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Trends Analysis of Long-Term Meteorological Data

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ABSTRACT

Considering the potential impacts of climate change on meteorological data is likely to be more reliable in the design of hydrological systems. One of the recognized methods for the assessment the influence of climate changes by analyzing the weather data. The study aims were inspecting the maximum, minimum temperature and rainfall data for any discernible trends in the city of Delhi between 1901 – 2010 periods. Mann-Kendall non-parametric test including correlation was adopted to analyze the available data for three periods: 1901-2010; 1901-1955 and 1956-2010. Annual, monsoonal and pre-monsoon rainfalls have been examined for trends analysis. Results show that the maximum and minimum annual temperatures exhibit an increasing and decreasing trend, respectively. On the other hand, monsoonal and annual rainfall shows increasing trends. A strong negative correlation is noted between annual rainfall and annual maximum temperature for 1901-1955 and 1956-2010 periods as well as for the entire period of analysis. A strong negative correlation is also noted between the monsoonal rainfall and the annual maximum temperature. In addition to previous findings, a noticeable correlation is shown between minimum temperature and annual rainfall for 1956-2010 periods of records. However, a weak and negative correlation was reported between minimum temperature and annual rainfall for the periods between 1901-1955 and 1956-2010.

Keywords:

Meteorological data analysis, climate change, Mann-Kendall test, correlation coefficient, Delhi trends.

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1. INTRODUCTION

The rise in temperature and a change of precipitation and runoff amounts in several regions of the world is mainly influenced by increasing the concentration of greenhouse gases. Correspondingly, the water resources in most regions in the world are greatly influenced because of its direct relationship by changes of the climatic conditions. Jiang et al. [1] shows that climate change has important implications for studying water supply and flood response strategies. The California water system investigated dependence on mountain snow accumulation and the snowmelt process [2]. Vulnerable to global warming effect other influences that have been recognized. It's included but not limited to changes in patterns of rainfall, operation of reservoirs, runoff production, and processes of erosion, water quality. Hadi and Tombul [3] examined the patterns in temperature and precipitation over Turkey during the long-term period between 1901 and 2014. Asfaw et al. [4] employed the Mann-Kendall test for examining the meteorological variables in north central Ethiopia from 1901 to 2014. The results revealed a decreasing trend for annual, seasonal mean (February to May and June to September) rainfall with a rate of 15.03, 1.93 and 13.12 mm per decade respectively; while they revealed an increasing trend for mean, minimum and maximum temperature with rate of change 0.046, 0.067 and 0.026 °C per decade respectively. According to the report done by IPCC [5, 6], there was a probability of a significant warming over South Asian subregions. Results of B1 and A1F1 scenarios of Global Circulation Model (GCM) run under the Special Report on Emission Scenarios (SRES) clearly indicated an increasing in the average temperature over South Asia. Several studies have been conducted in various parts of South Asia to investigate potential climate trends and changes. Temperature and rainfall data analysis for India's northeast region revealed increasing variability in magnitude and trend direction from one meteorological subdivision to another [7]. Using long-term mean annual temperature data from 1901 to 1982, it was discovered that there is an increasing trend in mean surface air temperatures all over India Hingane, et al. [8]. It was discovered that the climate has warmed at a rate of 0.4°C over the last eight decades, owing primarily to an increase in maximum temperatures. [9], on the other hand, revealed an increase in mean annual temperatures in India at a rate of 0.57°C per 100 years. The rapid urbanization led to the rise in the minimum temperature as a part of mean annual temperatures [10]. The mean temperature all over India has increased by 1.1°C and 0.94°C per 100 years for the winter and post monsoon seasons, respectively [11]. Singh, et al. [12] analyzed seasonal and annual of different temperature variables for the 43 stations covering the study area in the northeast and central India. Seven out of nine river basins studies showed warming trend while the last two basins showed cooling trend. It can be concluded from the several studies that the area of south Asia has been affected by the global warming trend. Water resources are identified as very sensitive to changes of climate. Temperature and precipitation are the most important parameters impact on climate change. Numerous studies have also shown warming trend in Bangladesh, Pakistan, Nepal and China.

Bangladesh's temperature has risen at a rate of 0.5°C per 100 years [13]. Nepal, Himalayan and Trans-Himalayan, have also shown increasing trends in winter maximum temperatures. Pakistan had an increasing temperature trend of 0.9°C by 2020, and the forecast temperature rise could be doubled by 2050 [14]. Khattak, et al. [15] reported an increasing trend in winter maximum temperature in Upper Indus Basin. Marco, et al. [16] analyzed the long-term monthly precipitation and temperature data set of 160 climate stations from 1951-2002 all over the China. [17, 18] They used Mann-Kendall test to analyzed temperature and precipitation data in China.

Numerous studies have also been carried out to determine the changes in precipitation trend in south Asia region. Tirkey et al. [19] were used 113 years (1901-2013) of monthly, annual, and seasonal (pre-monsoon, monsoon, post-monsoon, and winter) precipitation data over the Satluj basin in Himachal Pradesh state, India. The analyzing data was carried out by using Mann-Kendall test and Sen's slope estimator. [20] Analyzed monthly rainfall data for 34 years in Bharathapuzha River basin in Kerala and showed that there was an annual significant decreasing trend, southwest, and pre-monsoon rainfall of the basin towards the ends of the study period. Ramesh and P. Goswami [21] investigated daily observed rainfall data for the period 1951–2003 over India. The results showed shrinking in the length and the coverage of the Indian summer monsoon. [22] An increasing was expected in hazards related to heavy rain over central India in the future by examined a daily rainfall data set from 1951 to 2000. Special variation in long-periods records of precipitation data in Upper Indus River Basin (UIRB) has been investigated by correlation and regression analysis. Result showed an increasing trend in summer, winter and in the annual precipitation during the period 1961-1999 at several stations in the study area [23]. [24] Observed rising trend in precipitation in the middle and lower part of Yangtze basin, China. Whereas decreasing precipitation trend deduced in Iran [25]. The trends of seasonal maximum and minimum temperatures and rainfall for nine stations in the north eastern part of India for the period 1913-2012 was examined [26]. The study showed increasing trends in maximum and minimum temperatures in almost all the stations, while most of the stations detected either decreasing trend or no trend of rainfall.

However, the goal of the current study is to analyze and recognize trends in average monthly maximum, minimum, and rainfall data for Delhi over a 110-year period (from 1901 to 2010).

2. STUDY AREA AND DATA COLLECTION

Most of the rainfall in India occurs during the monsoon season that extends from June to September with a wide range of spatial patterns. The concentration of the present research was on the analysis of long-term maximum, minimum temperatures and rainfall data for the city of Delhi in northern India, covering an area of approximately 1500 km^2. Hot and humid summers with cold and dry winters can be observed in Delhi. The temperature varies for about 45°C between summers and winters during the year and the average rainfall is about 714 mm with 80% precipitation during the monsoon period. For about 160 kilometers south of the Himalayas, Delhi is located on the left and right banks of the Yamuna River, a tributary of the Ganga River. In the recent years, harmful effects observed on the population health in Delhi have been increased because increasing the concentration of air pollution as a result of emitted Gases from vehicles and suspended particulate matter in air. Considering the rate of pollution in Delhi, it is important to assess the impact of temperature and rainfall changes on climate change in the city. The time series of mean monthly maximum (TMX), minimum temperatures (TMN), and total monthly precipitation (MPPT) for the period 1901-2010 for the city of Delhi was provided by the Indian Meteorological Department, Pune. These data were used in the current study. Figure (1) shows the study area.

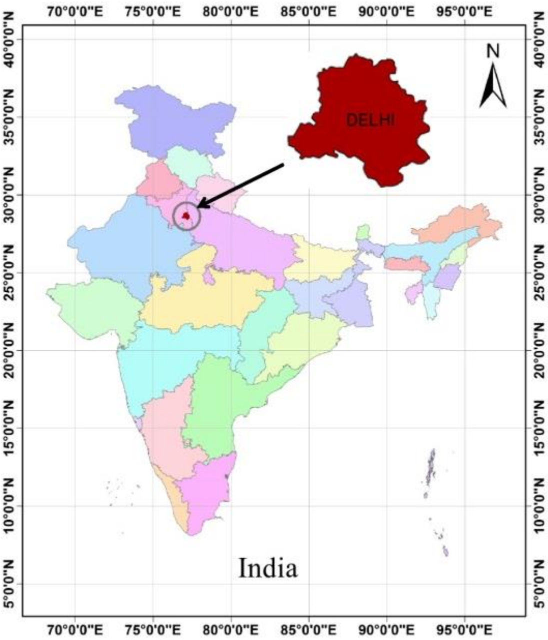


Fig.1. Location map of Delhi

The data used in this study is available for the city of Delhi from 1901 to 2010. The data was divided into two time periods. The first analysis time series includes records from 1901 to 1955, while the second analysis time series includes records from 1956 to 2010.

3. TREND ANALYSIS USING MANN-KENDALL APPROACH

As mentioned earlier, the objective of the present study is to investigate trends in monthly rainfall, maximum temperature, and minimum temperature for Delhi. Trend analysis for three different periods of analysis; 1901-2010, 1901-1955, and 1956-2010 has been carried out for nine variables using Mann-Kendall nonparametric test for the entire analysis period as well as the partitioned data sets [27, 28]. It is one of the most commonly used non-parametric tests for detecting trends in hydro-meteorological time series.

Mann-Kendall non-parametric test is widely used to analyze environmental, climate or hydrological time series data. Numerous studies have been carried out dependent upon Mann-Kendall test to determine the trends in the hydro-meteorological variables due to climate change [12, 15, 29-34].

The reason for selecting different periods of analysis was to determine the difference in trends between different periods of analysis. The entire period (1900-2010) and two-time series for (1900-1955) and (1956-2010) have been analyzed for trends.

The first three variables (ARAIN, MRAIN and PMONS) are corresponding to the annual rainfall, monsoonal rainfall, and pre-monsoonal rainfall as proportion of annual rainfall. Fourth variable is the mean annual maximum temperature (ATMX) and whereas fifth variable is the mean annual minimum temperature (ATMN). Sixth and seventh variables represent the mean maximum temperature (TMX-MAM) and mean minimum temperature (TMN-MAM), respectively for the pre-monsoon period (March-May). The averaged (TMX-JJAS) and (TMN-JJAS) over the monsoon period (June to September) are represented by eighth and ninth variables, respectively.

Many parametric and non- parametric equations have been employed by a number of researchers for detection of trends [35]-[36]. The parametric method is more powerful than the non-parametric method, but data normality should be satisfied. In this study the non-parametric method was applied to identify the trends in different variables in hydro-meteorological data characterized by not normally distributed [37].

A number of techniques have been employed for the analysis of hydro-meteorological data. The Mann Kendall non-parametric test was used to determine whether there is any increasing or decreasing trends in the study area and to identify whether the trend is statistically significant or not. The Mann Kendall test is a ranked approach. It works by sequentially comparing each value of the time series with the remaining value. The statistic S is the sum of all the counting as given in equation 1 [38].

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{\mathrm{n}} Sgn(x_j - x_k) \quad (1)$$

Where

$$Sgn(x_j - x_k) = \begin{bmatrix} 1 \;\; if \;\; (x_j - x_k) > 0 \\ 0 \;\; if \;\; (x_j - x_k) = 0 \\ -1 \;\; if \;\; (x_j - x_k) < 0 \end{bmatrix} \quad (2)$$

And n is the length of the data set, xj and xk are the sequential data values. S with a positive value indicates an upward trend, while S with a negative value indicates a downward trend. If the number of samples greater than 10, the test is conducted using normal distribution [39] with the mean and variance as follows.

$$E[S] \tag{3}$$

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p\,(t_p-1)(2t_p+5)\right] \tag{4}$$

where tp represents the number of data points in the pth tied group and q represents the number of tied groups in the data set. The standardized test statistic (Zmk) is illustrated as follows:

$$Z_{mk} = \begin{bmatrix} \dfrac{S-1}{\sqrt{Var(S)}} & if \quad S > 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & if \quad S < 0 \\ 0 & if \quad S = 0 \end{bmatrix} \tag{5}$$

where Zmk denotes the Mann-Kendall test statistics, which follow a standard normal distribution with a mean of zero and a variance of one.

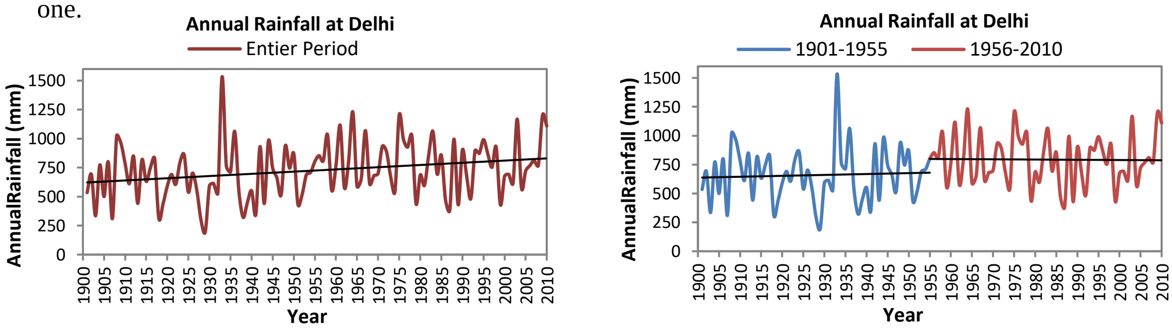
In a two-sided trend test, the null hypothesis Ho is accepted if $-Z1\text{-}\alpha/2 \leq Zmk \leq Z1\text{-}\alpha/2$, where ($\alpha$) is the significance level indicating trend strength.

4. ANALYSIS OF DATA AND DISCUSSION

4.1 Precipitation Trends

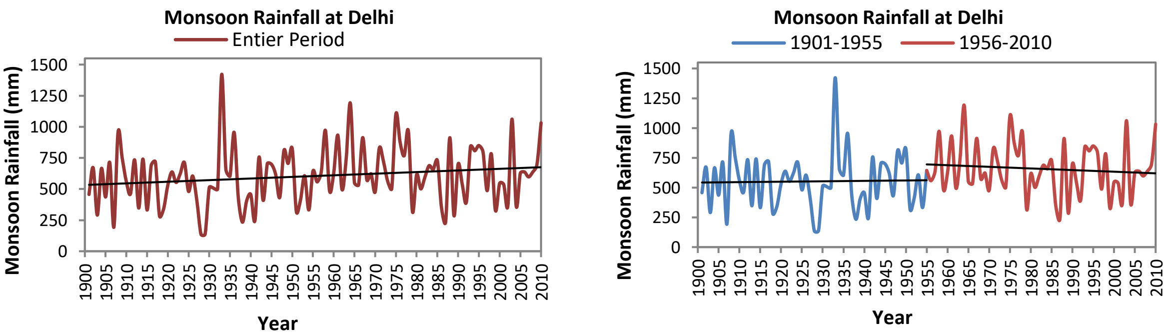
Total annual rainfall and total monsoonal rainfall for each year of data have been calculated by adding the total monthly rainfall for each month, as well as the monthly rainfall from June to September. Figures (2, 3) show the plots of total annual rainfall and the total monsoonal rainfall, respectively, for the entire and subdivision periods. Monsoon rainfall over Delhi shows interesting oscillations trends during the months from June to September (Figure 3).

Figure 4 shows the comparison of variation of the monsoonal and annual rainfall for the two different time series.



(a) (b)

Fig.2. (a) Annual rainfall - (1901-2010), (b) Annual rainfall, for periods (1901-1955) and (1956-2010)



(a) (b)

Fig.3. (a) Monsoonal rainfall - (1901-2010), (b) Monsoonal rainfall, for periods (1901-1955) and (1956-2010)

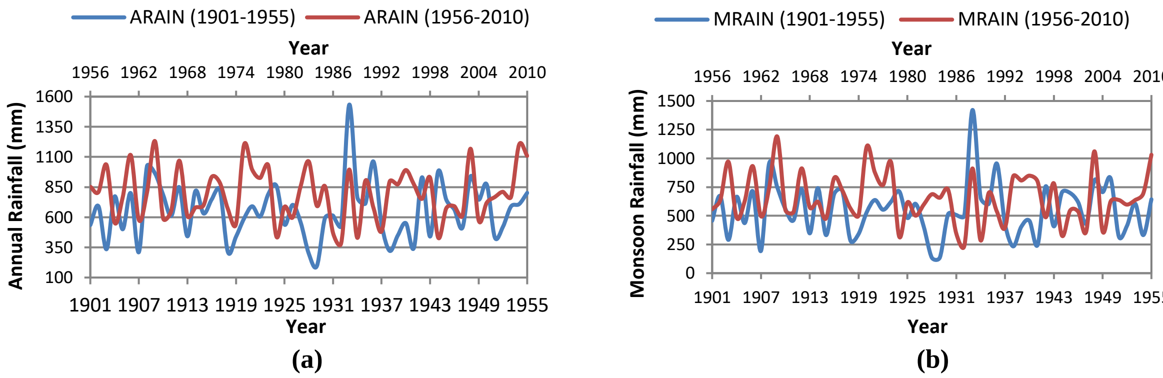


Fig.4. (a) Annual rainfall - (JJAS), (b) Monsoonal rainfall, for period (1901-1955) and (1956-2010)

4.2 Temperature Trends

The annual, pre-monsoon and monsoonal of maximum and minimum temperature data was examined for the available data.

The plots of temperature trends for the entire period and the subdivisions periods are shown in the figures (5-10). Figures 11–13 show a comparison of seasonal, monsoonal, and annual maximum and minimum temperature variation between the two time periods (1901–1955) and (1956-2010).

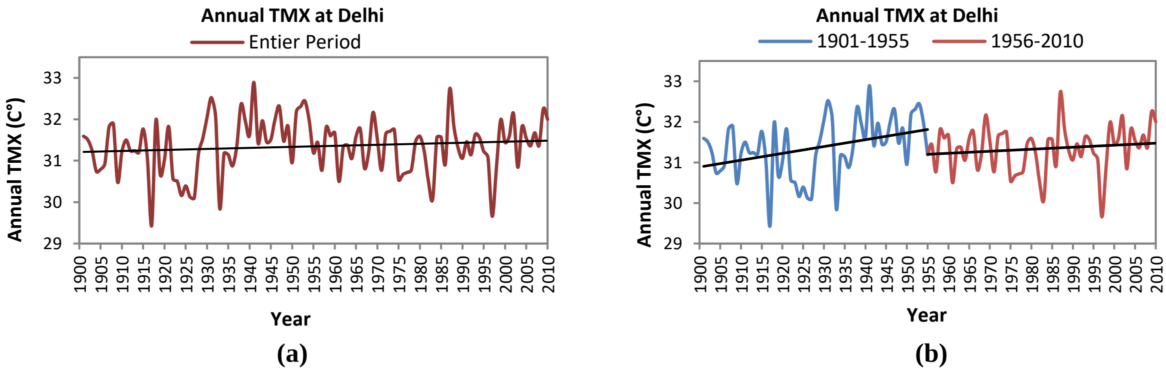


Fig.5. (a) Annual TMX - (1901-2010), (b) Annual TMX, for periods (1901-1955) and (1956-2010)

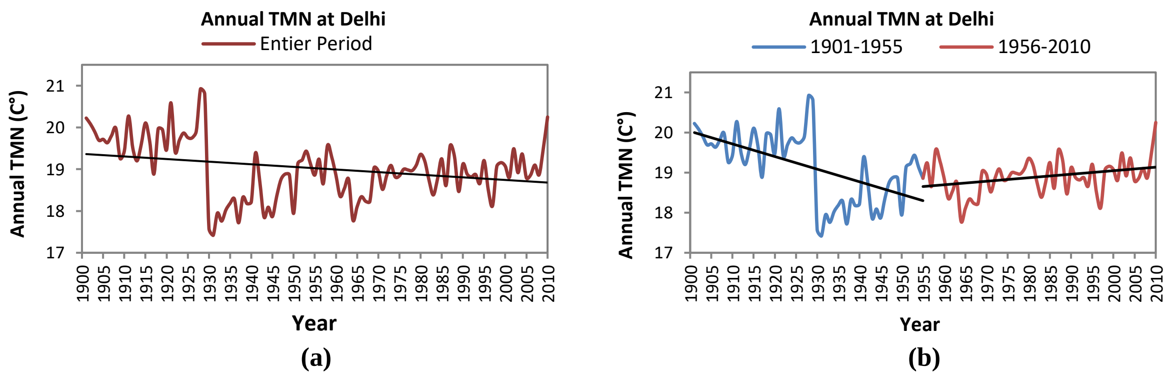
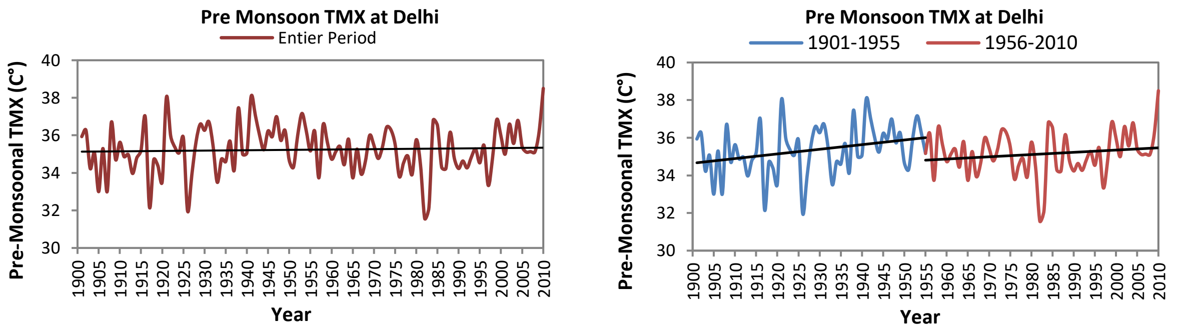
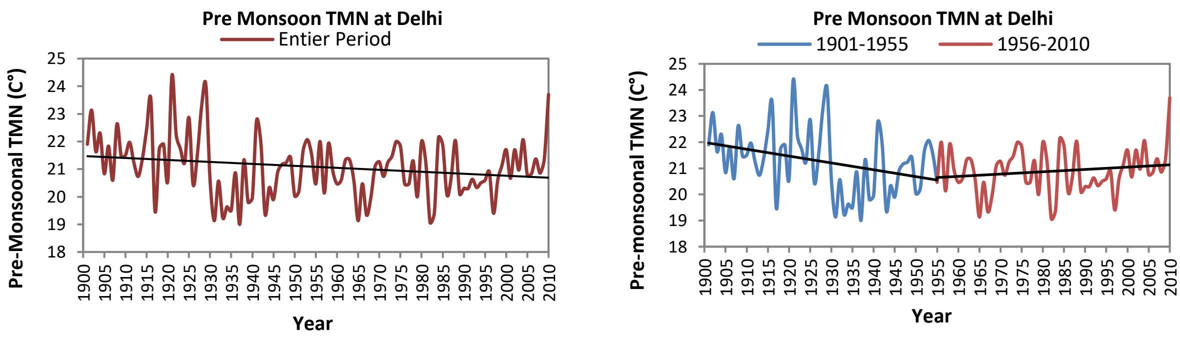


Fig.6. (a) Annual TMN - (1901-2010), (b) Annual TMN, for periods (1901-1955) and (1956-2010)



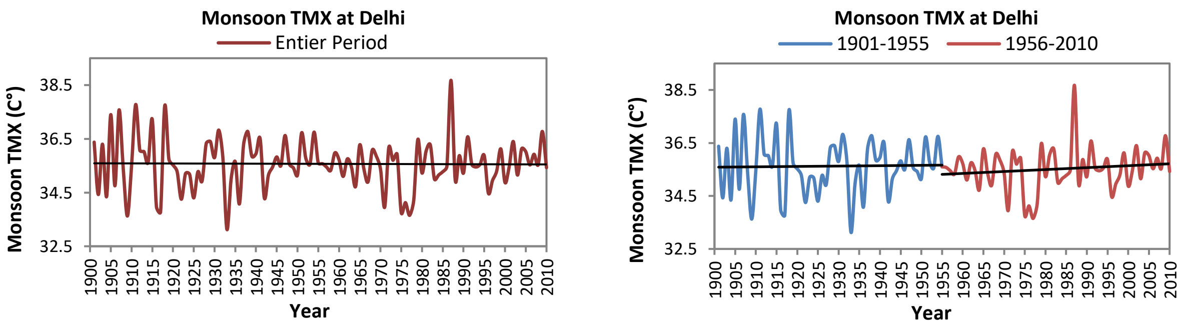
(a) **(b)**

Fig.7. (a) Pre-monsoon TNX - (1901-2010), (b) Pre-monsoon TMX, for periods (1901-1955) and (1956-2010)



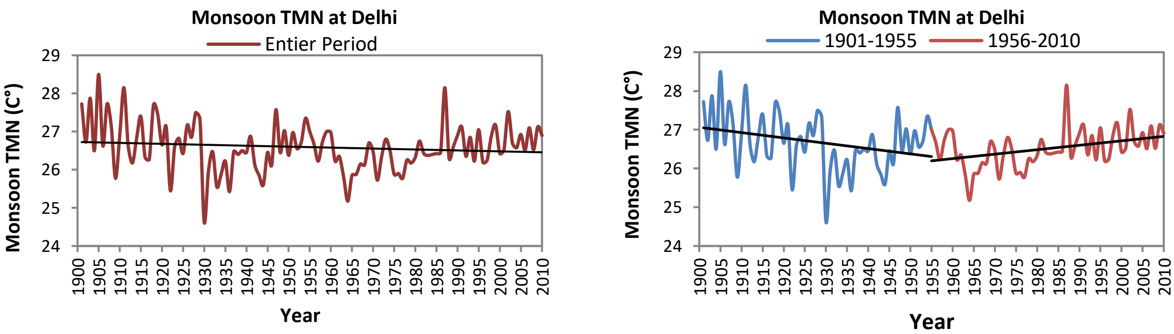
(a) **(b)**

Fig.8. (a) Pre-monsoon TNN - (1901-2010), (b) Pre-monsoon TMN, for periods (1901-1955) and (1956-2010)



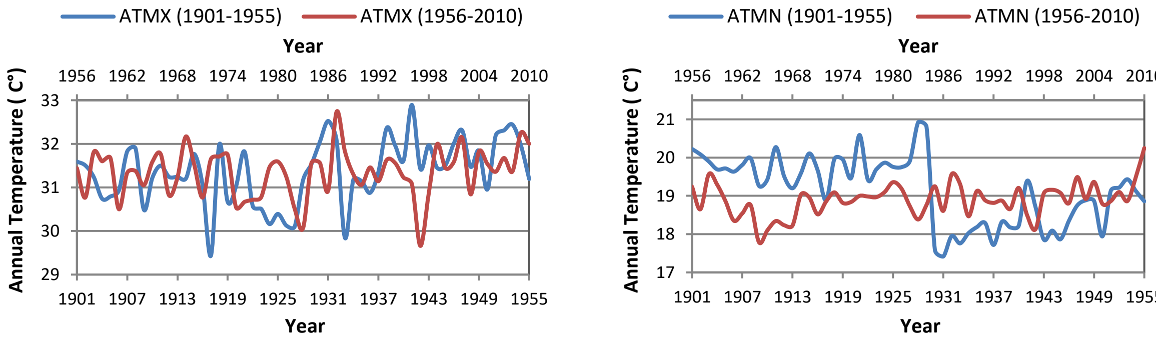
(a) **(b)**

Fig.9. (a) Monsoon TNX - (1901-2010), (b) Monsoon TMX, for periods (1901-1955) and (1956-2010)



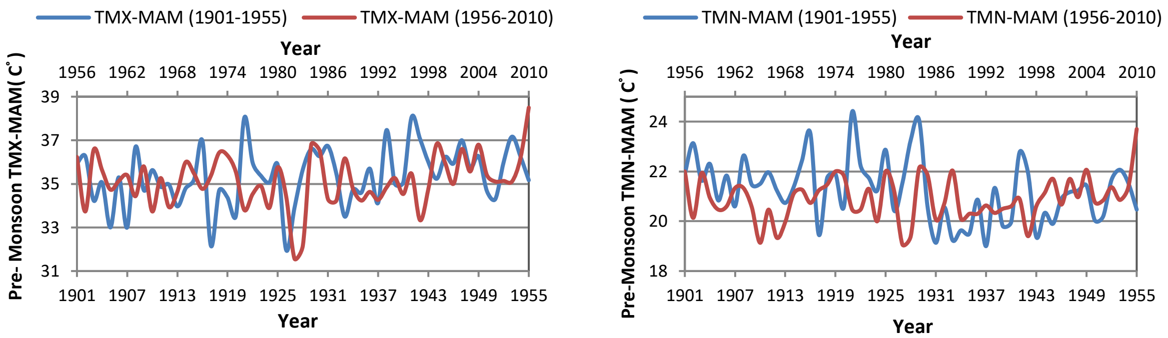
(a) **(b)**

Fig.10. (a) Monsoon TNN - (1901-2010), (b) Monsoon TMN, for periods (1901-1955) and (1956-2010)



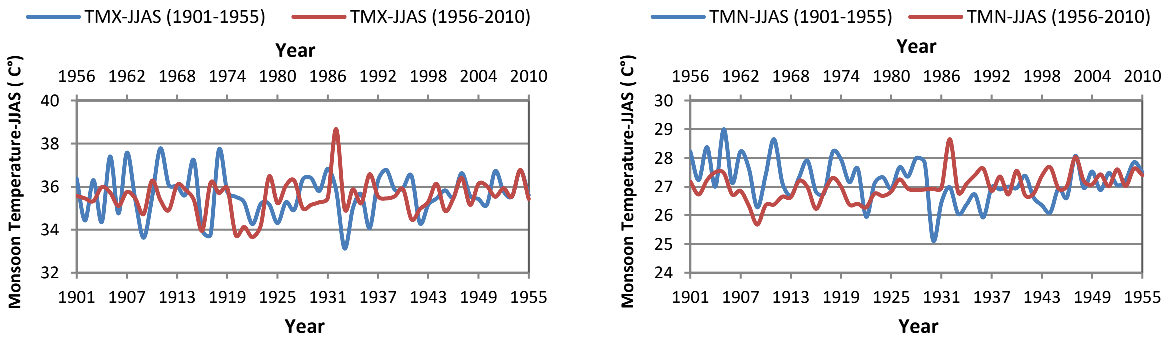
(a) (b)

Fig.11. (a) Annual TMX, (b) Annual TMN, for period (1901-1955) and (1956-2010)



(a) (b)

Fig.12. (a) Pre-Monsoon TMX-MAM, (b) Pre-Monsoon TMN-MAM, for period (1901-1955) and (1956-2010)



(a) (b)

Fig.13. comparison (a) Monsoonal TMX-(JJAS), (b) Monsoonal TMN-(JJAS), for period (1901-1955) and (1956-2010)

Table 1 shows the trends analysis of the monsoonal and annual rainfall at Delhi. The analysis has been carried out for the entire period of analysis and for the partitioned data sets. The results exhibit statistically significant increasing trends on monsoon and annual rainfall at entire period (1901-2010) only. For the annual and pre-monsoonal there are increasing trends for the all-time series; with statistically significant trend in the recent years of data analysis, while the annual and seasonal minimum temperature exhibit decreasing statistically significant trends for the entire period and the period (1901-1955) as shown in table 2 and table 3.

The results show significant increasing trend for the period (1956-2010) in annual minimum temperature. However, it can be seen from table 4 that there are decreasing and increasing statistically significant trends in monsoon (JJAS) minimum temperature for the periods (1901-1955) and (1956-2010) respectively. However, results show that there are no statistically significant trends in the three periods for the monsoon (JJAS) maximum temperature.

Table 1 Trends in Annual, Monsoonal Rainfall and Proportion Monsoonal for different periods of analysis

Period	ARAIN		MRAIN		PMONS	
	Slope	p-value	Slope	p-value	Slope	p-value
1901-2010	1.9312	**0.008**	1.3457	**0.069**	-0.001	0.305
1901-1955	0.2462	0.908	-0.2652	0.896	0.001	0.925
1956-2010	0.0294	1.000	-0.9783	0.622	-0.002	**0.061**

Table 2 Trends in annual TMX and TMN for different periods of analysis

Period	ATMX		ATMN	
	Slope	p-value	Slope	p-value
1901-2010	0.002	0.260	-0.006	**0.016**
1901-1955	0.016	**0.009**	-0.026	**0.000**
1956-2010	0.005	0.270	0.009	**0.023**

Table 3 Trends in Pre-Monsoonal TMX and TMN for different periods of analysis

Period	TMX-MAM		TMN-MAM	
	Slope	p-value	Slope	p-value
1901-2010	0.001	0.714	-0.006	**0.079**
1901-1955	0.024	**0.028**	-0.023	**0.019**
1956-2010	0.012	0.242	0.007	0.217

Table 4 Trends in MTMX and MTMN for different periods of analysis

Period	MTMX		MTMN	
	Slope	p-value	Slope	p-value
1901-2010	-0.001	0.814	-0.002	0.446
1901-1955	0.005	0.706	-0.011	**0.053**
1956-2010	0.005	0.334	0.013	**0.000**

Table 5 Analysis for years with annual rainfall less than or greater than the long-term annual rainfall

Period	Number of years when average annual rainfall greater than the long-term average annual rainfall	Number of years when average annual rainfall less than the long-term average annual rainfall
1901-2010	52	58
1901-1955	28	27
1956-2010	27	28

Table 6 Analysis for years with annual TMX less than or greater than the long-term annual TMX

Period	Number of years when average annual TMX greater than the long-term average annual TMX	Number of years when average annual TMX less than the long-term average annual TMX
1901-2010	61	49
1901-1955	28	27
1956-2010	32	23

Table 7 Analysis for years with annual TMN less than or greater than the long-term annual TMN

Period	Number of years when average annual TMN greater than the long-term average annual TMN	Number of years when average annual TMN less than the long-term average annual TMN
1901-2010	54	56
1901-1955	31	24
1956-2010	26	29

Tables 5 to 7 show the number of years when the values of annual rainfall, annual maximum and minimum temperatures greater and less than the values of the long-term average annual of rainfall, maximum and minimum temperatures.

5. CONCLUSION

The study of the anomalies of different temperature and rainfall variables and their trends are important requirement for the planning and management of water resources. The Mann-Kendall non-parametric test was used to detect any trends that might be evident from the hydro-meteorological data, which included annual, pre-monsoon, and seasonal trends. Based on the analysis of the obtained results, the following conclusions can be made:

1. When the analysis was performed for the entire period 1901-2010, it revealed an increasing trend in the maximum annual temperature and
   a decreasing trend in the annual minimum temperature.
2. The temperature rise may be more pronounced in the last period (i.e. 1956-2010).
3. An increasing pattern is observed in the annual and monsoon rainfall with statistically significant trend in the entire period. While the trend analysis of the pre-monsoonal rainfall exhibits statistically significant decreasing trend in the last period (i.e. 1956-2010). However, for the same time period, there is a decreasing trend in monsoon rainfall.
4. For all three time periods studied, there is a strong negative correlation between annual rainfall and annual maximum temperature.
5. For the recent years of analysis, there is a weak correlation between annual rainfall and minimum temperature.
6. The variance of the inter-annual rainfall is much greater than in the temperature data.

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تحليل الاتجاهات لبيانات الأرصاد الجوية طويلة المدى

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الملخص:
من المرجح أن تكون دراسة التأثيرات المحتملة لتغير المناخ على بيانات الأرصاد الجوية ذات موثوقية في تصميم النظم الهيدرولوجية. إحدى الطرق المعترف بها لتقييم تأثير التغيرات المناخية من خلال تحليل بيانات الطقس. إحدى الطرق المعترف بها لتقييم تأثير التغيرات المناخية من خلال تحليل بيانات الطقس. تهدف الدراسة إلى فحص البيانات الخاصة بدرجات الحرارة العظمى والصغرى وهطول الأمطار لبيان اي اتجاهات في التحليل التي يمكن تمييزها في مدينة دلهي للفترة من 1901 والى 2010.

اعتمد اختبار مان-كيندال غير البارامترى وعلاقة الارتباط الاحصائي لتحليل البيانات المتاحة لثلاث فترات زمنية:1901-2010؛ 1901-1955 و1956-2010. استخدم تحليل الاتجاهات لغرض فحص بيانات هطول الأمطار السنوية وبيانات الامطار الموسمية والامطار قبل الموسمية. بينت النتائج أن درجات الحرارة العظمى والصغرى اظهرت مؤشرات متزايدة ومتناقصة على التوالي، في حين أن الأمطار الموسمية والسنوية اظهرت مؤشرات متزايدة. بالنسبة لفترتي التحليل 1901-1955 و1956-2010 بالإضافة إلى فترة التحليل بأكملها، كان هناك ترابط سلبي قوي بين هطول الأمطار السنوي ودرجة الحرارة العظمى السنوية. اظهرت بيانات هطول الأمطار الموسمية ودرجة الحرارة السنوية العظمى ارتباطًا سلبيًا قويًا. علاوة على ذلك، ظهر ارتباط جيد بين بيانات درجات الحرارة الصغرى وهطول الأمطار السنوية لفترة التحليل 1956-2010 من البيانات المسجلة. بينما تم تأشير ترابط ضعيف وسلبي بين درجة الحرارة الصغرى وهطول الأمطار السنوي وللفترتين 1901-1955 و1956-2010.

الكلمات الداله :

تحليل بيانات الأرصاد الجوية، تغير المناخ، اختبار مان كيندال، معامل الارتباط، اتجاهات دلهي.