Rainfall data processing and trend analysis in Himachal Pradesh, India

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Abstract

Present study investigates the rainfall trend in Himachal Pradesh (HP) for the period 1951-2004 (54 years) at different significant levels as 90%, 95%, 99% and 99.9% using Mann-Kendall test. The data used for the study is annual (January-December); monsoon (June-September) and non-monsoon (October-May). On the basis of Z-statistics of each significance level the trends in rainfall data of HP have been determined. For the purpose of the trend analysis gridded daily rainfall data has been considered. The study identifies areas of negative and positive rainfall trends in annual, monsoon and non-monsoon periods. Furthermore, the study also presents the statistical analysis of the rainfall data. The study is useful in assessing the water resource potential and thereby consideration of agricultural patterns, availing irrigation facilities and other requirements.

Keywords: *Rainfall Trend, Mann-Kendall, Himachal Pradesh*

1. Introduction

The state of Himachal Pradesh is roughly located between 76.5°E – 78.5°E longitudes and 30.5°N – 32.5°N latitudes and occupies area around 55,673 km^2. It consists of 12 districts and is surrounded by Jammu and Kashmir on the north side, Punjab on the west side, Haryana and Uttarakhand on the south-east side and Tibet on the east. The economy of the state is mainly dependant on hydro-electricity, tourism and agriculture through various practices on different soil conditions (Tripathi et al 2005, 2006) and due to these the state has been ranked 4th in the highest per capita income of the Indian states (https://en.wikipedia.org/wiki/Himachal_Pradesh). The drainage system of Himachal Pradesh are due to the perennial rivers Chandra Bhaga or the Chenab, the Ravi, the Beas, the Sutlej and the Yamuna and these are fed by snow and rainfall. The climate varies from hot and sub-humid tropical in the southern tracts to, with more elevation, cold, alpine and glacial in the northern and eastern mountain ranges. The maximum rainfall in the state has been received at Dharamsala. There are three seasons: summer (mid April to end of June), winter (November to March) and rainy season (end of June to September). About 93% of the population directly depends on agriculture (https://en.wikipedia.org/wiki/Himachal_Pradesh) contributing 45% of the gross state domestic product of the state which is mainly dependant on rainfall.

A rapid growth in population and increasing developmental activities have caused significant changes in climatic factors like variations in rainfall patterns which had a negative impact on agriculture productivity and water resources management. Numerous workers have studied rainfall variations over the last 5 decades for investigating the effect of local climate anomaly in normal rainfall forcing over India during recent ENSO events (Sarkar et. al. 2004). Goswami et al. (2006) used a high resolution daily gridded rainfall data set which showed significant rising trends in the frequency and the magnitude of extreme rain events over central India during the monsoon season. Rajeevan et al. (2008) studied inter-annual, inter-decadal and long-term trends of extreme rainfall events which are modulated by the sea surface temperature (SST) variations over the tropical Indian Ocean. Garg et al. (2012) have reported 30 years rainfall trends of Sahranpur, Uttar Pradesh and Kumar and Jain (2011) studied 22 basins and they found that out of 22 basins 15 showed a decreasing trend in annual rainfall and one basin showed a significant decreasing trend at 95% confidence level. Krishan et al. (2015) has shown a increasing trend in annual, monsoon, pre-monsoon and post-monsoon rainfall in all the districts of Punjab. Since all these studies have been carried out with only single significance level at different places and could not fulfill all the requirements of the different planners, therefore, in the present study an attempt has been made to investigate the rainfall trends over Himachal Pradesh at different significant levels of 90%, 95%, 99% and 99.9%, thus allowing different planners to take either of the results depending upon the requirements. The study is useful in assessing the water resource potential for consideration of many requirements including agricultural patterns and availing irrigation facilities.

2. Methodology

The significance of the trend has been determined using Man-Kendall (MK) test.

2.1 *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.

2.2 *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.

2.2.1 *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 $x_j - x_k = 0$

= -1if $x_j - x_k < 1$

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.

2.2.2 *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.

2.2.3 *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

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

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 p of data points and neighbouring points between distances r_0 to R, the summed weight is approximately

$$\sum_j w_j \approx \int_{r0}^{R} \frac{2\pi rpdr}{r^p} = 2\pi p \int_{r0}^{R} r^{1-p} dr,$$

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:

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

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.

3. Results and discussion

Trend analysis of annual, monsoon and non-monsoon rainfall has been carried out using Mann-Kendall test for three significance levels i.e. 90%, 95%, 99% and 99.9%. On the basis of Z-statistics of each significance level the trends in rainfall data of HP have been determined. For the purpose of the trend analysis gridded daily rainfall data has been considered. The study identifies areas of negative and positive rainfall trends in annual, monsoon and non-monsoon periods. Furthermore, the study also presents the statistical analysis of the rainfall data (Table 1).

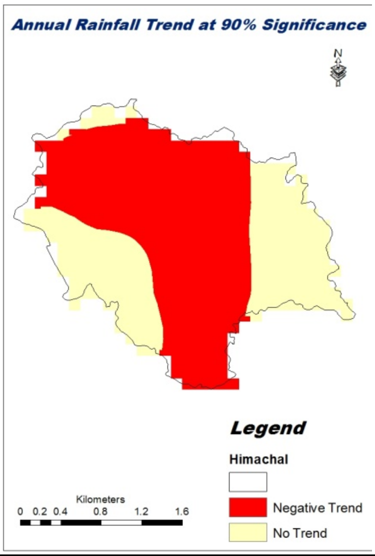

Figure 1. Annual rainfall trend at 90% significance level

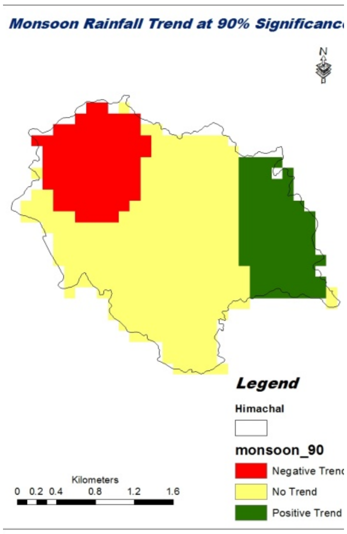

Figure 2. Monsoon rainfall trend at 90% significance level

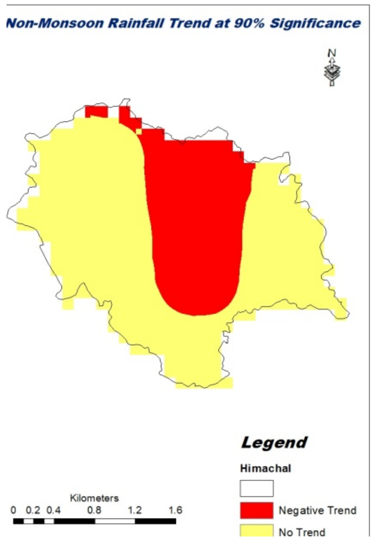

Figure 3. Non-monsoon rainfall trend at 90% significance level

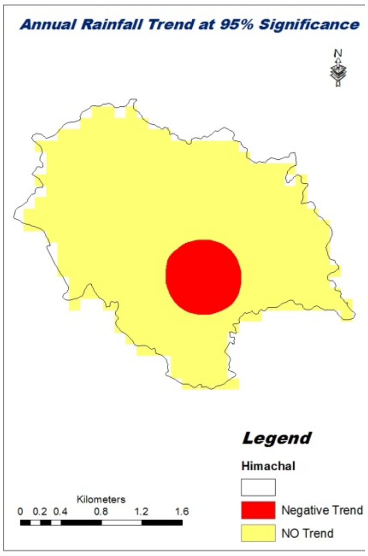

Figure 4. Annual rainfall trend at 95% significance level

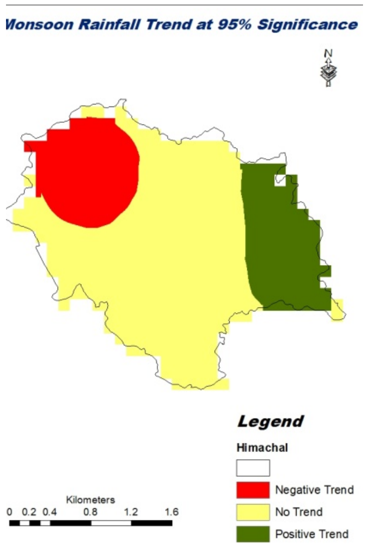

Figure 5. Monsoon rainfall trend at 95% significance level

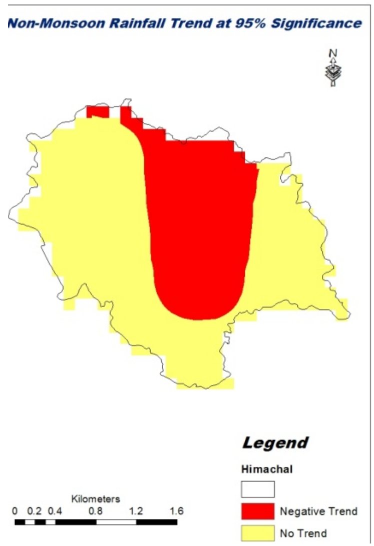

Figure 6. Non-monsoon rainfall trend at 95% significance level

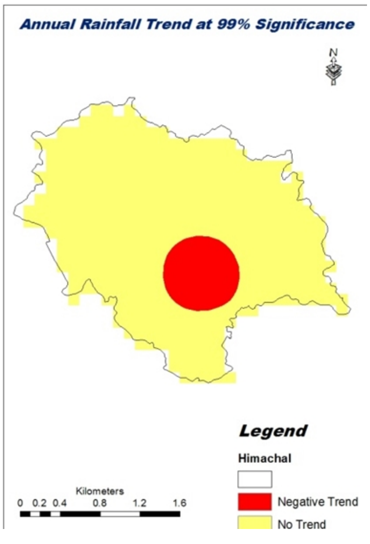

Figure 7. Annual rainfall trend at 99% significance level

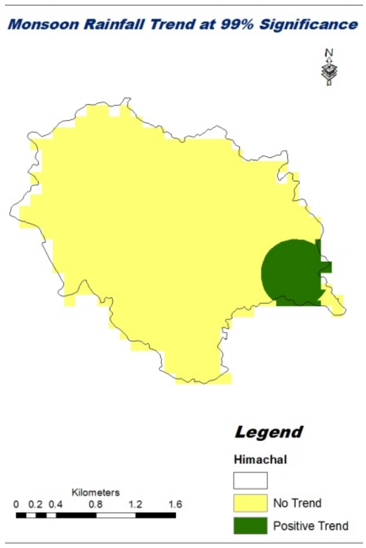

Figure 8. Monsoon rainfall trend at 99% significance level

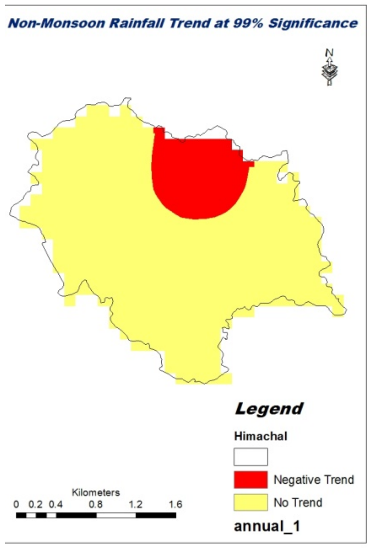

Figure 9. Non-monsoon rainfall trend at 99% significance level

Table: Statistical analysis of rainfall data of Himachal Pradesh (1951-2004)
Trend at 90%

LAT	LONG	Test Z	S_Annual	Q	Test Z	S_Mon	Q	Test Z	S_Non	Q
30.5	77.5	-1.73	-1.000	-9.300	-1.33	0.000	-6.739	-1.42	0.000	-1.967
31.5	76.5	-0.12	0.000	-0.381	-0.10	0.000	-0.517	0.28	0.000	0.287
31.5	77.5	-2.79	-1.000	-5.469	-1.34	0.000	-2.121	-2.27	-1.000	-3.085
31.5	78.5	0.98	0.000	3.222	3.24	1.000	3.779	-1.45	0.000	-2.136
32.5	76.5	-1.78	-1.000	-10.141	-1.96	-1.000	-8.279	-0.63	0.000	-0.918
32.5	77.5	-1.85	-1.000	-7.830	-0.97	0.000	-1.913	-2.79	-1.000	-7.928

Trend at 95%

LAT	LONG	Test Z	S_Annual	Q	Test Z	S_Mon	Q	Test Z	S_Non	Q
30.5	77.5	-1.73	0	-9.300	-1.33	0	-6.739	-1.42	0	-1.967
31.5	76.5	-0.12	0	-0.381	-0.10	0	-0.517	0.28	0	0.287
31.5	77.5	-2.79	-1	-5.469	-1.34	0	-2.121	-2.27	-1	-3.085
31.5	78.5	0.98	0	3.222	3.24	1	3.779	-1.45	0	-2.136
32.5	76.5	-1.78	0	-10.141	-1.96	-1	-8.279	-0.63	0	-0.918
32.5	77.5	-1.85	0	-7.830	-0.97	0	-1.913	-2.79	-1	-7.928

Trend at 99%

LAT	LONG	Test Z	S_Annual	Q	Test Z	S_Mon	Q	Test Z	S_Non	Q
30.5	77.5	-1.73	0	-9.300	-1.33	0	-6.739	-1.42	0	-1.967
31.5	76.5	-0.12	0	-0.381	-0.10	0	-0.517	0.28	0	0.287
31.5	77.5	-2.79	-1	-5.469	-1.34	0	-2.121	-2.27	0	-3.085
31.5	78.5	0.98	0	3.222	3.24	1	3.779	-1.45	0	-2.136

32.5	76.5	-1.78	0	-10.141	-1.96	0	-8.279	-0.63	0	-0.918
32.5	77.5	-1.85	0	-7.830	-0.97	0	-1.913	-2.79	-1	-7.928

Trend at 99.9%

LAT	LONG	Test Z	S_Annual	Q	Test Z	S_Mon	Q	Test Z	S_Non	Q
30.5	77.5	-1.73	0	-9.300	-1.33	0	-6.739	-1.42	0	-1.967
31.5	76.5	-0.12	0	-0.381	-0.10	0	-0.517	0.28	0	0.287
31.5	77.5	-2.79	0	-5.469	-1.34	0	-2.121	-2.27	0	-3.085
31.5	78.5	0.98	0	3.222	3.24	0	3.779	-1.45	0	-2.136
32.5	76.5	-1.78	0	-10.141	-1.96	0	-8.279	-0.63	0	-0.918
32.5	77.5	-1.85	0	-7.830	-0.97	0	-1.913	-2.79	0	-7.928

3.1 *Trend at 90% significance level*

Rainfall trend at 90% significance level for annual, monsoon and non-monsoon rainfall are shown in figs.1-3. The annual and non-monsoon rainfall trend indicated no positive trend, however, positive trend observed in monsoon rainfall. In general, no rainfall trend is observed in more area. It seems that there is less variation in annual rainfall totals in comparison to monsoon rainfall.

3.2 *Trend at 95% significance level*

As evident from figs 4-6 that similar rainfall trends are observed at 95% level of significance as were observed at 90% level of significance except the area of negative trend decreased in annual rainfall trend.

3.3 *Trend at 99% significance level*

Rainfall data at 99% significance level in Himachal Pradesh is depicted in fig. 7-9 and it has been found that in annual, monsoon and non-monsoon rainfall in more than 75% of the area there is no trend and rest is occupied by the areas having negative trend in annual and non-monsoon trends and areas having positive trend in monsoon rainfall.

3.4 *Trend at 99.9% significance level*

There was no trend in rainfall data at 99.9% significance level in Himachal Pradesh.

4. Conclusions

The rainfall trend in annual, monsoon and non-monsoon periods over was examined in Himachal Pradesh at different significance levels of 90%, 95%, 99% and 99.9% with the concept of understanding of rainfall trend at different significance level which is considered useful to assess the water resource potential for contemplation of many requirements including agricultural patterns and availing irrigation facilities. In the present study we have found that negative trend of rainfall is increasing in annual, monsoon and non-monsoon periods while small areas of the state also shows some negative rainfall trend. Very few areas of the state show positive rainfall trend and is observed in monsoon rainfall only. The results obtained in this study are quite noteworthy for planners and agriculturist for assessing the water resource potential and thereby consideration of agricultural patterns, availing irrigation facilities and other requirements.

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