



Evaluating Rainfall Trends at Hisar (Haryana) in the Semi-arid Zone of North India

Anurag*, Anil Kumar, Diwan Singh, Raj Singh, Surender Singh and Chander Shekhar

Department of Agricultural Meteorology, CCS Haryana Agricultural University, Hisar 125 004, India

Received: February 2017

Abstract: The present study focuses on assessing the trend and variability in rainfall at Hisar (Haryana) situated in semi-arid zone of north India. The region faces adverse effects of moisture deficit almost every year. Normally, eight months a year except monsoon season (June-September), the potential evapotranspiration demand exceeds the rainfall. In this study, rainfall, one of the most important climatic variables was analyzed on basis of long-term historical data recorded at Hisar station. Daily rainfall data of 44 years period (1970 to 2014) was processed to study the monthly and seasonal variability. Mann-Kendall test and Sen's slope estimator were used for determining the trend and slope magnitude. The outcome of these statistical tests revealed both, rising as well as falling trends of precipitation over different time periods in a year. Starting and ending time of monsoon showed a significant shift. Overall, the rainfall showed an increasing trend of @ 2.3 mm year⁻¹. The seasonal trend analysis revealed a significant increase in rainfall during pre-monsoon season but no major change during the post-monsoon period.

Key words: Hisar, rainfall, trend analysis, Mann-Kendall (MK) test, Sen's slope estimator, MAKESENS.

Changes in climate have influenced natural and human systems and recent findings indicate that global warming is more pronounced than expected. The impact would be more in the tropical areas i.e. region of developing countries, including India. Increasing temperature trends of 0.6°C during last century and noticeable changes in rainfall events (high, low and medium) over India have been observed (Rathore *et al.*, 2013; Goswami *et al.*, 2006). It is likely that in a warmer climate heavy rainfall would increase with change in intensity. This could lead to longer dry spells and a higher risk of floods (Rahman *et al.*, 2013). Changes in rainfall pattern would also have great impact on agricultural ecosystem especially of north western semi-arid parts of India.

As discussed in IPCC 5th Report (IPCC, 2014), the global ocean will continue to warm during the 21st century, with the strongest warming projected for the surface in tropical and Northern Hemisphere sub-tropical regions. In addition, changes in precipitation will not be uniform (Pachauri and Meyer, 2014). In the light of these projections, it can be assumed that rainfall pattern in dry regions of Haryana can also undergo considerable changes. Increasing

trend of annual rainfall in Haryana was also reported by India Meteorological Department (Rathore *et al.*, 2013).

The rise in average global surface temperature (0.74° over a period from 1906-2005) along with increase in number of warmer years during past decades have been observed by IPCC (Mandal *et al.*, 2013). It is also observed by IPCC that last three decades have remained successively warmer than preceding decades. The warming will also reflect regional contrast and faster warming would have intensive impacts on water cycle in general and in arid location like Hisar in particular where the annual rainfall averages to a mere 470 mm. The Arabian Sea branch of SW monsoon passes over the region without much rainfall as the Aravallis are parallel to it. It then reaches the lower Himalaya ranges where it joins the Bay of Bengal branch of SW monsoon which is already exhausted by then. Perhaps, this area is more susceptible to climate change as geographically, it lies in the transition zone between the hot dry climate of Thar Desert and cold sub-humid climate of Himalayas (Singh *et al.*, 2014).

Hisar station lies at latitude of 29°10'N and longitude of 75°46'E and an altitude of 215.2 m above mean sea level. It is representative

*E-mail: anurag.airon@gmail.com

of western agroclimatic region and Hot Arid Ecological regions of Haryana. It is characterized by hot summer and cool winter, receiving mean annual precipitation of about 470 mm, which is typical of arid regions. This rainfall is just adequate to cover 15-20% of annual potential evapotranspiration (PET) demand resulting in large deficit of water throughout the year. The ecosystem represents arid soil moisture and hyperthermic soil temperature regimes with an annual length of growing period of less than 90 days (Singh *et al.*, 2010).

Annual rainfall indicated a small increasing trend for the North West and Peninsular India (Kumar *et al.*, 2010). The average annual rainfall has increased over Haryana state whereas it significantly decreased over nearby states Punjab and Uttar Pradesh (Rathore *et al.*, 2013). In the scenario of low rainfall at Hisar, there arises a need to carry out a study on rainfall changes over a long period with in-depth analysis of monthly, seasonal and annual rainfall trends. In the present study the rainfall trend over Hisar has been analyzed to know the direction of change (+/-) and also to quantify the magnitude of such change, if any, on long-term data of 45 years (1970-2014) along with its significance. The analysis has been carried out on monthly and seasonal rainfall trends. Trend for number of rainy days over seasons has also been analysed.

Materials and Methods

Rainfall data used

Daily rainfall data recorded at Agromet Observatory in Department of Agricultural Meteorology, CCS HAU Hisar, Haryana was collected for a 45 year period (1970-2014). The magnitude of variability in the time span was determined using various statistical methods. Trend analysis was carried out by Mann-Kendall test and the magnitudes of the trends in rainfall were estimated using Sen's slope. Analysis was carried out by using MAKESENS, an excel template for trend analysis (Salmi *et al.*, 2002), which tests the presence of monotonic increasing and decreasing trends and quantifies the slope/magnitude of change per unit time with their direction (rising and falling) and significance. This tool can be downloaded from internet (MK weblink) or macro can be written in excel using codes provided therein.

Methodology

Different statistical test methods available to detect trends in hydrological and hydrometeorological time series can be classified as parametric and non-parametric test. Parametric tests are more powerful but require that data to be independent and normally distributed, which is rarely true for hydrological time series data. For non-parametric tests, data must be independent, but outliers are better tolerated.

The widely accepted non-parametric test for weather variables working with time series trends are the Mann-Kendall. Hence, changes in trends of monthly, seasonal and annual rainfall along with changing trends in rainy days were detected in time series using Mann-Kendall (MK) test. Mann-Kendall test is used to test the null hypothesis H_0 of no trend, against the alternative hypothesis, H_1 of an increasing or decreasing monotonic trend. This is a rank correlation statistical test based on a comparison of the observed number of discordances and the value of the same quantity expected from a random series. In the computation of this statistical test MAKESENS exploits the normal approximation (Z) statistics (Salmi *et al.*, 2002). The absolute value of Z was compared with the standard normal cumulative distribution to detect if there is any trend at the selected level of significance (α) (Mandal *et al.*, 2013). The trend is said to be increasing or decreasing if value of Z is positive or negative, respectively.

When a linear trend is present in a time series, then the slope (change per unit time) can be estimated by using a simple non-parametric procedure, the Sen's slope estimator (Sen, 1968). These methods have become very useful in analyzing meteorological or atmospheric data, or where regular observations are to be analyzed over a long period.

Results and Discussion

Rainfall data of 45 years (1970-2014) has shown high variability over time. The mean annual rainfall was found 472 mm with standard deviation of 163.3 mm and coefficient of variation (CV) of 34.6%. Monsoon rainfall contribution remained highest among different seasons. Annual rainfall had high fluctuations throughout the span, however beyond 2000 it showed an increasing trend (Fig. 1).

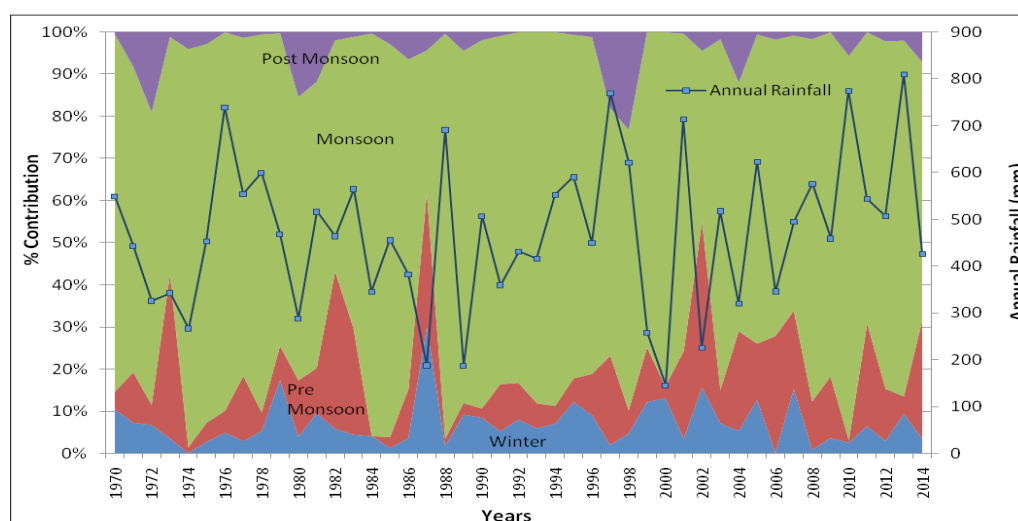


Fig. 1. Annual and seasonal rainfall pattern at Hisar during 1970-2014.

Table 1. Characteristics and trends of rainfall and rainy days at Hisar (1970-2014)

Rainfall	Mean	SD	CV %	Z	Q
Month					
Jan	12.3	11.8	96.5	-0.7	-0.1
Feb	17.5	18.3	104.7	0.6	0.1
Mar	13.4	16.5	123.5	0	0
Apr	12.2	19.9	163.5	1.0	0
May	31.1	31.5	101.1	1.5	0.4
Jun	56.0	38.9	69.4	1.9+	0.7
Jul	128.4	77.9	60.6	-0.5	-0.4
Aug	115.1	83.6	72.7	-1.0	-0.9
Sep	68.9	66.4	96.4	2.0*	1.1
Oct	9.5	26.4	279.8	0.1	0
Nov	3.2	11.7	361.4	-0.2	0
Dec	5.2	8.9	173.3	0	0
Seasons					
Winter	29.8	21.4	71.8	0.4	0.1
Pre Mons.	56.7	46.4	81.9	1.9+	1.0
Monsoon	368.4	153.2	41.6	0.9	1.4
Post Mons.	17.8	31.3	175.5	-0.1	0
Annual	472.6	163.3	34.6	1.2	2.3
Rainy Days					
Winter	2.8	1.6	56.9	0.3	0
Pre Mons.	4.5	3.0	68.3	1.4	0.04
Monsoon	19.2	5.9	30.9	-0.2	0
Post Mons.	1.4	1.8	124.0	0.4	0
Annual	27.9	6.7	24.1	0.7	0.05

Z = Mann Kendall Test, Q = Sen's Slope (mm year⁻¹).

* $\alpha = 0.05$ level of significance, + $\alpha = 0.1$ level of significance.

Monthly trend direction (Z), magnitude and significance of rainfall in Hisar region are shown in Table 1. Z test for annual rainfall (1970-2014) gives a positive value of 1.2, thus implying a non-significant increasing trend of annual rainfall at Hisar. Sen's slope (Q) quantifies the increasing trend @ 2.3 mm year⁻¹.

Monthly rainfall

Monthly rainfall pattern during 1970-2014 (Table 1) showed that July received the highest rainfall (128.4 ± 78 mm), whereas November had the lowest (3.2 ± 11.7 mm). Variability of rainfall among most of the months was observed to be quite high (CV >100%) except for January and four months of monsoon season (June to September). Rainfall of October, November and December months was highly inconsistent with higher CV (about 200%). Minimum rainfall ever recorded was zero in all months except for August. Thus implying thereby that in the arid type of climatic conditions that characterize this region, the failure of rainfall in any month is not uncommon. In the monsoon season (June-Sept.), July received the highest rainfall (128.4 ± 78 mm) followed by August (115 ± 83.6 mm) and September (69 ± 66.4 mm). The CV showed a reverse pattern viz., September had highest (96.4%) followed by August (72.7%) and July (60.6%). The amount of rainfall received at Hisar during eight months outside the monsoon season was meager and quite variable.

Trend of monthly rainfall showed a non-significant increasing trend for February, April, May and October and non-significant

decreasing trend for January, July, August and November. The month of June showed a significant ($Z = 1.9$ at $\alpha = 0.1$) increasing trend of rainfall @ 0.7 mm year^{-1} . September had an increasing trend of rainfall @ 1.1 mm year^{-1} with better level of significance ($Z = 2$ at $\alpha = 0.05$). The remaining two months of monsoon (July and August) in which highest monthly rainfall occurs (27% and 24% of annual, respectively), showed a non-significant decreasing trend ($Z = -0.5$ and -1 , respectively) and the rate of decrease as per Sen's slope was 0.4 and 0.9 mm year^{-1} , respectively. Although the rate of decrease was not that high, yet the negative trend of rainfall during these months pointed towards higher variability expected in monthly rainfall characteristics in this arid area.

Seasonal rainfall

Seasonal rainfall was observed in four standard meteorological seasons viz., winter (January-February), pre-monsoon (March to May), monsoon (June to September) and post-monsoon (October to December). Hisar region receives rainfall from two systems viz., south west monsoon (SW monsoon) and western disturbances (WD) in different seasons. SW monsoon period extends from June to September months having July and August as main period of monsoon. Hisar received maximum rainfall (about 78%) of the annual rainfall during this period. Monsoon period received highest rainfall of $368.4 \pm 153 \text{ mm}$ followed by pre-monsoon period with $56.7 \pm 46.4 \text{ mm}$ rainfall in normal annual rainfall. Winter season had $30 \pm 21.4 \text{ mm}$ of rainfall.

Western disturbances remain prominent for a long time that start from November and lasts till April or May. Rainfall occurring from WDs was highly variable. The post-monsoon, winter and pre-monsoon season that have most of rainfall due to WDs had high CV of 175.5%, 71.8% and 81.9%, respectively. Events of absence of rainfall were also not uncommon in these seasons. Rainfall in these seasons is very crucial for agriculture as it affects the rabi crops i.e. wheat and mustard that have maximum sown area in the western agroclimatic zone of the State.

Like annual trend, the seasonal rainfall showed increasing trend in all seasons except post-monsoon. Rainfall of pre-monsoon was found increasing significantly ($Z = 1.9$ at $\alpha =$

0.1) @ 1 mm per year . The monsoon season also showed a non-significant increasing trend ($Z = 0.9$) of rainfall @ 1.4 mm year^{-1} . Increasing trend of monsoon rainfall augurs well and indicative of favorable change for this area, provided the same trend would occur with respect to the number of rainy days. But, unfortunately it was not so as revealed in the present study (Table 1). The number of rainy days actually showed a decreasing trend ($Z = -0.2$) during the monsoon season, implying thereby that the intensity of rainfall would increase instead.

The most peculiar result of this analysis, in consonance with IPCC estimates, was the changing monthly trend of monsoon period. The middle months of monsoon period (July and August) which contributed highest monthly rainfall with least CV as described earlier, had shown a decreasing trend in Mann-Kendall test. On the other hand, the starting and ending months of monsoon (i.e. June and September) showed significant increasing trend. Although magnitude of trend as per Sen's slope estimates might have low confidence level due to lot of ties in data, but increasing trend was significant which indicated a discernible change in monsoon rainfall trend at Hisar.

Rainy days

Seasonal rainy days showed unequal distribution in year. The normal annual rainy days were found to be 27.9 ± 6.7 with CV of 24%, out of which only monsoon season had 69% of total rainy days (i.e. 19.2 rainy days). Thus, the normal intensity of rainfall in monsoon season was $19.2 \text{ mm per rainy day}$ which is quite low. The remaining three seasons had fewer rainy days as post-monsoon had least i.e. 1.4 ± 1.8 days, winter had 2.8 ± 1.6 and pre-monsoon season had just 4.5 ± 3 rainy days. Coefficient of variation for rainy days was lowest for monsoon (30.9%) and highest for post-monsoon season (124%) that again hint on erratic nature of rainfall at Hisar.

Annual rainy days showed a non-significant increasing trend ($Z = 0.7$). The number of rainy days during all seasons showed an increasing trend (+ve Z value), except for monsoon season, which showed a decreasing trend. The Z value of none of the season was found significant and Sen's slope estimator didn't show any rate of change which may be due to more ties in values.

Conclusion

Haryana is mainly an agrarian state where 83% geographical area is under agriculture as per Statistical Abstract of Haryana, 2014. The western agroclimatic zone has semi-arid climatic conditions and no perennial river flowing in the region. Intensive cropping pattern of agriculture prevails in the state and in-depth analysis of rainfall viz., monthly, seasonal etc. is quite important as it affects various phases of crop development. The rainfall data of 45 years (1970-2014) showed an increasing trend of rainfall @ 2.3 mm year⁻¹. Decreasing trend was observed in January, July, August and November months whereas February, April, May, June, September and October showed an increasing trend. Mann-Kendall test (Z value) showed that June and September had statistically significant increasing trends of rainfall @ 0.7 and 1.1 mm year⁻¹ respectively. Seasonal statistics showed significant increasing trend for pre-monsoon period (@ 1.0 mm year⁻¹).

IPCC had predicted that monsoon span would show fluctuation at starting and ending times wherein monsoon onset dates are likely to become earlier or not to change much. Monsoon retreat dates are likely to be delayed also resulting in lengthening of the monsoon season in many regions (IPCC, 2014). Similar results were also revealed in the present study where starting and ending months of monsoon i.e. June and September showed increasing rainfall trends @ 0.7 and 1.1 mm year⁻¹ respectively and middle months i.e. July and August had shown decreasing rainfall trends @ 0.4 and 0.9 mm year⁻¹, respectively.

References

- Goswami, B.N., Venugopal, V., Sengupta, D., Madhusoodanan, M.S. and Xavier, P.K. 2006. Increasing trend of extreme rain Events over India in a warming environment. *Science* 314(5804): 1442-1445.
- IPCC 2014. *Climate Change: Impacts, Adaptation, and Vulnerability*. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Summary for policymakers. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Kumar, V., Jain, S.K. and Singh, Y. 2010. Analysis of long-term rainfall trends in India. *Hydrological Sciences Journal* 55(4): 484-496.
- Mandal, S., Choudhury, B.U., Mondal, M. and Bej, S. 2013. Trend analysis of weather variables in Sagar Island West Bengal India a long-term perspective (1982-2010). *Current Science* 105(7): 947-953.
- MK Link. www.ilmantaatu.fi/ilmansaasteet/julkaisu/pdf/MAKESENS_1_0.xls.
- Pachauri, R.K. and Meyer, L. 2014. Climate change 2014 (Synthesis report) Summary for policymakers, IPCC. Online article accessed on 5 Feb. 2015. http://www.climate-service-center.de/imperia/md/video/csc/syr_ar5_spmcorr1.pdf.
- Rahman, A. and Begum, M. 2013. Application of non-parametric test for trend detection of rainfall in the largest island of Bangladesh. *ARNP Journal of Earth sciences* 2(2): 40-44.
- Rathore, L.S., Attri, S.D. and Jaswal, A.K. 2013. *State Level Climate Change Trends in India*. Indian Meteorological Department (Govt. of India), New Delhi, India.
- Salmi, T., Määttä, A., Anttila, P., Ruoho, T. and Amnell, T. 2002. Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen's slope estimates - The Excel template application MAKESENS. Finnish Meteorological Institute, Helsinki, Finland.
- Sen, P.K. 1968. Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association* 63(324): 1379-1389.
- Singh, D., Singh, M., Singh, R., Singh, S. and Rao, V.U.M. 2014. Climatic variability and its periodicity at Hisar (Haryana). *Technical Bulletin No. 19*, Department of Agricultural Meteorology, CCS Haryana Agricultural University, Hisar, Haryana, India.
- Singh, D., Singh, R., Anurag, Shekar, C., Rao, V.U.M. and Singh, S. 2010. Agroclimatic atlas of Haryana. *Technical Bulletin No. 15*, Department of Agricultural Meteorology, CCS Haryana Agricultural University, Hisar, Haryana, India.
- Statistical Abstract of Haryana 2014. Publication No. 1065, Department of economic and statistical analysis, Govt. of Haryana, India.

