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Statistical Studies on Rainfall and Time-based Deviations in Precipitation Trends in Vaigai River Basin, TN State, India

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Food shortage and water shortage remains the most critical issues throughout the world. Understanding the variability in rainfall will help to make predictions about the rainfall patterns as well as addressing the issues of food-water-energy nexus. Herein, a trend analysis of rainfall was carried out in selected seven rainfall stations of Vaigai river basin in Tamil Nadu state, India. Statistical trend analysis was carried out, to observe the trend pattern for the period from 1959 to 2016. To determine the trend of rainfall, non-parametric Mann-Kendall test and Spearman Rho tests were used. This investigation provides insights about precipitation trends during annual, post-monsoon, pre-monsoon periods. These findings will provide clues for developing efficient water management systems using different simulation techniques and artificial intelligence approaches.

[**Keywords:** Mann-Kendall test, Precipitation, Rainfall, Spearman's Rho test, Trend analysis]

Introduction

Rainfall and its precipitation (hydro-metrological conditions) are the key factors associated with the planning of water resources, water allocation and overall development of the locality. Any change in the rainfall (seasonal or annual) and its precipitation in a locality lead to variation in runoff flow in that region with consequent influence on the water resources management. The knowledge of precipitation trend can provide us information about the behavior of observed variables in the future, which can be more important in designing hydraulic structures. It also helps in predicting the quantity of water available to various demands such as production of hydro-electric power, household, agriculture and industrial water requirements. Investigating the rainfall patterns also helps in predicting the floods, famines or any other disasters and develops best possible water management strategies to minimize the losses. The rainfall (hydrological variable) trend prediction study on frequency, intensity and duration of rainfall, frequency of flood, flood regulation has direct impacts not only on individuals, agriculture, and industry, but also on the economy of the country.

There is a huge demand for analyzing the rainfall patterns in different regions worldwide. Several agencies worldwide, has taken serious efforts to make use of satellite data relevant to water resources using Geographical Information Systems and develop systems for water management applications. Among the other water parameters, predicting the rainfall has lot of significance especially in tropical countries. The rainfall (hydrological variable) trend prediction plays a vital role on the estimation of future tendency and it is considered as an effective technique for planning, design and management of water resources of any study area. Adequate analysis and prediction of precipitation can enhance the effectiveness of these activities for increased agricultural production. Because of spatial and temporal variations in nature, the prediction of rainfall characteristics is very difficult.

Different statistical techniques were adopted to quantify increasing or decreasing trends in monthly, seasonal and annual rainfall patterns. Milanovic et al.[1] analyzed the significant increasing trends in rainfall patterns in five stations in Serbia for the period 1946–2011 by adopting the Mann Kendall and

Spearman Rho Tests[1]. Reports are also available on the use of non-parametric methods (such as the Mann-Kendall tests and Time series techniques) for analyzing the long term precipitation in Gorgan weather station in north Iran during 1956 to 2005[2]. The results of the moving average time series showed a deep decreasing trend over a 50-year time period. The time series diagrams (u and u') have showed that there was a significant trend or a sudden change detection in the time series.

Similar investigations were also carried out in the rainfall patterns in India. Pandit[3], analyzed seasonal rainfall trends in Allahabad, India using the non-parametric Mann-Kendall trend test and Sens's slope estimator[3]. Reports on rainfall trends of Kangra district, Himachal Pradesh, using Mann-Kendall test and Sen's slope estimator (mean monthly and seasonal) for the period of 1950 – 2005 a significant negative trend were observed for the annual rainfall data[4]. Swain et al.[5], used the non-parametric tests such as Mann-Kendall and Sen's slope estimator to investigate the trend in monthly rainfall data of Raipur District from 1901 to 2002, Chhattisgarh, India. The results showed that the significant decrease in rainfall trends were observed during the southwest monsoon period, which resulted in decrease in annual rainfall. The spatial and temporal trends of rainfall using non-parametric tests (Mann-Kendall test and Sens's slope estimator) for 30 coastal districts in Odisha state was documented in the literature[6]. They provided the district wise information about the long term rainfall trends and also on the impact of climate change for the various parts of Odisha state. Reports are also available on the use of Sen's slope to detect the magnitude of rainfall; Cumulative Summation (CUMSUM) and cumulative deviation test for detecting the change points[7]. Several reports have also been documented in the literature on using kurtosis coefficient using the time series distribution, Mann-Kendall and Linear regression analysis for rainfall prediction[8-11].

It is evident from the above literature studies that, most of the statistical studies were carried out using Mann-Kendall and Sen's slope estimator techniques. However, very limited studies were carried out on the rainfall patterns using other statistical techniques such as MK (Mann-Kendall), SR (Spearman Rho) test and Linear Regression test. Therefore, an attempt is made by the authors to study the trend of rainfall patterns in Vaigai river basin using Mann-Kendall, Spearman Rho test and Linear Regression test.

Though there are 34 river basins available in Tamil Nadu State of south India, none is a perennial one. Hence, the state is profoundly reliant on monsoon rains for recharging its water resources. The annual average rainfall in Tamil Nadu state is around 970 mm[12] (48 % during the north-east monsoon, 33 % during the south-west monsoon, 14 % in the summer and 5 % in the winter). The state is completely reliant on rains. Failure of monsoon leads to grave water shortage and end up with severe droughts. In a span of 10 years, say during 1995 – 96 to 2005 – 2006, the north east monsoon rainfall has increased from 34 % to 63 % while the rainfall from south west monsoon has decreased from 48 % to 24 %. The per capita storage capacity in Tamil Nadu is 175 cumec, which is 33 % less than the all India average of 262 cum[12].

For the purpose of hydrological studies, the thirty-four river basins in Tamil Nadu are grouped into seventeen river basins[13]. Among these 17 river basins, Vaigai river basin suffers huge water demand for irrigation due to less potential availability of surface water. Moreover, it has varied climatic conditions resulting in unreliable rainfall. Considering the necessity that a study on trend of rainfall in Vaigai river basin will help the authorities to make necessary arrangements for storage and optimum use of resources, the present study is made to analyze the rainfall trend in Vaigai river basin.

Catchment area of Vaigai basin receives maximum rainfall during October and November. Figure 1 shows the Rainfall stations situated in Vaigai River Basin, which are: 1. Uthamapalayam (UM) (Suriliar watershed), 2. Gudalur_M (GM) (Suriliar),

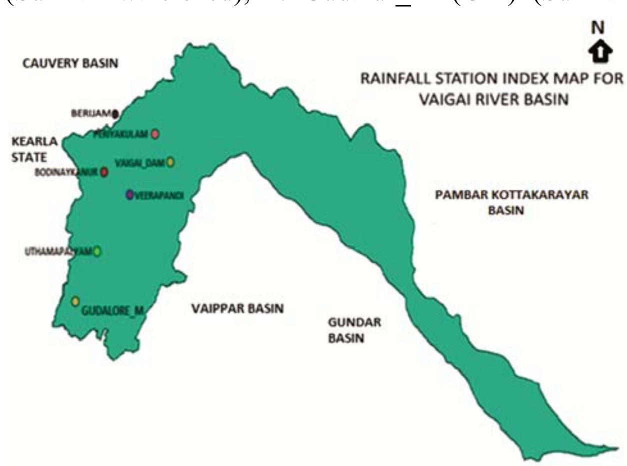

Fig. 1 — Rainfall stations in Vaigai river basin

3. Veerapandi (VP) (Suriliar watershed), 4. Bodinayakkanur (BN) (Suriliar-Foot hills of Palani), 5.Vaigai Dam (VD) (Suriliar watershed), 6. Periyakulam (PK) (Theni sub basin) and 7. Berijam (BJ) (Kodaikanal hills).

The basin is divided into sub-zones based on the control structures situated in the basin from Periyar Reservoir to Bay of Bengal and presented in Table 1. The details of study area of Vaigai river basin is presented in Table 2. Studies were conducted based on the available data for the period from 1959 to 2016, obtained from the office of State Surface and Ground Water Data Centre, Public Works Department, Chennai, Tamil Nadu and also from Indian Metrological Department (IMD), Pune.

Materials and Methods

A. Rainfall Analysis

Rainfall analysis was carried out considering four seasons i.e., (i) Pre-monsoon (March–May), (ii) Monsoon (June–September), (iii) Post-monsoon (October–November) and (iv)Winter (December–February). The statistical factors such as mean, maximum, minimum, standard deviation, coefficient of variation, skewness, kurtosis and correlation coefficient of rainfall data have been computed for studying the spatial and temporal changes in rainfall for the study area.

B. Trend detection

1. *Mann-Kendall Test*

Mann-Kendall Test is a rank-based nonparametric test, used for identifying trends in a time series and is resistant to the effects of outliers[13].

Table 1 — Locations of various zones of Vaigai river basin

Zone	Starting point	End point
I	Periyar Reservoir	Vaigai Dam
II	Vaigai Dam	Perannai Regulator
III	Perannai Regulator	Viraganur Regulator
IV	Viraganur Regulator	Parthibanur Regulator
V	Parthibanur Regulator	Bay of Bengal

The Mann-Kendall test is extensively used non-parametric test for detecting trend in hydro-metrological time series analysis[14-16]. In Mann-Kendall test, a time series x_i was ranked from i = 1, 2… n-1 and another time series x_j from j = 2, 3… n, where n is the number of data points in the set. Each data point in x_i was then used as a reference point and compared with all other data points in x_j (j > i), to obtain the values of the sign for each comparison using equation (1).

$$sgn(x_j - x_i) = \begin{cases} +1, \text{if } x_j > x_i \\ 0, \text{if } x_j = x_i \\ -1, \text{if } x_j < x_i \end{cases} \quad \ldots (1)$$

The Mann-Kendall's statistics (S) was determined using Equation[17] (2).

$$s = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \quad \ldots (2)$$

where, n is the number of observed data points. For n ≥10, the S static is follows normally distribution in a time series with mean of zero. The variance (S) was computed using equation (3).

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p-1)(2t_p+5)}{18} \quad \ldots (3)$$

where, 'g' is the number of tied groups (a tied group is a set of sample data having the same value) and t_p is the number of data points in the p^{th} tied group.

The test statistics Z (MK Coefficient) is determined by the Equation (4).

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} \; if \; S > 0 \\ 0 \; if \; S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} \; if \; S < 0 \end{cases} \quad \ldots (4)$$

A positive value of Z denotes an upward trend on the other hand the negative value of Z denotes a downward trend.

Table 2 — The details of study area of Vaigai river basin in Tamil Nadu state, India

S. No	Station Name	District	Tahsil / Taluk	Latitude	Longitude	Altitude
1	Berijam	Dindigul	Kodaikanal	10°10'40"	77°23'33"	2165
2	Bodinaykannur	Theni	Uthamapalayam	10°01'11"	77°19'40"	637.5
3	Gudalore_M	Theni	Uthamapalayam	09°40'48"	77°14'07"	891
4	Uthamapalayam	Theni	Uthamapalayam	09°48'05"	77°19'42"	736
5	Periyakulam	Theni	Periyakulam	10°07'31"	7°32'03"	1057
6	Vaigai Dam	Theni	Andipatti	10°03'05"	77°35'45"	851
7	Veerapandi	Theni	Periyakulam	09°57'45"	77°26'09"	651.1

2. *Spearman's Rho Test*

Spearman's Rho is a rank-based test used to correlate two variables, say time and the data series[18]. Here, one variable is taken as the time in years and the other variable as the corresponding time series data. Similar to the Mann-Kendall Test, the n time series values are replaced by their ranks. The test statistic ρ_s is the correlation coefficient (5), which is obtained by using ranks as follows:

Test statistics is defined by Siegel and Castellan[19] as:

$$\rho_s = \frac{S_{XY}}{\sqrt{(S_X S_X)}} \quad \ldots (5)$$

where,

$$S_X = \sum_{i=1}^{n}(X_i - \overline{X})^2$$
$$S_Y = \sum_{i=1}^{n}(Y_i - \overline{Y})^2$$
$$S_{XY} = \sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2 (Y_i - \overline{Y})$$

and X_i (time), Y_i (variable of interest), x and y refer to the ranks (x, y, S_x and S_y have the same value in a trend analysis).

For large samples, the quantity $\rho_s = \sqrt{n\text{-}1}$ is approximately normally distributed with mean of 0 and variance of 1 (critical test statistic values for various significance levels can be obtained from normal probability tables).

Results and Discussion:

A. Statistical Analysis of Rainfall

Figure 2 represents the comparison of annual rainfall statistics at all the seven rainfall stations. The statistical analysis of rainfall data is presented in Table 3. From the table it can be seen that Berijam rainfall station has received the highest mean annual and seasonal rainfall.

The annual mean rainfall fluctuated from 1095.5 mm for Berijam to 648.48 mm for Vaigai Dam representing an extensive deviation from one station to another station.

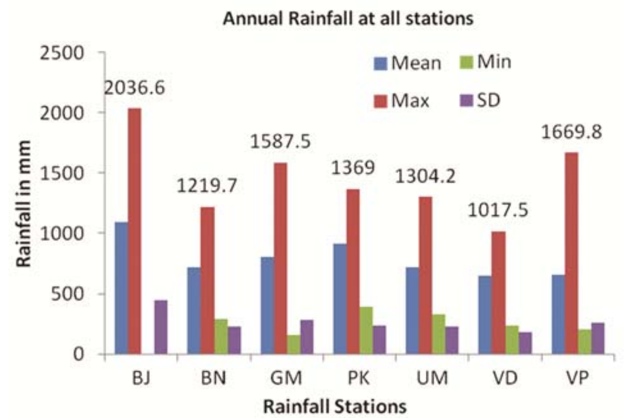

Fig. 2 — Comparison of annual rainfall statistics at rainfall stations.

Table 3 — Statistical characteristics of seven rain gauge stations

Rainfall stations	Time series	Mean (mm)	Max (mm)	Min (mm)	SD	Co-efficient of variation	Skewness	Kurtosis	Correlation co-efficient
Berijam Rainfall Station	Annual	1095.5	2036.6	0	446.03	40.7149	-0.16992	-0.16086	-0.06482829
	Pre-monsoon	72.65	229.27	0	44.20	60.8473	0.759548	1.5539	-0.02040614
	Monsoon	87.87	216.38	0	54.67	62.2172	0.490178	-0.33275	-0.07214749
	Post-monsoon	191.13	466.5	0	112.09	58.6445	0.304467	-0.30544	0.035863
	Winter	47.94	190.33	0	44.34	92.4822	1.380655	1.889325	-0.13887685
Bodinaykannur Rainfall Station	Annual	715.29	1219.7	292.86	230.27	32.1924	0.237027	-0.80823	-0.24354747
	Pre-monsoon	60.056	147.4	6.87	31.28	52.0813	0.672234	-0.19198	-0.20171838
	Monsoon	37.269	189.35	4.95	28.57	76.654	2.901667	13.27342	-0.07097318
	Post-monsoon	155.11	313.5	0	70.773	45.628	0.383045	-0.00383	-0.14043228
	Winter	25.277	100.67	0	24.12	95.4492	1.387229	1.63794	-0.12663339
Gudalur_M Rainfall Station	Annual	807.93	1587.5	156.7	281.94	34.8967	0.151231	0.455665	-0.03292896
	Pre-monsoon	60.314	151.67	0	31.44	52.1324	0.638495	0.693727	-0.07556661
	Monsoon	70.225	202.13	1.875	40.13	57.1412	0.84915	0.873203	-0.12829801
	Post-monsoon	139.2	429.5	0	73.76	52.99	0.967817	2.929977	0.14001616
	Winter	22.564	98	0	21.34	94.5557	1.602829	2.752656	-0.03465797
Periyakulam Rainfall Station	Annual	913.79	1369	393.7	235.66	25.7898	-0.05237	-0.75253	0.42627694
	Pre-monsoon	76.49	199.07	0	39.39	51.4976	0.853572	0.917404	0.26204847
	Monsoon	51.739	144.38	14.38	25.16	48.6278	1.280673	2.23382	0.16925959
	Post-monsoon	184.36	371.5	33.75	79.92	43.3535	0.4442	-0.30158	0.29456257
	Winter	36.216	112.23	0	30.78	84.9771	0.908894	-0.20578	0.0581835

(*Contd.*)

Table 3 — Statistical characteristics of seven rain gauge stations (*Contd*.)

Rainfall stations	Time series	Mean (mm)	Max (mm)	Min (mm)	SD	Co-efficient of variation	Skewness	Kurtosis	Correlation co-efficient
Uthamapalayam Rainfall Station	Annual	716.42	1304.2	327.2	224.57	31.3465	0.654455	0.322937	0.15862192
	Pre-monsoon	52.213	132	0	28.29	54.1732	0.700082	0.15846	0.17199586
	Monsoon	44.723	89.25	8.725	19.19	42.9173	0.325224	-0.53535	-0.02185625
	Post-monsoon	155.48	335	53.75	66.61	42.8414	0.812356	0.67607	0.16861788
	Winter	23.311	104.4	0	24.33	104.357	1.693008	2.43027	0.00332248
Vaigai Dam Rainfall Station	Annual	648.48	1017.5	237.5	180.70	27.8658	-0.00274	-0.33900	-0.07696867
	Pre-monsoon	45.27	112.4	1.67	23.01	50.8353	1.186732	1.488955	0.06176432
	Monsoon	39.331	101.63	2.55	20.97	53.3153	0.745057	1.014242	-0.17697015
	Post-monsoon	138.5	312.5	21.5	63.63	45.9397	0.810599	0.860098	0.06572582
	Winter	26.11	117	0	24.31	93.0941	1.473512	2.492902	-0.16032749
Veerapandi Rainfall Station	Annual	656.27	1669.8	202.8	257.10	39.1753	1.120497	2.979902	0.32879423
	Pre-monsoon	49.367	184.33	5.07	31.45	63.6978	1.782573	5.012836	0.42113669
	Monsoon	33.46	115.25	2.5	22.71	67.8835	1.236473	1.772524	0.14484889
	Post-monsoon	144.47	382	11.85	75.51	52.2667	0.525894	0.525102	0.15978468
	Winter	28.467	180.67	0.4	34.05	119.612	2.38889	7.162368	0.07355225

It is evident from the statistical properties, that all the stations receive the maximum amount of rainfall during the post-monsoon season and minimum during the winter season. The graphical representation of temporal variations of annual and seasonal rainfall series for seven rainfall stations are given in Figures 3 - 9.

The coefficient of variation (CV) of the annual rainfall varies between 40.71 % (Berijam) and 25.79 % (Periyakulam) indicating that there is a significant variation in the total amount of rainfall between the locations. The standard deviation varies between 19.19 mm at Uthamapalayam station during monsoon season to 445.03 mm at Berijam station during annual season.

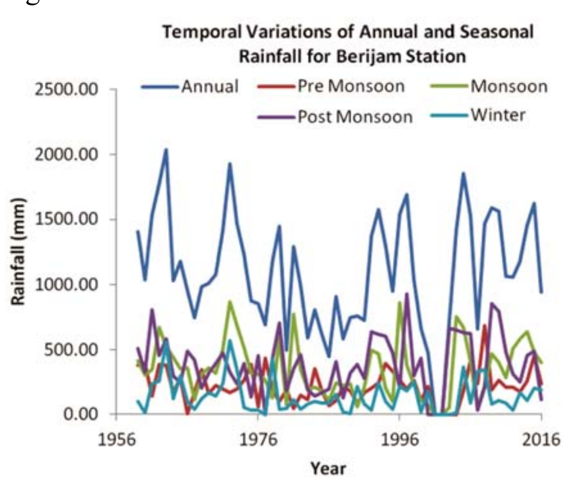

Fig. 3 — Temporal variations of annual and seasonal rainfall for Berijam station

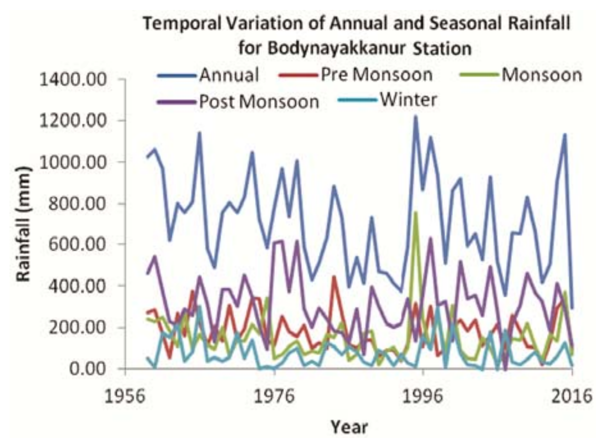

Fig. 4 — Temporal variation of annual and seasonal rainfall for Bodynayakkanur station

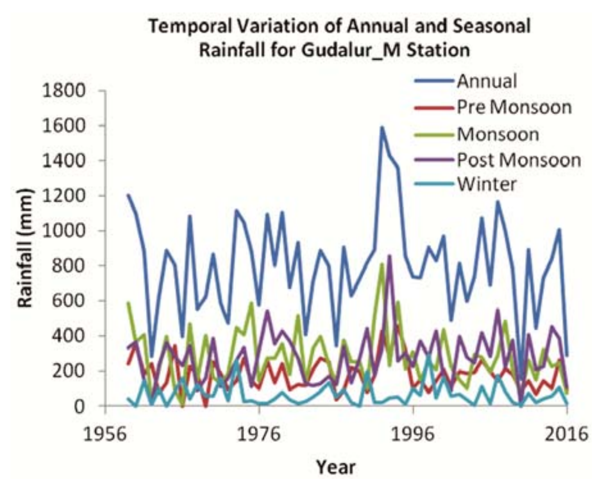

Fig. 5 — Temporal variation of annual and seasonal rainfall for Gudalur_M station

At most of the stations, the skewness coefficients are positive (skewed to the right) indicating that the low rainfall occurs regularly, while high value rainfall happens very often. Rainfall during monsoon season in Bodynayakkanur station and the rainfall during winter season in Veerapandi station have seen as more skewed. The skewness coefficient for most of the stations is identical to or nearly identical to zero indicating the data follows a normal distribution. Most of the stations show a negative kurtosis coefficient which represent that a distribution is flatter rather than the normal distribution. Only Bodynayakkanur station has a kurtosis coefficient greater than 13 representing that low rainfall values are observed more often than high rainfall values.

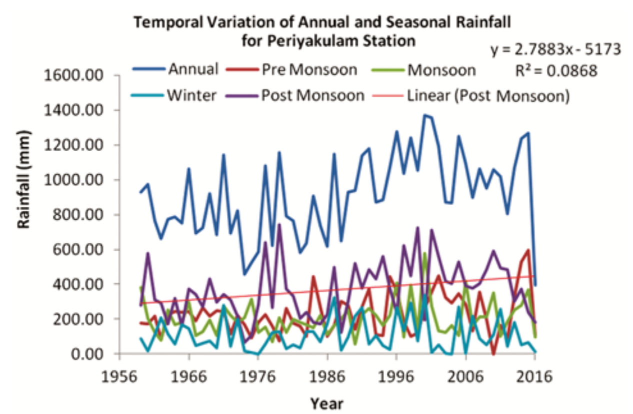

Fig. 6 — Temporal variation of annual and seasonal rainfall for Periyakulam station

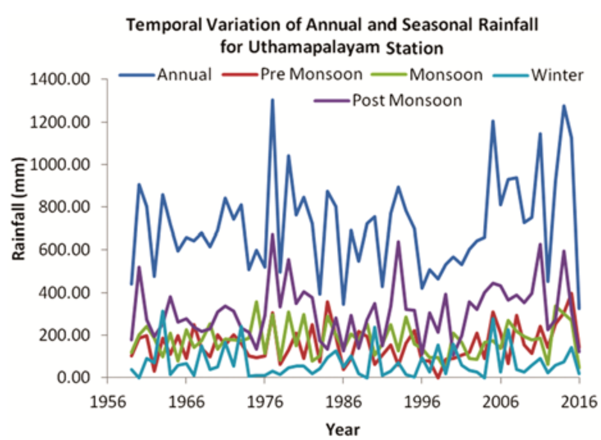

Fig. 7 — Temporal variation of annual and seasonal rainfall for Uthamapalayam station

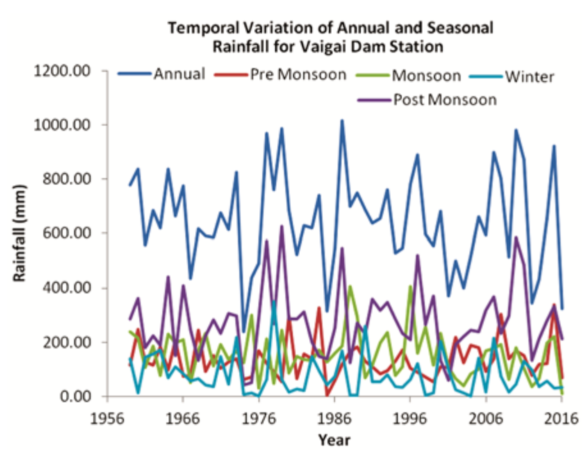

Fig. 8 — Temporal variation of annual and seasonal rainfall for Vaigaidam station

B.Trend Analysis

Annual Trends

Annual trends of precipitation obtained by Mann Kendall test and Spearman Rho test are given in Table 4. The annual trends predicted by Mann-Kendall test, were almost similar to the precipitation trends obtained from Spearman Rho test. The statistical tests in annual precipitation data showed

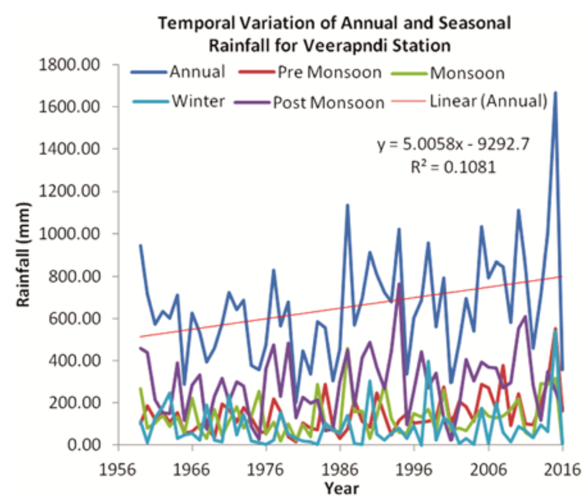

Fig. 9 — Temporal variation of annual and seasonal rainfall for Veerapandi station

Table 4 — Statistical Test values of Trend distribution for Annual Precipitation

S.No	Rain Gauge Station	Annual Basis	
		Z	ρ
1	Berijam	-0.302	-0.09
2	Bodinaykannur	-1.918*	-1.737*
3	Gudalur_M	-0.134	-0.188
4	Periyakulam	+3.26***	+3.358***
5	Uthamapalayam	+0.926	+0.835
6	Vaigai dam	-0.792	-0.757
7	Veerapandi	+1.999**	+2.051**

Level of significance: *** = 0.01, ** = 0.05, * = 0.10

that both +ve (increasing) and -ve (decreasing) trends were recognized and the trends shown were non-significant at 5 % significance levels. Amongst the positive trends, Veerapandi station showed significant increasing trends at 5 % significance level in both Mann-Kendall test results (+1.999) and Spearman Rho test results (+2.051).

Seasonal Trends

The Mann-Kendall test and Spearman Rho test were also applied to detect the seasonal trends of precipitation for all the seven rain gauge stations (Tables 5 and 6). From the seasonal analysis results shows that the Veerapandi station exhibited significant increasing trend in Pre-monsoon season (at 1 % significance level) in both Mann-Kendall test (+2.676), and Spearman Rho test (+2.694). However, the Bodynayakkanur station showed significant decreasing trend in Pre-monsoon season (at 10 % significance level) in both Mann-Kendall test (-1.804), and Spearman Rho test (-1.671).

From the seasonal analysis results, it is evident that the Periyakulam station showed significant increasing (+ve) trend in Post-monsoon season (at 5 % significance level) in both Mann-Kendall test (+2.187), and Spearman Rho test (+2.475). The Vaigai Dam station showed significant decreasing trend in Monsoon season (at 10 % significance level) in both Mann-Kendall test (-1.704), and Spearman Rho test (-1.679).

Table 5 — Trend distribution for winter and pre-monsoon precipitation

S.No	Rain Gauge Station	Winter		Pre-monsoon	
		Z	Rho	Z	Rho
1	Berijam	-0.631	-0.697	-0.121	-0.018
2	Bodynayakkanur	-0.966	-0.993	-1.804*	-1.671*
3	Gudalur_M	-0.054	-0.068	-0.792	-0.733
4	Periyakulam	-0.034	-0.049	+1.55	+1.527
5	Uthamapalayam	+0.362	+0.325	+0.919	+0.921
6	Vaigai dam	-1.368	-1.356	+0.268	+0.318
7	Veerapandi	-0.188	-0.203	+2.676***	+2.694***

Level of significance: *** = 0.01, ** = 0.05, * = 0.10

Table 6 — Trend distribution for monsoon and post-monsoon precipitation

S.No	Rain Gauge Station	Monsoon		Post-monsoon	
		Z	ρ	Z	ρ
1	Berijam	-1.073	-0.687	+0.007	+0.184
2	Bodynayakkanur	-1.55	-1.544	-0.838	-0.898
3	Gudalur_M	-0.939	-0.891	+1.154	+1.101
4	Periyakulam	+0.966	+0.944	+2.187**	+2.475**
5	Uthamapalayam	-0.268	-0.226	+1.623	+1.604
6	Vaigai dam	-1.704*	-1.679*	+0.409	+0.441
7	Veerapandi	+0.993	+0.947	+0.912	+1.082

Level of significance: *** = 0.01, ** = 0.05, * = 0.10

Monthly Trends

The monthly precipitation trends for all the seven rain gauge stations were detected using the MK (Mann-Kendall) and SR (Spearman Rho) tests and the results were presented in Tables 7 - 12.

Table 7 — Trend distribution for precipitation during January and February

S. No	Rain Gauge Station	January		February	
		Z	ρ	Z	ρ
1	Berijam	-0.939	+0.858	-0.563	+0.685
2	Bodinaykannur	-1.10	+0.693	-0.738	+0.334
3	Gudalur_M	+1.321	+4.012***	+0.101	+2.291**
4	Periyakulam	+0.349	+2.087**	-0.02	+1.338
5	Uthamapalayam	+0.295	+2.345**	+0.718	+2.582***
6	Vaigaidam	+0.288	+2.15**	+0.275	+1.75*
7	Veerapandi	+0.322	+2.922***	+0.034	+1.84*

Level of significance: *** = 0.01, ** = 0.05, * = 0.10

Table 8 — Trend distribution for precipitation during March and April

S. No	Rain Gauge Station	March		April	
		Z	ρ	Z	ρ
1	Berijam	-0.597	+0.167	-1.63	-1.56
2	Bodynayakkanur	-0.59	-0.212	-0.537	-0.554
3	Gudalur_M	+0.557	+0.908	-0.208	-0.274
4	Periyakulam	+0.443	+0.689	+0.704	+0.649
5	Uthamapalayam	+0.946	+1.453	-0.342	-0.292
6	Vaigai dam	+0.49	+1.013	-0.356	-0.341
7	Veerapandi	+1.657*	+1.833*	+2.167**	+2.389**

Level of significance: *** = 0.01, ** = 0.05, * = 0.10

Table 9 — Trend distribution for precipitation during May and June

S.No	Rain Gauge Station	May		June	
		Z	ρ	Z	ρ
1	Berijam	+0.684	+0.685	+0.899	+1.005
2	Bodynayakkanur	-1.67*	-1.572	+0.288	+0.325
3	Gudalur_M	-0.865	-0.936	+0.396	+0.506
4	Periyakulam	-0.215	-0.195	+0.812	+0.959
5	Uthamapalayam	-0.047	+0.152	+0.563	+0.691
6	Vaigaidam	+0.382	+0.37	-0.349	+0.197
7	Veerapandi	+0.939	+1.186	+0.188	+0.623

Level of significance: *** = 0.01, ** = 0.05, * = 0.10

Table 10 — Trend distribution for precipitation during July and August

S.No	Rain Gauge Station	July		August	
		Z	ρ	Z	ρ
1	Berijam	-1.784*	-1.801*	-0.637	-0.343
2	Bodynayakkanur	-3.30***	-3.121***	-0.496	-0.311
3	Gudalur_M	-2.066**	-1.924*	+0.168	+0.179
4	Periyakulam	-0.463	-0.400	+2.147**	+2.219**
5	Uthamapalayam	-1.523	-1.495	+1.187	+1.226
6	Vaigaidam	-2.308**	-1.906*	+0.704	+0.921
7	Veerapandi	-0.161	-0.124	+2.562**	+2.651***

Level of significance: *** = 0.01, ** = 0.05, * = 0.10

Table 11 — Trend distribution for precipitation during September and October

S. No	Rain Gauge Station	September		October	
		Z	ρ	Z	ρ
1	Berijam	-0.309	-0.161	-0.838	-0.726
2	Bodinaykannur	-0.57	-0.81	-1.523	-1.485
3	Gudalur_M	-0.792	-0.716	+1.281	+1.319
4	Periyakulam	-0.543	-0.542	+1.496	+1.60
5	Uthamapalayam	-1.221	-1.314	+0.597	+0.568
6	Vaigaidam	-1.59	-1.585	+0.805	+0.859
7	Veerapandi	+0.134	+0.047	+0.865	+0.951

Level of significance: *** = 0.01, ** = 0.05, * = 0.10

Table 12 — Trend distribution for precipitation during November and December

S. No	Rain Gauge Station	November		December	
		Z	ρ	Z	ρ
1	Berijam	+0.154	+0.073	-1.12	-0.883
2	Bodinaykannur	-0.161	-0.09	-0.953	-1.015
3	Gudalur_M	-0.416	-0.416	-0.429	-0.265
4	Periyakulam	+1.06	+1.16	-0.523	-0.422
5	Uthamapalayam	+1.08	+1.151	-0.06	+0.091
6	Vaigaidam	-0.315	-0.437	-1.382	-1.353
7	Veerapandi	+0.59	+0.563	-1.147	-0.945

Level of significance: *** = 0.01, ** = 0.05, * = 0.10

It is seen from the monthly analysis that, Gudalore_M, Periyakulam, Uthamapalaym, Vaigai dam and Veerapandi stations showed significantly increasing trend in the month of January. The Veerapandi station shows significant increasing trend during March, April and August. The Periyakulam station shows significant increasing (+ve) trend in August month. The following station shows significant decreasing (-ve) trends: Bodinaykannur (May and July months), Berijam, Gudalur_M and Vaigai Dam (July month).

In the yearly analysis, Bodinayakkanur showed decreasing trend and Periyakulam and Veerapandi showed increasing Trend. In the seasonal analysis, Bodinayakkanur and Vaigai dam showed decreasing trend whereas,Veerapandi and Periyakulam showed increasing trend.

In the monthly analysis, Gudalore_M, Periyakulam, Uthamapalaym and Vaigai dam showed increasing trend in January. Climatic variations and human activities could be the reason for varying trends detected in precipitation of all seven rainfall stations.

Conclusion

The annual and seasonal rainfall variability study for the period 1959 - 2016 was analyzed for seven identified rainfall stations of Vaigai river basin catchment area of Tamil Nadu State. The annual, seasonal precipitation trends were investigated by Mann-Kendall (MK) test, Spearman Rho (SR) test, and simple linear regression analysis. The seven identified rainfall stations shows increasing and decreasing trends during seasonal and monthly rainfall periods. The trends, temporal variability clearly shows the climatic impact in the Vaigai River basin. An assessment of trends and temporal pattern is a basic and important necessity for proper water resources management, agricultural development and economic prosperity of this region. The presented results are starting point of future work, which will be oriented towards the analysis of significance of trends of precipitation using Senslope estimator and Change point detection using Cumulative deviations and CUMSUM tests on designing of irrigation systems

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