AGRES – *An International e. Journal (2017) Vol. 6, Issue 2:318-328* ISSN : 2277-9663

ASSESSMENT OF RAINFALL VARIABILITY OF A SARASWATI BASIN, NORTH GUJARAT, INDIA

***PARMAR, B. S. AND DEORA B. S.**

**CENTRE FOR NATURAL RESOURCES MANAGEMENT (CNRM)
SARDARKRUSHINAGAR DANTIWADA AGRICULTURAL UNIVERSITY
SARADARKRUSHINAGAR – 385 506, DIST: BANASKANTHA, GUJARAT, INDIA**

EMAIL: parmarbs26@gmail.com

ABSTRACT

The rainfall analysis was carried out as part of a process for assessment of groundwater potential of Saraswati bain, North Gujarat, India. The rainfall of 32 years of the 16 rain gauge stations under the basin were analyzed to know the spatial and temporal variability. The homogeneity, normality and presence of trend were determined through series analysis by organizing the rainfall data in different series. For homogeneity analysis, seven statistical tests were employed to seasonal rainfall, one day maximum rainfall and consecutive June, July, August and September rainfall series. The normality of the rainfall was tested by applying three tests commonly used for the hydrological series. For detection of trend, four tests were employed. It was found that the highest average annual rainfall was received at Danta (886.3 mm) station located at windward side of Aravalli range (upper most reaches), whereas the lowest was received at Raphu (441.4 mm) located near outlet of the basin (lower most reaches). The average annual rainfall of the basin was assessed 631.8 mm. In statistical analysis for homogeneity, monthly rainfall series was leading among all, indicated homogeneity in 88.5 per cent stations followed by seasonal rainfall series and one day maximum rainfall series with homogeneity in 85.7 per cent and 84.5 per cent cases stations, respectively. The statistical test wise, the Hartley test and Link Wallace test were leading with highest output, indicated homogeneity in 97.9 per cent and 93.2 per cent stations, followed by Tukey test and Cumulative deviation test in 92.2 per cent and 91.7 per cent stations, respectively. The overall results suggested the homogeneity of rainfall data. All the seven rainfall series were found to be normally distributed. The trend analysis indicated absence of trend among all the rainfall series barring a few stations in some years.

KEY WORDS: Basin, rainfall, Saraswati

INTRODUCTION

Groundwater is one of the most critical water resource which supports livelihood, economic development and ecological diversity (Zektser, 2000; Humphreys, 2009; Steube *et al.*, 2009). In arid and semi arid region, rainfall is the principle source of groundwater recharge. Therefore, assessment of groundwater primarily needs analysis of rainfall pattern. The occurrence of rainfall and its extremes are the most important climatic factors having both short term as well as long term impacts on the availability of groundwater. Hence, the rainfall analysis is the prime requirement for water resources planning and management. The rainfall in country is unevenly distributed spatially and temporally. The majority of the statistical analysis of the hydrological analysis of the time series data at the time scales usually come across in water resources planning studies are based on the prime assumptions that rainfall time series is homogenous, stationary, free from trends (Machiwal and Jha, 2008).

For semi-arid regions like North Gujarat also, the rainfall is uneven and scanty in nature. The temporal and spatial distribution of rainfall in a geo-hydrological unit has a crucial role for effective groundwater recharge. Therefore, comprehensive analysis of rainfall as hydrological data is one of the prime requirements for careful assessment of groundwater resources. The availability of restricted spatio-temporal groundwater-level data is one of the major limitations in groundwater studies. In the circumstances, due weightage is being given to the rainfall characteristics for assessment of groundwater recharge. It is very common to use only one or two tests for hydrological time series analysis, which facilitates easy decision-making. However, Machiwal and Jha (2008) recommended that sufficient number of statistical tests must be applied for detecting a particular time series characteristics and the results should be analyzed critically to arrive at a reliable decision. Hence, unlike the customary approach in time series analysis, multiple statistical tests have been applied to make realistic decisions.

Several statistical approaches are available for detecting and estimating trends that may be present in environmental variables of interest and for that purpose trends are generally analyzed both at the annual and or at the seasonal scale. As on the one hand, trends at the annual scale measure the inter-annual variability, which would have a negative or positive tendency. On the other hand, the implications of changes at the seasonal scale are particularly significant for water resource management processes. The application of these tests is demonstrated through a study on the time series analysis of one day maximum rainfall, monthly rainfall and seasonal rainfall of various rain gauge stations of Saraswati basin.

MATERIALS AND METHODS

Description of study area

Location and climate

The area under study is the Saraswati river basin, located between 72°03' and 72°53' East longitude and 23°50' and 24°22' North latitude, in North Gujarat, India. The average annual rainfall of the basin is 631.8 mm occurring during June to September varied from lowest 441.4 mm of Raphu (District: Patan) to highest 886.3 mm of Danta (District: Banaskantha). The rainfall influenced by the southwest monsoon, commences by end of June and recedes in by second fortnight of September. The minimum temperature varies from 9.5^0 C to 27^0 C, whereas the maximum temperature varies from 26^0 C to 42^0 C with mean annual temperature between 25^0 C to 28^0 C.

Collection and organization of Data

The agro-meteorological data required for the present study were collected from State Water Data Centre, Narmada Water Resources, Water Supply and Kalpasar Department, Government of Gujarat, Gandhinagar. The daily rainfall data were collected for the period of 32 years (from 1981 to 2012) for 16 rain gauge stations located across the basin. The collected data were organized in different series *viz*., one day maximum, monthly and seasonal scale for time series analysis through statistical tests.

Applications of time series analysis

The main characteristics of the hydrologic time series, *i.e.*, homogeneity, normality, and presence of trend are being detected for planning and assessment of groundwater resources. Homogeneity implies that the data in the series belong to one population and therefore, have a time-invariant mean. Non-homogeneity arises due to changes in the method of data collection and/or the environment in which it is done (Fernando and Jayawardena, 1994). Trend exists in a data set, if there is a significant correlation between the observations and time. Trends in hydrological series are normally introduced through natural or artificial changes. Time series analysis has vast scope in geology, ocean technology, seismology, and it has also been applied to many hydrological and climatological situations. For instance, time series studies have been carried out for analyzing rainfall data (Mirza *et al*., 1998; Pugacheva *et al*., 2003 and Astel *et al*., 2004). Originally, the application of time series analysis was restricted to surface water problems, in particular analysis of extremes (floods and droughts). However, the domain of time series analysis has broadened to encompass the problems of groundwater as well (Shahin *et al*., 1993). With such a broad domain, time series analysis has emerged as a powerful tool for the efficient planning and management of scarce water resources. Natural time series (hydrological) that satisfy the assumptions of homogeneity, no trends, non-periodic, non-persistence and stationarity, seem to be the exception (Rao *et al*., 2003). In fact, preliminary statistical analyses should be carried out in all water resources studies involving the use of hydrological time series data (Adeloye and Montaseri, 2002). A comprehensive survey of the past studies on hydrological time series analysis revealed that many of the researchers have considered the aspects of time series analysis of homogeneity, trend and normality.

Analysis of hydrological time series for Saraswati basin

The main characteristics of the hydrologic time series, *i.e.*, normality, homogeneity and presence of trend were detected in one-day maximum, monthly and seasonal time series of rainfall for all the rainfall stations. A multiple statistical tests' approach suggested by Machiwal and Jha (2008) was applied for time series characteristics. The homogeneity was tested by seven tests (Bartlett test, Tukey test, cumulative deviations test, Bayesian test, Hartley test, von Neumann test and Link-Wallace test), normality by applying three tests (Shapiro-Wilk test, Kolmogorov-Smirnov test and Lilliefore's test) and trend was detected by using three most-widely used and powerful tests (Mann-Kendall test, Spearman rank order correlation test and Kendall rank correlation test). Moreover, a trend in the rainfall time series was quantified by applying Sen's slope estimation technique too.

RESULTS AND DISCUSSION

Rainfall variability

The station wise rainfall data were classified in different series to know spatial and temporal rainfall variation. The rainfall data of the 16 rain gauge stations under the basin were considered for analysis. For spatial variability assessment, the average annual rainfall of individual rain gauge stations was assessed. The spatial variability of the seasonal rainfall is presented in Figure1. The highest average seasonal rainfall was assessed 886.3 mm at Danta, while the lowest was obtained at Raphu (441.4 mm). The Danta station is located at the windward side of the Aravalli range (hills), received the highest rainfall, while the Raphu station is located at the outlet of the basin falls towards the Small rann of Kutch, where the area assumes arid characteristics. For statistical analysis of the rainfall properly, the data of the individual stations were organized in various series to know rainfall time series characteristics. The series wise rainfall was plotted on time scale to know annual variability (Figure 2). In anticipation of climate change and increasing extreme events the series of one day maximum rainfall was included for variability assessment. The maximum rainfall recorded in a year during the day at any station under the basin was considered as the one day maximum rainfall (ODMR) of the year for the basin. The lowest ODMR was recorded 100 mm at Raphu station in the year 1999, while highest ODMR was recorded 385 mm at Siddhapur in 1984. The variation of ODMR was appeared normal during the study period. The basin as a whole, for the June month, the average monthly rainfall was assessed 69.8 mm. The year wise variation for June was less (28.9 mm to 92.0 mm) before 1990, whereas comparatively more variation (6.6 mm to 303 mm) observed during later decades (1991-2012). Similar type of rainfall extreme variation was also observed in July (Figure 2) with shift of period from the year 2000 onwards instead the year 1990; with 45.3 mm to 472 mm during 1981 to 2000 and 19.7 mm to 724.9 mm during the year 2001-2012 with average annual of 251.1 mm.

For the August month, the average annual rainfall was assessed 217.0 mm (Figure 2). The rainfall pattern appeared normal during the study period; however the maximum rainfall of 917 mm was recorded in the year 2006. It was the highest rainfall recorded in any month at any station during the study period. The share in terms of monthly contribution of rainfall was maximum (39.8 %) during July followed by August (34.4%). In September, the variation was observed from 9.0 mm to 83.4 mm during 1981 to 1991 and 7.4 mm to 335.0 mm during 1991 to 2012.

The year wise average seasonal rainfall (SNRF) of Saraswati basin was assessed 631.8 mm with the minimum 184.7 mm and the maximum 1354.7 mm, respectively, in the year 1987 and 2006 (Figure 2). Similar to monthly rainfall pattern, the variability pattern of SNRF was observed for the basin. However, the higher extremes appeared dominating in comparison to lower extremes favourable for water resources.

Homogeneity

Homogeneity of the rainfall time series was tested by applying seven statistical tests *viz*., Cumulative Deviation test (CDT), Bayesian test (BYT), von Neumann test (VNT), Hartley test (HLT), Link–Wallace test (LWT), Bartlett test (BLT) and Tukey test (TT). The major limitation with all the multiple comparison tests of homogeneity (i.e. HLT, LWT, BLT and TT) is the requirement that the population should be normally distributed with equal variance, which makes the tests parametric in nature. The homogeneity of the one ODMR, monthly rainfall (MRF) and SNRF was carried out. The test results at 5 per cent levels of significance are considered for the decisions in hydrological studies (Machiwal and Jha, 2008), hence, in the present study also statistical test results were interpreted at 5 per cent significance level.

The results of test statistics for JUMR indicated homogeneity at 100 per cent stations each by CDT and HLT, followed by BYT and TT each, at 93.8 per cent stations (Figure 3). In VNT as suggested, the value of calculated statistics should be ≈ 2.0 for homogeneity. The range of calculated statistics was considered 1.75 to 2.25 for decisions. Accordingly, VNT indicated homogeneity at 81.3 stations for JUMR. Likewise for JLMR homogeneity was found at 100 per cent stations each by CDT, HLT and LWT followed by BYT (90.6 %) and TT (87.5%) (Figure 3). The homogeneity by VNT was indicated at 75 per cent stations, whereas homogeneity by BLT was indicated at 68.8 per cent stations only. Similarly, test statistics for AGMR suggested homogeneity at 100 per cent stations each by HLT and TT followed by BYT and CDT respectively, at 93.8 per cent and 90.60 per cent stations. The test statistics for STMR were found with 100 per cent homogeneity in stations similar to AGMR (Figure 3). The CDT observed homogeneity at 96.87 per cent stations, while BYT, LWT and BLT each indicated homogeneity at 87.5 per cent stations in September.

It is seen from the Figure 3 that the homogeneity for ODMR was observed at 100 per cent stations each by the HLT, LWT and TT, followed by 81.5 per cent stations each by BLT and CDT. However, the homogeneity indicated by BYT was comparatively less for ODMR (74.4 % stations). The test statistics for SNRF indicated homogeneity at 96.9 per cent stations by CDT, at 93.8 per cent stations each by HLT and LWT, at 90.6 per cent stations by BYT, at 81.5 per cent stations each by BLT and TT (Table 1 and Figure 3).

Looking from series wise results, the monthly series is leading among all, indicated homogeneity in 88.5 per cent stations followed by the SNRF and ODMR series with 85.7 per cent and 84.8 per cent stations, respectively. While looking from the test wise, the HLT and LWT were among leading with 97.9 per cent and 93.2 per cent, followed by TT, CDT, BYT and BLT with 92.2per cent, 91.7per cent, 85.5 per cent and 80.3 per cent stations, respectively (Figure 4). However, the presence of homogeneity was indicated above 80 per cent stations excluding VNT. On the other hand, based on the known physical parameters affecting the homogeneity, the results of CDT and BYT are considered superior over results of VNT (Machiwal and Jha, 2008). The possible reasons of absence of homogeneity in some case environmental or physical factors that cause non-homogeneity include the type, height and exposure of the rain guage (Buishand, 1982; Machiwal and Jha, 2014). For the present study, the location of the rain gauge station or the method of recording may have changed since its establishment. Those could be one of the reasons for non homogeneity among some stations for some indicated by statistical tests. Thus, given the history of the rain gauge stations, the HLT and LWT indicated homogeneity at maximum stations. Consequently, the population of all the rainfall time series of Saraswati river basin was considered homogeneous.

Normality and trend analysis of rainfall time series

The results of three normality tests *viz*., Shapiro-Wilk (S-W) test, Kolmogorov-Smirnov (K-S) test and Lilliefors (LL) test are presented in Figure 5. The Shapiro-Wilk (S-W) is one of the most powerful and omnibus normality test (Shapiro, 1980; Gilbert, 1987; USEPA, 2006).

Normality

The values of test statistics of all the rainfall time series were obtained more than 0.5 in Shapiro-Wilk (S-W) test indicating normality of the series. Therefore, if W > 0.5, the null hypothesis of normality cannot be rejected. In the recent years, the S-W test has become the preferred test of normality due to its good power properties as compared to a wide range of alternative tests (Mendes and Pala, 2004). The Kolmogorov-Smirnov (K-S) test is empirical distribution function (EDF) test in which the theoretical cumulative distribution function of the test distribution is compared with the EDF of the time series data (Convor, 1980, Armitage and Colton, 1998). This test was first proposed by Kolmogorov and then modified by Smirnov. This test finds difference between cumulative distribution of the time series data and the expected cumulative normal distribution, and computes its statistics (D–statistics) for the large discrepancy. The large value of D indicates presence of non-normality in the time series. But, in the present study the values of D- statistics in all the series and rain gauge stations were found less than 0.5. Therefore, the small values (i.e. D < 0.5) of this test statistics indicate normality. The results of the S-W test and K-S testes predicted that all the rainfall series follow normal distribution at 100 per cent stations (Figure 6). The results of Lilliefors (LL) test indicated normality at 100 per cent station in June, August and September month. However, the normality by this test was observed at 75 per cent, 50 per cent and 31 per cent station in ODMR, STMR and SNRF series, respectively. The test results of K-S were found in full agreement with S -W test than the Lelliefors tests. The LL-test is different from the “K-S test” as unknown population parameters are estimated, while the t- statistic is same. Thus, looking at the normality test results it was inferred that the rainfall time series of study area rainfall follow normal distribution.

Trend

The statistical trend analysis was carried out for the one day maximum, monthly and seasonal rainfall series. The results of the Mann-Kendall (MK) test, the Spearman rank order correlation (SROC) test, Kendall's rank correlation (KRC) tests and Sen's slope at 5 per cent significance level are presented in Figure 6. The critical values for Mann-Kendall (MK) test were obtained from Salas (1993). Similarly, critical values for Spearman rank order correlation (SROC) test were taken from Shahin *et al.,* (1993). The Mann-Kendall test is non parametric test for exploring a trend in a time series without specifying the type of trend (linear or non linear). It is witnessed from Figure 6 that test results of ODMR series as suggested by MK, KRC and SS series revealed that trend was absent at 100per cent stations whereas, the SROC indicated trend only at one station. Likewise, the results of JUMR series by all the tests revealed trend at single station only. The test statistics of JLMR revealed by SS, MK, KRC and SROC each indicated trend at one stations only (Figure 6). The results of AGMR series by all the tests revealed trend at comparatively more number of stations than other series, with exceptionally more (68.8 %) stations by SROC (Figure 6). The results of STMR revealed by MK, SROC and KRC indicated trend at one station whereas, SS indicated trend at four stations. The test statistics for SNRF series as suggested by SROC indicated trend in four (25%) stations while, MK and KRC indicated trend at two stations each. It was noticed from the trend analysis that, the trend was found in a few cases (stations/series) however, it was positive only. Looking at the results of the all the rainfall series and the tests, it was inferred that the trend was absent at majority of the stations of the study area. It indicated the rainfall in the study area is highly random in nature (Mooly and Parthsarthy, 1984).

CONCLUSION

The rainfall analysis of the Saraswati basin was a part of the process to assess the groundwater resources of the Saraswati basin. The analysis of rainfall time series was done by employing seven statistical tests on homogeneity, three tests on normality and four tests on trend to 32 years of SNRF, ODMR and consecutive June, July, August and September month rainfall of the Saraswati basin. As far as spatial variability is concerned, the highest rainfall was assessed 886.3 mm at Danta station and the lowest at Raphu station. Both the stations are located at extreme ends of the basin. In homogeneity analysis of rainfall, the MRF series was leading among all, indicated homogeneity in 88.5 per cent stations followed by SNRF and ODMR series with homogeneity in 85.7 per cent and 84.8 per cent cases, respectively. The statistical test wise, the HLT and CDT were leading with highest output, indicated homogeneity in 97.9 per cent and 93.2 per cent cases, followed by TT and CDT in 92.2per cent and 91.7 per cent cases, respectively. On the basis of the overall results on homogeneity, the data of all the rainfall series of the Saraswati basin were considered homogenous. The normality results indicated 100 per cent normality by S-W and K-S statistical tests. The LL test results also indicated normality in majority of stations, were not in full agreement with S-W and K-S results however, the overall results suggested that the rainfall time series of study area follow normal distribution. In trend detection tests, the ODMR indicated trend in one station only. Therefore, in context to climate change the positive extremities were not observed during the study period. The tests results for detection of trend, suggested that barring a few stations trend was absent in the rainfall of the study area.

REFERENCES

Adeloye, A. J. and Montaseri, M. (2002). Preliminary stream flow data analyses prior to water resources planning study. *J. Hydrol. Sci.*, **47**(5): 679-692.

Armitage, P. and Colton, T. (1998). *Encyclopedia of Biostatistics*, Wiley, New York. pp. 2772-2780.

Astel, A.; Mazerski, J.; Polkowska, Z. and Namiesnik, J. (2004). Application of PCA and time series analysis in studies of precipitation in Tricity (Poland). *Adv. Environ. Res.*, **8**(3-4): 337-349.

Buishand, T. A. (1982). Some methods for testing the homogeneity of rainfall records. *J. Hydrol.*, **58**: 11-27.

Convor, W. (1980). *Practical Non parametric Statistics*. John Wiley & Sons, New York

Fernando, D. A. K. and Jayawardena, A. W. (1994). Generation and forecasting of monsoon rainfall data. In: 20th WEDC Conference on Affordable Water Supply and Sanitation (Colombo, Sri Lanka): pp 310-313.

Gilbert, R.O. (1987). *Statistical Methods for Environmental Pollution Monitoring*, Wiley, NY.

Humphreys, W. F. (2009). Hydrogeology and groundwater ecology: does each inform the other? *Hydrogeol. J.*, **17**(1): 5-21.

Machiwal, D. and Jha, M. K. (2008). Comparative evaluation of statistical tests for time series analysis: application to hydrological time series. *Hydrol. Sci. J.*, **53**(2): 353-366.

Machiwal, D. and Jha, M. K. (2014). Characterizing rainfall-groundwater dynamics in a hard-rock aquifer system using time series, geographic information system and geostatistical modelling. *Hydrol. Process*, **28**: 2824-2843.

Mendes, M. and Pala, A. (2004). Evaluation of four tests when normality and homogeneity of variance assumptions are violated. *J. Appl. Sci.*, **4**: 38-42.

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. *J. Hydrol. Sci.*, **43**(6): 845-858.

Mooley, D. A. and Parthasarthy, B. (1984) Fluctuations of all India summer monsoon rainfall during 1871–1978. *Climatic Change*, **6**: 287-301.

Pugacheva, G.; Gusev, A.; Martin, I.; Schuch, N. and Pankov, V. (2003). 22-year periodicity in rainfalls in littoral Brazil. *Geophysical Research Abstracts*, 6797. EGS - AGU -EUG Joint Assembly, Abstracts from the meeting held in Nice, France, April 6-11, 2003.

Rao, A. R.; Hamed, K. H. and Chen, H. L. 2003. Non-stationarities in hydrologic and environmental time series. Water Science and Technology Library, 45. Kluwer Academic Publishers, Dordrecht, the Netherlands.

Salas, J. D. (1993). Analysis and Modeling of Hydrologic Time Series. In: Handbook of Hydrology, D.R. Maidment (Ed.), McGraw-Hill, New York.

Shahin, M.; van Oorschot, H. J. L. and de Lange, S. J. (1993). Statistical analysis in water resources engineering, Baljkema, A.A. (Eds). Rotterdam: The Netherlands. p. 394.

Shapiro, S. S. (1980). How to test normality and other distribution assumptions. *The ASQC Besic References in Quality Control: Statistical techniques.* Volume 3. American Society for Quality. Mailwaukee.

Steube, C.; Richter, S. and Griebler, C. (2009). First attempts towards an integrative concept for the ecological assessment of groundwater ecosystems. *Hydrogeol. J.*, **17**(1): 23-35.

USEPA, (2006). Data Quality Assessment: Statistical Methods for Practitioners. Guidance Document EPA QA/G-9S. US Environmental Protection Agency (USEPA), Office of Environmental Information: Washington D.C.

Zektser, I. S. (2000). *Groundwater and the Environment: Applications for the Global Community*. Lewis Publishers: Boca Raton, Florida; 175.

Table 1: Homogeneity results as indicated by different statistical tests at 5 per cent levels of significance for different rainfall time series of Saraswati river basin

Sr. No.	Statistical Test	Rainfall Homogeneity of Different Time Series (%)			Test Average (%)
		One-Day Maximum	Monthly	Seasonal	
1.	Cumulative Deviation test				
	Q /(n$^{1/2}$):	75.0	95.3	93.8	91.7
	R/(n$^{1/2}$):	87.3	98.4	100.0	
2.	Bayesian test				
	U:	68.8	89.1	93.8	85.5
	A:	80.0	93.8	87.5	
3.	von Neumann test	56.3	71.9	62.5	63.5
4.	Hartley test	100.0	100.0	94.0	97.9
5.	Link-Wallace test	100.0	85.9	94.0	93.2
6.	Bartlett test	81.5	78.1	81.0	80.3
7.	Tukey test	100.0	95.3	81.0	92.2
	Series average (%)	84.8	88.5	85.7	

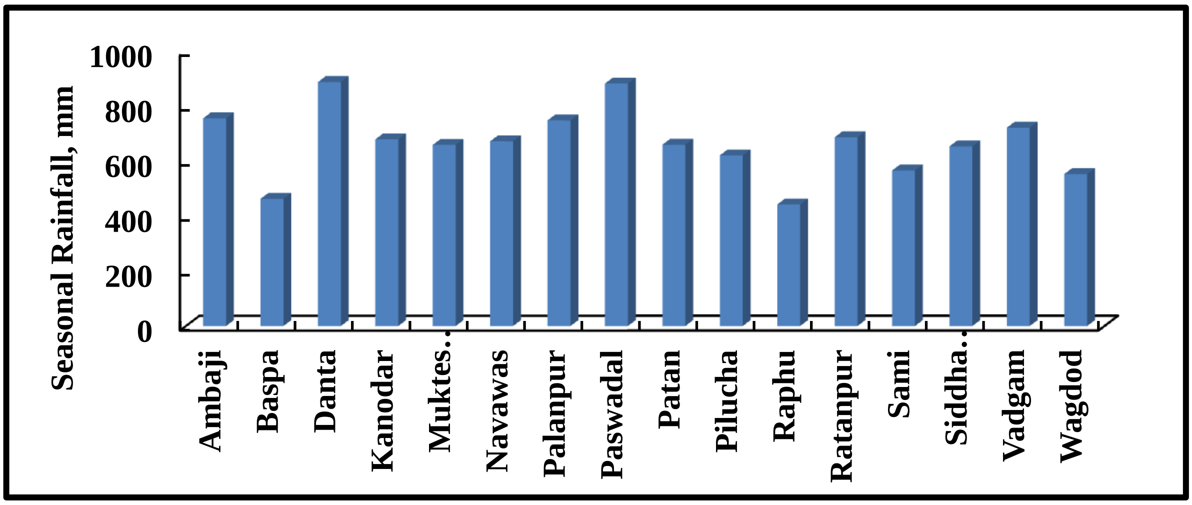

Figure 1: Station wise average seasonal rainfall during assessment period

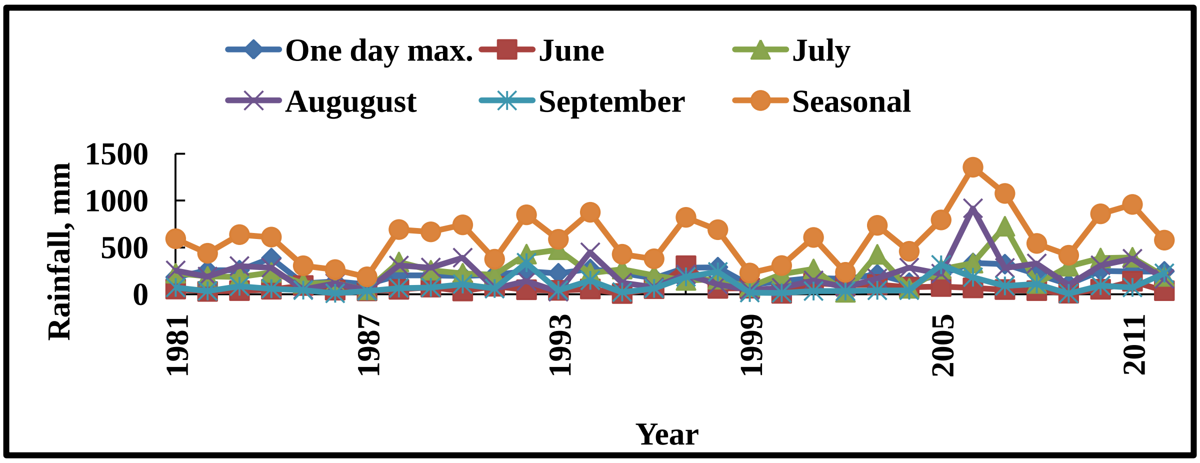

Figure 2: Year wise rainfall variation

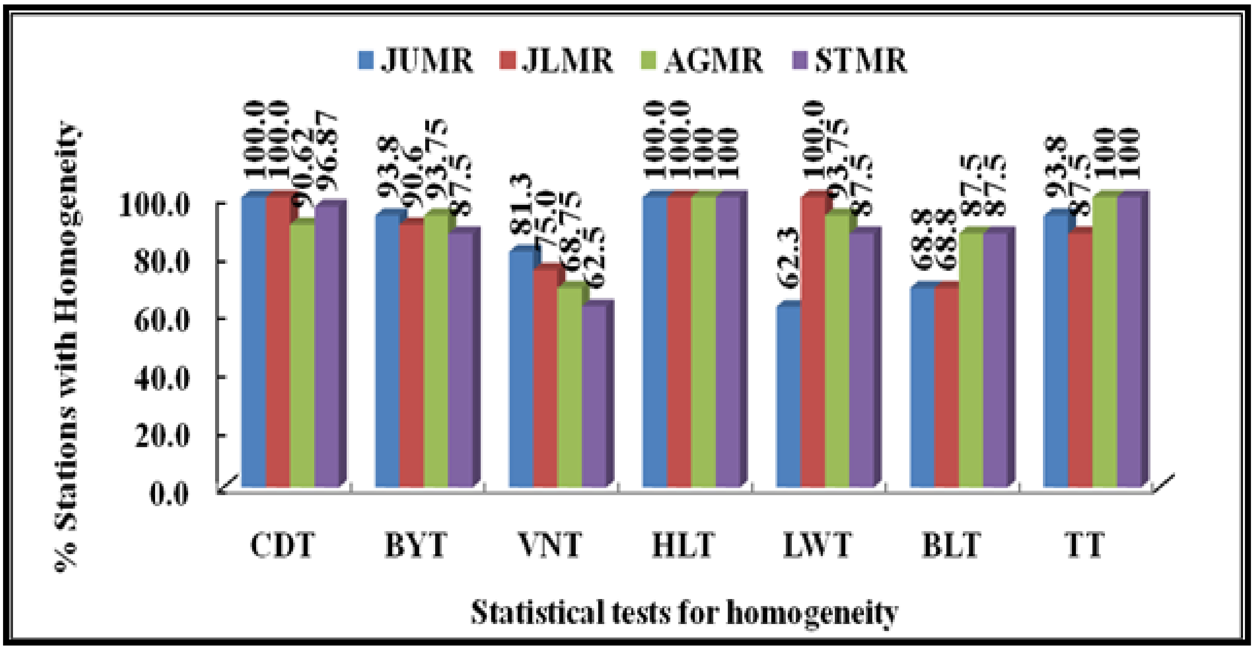

Figure 3: Homogeneity of monthly rainfall series as indicated by various statistical tests.

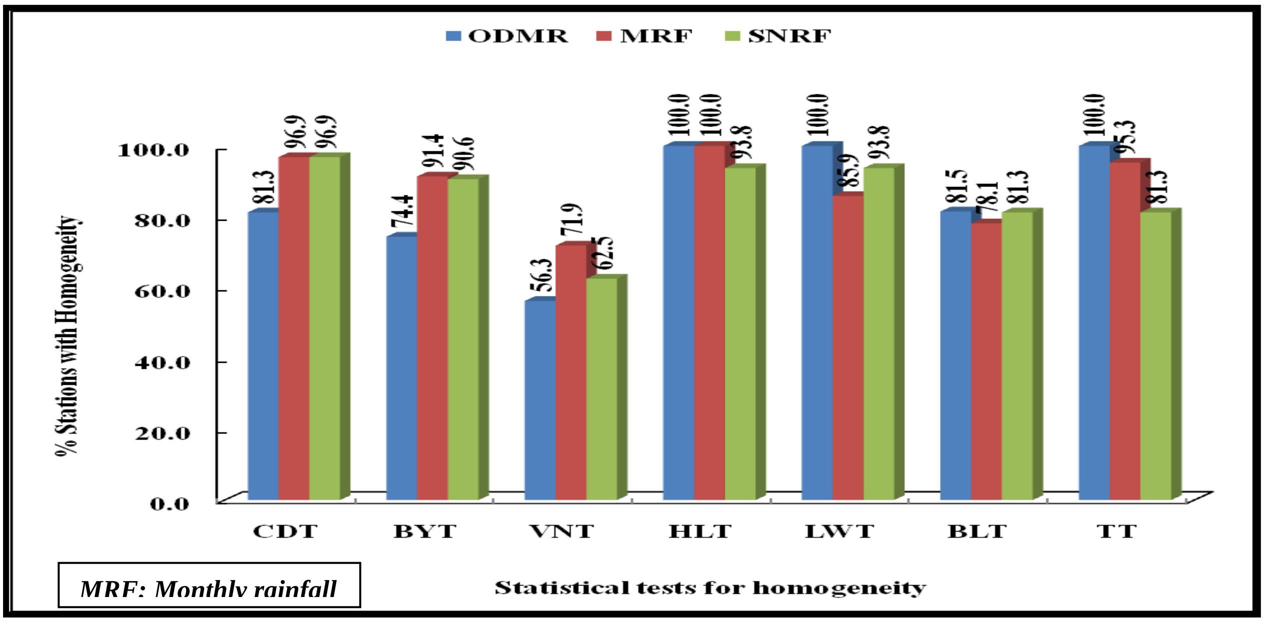

Figure 4: Spatial and temporal homogeneity of different rainfall series as indicated by various statistical tests

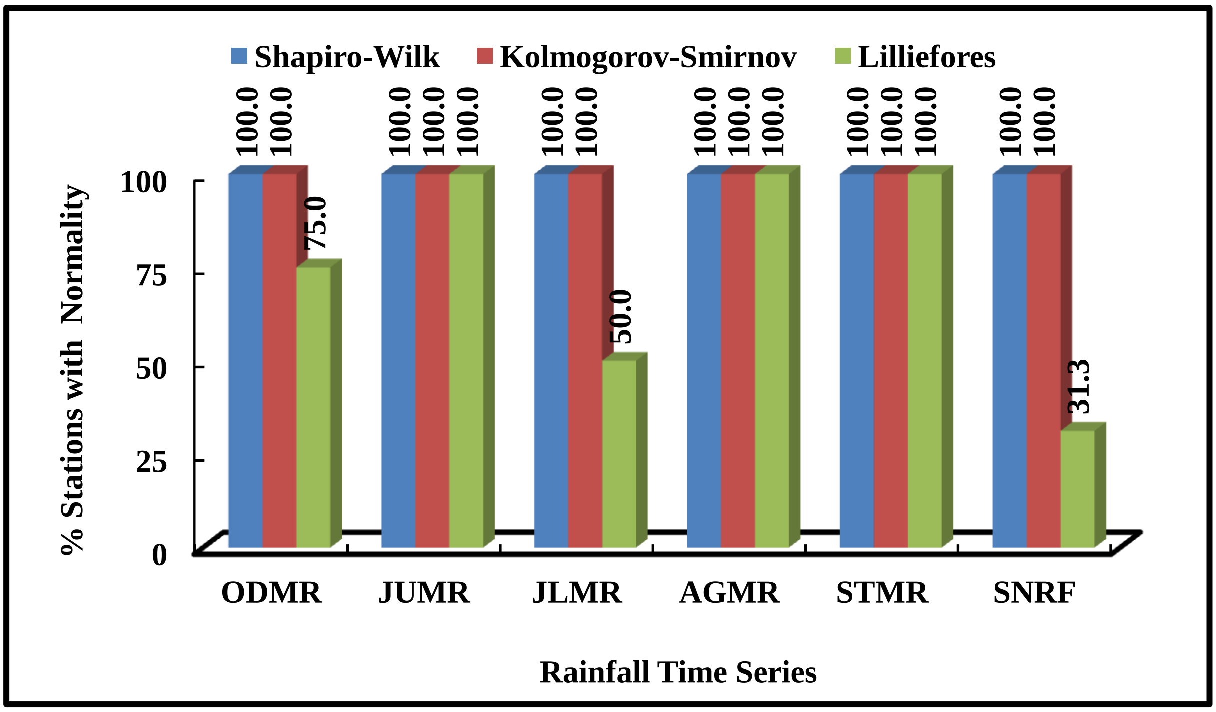

Figure 5: Normality tests results of rainfall series as indicated by different normality tests for study area rain gauge stations.

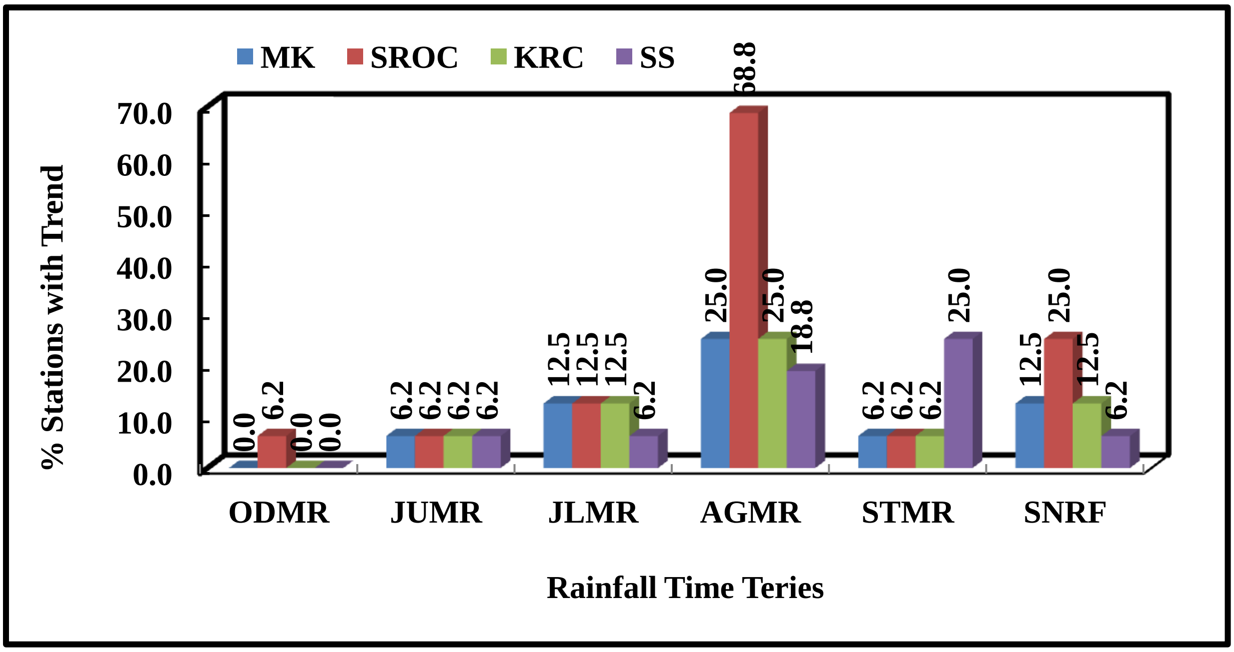

Figure 6: Series wise presence of rainfall trend in Saraswati basin

[MS received : June 28, 2017] *[MS accepted : June 29, 2017]*