MAUSAM, **73**, 2 (April 2022), 295-306

MAUSAM

DOI : https://doi.org/10.54302/mausam.v73i2.303
Homepage: https://mausamjournal.imd.gov.in/index.php/MAUSAM

UDC No. 551.577 (540.51)

Trend analyses in gridded rainfall data over the Sabarmati basin

PRAGALBH KRISHN, GULSHAN KUMAR and GANESH D. KALE*

Department of Civil Engineering, Sardar Vallabhbhai National Institute of Technology, Surat – 395 007, Gujarat, India

(*Received 13 April 2021, Modified 14 September 2021*)

***e mail : gdk@ced.svnit.ac.in**

सार – भारत में साबरमती बेसिन में 1960 के दशक से कम वर्षा हो रही है। मॉनसून के मौसम में, साबरमती बेसिन में वर्षा के दिनों की संख्या में सबसे अधिक कमी देखी गई। अतः साबरमती बेसिन में वर्षा का अध्ययन आवश्यक है। अतः वार्षिक, मौसमी और मासिक कालिक मापक्रम के अनुरूप साबरमती बेसिन के ग्रिडेड वर्षा डेटा का उपयोग मान-केंडल (एमके) परीक्षण, ब्लॉक-बूट स्टैपिंग के साथ एमके परीक्षण, सेन का स्लोप टेस्ट, इनोवेटिव ट्रेंड एनालिसिस प्लांट और स्मूथिंग कर्व के माध्यम से 54 वर्षों (1951 से 2004) की अवधि के लिए प्रवृत्ति विश्लेषण के लिए किया जाता है। परिणामों से पता चला कि वार्षिक, शीत, मॉनसून पूर्व और मॉनसून वर्षा के आँकड़ों के बहुत कम ग्रिड बिंदुओं पर सांख्यिकीय रूप से महत्वपूर्ण प्रवृत्ति मौजूद हैं और ये महत्वपूर्ण प्रवृत्ति घटते रूझान हैं। इस प्रकार, यदि भविष्य में भी यही प्रवृत्ति जारी रहती है, तो पानी की कमी होगी और दिए गए ग्रिड पर संबंधित कालिक मापक्रम में जल संसाधनों के प्रबंधन पर अधिक प्रभाव पड़ेगा।

ABSTRACT. Sabarmati basin (SB) in India has been experiencing decreased rainfall since 1960s. In the monsoon season, maximum reduction in number of rainy days was observed in the SB. Thus, study of rainfall in the SB is necessary. Therefore, gridded rainfall data of the SB corresponding to annual, seasonal and monthly temporal scales is used for trend analyses for the period of 54 years' (1951 to 2004) through application of Mann-Kendall (MK) test, MK test with block-boot strapping, Sen's slope test, smoothing curve and plot of innovative trend analysis. The results showed that, statistically significant trends (SSTs) are present at very few grid points of annual, winter, pre-monsoon and monsoon rainfall data and these SSTs are decreasing trends. Thus, if the same trend persists in future, then there will be scarcity of water and more strain on the management of water resources at the given grids in corresponding temporal scales.

Key words – Gridded data, Rainfall, Sabarmati basin, Trend analysis.

1. Introduction

Climate change (CC) is a worldwide apprehension (Panthi *et al*., 2015). Mahato (2014) given that, CC is any notable change occurred in the expected pattern of average weather of a region or entire Earth over long-term. These alterations in climate may took place over tens, thousand or even in millions of years. But, in current year's high emissions of greenhouse gases (GHGs) because of anthropogenic activities such as urbanization, industrialization, change in land use pattern, agriculture, deforestation etc., accelerated the pace of CC.

If the present scenario continues, then by 2030, the GHGs emissions might rise by 25-90% as compared to that of 2000 and subsequently the Earth would be warmer by 3 °C in this century. Intergovernmental Panel on CC (IPCC) anticipated that, even a rise of 1-2.5 °C can cause serious consequences including decreased yields from agriculture in tropical regions, leading to greater risk of hunger (United Nations Framework Convention on Climate Change, 2007).

Basin scale knowledge of CC is of most relevance for the use, planning and development of water (Singh *et al*., 2008). Precipitation is one amongst the most crucial variates for assessing the CC (Wang *et al*., 2011). Rainfall is one amongst the main climatic variates that influence the patterns of availability of water in both space and time. One amongst the challenges caused by climate variability/CC is determination, recognition and evaluation of rainfall trends and their ramifications on river flows to help in planning adaptation measures through suitable water resources management strategies (Taxak *et al*., 2014). Thus, trend analysis studies on precipitation data at the basin scale are essential.

Therefore, literature review of trend analysis studies on precipitation data of river basins (RBs) outside the India and across the world is carried out (Fu *et al*., 2004; Ampitiyawatta & Guo, 2009; Gemmer & Fischer, 2011; Reza *et al*., 2011; Wang *et al*., 2011; Zhang *et al*., 2012; Ramadan *et al*., 2013; Shi *et al*., 2013; Zain, 2014; Ahmad *et al*., 2015; Panthi *et al*., 2015; Tabari *et al*., 2015; Wu *et al*., 2016; Langat *et al*., 2017; Fentaw *et al*., 2017; Gao *et al*., 2019). In India also many trend analysis studies have been carried out on precipitation/rainfall of many RBs and these are discussed briefly in the following paragraphs.

Annual precipitation time series (TS) of each of the sixteen meteorological subdivisions comprising three RBs (*viz*., Meghna, Ganges and Brahmaputra) were analyzed by Mirza *et al*. (1998) for trends. For this, they applied Student's *t*-test, Mann-Kendall (MK) rank statistic and regression analysis. Also for persistence assessment they used first order auto-correlation analysis. Results shown that, precipitation over the Ganges basin was in general stable. In the Brahmaputra basin, precipitation in one sub-basin showed a negative trend and another showed a rising trend. At one amongst the three sub-divisions in the Meghna basin, a negative trend was found while another showed positive (increasing) trend. In the precipitation series of the Ganges basin, Markovian persistence was absent but it was found to be present in two common sub-divisions of Meghna and Brahmaputra basins.

Singh *et al*. (2008) have studied the trends in mean annual rainfall, heaviest rain, rainy days and relative humidity over the 43 stations across the 9 RBs namely Ganga, Lower Indus, Brahamani and Subarnarekha, Mahanadi, Mahi, Tapi, Sabarmati, Narmada and Luni and others for a period of 90 to 100 years. MK test was employed to detect and identify the trends. Majority of the basins showed a rising trend in annual mean rainfall, heaviest rain and relative humidity while a declining trend was observed in annual rainy days.

Chakraborty *et al*. (2013) have performed analysis of trend and variability in the rainfall data over the Seonath RB in the Chhattisgarh, India for the period of 1960 to 2008. Three important tests, *viz*., MK test, Modified MK test (MMK) and Spearman’s Rho (SR) test were employed to evaluate the trend. The Sen’s slope (SS) test was employed to assess trend magnitude. Also change points were assessed by applying CUSUM and cumulative deviations tests. For variability analysis, coefficient of variation was used. A negative trend was detected in yearly and seasonal precipitation series for the entire RB. The process was carried out in two phases, before (1960-1980) and after (1981-2008), due to change point at 1980. The change point analysis shown a rise in rainfall before the change year, whereas decrease in rainfall after the change point.

Taxak *et al*. (2014) have carried out analysis of temporal and spatial precipitation trends over long term and analysis of homogeneity for the Wainganga basin, which is Godavari River’s sub-basin. Annual series were prepared for every grid and annual scale analysis of trends was executed. The monthly precipitation data was partitioned into 4 seasons: cold winter, pre-monsoon (PREMON), monsoon and post-monsoon (POSTMON) for seasonal analysis. Autocorrelation significance was found by employing student's *t*-test at lag-1 in seasonal and annual precipitation data sets. MMK/MK test was employed on the autocorrelated/non-autocorrelated data sets to assess presence of the trend in seasonal and annual precipitation. Trend magnitude was estimated by employing Theil and SS test. For the annual and monsoon rainfall, positive trend was found over the basin corresponding to the duration of 1901 to 1948, which was then inverted for the period 1949 to 2012. An overall decrementing trend was found in annual rainfall series and monsoon rainfall series over the basin. There was an overall reduction (8.45%) in annual precipitation of the basin over the duration of 1901 to 2012.

Gajbhiye *et al*. (2016) have analyzed rainfall trend and variability over the basin of Sindh River located in Madhya Pradesh, India. The daily rainfall data were collected from ‘www.indiawaterportal.org/met_data/’ to inspect the temporal and spatial variability in the series of precipitation. SS estimator was used for determining the trend magnitude, whereas the statistical significance was analyzed by using MK test. Primary statistical characteristics of the seasonal (June to September) and annual rainfall events occurred over the time span of one hundred and two years (1901-2002) were analyzed and significant rising trend in both seasonal and annual rainfall were detected.

In order to understand rainfall alterations, Bera (2017) had applied MK test and SS estimator on 100 years rainfall data (1901-2000) of 236 districts in the entire Ganga basin. The analysis was executed for annual and seasonal temporal scales. Half of the districts exhibited a negative trend in annual rainfall, in which trends were statistically significant at 39 districts. Over the PREMON season, 78% of the total districts have shown decreasing trends in which statistically significant trends (SSTs) were found at 54 districts. Most of the districts under the Kosi, Sone and Gandak sub-basins have shown significant declining trends in annual, PREMON and POSTMON seasons. Author suggested the need of formulating some sub-basin and districts scale strategies to cope up with the conditions in the perspective of the CC.

Pandey and Khare (2017) have assessed the trends in reference evapotranspiration and precipitation over the Narmada RB (NRB), which is one of the most holy and crucial rivers of the Central India. Monthly precipitation and reference evapotranspiration data corresponding to the period of 1901-2002 were analyzed in the study. Various tests were carried out over the data obtained from twelve precipitation stations and twenty-eight reference evapotranspiration stations of the NRB. Trend analysis in annual precipitation series was executed by employing MK test and SR test at 5% and 10% significance levels respectively. The results of the study have clearly shown less change in average precipitation values at higher elevated region, *i.e*., Upper Narmada whereas significant alterations were observed in the regions, which were situated in lower portion of the Narmada. The lower part of the basin had shown positive trends with correspondent magnitudes varying between 0.060-0.033 mm/year for the annual precipitation while upper portion exhibited negative trend in annual precipitation with corresponding magnitudes varying between 0.10-0.025 mm/year.

Sharma *et al*. (2017) have assessed trends in rainfall of the upper Tapi basin originating from the Betul District, Madhya Pradesh, India. Data of twenty-four rain gauge stations was acquired from the Central Water Commission (CWC), Surat and India Meteorological Department (IMD), Pune to perform trend analysis. A total five temperature indicators and twelve rainfall indicators were used in the trend study. They have used MK or MMK test on non-serially correlated or serially correlated TS to detect the trends along with the SS estimator test and then represented percentage difference in trends of the extreme climatic indicators and the spatial variability of trends over the Upper Tapi basin in extreme conditions of climate over the basin. The results shown that, 17 out of 24 stations exhibited a retarding trend in total yearly rainfall of 70 years' duration.

Sridhar and Raviraj (2017) have evaluated seasonal and annual rainfall trends and corresponding magnitudes for the Amaravati Basin in the Tamil Nadu, India for the period of 1982-2014 by using data of 10 rain gauge stations of the basin. The MK test was employed for detecting trends that were not necessarily linear but monotonic. SS estimator was utilized for estimating the trend magnitude for the given TS. The MK test does not need to fulfil the supposition of normality of data and gives only direction and not the magnitude of the SSTs. The increasing trend was observed to be dominant in the rainfall occurring over the north-east monsoon season as compared to the other seasons.

Phalguna and Mirajkar (2018) have used IMD gridded rainfall data (GRD) of the Wainganga RB corresponding to the period 1913-2013 (101 Years) and having 0.25° × 0.25° spatial resolution data spread over the Maharashtra and the Madhya Pradesh. In the trend analysis of rainfall over the Wainganga RB, daily data was converted to annual, annual maximum, monthly and monthly maximum rainfall values. The Von-Neumen test, Standard normal homogeneity test, Pettitt's test and Buishand's test were employed for assessment of homogeneity of data. MK test, SS estimator and Sen's innovative trend analysis (Sen's ITA) were used in the trend analyses. The analysis had shown declining trend in annual rainfall and monthly rainfall over the basin. Study revealed that, intensity of rainfall over the shorter periods was increased in the basin, which might lead to increasing flood events in the future.

Bisht *et al*. (2018) have performed trend detection study on the eighty-five RBs of the India with the help of the two tests, *viz*., MK test and Theil-Sen's test corresponding to the time interval of 1901-2015, which was divided into two time periods; post-urbanization era (1971-2015) and pre-urbanization era (1901-1970). Overall trends were compared with the intra-basin trends, which indicated the mixed trends pattern due to implicit rainfall spatial heterogeneity, therefore, shown importance of scale for such type of studies.

Tirkey *et al*. (2020) have analysed variability of precipitation over the Satluj basin, Himachal Pradesh, India corresponding to the period 1901-2013. They have used MMK/MK test, SS estimator and coefficient of variation for the aforesaid analysis. For preparation of spatial maps of precipitation, inverse distance weighted technique was used in the study. Analysis was performed corresponding to annual, monthly and seasonal temporal scales. They have noticed both negative and positive trends in seasonal and monthly TS. The annual season for both MMK and MK indicated an increasing significant trend except for two Satluj Watershed. They also found that, POSTMON precipitation was having greater inter-annual variability as compared to the annual precipitation.

Basins located in the Central India including the Sabarmati basin (SB) have been experiencing decreased rainfall since 1960s (Singh *et al*., 2005). In the monsoon season, maximum decline in total rainy days was found in the SB (Jain and Kumar, 2012). Therefore, study of rainfall in the SB is necessary. Thus, in the current study, SB is contemplated as study area. None of the reviewed studies have executed trend analyses of GRD covering the entire basin. Thus, in the present study, trend analyses of GRD of the SB is executed for monthly, seasonal and annual temporal scales corresponding to the period of 1951-2004.

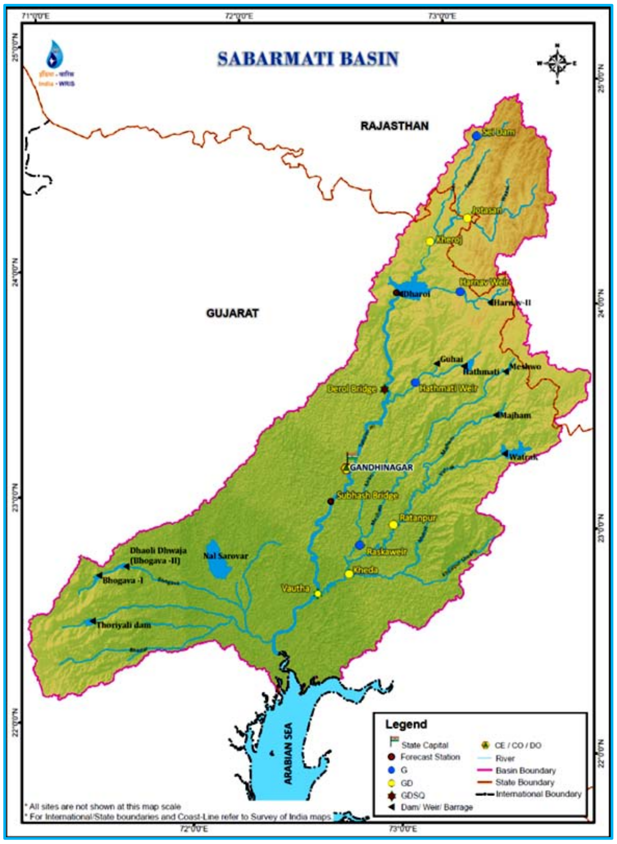

Fig. 1. Map of the SB (Source: http://www.india-wris.nrsc.gov.in)

Following research gaps were inferred from the reviewed literature : (*i*) none of the reviewed studies have executed trend analyses of GRD covering the entire SB and (*ii*) most of the reviewed studies have not employed ITA technique and smoothing curve (SMC) plot to support the trend analyses results. Thus, in the present work, trend analyses is carried out on the GRD of the SB for the period of 1951 to 2004 by using autocorrelation plot (correlogram), MK test, MK with block boot-strapping (MK-BBS) test, SS test, ITA plot and SMC.

2. Study area and data

2.1. D*escription about* s*tudy area*

River Sabarmati is one amongst the main west flowing rivers in the SB, which joins the Arabian Sea in the Gulf of Cambay. At an altitude of 762 m above mean sea level, Sabarmati River starts from the Aravali hills at the latitude of 20° 40' North and longitude of 73° 20' East in the Rajasthan, India. Map of SB is presented in Fig. 1. The river flows through the Rajasthan for a very short distance of only 48 km and major part flows through the Gujarat having 323 km length and then falls into the Gulf of Cambay.

TABLE 1

Longitudes and latitudes of the 11 grids over the SB

Grid Number	Latitude	Longitude
Grid no. 1	21.5	71.5
Grid no. 2	21.5	72.5
Grid no. 3	22.5	71.5
Grid no. 4	22.5	72.5
Grid no. 5	22.5	73.5
Grid no. 6	23.5	71.5
Grid no. 7	23.5	72.5
Grid no. 8	23.5	73.5
Grid no. 9	24.5	72.5
Grid no. 10	24.5	73.5
Grid no. 11	25.5	73.5

Out of 21,674 km^2 catchment area of basin, only 4124 km^2 lies in the Rajasthan and remaining 18,550 km^2 lies in the Gujarat. The principal tributaries of the Sabarmati river with corresponding drainage area are: Wakal (1,893 km^2), Sei (331.66 km^2), Harnav (865 km^2), Watrak (1,114 km^2) and Hathmati (1,574 km^2) (Ray *et al*., 2012).

CWC has divided the SB into two zones namely Upper basin and Lower basin and these are further divided for convenience into four sub basins (A, B, C and D). The sub-basin A falls in the Rajasthan while sub-basins B and C fall in the Gujarat and all three A, B and C are lying in Upper Basin, whereas sub-basin D falls in the Gujarat and covers the whole Lower Basin and some part of the Upper Basin. The average rainfall of basin is 787.5 mm, which is received during southwest monsoon season. This season starts by middle of the June and ends by the last week of the September. Sub-basin D gets the highest average rainfall of 809.3 mm, followed by 781.9 mm in sub-basin C and 747.7 mm in sub-basin B. Sub-basin A receives lowest average rainfall of 579.5 mm from the southwest monsoon (Ray *et al*., 2012).

The latitudes and longitudes of the different grid points over the SB are shown in Table 1.

The eleven grids lying over the SB and considered in the study are shown in Fig. 2.

2.2. *Data*

In the current study, GRD of 104 years is obtained from the IMD, Pune, but analysis period considered in the present study is from 1951 to 2004 (54 years). Warming of the climate system is certain, several of the observed changes are exceptional over the scales of decenniums to millennia since 1950s (IPCC, 2013). Thus, analysis period considered in the present study is starting from 1951. Burn and Elnur (2002) suggested a minimal 25 years record length to assure statistical validness of the trend results. In this study, period of analysis is 54 years, which guarantees statistical validness of the trend results. The data was existing in the form of daily rainfall data having resolution of 1° × 1° Lat./Long. The gridded data for the SB is extracted in the form of daily rainfall and then from daily rainfall data, TS of monthly, annual and seasonal rainfall are prepared for each grid point over the basin corresponding to analysis period. The seasons considered in the analysis are: winter (from January-February), pre-monsoon (from March-May), monsoon (from June-September) and post-monsoon (from October-December) as adopted in Verma and Kale (2018).

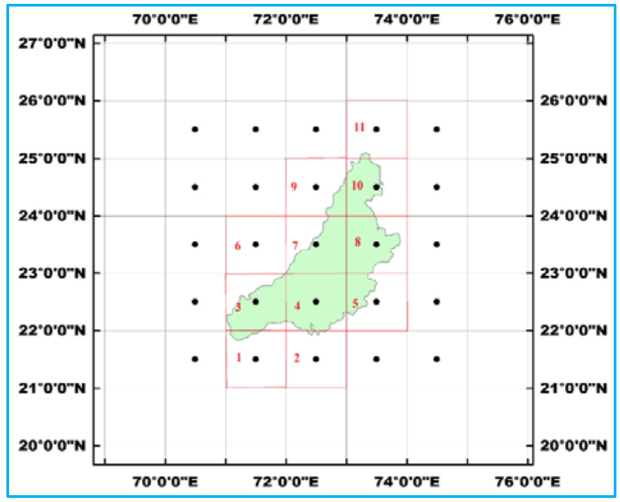

Fig. 2. Gridded map of the SB

2.3. *Methodology*

Following statistical tests/graphical techniques are used in this study for the analysis of trend.

(*i*) *MK test* - For the estimation of statistical significance of trend for serially uncorrelated data (Verma and Kale, 2018).

(*ii*) *SS test* - For evaluating the magnitude of the trend (Sonali and Nagesh Kumar, 2013).

(*iii*) *MKBBS test* - For the evaluation of statistical significance of trend for serially correlated data (Sonali and Nagesh Kumar, 2013).

(*iv*) *ITA plot* - For the evaluation of trend's nature, *viz.*, monotonous (M) or non-monotonous (NM) (Sonali and Nagesh Kumar, 2013).

2.3.1. *MK Test*

It is rank-based and non-parametric in nature. The test statistic (TSTAT) S is evaluated as follows:

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i=1} \operatorname{sign}\left(x_i - x_j\right) \tag{1}$$

where, n is the defined as data series length, x_i and x_j are the successional data in the series and

$$\operatorname{sign}\left(x_i - x_j\right) = \begin{cases} -1 \text{ for } \left(x_i - x_j\right) < 0 \\ 0 \text{ for } \left(x_i - x_j\right) = 0 \\ 1 \text{ for } \left(x_i - x_j\right) > 0 \end{cases} \tag{2}$$

$$E\,(S) = 0 \tag{3}$$

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{p-1}^{q} t_p\left(t_p - 1\right)\left(2t_p + 5\right)}{18} \tag{4}$$

where, t_p is defined as the tally of ties for p_{th} value and q is defined as tally of tied values. Effect of tied censored data is accounted by the 2nd term in the formula of variance.

The standardized TSTAT Z is estimated as follows:

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

To assess consistently incrementing or declining trend corresponding to significance level 'α', the null hypothesis of trend absence is discarded, if $Z_{1-\frac{\alpha}{2}}$ acquired from the tables of standard normal cumulative distribution is smaller than the absolute value of Z (Sonali and Nagesh Kumar, 2013).

2.3.2. *SS Test*

By employing the method of Sen (1968), the slope magnitude can be assessed by using equation 6 as follows:

$$b_{sen} = median\left[\frac{X_i - X_j}{(i-j)}\right] \text{ for all } i > j \tag{6}$$

where, i and j are time points and X_i and X_j are the respective data at these time points.

If n is the tally of data points in series, then $\frac{n(n-1)}{2}$ will be the slope estimates and median of these slope estimates is the b_{sen}, *i.e.*, TSTAT. Increasing trend is denoted by positive sign of b_{sen} and declining trend is denoted by negative sign of b_{sen} (Sonali and Nagesh Kumar, 2013).

2.3.3. *MKBBS Test*

Kundzewicz and Robson (2000) have proposed a block resampling technique to conserve the impact of lag correlation in a TS whilst resampling it. For a large number of times, original data is resampled by utilizing predefined block length. For assessing significance of the observed TSTAT, this approach is helpful, which is very important for the study on trend detection (Sonali and Nagesh Kumar, 2013).

The following steps are followed in the BBS technique as given in Sonali and Nagesh Kumar (2013):

(*i*) Calculate the TSTAT of the chosen test to detect the trend.

(*ii*) For the considered series, evaluate the serial correlation, which is least significant with respect to lag k. k+1 will be considered as the optimized block length.

(*iii*) For conserving the serial correlation, the original series is resampled in blocks. Resampling should be performed at least for 2000 times.

(*iv*) Estimating the TSTAT derived in step one for every resampled series. After that, development of a distribution is performed by utilizing all TSTATs obtained from the resampled series.

(*v*) The TSTAT is termed as significant, if the original TSTAT falls in the range of upper and lower bounds of the simulated distribution. Block size of unequal length is not a problem.

2.3.4. *ITA Plot*

Basis of this approach is the conception that, for two identical TS, their plot on the Cartesian coordinates against one another shows a 1:1 line (straight line of 45°) despite of not holding good for all the postulations with regard to distribution, length of sample and serial correlation. No trend exists in the TS, if all the data points are lying on 1:1 line. In this technique, decreasing or increasing monotonic trends are indicated by the position of scatter points below or above the 1:1 line. If the scatter points become visible on either sides of 1:1 line, then it denotes the existence of increasing and decreasing trend of non-monotonic nature concealed at various time scales in given TS (Sonali and Nagesh Kumar, 2013).

TABLE 2

Trend analyses results for annual GRD over the SB corresponding to the period of 1951-2004

Grid No.	SS Test (mm/year)	Trend Significant?		Nature of trend
		MK Test	MK-BBS Test	
1	-1.04		No	NM
2	0.94	No		NM
3	-1.13	No		NM
4	1.85	No		NM
5	-1.45		No	NM
6	-0.61	No		NM
7	-0.75		No	NM
8	-0.07		No	NM
9	-2.01		No	NM
10	**-3.67**	**Yes**		**NM**
11	-0.18		No	NM

Note : NM denotes non-monotonous trend

3. Results and discussion

In the current study, correlogram is used for assessing the dependence of the data. Significance of the trend is determined by employing MK test (for independent data) and MKBBS test (for dependent data). Resampling is performed without replacement for 5000 times. Trend magnitude is evaluated by SS test and nature of the trend is evaluated by ITA plot. SMC can help in interpretation by highlighting the general association amongst the variables (Kundzewicz and Robson, 2000). Therefore, SMC is employed to assess the pattern of data. In the current study, gridded data of annual rainfall, seasonal rainfall, *viz*., winter, PREMON, monsoon and POSTMON and monthly rainfall corresponding to the period of 1951 to 2004 are used for the trend analyses. Results of the trend analyses of the aforesaid data are given in the following sections. Result tables are shown only for that temporal scale in which significant trend is detected at least at one grid point. The grid at which significant trend is detected; its trend analyses results in results table are shown in bold. Correlogram, ITA plot and SMC (window 15) are presented only for one grid at

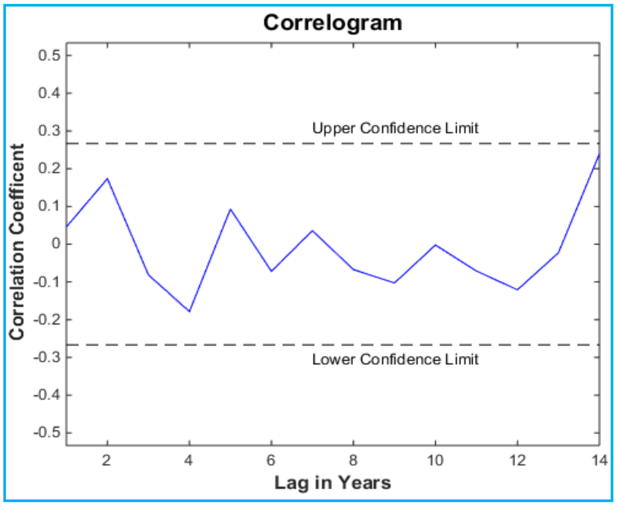

Fig. 3. Correlogram for annual RTS at grid 10 over the SB (1951-2004)

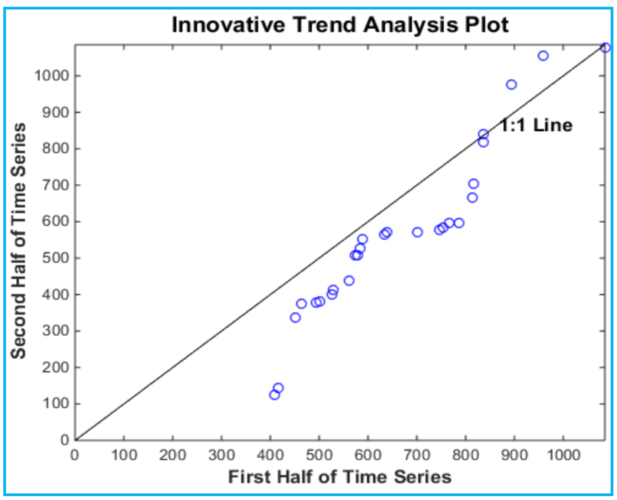

Fig. 4. ITA plot for annual RTS at grid 10 over the SB (1951-2004)

which significant trend is detected corresponding to annual, PREMON and monsoon temporal scales because of the word limit.

3.1. *Trend analyses results for the annual GRD over the SB (1951-2004)*

Trend analyses results for the annual GRD over the SB are shown in Table 2. For the annual GRD over the SB, it is observed that, SST is present only at grid 10 while SSTs are not detected at grids 1 to 9 and 11. SST detected in rainfall TS (RTS) of annual temporal scale at grid 10 has magnitude of -3.67 mm/year as evaluated by SS test whilst nature of the trend is NM (Fig. 4). Correlogram plot (Fig. 3) of the given TS indicates independent data and therefore, MK test is employed on the given RTS.

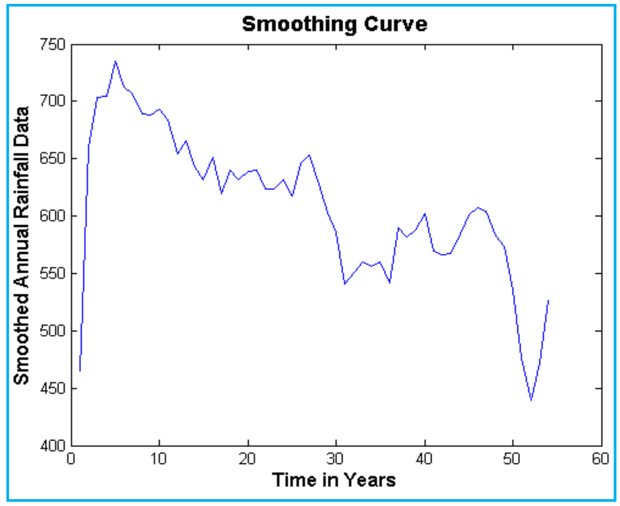

Fig. 5. SMC for annual RTS at grid 10 over the SB (1951-2004)

TABLE 3

Trend analyses results for winter GRD over the SB corresponding to the period of 1951-2004

Grid No.	SS Test (mm/year)	Trend Significant?		Nature of trend
		MK Test	MK-BBS Test	
1	0.00		No	M
2	0.00		No	NM
3	**0.00**	**Yes**		**NM**
4	0.00	No		NM
5	0.00	No		M
6	0.00	No		NM
7	0.00		No	NM
8	0.00	No		NM
9	0.00	No		NM
10	0.00		No	NM
11	0.00		No	NM

Note : NM denotes non-monotonous trend and M denotes monotonous trend

Negative magnitude of the significant trend detected in the annual RTS at grid 10 is corroborated by the declining pattern of the data present in the respective ITA plot (Fig. 4) and SMC (Fig. 5).

3.2. *Trend analyses results for the winter GRD over the SB (1951-2004)*

Results of the trend analyses for the winter GRD over the SB are shown in Table 3. For winter GRD over the SB, it is observed that, SST is present only in winter RTS at grid 3 while SSTs are not found in winter RTS at grids 1 to 2 and 4 to 11.

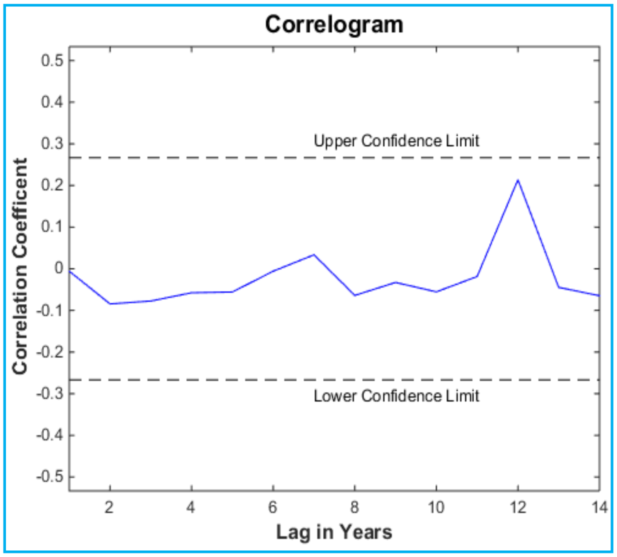

Fig. 6. Correlogram for winter RTS at grid 3 over the SB (1951-2004)

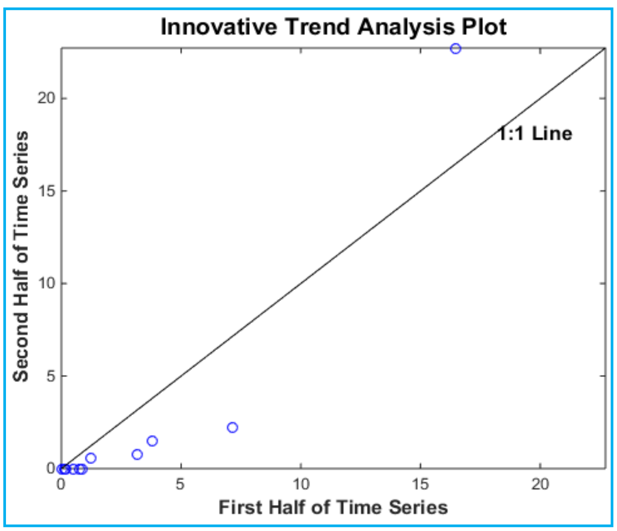

Fig. 7. ITA plot for winter RTS at grid 3 over the SB (1951-2004)

At the grid 3, the value of SS is 0.00, which is due to the equal distribution of the values of the slopes on the either side, as SS test takes the median of the all slope values. Thus, linear regression is employed to evaluate magnitude of the trend in this case. Significant trend detected in winter RTS at grid 3 has the magnitude of -0.01 mm/year, which is assessed by linear regression while NM is the nature of the trend. Correlogram plot (Fig. 6) of winter RTS at grid 3 indicates independent data and therefore, MK test is applied on the given RTS. Negative magnitude of the significant trend detected in winter RTS at grid 3 is corroborated by the declining pattern of the data present in the respective ITA plot (Fig. 7) and SMC (Fig. 8).

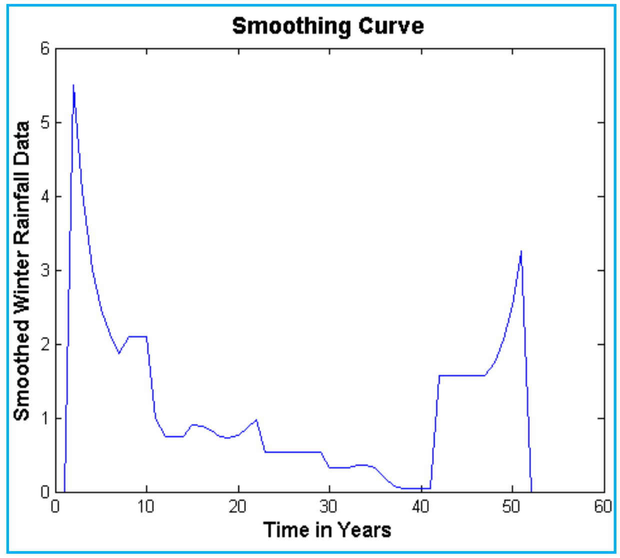

Fig. 8. SMC for winter RTS at grid 3 over the SB (1951-2004)

TABLE 4

Trend analyses results for the PREMON GRD over the SB corresponding to the period of 1951-2004

Grid No.	SS Test (mm/year)	Trend Significant?		Nature of trend
		MK Test	MK-BBS Test	
1	**-0.02**	**Yes**		**M**
2	0.00	No		NM
3	**0.00**	**Yes**		**NM**
4	0.00	No		NM
5	0.00	No		NM
6	0.00	No		NM
7	0.00		No	NM
8	0.00	No		NM
9	0.00		No	NM
10	-0.04	No		NM
11	0.11	No		NM

Note : NM denotes non-monotonous trend and M denotes monotonous trend

3.3. *Trend analyses results for the PREMON GRD over the SB (1951-2004)*

Results of the trend analyses for the PREMON GRD over the SB are shown in Table 4. From Table 4, it is observed that, SSTs are present in PREMON RTS at grids 1 and 3, while significant trends are not found in PREMON RTS at grids 2 and 4 to 11. Magnitude of the significant trend detected at grid 1 is -0.02 mm/year as evaluated by SS test whilst nature of the corresponding trend is monotonically decreasing.

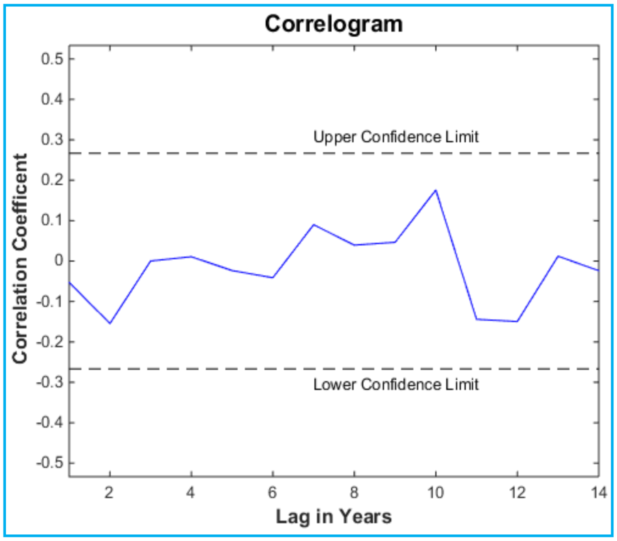

Fig. 9. Correlogram for PREMON RTS at grid 1 over the SB (1951-2004)

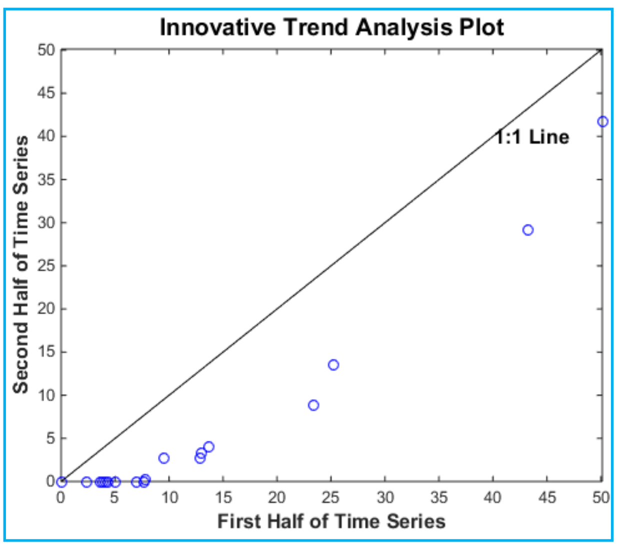

Fig. 10. ITA plot for PREMON RTS at grid 1 over the SB (1951-2004)

At the grid 3, the value of SS estimator is 0.00, which is due to the equal distribution of the values of the slopes on the either side, as SS test takes the median of the all slope values. Thus, linear regression is employed to evaluate the trend magnitude. Magnitude of the significant trend detected in PREMON rainfall at grid 3 is -0.02 mm/year as assessed by the linear regression while nature of the trend is NM.

Correlogram, ITA plot and SMC for the PREMON RTS at grid 1 are shown in Figs. 9-11 respectively. Correlogram shown in Fig. 9, indicates independent data and therefore, MK test is employed for the given RTS.

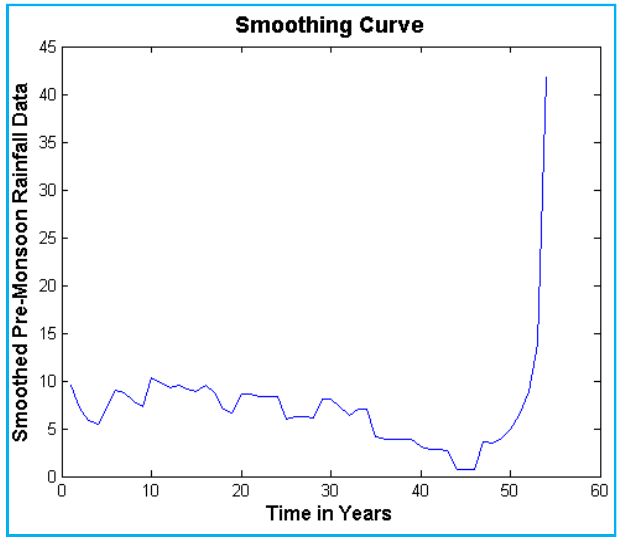

Fig. 11. SMC for PREMON RTS at grid 1 over the SB (1951-2004)

TABLE 5

Results of the trend analyses for the monsoon GRD over the SB for the period 1951-2004

Grid No.	SS Test (mm/year)	Trend Significant?		Nature of trend
		MK Test	MK-BBS Test	
1	-1.14	No		NM
2	0.73	No		NM
3	-1.42	No		NM
4	1.43	No		NM
5	-1.93		No	NM
6	-0.92	No		NM
7	-2.28		No	NM
8	-0.01		No	NM
9	-2.41		No	M
10	**-3.62**	**Yes**		**NM**
11	-0.71		No	NM

Note : NM denotes non-monotonous trend and M denotes monotonous trend

Negative magnitude of the significant trend detected in the PREMON RTS at grid 1 is corroborated by the declining data pattern present in respective ITA plot (Fig. 10) and SMC (Fig. 11).

3.4. *Trend analyses results for the monsoon GRD over the SB (1951-2004)*

Results of the trend analyses for monsoon GRD are shown in Table 5. From Table 5, it is observed that,

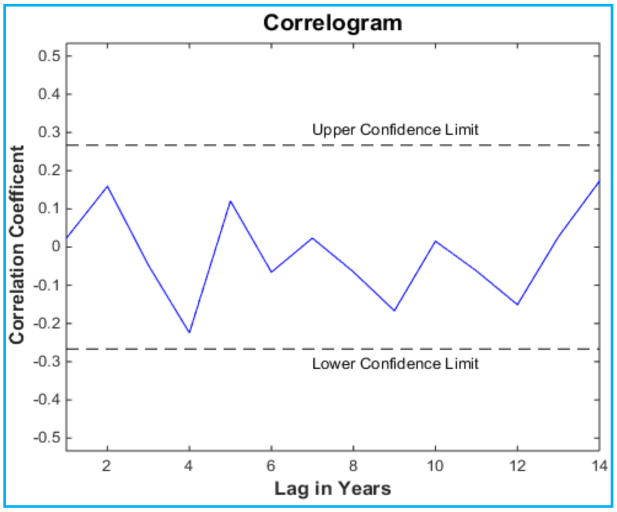

Fig. 12. Correlogram for monsoon RTS at grid 10 over the SB (1951-2004)

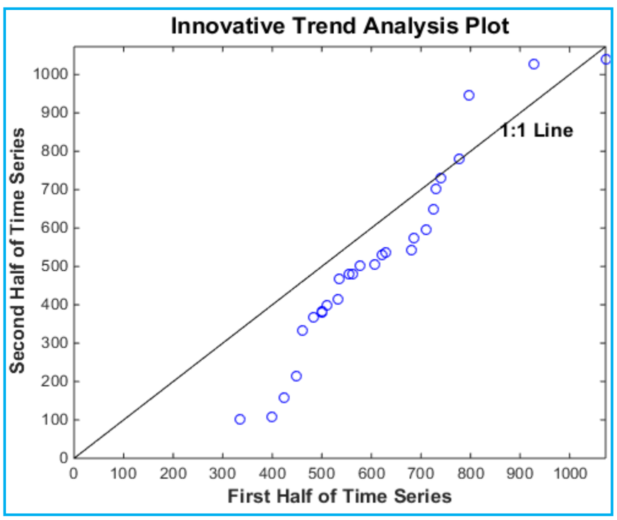

Fig. 13. ITA plot for monsoon RTS at grid 10 over the SB (1951-2004)

SST is present only in monsoon RTS at grid 10 while no significant trends are found in monsoon RTS at grids 1 to 9 and 11. Magnitude of the significant trend detected at grid 10 is -3.62 mm/year as evaluated by SS test whilst nature of the trend is NM.

Correlogram, ITA plot and SMC for monsoon RTS at grid 10 are shown in Figs. 12-14, respectively. The correlogram presented in Fig. 12 indicates independent data and therefore, on the given RTS, MK test is applied.

Negative magnitude of the significant trend detected in monsoon RTS at grid 10 is corroborated by the declining data pattern present in respective ITA plot (Fig. 13) and SMC (Fig. 14).

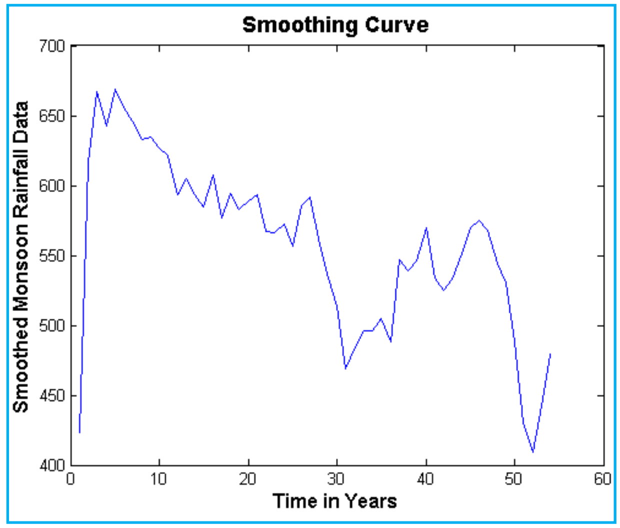

Fig. 14. SMC for monsoon RTS at grid 10 over the SB (1951-2004)

3.5. *Trend analyses results for the POSTMON GRD over the SB (1951-2004)*

SSTs are not found in POSTMON RTS at all grid points (eleven grid points) of the POSTMON GRD.

3.6. *Trend analyses results for monthly GRD over the SB (1951-2004)*

SSTs are not detected in monthly RTS at all grid points (eleven grid points) of the monthly GRD.

3.7. *Summary of results*

(*i*) Significant declining trend is found in annual RTS (1951-2004) at grid 10. The nature of trend is NM.

(*ii*) Significant declining trend is found in winter RTS (1951-2004) at grid 3. The nature of the trend is NM.

(*iii*) Significant declining trends are found in PREMON RTS (1951-2004) at grids 1 (M trend) and 3 (NM trend).

(*iv*) Significant negative trend is found in monsoon RTS (1951-2004) at grid 10. The nature of the trend is NM.

4. Conclusions

Significant negative trends are detected in: annual RTS (1951-2004) at grid 10, winter RTS (1951-2004) at grid 3, PREMON RTS (1951-2004) at grids 1 and 3 and monsoon RTS (1951-2004) at grid 10. This clearly shows decrease in the rainfall of the SB at the corresponding grids in corresponding temporal scales. If these significant negative trends are continued in future, these will add to the strain on the water resources management at the given grids in respective temporal scales.

Acknowledgements

Authors are grateful to India Meteorological Department, Pune for providing needed data required for the study.

Disclaimer: The contents and views articulated in this research article/paper are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

References

Ahmad, I., Tang, D., Wang, T., Wang, M. and Wagan, B., 2015, "Precipitation trends over time using Mann-Kendall and Spearman's Rho tests in Swat river basin, Pakistan", *Hindawi Publishing Corporation Advances in Meteorology*, 1-15.

Ampitiyawatta, A. D. and Guo, S., 2009, "Precipitation trend in the Kalu Ganga Basin in Sri Lanka", *J. Agricultural Science*, **4**, 10-18.

Bera, S., 2017, "Trend analysis of rainfall in Ganga Basin, India during 1901-2000", *American J. Climate Change*, **6**, 116-131.

Bisht, D. S., Chatterjee, C. N., Raghuwanshi, N. S. and Sridhar, V., 2018, "Spatio temporal trends of rainfall across Indian river basins", *Theoretical and Applied Climatology*, **132**, 1-2, 419-436.

Burn, D. H. and Elnur, M. A. H., 2002, "Detection of hydrologic events and variability", *J. Hydrology*., **255**, 107-122.

Chakraborty, S., Pandey, R. P., Chaube, U. C. and Mishra, S. K., 2013, "Trend and variability analysis of rainfall series at Seonath river basin, Chhattisgarh (India)", *J. Applied Sciences and Engineering Research*, **2**, 425-434.

Fentaw, F., Hailu, D. and Nigussie, A., 2017, "Trend and variability analysis of rainfall & stream flow series at Tekeze river basin, Ethiopia", *Int. J. Scientific & Engineering Research*, **8**, 665-680.

Fu, G., Chen, S., Liu, C. and Shepard, D., 2004, "Hydro-climatic trends of the Yellow river basin for the last 50 years", *Climatic Change*, **65**, 1-2, 149-178.

Gajbhiye, S., Meshram, C., Singh, S. K., Srivastava, P. K. and Islam, T., 2016, "Precipitation trend analysis of Sindh river basin, India, from 102-year record (1901-2002)", *Atmospheric Science Letters Atmos. Sci. Let.*, **17**, 71-77.

Gao, C., Gu, C., Hao, M., Ma, Q., Zhang, Q. and Hong, G., 2019, "Spatiotemporal trends and spatial distribution of precipitation in the Taihu basin during 1951-2014", *Foundation Environmental Protection & Research-FEPR, Ekoloji*, **28**, 107, 2341-2351.

Gemmer, M. and Fischer, T., 2011, "Trends in precipitation extremes in the Zhujiang river basin, South China", *American Meteorological Society*, **24**, 3, 750-761.

http://www.india-wris.nrsc.gov.in

IPCC, 2013, "Summary for policymakers. In : climate change 2013 : the physical science basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change", [Stocker, T.F., Qin, D., Plattner, G. K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P. M. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jain, S. K. and Kumar, V., 2012, "Trend analysis of rainfall and temperature data for India", *Current Science*, **102**, 1, 37-49.

Kundzewicz, Z. W. and Robson, A. (Eds.), 2000, "Detecting trend and other changes in hydrological data", WCDMP-45, WMO/TD-No. 1013, Geneva.

Langat, P. K., Kumar, L. and Koech, L., 2017, "Temporal variability and trends of rainfall and streamflow in Tana river basin, Kenya ", *Sustainability*, **9**, 1-18.

Mahato, A., 2014, "Climate change and its impact on agriculture", *Int. J. Scientific and Research Publications*, **4**, 1-6.

Mirza, M. Q., Warrick, R. A., Ericksen, N. J. and Kenny, G. J., 1998, "Trends and persistence in precipitation in the Ganges, Brahmaputra and Meghna river basins", *Hydrological Sciences J.*, **43**, 6, 845-858.

Pandey, B. K. and Khare, D., 2017, "Identification of trend in long term precipitation and reference evapotranspiration over Narmada river basin (India)", *Global and Planetary Change*, **161**, 172-182.

Panthi, J., Dahal, P., Shrestha, M. L., Aryal, S., Krakauer, N. Y., Pradhanang, S. M., Lakhankar, T., Jha, A. K., Sharma, M. and Karki, R., 2015, "Spatial and temporal variability of rainfall in the Gandaki river basin of Nepal Himalaya", *Climate*, **3**, 210-226.

Phalguna, M. and Mirajkar, A. B., 2018, "The Trend analysis of rainfall in the Wainganga river basin, India", *J. Engineering Research and Application*, **4**, 29-33.

Ramadan, H. H., Beighley, R. E. and Ramamurthy, A. S., 2013, "Temperature and precipitation trends in Lebanon's largest river: the Litani basin', *e J. Water Resources Planning and Management*, **139**, 86-95.

Ray, K., Joshi, B. N., Vasoya, I. M., Darji, N. S. and Gandhi, L. A., 2012, "QPF model for Sabarmati basin based on synoptic analogue method", *MAUSAM*, **63**, 4, 565-572.

Reza, Y. M., Javad, K. D., Mohammad, M. and Sharma, A., 2011, "Trend detection of the rainfall and air temperature data in Zayandehrud basin", *J. Applied Sciences*, **12**, 2125-2134.

Sen, P. K., 1968, "Estimates of regression coefficient based on Kendall's Tau", *J. American Statistical Association*, **63**, 324, 1379-1389.

Sharma, P. J., Loliyana, V. D. R., Reshmi, S., Timbadiya, P. V. and Patel, P. L., 2017, "Spatiotemporal trends in extreme rainfall and temperature indices over upper Tapi basin, India", *Theoretical and Applied Climatology*, **134**, 1329-1354.

Shi, W., Yu, X., Liao, W., Wang, Y. and Jia, B., 2013, "Spatial and temporal variability of daily precipitation concentration in the Lancang river basin, China", *J. Hydrology*, **495**, 197-207.

Singh, N., Sontakke, N. A., Singh, H. N. and Pandey, A. K., 2005, "Recent trend in spatiotemporal variation of rainfall over India- an investigation into basin-scale rainfall fluctuations, Regional Hydrological Impacts of Climate Change-Hydroclimatic Variability", *Proceedings of Symposium S6 Held During the Seventh IAHS Scientific Assembly at Foz do Iguacu, Brazil, IAHS Publication*, **296**, 273-282.

Singh, P., Kumar, V., Thomas, T. and Arora, M., 2008, "Changes in rainfall and relative humidity in river basins in northwest and central India", *Hydrological Processes*, **22**, 2982-2992.

Sonali, P. and Nagesh Kumar, D., 2013, “Review of trend detection methods and their application to detect temperature changes in India”, *J. Hydrology*, **476**, 212-227.

Sridhar, S. I. and Raviraj, A., 2017, “Statistical trend analysis of rainfall in Amaravathi river basin using Mann-Kendall test”, *Current World Environment*, **12**, 1, 89-96.

Tabari, H., Taye, M. T. and Willems, P., 2015, “Statistical assessment of precipitation trends in the upper Blue Nile river basin”, *Stochastic Environmental Research and Risk Assessment*, **29**, 7, 1751-1761.

Taxak, A. K., Murumkar, A. R. and Aryan, D. S., 2014, “Long term spatial and temporal rainfall trends and homogeneity analysis in Wainganga basin, Central India”, *Weather and Climate Extremes*, **4**, 50-61.

Tirkey, N., Parhi, P. K., Lohani, A. K. and Chandniha, S. K., 2020, “Analysis of precipitation variability over Satluj Basin, Himachal Pradesh, India : 1901-2013”, *Journal of Water and Climate Change*, 1-9. https://doi.org/10.2166/wcc.2020.136.

United Nations Framework Convention on Climate Change, 2007, “Climate change : impacts, vulnerabilities and adaptation in developing countries”, 1-64. http://unfccc.int/resource/docs/publications/impacts.pdf.

Verma, R. and Kale, G. D., 2018, “Trend detection analysis of gridded pet data over the Tapi basin”, *Water Conservation Science and Engineering*, **3**, 99-115.

Wang, W., Shao, Q., Peng, S., Zhang, Z., Xing, W., An, G. and Yong, B., 2011, “Spatial and temporal characteristics of changes in precipitation during 1957-2007 in the Haihe river basin, China”, *Stoch Environ Res Risk Assess*, **25**, 881-895.

Wu, Y., Wang, W. and Guoqing, G., 2016, “Detecting variation trends of temperature and precipitation for the Dadu river basin, China”, *Hindawi Publishing Corporation Advances in Meteorology*, 1-11.

Zain, A. H., 2014, “Detecting variability and trends in daily rainfall characteristics in Amman-Zarqa Basin, Jordan”, *Int. J. Applied Science and Technology*, **4**, 6, 11-23.

Zhang, Q., Singh, V. P., Peng, J., Chen, Y. D. and Li, J., 2012, “Spatial-temporal changes of precipitation structure across the Pearl river basin, China”, *J. Hydrology*, **440**, 113-122.