Analysis of Relationship between Meteorological Variables for the City of Delhi

Ayman T. Hamid, Mohammed Lateef Ahmed, and Mohammed Sharif

***Abstract*—**This paper investigates relationship between the meteorological variables for the city of Delhi in India. Mean monthly rainfall, maximum temperature, and minimum temperature data was analyzed for three periods; (1) 1901-2010; (2) 1901-1955; (3) 1956-2010. The analysis of the available data was carried out on the annual as well as seasonal scale. Results of analysis presented herein clearly indicates that there is a strong negative correlation between annual rainfall and annual maximum temperature for all the three periods of analysis. The correlation between the monsoonal rainfall and the annual maximum temperature is also negative and strong. The correlation between annual rainfall and annual minimum temperature is also negative but it is weak for the first two periods of analysis. There is, however, a good correlation between the annual rainfall and minimum temperature for the recent period of record.

***Keywords*—** meteorological, correlation, rainfall, temperature.

I. Introduction

THE concentration of greenhouse gases has been increasing at a rapid rate leading to enhanced warming in many regions of the world. Meteorological variables, in particular temperature and precipitation, act as input to the hydrological cycle and impact the hydrological response of a river basin. Temperature changes are accompanied by changes in precipitation and runoff amounts. As a consequence, many aspects of the natural environment, including water resources, are anticipated to experience potentially serious climatic impacts in many regions of the world. One of the most important and immediate effects of global warming would be the changes in local and regional water availability [14]. Many hydrological systems are anticipated to experience not only the changes in the average availability of water but also changes in the extremes [23],[14]. Reference [7] reported that increase in temperature has impacted the timing of snowmelt in the California Sierra Nevada Mountains leading to earlier system runoff. Other impacts of climate change that have been identified include changes in rainfall patterns, extreme weather events, and the quality of water availability. Reservoir operations, crop production, erosion processes, runoff production and many other hydrological processes are likely to be impacted by temperature changes.

The IPCC report [11] clearly indicates likelihood of considerable warming over sub-regions of south Asia. Results of multimodal GCM runs under Special Report on Emission Scenarios (SRES) scenarios B1 and A1F1 project an increase in average temperature over whole of South Asia with greatest increase being projected for winter months. The projected rise in temperature for winter months is particularly alarming as it exceeds the limit of global mean surface temperature rise of 1.8 C to 4 C reported by IPCC [12]. Numerous studies have been carried out in different parts of south Asia for detecting possible climate trends and changes. Reference [10] analyzed long-term mean annual temperature records from 1901 to 1982 over India and detected an increasing trend in mean surface air temperatures. It was observed that about 0.4°C warming has taken place over India during the last eight decades mainly due to rise in maximum temperatures. Reference [25], however, showed that the changes in mean annual temperatures are partly due to the rise in the minimum temperature caused by rapid urbanization. Reference [18] have reported an increase in mean annual temperatures in India at the rate of 0.57°C per 100 years. Reference [3] investigated temperature trend all over India using Mann-Kendall non parametric technique and linear regression method. The results showed that mean temperature has increased by 0.94°C per 100 years for the post monsoon season and 1.1°C per 100 years for the winter season. Reference [24] have carried out an extensive analysis of basin-wide temperature trends in northeast and central India. A warming trend was observed in seven of the nine river basins studied. The other two basins showed a cooling trend. Results of several studies have confirmed that the south Asia region is indeed warming and the trend of warming is broadly consistent with the global warming trend.

Warming trend has also been found for Bangladesh, Pakistan, Nepal and China. Reference [1] reported that the broad region encompassing Bangladesh has warmed at the rate of 0.5°C per 100 years. Reference [22] reported increases of 0.61°C, 0.90°C and 1.24°C per decade in winter maximum temperatures for Nepal, Himalayan and trans-Himalayan climate stations respectively. Reference [5] estimated a temperature rise of 0.9°C for Pakistan by 2020 and predicted that the temperature rise could double by 2050. Reference [16] analyzed temperature trends in Upper Indus Basin and detected an increasing trend in winter maximum temperature

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with the trend in slopes of 1.79, 1.66, and 1.20°C per 39 yr for the upper, middle, and lower regions, respectively. Reference [6] reported a warming trend over western Indian Himalayas, with the greatest increase in TMX ranging from 1.1 C to 2.5 C. Reference [17] analyzed the temperature data of 160 climate stations in China using Mann-Kendall and inverse distance methods. An increasing temperature trend was detected all over the country. Reference [8] examined temperature data of seven climate stations in the Karakoram and Hindu Kush mountains of the upper region of UIRB for seasonal and annual trends using regression techniques. Mean and maximum winter temperatures showed significant increase while mean and minimum summer temperatures showed consistent decline. Reference [26] analyzed monthly temperature and precipitation data for 51 climate stations and three hydrometric stations in the Yangtze basin, China. Significant positive and negative trends at 90, 95 and 99% significant level were detected using Mann-Kendall test. Reference [4] investigated temporal trends of annual and seasonal precipitation from 1951 to 2003 in the Hanjiang basin in China using Mann-Kendall and the linear regression methods.

Several precipitation trend studies have also been carried out in the south Asia region. Trend analysis of precipitation is relatively under explored in India. Reference [19] examined the general rainfall pattern in Bharathapuzha River basin in Kerala, using monthly rainfall data for 34 years from 28 raingauge stations. Their study indicated a significant decreasing trend in annual, southewest, and pre-monsoon rainfall of the basin towards the later years of the study period. Reference [20] reported the shrinking of the Indian summer monsoon in terms of total rain days as well as in terms of total area of rainfall. Reference [9] conducted a study using high resolution gridded rainfall data for a period from 1951 to 2003 eherein it was found that the frequency and magnitude of extreme rainfall events during summer monsoon over central India are increasing while moderate events are decreasing.

Reference [17] showed that there is an increasing precipitation trend throughout the year in southwest of Xinjiang which is an area adjacent to Northern part of Pakistan, and in Jammu-Kashmir which is southwest of Tibet. Reference [2] analyzed precipitation data of various stations in Upper Indus River Basin (UIRB) using linear regression with different record lengths. A significant increasing trend of precipitation in winter and summer during the period 1961-1999 was detected in upper region of UIRB. Reference [26] detected an upward precipitation trend in middle and lower part of Yangtze basin, China. On the contrary, [21] concluded that precipitation in Iran has a decreasing trend. Reference [15] investigated runoff trends for Ili and East rivers in central Asia. Regression and difference integral curve techniques were used for long term hydro-meteorological analysis. No statistically significant change was observed except for runoff. Results indicated that precipitation has no significant trend but a significant increasing trend for temperature was seen in most parts of the basin. Further, decreasing trend was seen in mean annual, spring, and winter runoffs in the Danjiangkou reservoir basin. Reference [13] reviewed studies pertaining to trends in rainfall, rainy days and temperature over India. The objective of the present research is to analyze correlations between average monthly maximum temperature (TMAX), minimum temperature (TMIN), and rainfall data (RAIN) for the city of Delhi.

II. Study Area

India receives 80 per cent of its annual rainfall during the southwest monsoon season of June to September. Rainfall over the country during this season shows a wide range of spatial variation. Delhi, the capital city of India is a land locked city with an area of approximately 1500 sq. km. Delhi is situated at a height of 235 m above sea level and lies in northern India Due to large distance from the sea, Delhi has an extreme type of continental climate. The summers in Delhi are very hot and winters very cold. The temperature range varies from 46 degrees in summers to 3 degrees in winters. The winters are marked by mist and fog in the mornings and often the Sun is seen afternoon. The cold wave from the Himalayan region makes winters very chilly. The winter season starts in November with the peak occurring towards the start of New year. Around mid-March the weather begins to get warmer and becomes hot in April. From April to June, the weather is extremely hot in Delhi. In summers the heat wave is immense. The arrival of monsoon normally takes place around end of June. The major portion of rainfall occurs in the rainy season between July to September due to southwest monsoon.

Delhi, the heart of the country is plagued today by environmental degradation. Air pollution in Delhi is particularly alarming because of its harmful effects on human health. Today Delhi has approximately three times more vehicles than Mumbai. Delhi is the metropolitan city where commuters are primarily dependent on the road transport system. This has led to an enormous increase in the number of vehicles with the associated problems of traffic-congestion and an alarming increase in air pollution. The major pollutants emitted by motor vehicles include CO, NOx, sulphur oxides, (SO), HC, lead (Pb) and suspended particulate matter (SPM). These pollutants have damaging effects on both human health and ecology. The human health effects of air pollution vary in the degree of severity, covering a range of minor effects to serious illness, as well as premature death in certain cases. Most of the conventional air pollutants are believed to directly affect the respiratory and cardio-vascular systems. In particular, high levels of SO2 and SPM are associated with increased mortality, morbidity and impaired pulmonary function, Lead prevents hemoglobin synthesis in red blood cells in bone marrow, impairs liver and kidney function and causes neurological damage. Given the level of pollution in Delhi, it is important to analyze its impact on temperature and rainfall characteristics of the city. The longterm average rainfall in Delhi is 714 mm. Table I shows the mean annual average monthly temperature and rainfall for the period (1901-2010).

Table II shows the ratio of mean monthly to the mean annual, and mean monthly to the mean annual precipitation for the three periods (1901-2010), (1901-1955) and (1956-2010).

TABLE I
MEAN ANNUAL AVERAGE MONTHLY TEMPERATURE AND RAINFALL FOR THE PERIOD (1901-2010)

Month	TMAX	TMIN	RAIN
January	23.9	20.8	7.7
February	21.4	23.7	10.3
March	14.5	29.8	15.5
April	11.0	36.2	21.6
May	17.4	39.8	26.2
June	67.3	39.4	28.3
July	198.1	35.2	27.1
August	207.6	33.7	26.3
September	131.5	34.0	24.7
October	20.3	32.9	19.4
November	3.9	28.0	12.8
December	8.6	22.7	8.3

It can be seen from Table II that the highest values of the ratio occur in the months of July and August. The pattern of results is similar for all the three periods of analysis. While [24] found the highest values of the ratio of mean daily maximum and mean monthly rainfall during June and September for the analysis period of 1940-1980.

TABLE II
THE RATIO BETWEEN THE MEAN MONTHLY AND MEAN MONSOON TO THE MEAN ANNUAL PRECIPITATION

Month	Ratio of Mean Monthly / Mean Annual		
	1901-2010	1901-1955	1956-2010
Jan	0.033	0.032	0.034
Feb	0.030	0.036	0.025
Mar	0.020	0.021	0.020
Apr	0.015	0.015	0.015
May	0.024	0.015	0.030
Jun	0.093	0.098	0.085
Jul	0.273	0.278	0.262
Aug	0.286	0.258	0.303
Sep	0.181	0.205	0.158
Oct	0.028	0.029	0.032
Nov	0.005	0.003	0.007
Dec	0.012	0.012	0.011
Monsoon	0.833	0.851	0.829

III. METHODOLOGY

The major objective of the present study is to analyze correlations of monthly, annual, seasonal TMX, TMN, and rainfall data for the city of Delhi. The data is available for the period 1901-2010. Analysis of data has been carried out for three different analysis periods. First, the time series with the data for the entire period is analyzed. Second, the time series with the data for the period 1901-1955 has been analyzed. Finally, the time series for the more recent data spanning from 1956 – 2010 has been analyzed. The following equation has been used for calculating the correlation coefficient

$$Correl(X,Y) = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}} \quad (1)$$

Where Correl(X, Y) is the correlation coefficient between the variables denoted by X and Y, $\bar{x}$ is the mean of all x values and $\bar{y}$ is the mean of all y values.

A positive value of Correl(X, Y) indicates that y increases as x increases whereas a negative value of Correl(X,Y) indicates that y decreases as x increases. A value of Correl(X,Y) close to 1.0 indicates a high degree of correlation whereas a value closer to 0 indicates a low degree of correlation between the variables considered. The correlations between the following variables have been investigated.

1. Total annual rainfall and mean annual maximum temperature
2. Total annual rainfall and mean annual minimum temperature
3. Total monsoonal rainfall and mean annual maximum temperature
4. Total monsoonal rainfall and mean annual minimum temperature

The data for Delhi is available for the period 1901-2010. The available data was partitioned in two analysis periods. The first analysis period consists of 1901-1955 record whereas the second analysis period consists of 1956-2010 record. The total monthly rainfall for each month has been summed up to obtain the total annual rainfall for each year whereas the monthly rainfall for June to September has been summed up to obtain the total monsoonal rainfall for each year of the data.

IV. RESULTS

Results of analysis for all the periods have been presented in the following sections. The variation of total annual rainfall with time is shown in Figure 1 whereas Figure 2 shows the variation of total monsoonal rainfall with time. The variation of annual average TMX, and annual average TMN is shown in Figures 3 and 4 respectively.

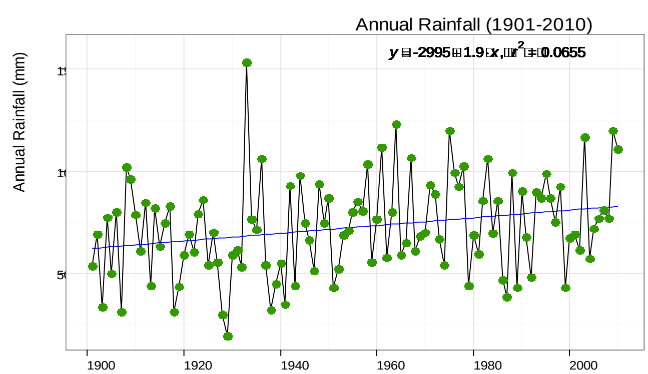

Fig. 1 Variation of total annual rainfall for the period 1901-2010

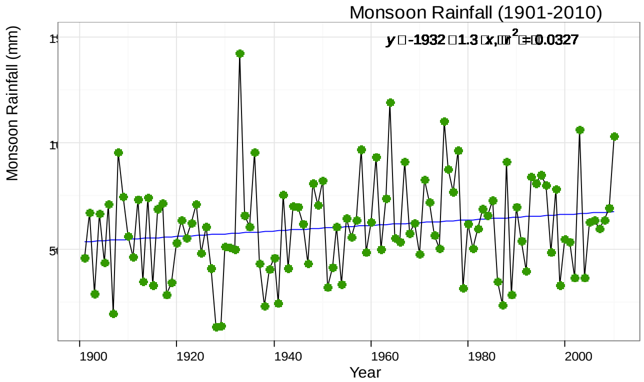

Fig. 2 Variation of total monsoonal rainfall for the period 1901-2010

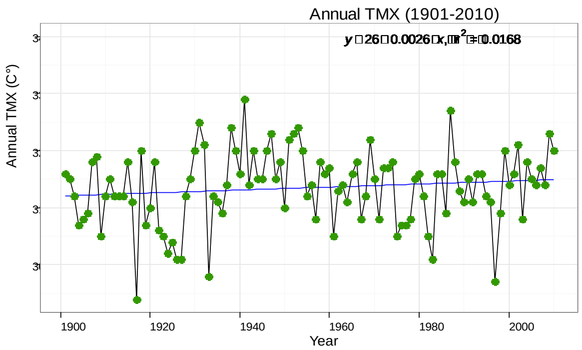

Fig. 3 Variation of annual average TMX for the period 1901-2010

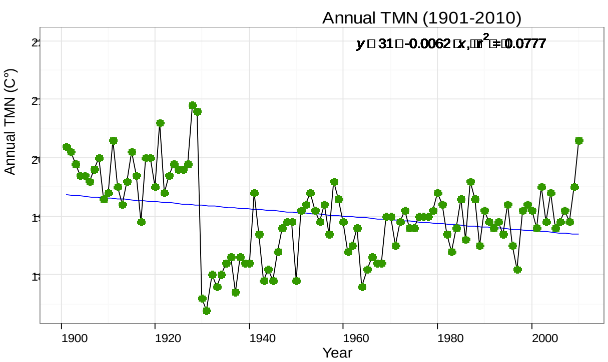

Fig. 4 Variation of annual average TMN for the period 1901-2010

Monsoon rainfall over Delhi during the months from June to September exhibits interesting oscillations. The monsoon generally sets in the last week of June and withdraws towards the second week of September. The list of variables used for computing the correlations is presented in Table III.

TABLE III
LIST OF VARIABLES CONSIDERED

S. No.	Variable	Abbreviation
1	Total annual rainfall	ARAIN
2	Total monsoonal rainfall	MRAIN
3	Mean annual maximum temperature	ATMX
4	Mean annual minimum temperature	ATMN
5	Mean maximum temperature for the period June – September	TMX-JJAS
6	Mean minimum temperature for the period June – September	TMN-JJAS

The analysis for correlation has been carried out for the entire period of analysis as well as for the partitioned data sets.

The coefficient of correlation between ARAIN and TMX, MRAIN and TMX, ARAIN and TMN, and MRAIN and TMN have been computed using equation 1, and are shown in Table IV

TABLE IV
VALUES OF CORRELATION COEFFICIENT

Period	Coefficient of Correlation			
	ARAIN-TMX	MRAIN-TMX	ARAIN-TMN	MRAIN-MN
1901-2010	-0.3965	-0.3716	-0.2347	-0.2579
1901-1955	-0.4366	-0.4244	-0.2845	-0.3132
1956-2010	-0.3761	-0.3219	-0.0235	-0.0734

The coefficient of correlation between MRAIN with the average value of TMX and TMN from April to June and from January to June are shown in the Table V.

TABLE V
VALUES OF CORRELATION COEFFICIENT

Period	Coefficient of Correlation			
	Monsoon Rainfall with Average-TMX (A-J)	Monsoon Rainfall with Average-TMX (J-J)	Monsoon Rainfall with Average-TMN (A-J)	Monsoon Rainfall with Average-TMN (J-J)
1901-2010	-0.0406	0.0449	-0.0972	-0.1365
1901-1955	-0.1366	0.0244	-0.1946	-0.2076
1956-2010	0.1403	0.1059	0.1789	0.1312

The Figures 5 to 10 show the correlation coefficient between the monsoonal and annual rainfall with the annual maximum temperature for the three periods of analysis: (1) 1901-2010; (2) 1901-1955, and (3) 1956-2010 respectively.

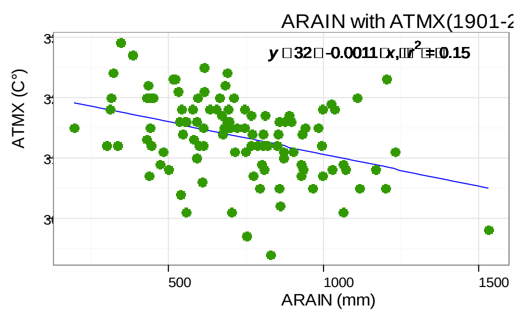

Fig. 5 Correlation between annual rainfall and annual TMX for the period 1901-2010

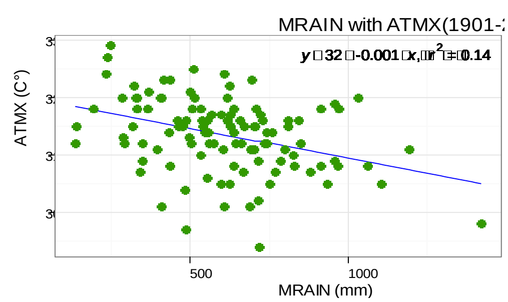

Fig. 6 Correlation between monsoonal rainfall and annual TMX for the period 1901-2010

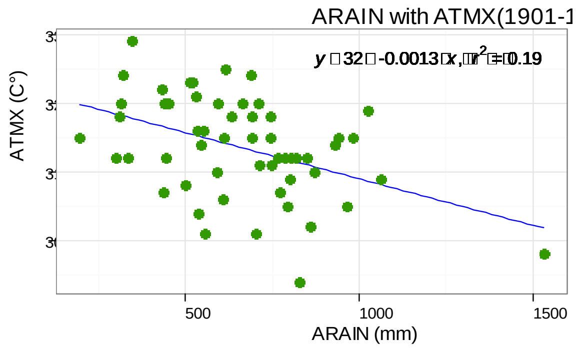

Fig. 7 Correlation between annual rainfall and annual TMX for the period 1901-1955

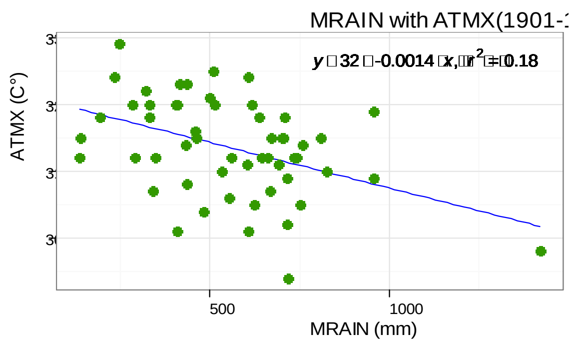

Fig. 8 Correlation between monsoonal rainfall and annual TMX for the period 1901-1955

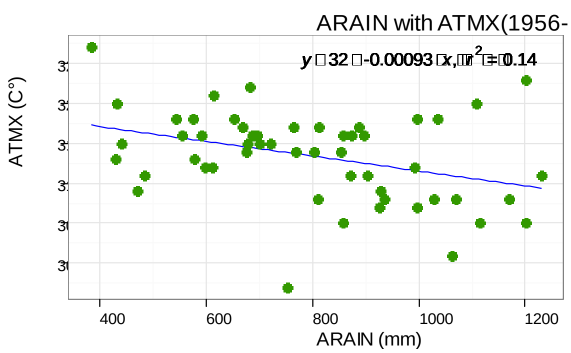

Fig. 9 Correlation between annual rainfall and annual TMX for the period 1956-2010

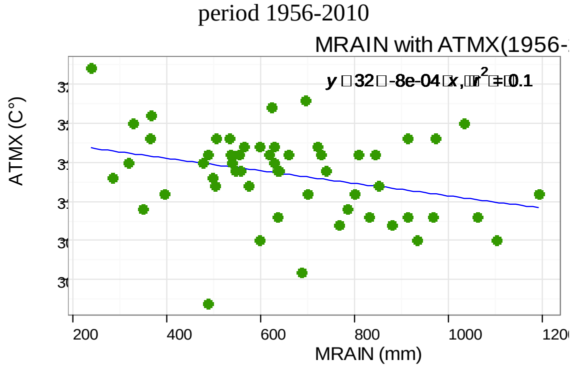

Fig. 10 Correlation between monsoonal rainfall and annual TMX for the period 1956-2010

The Figures 11 to 16 shown the correlation coefficient between the monsoonal and annual rainfall with the annual minimum temperature for the three periods of analysis: (1) 1901-2010; (2) 1901-1955, and (3) 1956-2010 respectively.

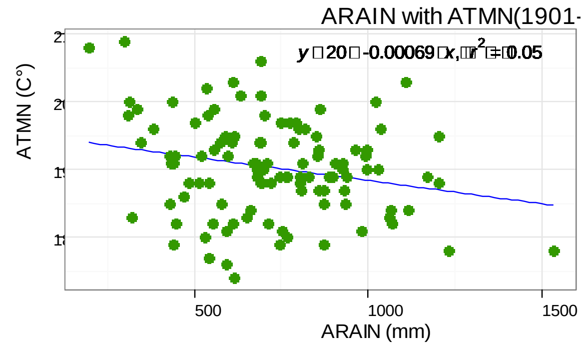

Fig. 11 Correlation between annual rainfall and annual TMN for the period 1901-2010

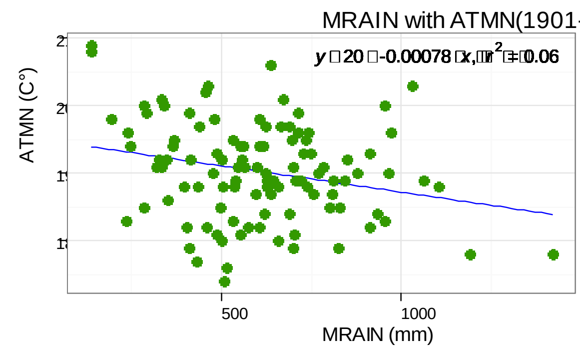

Fig. 12 Correlation between monsoonal rainfall and annual TMN for the period 1901-2010

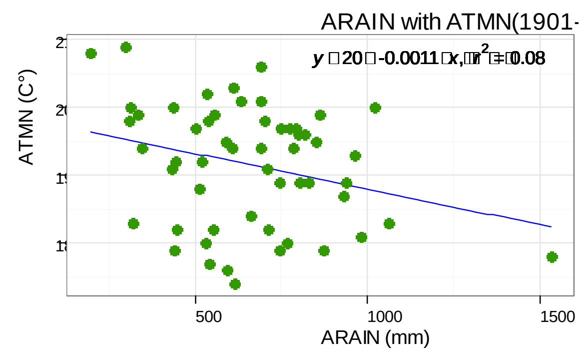

Fig. 13 Correlation between annual rainfall and annual TMN for the period 1901-1955

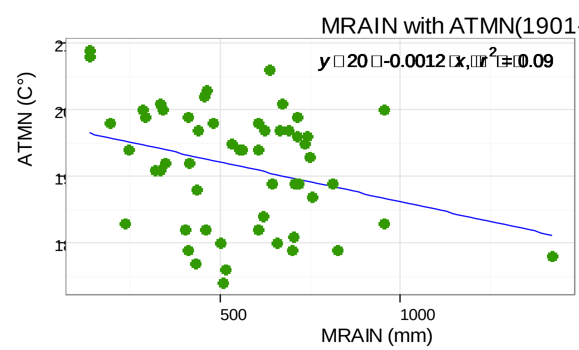

Fig. 14 Correlation between monsoonal rainfall and annual TMN for the period 1901-1955

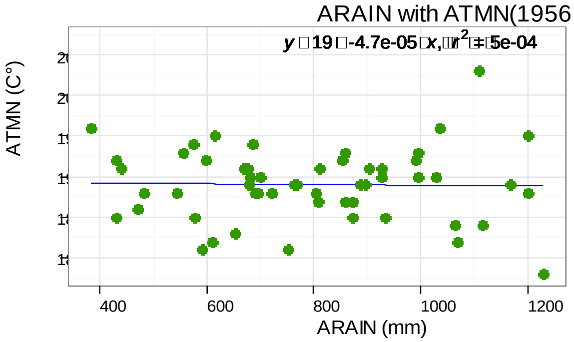

Fig. 15 Correlation between annual rainfall and annual TMN for the period 1956-2010

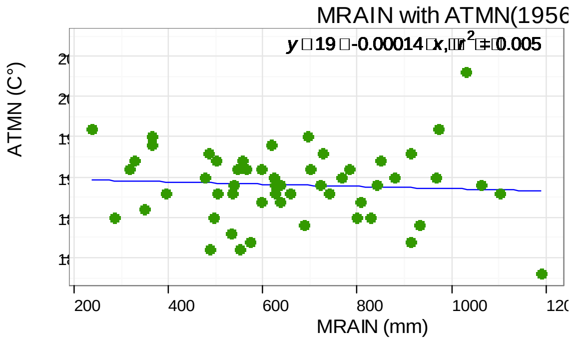

Fig. 16 Correlation between seasonal rainfall and annual TMN for the period 1956-2010

V. CONCLUSION

The objective of the present research was to determine correlations between several meteorological variables for the city of Delhi. The intent behind choosing Delhi as the study area was that it is a highly urbanized city with a rapidly growing population. The present population of Delhi is estimated to be more than 1.5 crores. It is an uphill task to cater to the water and energy demands for such a huge population. Any erratic pattern in the monsoonal rainfall in the city of Delhi is likely to further aggravate the water problem in Delhi. Currently, the water supply in the city of the order of 850 MGD whereas the water demand is 1350 MGD. In addition to satisfying water demand, it is also important to satisfy the energy demands which have grown from 3000 MW in 2008 to around 5500 MW in 2012. In addition to the well acknowledged global warming, the temperature in the city of Delhi is influenced by the huge vehicular traffic which is highest among all the metropolitan cities. Rising temperatures and increase in the duration of hot spells combined with erratic rainfall patterns have led to this rapid rise in the electricity demand in the city. Therefore, it is important to analyze the temperature and rainfall data for the city of Delhi to identify any trends that might be evident from the available data.

The time series of mean monthly temperature and rainfall data for the period 1901-2010 was obtained from the Indian Meteorological Department, Delhi. The available data length was partitioned into two different periods of equal length, and the analysis has been carried out for three periods; (1) 1901-2010; (2) 1901-1955; and (3) 1956-2010. Results of analysis indicate that the maximum annual temperature for the entire period of analysis has shown an increasing trend whereas the annual minimum temperature has shown a decreasing trend when the analysis was carried out for the entire period. Annual rainfall as well as the monsoonal rainfall has shown increasing trends. Correlation analysis for rainfall and temperature data, both maximum and minimum, has also been carried in this paper. There appears to be a strong negative correlation between annual rainfall and annual maximum temperature for all the three periods of analysis. The correlation between the monsoonal rainfall and the annual maximum temperature is also negative and strong. The correlation between annual rainfall and annual minimum temperature is also negative but it is weak for the first two periods of analysis. There is, however, a stronger correlation between the annual rainfall and minimum temperature for the recent period of record.

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