Identifying rainfall trends over North India using 1'X1' gridded rainfall data (1951-2004)

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Abstract

Present study identifies the possibilities of significant trends utilizing 1'X1' gridded daily rainfall data over North India for the period 1951-2004 (54 years). Here we have taken annual from january-december monsoon from June-September and non-monsoon periods from October to May. The non-parametric test like Mann-Kendall test has been exercised for rainfalls over individual grids at 90%, 95%, 99% and 99.9% significance level Spatial distribution of rainfall map has been prepared using Inverse Distance Weighting (IDW) in GIS for pictorial representation at different significant levels. The study identifies area of negative rainfall trend are more than positive rainfall trend in most parts of North India in annual and monsoon periods while in non-monsoon period rising trend of rainfall as well as decreasing rainfall trend is seen in upper parts of North India.

Keywords: *North India, Rainfall Trend, GIS, Mann-Kendall*

Introduction

The North India roughly located at 73ºE - 84ºE longitudes and 24ºN - 37ºN latitudes and occupies area around 6,63,849 km^2. It consists of eight states of India, namely, Jammu & Kashmir, Himachal Pradesh, Punjab, Chandigarh, Haryana, Delhi, Uttar Pradesh and Uttarakhand. This is an important region of agricultural production in the country. The monsoon season (June-September) contributes about 75% of the annual rainfall over North India (Yadav, Kumar & Rajeevan 2012). The agricultural productivity of this region largely depends on precipitation. With the growth in population in modernization era lot of significant changes have been observed in climatic factors resulting to variations in rainfall patterns. Rainfall variation due to climate change may have negative impact on agriculture productivity and water resources management of this region. Change in rainfall affects annual river runoff and water availability. Areas in which runoff is declining are likely to face a reduction in the value of the services provided by water resources. On the other hand, increased rainfall variability and seasonal runoff shifts may also have negative impacts on water supply, water quality and flood risks.

The present study investigates the rainfall trends over north India at different significant levels thus allowing different planners to take either of the results depending upon the requirements. The study is useful in assessing the water resource potential and thereby consideration of agricultural patterns, availing irrigation facilities and many of the other requirements.

Literature Review

In the earlier period many studies have been accomplished on rainfall variations. Sarkar et. al. (2004) examined the precipitation patterns over India for the last 50 years. They show variable interaction between ENSO and rainfall and also investigated the effect of local climate anomaly in normal rainfall forcing over India during recent ENSO events. Goswami et al. (2006) using a high resolution daily gridded rainfall data set showed that there are significant rising trends in the frequency and the magnitude of extreme rain events over central India during the monsoon season, using a high resolution daily gridded rainfall data set. The study also showed that significant decreasing trend in the frequency of moderate events during the same period, thus leading to no significant trend in the mean rainfall. Rajeevan et al. (2008) shows that inter-annual, inter-decadal and long-term trends of extreme rainfall events are modulated by the SST variations over the tropical Indian Ocean. Their study supports the hypothesis that the increasing trend of extreme rainfall events in the last five decades could be associated with the increasing trend of sea surface temperatures and surface latent heat flux over the tropical Indian Ocean. Kumar and Jain (2011) studied 22 basins and they found 15 showed a decreasing trend in annual rainfall; only one basin

showed a significant decreasing trend at 95% confidence level. Of the 6 basins showing an increasing trend, 1 basin showed a significant positive trend. The monsoon rainfall increased over 6 basins, decreased over 16 basins and a decreasing trend for 2 basins was found statistically significant. With the exception of Ganga, Brahmaputra and EFR4, all river basins experienced the same direction of trend in monsoon and annual rainfall. Four river basins experienced increasing (non-significant) trend in annual rainy days, three basins did not show any change in annual rainy days whereas 15 basins have shown a decreasing trend in annual rainy days. The decreasing trend in three basins was statistically significant. Most of the basins have shown the same direction of trend in rainfall and rainy days at the annual and seasonal scale.
It is evident from the available literature that, all the studies has been carried out only single significance level and could not fulfil all the requirements of the different planners. This study investigated the rainfall trends over north India at different significant levels thus allowing different planners to take either of the results depending upon the requirements.

Data Used

1'X1' gridded daily rainfall data over North India for the period 1951-2004 (54 years) was used for this study. For the trend analysis, the available rainfall data was classified into annual (January-December), monsoon (June-September) and non-monsoon (October to May) periods.

Methodology

The significance of the trend has been determined using Man-Kendall (MK) test. Spatial distribution of rainfall map has been prepared using Inverse Distance Weighting (IDW) methods in GIS.

Trend Analysis

The Mann-Kendall test is a non-parametric test for identifying trends in time series data. The test compares the relative magnitudes of sample data rather than the data values themselves (Gilbert, 1987). One benefit of this test is that the data need not conform to any particular distribution. Moreover, data reported as non-detects can be included by assigning them a common value that is smaller than the smallest measured value in the data set. The procedure that will be described in the subsequent paragraphs assumes that there exists only one data value per time period. When multiple data points exist for a single time period, the median value is used. The data values are evaluated as an ordered time series. Each data value is compared to all subsequent data values. The initial value of the Mann-Kendall statistic, S, is assumed to be 0 (e.g., no trend). If a data value from a later time period is higher than a data value from an earlier time period, S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S.

Mann-Kendall Test

The MK test is based on the test statistic S defined as follows:

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

Where

Sign $(x_j - x_k) = 1$ if $x_j - x_k > 0$

$= 0$ if $x_j - x_k = 0$

$= -1$ if $x_j - x_k < 1$

A very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend. However, it is necessary to compute the probability associated with S and the sample size, n, to statistically quantify the significance of the trend.

Inverse Distance Weighing (IDW)

The IDW function can be use when the set of points is dense enough to capture the extent of local surface variation needed for analysis. IDW determines cell values using a linear-weighted combination set of sample points. The weight assigned is a function of the distance of an input point from the output cell location. The greater the distance, the less influence the cell has on the output value.

Shepard's method

A general form of finding an interpolated value u at a given point x based on samples $u_i = u(x_i)$ for $i = 0,1,...N$ using IDW is an interpolating function:

$$u(x) = \sum_{i=0}^{N} \frac{w_i(x)u_i}{\sum_{j=0}^{N} w_j(X)'}$$

Where

$$w_i(X) = \frac{1}{d(X, X_i)^p}$$

is a simple IDW weighting function, as defined by Shepard, (Shepard and Donald, 1968). "A two-dimensional interpolation functions for irregularly-spaced data" (ACM National Conference, 1968) X denotes an interpolated (arbitrary) point, xi is an interpolating (known) point, d is a given distance (metric operator) from the known point xi to the unknown point x, N is the total number of known points used in interpolation and p is a positive real number, called the power parameter.

Here weight decreases as distance increases from the interpolated points. Greater values of P assign greater influence to values closest to the interpolated point, with the result turning into a mosaic of tiles with nearly constant interpolated value for large values of p. For two dimensions, power parameters $p \leq 2$, cause the interpolated values to be dominated by points far away, since with a density ρ of data points and neighbouring points between distances r_0 to R, the summed weight is approximately

$$\sum_j w_j \approx \int_{r_0}^{R} \frac{2\pi r \rho dr}{r^p} = 2\pi\rho \int_{r_0}^{R} r^{1-p} dr,$$

which diverges for $R \to \infty$ and $p \leq 2$. For N dimensions, the same argument holds for $p \leq N$. For the choice of value for p, one can consider the degree of smoothing desired in the interpolation, the density and distribution of samples being interpolated, and the maximum distance over which an individual sample is allowed to influence the surrounding ones.

Shepard's method is a consequence of minimization of a functional related to a measure of deviations between tuples of interpolating points {x, u} and i tuples of interpolated points {xi, ui}, defined as:

$$\phi(\mathrm{x}, \mathrm{u}) = \left(\sum_{i=0}^{N} \frac{(u - u_i)^2}{d(\mathrm{x}, \mathrm{x}_i)^p} \right)^{\frac{1}{p}},$$

derived from the minimizing condition:

$$\frac{\partial \phi(x, u)}{\partial u} = 0.$$

The method can easily be extended to other dimensional spaces and it is in fact a generalization of Lagrange approximation into a multidimensional spaces.

Result & Discussion

In the present study trend analysis of annual, monsoon and non-monsoon rainfall has been carried out. For this initially the available rainfall data was classified in the above periods. Further Mann-Kendall test was applied for three significance levels i.e. 90%, 95% and 99%. On the basis of Z-statistics of each significance level the trends in rainfall data of North India have been determined. For the purpose of the trend analysis gridded daily rainfall data of North India region has been considered. Table 1 shows the number of stations considered from each State for the analysis

S. No.	State	Stations
1	Jammu & Kashmir	31
2	Punjab	6
3	Himachal	7
4	Uttarakhand	6
5	Haryana	3
6	Uttar Pradesh	26

Table 1. State of North India

Trend at 90% significance level

Fig.1 & Fig.2 show rainfall trend at 90% significance level for annual and monsoon rainfall. The annual rainfall trend indicate that the some stations show negative rainfall trend while a very few stations show positive rainfall trend. In general the annual rainfall show trend in less no of stations in comparison to monsoon rainfall. When comparing Fig. 1 and Fig. 2 it is clear that the monsoon rainfall shows more negative trend in comparison to annual rainfall trend. Table 2 indicates that there is negative trend in 13 stations out of 79 stations and positive trend in only 3 stations in annual rainfall. It seems that there is less variation in annual rainfall totals in comparison to monsoon rainfall.

Jammu & Kashmir and Himachal show negative rainfall trend in a major part in comparison to positive rainfall trend at 90% significance level particularly during monsoon. The non monsoon rainfall data show positive trend in major part of the Jammu and Kashmir. Fig 3 shows rising rainfall trend as well as declining rainfall trend in upper part (Jammu & Kashmir) of North India in Non-monsoon period. Table 3 and Table 4 show statewise trend in

Annual 90% Significance					
S. No.	**State**	**Stations**	**Positive Trend**	**Negative Trend**	**No Trend**
1	Jammu & Kashmir	31	1	3	27
2	Punjab	6	1	0	5
3	Himachal	7	0	4	3
4	Uttarakhand	6	1	1	4
5	Haryana	3	0	0	3
6	Uttar Pradesh	26	0	5	21

Table 2. Annual Rainfall Trend at 90% Significance level

Monsoon 90% Significance					
S. No.	**State**	**Stations**	**Positive Trend**	**Negative Trend**	**No Trend**
1	Jammu & Kashmir	31	3	16	12
2	Punjab	6	1	0	5
3	Himachal	7	1	1	5
4	Uttarakhand	6	1	2	3
5	Haryana	3	0	0	3
6	Uttar Pradesh	26	2	4	20

zTable 3. Monsoon Rainfall Trend at 90% Significance level

Non-Monsoon 90% Significance					
S. No.	**State**	**Stations**	**Positive Trend**	**Negative Trend**	**No Trend**
1	Jammu & Kashmir	31	15	7	9
2	Punjab	6	1	0	5
3	Himachal	7	0	2	5
4	Uttarakhand	6	0	1	5
5	Haryana	3	0	0	3
6	Uttar Pradesh	26	1	1	24

Table 4. Non Monsoon Rainfall Trend at 90% Significance level

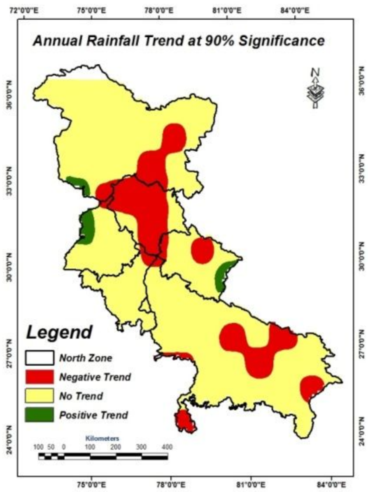

Figure 1. Annual rainfall trend at 90% significance level

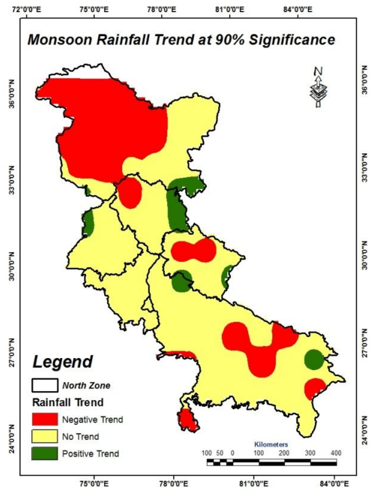

Figure 2. Monsoon rainfall trend at 90% significance level

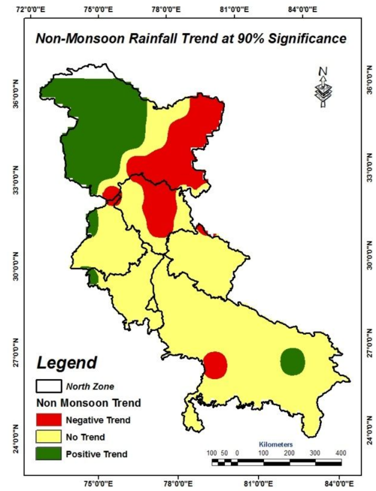

Figure 3. Non-monsoon rainfall trend at 90% significance level

Trend at 95% significance level

Fig 4 shows in mostly in North India no trend is found in the annual rainfall at 95% significance level. Only 6 stations are showing negative trend and 2 stations are showing positive trend in annual rainfall (Table 5). However few stations show negative trend and a very few stations show positive trend (Figure 5) in monsoon rainfall. The trend analysis of Monsoon data shows (Figure 5) that there is negative rainfall trend during non monsoon period in most part of the Jammu and Kashmir(Table 6). Trend analysis of non-monsoon data(Figure 6) indicates a positive trend in almost half part of Jammu and Kashmir and negative trend in almost another half part. While, very small areas of Jammu and Kashmir show no trend. However, rest of the north India show almost no trend (Table 7).

Annual 95% Significance					
S. No.	State	Stations	Positive Trend	Negative Trend	No Trend
1	Jammu & Kashmir	31	1	2	28
2	Punjab	6	0	0	6
3	Himachal	7	0	1	6
4	Uttarakhand	6	1	1	4
5	Haryana	3	0	0	3
6	Uttar Pradesh	26	0	3	23

Table 5. Annual Rainfall Trend at 95% Significance level

Monsoon 95% Significance					
S. No.	**State**	**Stations**	**Positive Trend**	**Negative Trend**	**No Trend**
1	Jammu & Kashmir	31	3	12	16
2	Punjab	6	0	0	6
3	Himachal	7	1	1	5
4	Uttarakhand	6	0	2	4
5	Haryana	3	0	0	3
6	Uttar Pradesh	26	0	2	24

Table 6. Monsoon Rainfall Trend at 95% Significance level

Non-Monsoon 95% Significance					
S. No.	**State**	**Stations**	**Positive Trend**	**Negative Trend**	**No Trend**
1	Jammu & Kashmir	31	16	5	10
2	Punjab	6	1	0	5
3	Himachal	7	0	2	5
4	Uttarakhand	6	0	1	5
5	Haryana	3	0	0	3
6	Uttar Pradesh	26	0	0	26

Table 7. Non Monsoon Rainfall Trend at 95% Significance level

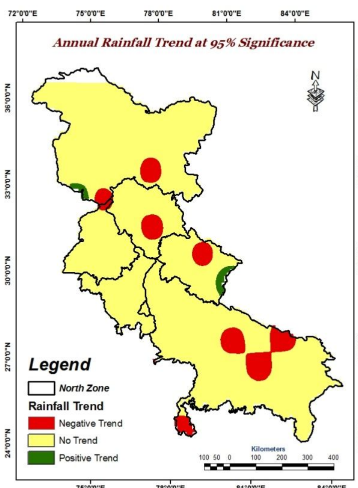

Figure 4. Annual rainfall trend at 95% significance level

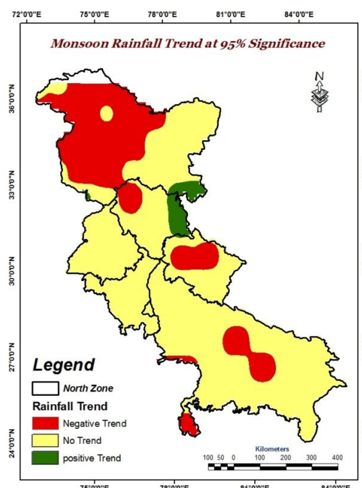

Figure 5. Monsoon rainfall trend at 95% significance level

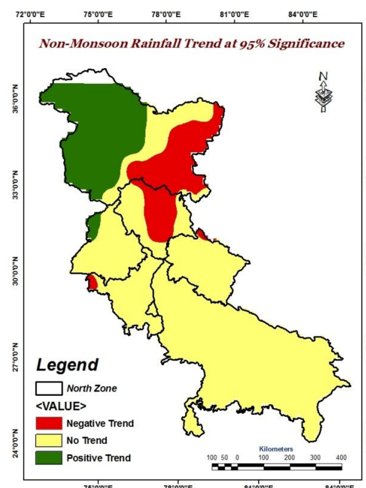

Figure 6. Non-monsoon rainfall trend at 95% significance level

Trend at 99% significance level

There almost no trend in annual rainfall data at 99% significance level in North India (Figure 7) only a very few stations show trend either positive or negative (Table 8). Similarly the monsoon rainfall data also show trend only at very few stations at 99% significance level (Figure 8). Only 1 station is showing positive trend and one station is showing negative trend in monsoon rainfall (Table 9). Declining trend (Table 10) is seen in Himachal and Uttarakhand and rising trend is seen in Jammu & Kashmir in non monsoon rainfall period at 99% significance level (Figure 9).

Annual 99% Significance					
S. No.	State	Stations	Positive Trend	Negative Trend	No Trend
1	Jammu & Kashmir	31	1	0	30
2	Punjab	6	0	0	6
3	Himachal	7	0	1	6
4	Uttarakhand	6	0	1	5
5	Haryana	3	0	0	3
6	Uttar Pradesh	26	0	0	26

Table 8. Annual Rainfall Trend at 99% Significance level

Monsoon 99% Significance					
S. No.	State	Stations	Positive Trend	Negative Trend	No Trend
1	Jammu & Kashmir	31	0	0	31
2	Punjab	6	0	0	6
3	Himachal	7	1	0	6
4	Uttarakhand	6	0	1	5
5	Haryana	3	0	0	3
6	Uttar Pradesh	26	0	0	26

Table 9. Monsoon Rainfall Trend at 99% Significance level

Non Monsoon 99% Significance					
S. No.	State	Stations	Positive Trend	Negative Trend	No Trend
1	Jammu & Kashmir	31	4	3	24
2	Punjab	6	0	0	6
3	Himachal	7	0	1	6
4	Uttarakhand	6	0	0	6
5	Haryana	3	0	0	3
6	Uttar Pradesh	26	0	0	26

Table 10. Non Monsoon Rainfall Trend at 99% Significance level

Annual 99% Significance					
S. No.	State	Stations	Positive Trend	Negative Trend	No Trend
1	Jammu & Kashmir	31	1	0	30
2	Punjab	6	0	0	6
3	Himachal	7	0	1	6
4	Uttarakhand	6	0	1	5
5	Haryana	3	0	0	3
6	Uttar Pradesh	26	0	0	26

Table 10. Annual Rainfall Trend at 99% Significance level

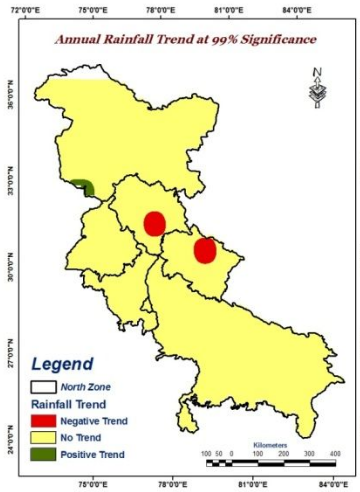

Figure 7. Annual rainfall trend at 99% significance level

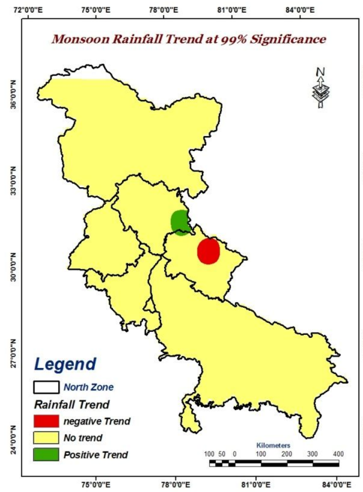

Figure 8. Monsoon rainfall trend at 99% significance level

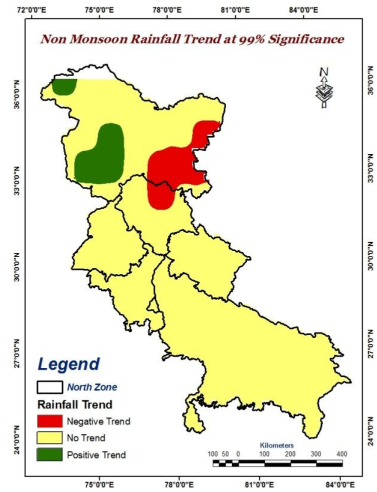

Figure 9. Non-monsoon rainfall trend at 99% significance level

Conclusion

We have examined rainfall trend in annual, monsoon and non-monsoon periods over North India at different significance level. An understanding of rainfall trend at different significance level is useful to assess the water resource potential and thereby consideration of agricultural patterns, availing irrigation facilities and many of the other requirements. In the present study we have found that negative trend of rainfall is increasing in annual and monsoon periods, most of the area that shows negative trend in annual rainfall period is found in Jammu & Kashmir, Himachal Pradesh and Uttar Pradesh. In the monsoon rainfall period negative rainfall trend is rising in Jammu & Kashmir. Small area of Uttar Pradesh, Uttarakhand and Himachal Pradesh also shows negative rainfall trend. It has been found that very few areas of Uttar Pradesh, Uttarakhand, Punjab, Himachal and Jammu & Kashmir shows positive rainfall trend. The result of non-monsoon period shows that positive rainfall trend is increasing and negative rainfall trend is also presented in upper part of North India. The results obtained in this study are quite noteworthy for planners and agriculturist.

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