Nature Environment and Pollution Technology
An International Quarterly Scientific Journal
p-ISSN: 0972-6268
(Print copies up to 2016)
e-ISSN: 2395-3454
Vol. 24 | No. 3 | Article ID B4258 | 2025
Original Research Paper
https://doi.org/10.46488/NEPT.2025.v24i03.B4258
Open Access Journal

Trend Analysis of Meteorological Parameters in the Perspective on Climate Change in Kolkata District During 1901-2019

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Abbreviation: Nat. Env. & Poll. Technol.
Website: www.neptjournal.com

Received: 19-08-2024
Revised: 25-10-2024
Accepted: 09-11-2024

Key Words:

Rainfall anomaly
Climate Research Unit (CRU)
Rainfall
Temperature
Temporal changes

Citation for the Paper:

Paira, K., Ao, M., Mondal, B., Mundu, G.B., 2025. Trend analysis of meteorological parameters in the perspective on climate change in Kolkata District during 1901-2019. *Nature Environment and Pollution Technology*, 24(3), B4258. https://doi.org/10.46488/NEPT.2025.v24i03.B4258

Note: Since 2025, the journal has adopted the use of Article IDs in citations instead of traditional consecutive page numbers. Each article is now given individual page ranges starting from page 1.

ABSTRACT

Analysis of temporal dynamics of climatic parameters is indispensable for advancing the "Sustainable Development Goals (SDGs)-11 and 13". This study aims to assess the trend of temperature and rainfall in Kolkata District using CRU (Climate Research Unit) data from 1901 to 2019. Statistical methods such as anomaly index, CV ("coefficient of variation"), and PCI ("Precipitation Concentration Index") were employed along with ITA (Innovative trend analysis) techniques, Mann-Kendall test, and Spearman's Rho tools. These measures are widely used in climate and environmental research to recognize the trend of climate change. The Mann-Kendall and Spearman's Rho tools both reveal that the seasonal (summer and winter) and yearly temperatures are rising significantly ($P<0.01\%$). In contrast, the result shows a significant rise in annual and monsoon rainfall and a notable upward trend in temperature throughout all months. Trend analysis shows a rising trend of temperature, as well as, rainfall in Kolkata District, whereas PCI shows moderate (16 years), high (79 years), and very high (24 years) concentrations of precipitation. The current research proposes increasing government efforts to decrease greenhouse gas emissions and enhance urban environmental conditions by regulating air pollution emissions. These measures, if implemented effectively, can significantly lessen the effect of the changing climate and enhance the quality of life in Kolkata. Effective land use management and stringent population control policies are essential for achieving SDG 13 and promoting inclusivity, safety, resilience, and sustainability in Kolkata (SDG 11).

INTRODUCTION

Climate change, a significant global environmental phenomenon, carries profound implications for human existence, economic growth, and ecosystems (Das & Bhattacharya 2018). It is a phenomenon by which all sectors of life in the present day experience the extreme barbarity of climatic theatricality (Prarikeslan et al. 2023). According to "Human Development Report-2007-08", climate change is the most significant phenomenon that humanity is currently confronting since the beginning of the 21st century. There is a possibility of an unprecedented catastrophe in the growth of human civilization if we fail to address this challenge. Numerous studies have confirmed a warming trend on Earth (Jones et al. 2013, Levites et al. 2012, Miller 2012) between 1951 and 2012, with a decadal rate of 0.12°C (IPCC 2013). This warming has already begun to impact the atmosphere, affecting both ocean and land.

The "Intergovernmental Panel on Climate Change" (Stocker et al. 2013) asserts that the key reason for global warming is anthropogenic activity. Specifically the emission of various greenhouse gases (GHGs) such as carbon dioxide and methane from the burning of fossil fuels. The concentration of carbon dioxide (CO^2) has risen by 40% since the pre-industrial era, primarily due to these emissions (Stocker et al. 2013, Huang et al. 2015). IPCC's fourth assessment report (2007) reiterates that climate change is expected to intensify risks and large-scale disasters. This could also contribute to systematic change due to human activities such as the emission of Greenhouse gases. The average temperature of the earth has also increased by 0.74 °C from the pre-industrial era due to the substantial concentration of CO^2 in the atmosphere (UNFCCC 2007).

Climate change is a universally recognized reality. Short to large-scale effects have been observed on climate instability, natural resources, and humans. According to the IPCC (2014), the temperature of the earth might increase from 1.1 to 6.4 °C, and the sea level could rise by 28–79 cm as well by 2100. As a result, weather patterns will become less predictable, and intense climatic disasters such as floods, storms, droughts, and heat waves will take place more regularly. The IPCC anticipated that the projected decline in freshwater levels could negatively impact people in Central, South, East, and South-East Asia.

Climatic change hurts human beings, particularly the displaced people or refugees in India, Southeast Asia, and the Indian subcontinent (Lonergan 1998, Kolmannskog & Skretteberg 2009). It also raises the risk of rising sea levels and alters fundamental living patterns. Recently, research on climate change investigated the health implications of biodiversity loss via changing the microbiome, which might lead to neurologic illnesses, autoimmune, and inflammatory (Ray & Ming 2020). The severe impact of heat waves also poses serious distress in the form of disease, which affects more men than women. Nevertheless, all age groups are vulnerable to heat-associated poor health (Li et al. 2014). In addition, epidemiological studies demonstrated that a slight increase in the maximum or average daily temperature is associated with premature death. Numerous studies have demonstrated the adverse effects of environmental pollution on health (Majra & Gur 2009, Bush et al. 2011, Dhara et al. 2013, Sahu et al. 2013).

A study conducted in Dinhata, West Bengal, by Das & Bhattacharya (2018) examined temperature changes from 1980 to the present and reported that the overall annual, pre-monsoon, and monsoon rainfall has decreased, whereas the post-monsoon rainfall has increased over time. The study also revealed that the summer, winter, and average yearly temperatures have risen, whereas the annual minimum temperature was increased with the increase of the monthly minimum temperature. Using similar statistical tools to measure the change in temperature over Tripura, Tomar et al. (2017) found that except in January and December months, the temperature over two stations increased considerably between 1969 and 2014. Jaswal (2010) found a substantial rising trend of temperature in winter between 1970 and 2007. District-level analysis in Andhra Pradesh (during 2011-2020) done by Kavitha et al. (2023) pinpointed that monthly and seasonal rainfall exhibited an increasing trend, whereas the monthly highest rainfall was found to be varied during the last decade. Choudhuri et al. (2012) revealed that maximum temperatures at Mid-altitude Meghalaya demonstrated a considerable increasing trend, whereas minimum temperatures showed an inconsequential declining trend. A study in Sagar Island by Mandal et al. (2013) between 1982 and 2010 reported a considerable increase in the inter-annual mean and maximum temperature, as well as a consistent decline in yearly rainfall. Kothawale & Rupa (2005) conducted a trend study in India. They discovered that the mean annual temperature has grown considerably over the last century. Therefore, studying micro-regional climate variables is essential in detecting climate change, managing water resources and regional planning (Kavitha et al. 2023), public health, and economic setup. Extensive study on climate change by different researchers was observed across various regions worldwide, primarily focusing on temperature and precipitation. They have set off an alarm bell worldwide. From the ongoing discussion, trend analysis studies conducted so far in urban areas of India are not found to be very conclusive. Many of the urban areas in developing countries are vulnerable to climate change due to city location, existing infrastructure, population, economic losses (UN Habitat 2011), and social issues like poverty and hunger (Gasper et al. 2011). Additionally, the urban poor- i.e., slum dwellers in developing countries are indeed increasingly vulnerable (UN Habitat 2011). Despite these risks, many cities have not addressed this due to the lack of steady-state and relevant city policies and action plans. Hence, studying the trend of climatic scenarios at a micro-level, especially in an urban region, is indispensable for understanding and designing mitigation plans as well as the implementation of cost-effective and sustainable adaptation measures.

Therefore, due to the dearth of studies at the micro level, the primary objective of our study is to examine the temporal trend of meteorological parameters in Kolkata, India.

MATERIALS AND METHODS

Study Area

According to the "Intergovernmental Panel on Climate Change", the Kolkata metropolitan area and its surroundings are warming tremendously. According to the atlas, the annual mean temperature of Kolkata might increase by almost 4.5ºC between 2081 and 2100, compared to the pre-industrial period, if the emission of greenhouse gases is not restrained (Basu 2021). During the period 1950 to 2018, Kolkata Metropolitan reported the maximum increase in

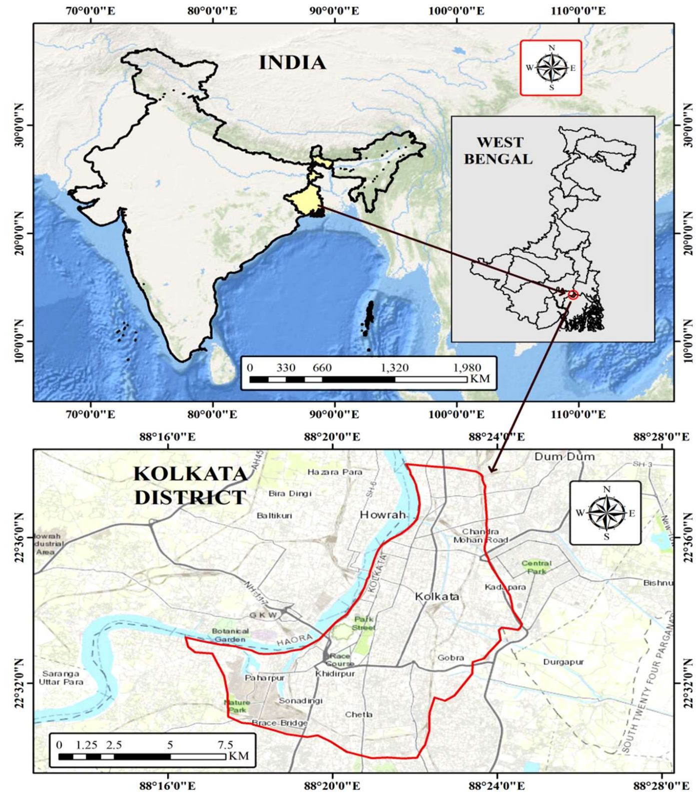

Fig. 1: Location map of the study area.

surface air temperature. Kolkata district is currently facing huge demographic pressure. A rapid population growth of 3.94% between 1991 and 2001 is visible in the Kolkata district. Additionally, the district was home to a population of 4,496,694 with a density of 24,306 people per sq. km (Census 2011), solidifying its status as one of the largest and densest cities. The greenery quotient of Kolkata is also one of the lowest in the country (Dhara 2019), and the city is experiencing water logging due to unplanned urban growth and massive population growth within the city (Paul 2021). A study on Kolkata by Shackleton et al. (2023) revealed a significant correlation between temperature and summer cholera, while they identified rainfall as the primary factor driving monsoon cholera. The meteorological condition, particularly the rising temperature and the present level of air pollutants in Kolkata also has the potential to impact public health drastically. Therefore, the city was selected in this study to investigate the trend of long-term climate parameters for understanding climate change by which its possible adverse impacts on the city can be minimized.

Data Source

Temperature and rainfall data have been accumulated from the Climate Research Unit, followed by Harris et al. (2020) for the period from 1901 to 2019 (119 years). The station of CRU TS 4.04 temperature is CALCUTTA/ALIPO, which is centered at 22º 33'54.22" N and 88º 21'30.76" E (Fig. 1).

Data Analysis Tools

The current study examined rainfall and temperature data using trend and variability analysis. The variability was analyzed by applying the Precipitation Concentration Index/PCI (Oliver 1980 modified by De Luis et al. 2011), Coefficient of Variation/CV (Hare 2003), and anomalies (Agnew & Chappel 1999, Woldeamlak & Conway 2007, Viste et al. 2012, Gebreet al. 2013, Asfaw et al. 2018). Nevertheless, non-parametric tests were used for trend analysis and detection. The MK test, a widely used method for identifying trends in climatological variables (Mekonnen & Woldeamlak 2014, Tabari et al. 2015, Gebremedhin et al. 2016), as well as the non-parametric Spearman's Rho test, were used in this investigation. Since there is are likelihood of outliers being present in the dataset, the non-parametric MK test is useful because its statistic is based on the positive or negative (+ or -) signs rather than the values of the random variable, and, therefore, the trends examined are less affected by the outliers (Birsan et al. 2005). Furthermore, World Metrological Data has been extensively recommended for this test for free exercise to the public to measure trends (Shi et al. 2013) and to identify the statistically significant trends of long-term data. The Spearman's rho (SR) test is a rank-based non-parametric statistical test that can also be used to detect monotonic trends in a time series (Lehmann 1975, Sneyers 1990). Therefore, the power of both methods relies on the size of the sample, pre-ascribed significance level, magnitude of the trend, and degree of variation within a time series. That is, the higher the absolute magnitude of the trend, the tests become more powerful with the increase in sample size, tests become more powerful, and the power of the tests decreases with the increase of the degree of variation within a time series. So, two tests have identical power in detecting a trend (Yue et al. 2002).

Şen's (2012) Innovative Trend Analysis (ITA) was also used for trend analysis. Recently, the ITA method has been applied extensively for trend detection of meteorological and hydrological parameters in different parts of the world (Dabanlı et al. 2016, Tabari et al. 2017, Zhou et al. 2018, Ahmas et al. 2018, Caloiero et al. 2018). Some of the researchers believed that the ITA method has more advantages and is also more practical in detecting hydro-meteorological series trends than the MK test (Dabanlı et al. 2016, Wu & Qian 2017). The study's location map was constructed using the QGIS 3.28, and data analysis was done using SPSS (v21.0) and Excel spreadsheets (Fig. 2).

RESULTS

Temperature Trend in Kolkata District (1901-2019)

Annual temperature ranged between 25.19 to 28.02°C, with a mean value of 26.77 (± 0.42°C). CV was found to be highest in March with 4.73% and lowest in June with 1.26%. The mean annual temperature was found to be largely constant (CV=1.56%) than the mean winter and mean summer temperature, whereas the mean summer was more consistent (CV=2.77%) than the winter mean temperature (CV=3.39%) (see Table 1).

Mann-Kendall and rho statistics both demonstrated a substantial (*p*<0.01) increasing tendency in the average annual (□ = 0.33, ρ = 0.46), summer (□ = 0.23, ρ = 0.34),

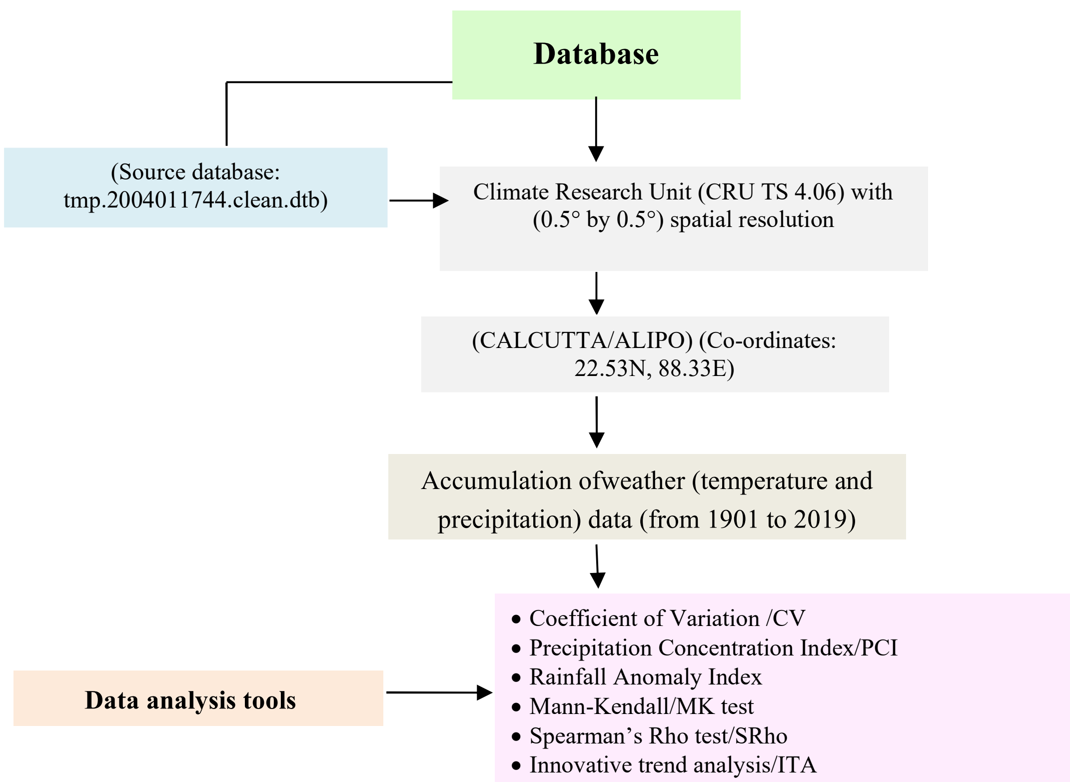

Fig. 2: Data source and analysis techniques.

Table 1: Trend of seasonal and annual temperature.

Seasonal/Annual	Minimum(°C)	Maximum(°C)	Mean(°C)	SD	CV	ρ	τ
Summer	25.73	31.86	29.61	.82	2.77	.34***	.23***
Winter	16.98	23.06	20.92	.71	3.39	.33***	.24***
Annual	25.19	28.02	26.77	.42	1.56	.46***	.33***

τ, Kendall's tau, ρ, spearman's Rho

Note: significance value ***p< 0.01, **p< 0.05

and winter (□ = 0.24, ρ = 0.33) temperatures (see Table 1). Correspondingly, the Mann-Kendall trend statistics indicate a significant (p<0.01) rising trend in the average temperature of every month except January, while the result of rho shows a noteworthy (p < 0.05 and p<0.05) increasing trend in every month except January (Table 2).

The average annual temperature was observed to be rising in the anomaly graph (Fig. 3). It is evident from the graph that the temperature trend line indicates a gradual but steady increase in temperature over time (Fig. 3), and the association between anomaly and time revealed a positive relationship (r= +0.47). The result of ITA in the case of temperature has confirmed the ascendancy of increasing trend throughout the considered period, as the scatter points are aggregates mostly above the trendless line (Fig. 4).

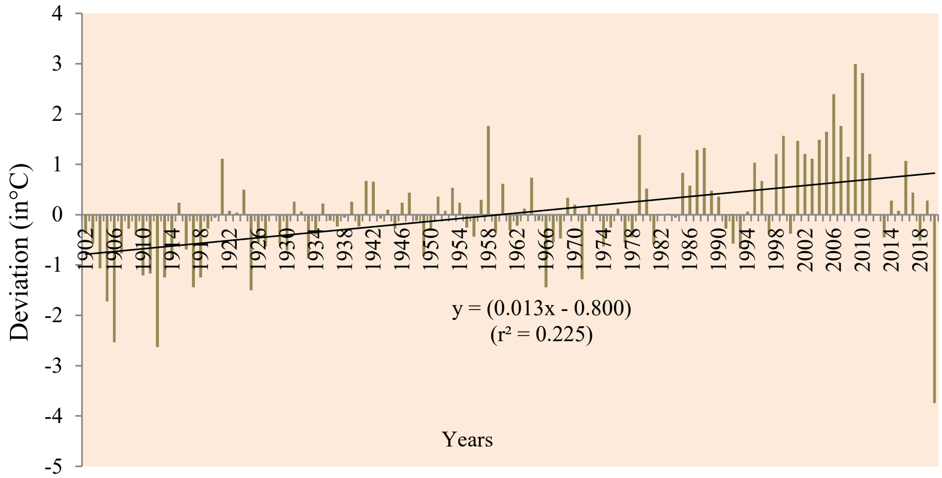

Fig. 3: Temperature anomaly.

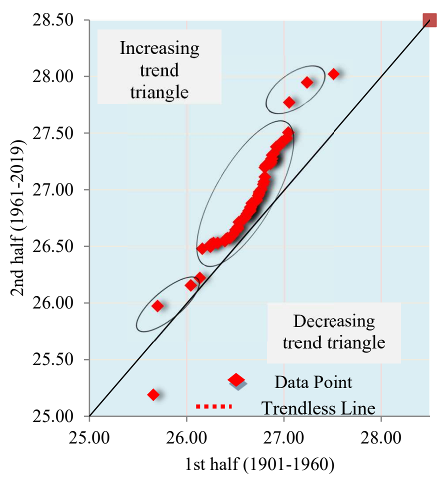

Fig 4: ITA graph of temperature.

Table 2: Status of monthly temperature and trend statistics.

Months	Minimum(°C)	Maximum(°C)	Mean(°C)	SD	CV	ρ	τ
January	15.67	22.1	19.90	0.83	4.17	.05	0.04
February	19	25.9	22.69	0.97	4.27	.32***	.23***
March	17.1	29.8	27.46	1.30	4.73	.28***	.19***
April	21.5	33.76	30.41	1.24	4.08	.23**	.17***
May	21.5	32.7	30.97	1.10	3.55	.29***	.21***
June	28.3	31.8	30.35	0.69	2.27	.23**	.16***
July	28.4	30.4	29.25	0.37	1.26	.25***	.19***
August	27.7	29.9	28.92	0.39	1.34	.49***	.36***
September	27.38	29.9	29.09	0.37	1.27	.24***	.16***
October	26.1	29.90	27.86	0.56	2.01	.30***	.28***
November	20.83	26.8	24.11	0.90	3.73	.38***	.27***
December	16.29	23.3	20.17	0.90	4.46	.33***	.25***

τ, Kendall's tau; ρ, spearman's Rho

Note: significance value ***$p< 0.01$, **$p< 0.05$

Rainfall trend in Kolkata District (1901-2019)

The annual rainfall, which varied between 889.50mm to 2056.62 mm, with an average of 1474.66 ± 230.66 mm, was a consistent feature throughout the long-term period from 1901 to 2019. However, in the monsoon season, the amount of rainfall was found to be highly variable, ranging between 658.60mm to 1654.90 mm. The average rainfall was 1109.29mm (± 202.39) (Table 3)

The monthly highest mean rainfall was recorded in August, measuring 311.46 ± 83.83 mm. In contrast, the lowest average monthly rainfall was observed in December, with a value of 6.94 ± 14.51 mm. In September 1986, the region received the highest recorded rainfall, reaching a maximum of 614.70 mm. Contrariwise, months such as January to April and October to December recorded the lowest rainfall, with a minimum of 0 mm, as shown in Table 4. Highest rainfall was observed during the monsoon season (Fig. 5).

The annual data of rainfall revealed higher consistency (CV=15.64%) than the remaining seasons, whereas the consistency of monsoonal rainfall is highest (CV=18.24%) among the seasons (see Table 3). The consistency was minimum and maximum, respectively, in August (CV=26.91%) and December (CV=209.07%). As a result, August experienced more consistent rainfall (Table 4).

Both MK and rho statistics demonstrated a considerable ($p<0.05$) rising trend of monsoonal (ρ =0.18, = 0.12) and annual (ρ =0.21, = 0.14) rainfall. However, no significant

Table 3: Trend of seasonal and annual rainfall.

Measures	Rainfall [mm]				
	Pre-monsoon rainfall [mm]	Monsoon rainfall [mm]	Post-monsoon Rainfall [mm]	Winter rainfall [mm]	Annual Rainfall [mm]
Minimum	55.9	658.60	5.50	0.00	889.50
Maximum	450.90	1654.90	322.40	160.20	2056.62
Mean	199.53	1109.29	125.28	40.55	1474.66
SD	78.77	202.39	70.72	30.51	230.66
CV	39.47	18.24	56.44	75.24	15.64
ρ	0.09	0.18**	0.14	0.10	0.21**
	0.07	0.12**	0.09	0.07	0.14**

τ, Kendall's tau, ρ, spearman's Rho

Note: significance value ***$p< 0.01$, **$p< 0.05$*

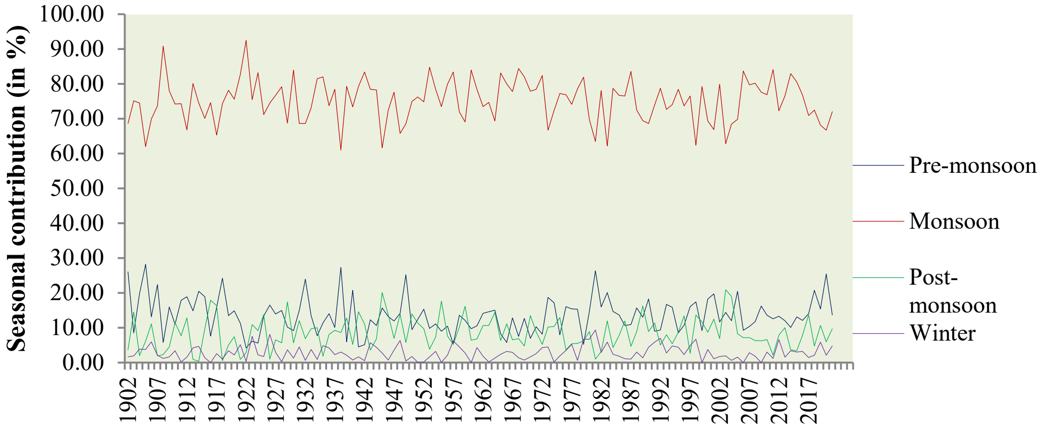

Fig. 5: Seasonal distribution of rainfall.

association with time was found for the remaining seasons (see Table 1). Considering the monthly rainfall, September exhibited a noteworthy (*p*<0.01) increasing (□ = 0.18, ρ =0.27) trend. Additionally, December also demonstrated a substantial (*p*< 0.05) upward trend in rho statistics (see Table 4). The graph depicting the deviation in rainfall showed an upward trajectory in the amount of precipitation received each year. The correlation analysis between the duration

Table 4: Status of monthly Rainfall with trend statistics.

Months	Minimum (mm)	Maximum (mm)	Mean (mm)	SD	CV	ρ	τ
January	0.00	56.10	11.38	13.51	118.71	.032	.021
February	0.00	15.6	22.23	23.11	103.95	.003	.005
March	0.00	148.3	30.89	31.19	100.97	.029	.029
April	0.00	189.80	57.35	40.09	69.90	.123	.089
May	8.20	283.40	111.28	55.30	49.69	.067	.047
June	43.70	592.90	253.17	107.59	42.49	-.057	-.037
July	111.60	551.60	303.31	93.66	30.87	.127	.086
August	147.40	553.50	311.46	83.83	26.91	.109	.069
September	18.60	614.70	241.34	94.90	39.32	.27***	.18***
October	0.00	322.40	111.62	67.44	60.41	.109	.065
November	0.00	77.40	13.66	18.62	136.31	.146	.097
December	0.00	96.87	6.94	14.51	209.07	.174**	.122

τ, Kendall's tau, ρ, spearman's Rho

Note: significance value ****p*< 0.01, ***p*< 0.05

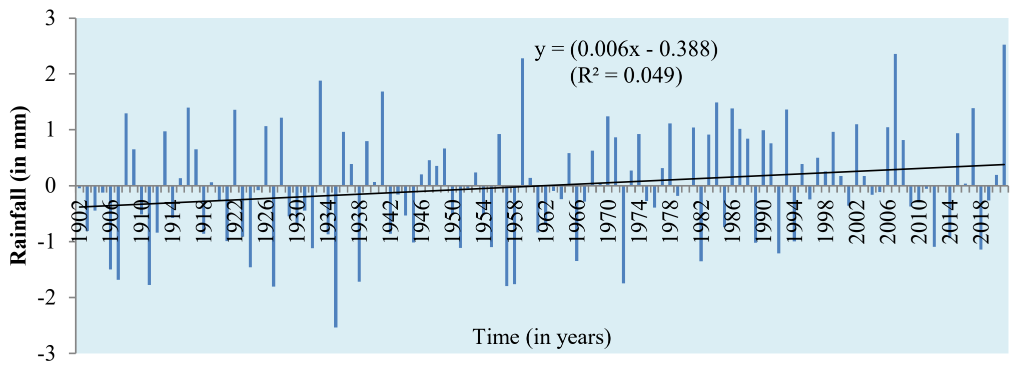

Fig. 6: Rainfall anomaly.

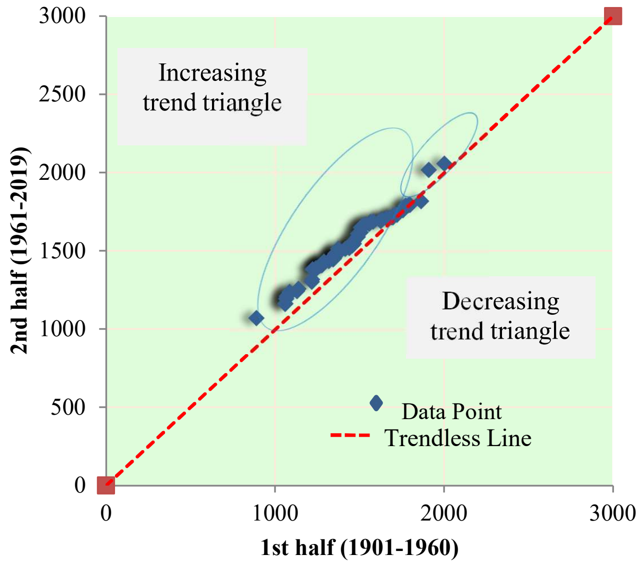

Fig. 7: ITA graph of rainfall.

(in years) and deviation from the average rainfall showed a positive correlation (r= +0.22). The trend of rainfall indicates a moderate and consistent rise over time (Fig. 6).

Innovative trend analysis (ITA) recognized the prevalence of increasing tendency throughout the study period, as most of the scatter points aggregated around the 1:1 line. Fig. 7 shows that most data points fall inside the positive trend triangle. The study duration (1901-2019) showed that the mean precipitation concentration index (PCI) was determined to be 17.45. This indicates that there were no years with little precipitation and, importantly, no uniform distribution of rainfall concentration (PCI=<10). From total study years, 16 have been found in moderate index, 79 have been found in high concentration index and the remaining 24 years have been observed to be very high (see Table 5). The PCI score confirms that the consistency and influence of monsoonal winds remain constant in Kolkata. Additionally, the PCI scores also increased by pre-monsoonal rainfall, largely due to intense thunderstorms (referred to locally as Kaal Baisakhi), also increased the PCI scores.

Table 5: Precipitation Concentration Index.

Index	Description	Number of years (1901-2019)
<10	Low concentration (almost uniform)	0
11-15	Moderate concentration	16
16-20	High concentration	79
≥21	Very high concentration	24

Note: Average PCI (1901–2019) =17.45 (implied high concentration of Rainfall)

DISCUSSION

The present research aimed to analyze and understand the trends and fluctuations of two major meteorological characteristics, namely temperature, and rainfall in Kolkata from 1901 to 2019. The MK and Spearman's Rho tests were used to examine the weather parameters' monthly, seasonal, and annual trends. The overall results demonstrated a noticeable change in the research region's temperature and precipitation patterns throughout the analysis. The results of the analysis indicate that the annual and seasonal (winter and summer) temperatures, as well as the temperature throughout all the months, are rising significantly (p<0.01). However, temperatures in January do not demonstrate any considerable trend. A previous study by Goswami (2018) indicates that the long-term mean minimum temperature data of Kolkata shows a declining trend in January that intensifies the cold spell during winter, resulting in a non-significant trend of temperature during this month of every year. The study's use of innovative trend analysis for statistical purposes also revealed an increasing temperature trend, as shown in the graph, where most scatter points were concentrated on the side of the positive trend triangle. Out of all the months, June had a consistent temperature. This intensifying temperature amplifies the risk of heat-associated diseases and water shortages in urban regions (Paul 2021, Ravindra et al. 2024). Throughout the research period, monsoonal and annual rainfall rose significantly. Regarding monthly distribution, rainfall amplified drastically only in September and December months. The highest CV was observed during the winter season, which implies more inter-annual variability for this season, whereas the lowest inter-annual variability was observed in the monsoon season as a significant amount of rain occurs almost every year during this season due to the Indian Summer Monsoon (De et al. 2023)

The investigation of ITA and precipitation anomaly demonstrated a positive correlation between precipitation and slope across the duration of the research. The analysis found no persistent year with a low concentration of precipitation. However, the study noticed a high precipitation concentration for 79 years and a very high concentration for 24 years. Precipitation during the monsoon was found to be more consistent as the study shows less CV throughout the monsoonal months, i.e. June (42.49%), July (30.87%), August (26.91%), and September (39.32%). The variation between the maximum and minimum rainfall levels was significant during the monsoon season. A study by Hunt & Fletcher (2019) suggests that the central Bay of Bengal (BoB) is the region of strongest synoptic organization. Hence, in the present study, the variation that is observed in monsoon season rainfall may be attributed to the modulation by synoptic-scale tropical low-pressure areas (LPAs), the strongest of which is known as monsoon depressions. In addition, the Indian summer monsoon is a part of global circulation and exhibits variability in a variety of time scales, such as intra-seasonal, inter-annual, and inter-decadal, which may be connected to climate variations of a more global scale (Naidu et al. 2011). The present study's findings on temperature aligns with the other study done by various researchers in different parts of India taking different historical periods and found that temperature is significantly rising with time (Kothawale & Rupa 2005, Jaswal 2010, Choudhuri et al. 2012, Mandal et al. 2021, Das & Bhattacharya 2018).

The present study shows that monsoonal rainfall rose significantly throughout the study period, which may cause Pluvial flooding in Kolkata. Although this flooding is produced by various factors such as the natural slope, increasing concretization, indiscriminate dumping, and logging of drainage lines (Paul 2021), situated low in the Ganga delta is also a reason which makes the city more vulnerable to climate change (Randhawa 2024). Besides, the unassuming flooding at the high tide in Hoogly River is a recurring hazard in Kolkata (Dasgupta et al. 2013). Hence, more intense rainfall especially during monsoon, can lead to pervasive and severe flooding and bring the city to a standstill for many days.

The investigation on long-term trends of temperature on a monthly, seasonal, and annual basis, as well as the distribution of precipitation in Kolkata, indicates that various human-induced causes such as loss of vegetation and expansion of heat absorbing surfaces, livelihood, and consumption trend together with fuel burning and emission rates affect the magnitude of pollution in the city (Das 2022) and extensively linked with constant increase of surface temperature. Since the 1960s, India has seen a rapid rise in carbon dioxide (CO_2) emissions, mainly as a result of several anthropogenic activities for economic development. These activities also indirectly contribute to global warming. The increased range of these short-term climates forcing (SLCPs) pollutants traps excess heat and results in local climate warming. Raising temperatures and air pollution have a severe impact on public health since they aggravate respiratory and cardiovascular disorders, as well as a variety of chronic illnesses, including diabetes, cerebrovascular and renal disease.

Therefore, the present study suggests more government investments and initiatives to reduce greenhouse gas emissions and improve environmental quality by managing air pollutants in the area. Because over emission of greenhouse gases by human activities has led to the phenomenon of global warming and resulted in climate change (Prarikeslan et al. 2023). The urban planners, policymakers, and environmental managers in Kolkata should identify the root causes of climate change-related vulnerabilities the city may face, including natural system and socio-economic factors. Focusing more on a time-bound qualitative approach could help in assessing climate risk and adaption needs of the city, including: 'The City Resilience Index' (CRI), the 'Urban Adaptation Support Tool', and the 'UKCIP Adaptation Wizard' (Metroeconomica 2004), 'Climate Smart Cities Assessment Framework' (NIUA 2021). Additionally, multi-pronged approaches such as improving drainage systems, creating green spaces, and Adapting building codes to future climate settings and severe weather events (European Environment Agency 2023) could make the city more climate-friendly and less susceptible to climate change. IPCC (2007), after evaluating the deviation and distribution of climatic parameters, has also recommended developing an adaptation and preparedness plan at the regional level to deal with the changing climate. This will help in determining a sustainable method to formulate a rural-urban ecological conservation and environmental plan. In addition, management of land use and strict policies regarding population control could also be necessary to fulfill SDG 13 and make the city more inclusive, safe, resilient, and sustainable (SDG 11).

Strengths, Limitations, and Future Research Directions

This study is limited to the coarse resolution of CRU data, which may not capture small-scale variations of climatic parameters completely. Additionally, this study examined rainfall and temperature parameters, which may not express Kolkata's complex climate change trends. Adding humidity, air pressure, urban heat island effects, and other microclimates may assist in a better understanding of climate change in the study area.

To improve the accuracy of the variation of Observational station data, high-resolution satellite images and machine learning-based modeling are needed to improve the accuracy and also to capture the fine-scale variation and climate change.

CONCLUSIONS

The primary aim of this study was to explore the temporal fluctuations in monthly, seasonal, and yearly meteorological factors in the city of Kolkata, India. The findings indicate a significant increase in both seasonal (winter and summer) and yearly temperatures, as well as rainfall. The monthly data clearly shows a consistent upward trend in temperature across all months. The statistical evaluation of the innovative trend also indicated an upward tendency in both temperature and rainfall. The PCI shows a significant amount of precipitation, ranging from high to extremely high levels, throughout the majority of the years included in the research. Both the Mann-Kendall and Spearman's Rho statistics detected a substantial upward trend in the average summer, winter, and annual temperature. Furthermore, a considerable upward trend was discovered in the annual and monsoon season rainfall. The "United Nations World Meteorological Organization" demonstrated the risk of climate change, stating that "*we are the first generation to fully understand it and the last generation to be able to do something about it*". Our study's greatest strength is its contribution to the existing body of literature. We specifically focus on the temporal variation of climatic parameters in Kolkata, where various factors such as overpopulation, changes in social needs and demand, and the increase in factories with inadequate technological advancements have directly and indirectly contributed to the unpredictable nature of the environment. Given the urgency of the situation, immediate action is crucial to diminish the consequences of climatic issues.

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