Climate Change, Fourth Assessment report, Summary for Policymakers, 23.

Jagannathan, P. and Parthasarathy, B., 1973, "Trends and periodicities of rainfall over India", *Mon. Wear. Rev.*, **101**, 691-700.

Jeganathan, A. and Andimuthu, R., 2013, "Temperature trends of Chennai City, India", *Theor. Appl. Climatol.*, **111**, 417-425.

Khan, A. and Chatterjee, S., 2016, "Numerical simulation of urban heat island intensity under urban-suburban surface and reference site in Kolkata, India", *Model. Earth. Syst. Environ.*, **2:71**.

Koteswaram, P. and Alvi, S. M. A., 1969, "Secular trends and periodicities in rainfall at west coast stations in India", *Curr. Sci.*, **38**, 10, 229-231.

Lal, M., 2001, "Climate change implications for India's water resources", *J. Soc. Econ. Dev.*, **III(1)**, 57-87.

Mandal, J., Ghosh, N. and Mukhopadhyay, A., 2019, "Urban growth dynamics and changing land-use and land- cover of megacity Kolkata and its environs", *Journal of the Indian Society of Remote Sensing*, **47**, 10, 1707-1725.

Mann, H. B., 1945, "Non-parametric tests against trend", *Econometrica*, **13**, 163-171.

Mehrotra, S., Bardhan, R. and Ramamritham, K., 2018, "Urban informal housing and surface urban heat island intensity : Exploring spatial association in the city of Mumbai", *Environment and Urbanization Asia*, **9**, 2, 158-177.

Oke, T. R., 1982, "The energetic basis of the urban heat island", *Quart. J. R. Met. Soc.*, **108**, 455, 1-24.

Panda, A. and Sahu, N., 2019, "Trend analysis of seasonal rainfall and temperature pattern in Kalahandi, Bolangir and Koraput districts of Odisha, India", *Atmos. Sci. Lett.*, **20**, e932.

Raghavendra, V. K., 1974, "Trends and periodicities of rainfall in sub-divisions of Maharashtra state", *Indian J. Meteorol. Geophys.*, **25**, 197-210.

Ramachandra, T. V., Aithal, B. H. and Sowmyashree, M. V., December 2014, "Urban structure in Kolkata : metrics and modelling through geo- informatics", *Appl. Geomat.*, **6**, 4, 1-16.

Sahana, M., Hong, H. and Sajjad, H., 2018, "Analyzing urban spatial patterns and trend of urban growth using urban sprawl matrix: A study on Kolkata urban agglomeration, India", *Science of the Total Environment*, **628-629**, 1557-1566.

Sarker, R. P. and Thapliyal, V., 1988, "Climate change and variability", *MAUSAM*, **39**, 2, 127-138.

Sen, P. K., 2012, "Estimates of the regression coefficient based on Kendall's tau", *J. Atm. Stat. Assoc.*, **63**, 324, 1379-1389.

Sinha Ray, K. C. and De, U. S., 2003, "Climate change in India as evidenced from instrumental records", *WMO Bull*, **52**, 53-59.

Tayanc, M. and Toros, H., 1997, "Urbanisation effects on regional climate change in the case of four large cities of Turkey", *Climatic Change*, **35**, 501-524.

Thapliyal, V. and Kulshrestha, S. M., 1991, "Climate changes and trends over India", *MAUSAM*, **42**, 333-338.

Tigga, A. and Hema Malini, B., 2011, "Temperature trends in Ranchi city, Jharkhand", *Punjab Geogr.*, **7**, 20-31.

Trusilova, K., Jung, M., Churkina, G., Karstenes, U., Heiman, M. and Claussen, M., 2008, "Urbanization impacts on the climate of Europe: Numerical experiment by PSUNCAR Mesoscale Model (MM)", *J. Appl. Meteorol. Climatol.*, **47**, 1442-1455.

PRAVAT RABI NASKAR

Meteorological office Port Blair,
India Meteorological Department,
MoES, Port Blair – 744 106, India

(*Received 8 May 2020, Accepted 29 October 2021*)
e mail : pravat091@gmail.com