Spatial And Statistical Tuning Of Trends Of Climate In Coastal Districts Of Tamil Nadu, India

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Abstract: As plots of rainfall and temperature data from 1980 to 2015 apparently give trends with negative and positive sense, it is decided to fine tune the analysis by examining the same by relation between temperature and rainfall, spatial distribution, Mann Kendall and Sen's slope non-parametric tests and goodness of fit test. Spatial and correlation between temperature and rainfall study has given the clear idea about the distribution of this two climatic parameters over the coastal region of Tamil Nadu. At the same time, no-trend hypothesis is to be accepted from the Kendall tau and S statistic for rainfall and temperature data sets. However, Sen's negative value (-0.141) means a lowering monotonic trend for rainfall with reference to the data accessed and studied. Kendall's tau rejects no-trend hypothesis in the case of temperature analysis which suggests that there is a trend and is in positive side which may be considered as corroboration with overall global warming. The rising trend of temperature is further indicated by Sen's positive Q value (= 0.041). It may be considered as a warning by nature to Tamil Nadu to prepare themselves for draught conditions.

Index Terms: Temperature, Rainfall, Climate Change, Tamil Nadu, Mann-Kendall test, Sen's slope test

1. Introduction

Currently, global warming and climate changes are of major global concerns. Rainfall pattern alteration and increasing temperature are presented as principal effects of climate change (Khavse et al 2015). According to the IPCC reports, the surface air temperature was risen almost 0.74˚C during the last century, for which attributable causes are the burning of fossil fuels and biomass, increasing industrial activities and altering land-use patterns — the elevators of concentration of CO_2 and other greenhouse gases (Mullick et al 2018). From 1990s onwards, some regional studies have examined varying temperature and rainfall and suggested the link of global warming to the significant changes in the temperature and rainfall (Keggenhoff et al 2014). Stimulated by the increasing sea surface temperature (SST), globally, the sea level rise (SLR) has been expected to a maximum of 59 cm in 2100 (IPCC 2007). A few other regional studies pertaining to temperature - rainfall trend and relations examined its impacts on climatology in different spatial and temporal scales (Dash et al 2007; Rathod et al 2010; Balachandran et al 2006; Sumathi et al 2011; Jain et al 2012; Sathyamoorthy et al 2016). However, they expressed some skepticism over the regional trends of temperature and rainfall (Jain et al 2013). In such instances, statistical tests such as Mann-Kendall (nonparametric) and Sen's slope tests are said to be handy in obtaining reliability over the results (Karmeshu et al 2012; Atilgan et al 2017; Mishra et al 2014). Tamil Nadu Coast (TNC) has been experiencing several dry spells and severe downpours with pronounced loss of life and property with lingering agony. Apparently trends of meteorological data of TNC exhibit declining state. For all predictive purposes and unraveling hidden agenda of climate, it is contemplated to analyses 35 year rainfall and temperature data of 13 coastal districts of TNC by fitting trends and examining them through more robust statistical tools such as Mann-Kendall and Sen's slope tests as they are yielding more robust results despite the presence of outliers and missing values in the data set. And further it is expected to give indications as to its local congruency with global and country level climatological understandings.

2. Study area

Figure 1 shows the 1076 km long Tamil Nadu coast spanning from Pulicat Lake, Tiruvalluvar District at North (Lat. 13° 06' 04" N and Long. 80° 24' 95" E) to Kanniyakumari (Lat. 8° 08' 83" N and Long. 77° 53' 84" E) at South. This stretch includes 13 coastal districts which share the coast of Tamil Nadu. Marine, fluvial and aeolian depositional and erosional coastal geomorphological features that adorn TNC are beach ridges, estuaries, lagoons, mangroves, salt marshes, creeks, coral reefs, mud flats, deltas, sandy beaches, sand dunes besides modern structures serving protection, fishing and transportation.

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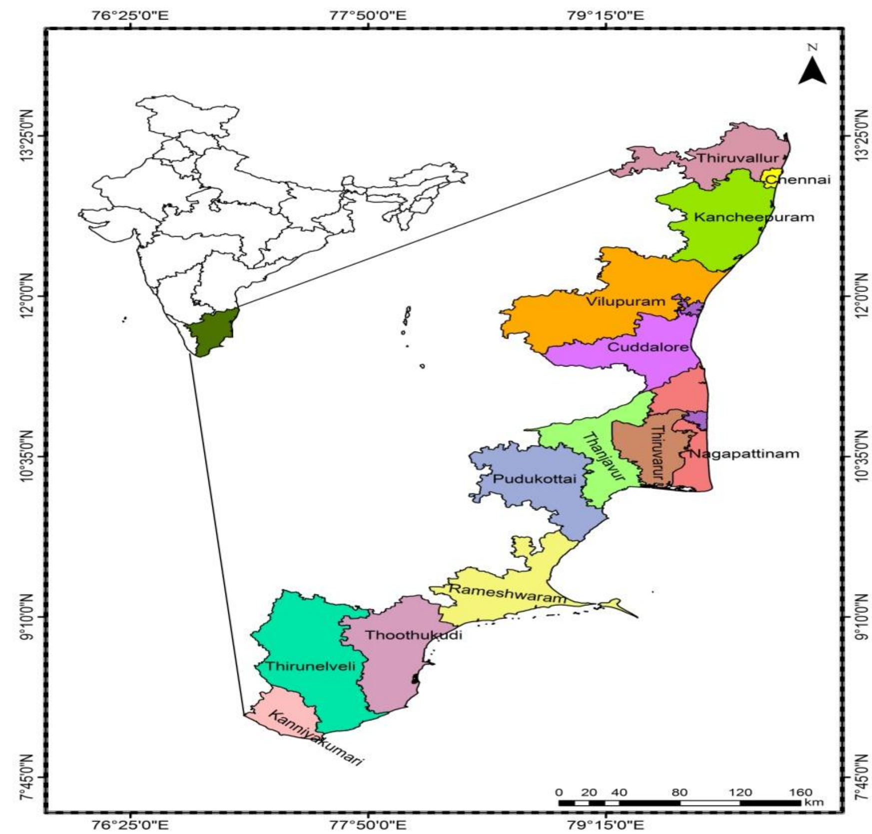

Figure 1. *Location map of the Study area*

Tamil Nadu experiences the true tropical climate as it is located just about 8-10 degrees north of equator where atmospheric circulation is mostly vertical. The average temperature in the coastal region of Tamil Nadu in summer season ranges between 28˚C and 40˚C and in the short-lived winter season it ranges between 18˚C and 26˚C. The seasonal monsoon turnaround of wind is seasonally, the Tamil Nadu coast experience two monsoon periods one is prominent Northeast (NE) monsoon and second one is relatively weak Southwest (SW) monsoon. During Southwest monsoon Tamil Nadu coasts receives around 60% of annual rainfall and during northeast monsoon season rain receives around 40-50% (Selvaraj et al 2011). Out of about 1000 cyclones occurred over the Bay of Bengal in the last century 155 passed through Tamil Nadu state (Janakarajan 2007 and Muthusankar et al 2013); the average tide ranges for Tamil Nadu coast is around 1m and the average wind speed is up to 200kmph (Ramesh et al 2008; Sundar and Sannasiraj 2014).

3. Data and methodology

The study is based on 35-year data, composed of long-term temperature and rainfall historical records spanning from 1980 to 2015 of TNC, were collected from IMD (Indian Meteorological Department), Pune. In the case, this contains different types of statistical test were used wise relation between Temperature and rainfall, spatial analysis, Time series analysis (Mann-Kendall and Sen's-slope Test) and goodness of fit test. Based on this test, it's provided and predicts the future changes in temperature and rainfall variables.

3.1. Relation between temperature and rainfall

The correlation between rainfall and temperature along the coastal Tamil Nadu has been detailed by many authors. This relationship may bear up to change the soil moisture conditions because it may impact the surface temperature (Cong et al 2012). Scatter plots were made for both temperature and rainfall data with 95% confident interval by using Excel worksheet (Fig. 2).

3.2. Spatial analysis

The ArcGIS tool contains many interpolation tools to create surface grids from point data. The interpolation is a method or mathematical function used to conclude the values of cells at locations where there are no measured values are available, based on the rules of spatial dependence which calculate the degree of relationship between near and distant geostatistical cells within the boundary (Mookken et al 2011; Childs 2014). Here, the Inverse Distance Weight (IDW) method was used to create surface interpolation to recognize the temperature and rainfall distribution over the coastal Tamil Nadu and the advantages of this method are perceptive and dynamic. Further, it works finest with evenly distributed points.

3.3. Time series analysis

Examination of meteorological data (averages of temperature and rainfall for entire coastal region for the period from 1980 to 2015) for its trend content by simple parametric linear fit gives trend slope, m, and constant, b, in the equation $Y = mX + b$, where Y and X were dependent and independent variables. This predictive equation covers the entire range of data under certain assumptions like 'data is distribution-free'. Further, the analysis was used to explore the possibility of forecasting meteorological parameters' expected behavior beyond the historical data. However, this least squares method modifies the trend according to the presence of outlier data. If so, such curves could not reflect the long-term monotonic trends (Shadmani et al 2012; Das 2018). To resolve this problem, rank-based nonparametric tests, advanced by Mann-Kendall and Sen, were deployed for significant trend determinations in this time series analysis.

3.4. Mann-Kendall (MK) Test (S)

This test is often used to fine tune the trend parameters as it minimizes the effects due to missing and outlier data. It is accomplished by ranking of medians of differences of pairs of data; wherein each value is paired with the rest of values in the data set and their differences are calculated and arranged into ascending order and median is obtained. Thus it enables to adjudge the monotonic upward or downward climatic trends over time with statistical significance. Following hypotheses were set:

H_0 (null hypothesis): Climatic parameters exhibit no trend
H_1 (alternative hypothesis): Climatic parameters display trend (Hasan et al 2012).

Here, H_0 and H_1 are proportionate to the nonexistence and existence of a trend in the time series data and this MK statistical test always depends on positive and negative signs (Gedefew 2018). The MK test statistic 'S' is calculated by the following equations:

$$S = \sum_{p=1}^{n-1} \sum_{q=p+1}^{n} Sgn(X_q - X_p) \quad \text{---- (1)}$$

where, q=2, 3...n and p=1, 2... n-1, respectively, and the equation 2 is

$$Sgn(X_q - X_p) = \begin{cases} -1 & \text{if } X_q - X_p > 0 \\ 0 & \text{if } X_q - X_p = 0 \\ +1 & \text{if } X_q - X_p < 0 \end{cases} \quad \text{---- (2)}$$

According to equation 2 the positive value of S denotes "upward or increasing trend" and the negative value of S indicates "downward or decreasing trend".

As the present dataset contains more than ten values the test is to be conducted with normality (Z); for which variance of S is then calculated as follows:

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

where, tied values (t), if any, in the n long data set, p and q are pth tied value and total number of ties respectively.
Using Var(S) values normality (Z) of MK values are tested.

$$Z = \frac{S-1}{\sqrt{Var(S)}} \quad \text{if } S > 0$$

$$Z = 0 \quad \text{if } S = 0$$

$$Z = \frac{S+1}{\sqrt{Var(S)}} \quad \text{if } S < 0$$

Positive values of Z_{MK} indicate increasing trends, while negative Z_{MK} values indicate decreasing trends in the time series. When $Z_{MK} > Z_{1-\alpha/2}$ the null hypothesis is rejected and decided that a significant trend exists in the time series. $Z_{1-\alpha/2}$ is the critical value of Z from the standard normal table; for 5% significant level, the value of $Z_{1-\alpha/2}$ is 1.96.

3.5. Sen's Slope test (Q)

The Sen's Slope estimator test was developed by Sen (1968). Sen's slope, a nonparametric procedure, is an alternative for estimating the slope for a univariate time series. In this autocorrelation procedure, the trend is assessed by creating n-1 pairs of data; wherein the first two numbers will form the first pair. The second pair will be the second and third number of the same variable; and thus n-1 pairs will form the data set. In fact, the pair includes observations at two successive time slots. Slope (Q_p) can be calculated by substituting variable X's observations at two successive time stamps, (viz., day-1 and day-2 or January and February or year-1 and year-2) in the following formula:

$$Q_p = \frac{X_p - X_k}{p - k} \quad \text{for } p = 1,2,\ldots n \quad \text{..... (4)}$$

where, Q is a slope estimate, X_p and X_k are the data points at times p and k (p > k). This test used to detect the magnitude of the trend 'i'. Having achieved the trend the next step was to determine the magnitude of the slope through Sen's slope (Q) equation: As Sen's slope estimator Q is the median of slopes, Q is calculated depending upon the number of values in the dataset as follows:

$$Q_{med} = \begin{cases} Q_{\frac{N+1}{2}} & \text{if N is odd} \\ \frac{1}{2}\left(Q_{\frac{N}{2}} + Q_{\frac{N+1}{2}}\right) & \text{if N is even} \end{cases} \quad \text{---- (5)}$$

Where, if N is odd the Sen's slop estimator is predicted as $Q_{med}=Q_{(N+1)/2}$, and if N is even this statistical test predicted as $Q_{med}=[Q_{N/2}+Q_{(N+1)/2}]/2$. The Q_{med} is the replicate the value of the trend, when the median slope is statistically different than zero, the confidence interval of 1 Q_{med} at specific probability. The 95% confidence intervals were estimated based on non-parametric techniques. The confident interval C_α can be calculated following the equation 6.

$$C_\alpha = Z_{1-(\alpha/2)} \sqrt{V(s)} \quad \text{---- (6)}$$

Where the Z is standard normal deviation, V(s) denotes Variance (s) and $Z_{(1-\alpha)/2,}$ collected from standard normal distribution. This study methodology contains two different significance intervals to estimate the confident interval, one is α=0.01 and second one is α=0.05. Then M_1 = (N- Cα)/2 and M_2= (N+ Cα)/2 are calculated. Here, lower (Q_{min}) and upper (Q_{max}) are the M_1^{th} largest. Based on the confidence interval, the Q_{min} and Q_{max} are the largest of the m^{th} order and $(m+1)^{th}$ largest value of the n order slope estimates Q. If the lower limit is interpolated when the M_1 is not the whole number, then the upper limit is interpolated when the M_2 is not the whole number.

3.6. Goodness of Fit Test

Goodness of Fit test describes how well the set of observed data and analysis at a specific site are consistent with a hypothesized regional distribution (Chowdhury et al 1990).

These statistical tests are used to ensure the validity of an assumed probability or particular distribution model. There are three types of methods used to verify the normality: 1. Graphical Methods (histograms, box plots and Q-Q plot), 2. Numerical methods (skewness and kurtosis) and 3. Formal normality tests. The rainfall and temperature data were examined with three probability models (Chi-Square, Anderson Darling and Kolmogorov-Smirnov) to find the goodness of fit. The chi-square test provided best fitted theoretical probability distribution based on the Gaussian assumption of normality. This goodness of fit test (chi-square) depends only on the observed and expected values at given degrees of freedom. This test was performed for assessing the temperature and rainfall distribution When the distance (or test statistics) is very low comparing to the critical value the fit is contemplated as good that also depends on the sample size and the significance level chosen.

4. Result

4.1. Relation between temperature and rainfall

Figure 2 depicts 35-year rainfall and temperature relationships that indicate an unhealthy relationship between this two climatic variables. According to this figure represents the maximum rainfall was occurred in 1996 (1187.93 mm) at the same time the temperature was 27.9˚C in same year. The amount of rainfall along with its frequency gradually decreased due to the increasing the surface temperature.

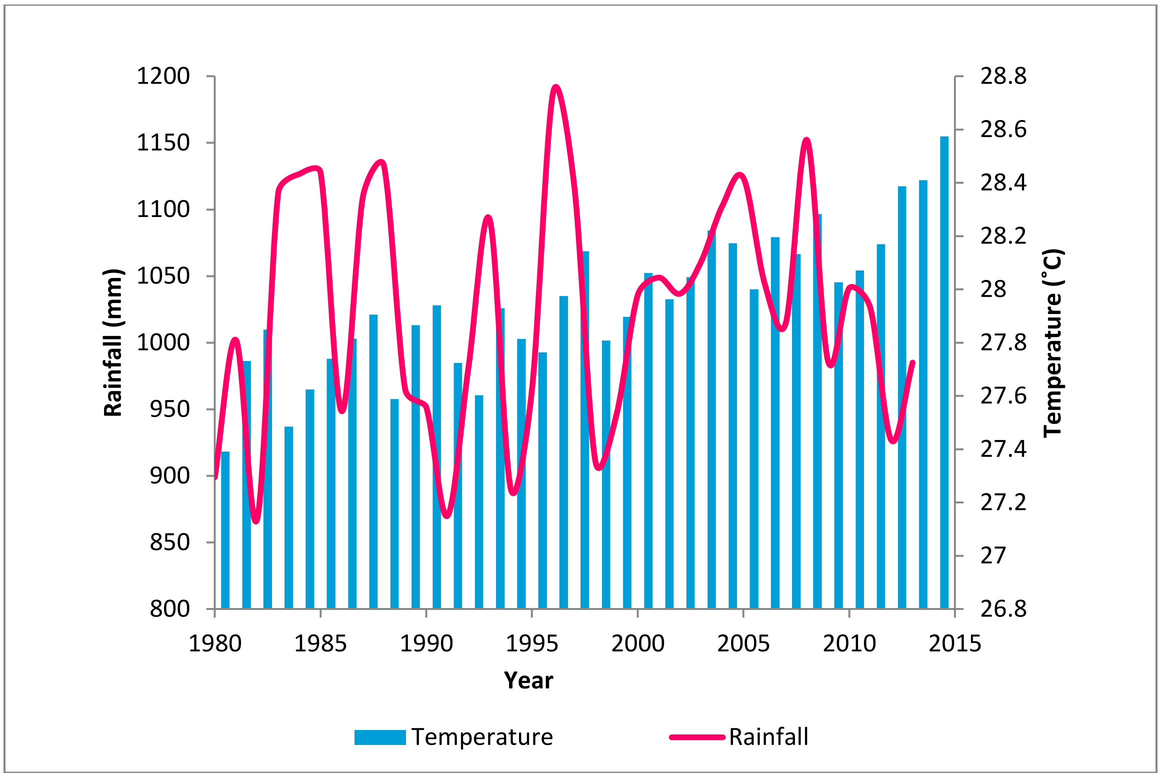

Figure 2. *Relation between temperature and rainfall variability*

According to the recent studies, concentration of higher atmospheric greenhouse gases encourage long-term trends in Indian climatic parameters over the last half of the century (Lacombe and McCartney 2013). This inverse relation indicates the effects of industrial development, urbanization and changes in atmospheric conditions.

4.2. Spatial distribution

Fig.3 (a) and (b) show the annual total rainfall and mean annual temperature along the coastal districts of Tamil Nadu. Result of this spatial analysis study (Fig.3 (a)), clearly indicated the Kanniyakumari district received maximum rainfall comparing to the other coastal districts. As this region lies at the meeting point of three water bodies and inclusive of Intertropical Convergence zone (ITCZ), it gets higher rainfall (Skymet weather 2018). Fig. 3(b) shows the maximum temperature occurred in Chennai and Cauvery delta region (Nagapattinam, Thiruvarur and Thanjavur) of Tamil Nadu. Chennai is located in landlocked site and in its fast urbanization phase this district gets warmer. The delta region lies between Tropic of cancer and equator; during the tropical climate, the sun rays vertically fall at this region and the heat concentrates on the small area; so temperature will be risen and summers are always warm (Yuvaraj et al 2016).

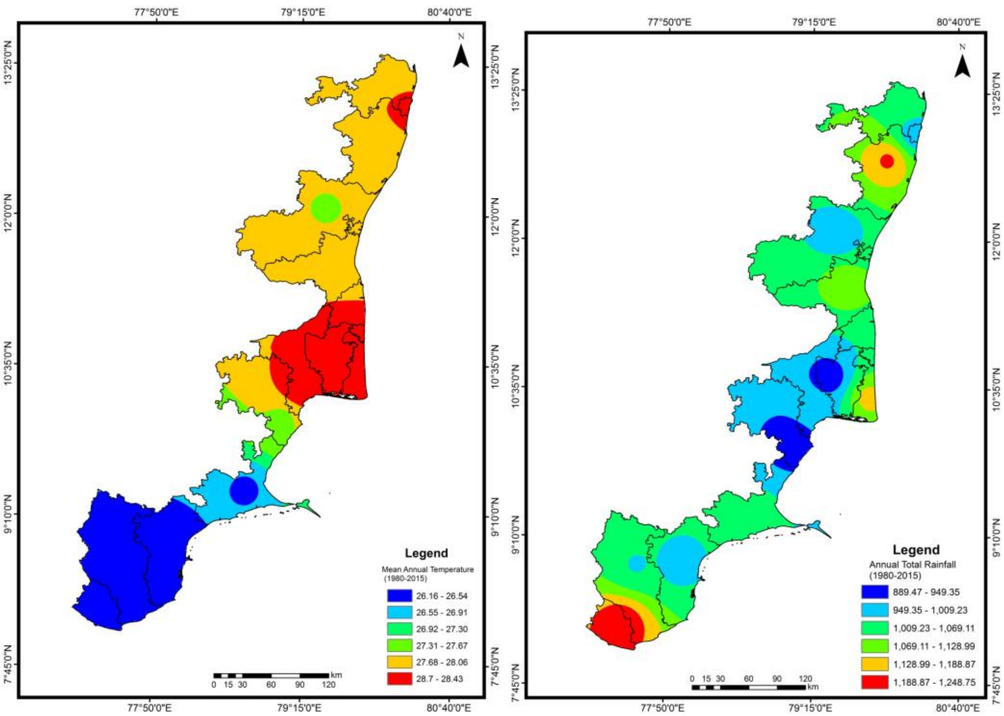

Figure 3 *(a) and (b) The spatial distributions of total annual rainfall and mean annual temperature along the coastal districts of Tamil Nadu from 1980 to 1915*

4.3. Time series trend test

The trends of mean annual temperature and the total annual rainfall were analysed using Mann-Kendall and Sen's slope estimator tests. The following Table (1) contains the result of Mann-Kendall and Sen's slope test for rainfall and temperature trends. Based on the result, as the p value is greater than the significance level, the alpha (α), 0.05, the null hypothesis (H_0) is accepted. It indicates that there is no trend in the time series of rainfall. It is in the case of temperature, p value is less than the set alpha and hence H_0 is rejected leading to the expectation of existence of trend in the temperature. Sen's slope study revealed that the rainfall trend paced to the negative (decreasing) trend and the temperature trend is positive. The magnitudes of Q for 35 years total annual rainfall and mean annual temperature are -0.891 and 0.041 respectively.

Table 1 *Results of Mann-Kendall test for rainfall and Temperature data from 1980 to 2015 over the coastal districts of Tamil Nadu*

Mann-Kendall Statistics	Rainfall	Temperature
Kendall's tau	0.04	0.77
S	-26	459
Var (S)	4957.333	4958.333
p-value (Two-tailed)	0.722536	< 0.0001
Alpha	0.05	0.05
Test Interpretation	Accept H_0	Reject H_0
Sen's Slope		
Slope (Q)	-0.891	0.041
Lower bound (95%)	-4.672	0.033
Upper bound (95%)	2.681	0.045

4.4. Goodness of Fit test

The result of goodness of fit in the middle of all probability distributions developed for the 35 years along the coastal districts of Tamil Nadu. This data set was analyzed through three probability distributions (Error, Normal and Pearson 6). Those three probability distributions were subjected to three goodness of fit test (Kolmogorov-Smirnov (KS), Anderson Darling (AD) and Chi-Square (χ^2)) to decide the best-fitting probability distribution model for temperature and rainfall parameters. The probability distributions are estimated with the help of method of moments (MOM) and the results are given in the Table 2.

Table 2. Results of Goodness of fit statistical test

Parameters	Goodness of fit statistics (Pearson 6)				Parameter (L-moment)
	Probability distribution	Kolmogorov-Smirnov	Anderson Darling	Chi-Square	
Temperature	Error	0.125	0.437	2.424	K=3.626, σ=0.410, μ=28.1
	Normal	0.142	0.544	6.38	σ=0.410, μ=28.1
	Pearson 6	0.146	0.548	6.357	α_1= 43270, α_2= 5458.5 β=3.544
Rainfall	Error	0.065	0.139	0.663	K=6.058, σ= 90.486, μ= 1017.3
	Normal	0.091	0.315	1.989	σ= 90.486, μ= 1017.3
	Pearson 6	0.072	0.327	0.927	α_1= 90.58, α_2= 6.0509E+8, β=6.8070E+9

Based on the Table 2 and Figure 4 shows using with the **Kolmogoro-Smirnov** test observed the error distribution provides the weak fit, the normal distribution provide good fit and the Pearson 6 provides good fit. The **Anderson Darling** test provides the error distribution provides the weak fit, the normal distribution provides good fit and the Pearson 6 provides the good fit. Based on the **Chi-Square** test revealed the weak fit for error distribution, good fit for normal distribution and Pearson 6 provides the good fit for the Temperature data over the 35 years.

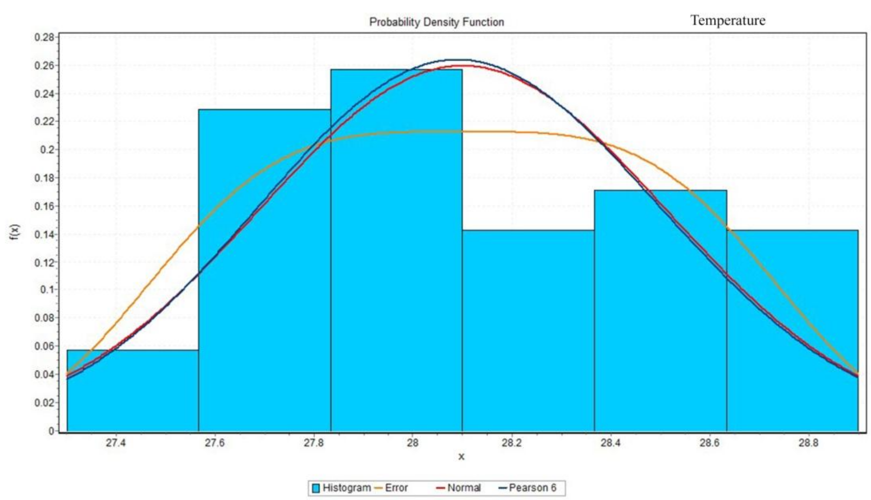

Figure 4 *Goodness of fit test for temperature*

According to Table 2 and Figs. 4 and 5 **Kolmogoro-Smirnov** test provides weak fit; the normal distribution and the Pearson 6 check provides good fits. The **Anderson Darling** test examination also provided similar results. This is reinforced by similar decisions of the **Chi-Square** test through the error distribution (weak fit), normal distribution (good fit) and the Pearson 6 distribution (good fit) for the rainfall parameters.

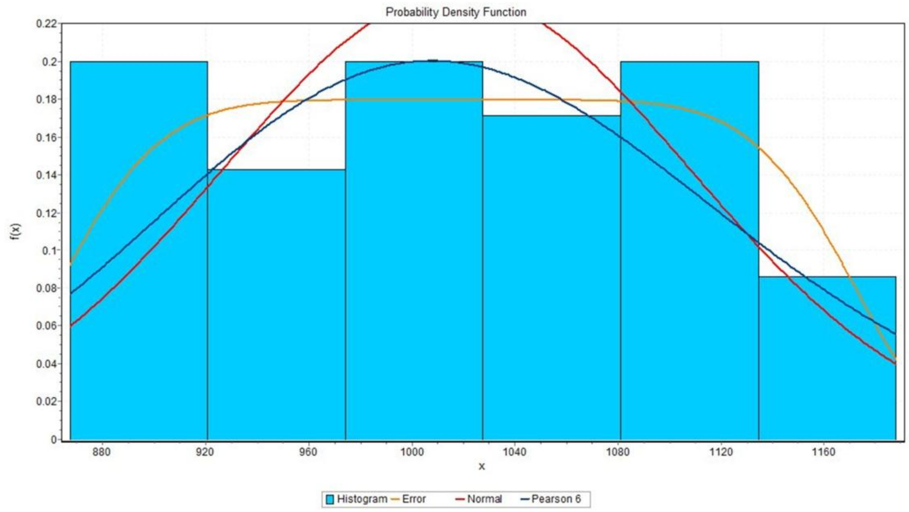

Figure 5 *Goodness of fit test for rainfall*

5. Discussion

Spatial analysis clearly found evidence that the Chennai and delta regions are the most climate-stressed regions in Tamil Nadu, especially the coastal districts. These regions in the last 35 years have experienced considerable changes in decreasing rainfall and increasing temperature. The spatial interpolation pattern shows the most parts of the coastal districts experienced increases in temperature but not in rainfall variability. The MK and Sen's slope estimator test analysis showed that decreasing and increasing trend of rainfall and temperature was examined the entire districts of Tamil Nadu. Rainfall analysis reported in Table 1 accepts null hypothesis that precipitation parameter has not shown any trend. However, Sen's negative value (-0.141) means a lowering monotonic trend with reference to the data accessed and studied. It may be considered as a warning of nature to Tamil Nadu to prepare themselves for draught conditions. Table 1 also provides means to believe that the temperature is on the rise over Tamil Nadu Coast. Rejection of null hypothesis in the case of temperature analysis suggests that there is a trend and is in positive side which may be considered as corroboration with overall global warming. Kendall's tau rejects no-trend hypothesis. The rising trend of temperature is further indicated by Sen's positive Q value (= 0.041). The poor natural conditions and the rapid urban development along the coastal region in Tamil Nadu can cause the high risk such as drought and flood. For example, the delta regions of Tamil Nadu suffer the problems both in water shortage and flood and waterlogging in recent years. Because, this problems are may be caused by changing in rainfall pattern. Therefore, the future study should be given the awareness to the relationship between the changes in temperature and rainfall, in order to achieve deep perceptive and knowledge.

6. Conclusion

The goal of this study is to determine the rainfall and temperature distribution and its trends in the case of annual rainfall and mean annual temperature using 35 years of data (1980-2015) from 13 locations in coastal districts by using different statistical analysis and its spatial interpolation method. Considering Mann Kendall's tau and S statistic along with Sen's slope estimator Q, the emerging climatic scenario over Tamil Nadu Coast portraying decreasing rainfall and rising temperature is a threat to not only to local economy and society but also to entire Tamil Nadu. Recent water shortages in the headquarters of Tamil Nadu State, Chennai, may be an indication in the line of thought. Bivariate correlation of Rainfall versus Temperature also reveals that rising temperature marks the lowering of precipitation along the study coast.

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