ISSN (Print): 0974-6846 ISSN (Online): 0974-5645

Trend Analysis of Precipitation by MK Test in Kumaon Region of Uttarakhand (1901–2010)

Nitin Mishra^{1*}, Murari Kumar² and Sanjeev Kumar¹

¹Department of Civil Engineering, GEU, 566/6, Bell Road, Society Area, Clement Town, Dehradun - 248002, Uttarakhand, India; nitinuag@gmail.com, er.sanjeevkr@gmail.com ²School of Civil Engineering, LPU, Jalandhar-Delhi, G.T. Road, National Highway 1, Jalandhar, Phagwara - 144411, Punjab, India; murari.19597@lpu.co.in

Abstract

Objective: To identify trend in annual precipitation time series using the M-K and Sen's T-tests. **Methods/Analysis:** Climate change has disrupted the major climatic parameters at a global level. However, there is no equal change for all regions and have localized intensity especially in India. These changes should be identified nearby to manage the natural water resources. One of the most important climatic parameters is precipitation. As a starting point towards the apprehension of global climate change precipitation has been widely measured. The main objective of this study is to analyze the temporal variability of precipitation for the period 110 years, to enhance the hydrological status of the Uttarakhand districts of Kumaon region. The aim is to identify trend in annual precipitation time series using the M-K and Sen's T tests. Sen's estimator method has been used to estimate the extent of trend in precipitation. Before applying the M-K test for the trend in precipitation auto correlation effect is reduced. **Finding:** The analysis of M-K test shows non-significance increasing (positive) trend on annual basis. These areas experience a heavier rainfall for duration of shorter splash, which leads to very less scope for groundwater recharge and more runoff in these areas. Thus, these findings give a broad overview of the regional rainfall behavior in the study area. **Applications/Improvements:** The similar study can be carried out for other places as well with more locations for more diversity in the results attributing to the surroundings etc. to get a more clear and precise view about the trend in annual precipitation.

Keywords: Mann-Kendall Tests, Non-Parametric Tests and Auto Correlation, Precipitation, Sen's Estimator Tests

1. Introduction

Climate change has begun to mark itself worldwide as scientific facts in the form of increased downpours and storms, rising in temperature, diminishing of glaciers and rise in sea level etc. US EPA studies identify the patterns of global temperature with the help of using data from 1901 to the present by National Oce1anic and Atmospheric Administration's National Climatic Data Centre (NCDC). This report states that in the late 1970's the average global warming was 0.35° to 0.51°F per decade and the global average surface temperature

since 1901 has risen with an average rate of 0.13°F per decade.

The essential element of climate is temperature and precipitation and the changes in these can affect human health, plants, animals and ecosystems. A raise in temperature can result in heat wave incidents and leads to illness and death and also cause change in species of animals and plants. The rainfall trends increases can result in an increment in the floods frequency and a decrease could lead in instances of drought¹. An increasing temperature trend causes more evaporation, which leads to increase in rainfall. It is found that the mean annual

temperature of India has raised at the rate of 0.05 °C/decade, which is due to rise of maximum temperature (0.07 °C/decade) and minimum temperature (0.02 °C/decade) from 1901 to 2003.

The trend and magnitude of temperature over the last century had increase over the Indian sub continent and is mostly constant with the worldwide^{2–5}. A rising trend of mean annual temperature from 1881-1997 at a rate of 0.57°C per 100 years. The changes in precipitation forms and its splashing timing can have widespread effect on the availability of water and can cause change in animal and plant species.

The average temperature is increasing in the Upper Ganga Canal Command area with level of non-significant trend. Increasing trend in rainfall was predicted in the Upper Ganga Canal Command Area and it was concluded that there may be an impact of climate change which is contributing to the prolonged and heavy rainfall that is rising with time⁶.

The temperature in the high altitude regions of Uttarakhand found an increasing trend in average temperature in the region⁷. The main objective of this study is to identify the monotonic trend of precipitation by using MK Test and Sen's Slop estimator.

2. Study Area

Kumaon region covers an area of more than 35,000 sq. kms. and has Nainital as headquarter. The Kumon Region hassix districts namely Almora, Bageshwar, Champawat, Nainital, Pithoragarh, and Udham Singh Nagar with Nainital town as the administrative center of the region. The Kumaon region has a population density of 170 per sq. Km. The total population of the region is 3565383 which comprises of 1800795 male and 1764588 Female.

Towards the northern side lies the Tibet, on the eastern side is Nepal, Uttar Pradesh lies at the southern side and on western side laies the Garhwal region which is one of the part of Uttarakhand state. The people of the Kumaon region are called Kumaonis, who are well known for their martial skills and bravery. The most important towns of the Kumaon region are Haldwani, Nainital, Rudrapur, Almora, Pithoragarh, Mukteshwar and Ranikhet as shown in Figure 1.

The Kumaon region apart from the Himalayan mountains has two sub-mountain strips called the Terai and the Bhabhar. Rest of Kumaon, has a maze of mountains, except

the Great Himalayas. The main rivers are the Sharda (Kali), the Pindari and Kailganga, are the tributary of Alaknanda.



Figure 1. Map showing the Study Area.

3. Trend Analysis

The auto correlation effect from time series of precipitation and temperature is necessary to be removed in a trend analysis. In a non parametric test if the auto correlation is positive then it suggest a significant trend which is more than specified by the Significance level. The procedure of analysis methodology used for MK Test in the study area is shown in Figure 2.

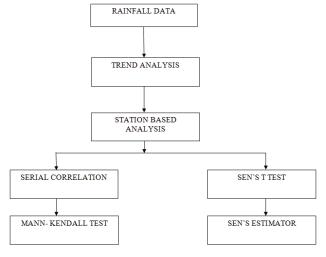


Figure 2. Procedures of analysis methodology used in Study Area

Pre-whitening should be done in a time series. To reduce the effect of serial correlation pre-whitening technique should be applied on the non parametric test².

$$^{pw}x_{j} = x_{j} - cx_{i-1}$$
 (1)

Where pwx, is the pre-whitened data to be used in the subsequent trend analysis and c is the lag-1 serial correlation coefficient as determined directly from the data using Equation 1.

3.1 M-K Test (Mann-Kendall)

Trend analysis test was frequently used in similar application and is a resourceful tool for analyzing the trends in hydrological and other associated variables. 10. Mann-Kendall (MK) test also known as Kendall's r-statistic, which is extensively used to analyze arbitrariness against trend. It is a rank-based procedure, which is robust to the influence of extremes and good for use with skewed variables. The objective of the M-K test is to review statistically, if there is a monotonic upward or downward trend of the variable of interest over time¹¹⁻¹³. A monotonic downward trend indicates that the variable is constantly decreases and upward trend indicates the increase with respect to time, but the trend may be or may not be linear. For a parametric linear regression analysis MK test may be applied which can be used to study if the slope of the predictable linear regression line is different from zero. The residuals from the fitted regression line are normally distributed as regression analysis requires. As M-K test is a non-parametric (distribution-free) analysis so this hypothesis is not required.

According to M-K test, the null hypothesis H₀ states that the discontinuous data (x_1, \ldots, x_n) is a sample of n independent and identically distributed random variables. The alternative hypothesis H₁ is not similar for all k, j < n with k = j for the distributions of x_k and x_j . The S (Test Statistics), having mean zero and equation (4) is used to calculate the variances using equations (2) and (3) and asymptotically normal.

$$S = \sum_{k-1}^{n-1} \sum_{j=k+1}^{n} sgn(X_{j} - X_{k})$$
 (2)

$$sgn(x_{j}-x_{k}) = \begin{cases} +1 & if(x_{j}-x_{k}) > 0\\ 0 & if(x_{j}-x_{k}) = 0\\ -1 & if(x_{j}-x_{k}) < 0 \end{cases}$$
(3)

$$Var(S) = \left\lceil \frac{n(n-1)(2n+5) - \sum_{t} t(t-1)(2t+5)}{18} \right\rceil$$
 (4)

The notation t denotes the scope of any known tie and the summary of all ties. In cases where the sample size n > 10, z (standard normal variety) is estimated by applying equation (5). H_0 should thus be accepted if $|z| \le z 1-\alpha/2$ (here $\alpha = 0.1$) at the level of significance in a two-sided test for trend. A value of S if positive represents an 'increasing trend' and a negative represents 'descending trend'14.

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0\\ 0 & \text{if } S = 0\\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases}$$
 (5)

3.2 SEN'S Slope Estimator

Sen's estimator is required to predict the magnitude of trend. By this method the true slope is estimated and linear trend is present. Here, the slope (T) of all data pairs is first computed as Sen¹⁵.

$$T_{i} = \frac{x_{j} - x_{k}}{j - k}$$
 For $i = 1, 2, ..., N$ (6)

In which x, and x, are represented as data values at time j and k (j>k) correspondingly. The median of these N values of T_i is considered as Sen's estimator of slope which is given as

$$Q_i = \begin{cases} T_{\frac{N+1}{2}} & \text{N is odd} \\ \frac{1}{2} \left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}} \right) & \text{N is even} \end{cases}$$
 (7)

The Sen's estimator is estimated as $\boldsymbol{Q}_{i} \!\!=\! \boldsymbol{T}_{(N+1)/2}\!,$ if N is odd and it is estimated as $Q_i = [T_{N/2} + T_{(N+2)/2}]/2$ if N is even. Lastly Q_i is estimated at 100 (1-α) % confidence interval by a two sided test and then by the non-parametric test Q, a exact slope can be derived in the time series with a positive value signifies an increasing or upward trend and a negative value signifies a decreasing or downward trend.

4. Results

Trend analysis of rainfall for the period of 1901-2010 (110 years) in Uttarakhand region has been done in the present study. Mann-Kendall and Sen's Slope Estimator has been used for the determination of the rainfall trend detection. Initially, value of Serial correlation coefficient after prewhiting the rainfall series for 1901-2010 of all the four station are given in Table 1 with their latitude and longitude.

Rainfall Trend in Uttrakhand region is presented station wise (1901-2010) namely: Alomra, Bageshwar, Champawat, Nanital, Pithoragarh, Udham Singh Nagar as shown in Table 2 and Table 3 and their graphical representation in Figure 3 and Figure 4.

Almora: In Almora station, on annual basis rainfall trend results shows the increasing trend with No significant level. On other hand, Seasonal basis the pre-monsoon series shows the increasing trend with 95% confidence of level and monsoon series shows the decreasing trend with 99% confidence of level. Post monsoon shows the decreasing trend and winter series shows increasing trend with level of non-significance. on monthly basis, the month of march and may shows the increasing trend with 90% level of confidence, month of July show decreasing trend with 90% level of confidence, the month of august shows the decreasing trend with 95% level of confidence and month of November show increasing trend with 95% level of confidence.

Bageshwar: In Bageshwar station, on annual basis rainfall trend results shows the increasing trend with No significant

level. On other hand, Seasonal basis the pre-monsoon series shows the increasing trend with no significance level and monsoon series shows the decreasing trend with 99% confidence of level. Post monsoon shows the increasing trend and winter series shows decreasing trend with level of non-significance. On monthly basis, the month of January and July shows the decreasing trend with 90% level of confidence, month of November show increasing trend with 90% level of confidence and month of August show decreasing trend with 99% level of confidence.

Champawat: In Champawat station, on annual basis rainfall trend results shows the increasing trend with No significant level. On other hand, Seasonal basis the pre-monsoon series shows the increasing trend with 95% level of confidence and monsoon series shows the decreasing trend with 99.9% confidence of level. Post monsoon shows and winter series shows the increasing trend with level of non-significance. On monthly basis, the month of July shows the decreasing trend with 95% level of confidence, August shows the decreasing trend with 99.9% level of confidence, month of May show increasing trend with 90% level of confidence and month of November show increasing trend with 99% level of confidence.

Table 1. Values of Variance, Covariance and Serial correlation after pre-whiting the Rainfall series

S. No.	City	Latitude	Longitude		Annual	Pre- Monsoon	Monsoon	Post-Monsoon
				Variance	47269.6	1370.63	64151.71	1605.12
1	Almora	29.59	79.65	Covariance	228.06	242.08	2362.55	-18.73
				Serial Correlation	0	0.18	0.04	-0.01
1 Al 2 Bl 3 Cl 4 Na 5 Pi	Bhageshwar	29.85	79.77	Variance	47269.6	1829.6	66176.07	2323.42
				Covariance	228.06	227.93	3533.05	-16.91
				Serial Correlation	0	0.12	0.05	-0.01
			80.10	Variance	47269.6	1179.84	80453.71	2435.65
3 4 5	Champawat	29.33		Covariance	228.06	274.3	6306.91	-42.31
				Serial Correlation	0	0.23	0.08	-0.02
		29.38	79.45	Variance	47269.6	728.66	58708.32	1473.22
3 C	Nanital			Covariance	228.06	169.83	2468.52	-30.64
				Serial Correlation	0	0.23	0.04	-0.02
	Pithoragarh	29.58	80.22	Variance	47269.6	3124.04	57928.05	2700.2
3 4 5				Covariance	228.06	264.15	2726.16	-22.92
				Serial Correlation	0	0.08	0.05	-0.01
	Udham Singh Nagar	28.98	79.40	Variance	47269.6	543.3	50771.15	1317.4
6				Covariance	228.06	98.07	-1703.11	-28.07
				Serial Correlation	0	0.18	-0.03	-0.02

Table 2. Rainfall Trend in the Alomra, Bageshwar and Champawat Regions of Uttarakhand is presented station wise (1901–2010)

Time series	Almora			Bhageshwar			Champawat		
	Test Z	Signific.	Q	Test Z	Signific.	Q	Test Z	Signific.	Q
JAN	-1.10		-0.065	-1.70	+	-0.100	-0.77		-0.043
FEB	0.27		0.019	-0.26		-0.020	0.54		0.028
MAR	1.87	+	0.080	0.98		0.054	1.26		0.050
APR	0.44		0.013	-0.86		-0.042	0.96		0.028
MAY	1.81	+	0.131	0.82		0.062	1.85	+	0.134
JUN	-0.60		-0.159	-0.97		-0.261	-0.87		-0.229
JUL	-1.76	+	-0.680	-1.78	+	-0.632	-2.34	*	-0.943
AUG	-2.57	*	-0.895	-3.17	**	-1.082	-3.57	***	-1.300
SEP	0.34		0.100	-0.22		-0.053	-0.15		-0.052
OCT	-0.29		-0.015	-0.40		-0.025	-0.38		-0.029
NOV	2.07	*	0.023	1.81	+	0.024	2.74	**	0.025
DEC	-0.25		-0.006	-0.67		-0.018	-0.36		-0.005
Annual	0.96		0.637	0.96		0.637	0.96		0.637
pre-monsoon (Mar-May)	2.36	*	0.230	0.75		0.081	2.45	*	0.239
monsoon (June-Sept)	-2.59	**	-1.966	-3.25	**	-2.498	-3.53	***	-2.896
post-monsoon (oct-Nov)	-0.03		-0.003	0.00		0.000	0.17		0.011
Winter (Dec-Feb)	0.05		0.005	-0.97		-0.114	0.07		0.007

Table 3. Rainfall Trend in the Nanital, Pithoragarh and Udham Singh Nagar Regions of Uttarakhand is presented station wise (1901-2010)

Time series	Nanital			Pithoragarh			Udham Singh Nagar		
	Test Z	Signific.	Q	Test Z	Signific.	Q	Test Z	Signific.	Q
JAN	-1.00		-0.045	-1.46		-0.108	-1.15		-0.050
FEB	0.52		0.027	-0.40		-0.035	0.24		0.011
MAR	1.45		0.056	0.58		0.039	1.08		0.035
APR	0.74		0.018	-0.81		-0.052	0.14		0.003
MAY	2.07	*	0.112	0.80		0.076	1.65	+	0.085
JUN	-0.50		-0.116	-0.89		-0.199	-0.20		-0.030
JUL	-1.68	+	-0.567	-1.61		-0.542	-0.47		-0.152
AUG	-2.39	*	-0.868	-3.51	***	-1.038	-2.37	*	-0.768
SEP	0.10		0.028	-0.26		-0.050	1.13		0.303
OCT	-0.04		-0.003	-0.59		-0.049	-0.26		-0.010
NOV	1.84	+	0.015	0.99		0.013	0.48		0.004
DEC	0.01		0.000	-0.73		-0.023	-0.33		-0.005
Annual	0.96		0.637	0.96		0.637	0.96		0.637
pre-monsoon (Mar-May)	2.83	**	0.204	0.20		0.034	2.29	*	0.154
monsoon (June-Sept)	-2.51	*	-1.845	-3.20	**	-2.236	-1.17		-0.799
post-monsoon (oct-Nov)	0.34		0.019	-0.28		-0.030	-0.29		-0.015
Winter (Dec-Feb)	0.10		0.009	-0.90		-0.144	-0.36		-0.025

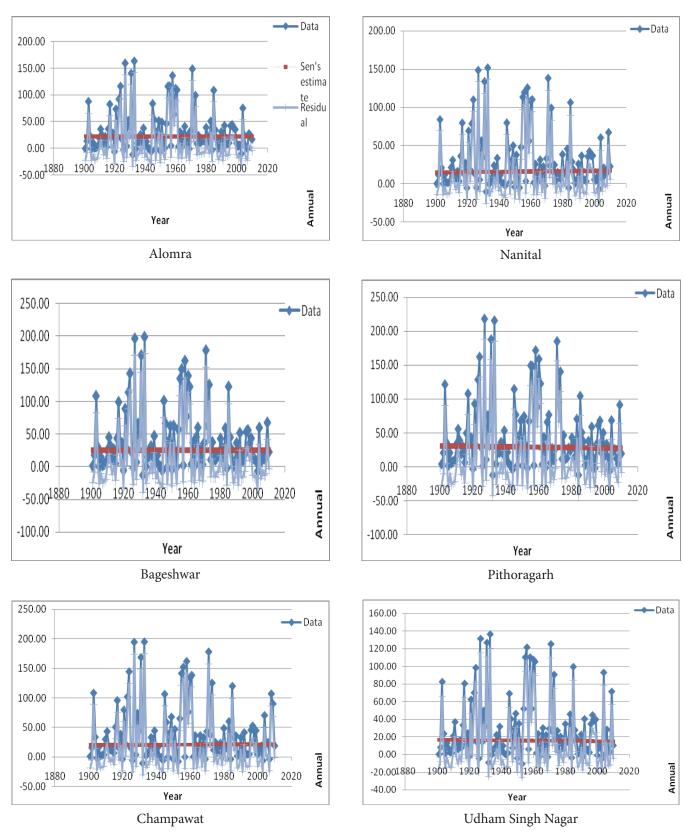


Figure 3. Rainfall Trend Graph represented for Alomra, Bageshwar and Champawat stations (1901–2010).

Figure 4. Rainfall Trend Graph represented for Nanital, Pithoragarh and Udham Singh Nagar stations (1901–2010).

Nanital: In Nanital station, on annual basis rainfall trend results shows the increasing trend with No significant level. On other hand, Seasonal basis the pre-monsoon series shows the increasing trend with 99% level of confidence and monsoon series shows the decreasing trend with 95% confidence of level. Post monsoon shows and winter series shows the increasing trend with level of non-significance. On monthly basis, the month of July shows the increasing trend with 90% level of confidence, August shows the decreasing trend with 95% level of confidence, month of May show increasing trend with 95% level of confidence and month of November show increasing trend with 90% level of confidence.

Pithoragarh: In Pithoragarh station, on annual basis rainfall trend results shows the increasing trend with No significant level. On other hand, Seasonal basis the premonsoon series shows the increasing trend with level of non-significance and monsoon series shows the decreasing trend with 99% confidence of level. Post monsoon shows and winter series shows the decreasing trend with level of non-significance. On monthly basis, the month of August shows the decreasing trend with 99.9% level of confidence.

Udham Singh Nagar: In Udham Singh Nagar station, on annual basis rainfall trend results shows the increasing trend with No significant level. On other hand, Seasonal basis the pre-monsoon series shows the increasing trend with 95% level of confidence and monsoon series shows the decreasing trend with level of non-significance. Post monsoon shows and winter series shows the decreasing trend with level of non-significance. On monthly basis, the month of May shows the increasing trend with 90% level of confidence and August shows the decreasing trend with 95% level of confidence.

5. Conclusion

The study analyzed the rainfall data of 110-years from 1901 to 2010 to determine the trend of rainfall in the Kumaon regions of Uttrakhand. As this region is rapidly growing, any change in the rainfall trend pattern may have considerable impact on the people of this region. The Z value of MK Test revealed increasing trend in rainfall so it can be concluded that there may be an impact of climate change is present which is

contributing to the prolonged and heavy rainfall that is rising with time. Similarly, Sen's Slope has also estimated increasing magnitude of slope for rainfall data. This study is to find out the annual trend for rainfall time series which is found to be increasing (positive) with level of non significance trend, pre-monsoon trend increasing with different level of confidence for different region, monsoon trend is decreasing with different level of confidence for different region while post-monsoon and winter trend are not constant they are in increasing trend for some region and in decreasing trend for with level of no significance.

6. Acknowledgment

The authors heartily acknowledges Indian Water Portal for providing the Precipitation data of 110 years. They are also thankful to all authors and publishers for all the necessary information and the research done by them which has been utilized by the authors in making this study as achievable.

7. References

- 1. Kothawale DR, Rupakumar K. On the recent changes in surface temperature trends over India. Geophysical Research Letters. 2005 Sep; 32(18):1-4.
- 2. Hingane LS. Is a signature of socio-economic impact written on the climate? Climatic Change. 2005; 32:91-101.
- Pant GB, Kumar KR. Chichester: John Wiley & Sons Ltd: Climates of South Asia. 1997 May.
- Arora M, Goel NK, Singh P. Evaluation of temperature trends over India. Hydrological Sciences Journal. 2005 Feb; 50(1):81-93.
- 5. Dash SK, Jenamani RK, Kalsia SR. Panda SK. Some evidence of climate change in twentieth-century India. Climatic change. 2007 Dec; 85(3):299-321.
- Mishra N, Khare D, Shukla R, Singh L. A study of temperature Variation in Upper Ganga Canal Command India. Advances in Water Resource and Protection (AWRP). 2013 Jul; 1(3):1-7.
- 7. Kumar Kalyani, Mishra N, Gupta S. Trend Analysis of Temperature by Mann-Kendall Test in the High Altitude Regions of Uttarakhand, India: AARJMD. 2014 Feb; 1(18):387-99.
- Kulkarni A, Von Storch H. Monte Carlo experiments on the effect of serial correlation on the Mann-Kendall test of trend. Meteorologische Zeitschrift. 1995 Jan; 4(2):82-5.

- 9. Von Storch H, Navarra A. New York: Springer-Verlag: Analysis of Climate Variability-Applications of Statistical Techniques. 1995.
- 10. Hirsch RM, Slack JR. Non-parametric trend test for seasonal data with serial dependence. Water Resources Research. 1984 Jun; 20(6):727–32.
- 11. Mann HB. Non-parametric tests against trend. Econometrica. 1994; 13:163–71.
- 12. Kendall MG. London: Charles Griffin: Rank Correlation Methods, 4th edition. 1975.

- 13. Gilbert RO. NY: Wiley: Statistical Methods for Environmental Pollution Monitoring. 1987 Feb.
- 14. Turgay Partal, Ercan Kahy. Trend analysis in Turkish precipitation data. Hydrological Processes. 2006 Jun; 20(9):2011–26.
- 15. Sen PK. Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association. 1968; 63(4):1379–89.