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Long Term Trend Analysis of Mega Cities in Northern India using Rainfall Data

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Abstract

Land use change is occurring rapidly and it has huge impact on the local climate. The study area includes 17 mega cities located within 25°18′00″N to 34°5′24″N of India. The current study is based on trend of historical rainfall which is analyzed by Mann-Kendall method using monthly rainfall data (1901-2011). Before using this method, pre-whitening method was applied for removing the error from the data. Sen's Slope estimator is used to derive the magnitude of the data. Standard Normal Homogeneity Test (SNHT) was used for identifying the break point of the data series. Finally true slope of an existing trend and variance of the residuals was calculated for all selected cities using Sen's method. Increasing trend has been found in Jaipur, Jodhpur, Faridabad, Meerut, Ghaziabad, Delhi, Chandigarh, Ludhiana, Amritsar, Srinagar whereas, Allahabad, Varanasi, Patna, Kanpur, Gwalior, Agra shows decreasing trend. No trend is observed in Kota. Monsoon season depicted decrease in the rainfall magnitude in most of the regions of north India. This result is extremely significant as monsoon rainfall serves the major water demand for agriculture and water resources. Change Percentage for 111 years had shown rainfall variability throughout North India centre's with the highest increase in Delhi centre's (32.43 %) and decrease in Patna centre's (-16.22 %) annually.

Keywords: Mann-Kendall, Mega Cities, Pre-Whitening Method, Rate of Change, Standard Normal Homogeneity Test (SNHT)

1. Introduction

It has been seen that the earth's average temperature increases 0.6°C in 20th century and further awaiting a drastic increase in temperature from 1.4°C to 5.4°C as per the projections made by the various climate prediction models. This scenario generated under the different levels of stabilization of CO₂ emissions, pace of de-carbonization of economy, demographic and economic development pattern¹. The IPCC projected the global precipitation to be increase but, at the same time both increase and decrease are projected at the regional scale. The AR4 synthesis report shows that the precipitation change was more spatially variable than temperature change. It is also demonstrated that the climate change assessment at subnational (i.e. State or province) and local scale is needed to study both quantitative and qualitative analysis.

In ²observed varied trend in Indian summer monsoon rainfall which has not only affected by global

warming but may also be affected by local changes due to rapid urbanization, industrialization and deforestation. Therefore, there is a need to study the climate change at regional and local scale to assess the climate change impacts on various sectors3. Several studies of climate change assessment have been carried out considering the various region specific aspects and their inter-relation of the climatic parameters at the various spatial (i.e. national, regional and local level) and temporal (monthly, seasonal and annual) scale. In 4reported annual and seasonal rainfall at various spatial (gauge, watershed and national) and temporal scale to detect the trend and spatial distribution of rainfall in Ethiopia. The result showed no significant change in the annual rainfall at watershed scale and national level While, seasonal rainfall in some watershed shows decreasing trends and other did not show any significant change. There is need to analyze the other parameters also within the political and natural boundaries of countries/provinces/districts

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to clearly understand the effects of scale on climate change assessment.

In 5the spatial pattern trends of rainfall over Indian subdivisions were assessed. The decreasing trends of rainfall over North India excluding Punjab, Haryana, West Rajasthan and Saurashtra, and increased in the south India excluding Kerala and Madhya Maharashtra. The seasonal and annual air temperature has been increasing at the rate of 0.57°C per hundred years in India which estimated using the data from 1881 to 1997⁶. Moreover study conducted in⁷ examined the Trend and Change Point Detection of Precipitation in Urbanizing Districts of Uttarakhand in India and that concluded that the stations to the west show significant trends compared to station which is towards east. Monsoon especially in July month a trend of increasing rainfall is observed in the studied Indian cities. In 8reported the impact upon the Indian Socio-economic Fronts by Climate Change and noticed that the economy of India is based mostly upon monsoon rain fall patterns. The climate change has vulnerable impact over monsoon rain fall patterns. The anticipated sea level raise will adversely affect coastline ecosystems and submergence of coastal islands and deltas. In 9the rainfall scenario in future over Cauvery Basin in India with GCM Data under A1B Scenario was studied and concluded that the rainfall would be higher by 33, 15 and 10% than the current quantity in the upper Cauvery, mid Cauvery and delta region respectively during end century.

In 10 an effort has been made to assess the urban climate trend from major Indian cities: Hyderabad, Patna, Ahmedabad, Surat, Bangalore, Mumbai, Nagpur, Pune, Jaipur, Chennai, New Delhi, Kanpur, Lucknow and Kolkata whose population more than 10 lakh. The study shows significant increasing trends in annual and monsoon rainfall over Chennai, New Delhi, Kolkata and Mumbai.

In Indian context, no studies have been reported in literature, which investigated climate in term inter-seasonal and inter-annual variation of precipitation at urban centre's (Mega city) of north part of India. Keeping above discussed view in mind, present study was undertaken with the objective to assess the rainfall trends in a changing climate at the urban centre's of Northern India. This paper is organized in five sections considering the north part of India (mega center) as a study area. Section one include the review literature as per concerned study. Section two describes about the study area and data used in the study.

Section three describes the methodology adopted for the research work. Section four and five describes the findings of research work which has been analyzed out by the past data sets and presents the general conclusions on climate change assessment at spatial and temporal scale using the adopted methodology.

2. Study Area and Data used

2.1 Study Area

In this study, we have selected the Mega cities; population more than 10 lakhs in north part of India11 shown the Table 1 and Figure 1.

2.2 Data Used

As the gridded rainfall datasets are used in many hydrological and climatologically studies, in Australia and elsewhere, including for hydro climatic forecasting, climate attribution studies and climate model performance assessments¹². Therefore, this study utilizes $1^{\circ} \times 1^{\circ}$ gridded data set of Monthly rainfall for the year 1901 to 2011. The gridded data set of was procured from Indian Meteorological department (IMD), Pune which were

Table 1. Million⁺ cities in North India as per Census 2011

Sl No.	Urban centers	States	Latitude (N)	Longitude (E)
1	Delhi	Delhi	29.0167	77.3833
2	Jaipur	Rajasthan	26.9200	72.8200
3	Kanpur	Uttar Pradesh	26.4583	80.7173
4	Ghaziabad	Uttar Pradesh	28.6618	77.4242
5	Patna	Bihar	25.6155	85.1355
6	Agra	Uttar Pradesh	27.1833	78.0167
7	Ludhiana	Punjab	30.9100	75.8500
8	Varanasi	Uttar Pradesh	25.2807	82.9557
9	Meerut	Uttar Pradesh	28.9807	77.7000
10	Faridabad	Haryana	24.4300	77.3200
11	Srinagar	J&K	34.0897	74.7900
12	Allahabad	Uttar Pradesh	25.4500	81.8500
13	Amritsar	Punjab	31.6167	74.8500
14	Jodhpur	Rajasthan	26.2900	73.0300
15	Gwalior	Madhya Pradesh	26.2200	78.1800
16	Chandigarh	Chandigarh	30.7353	76.7911
17	Kota	Rajasthan	25.1800	75.8300

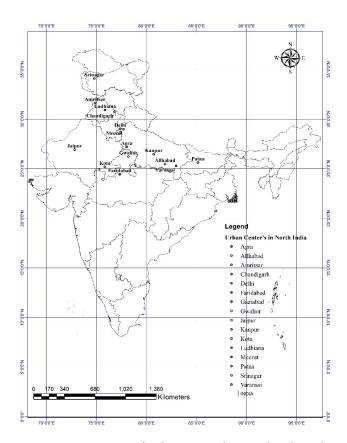


Figure 1. Location of urban Centre's considered in the North part of India for study.

developed at India level by using network of rain gauge stations spread over the India.

3. Methodology

The assessment of climate change at urban center's of North India has been carried out in seasonal and annual scale through the non-parametric Mann-Kendall (MK) test to analyze the variations and trends in climatic variables.

3.1 Trend Analysis

3.1.1 Mann-Kendall Test

The MK test is a non-parametric test for detecting trends¹³ and the non-linear trend as well as the turning point distribution is derived from Kendall test statistics14. The MK method searches for a trend in a time series without specifying whether the trend is linear or nonlinear. It has been found to be an excellent tool for trend detection and many researchers have used this test to assess the significance of trends in hydro-climatic time series such as water quality, stream flow, temperature and precipitation^{15,16}. The nonparametric MK test is applied to a time series x ranked from i = 1, 2 ... n - 1 and x_i ranked from j = i + 1, 2... n. Each data point x is used as a reference point and is compared with all other data points x such that,

$$\operatorname{sgn}(x_{j} - x_{i}) = \begin{cases} 1, & if(x_{j} - x_{i}) > 0 \\ 0, & if(x_{j} - x_{i}) = 0 \\ -1, & if(x_{j} - x_{i}) < 0 \end{cases}$$

The Kendall test statistic, S is given below;

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_{j} - x_{k})$$

Where, $sgn(x_i - x_i)$ is the sig num function. The test statistic, S is assumed to be asymptotically normal, with E(S) = 0 for the sample size $n \ge 8$ and variance as follows:

$$V(S) = \frac{[n(n-1)(2n+5) - \sum_{t} t(t-1)(2t+5)]}{18}$$

Where, t, denotes number of ties up to sample i.

The standardized MK test statistics Z_{mk} is estimated as follows:

$$Z_{\text{mk}} = \frac{S-1}{\sqrt{V(S)}} \quad \text{if } S > 0$$

$$Z_{\text{mk}} = 0 \quad \text{if } S < 0$$

$$\frac{S+1}{\sqrt{V(S)}} \quad \text{if } S < 0$$

The standardized MK test statistics (Z_{mk}) follows the standard normal distribution with mean of zero and variance of one. If $\pm Z_{mk} \le Z_{1-\alpha/2}$ (here $\alpha = 0.1$), then null hypothesis for the no trend is accepted in a two sided test for trend and the null hypothesis for the no trend is rejected if $\pm Z_{mk} \ge Z_{1-\alpha/2}$. Failing to reject H0 *i.e.* null hypothesis does not mean that there is no trend. Rather, it is a statement that the evidence available is not sufficient to conclude that there is a trend¹⁷. A positive value of Z_{mk} indicates an 'upward trend' and negative value indicates 'downward trend'. For 10% level of significance, the critical value $Z_{1-\alpha/2}$ from the standard normal table is 1.645. The significance levels (p-values) for each trend test can be obtained from¹⁸,

$$p = 0.5 - \emptyset(|Z_{mk}|)$$

Where \emptyset () denotes the cumulative distribution function (cdf) of a standard normal variate. At the significance level of 0.1, if $p \le 0.1$, then the existing trend is considered to be statistically significant.

3.1.2 Sen's Estimator of Slope

If a linear trend is present in a time series, then the true slope of trend can be estimated by using a simple non-parametric procedure developed by 19,20. The slope estimates is computed by

$$Q_i = Median\left(\frac{x_i - x_k}{j - k}\right) \forall k < j$$

Where x_i and x_k are data values at times j and k(j > k)respectively. The median of N values of Q is Sen's estimator of slope. If N is odd, then Sen's estimator is computed by $Q_{med} = Q_{(N+1)/2}$ and if N is even, then Sen's estimator is computed by $Q_{med} = [Q_{N/2} + Q_{(N+2)/2}]/2$. Finally, Q_{med} is tested by two-sided test at 100 (1-α) % confidence interval and, the true slope may be obtained by the nonparametric test.

3.2 Percentage Change Over the Period

The percentage change over the 111 years have been estimated by following the assumption of linear trend, estimating magnitude by Theil and Sen's median slope and assessing the mean over the period

$$\% change = \left(\frac{Medianslope \times lengthofperiod}{mean}\right)$$

4. Result and Discussion

4.1 Trend analysis of Rainfall Urban Centre's of North India

In Mega cities of North India the rainfall seasonal trend (pre monsoon, monsoon, post monsoon and winter) and annual average rainfall have been summarized in Table 2, Table 3 and Table 4.

Pre-whitening is the most commonly used procedure to eliminate the effect of serial correlation in trend analysis. But pre-whitening has the disadvantage of accepting the hypothesis of no trend with a high probability when a trend exists. In Table 2 shows Serial correlation at urban centers of north India. Only the station Ghaziabad shows negative Serial correlation in annual average rainfall series remaining sixteen urban center's indicate the positive Serial correlation. For seasonal trend all the mega station

Table 2. Serial correlation at urban centre's of north part of India

Serial correlation					
Station name	Annual	Pre- Monsoon	Monsoon	Post- Monsoon	Winter
Delhi	0.011	0.315	-0.012	0.077	-0.042
Jaipur	0.028	0.158	0.043	0.065	0.132
Kanpur	0.027	0.087	-0.009	0.226	0.018
Ghaziabad	-0.005	0.225	-0.018	0.14	0.066
Patna	0.281	0.176	0.332	0.088	-0.061
Agra	0.11	0.234	0.092	0.13	0.042
Ludhiana	0.075	0.287	0.001	-0.019	0.031
Varanasi	0.145	0.076	0.143	0.161	-0.134
Meerut	0.01	0.14	-0.022	0.149	0.023
Faridabad	0.023	0.248	0.017	0.074	0.057
Srinagar	0.073	0.056	0.065	0.119	0.103
Allahabad	0.108	0.064	0.109	0.161	-0.135
Amritsar	0.13	0.186	0.036	0.133	0.074
Jodhpur	0.054	0.009	0.081	0.099	0.093
Gwalior	0.026	0.158	0.012	0.098	-0.056
Chandigarh	0.177	0.34	0.096	-0.013	-0.042
Kota	0.077	0.02	0.068	0.115	-0.013

Table 3. Sen's slope at urban centre's of north part of India

Sen's slope					
Urban center	Annual	Pre-	Monsoon	Post-	Winter
		Monsoon		Monsoon	
Delhi	1.69	0.13	1.27	0.02	0.01
Jaipur	0.71	0.07	0.45	0.02	-0.03
Kanpur	-0.77	0.06	-0.75	0.04	-0.1
Gaziabad	0.47	0.12	0.2	0	-0.06
Patna	-1.59	0.11	-1.55	-0.07	-0.06
Agra	-0.72	0.1	-0.92	0.04	-0.06
Ludhiana	1.17	0.1	0.95	0.03	-0.01
Varanasi	-1.66	0.06	-1.6	-0.05	-0.07
Meerut	0.19	0.09	-0.05	0	-0.05
Faridabad	0.81	0.08	0.49	0	-0.03
Srinagar	1.65	0.34	0.92	0.11	0.06
Allhabad	-1.29	0.05	-1.21	0.04	-0.03
Amritsar	1.32	0.13	1.22	0.04	-0.02
Jodhpur	0.11	0.01	0.12	0.01	0
Gwalior	-0.37	0.08	-0.59	0.04	-0.03
Chandigarh	1.5	0.15	1.18	0.02	-0.05
Kota	0.03	0.03	-0.13	0	-0.02

Note: Highlighted bold values indicates positive trend and italic bold show negative trend at 5% level of significant

Table 4. Z value at urban center's of north part of India

Z value					
Station name	Annual	Pre- Monsoon	Monsoon	Post- Monsoon	Winter
Delhi	3.10	2.17	2.30	1.34	0.11
Jaipur	1.33	2.07	0.93	1.04	-0.97
Kanpur	-1.19	1.81	-1.12	0.69	-1.47
Gaziabad	0.81	1.98	0.31	0.14	-0.89
Patna	-2.68	1.48	-2.66	-0.48	-1.01
Agra	-0.94	2.54	-1.29	1.04	-1.54
Ludhiana	2.87	1.63	2.72	1.61	-0.17
Varanasi	-2.61	1.00	-2.40	-0.45	-0.73
Meerut	0.27	1.69	-0.09	-0.10	-0.83
Faridabad	1.43	1.62	0.87	0.34	-0.55
Srinagar	2.66	1.36	1.66	1.68	0.30
Allahabad	-1.76	1.01	-1.70	0.52	-0.36
Amritsar	2.99	1.65	3.08	2.14	-0.28
Jodhpur	0.39	0.49	0.37	1.36	-0.05
Gwalior	-0.49	2.39	-0.90	0.74	-0.63
Chandigarh	2.76	2.01	2.39	0.83	-0.54
Kota	0.04	1.51	-0.20	-0.01	-0.92

Note: Highlighted bold values indicates positive trend and italic bold show negative trend at 5% significance level.

found positive serial correlation for pre-monsoon season. But in other seasons some Mega cities shows the negative serial correlation.

Now we applied the MK test, the Sen's estimator of slope to find out the change per unit time of the significant trends, observed in time series of annual and seasonal average rainfall over a period of 111 years (1901-2011). Table 3 indicate the result of Sen's slope for mega cities and bold values in the table shows positive true slope of an existing trend and italic bold shows negative true slope of an existing trend at 95% confidence level.

Table 4 shows the results of MK test for annual and seasonal rainfall time series. In annual times series the highest increasing trend is found in mega city Delhi is about 3.10 at 5% level of significant and highest negative trend is found in mega city Patna is about -2.68 at 5% significant level. And in seasonal time's series, the premonsoon season shows the positive trend in all the mega cities and the highest positive trend is analysed in Agra station. In monsoon season and post monsoon season

Amritsar mega city shows the highest increasing trend and again Patna mega city shows the highest deceasing trend in monsoon time series. In addition, in the winter season, rainfall time series we analyzed that aspect Delhi and Jodhpur all the mega cities shows the deceasing trend for last century.

Outcomes of Mk test on annual basis with respect to urban center population has been represented in Figure 2. The results obtained from seasonal and annual time series have been inter-compared with each other and predominant effects were observed over a 111 years period in the urban centers of North India.

Moreover, MK test for the annual and seasonal (pre monsoon, monsoon, post monsoon and winter) average rainfall fails to detect the significant trend at 5% significance level at most of these urban centers. Among the study area of districts of Kanpur, Patna, Agra, Varanasi, Allahabad and Gwalior exhibited decreasing trend in the annual while Kanpur showed decreasing trend in annual rainfall at 5% level of significance; while Dehli, Jaipur, Gaziabad, Agra, Ludhiana, Meerut, Faridabad, Srinagar, Amritsar, Johpur, Chandigarh showed increasing trend.

Table 5 and Figure 3 indicate Percentage Change at urban centers of north part of India and the bold values indicates positive percentage Change in rainfall trend and italic bold show negative percentage Change in rainfall trend. Shift year has also been investigated in the study using Standard Normal Homogeneity Test (SNHT). The results presented in Table 6 show the (change point) shifting of year wise rainfall trend in data series for the 17 mega cities, northern part of India. Hence the most probable year of change was found after the year 1998 in annual rainfall during the period 1901 to 2011.

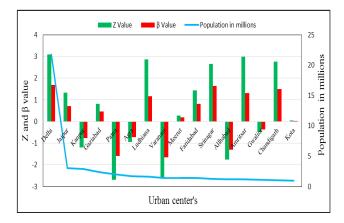


Figure 2. Shows the change in Z and β value of annual rainfall time series with urban center's population.

Table 5. Percentage Change at urban centre's of north part of India

Percentage Change					
urban center	Annual	Pre- Monsoon	Monsoon	Post- Monsoon	Winter
Delhi	32.43	44.89	28.18	13.34	2.7
Jaipur	13.72	36.92	9.46	15.74	-21.88
Kanpur	-9.71	40.24	-10.48	13.54	-31.25
Gaziabad	8.17	41.23	4.11	1.76	-18.54
Patna	-16.22	27.8	-18.37	-10.08	-18.17
Agra	-11.09	58.84	-15.33	21.35	-33.09
Ludhiana	27.04	28.31	26.62	38.94	-3.51
Varanasi	-18.41	23.28	-20.07	-11.56	-17.88
Meerut	3.21	28.62	-0.98	-2.04	-15.24
Faridabad	15.04	34.77	10.15	2.42	-10.25
Srinagar	21.92	19.44	23.31	33.86	4.12
Allahabad	-13.97	22.74	-14.78	11.68	-6.2
Amritsar	30.68	29.7	36.26	48.23	-3.65
Jodhpur	4.06	8.19	4.79	13.41	-1.34
Gwalior	-4.71	47.99	-8.3	14.85	-14.63
Chandigarh	24.79	36.48	23.43	16.19	-9.26
Kota	0.35	31.39	-1.92	-0.26	-18.7

Note: Highlighted bold values indicates positive trend and italic bold show negative trend at 5% level of significance

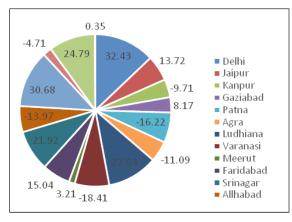


Figure 3. Pie chart shows the % Change in annual rainfall over 111 years for urban center's.

5. Conclusion

The current study is based on long term trend analysis by Mann-Kendall test using monthly rainfall data (1901-2011). Need of Long term rainfall trend in mega cities is due to certain factors such as change of land use and cover, conversion of village to mega cities, conversion

Result of Standard Homogeneity Test (SHNT) Table 6.

Shifting Point					
CITY	SHNT(T _o)	YEAR	P -Value		
Delhi0	12.799	1954	0.007		
Jaipur	4.555	1907	0.443		
Kanpur	8.468	1985	0.068		
Gaziabad	6.905	1998	0.158		
Patna	13.625	1991	0.006		
Agra	19.409	1999	0.001		
Ludhiana	15.031	1974	0.002		
Varanasi	22.769	1990	0.002		
Meerut	10.84	1998	0.018		
Faridabad	6.889	1941	0.161		
Srinagar	14.668	2009	0.005		
Allahabad	15.488	1982	0.002		
Amritsar	19.465	1974	0.002		
Jodhpur	4.183	1905	0.497		
Gwalior	9.175	1999	0.042		
Chandigarh	31.017	2003	0.003		
Kota	4.918	2010	0.377		

Note: Series is homogenous at 5% significant level if T_a is less than 9.26

of mud houses to concrete building and population increases drastically in northern part of India. These factors changes the whole scenario in northern part of India, humans called that development but natural suffer as climate change. Out of 17 mega cities, 10 recoded the significant increasing trend mof rainfall such as Jaipur, Jodhpur, Faridabad, Meerut, Ghaziabad, Delhi, Chandigarh, Ludhiana, Amritsar, Srinagar while 6 mega cities such as Allahabad, Varanasi, Patna, Kanpur, Gwalior, Agra recorded the decreasing trend. Only one mega city Kota of northern India shows the null trend.

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