STATISTICAL RESEARCH ON RAINFALL AND RIVER DISCHARGE PATTERNS OVER TIME FROM A HYDROLOGICAL PERSPECTIVE

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Abstract. Climate signals are the indicators of climate change evidence in a particular region or area, which can be witnessed through an erratic rainfall pattern showing less variability than usual which simultaneously affects the hydrological cycle of water systems in major. The behaviour of any weather pattern can be visualized by statistical analysis in combination with trend patterns. This study was made to draw the rainfall and river discharge variability of the Thamirabarani River, Tamilnadu, India through statistical analogy. The trend analysis was carried out by non-parametric Mann-Kendall, Spearman's Rho and Linear Regression Test for ten Rain Gauge stations and one Stream Gauge station from 1980 to 2018 (39 years). The results were interpreted for annual and seasonal patterns where seasonal includes South-west monsoon, North-east monsoon, Winter and Summer periods respectively. This statistical analysis of weather parameters is a preliminary investigation for further research, through hydrological simulations, predictions and scenarios a better management and planning of water resources can be achieved in the Thamirabarani River basin, Tamilnadu, India.
Keywords: *weather parameters, river basin, statistical test, trend analysis, temporal variation, spatial distribution, climate signals*

Introduction

Across the world, scientists now agree that there is climate change due to anthropogenic activities. The phrase climate change has to be a priority on the list while developing planning and management of natural resources. It creates inequitable burden to the poor and developing countries as well as impacting the world's water resources. The projected future climatic scenarios indicate the rise in global temperatures from 1.4 to 5.8 degrees Celsius. Therefore, the slight shift in climate patterns of the 21st century may be significant and disruptive whereas if it will be on the higher end of the spectrum it could be catastrophic. All the above framed contexts are the guidelines by IPCC SR15 report to be followed when it comes to research and investigations.

Rainfall is the major water resources for the earth which is collected in various forms as precipitation in various shapes and structures on the surface as well as ground sources without major losses. It is the fact that water is a naturally recycled resource but the spatial and temporal scales of its pattern has been changed in wide-range. For the sustainable development of planning and management of water resources primarily, the rainfall patterns have to be analyzed in different perspective. The accuracy in rainfall measurement have been increased by the scientific methods like remote sensing and

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automatic measurements etc. Before the validation, simulation, calibration and prediction of hydrological parameters such as rainfall and temperature, it is very necessary to understand the behavior of raw observed data. This real-time dataset statistical study has to be given precedence in any methodology with respect to water resources and its management. Because of the statistical analysis and trend prediction, the behavior of any weather parameter could be well understood in accordance with its periodical manner, extremities and also the causes. Rainfall and river discharge are interconnected as the water discharge is a dependent factor on the rainfall pattern, though both are separately observed in terms of data measurements. The impact of rainfall amount on river discharge shown through statistical analysis and trend prediction is the study to be discussed below along with the help literature review.

The precipitation trends of rainfall give immense results about the increase or decrease of trend pattern with the help of conventional Mann-Kendall, Mann-Kendall and Sen's slope estimator statistical hypothesis testing (Gajbhiye et al., 2016; Gocic and Trajkovic, 2013; Hussien et al., 2019). The trend prediction which can be attempted successfully through Mann-Kendall and Spearman's Rho Test of statistical analysis used to correlate the data in the form of monthly, seasonal and annual time series (Ahmad et al., 2015; Palanichamy and Sankaralingam, 2020). The spatial and temporal variation can be scaled down with the long-term rainfall records by the Mann-Kendall test that shows the trend patterns as well as the extremities (Anand and Karunanidhi, 2020). The statistical analysis can also be done with various number of hypothetical testing such as Linear Time series analysis, Mann-Kendall Z-statistics, Sen's slope estimator and Linear growth model along with combination of weather parameters for better understanding of the climate strategies (Bello et al., 2020; Pandit, 2016). The rainfall records or patterns of measurement not only show a trend in its variation but also conclude the abnormal conditions of the climate as signals for the long time period (Das and Tripathy, 2020). The prediction, fluctuations and anomalies can be investigated through trend patterns of rainfall which tends to accelerate the river discharge inferred through this spatio-statistical analysis of Auto Regressive Integrated Moving Average (ARIMA) approach (Dawood et al., 2020). The analysis of spatio-temporal trends of rainfall is done by Theil and Sen's Slope estimator test for rainfall magnitude as well as Inverse Weight Distance (IDW) through ArcGIS (Geographic Information System) software to predict the variation in trend patterns (Diop et al., 2016). The rainfall trend prediction through non-parametric Mann-Kendall and Sen's slope estimator testing shows significant variation that portraits the spatial scale by interpolation techniques in Quantum GIS (Geographic Information System) software for the management studies (Meshram et al., 2018).

The rainfall trend pattern sometimes helps us to understand the efficiency of result in terms of quantity like its impact on regional or global climate scales by the methods such as Mann Kendal's rank correlation statistics and wavelet analysis (Nikhil Raj and Azeez, 2012). Rainfall and temperature are the dependent factors that never fails to show their impacts on each other, which is evident through the geo-statistical and descriptive statistics and also the clear signature of change in climate through observed data will be making the adaptation and mitigation measures (Savo et al., 2012; Talib et al., 2021). The annual and seasonal trends have been predicted for the temperature of long-term dataset using Modified Mann-Kendall and CUMSUM statistical testing by 95% of confidence interval suggesting mitigation measures for the recovery of water resources (Singh et al., 2015). An accuracy rate increases when there is an update in dataset likewise the satellite data using Artificial Neural Network (ANN) will improve the trend prediction and spatio-

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temporal variations in different aspects in statistical testing (Sobral et al., 2020). The trend analysis of rainfall will be more informative when it is compared with statistical and graphical methods, also in parallel used to make decisions in terms of trend as increasing or decreasing pattern (Rathnayake, 2019). Presence of two or more variable predicts widely where at least one independent and two or more dependent variables will be leading to proper construction of trend patterns as well as the variation and changes happening in time-scales of climatic data (Nyokabi et al., 2017). The precipitation trend variation gradually affects the water discharge trends which are noticeable in the case of Mann-Kendall and Pettit abrupt statistical testing and then leads to double mass curve and regression analysis for the prediction of quantitative impacts of climate change (Li et al., 2020). With the one parameter like stream flow it is possible to predict the trend pattern through the statistical analysis, which will be helpful in decision making when it comes to spatial and temporal scales of urbanized watersheds (Bhaskar et al., 2020). The trend analysis of stream flow prediction with respect to monthly, seasonal and annual pattern of mean values showed the variations and also used in change point analysis (Kale and Sönmez, 2019). The spatio-temporal trends, variability and teleconnections are analyzed using both parametric and non-parametric statistical testing with the help of gridded rainfall data. As per the inference, the study will draw down the large scale impacts of Sea Surface Temperature (SST) through this trend analysis (Sah et al., 2021). The Rainfall and its runoff plays a major role with other hydro-climatic variables while the trend patterns of rainfall and runoff using Mann-Kendall test and Sen's slope estimator has taken into an account primarily for the prediction of annual and seasonal variations and its impacts on other hydrological parameters respectively (Solaimani et al., 2021; Alifujiang et al., 2021). Therefore, this study has been framed by authors to predict the trend pattern in spatio-temporal scales for Rainfall and River discharge in Thamirabarani River, Tamilnadu, India using Mann-Kendall, Spearman's Rho and Linear Regression test in reference to highlighted literature.

Study area

Thamirabarani River was selected as the focus element in this study. This river is one of the oldest systems in Tamil Nadu, India. The river is short but it is a perennial source in the Southern part of Tamilnadu, India. Irrigation development is a major source of income for the people living adjoining the Thamirabarani river. Hence, Thamirabarani River was chosen to examine the behavior of extremities with a reference to statistical perspective. It originates from the peaks of Pothigai hills on the Eastern slopes of the Western Ghats at an altitude of 2000 m and confluences with the Bay of Bengal at Gulf of Mannar, India. It is the lifeline for the people of Tirunelveli and Thoothukudi districts, Tamilnadu, India. The total area of the basin is 5,650 km^2, of which hilly portion is 688 km^2. The basin is situated between 8°21'N and 9°13'N Latitudes and 77°10'E and 78°8'E Longitudes. It enjoys the benefit of both the Southwest and Northeast monsoons as it receives supply from the rainfall over Western Ghats, India. The river traverses about 125 km through Thirunelveli and Thoothukudi districts in Tamil Nadu, India.

The catchment area is divided into seven sub-basins as Upper Thamirabarani, Lower Thamirabarani, Chittar, Gadananadhi, Uppodai, Manimuttar and Pachaiyar as presented on the map (*Fig. 1*). It has 33 rain gauge stations throughout its basin at present. Amongst that only 10 out of 33 rain gauge stations (*Fig. 2*) are selected for an analysis, due to the data reliability in observed rainfall measurements for a long-term period of 39 years. The

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selected rain gauge stations were spatially distributed throughout the basin without any bar adjustment in its topographic features which plays vital role in rain gauge station placements. In addition to this, there is presence of two full climatic stations one at upstream (Cheranmadevi), the other at the middle of the basin (Kalampatti) as well as one stream gauge station (Murappanadu) at downstream (*Fig. 2*). The one major critical point station named Murappanadu stream gauge was selected as it joins two major stream order at this point before the outlet of basin enters the Bay of Bengal. Also, the block map for Thamirabarani basin (*Fig. 3*) is represented below for the study reference.

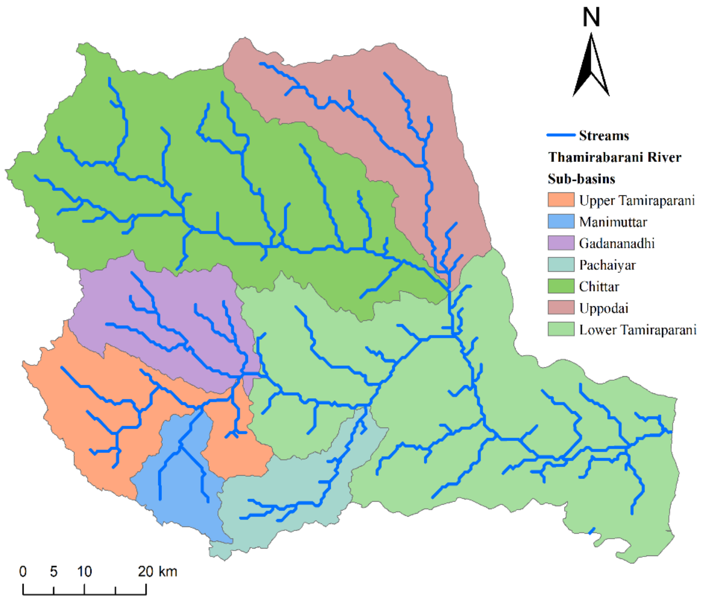

***Figure 1.** Thamirabarani River and its sub-basins*

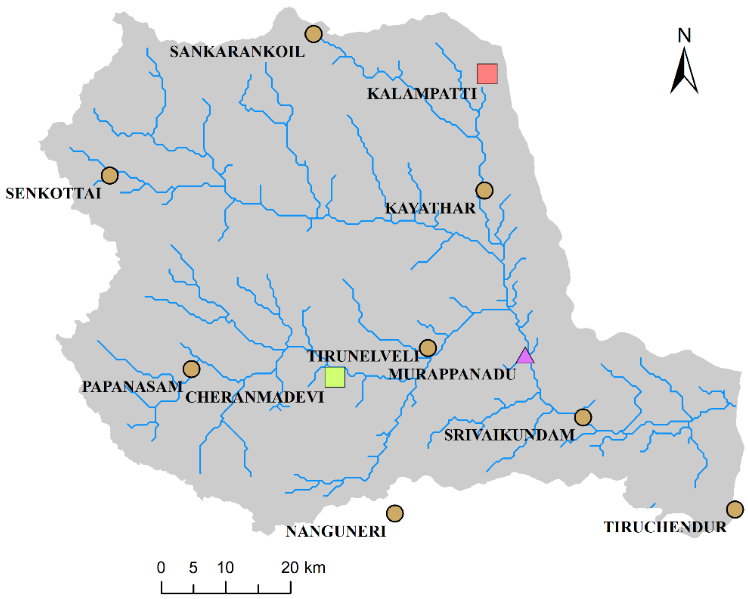

***Figure 2.** Rain gauge station locations in Thamirabarani River basin*

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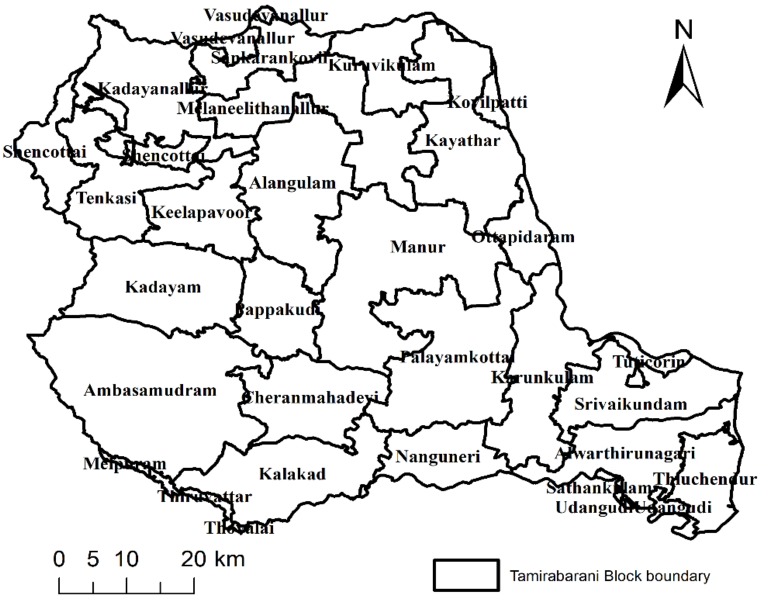

Figure 3. *Block boundaries in Thamirabarani River basin*

The rain gauge stations under respective sub-basins are listed out in *Table 1* and its salient features for the study area of Thamirabarani river basin is compiled in *Table 2*. As per the availability of raw observed data obtained from Central Water Commission (CWC), India and Institute for Water Studies (IWS), Taramani, and Chennai for 39 years (1980-2018), the rain gauge stations were chosen in accordance with the installation period and utilized below for the methodology.

Table 1. *Stream gauge and rain gauge stations under sub-basin zones*

Zones	Sub-basin	Rain gauge station
1	Upper Thamirabarani	Papanasam
2	Lower Thamirabarani	Murappanadu – Stream gauge station Srivaikundam Tiruchendur
3	Gadananadhi	Cheranmahadevi – Full Climate Station (FCS)
4	Manimuttar	Nanguneri
5	Pachaiyaar	Tirunelveli
6	Chittar	Senkottai
7	Uppodai	Sankarankoil Kalampatti - Full Climate Station (FCS) Kayathar

The Cheranmahadevi and Kalampatti are the only weather stations observing all the possible weather parameters for thamirabarani river basin maintained by Central Water Commission (CWC), India and the Papanasam station is installed with automatic rainfall measurements by Institute for Water Studies (IWS), Taramani and Chennai, India.

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Table 2. *The geographic details of Thamirabarani River basin*

S. No	Rain gauge station name	District	Tasil/Taluk	Latitude	Longitude	Altitude (masl)
1	Cheranmahadevi	Tirunelveli	Cheranmahadevi	08°41’17”	77°33’49”	63
2	Kalampatti	Thoothukudi	Kayathar	09°08’48”	77°47’23”	78
3	Kayathar	Thoothukudi	Kayathar	08°56’50”	77°46’33”	62
4	Nanguneri	Tirunelveli	Nanguneri	08°29’48”	77°38’47”	106
5	Papanasam	Tirunelveli	Ambasamudram	08°42’02”	77°21’42”	8
6	Sankarankoil	Tirunelveli	Sankarankoil	09°10’04”	77°32’12”	138
7	Senkottai	Tirunelveli	Senkottai	08°58’18”	77°14’54”	156
8	Srivaikundam	Thoothukudi	Srivaikundam	08°37’45”	77°54’44”	19
9	Tiruchendur	Thoothukudi	Tiruchendur	08°29’56”	78°07’30”	14
10	Tirunelveli	Tirunelveli	Manur	08°43’40”	77°41’41”	33
11	Murappanadu	Thoothukudi	Srivaikundam	08°43’01”	77°49’54”	26

Materials and methods

Rainfall and river discharge analysis

With the available monthly data, the rainfall is categorized for four seasons faced by the study area i.e. (I) Pre-monsoon (March – May) which is also referred as summer or mango showers, (II) Monsoon (June-September) as South-west monsoon, (III) Post-monsoon (October-December) as North-east monsoon and (IV) Winter (December – February). Therefore, these four seasons are grouped into Seasonal pattern and altogether as an Annual Rainfall pattern. This rainfall pattern is subjected to be applied for both rain gauge and stream gauge stations where the former measures rainfall in mm and the latter does river discharge in m^3/s. The preliminary factors of statistical test such as maximum, minimum, mean, standard deviation, variance, coefficient of variation, skewness and kurtosis were determined for both annual and seasonal datasets to study the behavior of spatial as well as temporal scale changes in the rainfall amount and pattern for the river basin. The statistical testing of river discharge data will predict the hydrological causes through the trend occurrence in the monthly, seasonal and annual scenarios.

Trend prediction

Mann-Kendall test

The Mann-Kendall test is a non-parametric (distribution-free) test which means there is no requirement of assumptions unlike linear regression analysis. This test is to assess whether the trend pattern is upward or downward monotonically over the period of time and is best viewed as exploratory analysis. It is most appropriately used to identify stations where changes are significant or of large magnitude and to quantify these findings. According to literature review, the best fitted method to do statistical analysis of weather parameters is Mann-Kendall as the major test done at first further acts as a dependent variable for other detection tests. The observed measurements over time are arranged in an order of x_1, x_2 … x_{n-1} as x_i and x_2, x_3 … x_n as x_j where the number of times represented as 1, 2, 3 … n respectively. The sign of all possible differences (x_j -

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x_i) where j > I are determined. The sgn (x_j - x_i) is an indicator function and the values are compared using *Equation 1:*

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

The Mann-Kendall's statistic (S) was determined as the difference between the number of positive and negative differences by *Equation 2:*

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\left(x_j - x_i\right) \quad \text{(Eq.2)}$$

where n is the number of collected data samples. The S-test have to be computed with variance if n > 10. Hence, the variance of S was calculated by *Equation 3:*

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p\left(t_p - 1\right)\left(2t_p + 5\right)\right] \quad \text{(Eq.3)}$$

where 'g' is the number of tied groups i.e. a set of data sample having the same value and t_p is the number of data samples in the p^{th} tied group. The MK test statistic (Z) was determined by *Equation 4:*

$$z_{MK} = \begin{cases} \frac{S-1}{\sqrt{Var\,(S)}}\, if\; S > 0 \\ 0\; if S = 0 \\ \frac{S+1}{\sqrt{Var\,(S)}}\, if\; S < 0 \end{cases} \quad \text{(Eq.4)}$$

The positive (negative) value will show the trend to increase (decrease) over time and the trend is detected eventually as per the classification requirements.

Spearman's rho test

Spearman's rank correlation coefficient is the statistical measure between the two datasets to ensure the strength of its link. This test comes under non-parametric methods and also used to correlate two variables in a group of data. As said here, the observed data include one with time in years and the other as rainfall time series data in month per millimeters. Similar to Mann-Kendall test, the numbers of time series data are replaced by ranks in order. The test statistic (ρ_s) was designed by Siegel and Castellan framed as *Equation 5:*

$$\rho_s = \frac{S_{xy}}{\sqrt{S_x S_y}} \quad \text{(Eq. 5)}$$

where ρ_s is the correlation coefficient, $S_x = \sum_{i=1}^{n}(X_i - \bar{X})^2$, $S_y = \sum_{i=1}^{n}(Y_i - \bar{Y})^2$, $S_{xy} = \sum_{i=1}^{n}(X_i - \bar{X})^2\,(Y_i - \bar{Y})^2$ 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 values in analyzing the trend). For long-term samples, the quantity $\rho_s = (n-1)^{1/2}$ is approximately normally distributed with mean of 0

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and variance of 1 (critical test statistic values for various significance levels can be obtained from probability tables).

Linear regression test

Regression analysis also comes under statistical technique that attempts to explore and model the relationship between two or more variables. The model here designed and tested are simple linear regression in which one as independent variable (regressors or predictors) and the other as dependent variable (response) tends to produce straight line with the help of residuals formed. The linear regression formula is represented below in *Equation 6:*

$$E(Y) = \beta_o + \beta_1 x \quad \text{(Eq.6)}$$

where β_o = intercept and β_1 = slope of the regression coefficients followed by x as independent variable and Y as dependent variable. The slope, β_1, can be interpreted as the change in the mean value of Y for a unit change in x. The random error term, ϵ, is assumed to follow the normal distribution with a mean of 0 and variance of σ^2. Since Y is the sum of this random term and the mean value, E(Y), which is a constant, the variance of Y at any given value of x is also σ^2. Therefore, at any given value of x, say x_i, the dependent variable Y follows a normal distribution with a mean of $\beta_o + \beta_1 x_i$ and a standard deviation of σ.

This linear regression is an inbuilt test for both Mann-Kendall and Spearman's Rho test and the main purpose of this test is to produce the trend line for the given data samples with the help of mean and variance. It is the basic method for all statistical analysis and models. Therefore, this method of hypothetical testing is applied to the weather parameters in correlation namely, Rainfall and River discharge will draw the trends. Further, its prediction has been projected for the deep down micro-level studies and its measures in the hydrological aspects.

Results and discussion

Statistical analysis of rainfall

The statistical characteristics are calculated for the best fit of models which is considered to be the preliminary stage in statistical testing. There are various mathematical statistic formulations available in that only eight factors namely, minimum, maximum, mean, standard deviation, variance, co-efficient of variation, skewness and kurtosis are selected as the most suited parameters in statistics for hydro-meteorological variables such as rainfall.

The graphical representation of basic factors calculated as descriptive statistics such as minimum, maximum, mean and standard deviation of annual rainfall data are presented (*Fig. 4*). From the graph, it has been clearly recorded that the maximum annual rainfall is at Papanasam station (6131 mm) which is located at upstream side and the minimum annual rainfall is at Kayathar station (12.2 mm) at downstream side of the basin. Though, the annual mean rainfall varies from 1511.1 mm for Senkottai station to 573.2 mm for Tirunelveli station whereas the fluctuation is too great in terms of spatial and temporal scales. Similarly, the standard deviation with lesser value is closer to mean

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at Srivaikundam station (221.6 mm) and the larger value is the most normally distributed one at Papanasam station (913.8 mm).

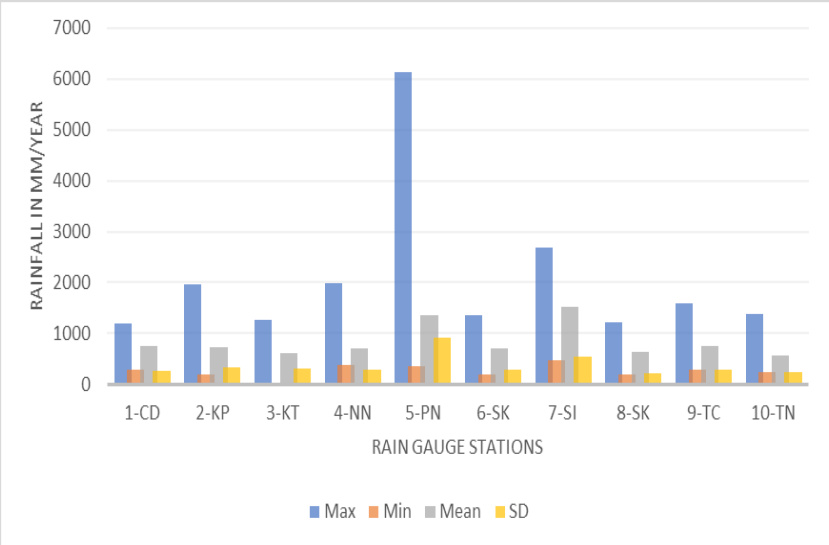

Figure 4. *Annual rainfall of ten rain gauge stations and its four statistical factors*

The confined eight statistical factors are formulated and calculated as parameters of statistical testing for all the ten rain gauge stations with respect to annual and seasonal pattern, the values are presented in *Table 3*.

The other four minor parameters such as variance, coefficient of variation, skewness and kurtosis are all dependent variables of the former statistics calculations which are explained above (*Fig. 4*). Variance is the square of the standard deviation the results in *Table 3* show that higher variance values are far away from the mean and the lower one is closer to it.

As per *Table 3*, the coefficient of variation for annual rainfall amount varies from 66.7% in Papanasam station to 33.1% in Cheranmahadevi station. This statistical property is used when the data set is widely distributed by its mean then it can replace standard deviation while the CV values less than one are represented as low-variance and greater than one as high-variance that are exponentially distributed system. So, the annual rainfall amount is within the range of low-variance for both the stations. Almost all the stations and rainfall patterns both annual as well as seasonal are under positive values except for two, which indicates that they are skewed to the right in the normal distribution curve. The rainfall during annual as well as north-east monsoon (NEM) period in Papanasam station and rainfall during summer (SMR) in Nanguneri station were noticed as more skewed one. Most of the skewness coefficient values are identical to or nearly identical to zero representing that the data falls under normal distribution case. In case of kurtosis coefficient, the values lesser than three tends to be the flattened curve in normal distribution and greater values than three are replaced to Laplace distribution. The kurtosis property purely depends on the data set and here, the Papanasam station exhibits the higher value says that the peak values are the outliers to normal distribution and can be flattened by Laplace distribution. So, the peak values greater than three are in 13 out of 50 station points as outliers which can be corrected in Mann-Kendall test.

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Table 3. *Statistical characterization of rainfall data*

Sl. No	Rainfall stations	Time series	Max (mm)	Min (mm)	Mean (mm)	Standard deviation (mm)	Variance	Coefficient of variation	Skewness	Kurtosis
1	Cheranmahadevi	ANNUAL	1190.6	278.3	750.97026	255.08247	65067.06	33.96705	-0.26387	-0.68641
		SWM	219.2	0	70.90436	46.88552	2198.25	66.12501	0.84964	1.19033
		NEM	913.64	195.8	485.86564	203.53673	41427.2	41.89157	0.37464	-0.82444
		WNT	269.5	0	55.38795	67.14279	4508.15	121.22275	1.82416	2.90625
		SMR	556.8	13	138.81231	96.28804	9271.39	69.36564	2.30288	8.45497
2	Kalampatti	ANNUAL	1959.63	183.06	739.60821	325.47771	105935.74	44.00677	1.41522	4.46048
		SWM	861.15	36.72	147.36897	165.44794	27373.02	112.26782	3.2734	11.67695
		NEM	848.63	110.42	413.26256	163.5359	26743.99	39.57191	0.23367	0.01874
		WNT	251.33	0	51.4841	63.28029	4004.39	122.91229	1.64741	2.13664
		SMR	357.58	12.95	127.49256	84.83762	7197.42	66.54319	1.26933	1.02199
3	Kayathar	ANNUAL	1267.7	12.2	621.39795	307.12609	94326.44	49.42502	-0.21749	0.08799
		SWM	383	0	85.63077	84.83089	7196.28	99.0659	1.40267	2.40541
		NEM	802	0	399.48	232.81809	54204.26	58.28029	0.1674	-0.66574
		WNT	118.5	0	21.01282	29.78485	887.14	141.7461	2.04252	4.41538
		SMR	454	0	115.27435	93.46954	8736.56	81.08442	1.23594	3.0657
4	Nanguneri	ANNUAL	1983.6	381	697.53333	280.78571	78840.61	40.25409	2.63262	10.85948
		SWM	251.5	2.1	79.44615	46.84578	2194.53	58.96544	1.17935	3.52142
		NEM	1129.5	147	437.92308	196.63616	38665.78	44.90199	1.3202	3.00585
		WNT	224	0	45.61026	51.63969	2666.66	113.21946	1.74823	3.4378
		SMR	751	7.2	134.55385	132.46313	17546.48	98.44619	3.28104	12.92621
5	Papanasam	ANNUAL	6131	362	1369.53846	913.81791	835063.17	66.72452	3.86418	19.65916
		SWM	780	6	186.84615	153.60573	23594.72	82.20974	2.07961	5.94568
		NEM	3130	190	850.58205	511.00197	261123.01	60.07674	2.65563	9.82523
		WNT	2070	0	156.04359	334.37772	111808.46	214.28482	5.22784	29.9223
		SMR	784	42	176.06667	139.74534	19528.76	79.37069	2.6712	9.17811
6	Sankarankoil	ANNUAL	1369	196.9	699.86704	292.13715	85344.13	41.74181	0.73928	0.16106
		SWM	288	9.2	76.30331	55.73158	3106.01	73.03954	1.64517	4.18178
		NEM	1181	76	427.06317	241.54348	58344.63	56.55953	1.4156	2.29228
		WNT	202.6	0	45.77409	53.22803	2833.2	116.2832	1.52113	2.01334
		SMR	387.2	20	150.72255	89.13748	7945.46	59.13995	0.66235	0.03501
7	Senkottai	ANNUAL	2689.7	474	1511.08979	552.54031	305302.67	36.56586	0.57437	-0.28072
		SWM	1070.5	148.9	413.98569	224.80045	50535.53	54.30155	1.23589	1.10439
		NEM	2013	151	700.35572	333.48423	111211.65	47.61636	1.7108	5.13112
		WNT	450	0	101.44179	126.54623	16013.95	124.74762	1.49288	1.57487
		SMR	734.33	47.9	295.29992	185.61111	34452.54	62.85582	0.95804	0.22008
8	Srivaikundam	ANNUAL	1209.8	201.3	645.35442	221.60722	49109.79	34.33883	0.33953	0.20565
		SWM	179	0	64.22861	53.47743	2859.83	83.26103	0.74839	-0.55635
		NEM	953.7	109.7	429.31662	213.34664	45512.21	49.68902	0.61916	-0.20956
		WNT	239.2	0	47.49992	61.61936	3796.93	129.72571	1.72065	2.42218
		SMR	347.8	2	104.28427	76.18057	5803.47	73.05083	1.17828	1.5342
9	Tiruchendur	ANNUAL	1599.4	275.6	748.00056	285.09504	81277.75	38.11383	1.03674	1.33091
		SWM	109	0	30.67999	28.4335	808.44	92.67761	1.19992	0.76773
		NEM	1360.4	170.8	560.65897	267.16539	71377.35	47.65203	0.87972	0.7007
		WNT	297.7	0	65.82564	73.07422	5339.72	111.00622	1.51907	2.11038
		SMR	372.2	0	90.70459	84.68192	7179.62	93.36625	1.50382	2.43855
10	Tirunelveli	ANNUAL	1391	248.8	573.19958	232.93238	54258.65	40.63784	1.1619	2.51419
		SWM	184.4	2	67.12051	49.18344	2419.01	73.27632	0.77042	-0.04373
		NEM	876	112.2	361.83077	159.54201	25453.65	44.09299	0.92276	1.26563
		WNT	305.4	0	37.1641	65.17043	4247.18	175.35854	3.15812	10.45069
		SMR	316	2	107.08462	79.61844	6339.1	74.35096	1.10089	0.92111

*SWM = south-west monsoon; NEM = north-east monsoon; WNT = winter; SMR = summer

It is interpreted from the statistical properties that the rainfall amount contributed to the annual pattern in maximum by north-east monsoon (NEM) rainfall and minimum during winter (WNT) rainfall. The inference in whole from the descriptive statistics are the clear signature of rainfall data fluctuations and is now evident to proceed with the statistical testing using non-parametric methods for the trend analysis.

Trend analysis

Annual rainfall trends

With the analysis done through Mann-Kendall and Spearman's Rho test, annual rainfall data have predicted trends with the limit of confidence intervals such as 90, 95 and 99%. The projected trends are correlated with both Mann-Kendall and Spearman's Rho test as one prediction for each rain gauge stations. This statistical hypothesis testing produced significantly both increasing (+ve) and decreasing trend (-ve) while there are also results with non-significant trends. The obtained annual rainfall trend results for Mann-Kendall and Spearman's Rho test are tabulated below in *Table 4* and the visualization of results in terms of spatial scale with respect to rain gauge stations is shown in *Figure 5*.

Table 4. *Statistical analysis on annual rainfall pattern*

S. No	**Rain gauge station**	**Annual statistics**		
		Z	**ρ**	**Trend**
1	Cheranmahadevi	1.331	0.201	No trend
2	Kalampatti	0.363	0.024	No trend
3	Kayathar	1.887***	0.298***	Increasing trend
4	Nanguneri	0.073	0.025	No trend
5	Papanasam	0.847	0.164	No trend
6	Sankarankoil	1.766***	0.281***	Increasing trend
7	Senkottai	2.032**	0.331**	Increasing trend
8	Srivaikundam	0.992	0.142	No trend
9	Tiruchendur	0.847	0.146	No trend
10	Tirunelveli	-1.694***	-0.289***	Decreasing trend

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

Table 4 shows the positive (increasing) trends, the Senkottai station showed significantly increasing trend at 5% of significance level wherein the Kayathar and Sankarankoil station had 10% of significance level in its increasing trend. Also, when it comes to negative (decreasing) trend, the only station subjected to significantly decreasing trend at 10% confidence level was Tirunelveli station in the whole basin for rainfall annually. The stations showing no trend are indicated with pictorial representation (*Fig. 5*).

With the same statistical testing of Mann-Kendall and Spearman's Rho test, the monthly rainfall data grouped under four seasons such as south-west and north-east monsoon, winter and summer, experienced by the study area were also applied season-wise to detect the trend values. Hence, in *Table 5* the results are analyzed for both

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monsoon seasons while in *Table 6* results are recorded for both winter and summer seasons.

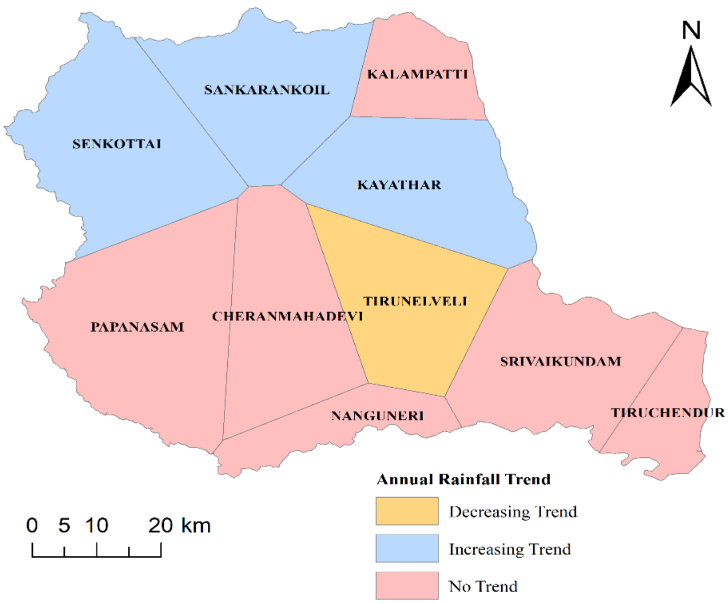

Figure 5. *Spatial variation of annual trend distribution in Thamirabarani River basin seasonal rainfall trends*

Table 5. *Statistical analysis on seasonal patterns of SWM and NEM*

S. No	Rain gauge station	Seasonal statistics					
		South-west monsoon (SWM)			North-east monsoon (NEM)		
		Z	ρ	Trend	Z	ρ	Trend
1	Cheranmahadevi	0.919	0.15	No Trend	1.694***	0.267***	Increasing Trend
2	Kalampatti	-1.113	-0.239	No Trend	0.242	0.009	No Trend
3	Kayathar	0.423	0.104	No Trend	2.468**	0.382**	Increasing Trend
4	Nanguneri	-0.823	-0.151	No Trend	0.774	0.113	No Trend
5	Papanasam	1.21	0.217	No Trend	0.895	0.176	No Trend
6	Sankarankoil	1.089	0.184	No Trend	0.774	0.103	No Trend
7	Senkottai	0.871	0.141	No Trend	1.839***	0.282***	Increasing Trend
8	Srivaikundam	-0.448	-0.084	No Trend	0.992	0.151	No Trend
9	Tiruchendur	-0.23	-0.03	No Trend	0.968	0.152	No Trend
10	Tirunelveli	-1.125	-0.175	No Trend	-1.125	-0.177	No Trend

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

From the seasonal analysis, it is clearly shown that only increasing trend exists when it comes to seasonal basis of rainfall. The annual rainfall pattern of positive (increasing) trends have got an impact from seasonal rainfall, which is proven by this statistical analysis of Mann-Kendall and Spearman’s Rho testing. With reference to *Tables 5* and *6*, the test results show no variation in trend i.e. non-significant trend was noticed during south-west monsoon and winter season meaning that the rainfall amount in all rain

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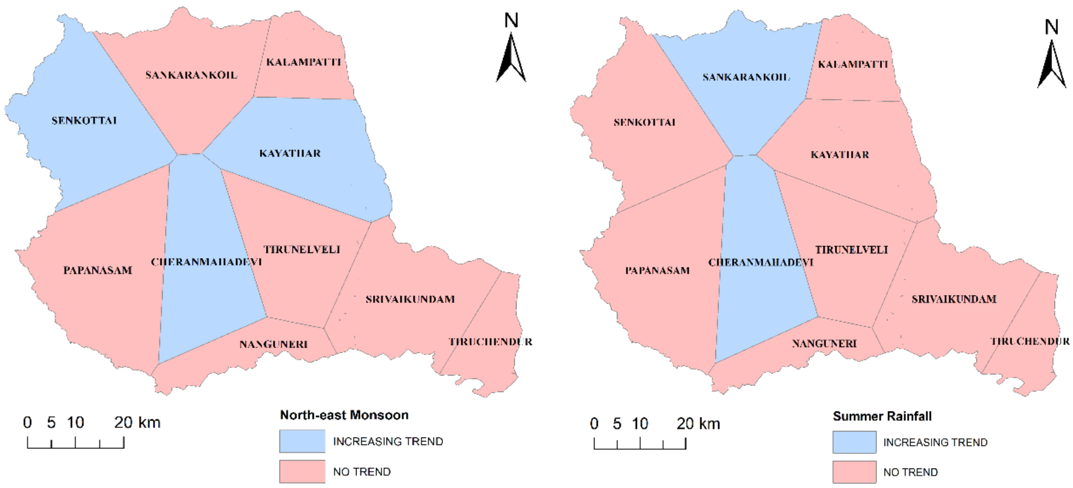
gauge stations are in normal range. In the case of north-east monsoon season, the Cheranmahadevi and Senkottai station on the upstream side of the basin gets increasing trend for 10% confidence level while the Kayathar station got 5% confidence level of increase in trend that must be taken into consideration. Similarly, during summer period there is an evidence of positive (increasing) trends with the same Cheranmahadevi station at 10% confidence level and the only noted rain gauge station of Sankarankoil have got increasing trend at 1% confidence level. The spatial scale representation of analyzed results showing only trends which are easier to interpret are mapped as north-east monsoon (*Fig. 6a*) and summer season (*Fig. 6b*) in two figures for better understanding of trend patterns in wide range throughout the basin.

Table 6. *Statistical analysis on seasonal patterns of winter and summer*

S. No	Rain gauge station	Seasonal statistics					
		Winter			Summer		
		Z	ρ	Trend	Z	ρ	Trend
1	Cheranmahadevi	0.46	0.122	No Trend	1.79***	0.309***	Increasing Trend
2	Kalampatti	0.254	0.078	No Trend	0.798	0.108	No Trend
3	Kayathar	-0.302	0.169	No Trend	0.992	0.175	No Trend
4	Nanguneri	-0.073	0.067	No Trend	0.327	0.049	No Trend
5	Papanasam	0	0.048	No Trend	1.198	0.212	No Trend
6	Sankarankoil	0.593	0.16	No Trend	3.097*	0.496*	Increasing Trend
7	Senkottai	0.532	0.13	No Trend	1.21	0.148	No Trend
8	Srivaikundam	-0.254	0.041	No Trend	0.169	0.024	No Trend
9	Tiruchendur	-0.593	-0.009	No Trend	0.835	0.138	No Trend
10	Tirunelveli	-1.04	-0.078	No Trend	-0.302	-0.052	No Trend

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



(a) North-east monsoon (October to December) (b) Summer (March to May)

Figure 6. *Spatial variation of seasonal trend distribution in Thamirabarani River basin annual, seasonal and monthly trends of river discharge*

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River discharge is the stream flow or surface runoff of the basin. It totally depends on the amount of rainfall and it is one of the direct dependent variable of an independent parameter rainfall in terms of hydrology. So, the statistical characteristics can be overviewed through rainfall statistical analysis and the trend prediction is made through the Mann-Kendall and Spearman's Rho test for annual, seasonal and monthly trends considered to undergo deep down predictions.

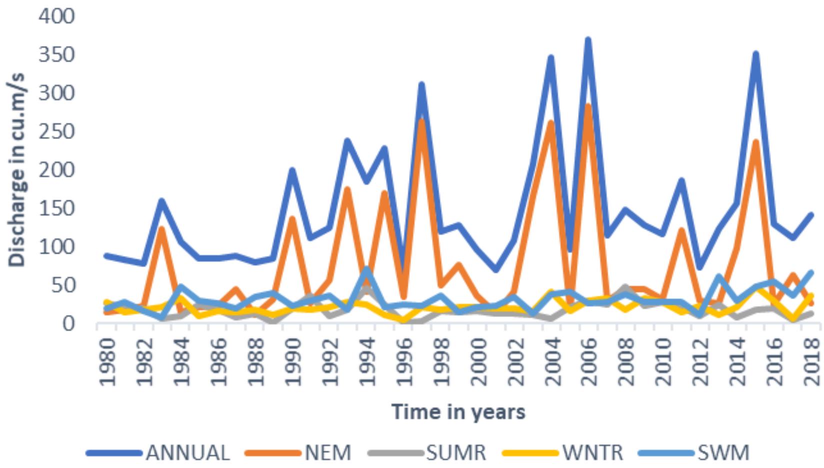

Figure 7. *Temporal variation of Murappanadu station river discharge*

Murappanadu stream gauge station is the only recorded discharge data in the basin located at the major stream order outlet. Due to its large scale contribution at that point of the basin, the recorded stream gauge data was analysed starting from annual to monthly discharge pattern for better trends in observation. The temporal scale representation of river discharge data (*Fig. 7*) from 1980-2018 concludes that the north-east monsoon impacts the discharge rate to increase and influence the annual discharge rate in intensive manner. The obtained test results and trend patterns for annual, seasonal and monthly time scales are tabulated in *Tables 7* and *8.*

Table 7. *Annual and seasonal trend distribution for river discharge*

S. No	Murappanadu stream gauge station	Statistical analysis		
		Z	ρ	Trend
1	Annual rainfall	2.298**	0.37**	Increasing trend
2	South-west monsoon	2.226**	0.339**	Increasing trend
3	North-east monsoon	1.621***	0.271***	Increasing trend
4	Winter	1.379	0.237	No trend
5	Summer	-0.073	0.013	No trend

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

From *Tables 7* and *8,* the river discharge trend prediction shows an increasing trend in both annual and seasonal pattern. It is evident from the trend values that the impact of south-west and north-east monsoon seasonal pattern creates the weather event by

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increasing (positive) in trends further, and affects the annual discharge amount from the river. The increasing (positive) trends for annual and monsoon seasonal pattern has been predicted with 5% of confidence level. Obviously, it is a must to view the monthly trends as it contributes in seasonal pattern of river discharge. The results of predicted monthly trend values show increase in trends (positive) for the month of January, March and September with 10% of confidence level whereas the month of July, August, November and December shows the increasing (positive trends) along with the 5% of confidence level.

Table 8. *Monthly trend distribution for river discharge*

S. No	**Murappanadu stream gauge station**	**Monthly statistical analysis**		
		Z	**ρ**	**Trend**
1	January	2.758***	0.392***	Increasing trend
2	February	0.012	0.027	No trend
3	March	1.633***	0.305***	Increasing trend
4	April	0	-0.009	No trend
5	May	-0.23	-0.053	No trend
6	June	-1.5	-0.241	No trend
7	July	2.395**	0.353**	Increasing trend
8	August	2.419**	0.38**	Increasing trend
9	September	1.802***	0.311***	Increasing trend
10	October	-0.012	-0.004	No trend
11	November	2.117**	0.345**	Increasing trend
12	December	2.298**	0.363**	Increasing trend

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

Comparative result analysis of rainfall and river discharge

According to the non-parametric Mann-Kendall, Spearman’s Rho and Linear Regression statistical testing in the annual rainfall analysis, the upstream side of the river basin has one station named Senkottai that is affected by increase (positive) in trend and in the middle of basin with two stations namely; Sankarankoil and Kayathar with increase (positive) in trends while the decreasing (negative) trend have been noticed in downstream side of the basin with station named Tirunelveli has to be investigated with its hydrological parameters for sustainable management of water resources. Simulatneously, the Murappanadu stream gauge station river discharge is facing the positive (increasing) trends due to the impact of rainfall points at its upstream rain gauge stations such as Cheranmahadevi, Senkottai, Kayathar, and Sankarankoil predicting increase (positive) in trends. Therefore, the analysis shows that there is variation in the climate of the basin therefore, the anthropogenic activities responsible for the cause and effect of rainfall have to be inspected in all the five rain gauge stations.

From the analytical point of view, it is observed that the rainfall in all three patterns such as annual, seasonal and monthly have been altered over the long period of time scale i.e., 39 years (1980-2018) which is indicating that there is a slight change in climate that is taking place slowly throughout the basin. The actual morphology of the basin is perennial having sufficient surface and ground water flow in varied flooding condition during its monsoon periods. But this flood conditions are now changing its nature as per

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the observed data due to an erratic rainfall making its impact on the heavy discharge towards the river banks. Therefore, the quantity of rainfall getting its impact in rainfall pattern simultaneously affects the river discharge as extreme events like floods. The change in climate is somewhat visible through the survey that there is an increase in deforestation along the Western Ghats, India (upstream side) as well as industrialization along the downstream side of the basin in terms of local scale. The global increase in Land Surface Temperature (LST) and Sea Surface Temperature (SST) impacts this river basin as it is subjected to both land and sea surfaces in terms of global scale which can be predicted appropriately through climate modelling as scenarios for past present and future conditions.

Micro-level impact study on trend pattern

To have a clear picture on the trend pattern from the whole basin to block level impact of trend can be predicted through Theissen polygon interpolation method with help of ArcGIS software. This interpolation method helps us to predict the rate of climate change in block level to the whole basin and able to make decision on the management level studies. The spatial representation of block level trend prediction for annual (*Fig. 8*), and seasonal such as north-east monsoon (*Fig. 9a*) and summer (*Fig. 9b*) is shown below and *Table 9* indicates the rate of trends with respect to basin blocks respectively. This pictorial representation (*Fig. 8*) shows that the rainfall stations subjected to the significant trends i.e. positive (increasing) and negative (decreasing) as well as non-significant trends in the whole basin has the capability to calculate the trend rate in percent. Hence, the spatial scale variation as figures for annual (*Fig. 8*) as well as seasonal (*Fig. 9*) patterns and the temporal scale of annual trend rate determination tabulated as *Table 9* the rate of climate change for the whole basin of Thamirabarani river has been concluded.

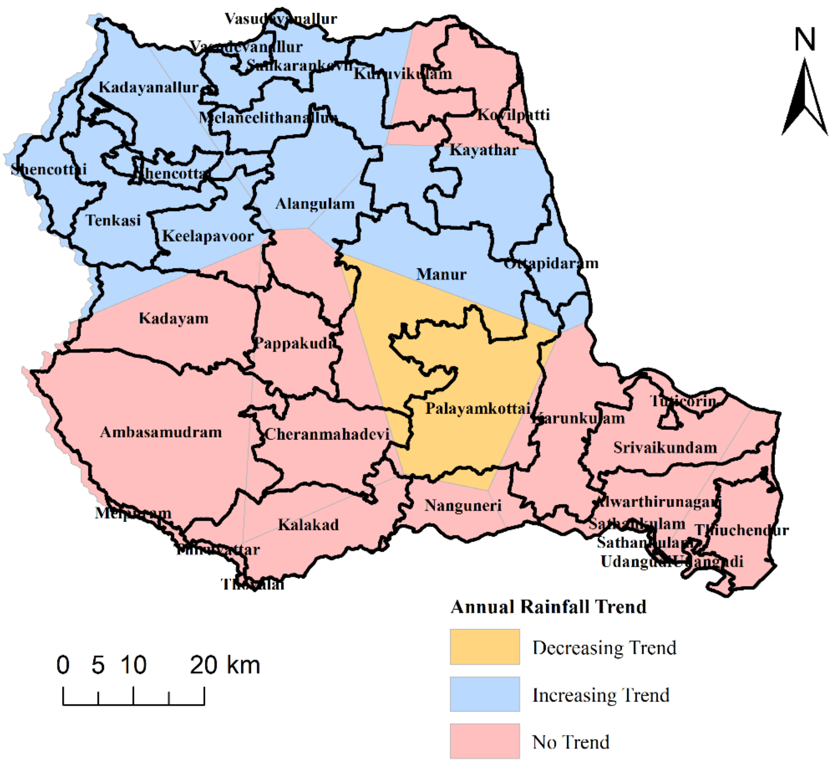

Figure 8. *Spatial representation of blocks influenced by annual rainfall trend*

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Table 9. *Block-level trend analysis on Thamirabarani River basin*

Sl. No	Name of the blocks	**Area (km^2)**	**Trend (%)**		
			Increasing trend	**Decreasing trend**	**No trend**
1	Alwathirunagari	211.64	-	-	100
2	Karunkulam	260.54	6.53	1.98	91.47
3	Kayathar	330.70	56.73	-	43.27
4	Kovilpatti	24.31	-	-	100
5	Ottapidaram	80.05	100	-	-
6	Sathankulam	7.16	-	-	100
7	Srivaikundam	227.85	-	-	100
8	Tiruchendur	117.27	-	-	100
9	Tuticorin	31.70	-	-	100
10	Udangudi	22.41	-	-	100
11	Alangulam	326.32	68.57	2.28	29.15
12	Ambasumdram	589.74	-	-	100
13	Cheranmadevi	218.34	-	5.99	94.01
14	Kadayam	291.48	15.70	-	84.30
15	Kadayanallur	263.97	100	-	-
16	Kalakad	271.91	-	-	100
17	Keelapavoor	176.79	78.74	-	21.26
18	Kuruvikulam	146.32	36.19	-	63.81
19	Manur	473.76	43.81	43.42	12.77
20	Meelaneelithanallur	308.69	91.93	-	8.07
21	Nanguneri	140.50	-	12.16	87.84
22	Palayamkottai	388.17	4.93	84.91	10.17
23	Papakudi	157.68	-	-	100
24	Sankarankoil	124.83	100	-	-
25	Senkottai	169.67	100	-	-
26	Tenkasi	203.44	100	-	-
27	Vasudevanallur	330.34	100	-	-
28	Melpuram	7.81	-	-	100
29	Thiruvattar	19.35	-	-	100
30	Thovalai	2.15	-	-	100
Total blocks		**5624.90 km^2**	**33.44%**	**5.02%**	**61.54%**

From *Table 9*, it is interpreted that these blocks in Thamirabarani River basin are involved in trend analysis. The thirty blocks along with ten rain gauge stations made its interpolation and determined each and every block trend patterns with respect to area of the basin. Therefore, as a result the increasing trend of 33.44% and decreasing trend of 5.02% was subjected to significant rate of change in climate along with remaining 61.54% of non-significant zero trends. This calculated rate of change by trend analysis will be leading to take measures and management in particular sub-watersheds of the whole basin whichever under severe cause.

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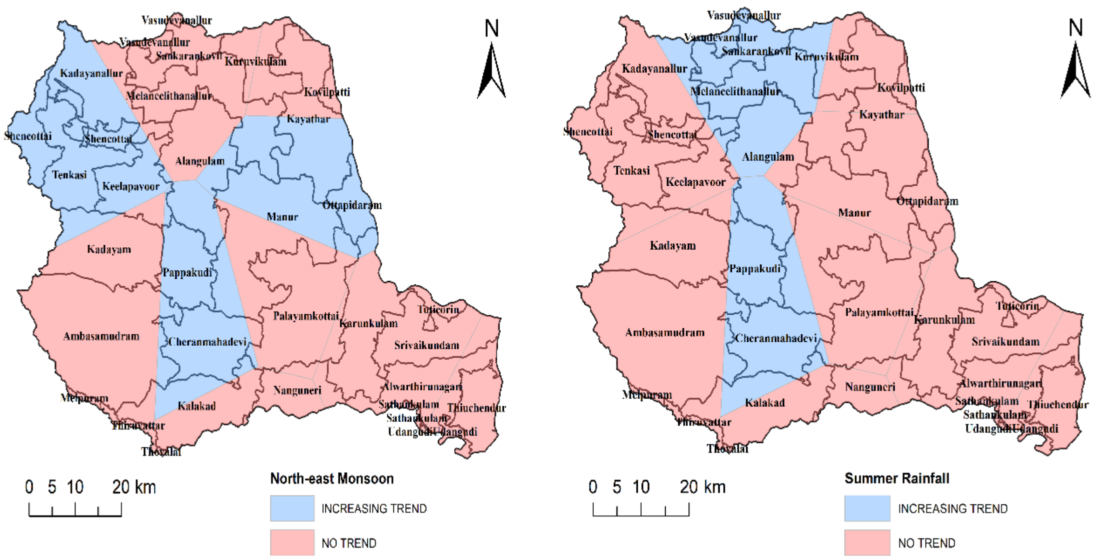

(a) North-east Monsoon (October to December) (b) Summer (March to May)

Figure 9. *Spatial representation of blocks influenced by seasonal rainfall trend*

Conclusion

With ten rain gauge stations and one stream gauge station, the analysis was done for annual and seasonal rainfall variability as well as annual, seasonal and monthly river discharge variation study in comparison with rainfall and its river discharge for the period of 39 years (1980-2018) in Thamirabarani river basin, Tamilnadu, India. The annual, seasonal and monthly trends are predicted by Mann-Kendall (MK) test, Spearman’s Rho (SR) test and Simple linear regression analysis with respective confidence intervals. Out of ten rain gauge stations, the five rain gauge stations are showing both increasing (positive) and decreasing (negative) trends during annual and seasonal periods while in the stream gauge station, the river discharge is showing only increasing (positive) trends throughout the annual, seasonal and monthly patterns. The trend patterns as well as temporal and spatial variability of rainfall and its river discharge clearly shows that the Thamirabarani river basin is under climatic impacts over the period of time. The comparative result of rainfall and river discharge shows that the fluctuations in rainfall range leads to rate of change in river discharge of the basin. With the micro-level study, the blocks taken with respect to rain gauge station throughout the basin by interpolation helps us to understand the trend patterns in terms of climate change rate. Hence, the study concludes that the 33.44% of increasing trend will make changes in extreme events like flood and 5.02% of decreasing trend have the probability of creating drought to the basin. The statistical analysis is the preliminary assessment for any river basin study which helps in better hydrological modelling, sustainable water management, agricultural development and economic prosperity of the region. The present study can be initiated as one of the major objective for future work regarding any analysis of hydrological parameters in modelling and software. Also, the statistical results will be oriented towards finding the significance of trends using worse likelihood test for the prediction of return period floods and auto-correlation modelling for weather forecasting.

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