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Nature Environment & Pollution Technology

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

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Abstract

Analysis of temporal dynamics of climatic parameters is indispensable for advancing the "Sustainable Development Goals (SDGs)-11 and 13". This study aims at assessing 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 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).

Key Words	Anomaly, Climate Research Unit (CRU), Rainfall, Temperature, Temporal changes
DOI	https://doi.org/10.46488/NEPT.2025.v24i03.D4258 (DOI will be active only after the final publication of the paper)
Citation of the Paper	Kanchan Paira, Moatula Ao, Brihaspati Mondal, Grace Bahalen Mundu, 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

INTRODUCTION

Climate change, a significant global environmental phenomenon, carries profound implications for human existence, economic growth, and ecosystems (Das and Bhattacharya. 2018). It is a phenomenon, by which all sectors of life in present day experiencing the extreme barbarity of climatic theatricality (Prarikeslan et al. 2023). According to "Human Development Report-2007-08", climate change is the most significant phenomena that humanity is currently confronting from 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 et al. 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 of global warming is anthropogenic activity. Specifically the emission of various greenhouse gases (GHGs) such as: carbon dioxide and methane from 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 in systematic change due to human activities such as the emission of Greenhouse gases. Average temperature of earth has also increased by 0.74 °C from the pre-industrial era due to substantial concentration of CO^2 in 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 earth might increase from 1.1 to 6.4 °C, and 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, heat waves, will take place more on a regular basis. 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, South East Asia, and the Indian subcontinent (Lonergan. 1998; Kolmannskog. 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 Bai 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 and Bhattacharya (2018) examined temperature changes from 1980 to present, 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; annual minimum temperature was increased with the increase of monthly minimum temperature. Using similar statistical tools to measure the change of temperature over Tripura, Tomar et al (2017) found that except in January and December months, the temperature over two stations has been augmented considerably between 1969 and 2014. Jaswal (2010) found a substantial rising trend of temperature in winter during 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 the consistent decline in yearly rainfall. Kothawale and 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 is 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 well understanding and designing of mitigation plan 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.

METHODOLOGY

Study area

According to the "Intergovernmental Panel on Climate Change", the Kolkata metropolitan area and its surroundings is warming tremendously. According to the atlas, the annual mean temperature of Kolkata might increased by almost 4.5ºC between 2081-2100, compared to pre-industrial period, if the emission of green house gases not restrained (Basu. 2021). During the period 1950 to 2018, Kolkata metropolitan reported the maximum increase in 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 the public health drastically. Therefore, the city was selected in this study to investigate the trend of long-term climate parameters for understanding the climate change by which its possible adverse impacts on the city can be minimized.

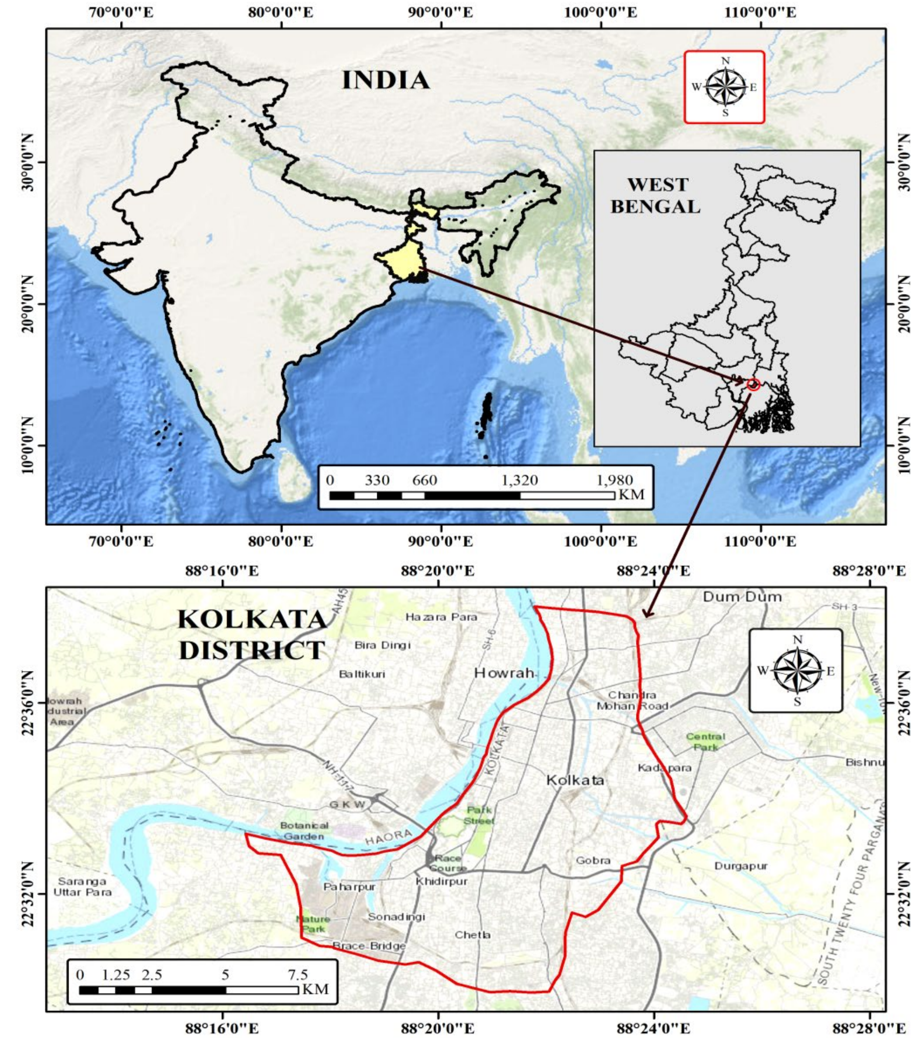

Fig. 1 Location map of the study area

Data Source

Temperature and rainfall data have been accumulated from 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 centred at 22º 33'54.22" N and 88º 21'30.76"E (fig 2).

Data analysis tools

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; A. 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 are likelihood of outliers to be 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 trend in a time series (Lehmann, 1975, Sneyers, 1990). Therefore, the power of both methods rely on the size of 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 trend, the tests become more powerful; with the increase of sample size, the tests become more powerful; and the power of the tests decreases with the increase of degree of variation within a time series,. So, two tests have identical power in detecting a trend (Yue et al., 2002)

Sen's (2012) Innovative Trend Analysis (ITA) was also used for trend analysis. Recently, 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 ITA method has more advantages and also more practical in detecting hydro-meteorological series trends than MK test (Dabanlı et al., 2016; Wu and 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.

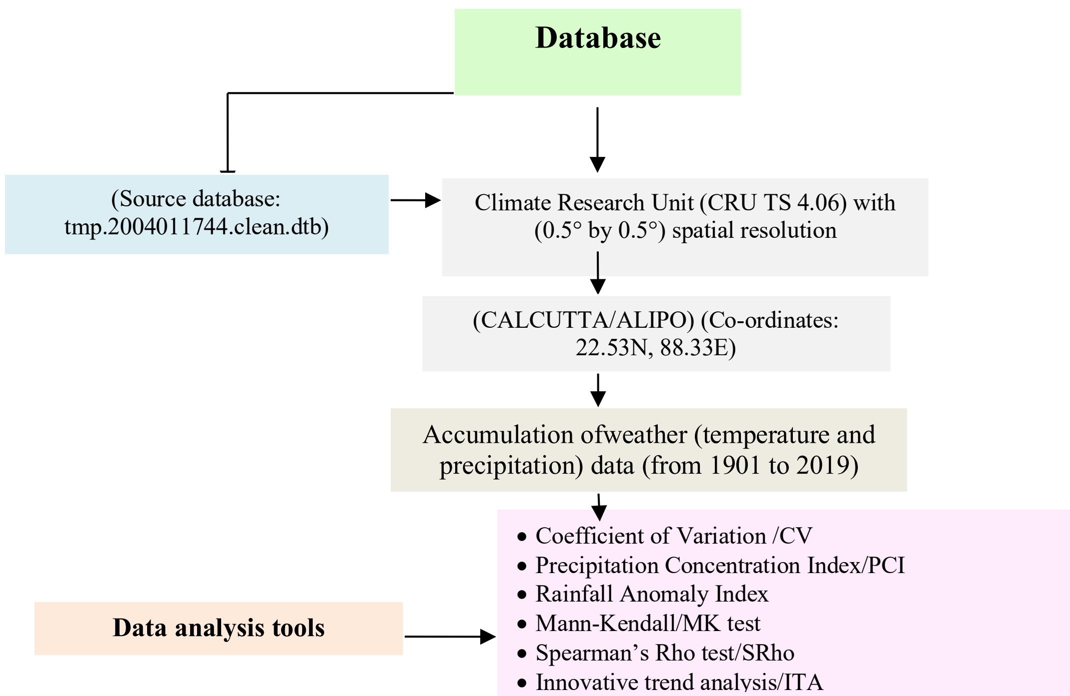

Fig 2: Data source and analysis techniques

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 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 (τ = 0.33, ρ =0.46), summer (τ = 0.23, ρ =0.34), and winter (τ = 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 months except January, while the result of rho shows a noteworthy (p < 0.05 and p<0.05) increasing trend in every months except January (see table 2).

The average annual temperature was observed to be rising in 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 case of temperature has confirmed the ascendancy of increasing trend throughout considered period, as the scatter points are aggregates mostly above the trendless line (Fig 4).

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

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

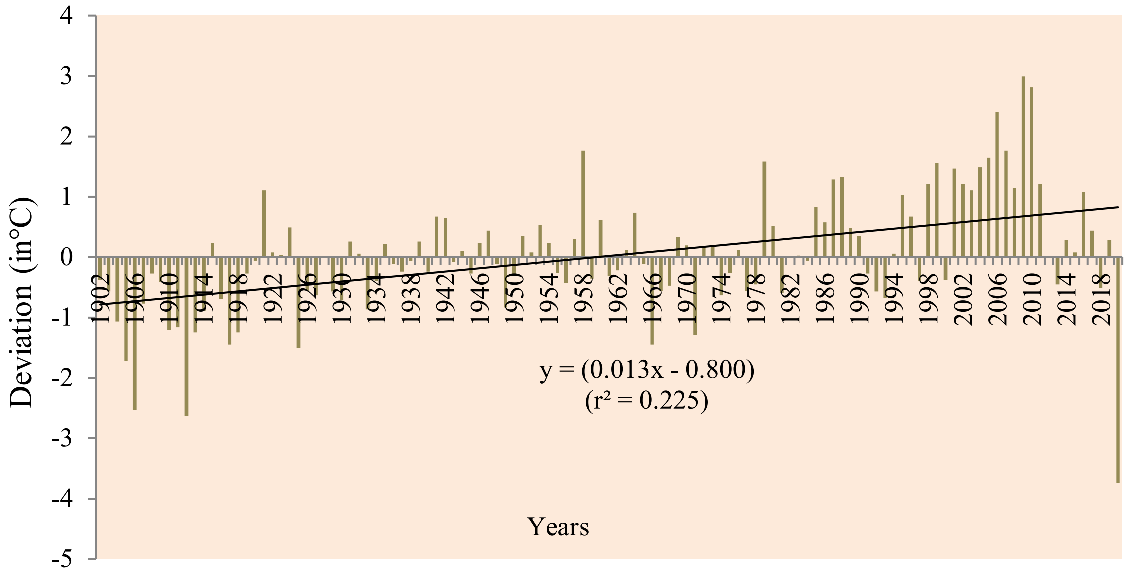

Fig. 3: Temperature anomaly

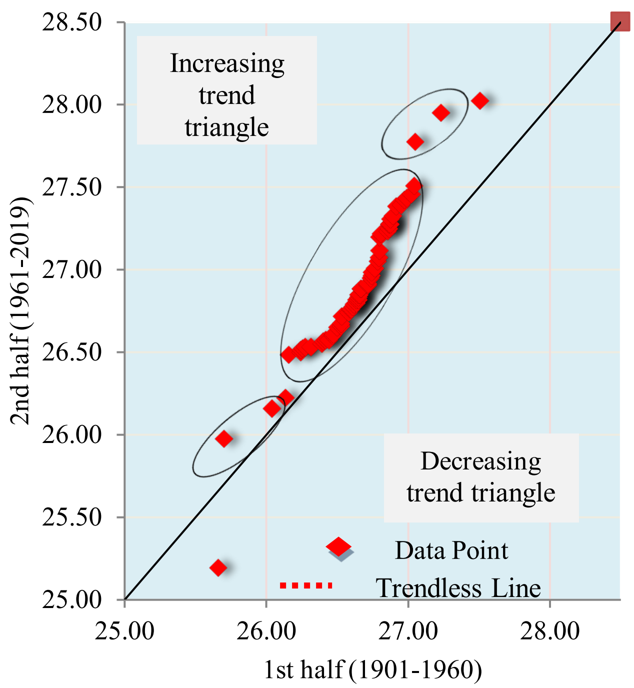

Fig 4: ITA graph of temperature

Rainfall trend in Kolkata District (1901-2019)

The annual rainfall, 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) (see table 3)

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, had recorded 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 high 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 (see table 4)

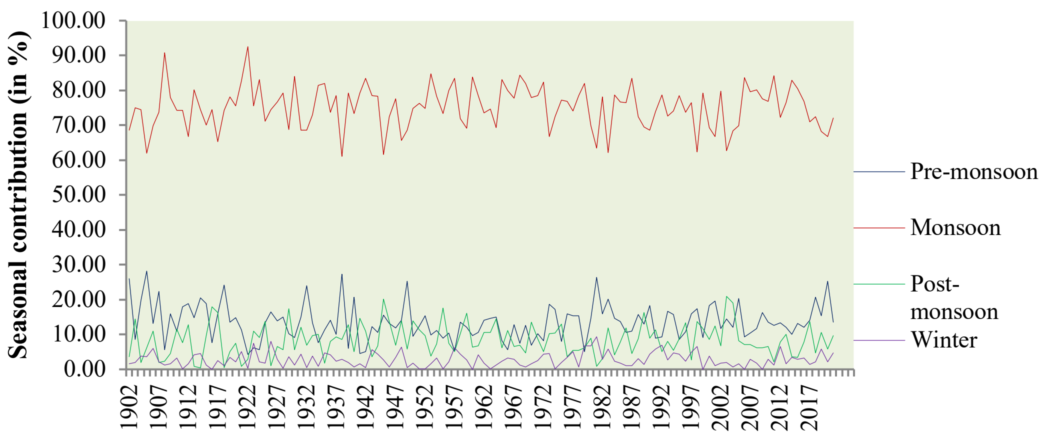

Fig 5: Seasonal distribution of rainfall

Both MK and rho statistics demonstrated a considerable (p<0.05) rising trend of monsoonal (ρ =0.18, τ = 0.12)

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**
τ	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

and annual (ρ =0.21, τ = 0.14) rainfall. However, no significant association with time was found for the remaining seasons (see table 1). Considering the monthly rainfall, September exhibited a noteworthy (p<0.01) increasing (τ = 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 (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).

Table 4: Status of monthly Rainfall with trend statistics							
Months	Minimum(mm)	Maximu m (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

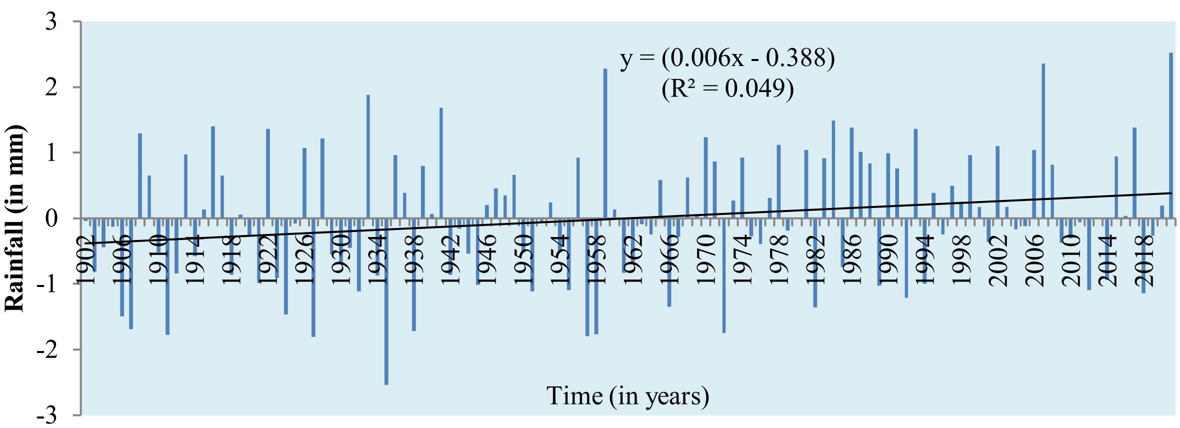

Fig 6: Rainfall anomaly

Innovative trend analysis (ITA) recognized the prevalence of increasing tendency throughout the study period, as most of the scatter points aggregating around the 1:1 line. Figure 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 24years 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 occurred due to intense thunderstorms (referred to locally as Kaal Baisakhi locally), also increased the PCI scores.

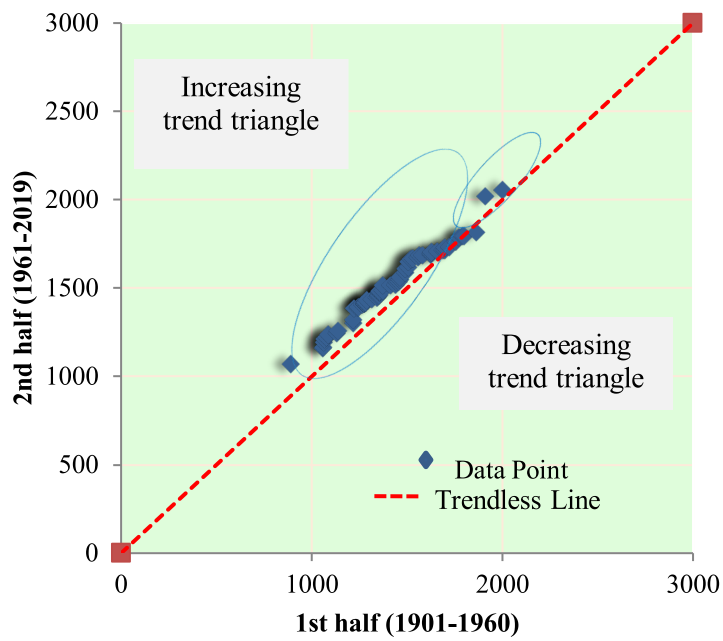

Fig 7: ITA graph of rainfall

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) temperature 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. Previous study by Goswami (2018) indicates that the long-term mean minimum temperature data of Kolkata shows declining trend in the month of January that intensifies the cold spell during winter, resulted in 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 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 region (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. Highest CV was observed during winter season that implies more inter-annual variability for this season, whereas lowest inter-annual variability was observed in monsoon season as significant amount of rain occurs almost in every year during this season due to 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 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 and Fletcher (2019) suggests that the central Bay of Bengal (BoB) is the region of strongest synoptic organisation. Hence, in present study, the variation that is observed in monsoon season rainfall that may be attributed to the modulation by synoptic-scale tropical low pressure areas (LPAs), the strongest of which are 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, inter-decadal, which may be connected to climate variations of a more global scale (Naidu et al., 2011). Present study findings on temperature aligns with the other study done by various researchers in different part 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. 2013; Das and Bhattacharya. 2018).

Present study shows that monsoonal rainfall rose significantly throughout the study period which may cause in 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), but 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 fetch 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 resulted in local climate to warm. 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 green house gases by human activities have 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 time-bound qualitative approach could help in assessing climate risk and adaption needs of the city including: '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 approach such as: improving drainage systems, creating green spaces, Adapting building codes to future climate setting 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 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 fulfil 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 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 absolutely express Kolkata's complex climate change trends. Adding humidity, air pressure, urban heat island effects, and other microclimates may assist in better understanding of climate change in the study area.

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

CONCLUSION

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.

Declarations

Funding

This research did not receive any funding from any source

Competing interests

Not applicable

Data Availability

Data is available to the public at: https://crudata.uea.ac.uk/cru/data/hrg/cru_ts_4.04/ge/

Author's Contribution

All the authors contributed to the study conception. Data preparation and analysis were performed by Kanchan Paira and Brihaspati Mondal. The first draft of the manuscript was written by Kanchan Paira.Kanchan Paira, Moatula Ao and Grace Bahalen Mundu reviewed and edited the first draft of manuscript. All authors read and approved the final manuscript.

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