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Article

Study the Temporal Variability of Climate Change in Urban City Karachi, Pakistan

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Abstract: Climate change particularly changes in temperature and rainfall patterns have serious long-term influences, mainly caused by human actions. It can leads to severe events like heat-waves, floods, increasing seas, and more extreme weather, which in turn affects across various aspects of socioeconomic factors, ecosystems, hydrology, health, and global warming. Temperature and rainfall are essential climatological variables that are being comprehensively studied across the Karachi city to understand and manage their dynamic nature. The objective of this study is to analyze the trend, magnitude, and change points in climatic variables to investigate their variability in the urban city Karachi. Rainfall and temperature datasets for the Karachi station from 1980 to 2020 was used. Monthly and annual precipitation as well as temperature (maximum, and minimum) was analyzed for possible trends using nonparametric Mann-Kendall (MK) test, while the Sen's slope (SS) estimator was used for magnitude of a trend. The Pettitt's test was applied to detect the abrupt change point in climatic variables. The results revealed increasing trend in annual and monthly maximum temperatures while for minimum temperature all the months illustrated significant increasing trend in the study period. The SS estimator revealed that the annual temperature increased with rate of 0.025° $\boldsymbol{C}$ per year for the certain time interval. However, in contrast to variation in the temperature trend, the mean annual rainfall of the study period was observed 180.4 mm with no significant increasing trend while 366.8 mm rainfall was observed in the month of the August 2020. The only month of the February has statistically significant decreasing trend with rate of change of $\mathbf{0.097mm/year}$ and no significant trends was present for all other months. This study provides evidence that can aid policy adaptation, and addressing climate change by responding extreme events like floods and heat-waves.

Keywords: trend detection; Mann-kindle test; Sen's slope estimator; temperature; rainfall

1. Introduction

Climate change plays a crucial role on the environment, socio-economic, and related sectors, including water resources, agriculture, food security, human health, and forest diversity, and is known as most threatening challenges facing humanity (Alibuhtto et al., 2019; Caloiero and Guagliardi, 2021). The temperature and rainfall are known as essential variables in the area of environmental and climatological sciences used to study trend detection, the magnitude of climate change, and trend-changing years (IPCC, 2007; Asfaw et al., 2018; Aucahuasi-Almidon et al., 2024).

Several researchers across the world have reported on the applications of trend detection for modeling climatic variables (Jhajharia et al., 2012; Zakwan & Ahmad, 2021; de Oliveira-Júnior et al., 2022). Heureux et al., (2022) investigated the spatial and temporal variations of climatic trends in perspective of the observed data and the occurrence of expected extreme conditions that may influence the long-term efficiency of the four primary crops (namely wheat, cotton, rice, and sugarcane) in the Punjab and Sindh provinces, using the non-parametric approach MK test. However, in the past few decades, a decline in rainfall patterns was observed in the coastal and arid regions of Pakistan. The mainstream regions of Pakistan, including Sindh, most of Balochistan, southern Punjab, and central parts of Gilgit-Baltistan, experienced arid to semi-arid climates with annual rainfall less than 250 mm. Only northern regions like parts of Punjab and Khyber Pakhtunkhwa receive sufficient rainfall to support humid conditions (Salma et al., 2012).

Karachi is one of the biggest city of Pakistan, faces significant challenges from climate change that impact its urban ecosystem, public health, and infrastructure resilience. The temporal variations of climate in Karachi exhibit a multifaceted interaction of factors influenced significantly by urbanization, climate change, and seasonal patterns. Karachi's climate is considered as hot arid and classified under the Köppen-Geiger classification as hot arid climate (Bughio et al., 2020). This classification is known as sign of the city's long, hot summers and comparatively mild winters, which supports with observed trends of increasing temperatures over recent years due to global warming (Mahmood et al., 2022).

One amazing reason of Karachi's climatic variability is the monsoon season, which usually extents from July to September. However, study of Fazal & Hotez, (2020) shows that while the timing of the monsoon season has remained largely stable over the last 25 years, the intensity and distribution of rainfall during this period have demonstrated significant unpredictability. Consequently, this variation can lead to both drought conditions and urban flooding in different years, severely impacting the local population and infrastructure. The interaction of increasing urbanization and climate variations has intensified these extremes, leading to heightened risks of flooding and heat-waves (Iftikhar & Iqbal, 2024).

However, despite its prime importance, an inclusive assessment of Karachi's climate trends remains limited. Most studies focus either on temperature or rainfall in separation along with simple trend techniques, often over short time periods. Furthermore, the long-term analysis of Karachi's distinctive climate desires, integrating both temperature and rainfall extremes with robust statistical approaches like change point analysis, is missing and extremely essential for urban planning and adaptation.

This lack of a comprehensive, long-term analysis using hard diagnostic techniques requiring policymakers a solid evidence necessary to efficiently order adaptation policies. For example, it is uncertain if the well-established urban development of Karachi in the 1990s caused an obvious regime shift in local climate histories. Therefore, an important gap exists in understanding the highlighting trends and possible change points in Karachi's historical climate datasets, which is important for projecting future risks assessment and strengthening in this growing metropolitan city.

To address the highlighted research gap, this study aims to provide a comprehensive assessment of historical climate trends (both temperature and rainfall) in Karachi from 1980 to 2020. The study aims to focus the following distinct objectives:

1. To investigate long-term trends in annual and monthly temperature datasets.
2. To estimation trends in annual and monthly total rainfall datasets.
3. To highlight statistically significant year of changing points in the temperature and rainfall datasets to identify the timing of possible climatic shifts.

This type of study has not previously been applied in Karachi city to analyze trends and determine abrupt changes in climatic variables simultaneously.

The paper is designed as under: Section 2 describes the data and methodology, Section 3 presents the results, and discusses, and Section 4 provides the concluding remarks."

Study Area

Karachi is the provincial capital city of Sindh, known as one of the most highly populated cities in South Asia (with about 27 million people and an annual growth of 3.5%). Karachi is largest city in Pakistan, covering an area of 3,527 square kilometers. It serves as the economic and financial center of the country and ranks among the ten most populous cities globally. Geographically, it is located between latitudes 24°45′ and 25°15′N, and longitudes 66°37′ and 67°37′ E.

The wind speed in Karachi remains high for more than half of the year, including the monsoon blow south-west while in winter the wind changes to east and north-east maintain an average temperature of 21°C (Anwar, 2012). In Karachi, a severe heat wave was experienced in June 2015, with a highest temperature of 45°C (Irfan et al., 2018). It has a long coastline in the south with the Arabian Sea.

In general, the climate of Karachi is pleasant, though it is infrequently highly humid and has a moderately temperate climate. The coolest month, January, has an average temperature of 18°C, whereas the hottest month, June, has a temperature that varies from 27°C to 32°C. The region has a dry climate with mild winters and hot summers. Consequently, its climate is marked by insufficient and variable rainfall (Bakhsh et al., 2011). The average annual rainfall is about 125-256 mm, but in certain years, rainfall is higher, as in 2022, when 862 mm was recorded during the monsoon season in history (PMD, 2022). The geographical map of Karachi region is presented in Figure 1 (Baqa et al., 2021).

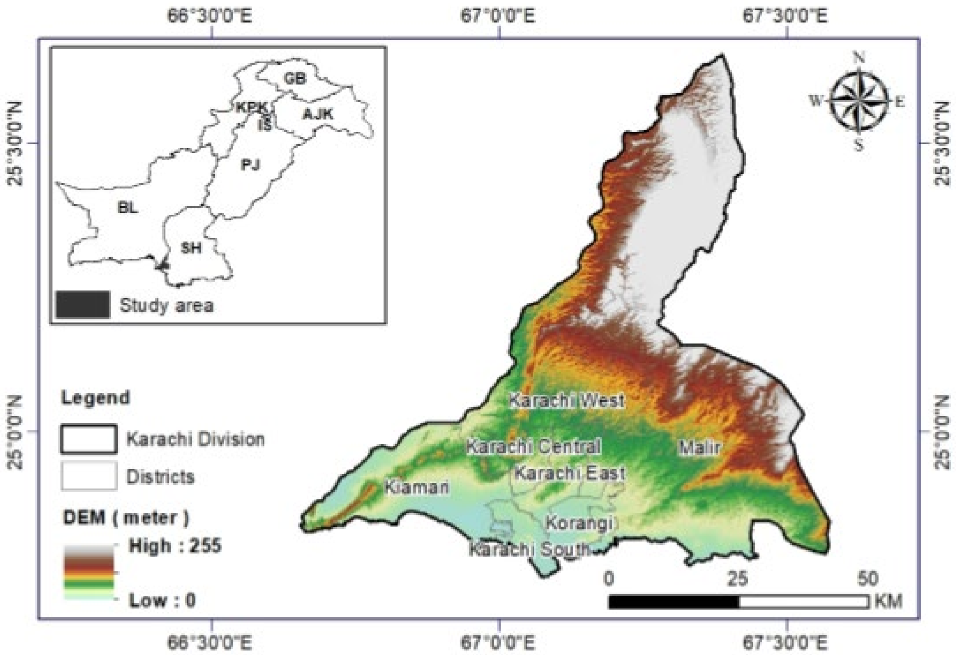


Figure 1. Geographical map of Karachi city.

2. Data set and Methodological Analysis

In this study, the climate datasets used consist of the annual, monthly maximum and minimum temperatures and monthly total rainfall records obtained from the Pakistan Meteorological Department (PMD) Karachi station, situated at 24°54'N and 67° 56'E. The dataset contains a period of 40 years (1980-2020) covering the area of Karachi.

Every field, including climatology, meteorology, and space research uses statistical analysis in various ways. Exploratory data analysis; an approach used in meteorological and climatological studies to observe the behavior of time series. It determined descriptive statistics i.e., mean median, variance, and standard deviation (Jan et al., 2018; Kabbilawsh et al., 2022; Dawadi et al., 2023). The broad framework of modeling approaches is thoroughly explained in Figure 2 and subsequent sections.

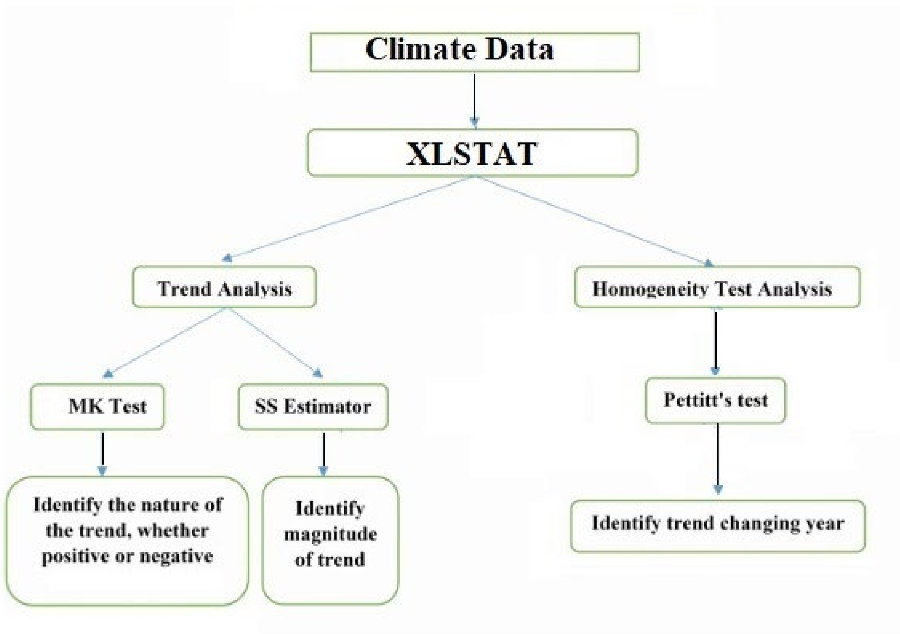


Figure 2. Flow Chart of methodological framework.

2.1. Trend Analysis Approaches

2.1.1. Description of Mann–Kendall (MK) Tests

The MK test is known as an important approach to detecting the manifestation of increasing or decreasing trends within a series of datasets. Many researchers used the rank-based nonparametric MK test in their studies to evaluate the magnitudes of a trend in climatological datasets (Hanssen-Bauer,& Førland, 1998; Zakwan & Ahmad, 2021; Chattopadhyay et al., 2012; Asfaw et al., 2018; Hussain et al., 2019; Farooq et al., 2021; Sharma, & Adhikari, 2022; Porwal, & Choudhary, 2023). Mathematically, the MK test can be written by considering the statistic S as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i), where\ sgn = \begin{cases} -1, & x < 0 \\ 0, & x = 0 \\ +1, & x > 0 \end{cases} \quad (1)$$

where, x_i and x_j are the time series data points, n is the length of the datasets.

The null hypothesis H_0 reveals that a time series $\{x_t: t = 1, 2, \dots n\}$ consist of independent and identically distributed (i.i.d.) datasets. Conversely, the alternative hypothesis H_1 suggests the existence of a monotonic trend within the series $\{X_t\}$. Where, the mean E[S] and variance V[S] of the statistic S are defined by the formula:

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

where, m is the number of tied values, and t_i is the number of data points for the ith values (Narwal et al., 2023). Under the null hypothesis, the quantity standard normal Z is obtained mathematically as

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & S > 0 \\ 0, & S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, & S < 0 \end{cases} \quad (3)$$

Here, the value of Z denotes the MK test statistic. It follows standard normal distribution with a mean of 0 and variance of 1, the null hypothesis of no trend is rejected if $|Z| > Z_{\alpha/2}$ where α is the significance level (Ray et al., 2021; Sharma, & Adhikari, 2022; Porwal, & Choudhary, 2023; Narwal et al., 2023). Furthermore, the Kendall's τ is defined as

$$\tau = 2\frac{S'}{n(n-1)} \quad (4)$$

where, the symbol S' indicates the Kendall's sum and evaluated as $S' = L - M$, where L is the number of cases with $(x_j - x_i) > 0$, and M represents the number of cases for which $(x_j - x_i) < 0$.

Since, Kendall's τ is a statistical parameter that can be obtained after implementation of the MK test. This correlation metric measures the degree of correlation between two variables. The value of parameter τ depends on the ranks of data, thus it can range between -1 and +1, with a positive relationship suggesting that the ranks of both variables increase simultaneously. Similarly, a negative value of τ indicates that both variable's inversely related. This indicates Kendall's τ is an important parameter to assure when performing if two variables are interconnected (Singh & Choudhary, 2023).

Autocorrelation is an important technique to detect trends in a time series datasets. Even in the absence of considerable trends, autocorrelation makes it possible to obtain them, and vice versa. When autocorrelation occurs in the time series datasets, the observed significance levels of the unique MK trend test are significantly deviates largely from nominal significance levels (Kocsis et al., 2020; Singh & Choudhary, 2023).

2.1.2. Description of Sen's Slope Estimator Test (Magnitude of Trend)

The Sen's slope estimator was applied to measure the magnitude of a trend in climatological datasets. Unlike traditional linear regression, which can be sensitive to outliers and assumes normally distributed errors, Sen's slope estimator contribute robustness against outliers and not obey the assumption of normal distribution (Sy et al., 2021). To estimate both the slope and intercept according to Sens method, we used following mathematical equation;

$$d_k = \frac{Y_f - Y_i}{j - i} \quad (1 \leq i < \leq n) \quad \dots (5)$$

where the slope represented by *d*, *Y* indicates the variable, *n* represents the number of observations, and

i, j are indices (Ray et al., 2021; Dubey et al, 2023; Jiqin et al., 2023).

2.1.3. Homogeneity Test

The Pettitt test, also referred to as the Homogeneity test, is a non-parametric statistical procedure used to identify a single change year in the central tendency of a univariate time series, indicating a shift in the median of the distribution. This test is particularly useful when the data do not follow a normal distribution or contain outliers. It identifies the point where the data's distribution shifts abruptly, making it valuable for analyzing trends in fields like hydrology, climatology, and economics (Kocsis et al., 2020; Singh and Choudhary, 2023). It describes the null hypothesis (H_o); there is no change in variation against the alternative hypothesis that H_1 there is a change in variations. The Pettitt test statistic is based on the ranks of the data and is calculated as:

$$K_T = max|U_t| \quad .... \quad (6)$$

where, U_t can be defined as

$$U_t = \sum_{i=1}^{t} \sum_{j=t+1}^{n} sign(x_t - x_j)$$

and

$$sign(x_t - x_j) = \begin{cases} 1, & if\ (x_t - x_j) > 0 \\ 0, & if\ (x_t - x_j) = 0 \\ -1, & if\ (x_t - x_j) < 0 \end{cases}$$

The test statistic measures the frequency with which a participant from the first sample exceeds the performance of a participant from the second sample. The lack of a change point serves as the null hypothesis in Pettitt's test (Conte et al., 2019; Kocsis et al., 2020). For computation purpose, statistical software XLSTAT version 2014 was used (XLSTAT, 2014).

3. Results and Discussions

3.1. Descriptive Statistics and Magnitude of temperature trend analysis

To understand the general behavior and magnitude of temperature over Karachi city, the dataset used to compute monthly (maximum & minimum) and annual temperature from 1980 to 2020 in perspective of the simple linear regression analysis with the significant trends. The statistical parameters identify mean, minimum (min.), maximum (max.) and standard deviation (std.). For this purpose, it is necessary to present the characteristics of the data series at first.

Tables 1 and 2 depicted the descriptive statistics of annual, maximum, and minimum temperatures, respectively. We carry out the parameters max., min., mean, and std., of each data set of temperature to check the variability over the entire year as well as aggregated by monthly (January to December) as shown in Tables 1 and 2.

The annual average value of max., temperature is 32.3° C with a standard deviation of 0.497. A minimum value of 24.4° C with std., 0.899 observed for max., temperature during the month of January while 37.7 ° C(with std., 0.993) recorded during month of May. Similarly, for min., temperature the lowest value recorded 8.4° C (std. 1.493) in the month of January, and max., value of 29.8 ° C with a std. of 0.597 in the month of Jun. These suggested investigating the temperature trend over time to identify patterns and variations.

Table 1. Results of monthly Max., and annual temperature (°C); Descriptive Statistics, Sens's Slope, and MK test for Karachi from 1980 to 2020 (α = 0.05).

Months	Descriptive Statistics and MK Test results							
	Basic statistics				Trend estimation			
	Min.	Max.	Mean	Std. Dev	MK tau (τ)	Sen.'s Slope (s)	p-value	Trend

Jan	24.4	28.5	26.3	0.899	0.063	0.007	0.583	No
Feb	26.0	31.3	28.5	1.375	0.236	0.043	0.034	Yes
Mar	29.8	36.2	32.3	1.439	0.228	0.044	0.041	Yes
Apr	32.1	36.6	34.8	1.064	0.229	0.036	0.008	Yes
May	33.9	38.7	35.6	0.933	0.156	0.019	0.165	No
Jun	34.3	37.7	35.6	0.790	0.232	0.023	0.039	Yes
July	28.0	36.7	33.5	1.269	0.232	0.025	0.040	Yes
Aug	30.5	34.6	32.3	0.921	0.342	0.042	0.002	Yes
Sep	31.3	36.2	33.3	1.134	0.215	0.028	0.050	Yes
Oct	32.3	37.0	35.4	1.037	0.140	0.019	0.212	No
Nov	30.4	33.9	32.5	0.892	0.148	0.015	0.190	No
Dec	25.9	31.0	28.3	1.047	0.042	0.004	0.717	No
Annual	31.3	33.4	32.3	0.497	0.078	0.002	0.011	Yes

Table 2. Results of monthly Min., temperature (°C); Descriptive Statistics, SS, and MK test for Karachi station from 1980-2020 (α = 0.05).

Months	**Descriptive Statistics and MK Test results**							
	Basic statistics				**Trend estimation**			
	Min.	**Max.**	**Mean**	**Std. Dev**	**MK tau (τ)**	**Sen.'s Slope (s)**	**p-value**	**Trend**
Jan	8.4	14.8	11.6	1.493	0.289	0.063	0.009	Yes
Feb	9.5	18.2	14.2	1.862	0.466	0.093	0.001	Yes
Mar	14.3	21.7	18.8	1.349	0.522	0.075	0.001	Yes
Apr	18.6	25.7	23.3	1.435	0.551	0.075	0.001	Yes
May	24.1	28.1	26.7	0.885	0.490	0.047	0.001	Yes
Jun	27.1	29.8	28.4	0.597	0.377	0.026	0.001	Yes
July	25.7	29.4	27.7	0.754	0.338	0.027	0.003	Yes
Aug	24.2	28.1	26.4	0.825	0.293	0.031	0.009	Yes
Sep	23.4	27.4	25.8	0.901	0.349	0.038	0.002	Yes
Oct	18.1	25.7	22.3	1.764	0.489	0.083	0.001	Yes
Nov	13.8	20.2	17.1	1.692	0.439	0.095	0.001	Yes
Dec	9.2	15.9	12.8	1.480	0.305	0.059	0.006	Yes

Moreover, the linear trend of monthly (from Jan to Dec) max., min., and annual time series (1980-to-2020) of temperature dataset of Karachi was presented to check existence of trend as revealed in the Figures 3, 4, 5 & 6 in perspective of the simple linear regression analysis with their significant trends. Furthermore, substantial increasing trend for annual max., and annual min., temperature variation from 0.025 °C to 0.06°C (Figures 3 & 5) were observed respectively.

In addition, seven months such as Feb, Mar, Apr, Jun, Jul, Aug, and Sep have given significant increasing trend while other five months i.e., Jan, May, Oct, Nov, and Dec given non-significant increasing trends for monthly max., temperature as revealed in Table 1 and Figure 4. For min., temperature all the months revealed a significant increasing trend as shown in the Figure 6, and Table 2.

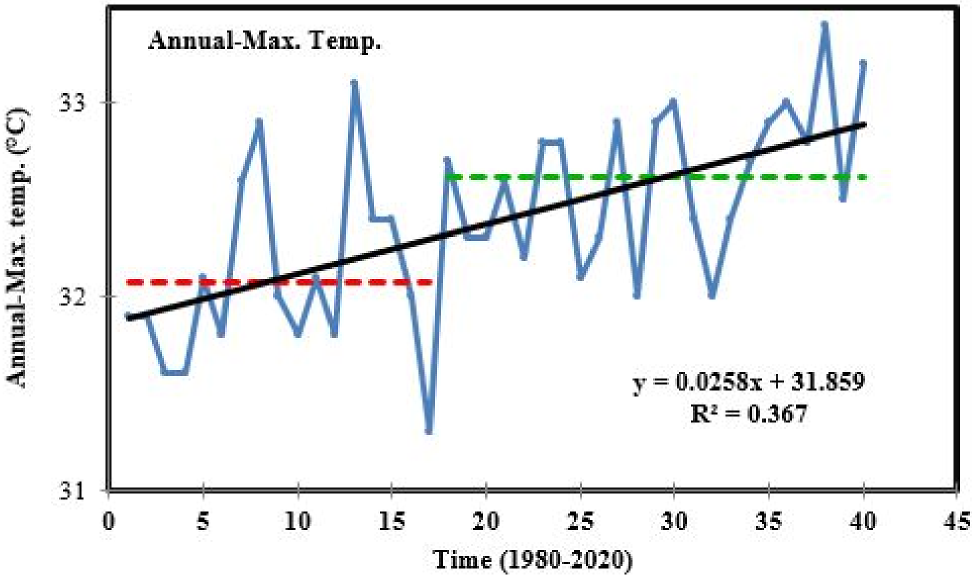
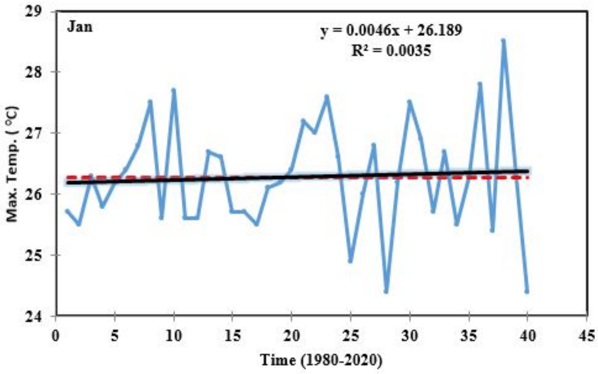
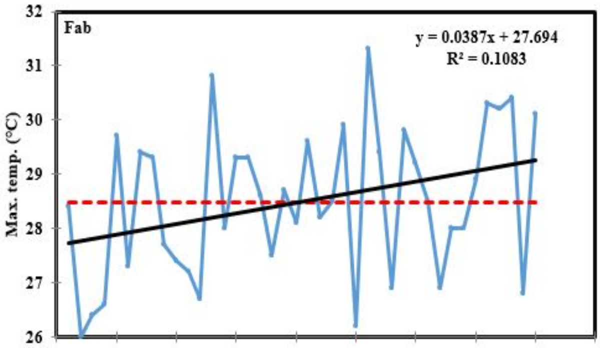
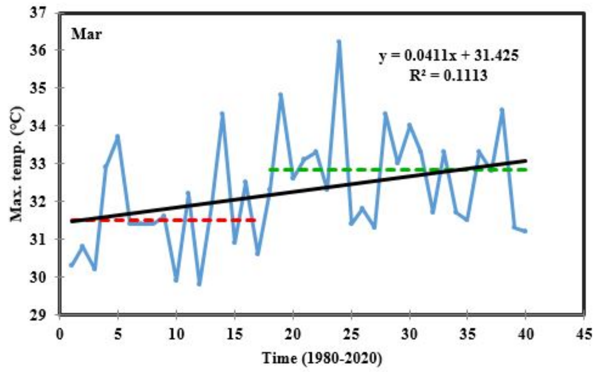
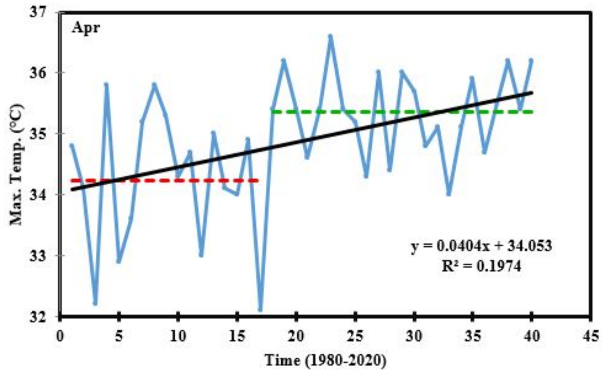


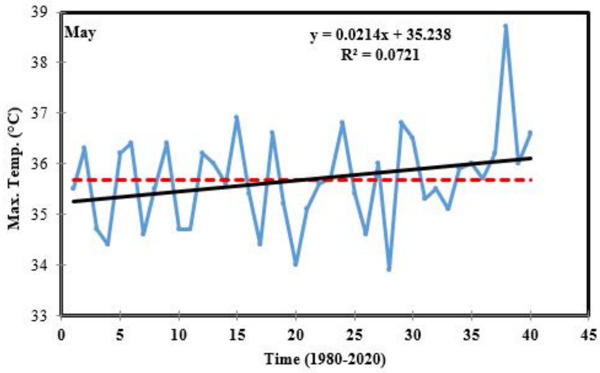
Figure 3. Annual time series plots for Karachi city with trend, significant year of changing point and shift in the mean Max., temperature (°C) in the year 1980-2020.

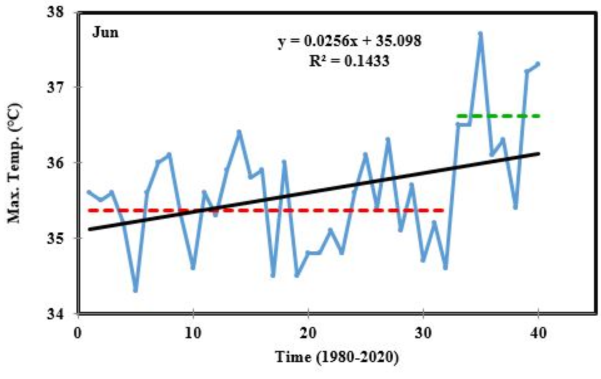


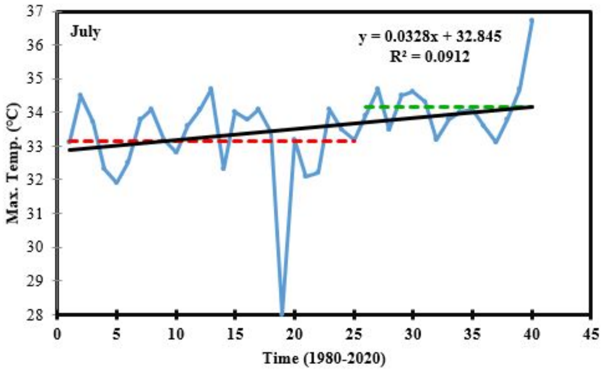


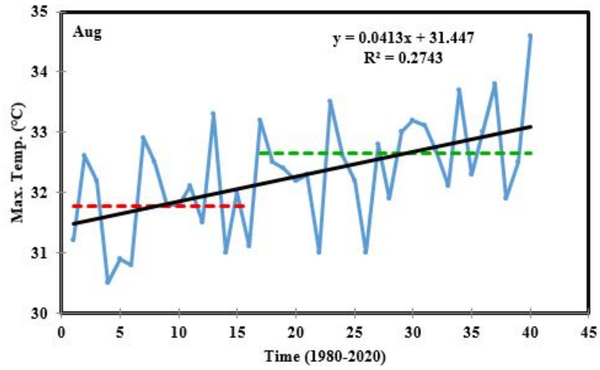

Mar
y = 0.0411x + 31.425
R² = 0.1113
Max. temp. (°C)
Time (1980-2020)

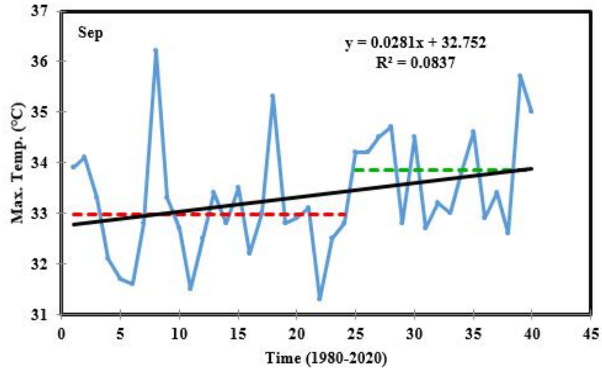

Apr
y = 0.0404x + 34.053
R² = 0.1974
Max. Temp. (°C)
Time (1980-2020)

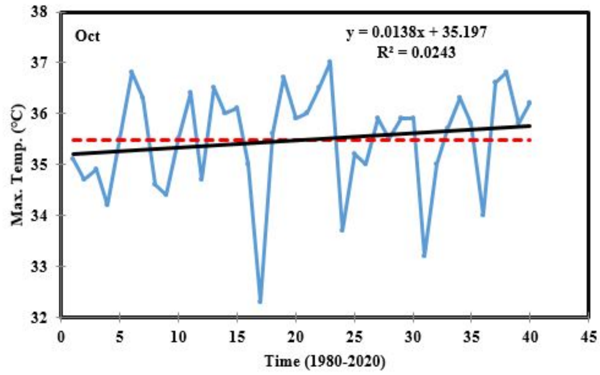

May
y = 0.0214x + 35.238
R² = 0.0721
Max. Temp. (°C)
Time (1980-2020)


Jun
y = 0.0256x + 35.098
R² = 0.1433
Max. Temp. (°C)
Time (1980-2020)


July
y = 0.0328x + 32.845
R² = 0.0912
Max. Temp. (°C)
Time (1980-2020)


Aug
y = 0.0413x + 31.447
R² = 0.2743
Max. Temp. (°C)
Time (1980-2020)


Sep
y = 0.0281x + 32.752
R² = 0.0837
Max. Temp. (°C)
Time (1980-2020)


Oct
y = 0.0138x + 35.197
R² = 0.0243
Max. Temp. (°C)
Time (1980-2020)

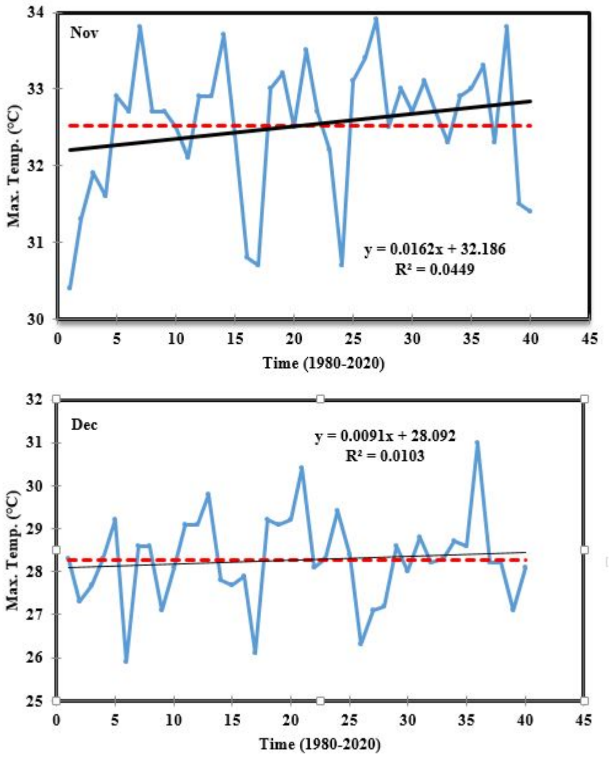


Figure 4. Monthly time series plots for Karachi city with trend, significant year of changing points and shift in the mean Max., temperature (°C) in the year 1980-2020.

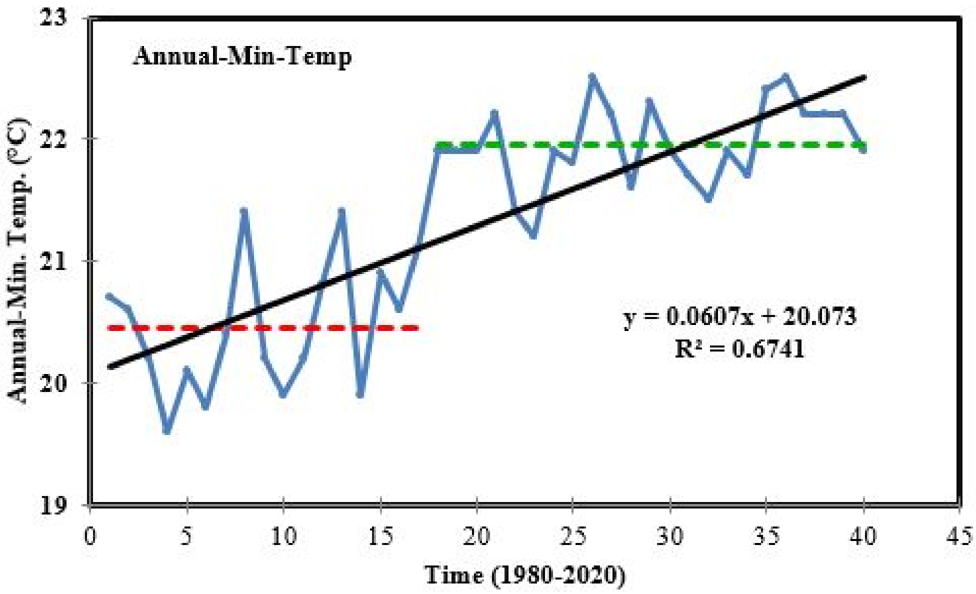
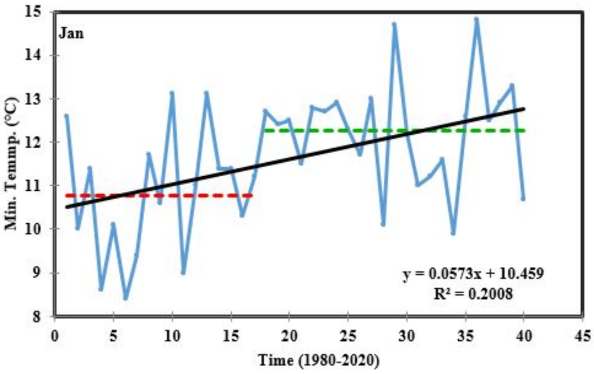
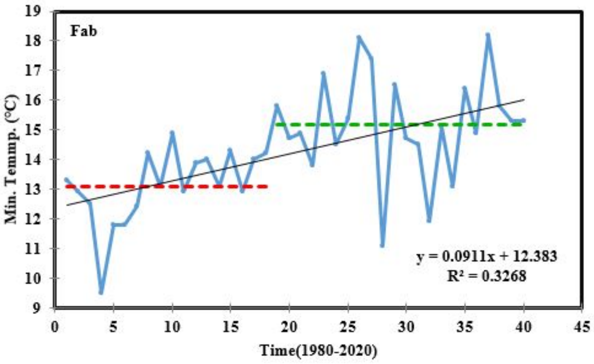
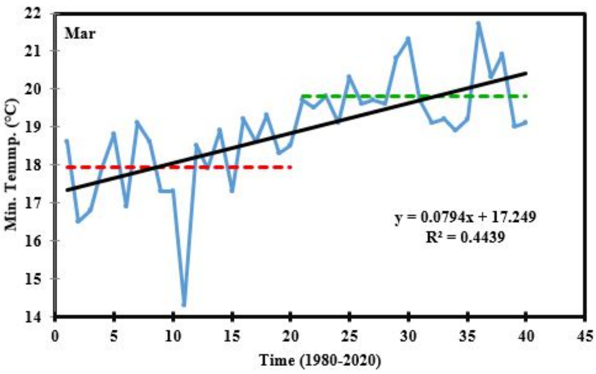
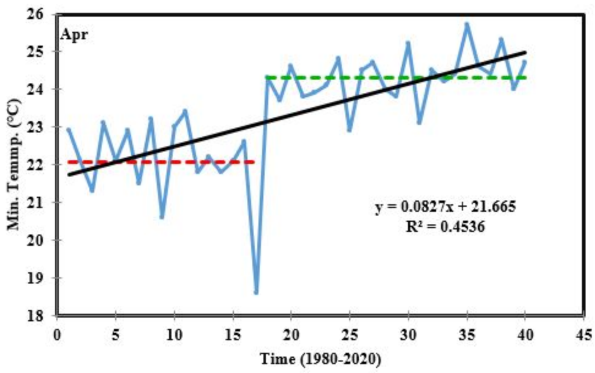


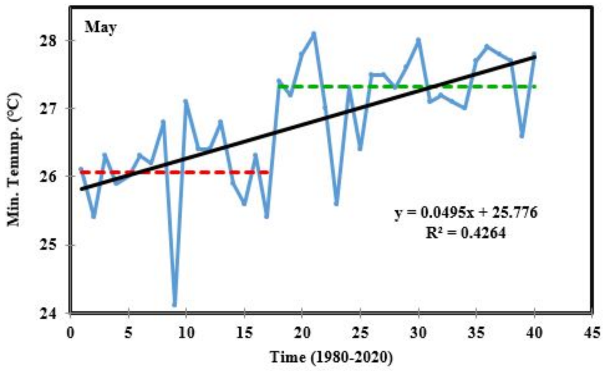
Figure 5. Annual time series plots for Karachi city with trend, significant year of changing point and shift in the mean Min., temperature (°C) in the year 1980-2020.

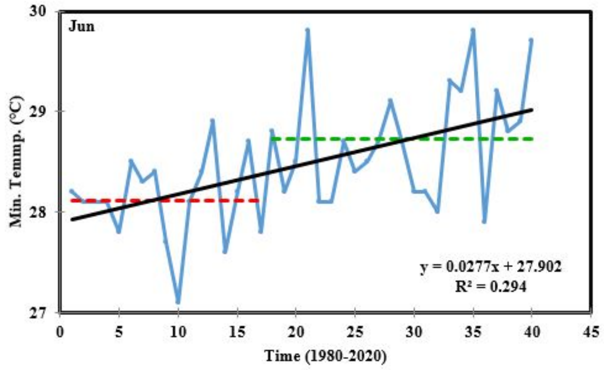

Jan
Min. Temmp. (°C)
y = 0.0573x + 10.459
R² = 0.2008
Time (1980-2020)

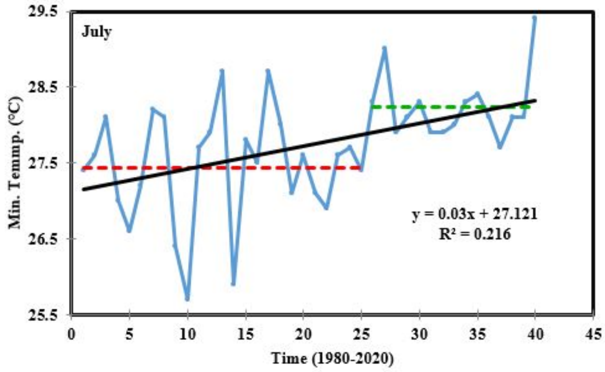

Fab
Min. Temmp. (°C)
y = 0.0911x + 12.383
R² = 0.3268
Time(1980-2020)

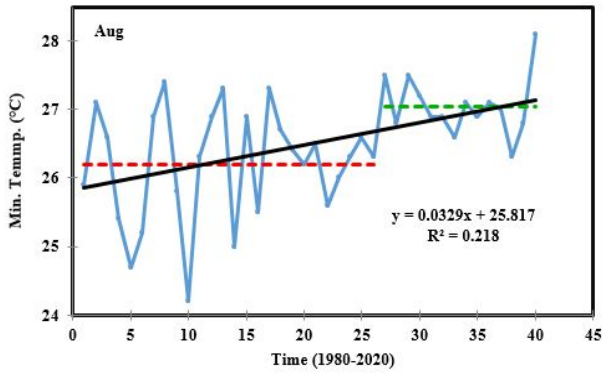

Mar
Min. Temmp. (°C)
y = 0.0794x + 17.249
R² = 0.4439
Time (1980-2020)


Apr
Min. Temmp. (°C)
y = 0.0827x + 21.665
R² = 0.4536
Time (1980-2020)


May
Min. Temmp. (°C)
y = 0.0495x + 25.776
R² = 0.4264
Time (1980-2020)


Jun
Min. Temmp. (°C)
y = 0.0277x + 27.902
R² = 0.294
Time (1980-2020)


July
Min. Temmp. (°C)
y = 0.03x + 27.121
R² = 0.216
Time (1980-2020)


Aug
Min. Temmp. (°C)
y = 0.0329x + 25.817
R² = 0.218
Time (1980-2020)

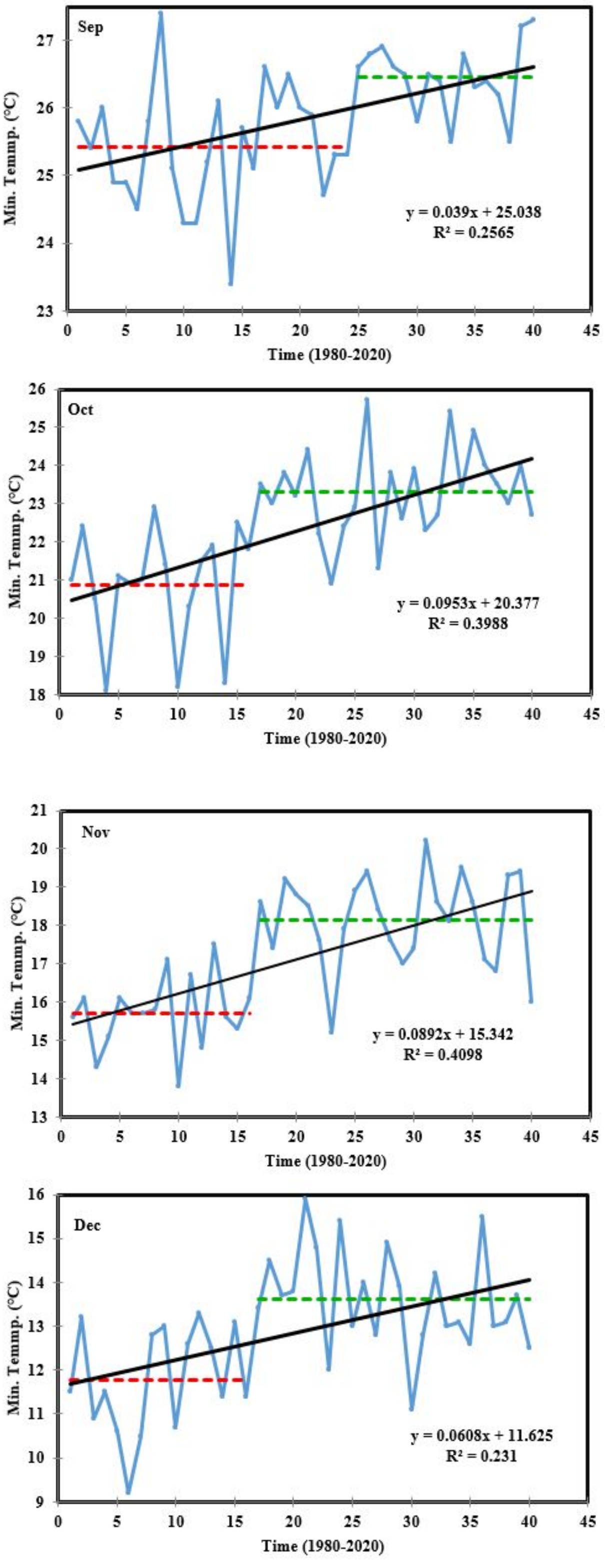


Figure 6. Monthly time series plots for Karachi city with trend, significant year of changing points and shift in the mean Min., temperature (°C) in the year 1980-2020.

3.2. Descriptive Statistics and Magnitude of rainfall trend analysis:

In this section, the annual and monthly datasets of rainfall amount for Karachi station were analyzed to depict the characteristic and variability. The mean annual precipitation amount during the entire period (1980-2020) was observed 180.4 mm along standard deviation of 133.4 mm as shown in Table 3.

Similarly, min., rainfall recorded as 0.00 mm on monthly basis while max., 366.8 mm rainfall was observed during month of August 2020 with 84.5 mm standard deviation. According to Pakistan Metrological Department (PMD) Karachi was experienced highest rainfall 862mm (in Gulshan-e-Hadeed) recorded in the year 2022 during the monsoon season with 308% above average rainfall in month of July. It has been noted that no significant increasing trend for annual rainfall about 1.844 mm per year (Figure 7).

These results revealed that only one month (February) gives significant downward trend with -0.259 mm per year while other eight months such as Jan, May, Jun, Aug, Sep, Oct, Nov, and Dec give upward trend (no significant) and other three months Mar, Apr and July give downward trend (no significant) for monthly rainfall datasets as revealed in the Figure 8.

Table 3. Results of monthly, and annual rainfall (mm); Descriptive Statistics, SS, and MK test for Karachi station from 1980-2020 (α = 0.05).

Months	**Descriptive Statistics and MK Test results**							
	Basic statistics				**Trend estimation**			
	Min.	**Max.**	**Mean**	**Std. Dev**	**MK tau (τ)**	**Sen.'s Slope (s)**	**p-value**	**Trend**
Jan	0.0	89.3	8.6	16.53	0.019	0.00	0.877	No
Feb	0.0	32.2	6.3	9.15	-0.259	-0.097	0.026	Yes
Mar	0.0	73.4	4.5	12.9	-0.028	0.000	0.828	No
Apr	0.0	47.6	3.1	10.4	-0.227	0.000	0.083	No
May	0.0	5.0	0.16	0.811	0.054	0.000	0.700	No
Jun	0.0	110.2	11.3	26.2	0.119	0.000	0.337	No
July	0.0	270.4	51.6	68.4	-0.017	0.000	0.888	No
Aug	0.0	366.8	68.7	84.5	0.064	0.069	0.568	No
Sep	0.0	212.6	18.9	40.7	0.184	0.000	0.132	No
Oct	0.0	39.3	2.04	7.42	0.147	0.000	0.258	No
Nov	0.0	8.3	0.53	1.592	0.073	0.000	0.575	No
Dec	0.0	61.3	4.35	11.067	0.112	0.000	0.365	No
Annual	0.0	481.5	180.4	133.2	0.064	1.003	0.571	Yes

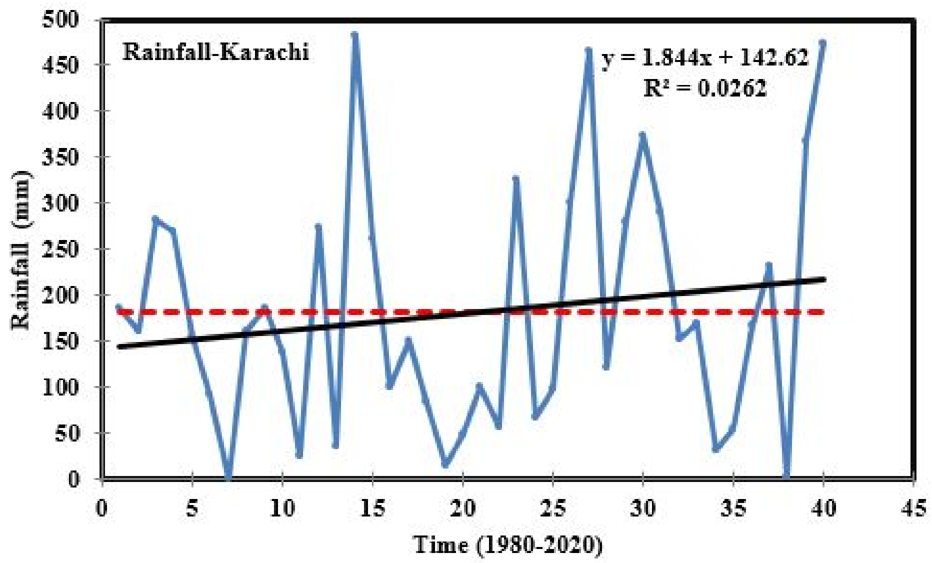
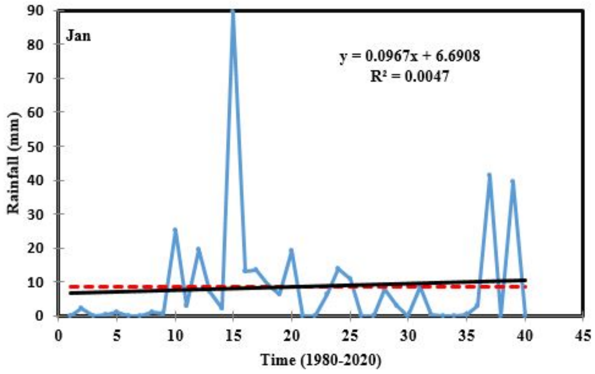
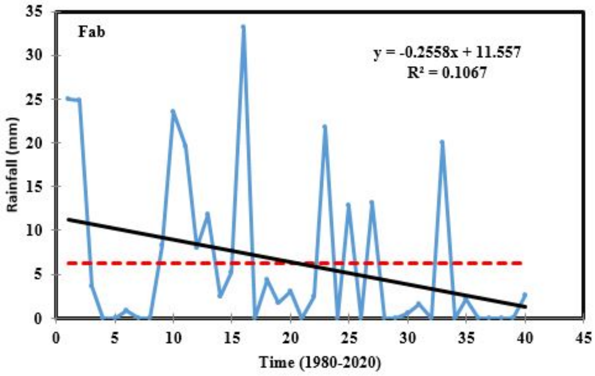


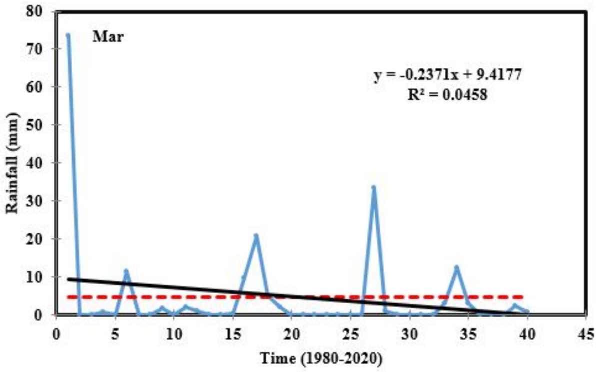
Figure 7. Annual time series plots for Karachi city with trend, significant year of changing point and shift in the total annual rainfall (mm) for the year 1980-2020.



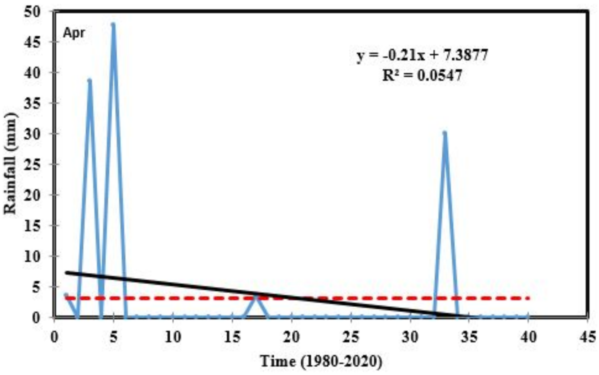
Jan
y = 0.0967x + 6.6908
R² = 0.0047
Rainfall (mm)
Time (1980-2020)



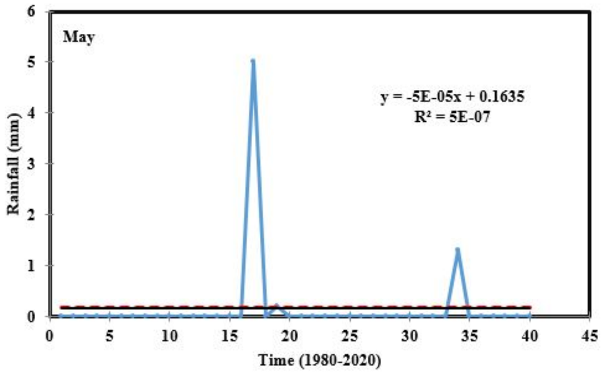
Fab
y = -0.2558x + 11.557
R² = 0.1067
Rainfall (mm)
Time (1980-2020)

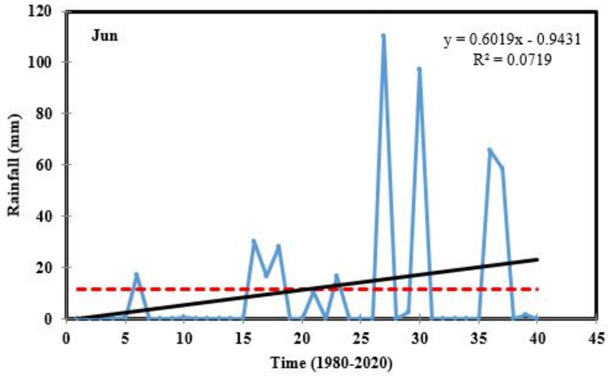


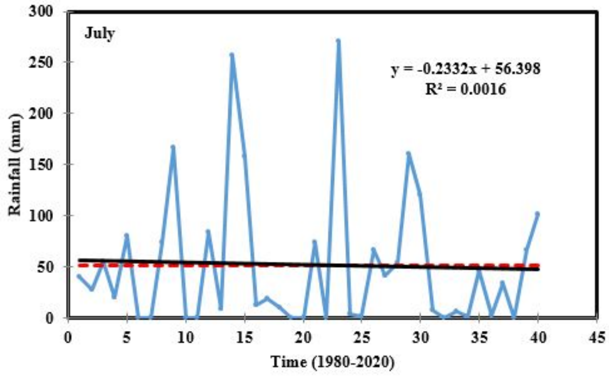
Mar
y = -0.2371x + 9.4177
R² = 0.0458
Rainfall (mm)
Time (1980-2020)

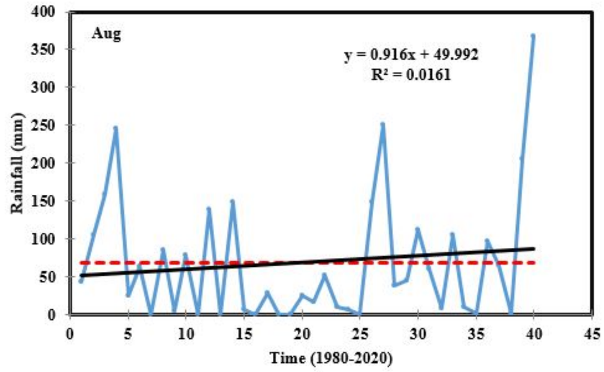


Apr
y = -0.21x + 7.3877
R² = 0.0547
Rainfall (mm)
Time (1980-2020)


May
y = -5E-05x + 0.1635
R² = 5E-07
Rainfall (mm)
Time (1980-2020)


Jun
y = 0.6019x - 0.9431
R² = 0.0719
Rainfall (mm)
Time (1980-2020)


July
y = -0.2332x + 56.398
R² = 0.0016
Rainfall (mm)
Time (1980-2020)


Aug
y = 0.916x + 49.992
R² = 0.0161
Rainfall (mm)
Time (1980-2020)

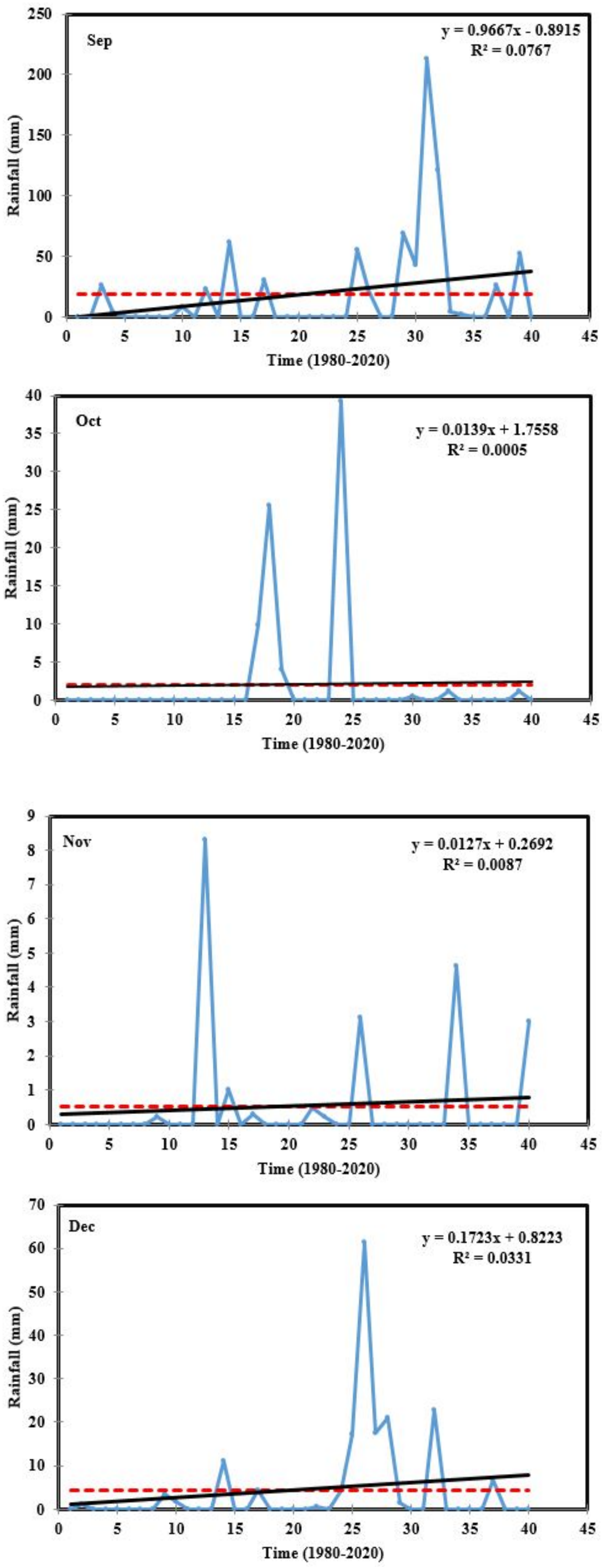


Figure 8. Monthly time series plots for Karachi city with trend, significant year of changing points and shift in the total rainfall (mm) in the year 1980-2020.

3.3. Trend estimation for climate change

It is known that the MK and Sen's slope estimator (SS) tests were applied on annually and monthly scale to identify increasing or decreasing trends (at significance level α=0.05) or not and for the magnitude (°C or mm/year) of the trends (Asfaw et al., 2018). In the MK test, the negative values show a decreasing trend, while a positive value indicates an increasing trend. The Sen's slope estimation value is applied to identify the change per unit time of these trends.

The result of the MK and Sen's Slope estimation test has been obtained for the max., temperature for each month of the year, as well as for the annual data for the Karachi station (Table 1). These results revealed that most of the months have shown increasing trend at a 5% significant level in monthly max., temperature. The remaining months have shown no significant increasing trends. It is also revealed an increasing trend in annual temperature ($\tau = 0.078, s = 0.043°C/year, p = 0.011$). From Table 2, it has been observed that all months exhibit statistically significant increasing trends in monthly min., temperature.

The study reports, an uncertain but persistent warming trend (~0.025 °C/year) in the years 1980 to 2020 at Karachi region. Many studies highlights the possible factors such as urbanization, monsoon patterns, and large-scale atmospheric circulation may contributed to the warming trend in Karachi through the urban heat island effect (UHI), wherein densely built environments absorb and retain heat more than surrounding rural areas (Rizvi et al., 2019; Arshad et al., 2020; Iftikhar & Iqbal, 2024). These patterns can increase in persistent heat-wave, such as Karachi experienced in 2015, a severe heat wave that caused in the deaths of approximately 1,200 people (Kamal, 2022).

It is noted that Karachi receives most of its annual rainfall during the southwest monsoon season, roughly from July to September. However, total monsoon rainfall in Karachi is somewhat low and highly variable in comparison to other regions of Pakistan, particularly the northern and northeastern parts where monsoon rains are heavier and more consistent (Rasul et al., 2005; Qureshi et al., 2023). Table 3 revealed that only February have obtained statistically significant decreasing trend on monthly rainfall with τ =-0.259,s $= -0.097$mm/year, p=0.026, and no significant trends were found for other months as well as in annual rainfall. These results suggested that insignificant variations in rainfall is a matter of concerns for various sectors of society, including land use planning and management, commerce, drainage system in urban areas, water board, as well as the economy, tourism, and agriculture sectors.

3.4. Homogeneity test analysis for the climate data series

It is known that identifying change points using the Pettitt's test offers valuable insights into abrupt shifts in time series datasets; contribute significant physical and practical implications over different fields such as climatology. However, a careful consideration of data characteristics and suitable diagnostic techniques is important for precise analysis and application.

In this section, the Pettitt's test was applied in which the null hypothesis was that there is no shift in the mean dataset whereas the alternative hypothesis was that there is a certain point at which a variation can be identified and the mean of the dataset shift at this change point. The Pettitt's test results were used to identify inhomogeneity in the mean annual, mean monthly max., min., temperature, and total rainfall dataset for the whole series from 1980-2020 are presented along with empirical significant level (p-value) in Table 4, Table 5, and Table 6, respectively. The inhomogeneity was estimated for a significance level of 95%, and the change of the breakpoints was observed.

The results obtained from Pettitt's test revealed that a significant changing year in the annual mean max., temperature occurred in 1997, which shows that annual mean max., temperature in the last 23 years is significantly greater than that of the previous years. Due to the shift in average, the temperature for the annual mean max., was 32.07°C before the changing year (red line in Figure 3), while it was 32. 62°C after the changing year (green line in Figure 3). This indicates a shift in the regional temperature system (i.e. warming trend) as shown in the Figure 3.

Similarly, statistically significant changing points for monthly max., temperature were detected in March, April, Jun, July, Aug, and September. In these months, overall significant shifts of mean is upward, and the change points occurred in 1997, 1997, 2012, 2005, 1996, and 2004 respectively as presented in Table 4. This could reflect comprehensive global climate patterns, such as increasing heat-waves, rising season changes, or increasing energy demands.

Conversely, the absence of a statistically significant change point in January, February, May, October, November, and December means there is no evidence of an unexpected or rapid change in the median of temperature during the observed period. Physically, such results revealed consistent behavior for max., temperature in these months with respect to abrupt transition as shown in Table 4 and Figure 4 (red line).

Table 4. Results of monthly Max., and annual temperature; Pettitt's homogeneity test (p values with significant changing points are in black) for Karachi station from 1980-2020 (α = 0.05).

Months	**Pettitt's homogeneity test results**			
	Change point (per year)	**Two-tailed test (p value)**	**Shift**	**Risk to reject null hypothesis (5%)**
Jan	1998	0.884	Constant	88.2
Feb	1991	0.099	Constant	9.87
Mar	1997	**0.018**	Increasing	1.82
Apr	1997	**0.004**	Increasing	0.4
May	2008	0.286	Constant	28.62
Jun	2012	**0.015**	Increasing	1.47
July	2005	**0.038**	Increasing	3.81
Aug	1996	**0.013**	Increasing	1.32
Sep	2004	**0.041**	Increasing	4.10
Oct	1990	0.600	Constant	69.99
Nov	1997	0.297	Constant	29.72
Dec	1997	0.784	Constant	78.43
Annual	1997	**0.003**	Increasing	0.25

In case of mean min., temperature dataset, a significant changing year was also observed in mean min., annual temperature in 1997 as depicted in Figure 5. Due to the shift in average, the annual mean min., temperature was 20.45°C before the break point (red line in Figure 5), while it was 21. 95°C after the break point (green line in Figure 5). Similar, significant years of changing point (upward shift) in min., temperature datasets for all months, were occurring between 1996 and 2006 as shown in Figure 6, and Table 5. This indicates a possible permanent upward shift in min., temperature, consistent with observed regional warming trends in Karachi city.

Table 5. Results of mean monthly Min., and annual temperature (°C); Pettitt's homogeneity test (p values of the significant year of changing points are in black) for Karachi station from 1980-2020 (α = 0.05).

Months	**Pettitt's homogeneity test results**			
	Change point (per year)	**Two-tailed test (p value)**	**Shift**	**Risk to reject null hypothesis (5%)**
Jan	1997	**0.017**	Increasing	1.68
Feb	1998	**0.000**	Increasing	0.01
Mar	2000	**0.0001**	Increasing	0.01
Apr	1997	**0.0001**	Increasing	0.01
May	1997	**0.0001**	Increasing	0.01
Jun	1997	**0.006**	Increasing	0.56
July	2005	**0.001**	Increasing	0.07
Aug	2006	**0.005**	Increasing	0.54
Sep	2004	**0.000**	Increasing	0.02
Oct	1996	**0.0001**	Increasing	0.01
Nov	1996	**0.0001**	Increasing	0.01
Dec	1996	**0.001**	Increasing	0.06
Annual	1997	**0.011**	Increasing	1.14

Similarly, Pettitt's test approach applied to annual and monthly rainfall series exhibited upward shift with no significant change points as illustrated in Figure 7 and Figure 8. This directs a homogeneous rainfall pattern over the study period in the region, with no evidence of sudden shifts in the timing or amount of rainfall at either the monthly or annual scale as shown in Table 6. Some previous studies showed that rainfall in Karachi has decreasing and fluctuating trends with no strong, universal abrupt shift observed (Ali et al., 2020; Akhtar and Abbas, 2021).

These evidences may suggest rainfall patterns in Karachi may have slow shifts (e.g. in seasonality, timing, intensity) rather than a sudden change in monthly or annually total rainfall over decades. Pettitt's tests may not detect a distinct change point however there is a trend. It's possible that the key climate factors, such as sea surface temperatures, monsoon patterns, and large-scale atmospheric conditions have not changed in a way that produces a strong, or abrupt shift in Karachi's overall rainfall. For example, while warmer sea temperatures could increase more moisture to the air, that doesn't necessarily result in more rainfall if the atmospheric systems aren't favorable for rainfall. In some cases, these factors may even counterbalance each other.

Table 6. Results of monthly, annual total rainfall; Pettitt's homogeneity test (p values with significant changing points are in black) for Karachi station from 1980-2020 (α = 0.05).

Months	Pettitt's homogeneity test results			
	Change point (per year)	Two-tailed test (p value)	Shift	Risk to reject null hypothesis (5%)
Jan	1989	**0.263**	Constant	26.31
Feb	2003	**0.089**	Constant	8.93
Mar	1999	**0.605**	Constant	60.47
Apr	1985	**0.078**	Constant	7.80
May	1996	**0.514**	Constant	51.38
Jun	1995	**0.288**	Constant	28.79
July	2010	**0.909**	Constant	90.89
Aug	2005	**0.210**	Constant	21.02
Sep	2004	**0.055**	Constant	5.53
Oct	1996	**0.090**	Constant	9.03
Nov	1992	**0.583**	Constant	58.33
Dec	2003	**0.265**	Constant	26.47
Annual	2005	**0.320**	Constant	32.01

The analysis of climate variables in Karachi from 1980 to 2020 reveals a clear upward trend in temperature, indicating a consistent warming pattern over the past decades. In contrast, rainfall trends during the same period appear statistically insignificant, suggesting high inter-annual variability without a definitive directional change. This difference between temperature and rainfall trends highlights the complexity of Karachi's increasing climate and highlights the cumulative impact of urban heat effects and broader regional warming, even as rainfall patterns remain irregular and less predictable.

4. Conclusions

The identification of trends in climate change is a foundation of environmental science and important for the planning organization of natural assets, cultivation techniques, and adaptation to changing climate conditions. This research was a sincere effort to inspect the long-term climate trends revealed by the region of Karachi over the defined time period 1980 to 2020 using non-parametric statistical approaches, such as the MK, SS estimation, and Pettitt's tests. Following conclusions were obtained from the study.

1. Karachi city revealed a significant increasing positive trend in the mean annual and monthly max., and min., temperature during the studied time period of 40 years.
2. The mean annual temperature in the study region ranged from 31.1° C to 33.4° C with annual average temperature of 32.3° C and increased at an annual rate of 0.025 °C per year for max., temperature while for min., temperature it was 0.06° C per year during the study time period

1980 to 2020. These results are very close to the global warming rate i.e $0.6°C$ estimated in last decades (Asfaw et al., 2018).

3. Additionally, the mean annual rainfall for the selected period was recorded 180.4 mm with standard deviation of 133.4 mm while 366.8 mm rainfall was recorded during month of August 2020 with 84.5 mm standard deviation.
4. The annual rainfall experienced no significant increasing trend while on monthly basis only February shown statistical significant decreasing trend with τ =-0.259,s $= -0.097 \text{mm/year}$, and no significant trends were obtained for other months.
5. Besides this, the shift in the mean maximum temperature was observed heterogeneous at annual and monthly time scales. A significant ($p < 0.05$) step jump (shift) upward was observed in the time series of annual mean max., temperature in the year 1997, and on monthly basis overall significant shifts of mean is upward and diverse change points occurred. Whereas, some months showed not significant shift i.e. they are considered as homogeneous.
6. In case of mean minimum temperature, similar significant upward shift were observed for both mean minimum annual as well as monthly minimum temperature. These results highlight a significant climate shift in Karachi.
7. Furthermore, for the annual and monthly time series datasets of precipitation, there is no significant shifts were detected by the Pettit's test approach. This indicated that that both annual and monthly datasets of precipitation showed homogenous.

These finding highlights needful information on historical climate trends in Karachi, which is a necessary foundation for informing future adaptation policy planning in Karachi.

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Declaration of Interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References
Ahmed, K., Shahid, S., Wang, X., Nawaz, N., & Khan, N. (2019). Spatiotemporal changes in aridity of Pakistan during 1901–2016. *Hydrology and Earth System Sciences*, *23*(7), 3081-3096. https://doi.org/10.5194/hess-23-3081-2019.

Ali, S., Khalid, B., Kiani, R. S., Babar, R., Nasir, S., Rehman, N., ... & Goheer, M. A. (2020). Spatio-temporal variability of summer monsoon onset over Pakistan. *Asia-Pacific Journal of Atmospheric Sciences*, *56*(1), 147-172. https://doi.org/10.1007/s13143-019-00130-z.

Akhter, M. F., & Abbas, S. (2021). Variability of provincial capital rainfall in Pakistan using wavelet transformation. *Pure and Applied Geophysics*, *178*(10), 4147-4157. https://doi.org/10.1007/s00024-021-02803-1.

Anwar, F. (2012). Karachi city climate change-adaptation strategy a roadmap. *Journal of Research in Architecture and Planning*, *11*(1). DOI;978-969-9491-04-7.

Arefin, R., Meshram, S. G., & Santos, C. A. G. (2021). Comparison of land use/land cover change of fused image and multispectral image of landsat mission: a case study of Rajshahi, Bangladesh. *Environmental Earth Sciences*, *80*(17), 1-16. https://doi.org/10.1007/s12665-021-09807-z.

Arshad, A., Ashraf, M., Sundari, R. S., Qamar, H., Wajid, M., & Hasan, M. U. (2020). Vulnerability assessment of urban expansion and modelling green spaces to build heat waves risk resiliency in Karachi. *International journal of disaster risk reduction*, *46*, 101468. doi:10.1016/j.ijdrr.2019.101468.

Asfaw, A., Simane, B., Hassen, A., &Bantider, A. (2018). Variability and time series trend analysis of rainfall and temperature in northcentral Ethiopia: A case study in Woleka sub-basin. *Weather and climate extremes*, *19*, 29-41. https://doi.org/10.1016/j.wace.2017.12.002.

Aucahuasi-Almidon, A., Cabrera-Carranza, C., & Garate-Quispe, J. (2024). Trend analysis and change-point detection of temperature and rainfall in southern Peruvian Amazon and its relation to deforestation. *Journal of Agrometeorology*, *26*(4), 425-430. DOI:10.54386/jam.v26i4.2687.

Bakhsh, H. A., Shakir, A. S., & Khan, N. M. (2011). Flood inundation modeling for Malir watershed of Karachi considering future mean sea level rise. *Pakistan Journal of Engineering and Applied Sciences*. https://journal.uet.edu.pk/ojs_old/index.php/pjeas/article/view/166.

Baqa, M. F., Chen, F., Lu, L., Qureshi, S., Tariq, A., Wang, S., ... & Li, Q. (2021). Monitoring and modeling the patterns and trends of urban growth using urban sprawl matrix and CA-Markov model: A case study of Karachi, Pakistan. *Land*, *10*(7), 700. https://doi.org/10.3390/land10070700.

Bouznad, I. E., Guastaldi, E., Zirulia, A., Brancale, M., Barbagli, A., & Bengusmia, D. (2020). Trend analysis and spatiotemporal prediction of precipitation, temperature, and evapotranspiration values using the ARIMA models: case of the Algerian Highlands. *Arabian Journal of Geosciences*, *13*(24), 1-17. DOI:10.1007/s12517-020-06330-6.

Caloiero, T., & Guagliardi, I. (2021). Climate change assessment: seasonal and annual temperature analysis trends in the Sardinia region (Italy). *Arabian Journal of Geosciences*, *14*(20), 1-10. https://doi.org/10.1007/s12517-021-08527-9.

Chattopadhyay, G., Chakraborthy, P., &Chattopadhyay, S. (2012). Mann–Kendall trend analysis of tropospheric ozone and its modeling using ARIMA. *Theoretical and Applied Climatology*, *110*(3), 321-328. https://doi.org/10.1007/s00704-012-0617-y.

Conte, L. C., Bayer, D. M., & Bayer, F. M. (2019). Bootstrap Pettitt test for detecting change points in hydroclimatological data: Case study of Itaipu Hydroelectric Plant, Brazil. *Hydrological Sciences Journal*, *64*(11), 1312-1326. https://doi.org/10.1080/02626667.2019.1632461.

Dawadi, B., Sharma, S., Reynard, E., and Shahi, K. (2023). Climatology, Variability, and Trend of the Winter Precipitation over Nepal. *Earth Syst Environ*. https://doi.org/10.1007/s41748-023-00338-0.

de Oliveira-Júnior, J. F., Shah, M., Abbas, A., Iqbal, M. S., Shahzad, R., de Gois, G., ... & de Souza, A. (2022). Spatiotemporal analysis of drought and rainfall in Pakistan via Standardized Precipitation Index: homogeneous regions, trend, wavelet, and influence of El Niño-southern oscillation. *Theoretical and Applied Climatology*, 1-20. https://doi.org/10.1007/s00704-022-04082-9.

Dimri, T., Ahmad, S., & Sharif, M. (2020). Time series analysis of climate variables using seasonal ARIMA approach. *Journal of Earth System Science*, *129*, 1-16. https://doi.org/10.1007/s12040-020-01408-x.

Dubey, V., Panigrahi, S., & Vidyarthi, V. K. (2023). Statistical trend analysis of major climatic factors over Chhattisgarh State, India. *Earth Systems and Environment*, 7(3), 629-648. https://doi.org/10.1007/s41748-023-00345-1.

Farooq, I., Shah, A. R., Salik, K. M., & Ismail, M. (2021). Annual, Seasonal and Monthly Trend Analysis of Temperature in Kazakhstan During 1970–2017 Using Non-parametric Statistical Methods and GIS Technologies. *Earth Systems and Environment*, *5*(3), 575-595. https://doi.org/10.1007/s41748-021-00244-3.

Hanssen-Bauer, I., & Førland, E. J. (1998). Long-term trends in precipitation and temperature in the Norwegian Arctic: can they be explained by changes in atmospheric circulation patterns?. *Climate Research*, *10*(2), 143-153.https://doi.org/10.3354/cr010143. https://rmcsindh.pmd.gov.pk/S-Weather.asp?st=OPKC.

Hussain, D., Kuo, C. Y., Hameed, A., Tseng, K. H., Jan, B., Abbas, N., ... & Imani, M. (2019). Spaceborne satellite for snow cover and hydrological characteristic of the Gilgit river basin, Hindukush–Karakoram mountains, Pakistan. *Sensors*, *19*(3), 531. https://doi.org/10.3390/s19030531.

Iftikhar, A., & Iqbal, J. (2024). Changes in Lulc and Drainage Network Patterns the Cause of Urban Flooding in Karachi City. *International Journal of Disaster Risk Management*, *6*(1), 91-102. https://www.ceeol.com/search/article-detail?id=1249007.

Irfan, M., Kazmi, S. J. H., & Arsalan, M. H. (2018). Sustainable harnessing of the surface water resources for Karachi: a geographic review. *Arabian Journal of Geosciences*, *11*(2), 1-11. https://doi.org/10.1007/s12517-017-3365-6.

Jan, B., Zai, M. A. K. Y., Afradi, F. K., & Aziz, Z. (2018). Study nonlinear dynamics of stratospheric ozone concentration at Pakistan Terrestrial region. *Journal of Atmospheric and Solar-Terrestrial Physics*, *168*, 48-57. https://doi.org/10.1016/j.jastp.2018.01.013.

Javari, M. (2017). Assessment of dynamic linear and non-linear models on rainfall variations predicting of Iran. *Agricultural Engineering International: CIGR Journal*, *19*(2) https://cigrjournal.org/index.php/Ejounral/article/view/4193.

Jhajharia, D., Yadav, B. K., Maske, S., Chattopadhyay, S., & Kar, A. K. (2012). Identification of trends in rainfall, rainy days and 24 h maximum rainfall over subtropical Assam in Northeast India. *Comptes Rendus Geoscience*, *344*(1), 1-13. https://doi.org/10.1016/j.crte.2011.11.002.

Jiqin, H., Gelata, F. T., & Chaka Gemeda, S. (2023). Application of MK trend and test of Sen's slope estimator to measure impact of climate change on the adoption of conservation agriculture in Ethiopia. *Journal of Water and Climate Change*, 14(3), 977-988. https://doi.org/10.2166/wcc.2023.508.

Kabbilawsh, P., Kumar, D. S., & Chithra, N. R. (2022). Performance evaluation of univariate time-series techniques for forecasting monthly rainfall data. *Journal of Water and Climate Change*, *13*(12), 4151-4176. https://doi.org/10.2166/wcc.2022.107.

Kamal, S. A. (2022). The effects of global warming: the case study of Karachi's heat waves & its implication. *International Journal of Policy Studies*, *2*(1). https://ijpstudies.com/index.php/ijps/article/view/22.

Kocsis, T., Kovács-Székely, I., & Anda, A. (2020). Homogeneity tests and non-parametric analyses of tendencies in precipitation time series in Keszthely, Western Hungary. *Theoretical and Applied Climatology*, *139*(3), 849-859. https://doi.org/10.1007/s00704-019-03014-4.

Marndi, A., Patra, G. K., & Gouda, K. C. (2020). Short-term forecasting of wind speed using time division ensemble of hierarchical deep neural networks. *Bulletin of Atmospheric Science and Technology*, *1*(1), 91-108. https://doi.org/10.1007/s42865-020-00009-2.

Mitu, K. N., & Hasan, K. (2021). Modeling and forecasting daily temperature time series in the memphis tennessee. *International Journal of Environmental Monitoring and Analysis*, *9*(6), 214-221. 10.11648/j.ijema.20210906.17.

Mohapatra, J. B., Sahu, A. P., Rout, B., Baral, S. S., & Das, D. P. (2021). Analysis of long-term rainfall patterns using high-resolution atmospheric data over Odisha. *Arabian Journal of Geosciences*, *14*(21), 1-12. https://doi.org/10.1007/s12517-021-08528-8.

Narwal, H., Rani, N., & Neha. (2023). Trend Analysis of Climatic Variables and their Possible Impact on the Health of People in Himachal Pradesh, India. *Journal of Climate Change*, *9*(3), 15-25. https://doi.org/10.3233/JCC230020.

Patil, M. K., & Kalange, D. N. (2015). Detection of Trend in Rainfall Data: A Case study of Sangli District. *Review of Research*, 4(6), 1-15, https://oldror.lbp.world/ColorArticle/1459.pdf.

Porwal, V., & Choudhary, M. P. (2023). Investigating variations and trend analysis for temperature and precipitation as a result of climate change in Rajasthan, India. *Journal of Climate Change*, *9*(3), 33-40. https://doi.org/10.3233/JCC230022.

Qureshi, H. U., Shah, S. M. H., Yassin, M. A., Abba, S. I., & Mustaffa, Z. (2023). Investigation of Causes and Characteristics of Monsoon Extremes in Pakistan: A Case Study for Summer Monsoon 2022. *The Journal of The Institution of Engineers Malaysia*, *83*(2), 6-19. https://doi.org/10.54552/v83i2.197.

Rasul, G., Chaudhry, Q. U. Z., Sixiong, Z., Qingcun, Z., Linlin, Q. I., & Gaoying, Z. (2005). A diagnostic study of heavy rainfall in Karachi due to merging of a mesoscale low and a diffused tropical depression during South Asian summer monsoon. *Advances in Atmospheric Sciences*, *22*(3), 375-391. https://doi.org/10.1007/BF02918751.

Ray, S., Das, S. S., Mishra, P., & Al Khatib, A. M. G. (2021). Time series SARIMA modelling and forecasting of monthly rainfall and temperature in the South Asian countries. *Earth Systems and Environment*, *5*(3), 531-546. https://doi.org/10.1007/s41748-021-00205-w.

Rizvi, S. H., Alam, K., & Iqbal, M. J. (2019). Spatio-temporal variations in urban heat island and its interaction with heat wave. *Journal of Atmospheric and Solar-Terrestrial Physics*, *185*, 50-57. https://doi.org/10.1016/j.jastp.2019.02.001.

Schaffer, A. L., Dobbins, T. A., & Pearson, S. A. (2021). Interrupted time series analysis using autoregressive integrated moving average (ARIMA) models: a guide for evaluating large-scale health interventions. *BMC medical research methodology*, *21*, 1-12. https://doi.org/10.1186/s12874-021-01235-8.

Sharma, V., & Adhikari, K. (2022). Rainfall and rainy days trend and ENSO phenomena in Himalayan Kingdom of Bhutan. *Acta Geophysica*, *70*(4), 1855-1869. https://doi.org/10.1007/s11600-022-00839-y.

Singh, H., & Choudhary, M. P. (2023). Trend and homogeneity test analysis for rainfall over a 121-year time period in the desert district of Western Rajasthan, India. *Water Practice & Technology*, *18*(7), 1681-1695. https://doi.org/10.2166/wpt.2023.100.

Sudarsan, G., & Lasitha, A. (2023). Rainfall Trend analysis using Mann-Kendall and Sen's slope test estimation-A case study. In *E3S Web of Conferences* (Vol. 405, p. 04013). EDP Sciences. https://doi.org/10.1051/e3sconf/202340504013.

Sy, S., Madonna, F., Rosoldi, M., Tramutola, E., Gagliardi, S., Proto, M., & Pappalardo, G. (2021). Sensitivity of trends to estimation methods and quantification of subsampling effects in global radiosounding temperature and humidity time series. *International Journal of Climatology*, *41*, E1992-E2014. https://doi.org/10.1002/joc.6827.

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Zakwan, M., & Ahmad, Z. (2021). Trend analysis of hydrological parameters of Ganga River. *Arabian Journal of Geosciences*, *14*(3), 1-15. https://doi.org/10.1007/s12517-021-06453-4.