NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ

Bulletin of Geography. Physical Geography Series, No. 23 (2022): 5–16
http://doi.org/10.12775/bgeo-2022-0006

Statistical analysis of rainfall trend and its variability (1901–2020) in Kolkata, India

ISSN 2080-7686

OPEN ACCESS

Md Juber Alam[1], Arijit Majumder*[2,b]

[1,2]Jadavpur University, Department of Geography, Kolkata, India

*E-mail: amajumder.geography@jadavpuruniversity.in
[b]https://orcid.org/0000-0001-9330-5310

Abstract. The current study focuses on the altering historical rainfall data analysis and its variability in Kolkata (Kolkata Municipal Corporation), a metropolitan city in India. The research area experiences detrimental urban floods (pluvial floods) at near-annual regularity during the monsoon, and during the pre-monsoon seasons it commonly experiences water shortage problems. Analysing trends and temporal variability of rainfall over 120 years from 1901 to 2020 is the main objective of this study. The original Mann–Kendall (M–K) test has been applied to the rainfall dataset in conjunction with Sen's Slope Estimator using Python 3.10, after the Durbin–Watson (DW) statistic initially suggested that there is no serial correlation effect. The M–K test, with a Kendall's tau of 0.17058 (significant at a 5% level), shows an upward trend in annual rainfall between 1901 and 2020. The Sen's slope, which measures the rate of change annually, has a value of 2.48152. Regression analysis and other dispersion measures are also used in this study to investigate the monthly rainfall trend and its variability. The phase-wise (30-year) analysis of annual rainfall variability reveals a considerable variation over 120 years. While fitting the linear regression line month by month over the entire period, mostly negative trends were found in the pre-monsoon and positive trends in the monsoon and post-monsoon seasons. The findings of this analysis could be useful to urban planners for water supply and management in the study area. The primary concern of planners for effectively managing rainwater and the accompanying issues should be the growing variability of annual precipitation.

Key words:
trend analysis,
Mann–Kendall test,
Sen's slope estimate,
rainfall variability

Introduction

The study of rainfall trend analysis is critically important in Indian cities like Kolkata that have a high water demand. It is the primary source of groundwater, which slowly seeps into the ground and raises the water table. Therefore, the proper trend analysis of rainwater is necessary for planners involved in supporting the sustainable use of rainwater. The analysis of long-period rainfall data provides information about the temporal pattern and its mutability. Detailed knowledge about the trend and capricious nature of rainfall is an imperative prerequisite for planners regarding urban water management to reduce the gap between water demand and availability. The term "climate" is typically used to refer to the average weather, or more precisely, to the statistical description of important parameters over timescales ranging from months to thousands or millions of years (IPCC-SAR 1995). The World Meteorological Organization specifies 30 years as the traditional time frame for averaging these variables. One of the fast-paced components of climate change is rainfall. The amount and pattern of rainfall obtained in each region are significant in determining the quantity of water required to meet the demands in various sectors such as agriculture, manufacturing, household and hydropower. The study of rainfall pattern analysis in highly urbanized areas is of dynamic importance for various purposes, such as flood forecasting, water resource management, hydrological modelling, climate change, planning, etc.

Effective Global Circulation Models (GCMs) have been used in a study (Malik et al. 2020) to determine the type and pattern of annual maximum precipitation events in the Kolkata Metropolitan Area. The rainfall data of the Alipore Kolkata station (1901–2013) were considered for analysis of that study and the results showed that the specified area's rainfall follows natural patterns of variability and oscillation. The Bhilangana River Basin in Uttarakhand Himalaya has been studied to detect spatio-temporal patterns and changeability in yearly, periodic and monthly rainfall connected with the number of rainy days. According to the findings, the catchment decreased by 15.75 millimetres of rainfall per decade on average between 1983 and 2008 at all surface observatories (Banerjee et al. 2020). The seasonal rainfall trends from 1901 to 2002 and the inclination were determined using the Mann–Kendall test, while the magnitude of these trends were determined using Theil–Sen's slope calculator (Kundu and Mondal 2019). Long-term spatial and chronological rainfall pattern based on 102 years of rainfall data from 12 meteorological stations of Gangetic West Bengal between 1901 and 2002 have been analysed on a weekly, seasonal and annual scale (Ghosh 2018). The results of that study showed that, between 1901 and 2002, the average annual precipitation increased 2.61 percent while the post-monsoon precipitation increased considerably by 33.87 percent. The Indian Meteorological Department's monthly rainfall data between 1901 and 2000 have been used to produce district-wise annual rainfall variance statistics throughout West Bengal, where a surplus (1.5–2 percent) was seen throughout the state (Das et al. 2018). Global climate transformation and the risk of intensifying droughts and floods will influence long-term rainfall patterns affecting water supply (Pal et al. 2017). The Mann–Kendall, Sen's slope and sequential Mann–Kendall tests have been used to analyse seasonal and annual rainfall chronological trends and their fluctuations through time in Bangladesh, in order to determine the abrupt changes in rainfall data over 50 years (Bari et al. 2016). Climatic variability has been analysed in south-west England based on present and historical climatic data, which shows that the study on local climate modification has a great importance, as the trends that initiate in localities can differ from nationwide and worldwide estimates (Kosanic et al. 2014). To measure rainfall and temperature trends over thirteen districts of Uttarakhand, the M–K test with Sen's slope estimate has been used, which revealed an increasing inclination of precipitation and temperature in some months in contrast to a decreasing trend in the other months, implying inconsistent inclusive variations in the region (Yadav et al. 2014). To fit a model on the monthly and periodic rainfall pattern over the Langat River basin, Malaysia, from 1970 to 2012, Holt's assessment has been applied, which showed an upward trend in March, July and November while showing a declining trend in May and September (Huang et al. 2015). In order to detect trends in temporary rainfall changes over India, the non-parametric Mann–Kendall test has been used, and the magnitude of the trend was determined using Sen's slope estimator (Kumar et al. 2010). Temporal rainfall shifts have been analysed in the north-east part of Cuttack, Orissa, with a statistical test that displayed an upward trend over a few months and a downward trend over another few months and with insignificant changes to the region in general (Mondal et al. 2012). A study has been performed to detect precipitation trends and variability in Scotland. In accomplishing their objectives in detail, the CUSUM and chronological Mann–Kendall test were incorporated (Afzal et al. 2011). Understanding climatic variability requires that climatic records covering a long-term period be available (Brunet and Jones 2011). Awareness of historical and tropical climate change has gained significant consideration by enhancing and expanding a wide variety of databases and more advanced data analysis around the globe (Kumar et al. 2010). Historical rainfall shifts over the Indian Himalayas have been monitored for trend analysis using the Mann–Kendall test. This revealed a rising trend in the period 1902–1964, whereas rainfall patterns were declining from 1965 to 1980 (Manatsa et al. 2008). The prediction of South Asian summer monsoon precipitation shows an increasing trend based on the multi-model ensemble technique (Kripalani et al. 2007). The interannual and short-term climate variability over the Southeast Asian region have been investigated and understood using seasonal and annual rainfall data from 135 stations over durations ranging from 25 to 125 years (Kripalani and Kulkarni 1997). A total of 135 years of monthly data (1871–2005) for 30 Indian sub-divisions (sub-regions) have been used to examine rainfall trends on a monthly, seasonal and annual scale. Current studies (Shrestha et al. 2000; Monirul Qader Mirza 2002; Dash et al. 2007; Panda 2007) elucidate that, although the frequency of rainy days and the annual rainfall have dropped in many parts of Asia, the occurrence of more intense rainfall events has increased.

Therefore, this study's objective is to determine the inconsistency and rainfall trend in Kolkata, highly urbanized districts in West Bengal, as well as in India. A detailed analysis of the study area's rainfall data for the period 1901–2020 has been carried out. The monthly and yearly pattern of rainfall and its changeability in different periods have been analysed. This incorporates comprehension of the region's rainfall patterns and their changeability. The realization of the uncertainties and patterns associated with rainfall would provide a database for improved water demand management.

Study area

The present investigation covers the entire Kolkata Municipal Corporation, which extends from 22°27'28" North to 22°38'20" North and 88°15'50" East to 88°28'45" East (Fig. 1). The total area under study covers 187 km^2, which has been obtained by vectorisation of the Kolkata Municipal Corporation (KMC) map in UTM projection and WGS84 datum on ArcMap 10.2. The district of North 24 Parganas borders the area under study to the north and north-east, the district of South 24 Parganas to the south and the Hooghly River to the west. The whole area is in the delta of the Ganges, which is repetitious in nature. The Bay of Bengal coast is about 96 km to the south. The climate of the study area is tropical. A highly humid summer, a brief spring, a rainy autumn and winter are the main seasons. The south-west monsoon continues to be the primary source of precipitation in the area under study; hence, four months of the year (June, July, August and September) receive the maximum amount of rainfall.

The land-use land-cover map of Kolkata municipal corporation has been generated from

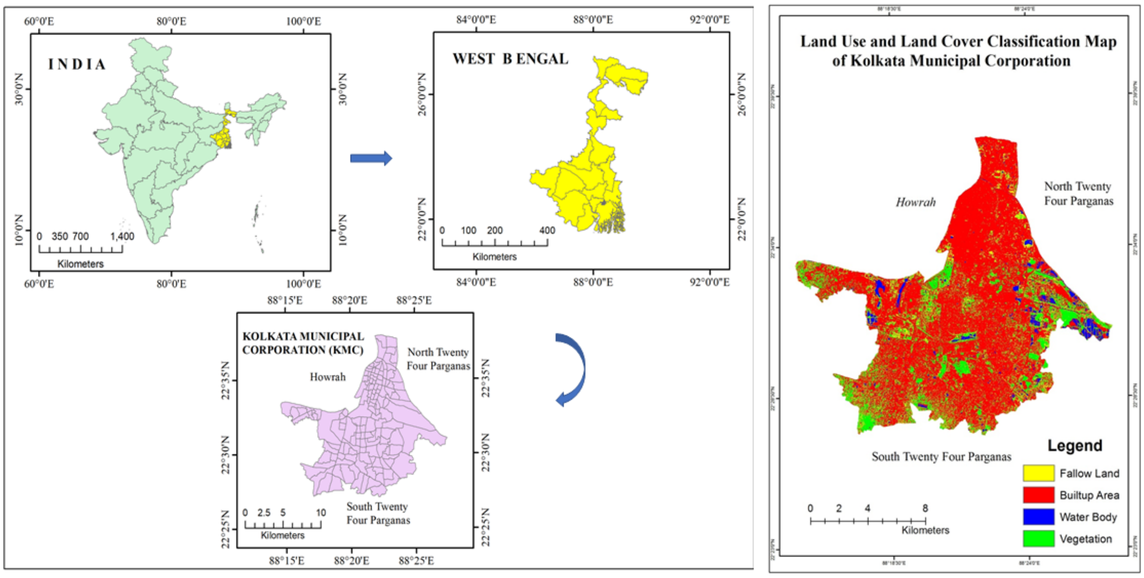

Fig. 1. Spatial extension of the study area. Source: Computed by ArcGIS 10.2

a Sentinel 2A (2019) image in ERDAS IMAGINE 2014. It was found that the total built-up area (Fig. 1) in KMC accounts for 82.23 percent of the total area. The massive cover of the built-up area coupled with the declining trend of groundwater level (CGWB) in KMC is a matter of concern regarding the future sustainability of water availability in the area. Therefore, this study becomes significant for the future sustainability of the city.

Materials and methods

Average monthly rainfall statistics have been retrieved for 120 years from 1901 to 2020 for Kolkata Municipal Corporation (KMC) from a web-based spatial data portal water resource information system of India (India Water Resources Information System, 2016) for water-related data dissemination. The IMD grid data of Kolkata have been used in this study to analyse the rainfall. The monthly rainfall data have been combined to total rainfall at periodic and yearly scales for trend analysis. In this study, the long-term rainfall data have been used to analyse rainfall trend and variability with the help of different statistical techniques using Python and MS Excel. In order to determine the trend of annual rainfall and its magnitude, a non-parametric Mann–Kendall test and Sen's slope estimator have been applied. In this analysis, Python (10.3 version) – a high-level, general-purpose programming language – has been used to measure the Mann–Kendall Pattern and calculate Sen's slope. The time series rainfall data has been analysed monthly and annually. Mean, standard deviation and coefficient of variation have been used to detect rainfall variability in the study area. Finally, various graphical methods have been used in this study.

Trend analysis

The trend is characterized as the overall development of an arrangement throughout an all-inclusive timeframe. It is the dependent component's drawn-out shift over a considerable period (Dash et al. 2007). Factual trends can be used to attempt to predict the future developments of a specific variable by breaking down chronicled patterns. The original Mann–Kendall test has been used to determine whether there is a significant trend in 120 years of rainfall over the research area, and Sen's slope estimator was used to determine the magnitude of the trend in the current analysis. For some time, the settled trend test Original Mann–Kendall has been used to classify global precipitation shifts.

Mann–Kendall (M–K) test

The M–K test is a non-parametric statistical tool commonly used in trend analysis of climate and hydrological time series data. In the field of environmental chronology, this test has been widely adopted (Mann 1945; Kendall 1975). This test has the advantage of being a non-parametric test that does not require that the series data be uniformly spread. It is also to be mentioned that the test lacks sensitivity to sudden breaks in time sequence. The rainfall data is independent and randomly ordered; therefore, according to the null hypothesis, H0 shows no pattern, while the alternative hypothesis H1 indicates a trend (increasing or decreasing). The M–K test does not make any assumptions about normalcy and reveals the direction, not the magnitude of significant trends. (Mann 1945). For a given data set Xi = x1, x2,…, xn, the M–K assessment statistic S is computed as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sign}(x_j - x_i)$$

Where x_j and x_i denote yearly rainfall amounts in years, with j higher than i and n the number of years. The following formula is used to find the value of sign (x_j-x_i):

$$\operatorname{sign}(x_i - x_j) = \begin{cases} -1 & \text{if} \quad (x_j - x_i) < 0 \\ 0 & \text{if} \quad (x_j - x_i) = 0 \\ 1 & \text{if} \quad (x_j - x_i) > 0 \end{cases}$$

This statistic indicates the sum of positive and negative differences for all variances evaluated. The test is carried out with a standard estimation (Z statistics) for large samples (N>10), with the mean and variance as follows:

$$\text{S has an average of E[S]} = 0$$

The following equation is used to determine the variance of S:

$$\mathrm{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{k=1}^{m} t_k(k)(k-1)(2k+5)}{18}$$

Where n is the number of years, m is the number of tied groups in the rainfall data sets, and t_k is the number of the k^{th} tied group's data points. To detect a significant trend, standardized test statistics, Z, are used. The values of S and $VAR(s)$ are utilized to measure test statistics Z, which is as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\mathrm{Var}(S)}} & \text{if } S < 0 \end{cases}$$

This particular test has been determined with the function *mk.original_test (df)* by importing pymannkendall library in Python. The Z value is used to determine whether a trend is factually relevant. A positive Z number denotes an upward trend, while a negative value denotes a downward trend. The statistically significant trend test is commenced at a specified significance level α. When $|Z| > Z_{1-\frac{\alpha}{2}}$, reject the null hypothesis, and the time series shows a significant trend.

Sen's slope estimator

A non-parametric approach to computing the rate or degree of inclination in the time series data was developed. In this method, the slope βi is determined as the following equation from all data sets:

$$\beta_i = \frac{x_j - x_k}{J-k} \qquad \text{for k = 1,2,3, ..., N}$$

Where x_j and x_k are the respective data values at the time j and k ($j>k$). There would be the same number as N = n(n-1)/2 slope estimates β_i if there are n values x_j in the time series. The median of these N estimates of β_i is Sen's evaluator of slant. *Bi*'s *N* estimates are positioned from the smallest to the largest, and Sen's slope estimator is determined as the following equation:

$$\beta med = \begin{cases} \beta_{i\left(\frac{N+1}{2}\right)} & \text{When N is odd} \\ \frac{1}{2}\{\beta i._{\frac{N}{2}} + \beta i(\mathrm{N}+2)/2\} & \text{When N is even} \end{cases}$$

The Sen's estimator is measured as βmed = βi (N+1)/2 if N is odd and βmed = [βi N/2 + βi (N+2)]/2 if N is even. In the end, βmed is measured at a 100 (1-α) percent confidence interval by a two-tailed test, and then the non-parametric assessment will achieve an actual slope. In the time series, a positive value of β_i denotes an upward or progressive trend, whereas the negative value of β_i suggests a downward or regressive trend. This approach has been used to measure the factual slope of a current trend such as the sum of change per year, and the test was carried out in this paper using Python version 3.10.

Autocorrelation effect

In a normal M–K test, it is assumed that the recorded dataset is serially independent. However, some substantial autocorrelation coefficients may occur in the time series data, and hence it is required to test autocorrelation while examining a series of historical data. To test autocorrelation, the Durbin–Watson (D–W) statistic has been applied by using the function *durbin_watson*(*model.resid*), which has been imported from the statsmodels library in Python to determine whether the residuals of the regression model are autocorrelated or not. The following formula has been used to obtain the D–W test statistic:

$$d = \sum_{t=2}^{T} ((e_t - e_{t-1})^2) / \sum_{t=1}^{T} e_t^2$$

Where T is the total number of observations. The value of the test statistic is approximately equal to 2*(1-r), where r is the sample autocorrelation of the residuals. The D–W statistic will always fall within the range of 0 to 4. Values between zero and less than two indicate positive autocorrelation. In contrast, values between two and four indicate negative autocorrelation, with 2.0 denoting the absence of any such correlation in the sample. If the data is autocorrelated, then a modified M–K test has to be used to detect the trend instead of the original M–K test.

Results and discussions

Annual rainfall trend analysis

In this study of 120 years of annual rainfall analysis, the highest rainfall between 1901 and 2020 was found in 1962 (3,588.19 mm), and the lowest annual rainfall was recorded in 2012 (385.33 mm). The mean annual rainfall and standard deviation for 120 years are 1,591.86 mm and 390.371 mm, respectively.

Autocorrelation check

The D–W statistic has been used to examine the autocorrelation effect over 120 years of annual rainfall using Python. This test yielded a value of 2.00, demonstrating that the data series are serially independent and therefore performing the original M–K test seem to have no bias on the trend analysis results.

Mann–Kendall test

The annual rainfall trends have been obtained using the non-parametric ordinary M–K test. To assess the presence or absence of the trend at 5% level of significance, the M–K test has been performed using Python (version 3.10). The results of this test for 1901 to 2020 are presented below in Table 1.

The M–K assessment displayed that Kendall's tau is 0.17058 and the p-value is 0.00577 at 5% significance level. In this study, the rainfall trend has been analysed with respect to time from 1901 to 2020. Kendall's tau, which ranges from 0 to 1 (0 represents no relationship and 1 represents perfect relationship), measures the non-parametric relationship between the columns of ranked data. It shows that there is a trend of total annual rainfall during the years from 1901 to 2020. Here, the derived p-value is less than the level of significance alpha=0.050, indicating that the null hypothesis H0 is rejected, and the alternative hypothesis Ha is accepted. This also suggests a trend in rainfall during testing, which is supported by the test results. It is also displayed in the results that the Z value is 2.76044, which confirms an increasing annual rainfall trend over time.

Sen's slope estimator

Sen's slope estimator has been adapted to compute the magnitudes of the trends for the yearly rainfall series in the study area from 1901 to 2021. The Sen's slope estimate (Table 2) shows a marginally increasing trend of annual rainfall over the area under study with Sen's slope of 2.4807. The Sen's slope of 2.48 implies that the rainfall is increasing at a rate of 2.48 millimetres annually. Figure 2 shows the Theil–Sen regression line, which is plotted in red, at 95% confidence interval (shown in a dotted line).

Monthly rainfall trend analysis

The trend of monthly rainfall over 120 years is obtained by linear regression, as illustrated in Figure 3. In this section, a month-wise rainfall trend has been plotted with linear regression over the whole time series data. From the analysis, it has been found that rainfall increased in the months from May to December, while it decreased over the months of January to April. In October, the highest increasing trend of rainfall is observed at the rate of 0.5537 millimetres per year, while a declining trend is detected in February by a maximum of 0.1118 mm per year (Fig. 3). From monthly rainfall trend analysis, it is observed that during June, i.e., the initial month of monsoon, the amount of rainfall is slightly increasing at a rate of 0.1306 mm per year (Fig. 3). It is also noted that, particularly in the pre-monsoon period, except for May, there is a negative trend of rainfall over the years which need to be taken as a great concern by planners because there were also water shortages in this period.

It is crucial to analyse monthly rainfall trend and its unpredictability, as it helps decision-makers to manage urban water resources in a sustainable way.

Annual rainfall variability

Exploring rainfall variability is an essential parameter for researchers and decision-makers for their decision-making in water conservation and solving any water-related problems.

Here, in Table 3, the coefficient of variation has been determined for the analysis of annual rainfall variability. Therefore, the total time periods of 120 years from 1901 to 2020 have been divided into four phases, each phase comprising 30 years (Table 3) of total annual rainfall. In this analysis, it has been detected that the mean annual rainfall increased from the first to the second phase and

Table 1. Result of Mann–Kendall trend test in Python 3.10

Mann–Kendall trend test result	
Trend	Increasing
h	TRUE
P	0.00577
Z	2.76044
Kendall's Tau	0.17058
S	1218
var (s)	194,366.6667
Alpha (α)	0.05

from the second to the third phase but declined in the fourth phase compared to the third. It has also been observed that the coefficient of variation increased from the first to the second and the second to the third phase but decreased in the fourth phase as compared to the third phase. So, it can be deciphered that the overall annual rainfall variability has been increasing over the years. Usually, it is seen that the coefficient of variation is lowest in the first phase (1901–1930) with 15.91% and highest in the third phase in the years 1961–1990 with 26.71%. This ever-increasing coefficient of variation implies that the inconsistency of temporal precipitation increases and demands more concern for water management in the study region.

Table 2. Sen's slope estimation

Sen's slope estimation results	
Intercept	1,396.12447
Slope	2.48152

Monthly rainfall variability

The box-and-whisker plot depicts the monthly variation of 120 years' rainfall from 1901 to 2020. Box-and-whisker plots have a compact appearance (Tukey 1977) that allows us to compare next to each other many variables that can be hard to decipher using more comprehensive illustrations such as bar charts (Banacos 2011). A middle horizontal line depicts the median, the box's upper and lower horizontal lines depict the interquartile range, and the whisker plot shows the range value.

Box-and-whisker plots are a common approach to depicting the distribution of data based on a five-number summary. The minimum, first quartile, median, third quartile and maximum make up the five-number summary. The middle line of the box represents the median value of the datasets and each box has lines extending from it to capture the remaining data's range. Half of the values of the box are higher than the median, while the other half are lower. Figure 4 shows that the month of July has the highest median monthly rainfall, while the month of December has the lowest. The length of each whisker in the above figure is a measure of

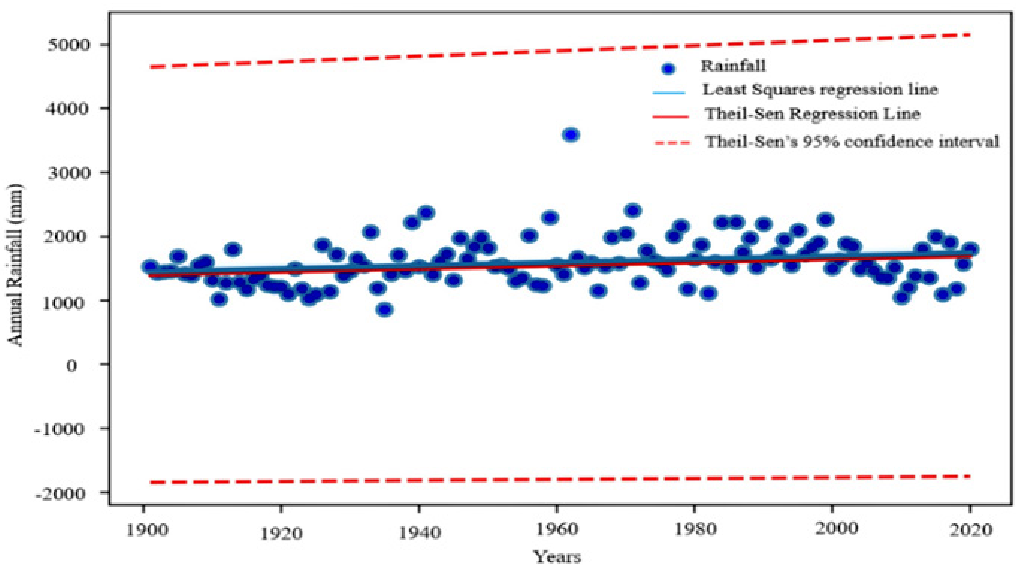

Fig. 2. Trend of annual precipitation total from 1901 to 2020 with Sen's slope estimation using Python

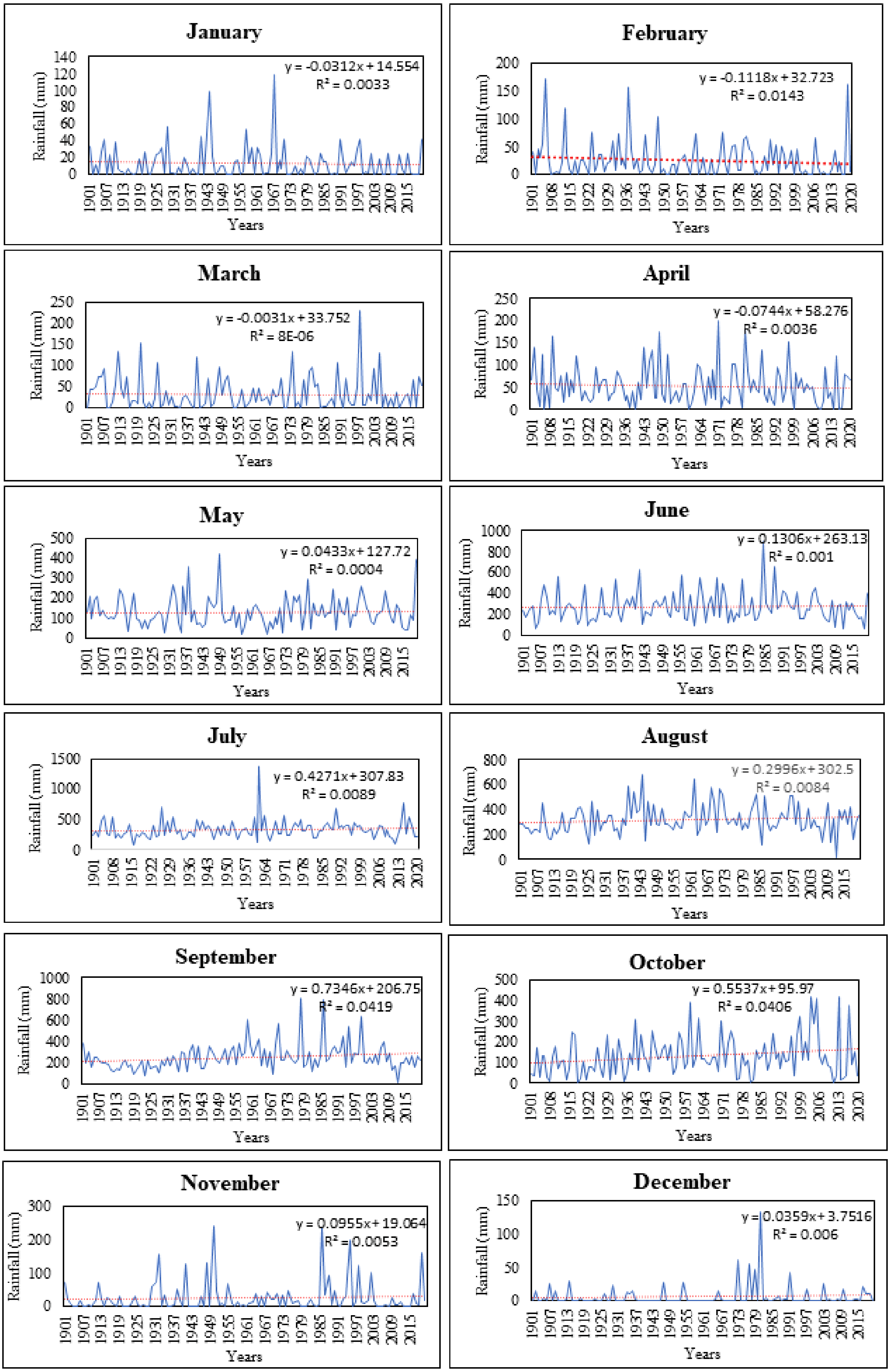

Fig. 3. Monthly rainfall totals with trend line, 1901–2020

the dataset's outer range, just as the extent of the interquartile range (as represented with the box in Fig. 4) is quintessential of the dataset's centre half's relative dispersion (10th to 25th percentile and 75th to 90th percentile). The above figure shows that the higher dispersion in the middle half of the datasets is in the month of monsoon periods. The whisker depicts how markedly different the extremes are from the remainder of the dataset. Significant dispersion of relative outliers has been observed in this analysis, with the highest extreme values occurring in June, July and September. This scenario is evident from (Fig. 4) the box-and-whisker plots that

The analysis of the long-term rainfall trend and its variability will be supportive in examining the viability of rain harvesting implementation. For instance, there will be less demand for storage in an area where rain falls throughout the years, and this will lower the cost of the system. On the other hand, the cost of the system will be significant where the rain falls during short-term periods with high intensity. In this approach, research on rainfall trends – and on variability in particular – is essential to estimate the rainfall storage capacity, which eventually helps to address the water crisis. the datasets are not customarily detailed. The analysis shows that the area's rainfall is decidedly capricious, and increasingly so over time.

The analysis of the long-term rainfall trend and its variability will be supportive in examining the viability of rain harvesting implementation. For instance, there will be less demand for storage in an area where rain falls throughout the years, and this will lower the cost of the system. On the other hand, the cost of the system will be significant where the rain falls during short-term periods with high intensity. In this approach, research on rainfall trends – and on variability in particular – is essential to estimate the rainfall storage capacity, which eventually helps to address the water crisis.

Conclusion

The current research examined the yearly and monthly rainfall trend and its variability over 120 years of rainfall for Kolkata Municipal Corporation (KMC). The Mann–Kendall test revealed a trend in yearly rainfall over 120 years, with Kendall's tau 0.17058, which is statistically significant at the 5% significance level. The *Z* value of 2.76044 indicates a positive trend. The Sen's slope estimator, which measures the extent of the trend, reveals that annual rainfall over the years is increasing at the rate of 2.48 millimetres per year. The monthly rainfall trend of twelve months over 120 years of rainfall shows that rainfall increases from May to December, as opposed to decreasing from January to April. In the analysis of annual rainfall variability over different phases from 1901 to 2020, rainfall variability increased with time, increasing up to the third phase but reducing during the last phase. The monthly rainfall pattern, range and variability have been described using box-and-whisker plots (Fig. 3), which depict the higher dispersion in the monsoon seasons, i.e., in June and July. In order to cope with the inconsistency of rainfall and to minimize water stress during the rainfall recession time, artificial water storage techniques can be applied. Hence, the most engaged stakeholders should consider the inconsistency of rainfall in the study region for managing water resources in particular.

Table 3. Phase-wise (fourth phase) temporal change of variability of annual rainfall over 120 years from 1901 to 2020

Years	1901–1930	1931–1960	1961–1990	1991–2020
Mean annual rainfall (millimetres)	1,373.94	1,632.83	1,773.122	1,590.10
Standard deviation (millimetres)	218.56	345.83	473.61	368.87
Coefficient of variation (%)	15.91	21.18	26.71	23.20

Table 4. Statistical characteristics of monthly rainfall variability and analysis table for box-and-whisker plot

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum (mm)	0.00	0.00	0.00	0.00	17.13	54.79	86.00	22.10	13.83	0.00	0.00	0.00
Quartile 1 (mm)	0.08	2.99	4.33	21.84	82.17	171.55	239.77	250.73	176.39	62.87	0.00	0.00
Median (mm)	3.04	17.05	18.62	43.37	119.36	249.66	312.79	298.55	223.73	110.64	6.95	0.00
Quartile 3 (mm)	21.75	35.40	48.19	73.04	167.05	330.89	395.46	380.62	298.28	177.66	27.60	2.21
Maximum (mm)	118.43	171.80	229.95	199.71	416.99	898.01	1,381.09	681.37	812.08	418.16	240.67	132.19
Mean (mm)	12.67	25.96	33.56	53.78	130.35	271.03	333.67	320.62	251.19	129.47	24.84	5.92
SD (mm)	18.82	32.40	39.18	43.10	73.41	139.63	156.43	113.44	124.32	95.16	45.52	16.05
CV (%)	148.63	124.81	116.75	80.14	56.32	51.52	46.88	35.38	49.49	73.50	183.22	270.96

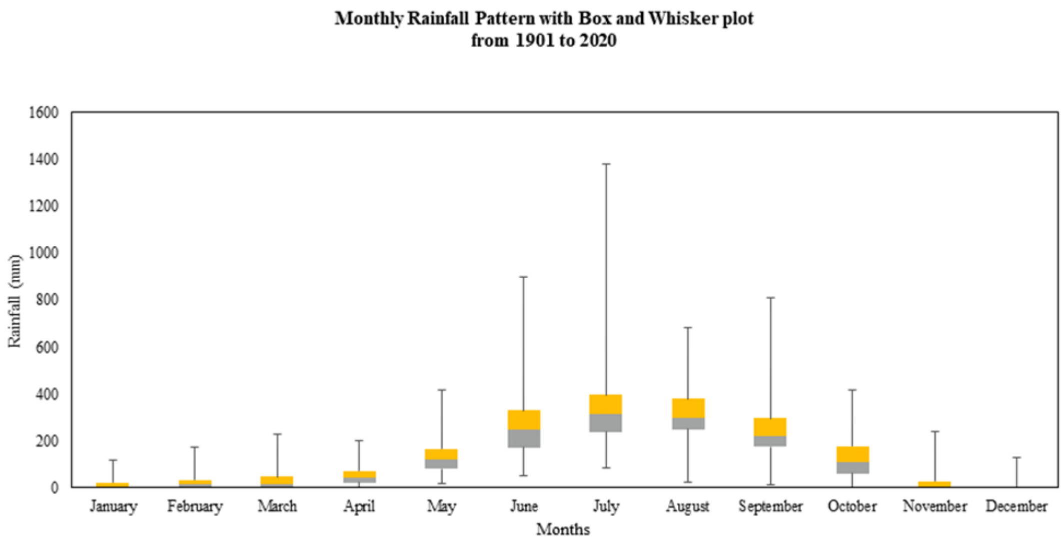

Fig. 4. Monthly rainfall pattern with box-and-whisker plot, 1901–2020

Data availability

The datasets analysed during the current study are available from the corresponding author on reasonable request.

Disclosure statement

No potential conflict of interest was reported by the authors.

Author contributions

Study design: MJA; data collection: MJA; statistical analysis: AM; result interpretation: MJA, AM; manuscript preparation: MJA, AM; literature review: MJA, AM.

References

AHMED I, DAS N, DEBNATH J and BHOWMIK M, 2018, Erosion induced channel migration and its impact on dwellers in the lower Gumti River, Tripura, India. *Spatial*

Information Research 26: 537–549. DOI: https://doi.org/10.1007/s41324-018-0196-9.

AFZAL M, MANSELL MG, and GAGNON AS, 2011, Trends and variability in daily precipitation in Scotland. *Procedia Environmental Sciences* 6: 15–26. DOI: https://doi.org/10.1016/j.proenv.2011.05.003.

BANACOS PC, 2011, Box and Whisker Plots for Local Climate Datasets: Interpretation and Creation using Excel 2007/2010. *Eastern Region Technical Attachment* 1: 2–20.

BANERJEE A, CHEN R, MEADOWS ME, SINGH RB, MAL S and SENGUPTA D, 2020, An analysis of long-term rainfall trends and variability in the uttarakhand himalaya using google earth engine. *Remote Sensing*, 12(4): 709. DOI: https://doi.org/10.3390/rs12040709.

BARI SH, RAHMAN MTU, HOQUE MA and HUSSAIN MM, 2016, Analysis of seasonal and annual rainfall trends in the northern region of Bangladesh. *Atmospheric Research* 176–177: 148–158. DOI: https://doi.org/10.1016/j.atmosres.2016.02.008.

BRUNET M and JONES P, 2011, Data rescue initiatives: Bringing historical climate data into the 21st century. *Climate Research* 47(1–2): 29–40. DOI: https://doi.org/10.3354/cr00960.

DAS L, PRASAD H and MEHER JK, 2018, 20th Century District-level Spatio-Temporal Annual Rainfall Changes Over West Bengal. *Journal of Climate Change* 4(2): 31–39. https://doi.org/10.3233/jcc-1800011.

DASH SK, JENAMANI RK, KALSI SR and PANDA SK, 2007, Some evidence of climate change in twentieth-century India. *Climatic Change* 85(3–4): 299–321. DOI: https://doi.org/10.1007/s10584-007-9305-9.

GHOSH KG, 2018, Analysis of Rainfall Trends and its Spatial Patterns During the Last Century over the Gangetic West Bengal, Eastern India. *Journal of Geovisualization and Spatial Analysis* 2(2). DOI: https://doi.org/10.1007/s41651-018-0022-x.

HUANG YF, PUAH YJ, CHUA KC and LEE TS, 2015, Analysis of monthly and seasonal rainfall trends using the Holt's test. *International Journal of Climatology* 35(7): 1500–1509. DOI: https://doi.org/10.1002/joc.4071.

INDIA WATER RESOURCES INFORMATION SYSTEM, 2016, Available at: https://indiawris.gov.in/wris/#/rainfall.

IPCC-SAR, 1995, Climate Change 1995: A report of the Intergovernmental Panel on Climate Change. *Environmental Science & Technology* 48(8): 4596–4603. https://archive.ipcc.ch/pdf/climate-changes-1995/ipcc-2nd-assessment/2nd-assessment-en.pdf%0Ahttps://www.ipcc.ch/site/assets/uploads/2018/05/2nd-assessment-en-1.pdf.

KENDALL MG, 1975, Rank Correlation Methods. Charles Griffin and Company Ltd. London and High Wycombe.

KOSANIC A, HARRISON S, ANDERSON K and KAVCIC I, 2014, Present and historical climate variability in South West England. *Climatic Change* 124(1–2): 221–237. DOI: https://doi.org/10.1007/s10584-014-1101-8.

KRIPALANI RH and KULKARNI A, 1997, Rainfall variability over South-East Asia - Connections with Indian monsoon and Enso extremes: New perspectives. *International Journal of Climatology* 17(11): 1155–1168. DOI: https://doi.org/10.1002/(SICI)1097-0088(199709)17:11<1155::AID-JOC188>3.0.CO;2-B.

KRIPALANI RH, OH JH, KULKARNI A, SABADE SS and CHAUDHARI HS, 2007, South Asian summer monsoon precipitation variability: Coupled climate model simulations and projections under IPCC AR4. *Theoretical and Applied Climatology* 90(3–4): 133–159. DOI: https://doi.org/10.1007/s00704-006-0282-0.

KUMAR V, JAIN SK and SINGH Y, 2010, Analyse des tendances pluviométriques de long terme en Inde. *Hydrological Sciences Journal* 55(4): 484–496. DOI: https://doi.org/10.1080/02626667.2010.481373.

KUNDU SK and MONDAL TK, 2019, Analysis of long-term rainfall trends and change point in West Bengal, India. *Theoretical and Applied Climatology* 138(3–4): 1647–1666. DOI: https://doi.org/10.1007/s00704-019-02916-7.

MALIK S, PAL SC, SATTAR A, SINGH SK, DAS B, CHAKRABORTTY R and MOHAMMAD P, 2020, Trend of extreme rainfall events using suitable Global Circulation Model to combat the water logging condition in Kolkata Metropolitan Area. *Urban Climate* 32: 100599. DOI: https://doi.org/10.1016/j.uclim.2020.100599.

MANATSA D, CHINGOMBE W and MATARIRA CH, 2008, The impact of the positive Indian Ocean dipole on Zimbabwe droughts Tropical climate is understood to be dominated by. *International Journal of Climatology* 2029: 2011–2029. DOI: https://doi.org/10.1002/joc

MANN HB, 1945, Non-Parametric Test Against Trend. *Econometrica* 13(3): 245–259. http://www.economist.com/node/18330371?story%7B_%7Did=18330371.

MONDAL A, KUNDU S and MUKHOPADHYAY A, 2012, Case Study 70 Rainfall trend analysis by mann-kendall test: a case study of north-eastern part of cuttack district, Orissa. *An Online International*

Journal 2(1): 70–78. http://www.cibtech.org/jgee.htm.

MONIRUL QADER MIRZA M, 2002, Global warming and changes in the probability of occurrence of floods in Bangladesh and implications. *Global Environmental Change* 12(2): 127–138. DOI: https://doi.org/10.1016/S0959-3780(02)00002-X.

PAL AB, KHARE D, MISHRA PK and SINGH L 2017, Trend Analysis of Rainfall, Temperature and Runoff Data: a Case Study of Rangoon Watershed in Nepal. *International Journal of Students' Research in Technology & Management* 5(3): 21–38. DOI: https://doi.org/10.18510/ijsrtm.2017.535.

PANDA SK, DASH SK, JENAMANI RK and KALSI S, 2007, Some evidence of climate change in twentieth-century India. Harper & Row, 1–626. DOI: https://doi.org/10.1007/s10584-007-9305-9.

SHRESTHA AB, WAKE CP, DIBB JE and MAYEWSKI PA, 2000, Precipitation fluctuations in the Nepal Himalaya and its vicinity and relationship with some large scale climatological parameters. *International Journal of Climatology* 20(3): 317–327. DOI: https://doi.org/10.1002/(SICI)1097-0088(20000315)20:3<317::AID-JOC476>3.0.CO;2-G.

TUKEY JW, 1977, Exploratory Data Analysis by John W. Tukey. *Biometrics* 33: 768. http://www.jstor.org/stable/2529486.

YADAV R, TRIPATHI SK, PRANUTHI G and DUBEY SK, 2014, Trend analysis by Mann-Kendall test for precipitation and temperature for thirteen districts of Uttarakhand. *Journal of Agrometeorology* 16(2): 164–171.

Received 18 February 2022
Accepted 03 August 2022