Environment and Ecology 36 (2A) : 664—671, April—June 2018
Website: environmentandecology.com ISSN 0970-0420

Precipitation Trend Analysis by Mann-Kendall Test of Different Districts of Malwa Agroclimatic Zone

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Received 17 February 2018; Accepted 8 March 2018; Published on 24 March 2018

Abstract Climate change has disrupted the major climatic parameters at a global level. However, the changes having localized intensity area not equal for all especially in India. These changes must be quantified locally to manage the natural water resources more effectively. Precipitation is one of the most important climatic parameters. It has been widely measured as a starting point towards the apprehension of global climate change. The purpose of this study is to observe the temporal variability of rainfall for the period of 1901–2014 (114 year), to improve the hydrological status of different districts of Malwa Agroclimatic Zone. The aim of the study is to determine the trend in annual precipitation time series using the Mann-Kendall and Sen's T test. The magnitudes of trend in precipitation have been estimated by Sen's estimator method. Auto correlation effects were reduced before applying the Mann-Kendall test for the trend in precipitation. On the annual basis, analysis of Mann-Kendall test shows decreasing and non-significance trend in rainfall times series of all the districts except Indore which showed significant changes. The uneven distribution of rainfall leads to more runoff in these areas. Leaving very less scope for groundwater recharge. Thus, these findings give a broad overview of the regional rainfall behavior in the study area.

Keywords Rainfall, Non-parametric tests, Trend analysis, Auto correlation, Mann-Kendall.

Introduction

Climate change has begun to mark itself worldwide as scientific facts in the form of increased downpours and stroms, diminishing glaciers, rising temperature and sea level. US EPA studies identify the global temperature patter from 1901 to the present help of using data by National Oceanic and Atmospheric Administration's National Climatic Data Center (NCDC). This report state the average global warming in the late 1970's was -17.58 °C to -17.49 °C per decade and the global average surface temperature has risen at an average rate of -17.70 °C per decades since 1901(David et al. 2003, Alexander et al. 2006, Arora et

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Table 1. Values of descriptive statistics and autocorrelation of the rainfall series in different district of Malwa agroclimatic zone.

Sl. No.	City	Latitude	Longitude	Statistics parameters	Annual	Pre-monsoon	Monsoon	Post-monsoon	Winter
				Mean	860.34	10.95	793.93	47.14	8.31
				Variance	85620.82	93.86	80901.37	1957.30	96.98
1	Indore	75.8577° E	22.7196° N	SD	19.98	3.59	58.54	16.37	3.39
				CV (%)	24.24	85.95	25.67	85.09	99.37
				Kurtosis	5.50	1.40	6.31	0.96	5.50
				Skewness	1.95	1.20	2.10	1.09	2.17
				Mean	977.57	13.53	897.82	53.70	12.52
				Variance	53646.22	130.63	50927.88	2391.49	239.87
2	Dewas	76.0508° E	22.9623° N	SD	292.61	9.69	284.43	44.24	9.85
				CV (%)	34.01	88.46	35.83	93.85	118.47
				Kurtosis	0.0023	0.19	0.26	0.11	11.08
				Skewness	0.35	0.89	0.56	0.88	2.92
				Mean	929.51	8.85	867.77	46.17	6.72
				Variance	49187.84	80.84	46467.46	1797.84	61.01
3	Ujjain	75.7849° E	23.1793° N	SD	221.78	8.99	215.56	42.40	7.81
				CV (%)	23.86	101.59	24.84	91.84	116.23
				Kurtosis	0.36	1.84	-0.04	-0.36	6.60
				Skewness	0.15	1.46	0.15	0.77	2.27
				Mean	988.57	11.72	916.09	47.00	13.77
				Variance	64923.03	95.99	61958.36	2014.57	225.78
4	Shajapur	76.2730° E	23.4273° N	SD	254.80	9.80	248.91	44.88	15.03
				CV (%)	25.77	83.57	27.17	95.50	109.15
				Kurtosis	2.94	0.70	3.99	-0.16	7.37
				Skewness	0.84	1.04	1.07	0.89	2.34
				Mean	863.91	12.79	803.92	39.69	7.50
				Variance	54758.76	145.17	54060.56	1506.72	53.56
5	Neemuch	74.8624° E	24.4764° N	SD	234.01	12.05	232.51	38.82	7.32
				CV (%)	27.09	94.17	28.92	97.81	97.51
				Kurtosis	1.01	0.86	1.67	-0.02	2.55
				Skewness	0.52	1.24	0.64	0.95	1.55
				Mean	939.42	7.95	888.42	38.00	5.04
				Variance	53037.17	59.10	53172.31	1315.35	27.39
6	Ratlam	75.0376° E	23.3342° N	SD	230.30	7.69	230.59	36.27	5.23
				CV (%)	24.51	96.70	25.96	95.44	103.75
				Kurtosis	1.02	1.94	1.14	0.98	1.93
				Skewness	0.42	1.42	0.50	1.01	1.46
				Mean	947.16	10.69	886.53	41.90	8.05
				Variance	53991.63	109.42	54153.38	1607.45	61.67
7	Mandsaur	75.0693° E	24.0768° N	SD	232.36	10.46	232.71	40.09	7.85
				CV (%)	24.53	97.90	26.25	95.69	97.60
				Kurtosis	0.40	1.32	0.60	-0.54	1.82
				Skewness	0.33	1.35	0.41	0.80	1.44
				Mean	954.87	12.30	886.11	39.67	16.79
				Variance	65686.62	92.48	64396.63	1762.85	273.58
8	Rajgarh	76.7337° E	23.8509° N	SD	256.29	9.62	253.76	41.99	16.54
				CV (%)	26.84	78.18	28.64	105.85	98.52
				Kurtosis	7.60	0.35	9.49	0.85	6.29
				Skewness	1.55	0.95	1.87	1.24	2.10

al. 2006, Dash et al. 2007, Gleick 1993).

Temperature and precipitation are essential element of climate and changes in them can affect human health, ecosystems, plants and animals. An increase in temperature can result in heat wave incidents and cause illness and death and also cause alter in species of animals and plants. Kothawale and Rupa Kumar (2005) found that precipitation trends increase can results in an increase in the floods frequency and a decades could increase in instances of drought. An increasing trend of temperature leads to more evaporation, which in turn, increase precipitation. It is found that over 1901–2003, mean annual temperature of all India has rised at the rate of 0.05 °C/ decades, which mostly due to the rise of maximum temperature (0.07 °C/decades) and minimum temperature (0.02 °C/decades).

Goswami et al. (2006) in their study carried out by several investigators found that the trend and magnitude of temperature rise over the Indian subcontinent is broadly constant with the worldwide over the last century. Pant and Kumar (1997) found that an increasing trend of mean annual temperature, at the rate of 0.57 °C per 100 years in the annual air temperature from 1881–1997. Similar changes in precipitation form and its timing can have widespread effect on the availability of water and can cause a shift 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 climatic change which is contributing to the prolonged and heavy rainfall that is rising with time (Mishra and Gupta 2015, Milliman et al. 2008, Kripalani et al. 2003, Klein et al. 2006, Von Storch and Navarra 1995).

Study area

The state of Madhya Pradesh occupies a total geographical area of 44.348 m ha out of which 55.9% (24.804 m ha) is under major *kharif* and *rabi* crops. The state is predominantly rain fed farming state, as only 29.5% of the net cultivated area (6.07 m ha) is irrigated. The state of Madhya Pradesh is blessed with varied agro-climatic conditions which permits the farmers' of the state to cultivate a number of crops like cereals, pulses, oilseeds, commercial crops and horticulture crops across different seasons of the year.

Malwa plateau agro climatic zone comprises 8 entire districts (Indore, Dewas, Mandsore, Neemuch, Raigarh, Ratlam, Shajapur, and Ujjain) and part of Dhar (Dhar, Badnawar, Sardarpur Tehsil) and Jhabua (Petlawad Tehsil) districts of Madhya Pradesh. Malwa agroclimatic zone is average rainfall 977 mm, the average rainfall in Malwa agroclimatic zone in the different districts Indore (985.2 mm), Ujjain (866.7 mm), Dewas (1219.7 mm), Rajgarh (971.3 mm), Neemuch (872.5 mm), Ratlam (982.7 mm), Mandsoure (1014.9 mm) and Shajapur (957.6 mm). The soils of the area are medium, deep and shallow black and contain 40–60% clay. pH ranges from 7–8, CEC 33–55 c mol kg^{-1} and bulk density varies from 1.2–1.6 Mgm^{-3}, low in N, medium to high in P and high in K, S and Zn deficiency are very common. Infiltration: 1.55–3.66 cm/h (Low-Medium). Major crops are soybean (*kharif*), chickpea and wheat (*rabi*). Other crops are maize, sorghum, pigeon pea (*kharif*) and spices, opium, medicinal crops (*rabi*).

Materials and Methods

Data collection

The monthly precipitation data was download form the website of the Indian Meteorological Department (IMD) through the India water-portal website (http://www.indiawaterportal.org) 1901 to 2002 and http://globalweather.tamu.edu (2003–14) for the time period. IMD has define four seasons, namely winter (December-February), pre-monsoon (March–May), monsoon (June-September) and post-monsoon (October-November) so using monthly rainfall data/seasonal and annual rainfall series were prepared. After that, statistical analysis and trend detection has been done using Microsoft office excel 2013.

Methodology

Trend analysis

As a first step of analysis, basic statistical parameters like mean, standard deviation (SD), skewness, kurtosis and coefficient of variation were estimated from the data for each station. Initially the autocorrelation test was applied to check serial dependence in the dataset. Strong antocorrelations affect the significant assessment of trend estimates by inflating the distribution of the test statistics. These much larger critical values need to be employed as significance threshold than in case of uncorrelated data. Apart form this, Loess regression curve was used to plot an check general patterns in data over the period of 1901 to 2014 for monthly, annual and seasonal series.

Autocorrelation

Lag-1 autocorrelation is used to check serial dependence between the data. The lag-1 autocorrelation coefficient is the simple correlation coefficient of the first observation N-1, X_t, t=1,2,3,........ N-1 and the next observation X_t and X_{t+1} is given by

$$\Upsilon_1 = \frac{\sum_{t=1}^{N-1} (X_t - X)(X_{t+1} - \bar{X})}{\sum_{t=1}^{N-1} (X_t - \bar{X})^2}$$

Where $W = \sum_{t=1}^{N-1} (X_t)$ is the overall mean.

The lag-1 autocorrelation coefficient r_1 is tested for its significance. The probability limits on the correlogram of an independent series of the two tailed test is given below

$$\Upsilon_1\ (95\%) = \frac{-1 \pm 1.96\sqrt{N-k-1}}{N-k}$$

Where N is the sample size and k is the lag.

The value of r_1 lie outside the confidence interval given above, the data area assume to be serially correlated otherwise the sample data are considered to be serially independent.

Mann-Kendall test

The Mann-Kendall trend test for assessing the trend present in the data. Initially, this test was used by Mann (Beniston 2003) and Kendall (Beniston et al. 1997) and subsequently derived the test statistics distribution (Brown et al. 1992, Chaouche et al. 2010). This hypothesis test is a nonparametric, rank-based method for evaluating the presence of trends in time series data. The data are ranked according to time and then each data point is successively treated as a reference data point and is compared to all data points that follow in time. Compared with parametric statistical tests, nonparametric test are thought to be move suitable for nonnormally distributed data (Dash and Hunt 2007). Since the time series data used in the study is mostly nonnormally distributed as evident from the skewness and kurtosis values given in Table 1 the nonparametric test were used in the study.

The Mann-Kendall test statistics is given by

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\ (\chi_j - \chi_i)$$

Where χ_i and χ_j are the sequential data values, n is the data set record length, and

$$sgn\ (\theta) = \begin{cases} +1, & if\ \theta > 0 \\ 0 & if\ \theta = 1 \\ -1, & if\ \theta < 0 \end{cases}$$

The Mann-Kendall test has two parameters that are of importance to the trend detection. These parameters are the significance level that indicated the trend's strength and the slope magnitude estimate which indicates the direction as well as the magnitude of the trend.

For independent, identically distributed random variables with no tied data values, we have E(S) = O;

$$Var\ (S) = \frac{n\ (n-1)\ (2n+5)}{18}$$

When some data value are tied, the correction to Var(S) is

$$Var\ (S) = \frac{n\ (n-1)\ (2n+5) - \sum_{i=1}^{n} t_i\ (i)\ (i-1)\ (2i+5)}{18}$$

Table 2. Rainfall trend in the different district of Malwa agroclimatic zone. *** if trend at α=0.001, ** if trend at α=0.01, * if trend at α=0.05, + if trend at α=0.1 level of significance.

	Indore			Dewas			Ujjain			Shajapur		
Time Series	Test Z	Sig	Q	Test Z	Sig	Q	Test Z	Sig	Q	Test Z	Sig	Q
Jan	-0.31	`	0.000	0.11		0.000	0.18		0.000	0.42		0.000
Feb	-0.20		-0.000	0.02		0.000	-0.37		0.000	-0.03		0.000
Mar	0.48		0.000	-0.70		0.000	0.11		0.000	0.37		0.000
Apr	-1.11		0.000	-1.59		0.000	-1.09		0.000	-1.31		0.000
May	-1.06		-0.008	-1.52		-0.012	-2.12	*	-0.008	-1.43		-0.007
Jun	2.02	*	0.447	1.07		0.216	0.81		0.159	0.87		0.144
Jul	0.80		0.272	0.29		0.113	-0.58		-0.217	-0.50		-0.184
Aug	3.90	***	1.067	2.78	**	0.838	1.25		0.411	0.95		0.336
Sep	0.20		0.054	-1.17		-0.335	-2.99	**	-0.968	-3.21	**	-1.055
Oct	0.98		0.033	0.31		0.007	-0.14		-0.001	0.15		0.000
Nov	-1.32		0.000	-1.52		0.000	-1.80	+	-0.003	-2.07	*	-0.004
Dec	-1.55		0.000	-2.25	*	0.000	-1.66	+	0.000	-1.78	*	0.000
Annual	2.69	**	0.158	1.25		0.072	-1.27		-0.071	-1.14		-0.075
Pre-monsoon	-0.26		-0.002	-1.14		-0.008	-1.14		-0.004	-0.72		-0.004
Monsoon	2.63	**	0.452	0.99		0.185	-1.05		-0.181	-1.17		-0.197
Post-monsoon	-0.02		0.000	-1.11		-0.040	-2.74	**	-0.514	-1.30		-0.042
Winter	-0.12		0.000	0.10		0.001	0.34		0.001	0.06		0.001

Table 2. Continued.

	Neemuch			Ratlam			Mandsaur			Rajgarh		
Time Series	Test Z	Sig	Q	Test Z	Sig	Q	Test Z	Sig	Q	Test Z	Sig	Q
Jan	-0.79	`	0.000	-0.36		0.000	-0.36		0.000	-0.54		0.000
Feb	-0.08		-0.000	-0.55		0.000	0.35		0.000	0.01		0.000
Mar	0.10		0.000	-0.40		0.000	0.02		0.000	0.18		0.000
Apr	0.24		0.000	-0.53		0.000	0.40		0.000	-0.10		0.000
May	-0.57		-0.003	-1.72	+	0.004	-0.84		-0.002	-1.38		-0.007
Jun	0.51		0.084	0.96		0.197	1.13		0.209	1.10		0.176
Jul	0.39		0.148	-0.39		-0.128	0.05		0.034	-0.68		-0.210
Aug	1.44		0.542	2.19	*	0.759	1.31		0.525	1.34		0.469
Sep	-2.76	**	0.805	-2.10	*	-0.697	-2.62	**	-0.826	-2.90	**	-0.934
Oct	0.12		0.000	0.05		0.000	-0.13		-0.000	0.50		0.009
Nov	-2.06	*	0.003	-1.60		0.002	-1.96	+	-0.003	-2.12	*	-0.003
Dec	-1.92	+	0.000	-1.35		0.000	-2.09	*	0.000	-1.68	+	0.000
Annual	0.41		0.022	0.24		0.013	-0.20		-0.011	-0.30		-0.017
Pre-monsoon	-0.13		-0.001	-1.21		-0.005	-0.16		0.000	-0.34		-0.003
Monsoon	-0.28		-0.038	0.23		0.039	-0.20		-0.039	-0.39		-0.060
Post-monsoon	-1.12		-0.027	-0.94		-0.016	-1.04		-0.023	-0.99		-0.022
Winter	-0.72		0.002	-0.58		-0.001	-0.50		0.002	-0.08		-0.001

Where t_i denotes the number of ties of extent i. For n larger than 10, the test statistic.

$$Zs = \begin{cases} \dfrac{S-1}{[Var(S)]^{0.5'}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \dfrac{S+1}{[Var(S)]^{0.5'}} & if\ S < 0 \end{cases}$$

Z_s follows the standard normal distribution (Beniston et al. 1997).

SEN'S slope estimator

The magnitude of trend slopes can be also calculated using the Mann-Kendall test as follows:

$$\beta = Median\left(\frac{\chi_j - \chi_i}{j - i}\right)$$

Where x_j and x_i are considered data value at time j and i (j>i), correspondingly. The median of these N values of β_1 is represented as Sen's estimator of slope which is given as

$$Q_i = \begin{cases} \beta_{(N+1)/2} & \text{when N is odd} \\ \frac{1}{2}(\beta_{N/2} + \beta_{(N+2)/2}) & \text{when N is even} \end{cases}$$

A positive value of Q indicates an upward trend, whereas a negative value represents a downward trend.

Results and Discussion

Trend analysis of rainfall for the period of 1901 to 2014 (114 years) in Malwa Agroclimatic zone 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 autocorrelation the rainfall series for 1901–2014 of the eight station are given in Table 1 with their latitude and longitude.

Rainfall trend in Malwa agroclimatic zone is presented station wise (1901 to 2014) for Indore, Dewas, Ujjain, Shajapur, Mandsaur, Neemuch, Rajgarh and Ratlam (Table 2).

Indore

In Indore district on annual basis rainfall trend result show the increasing trend with high 99.0% of significance level annual positive growth in Z statistics 2.69. In the other hand, seasonal basis monsoon trend with increasing positive (Z-2.63) and 99.9% significance level. Monsoon increasing decades wise increasing Q statistics positive 0.452 (Table 2). Pre-monsoon, post-monsoon and winter series show the decreasing trend with non-significance. On the monthly basis, the month of June increasing trend (Z-2.02), decades wise trend positive (Q-0.447) and 95% of significance level. Month of August show the increasing trend (Z-3.90 and Q-1.06) with 99.9% level of confidence.

Dewas

In Dewas district on annual basis rainfall trend result shows the increasing trend with no-significance level. On the hand, seasonal basis the pre-monsoon and post-monsoon show decreasing trend (-1.14 and -1.11) with non-significance. Monsoon and winter series shows the increasing trend with level of non-significance. On the monthly basis, the month of August show increasing trend (2.78) with 99% significance level and decades wise (Q-0.838). December shows the decreasing trend (-2.25) with 95% level of confidence.

Ujjain

In Ujjain district on annual basis rainfall trend result show the decreasing trend (-1.27) with non-significance level. On the other hand, seasonal hasis the post-monsoon series shows the decreasing trend (-2.74) with 99% level of confidence. Only winter increasing trend (0.34) with non-significance. Pre-monsoon and monsoon series shows the decreasing with non-significance. On monthly basis, the month of decreasing trend May (-2.12) (90%), September (-2.99) (95%), November (-1.80) and December (-1.66) (90%) Z-values and level of significance.

Shajapur

In Shajapur district on annual basis rainfall trend result show decreasing trend (-1.14) with non-significance level. On the other hand, seasonal basis of pre-monsoon, monsoon and post-monsoon decreasing trend (-1.30 to -0.72) with non-significance level only winter season little increasing trend (0.06) with non-significant. On monthly basis the month decreasing trend of September (-3.21), November (-2.07) and December (-1.78) with significance level.

Neemuch

In Neemuch district on annual basis rainfall trend result show decreasing trend (-0.41) with non-significance. On the other hand, seasonal basis decreasing trend pre-monsoon, monsoon, post-monsoon and winter with non-significance. On monthly basis the month of September (-2.76) with 99% significance trend. Month of November (-2.06) with 95% significance level and December (-1.92) with 90% significance decreasing trend.

Ratlam

In Ratlam district on annual basis rainfall trend result show increasing trend (Z-0.24) with non-significance and Q-0.013 decades wise increase trend. On the other hand, seasonal basis monsoon increasing trend in Z-0.23 and Q-0.039 with non-significance and pre-monsoon, post-monsoon and winter was decreasing trend and sen's slope was non-significance. On monthly basis of the month of August (Z-2.19) increasing trend with 95% significance trend. May and September decreasing trend with 90 and 95% with Z statistics (-1.72 and -2.10).

Mandsaur

In Mandsour district on annual basis rainfall trend result show decreasing trend (-0.20) with non significance. On the other hand, seasonal basis of rainfall trend pre-monsoon (-0.16), monsoon (-0.20), post-monsoon (-1.04) and winter (-0.50) decreasing trend with non-significance trend. On monthly basis of the month of September (-2.62) decreasing trend with 99% significance trend. Month of November (-1.96) and December (-2.09) decreasing trend with 90% and 95% significance trend.

Rajgarh

In Rajgarh district on annual basis rainfall trend result show decreasing trend (-0.30) with non-significance trend. On the other hand, seasonal basis of rainfall trend pre-monsoon, monsoon, post-monsoon and winter was decreasing trend (-0.08 to -0.99) with non-significance. On the monthly basis September was decreasing trend (-2.90) with 99% significance trend. Month of November and December decreasing trend with 95% and 90% significance trend.

Conclusion

Indore district on annual basis rainfall trend result show the increasing trend with high 99.0% of significance level annual positive growth in Z statistics 2.69%. In the other hand, seasonal basis monsoon trend with increasing positive (Z-2.63) and 99.9% significance level. In Dewas district on annual basis rainfall trend result shows the increasing trend with no-significance level. On the hand, seasonal basis the pre-monsoon and post-monsoon show decreasing trend (-1.14 and -1.11) with non-significance. In Ujjain district on annual basis rainfall trend result show the decreasing trend (-1.27) with non-significance level. On the other hand, seasonal basis the post-monsoon series shows the decreasing trend (-2.74) with 99% level of confidence. In Shajapur district on annual basis rainfall trend result show decreasing trend (-1.14) with non-significance level. On the other hand, seasonal basis of pre-monsoon, monsoon and post-monsoon decreasing trend (-1.30 to -0.72) with non-significance level. In Neemuch district on annual basis rainfall trend result show decreasing trend (-0.41) with non-significance. On the other hand, seasonal basis decreasing trend pre-monsoon, monsoon, post-monsoon and winter with non-significance in Ratlam district on annual basis rainfall trend result show increasing trend (Z-0.24) with non-significance and Q-0.013 decades wise increase trend. On the other hand, seasonal basis monsoon increasing trend in Z-0.23 and Q-0.039 with non-significance and pre-monsoon, post-monsoon. In Mandsour district on annual basis rainfall trend result show decreasing trend (-0.20) with non significance. On the other hand, seasonal basis of rainfall trend pre-monsoon (-0.16), monsoon (-0.20), post-monsoon (-1.04) and winter (-0.50) decreasing trend with non-significance trend. In Rajgarh district on annual basis rainfall trend result decreasing trend (-0.30) with non-significance trend. On the other hand, seasonal basis of rainfall trend pre-monsoon, monsoon, post-monsoon and winter was decreasing trend (-0.08 to -0.99) with non-significance.

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