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Evaluation of the trend of temperature in a part of Subansiri River basin

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ABSTRACT

The present study has been carried to evaluate the trend of temperature, in a part of Subansiri River basin, the biggest tributary of Brahmaputra River in India. The major objective of the study was to observe the trend of the maximum, mean and minimum temperature at selected grids within Indian region for the last three decades. The inter-dependence of the three variables with respect to time has been studied. Trend analysis has been carried out using three statistical techniques namely, linear regression method, Mann-Kendall test and Sen's estimator.

INTRODUCTION

The climate of earth was never stable for any extended period. Potential climate change and its impacts on hydrologic systems pose a threat to water resources throughout the world. There are a number of natural causes of climate variability, namely variations in the amount of energy emitted by the Sun, changes in the distance between the Earth and the Sun, the presence of volcanic pollution in the upper atmosphere and presence of greenhouse gases, etc. (Brasseur and Roeckner, 2005; Scafetta and West, 2005). Natural and human influences, called "forcing" in the climate-science literature alter the flow of radiant energy in the atmosphere, cooling and warming Earth by perturbing its energy balance. Positive forcing warms the planet while negative ones cool it. One of these forcing's induced by the greenhouse gases, which alter the planet's energy balance by absorbing infrared radiation that would otherwise escape to space. The major greenhouse gases include CO_2, methane, nitrous oxide, tropospheric ozone, chlorofluorocarbons (CFCs), and water vapour. With the exception of water vapour, the concentrations of the entire greenhouse gases are more or less directly depend on human activities. (Water vapour levels depend on Earth's temperature and the availability of liquid water, and thus are indirectly affected by humans). Other forcing's include reflective aerosols (mostly sulphate particles from burning of fossil fuel), black carbon particles (soot), land-cover changes, variations in solar output, and cloud-cover changes resulting from global temperature variations and aerosols (IPCC 2007).

The Intergovernmental Panel on Climate Change (IPCC) scientists, through their report released on February 2, 2007, said temperatures were probably going to increase by 1.8-4°C (3.2-7.2°F) by the end of the century. Global temperatures have been on the increase since 1750, following the industrial revolution of the developed world, fuelling the suspicion that the earth warming is not unrelated to human activities. Eleven of the last twelve years (1995 -2006) rank among the 12 warmest years ever recorded since global surface temperatures are measured (1850). Over the last 100 years, (1906–2005) there has been an increase in surface temperature of 0.74°C, which is larger than the 0.6°C increase given in the Third Assessment Report (TAR) for the 1901-2000 period. The warming trend over the last 50 years (0.13°C per decade) is nearly twice that for the last 100 years.

The important climatic variables that influence the ecosystem are precipitation, radiation, temperature and stream flow. It is a challenge to the scientific community to understand the complicated processes involved in climate change and alert the society to tackle the problem. Temperature is the driving force for all the climatic variability. Increasing temperatures will decrease snowfall because of which snow may cease to occur in areas where snowfall currently is marginal (Bown and Rivera, 2007). Increased temperatures in the winter may lead to early snowmelt events and a shift in runoff from the spring to late winter with a corresponding decrease in runoff in the summer period (Burn and Elnur, 2002). The major indications of the climate change and their adverse effects are the increase in frequency of flood/flash flood, Glacial Lake Outburst Flood (GLOF), glacial retreat, decrease in seasonal snow cover, rise in sea level, etc.

In last few decades, several individual and collaborative researches were undertaken to study climate change. The linear relationship is one of the most common methods used for detecting rainfall trends (Hameed et al., 1997; Silva, 2004). Both parametric and non-parametric tests are widely used for trend study. The advantage with a non-parametric test is that it only requires data to be independent and can tolerate outliers in the data (Hameed and Rao, 1998). One of the popular non-parametric tests widely used for detecting trends in the time series is the Mann-Kendall test (Mann, 1945; Kendall, 1955). The two important parameters of this test are the significance level that indicates the trend strength and the slope magnitude that indicates the direction as well as the magnitude of the trend (Burn and Elnur, 2002). The advantage of the test is that it is distribution-free, robust against outliers and has a higher power than many other commonly used tests (Hess et al., 2001). Many climate studies applying Mann-Kendall test have been carried out in the last decade. Modarresa and Silva (2007) studied the rainfall trend in Iran; Birsan et al. (2005) used the test to study the stream flow trend in Switzerland; Shan Yu et al. (2002) studied the impact of climate change on water resources in Taiwan; Arora et al. (2005) studied the temperature trends over India; Zhang et al. (2005) analysed the trend of precipitation, temperature and runoff in the Yangtze basin China. Mcbean and Rovers, (1998) examined historical trends in precipitation, temperature, and stream flows in the Great Lakes using regression analysis and Mann-Kendall statistics.

Keeping in view the above back ground, the present study has been carried to evaluate the trend of temperature, in a part of Subansiri River basin, the biggest tributary of Brahmaputra River in India. The SubansiriRiver basin located in the eastern Himalayan region has been selected for the study. Subansiri River is a large trans-boundary River flowing through two states of India namely, Arunachal Pradesh and Assam. Several major and minor hydro-electric power stations are being built over the river and several more are under consideration. Hence, it is very important to understand the impact of climate change on the hydrology of this mountain basin for proper planning and management of the water resources. Gangwar (2006) has reported that the trend of climate change in India has shown a sudden acceleration in pace after 1971. The 1990s was reported to be the warmest decade since the beginning of the record in 1860 (Jones et al., 1998; Hulme, 1999). Eleven of the warmest years were recorded since 1990, with 2005 as the warmest on record (ICIMOD, 2007). The present study is a step further to understand the behaviour of climate since late 70's in part of the Brahmaputra basin of India.

MATERIALS AND METHODS

1. GENERAL

Most statistical tests assume that the time series data are independent and identically distributed. The definition of climatic regime shifts, for example, is often based on "differing average climatic levels over a multi-annual duration" (Overland et al., 2006). It is not surprising, therefore, that a major part of the research effort is directed at developing the methods for detecting shifts in the mean. Parametric tests assume that the time series data and the errors (deviations from the trend) follow a particular distribution. Most parametric tests assume that the data are normally distributed. Parametric tests are useful as they also quantify the change in the data (e.g., change in mean or gradient of trend). Non-parametric tests are generally distribution-free. They detect trend/change, but do not quantify the size of the trend/change. They are very useful because most hydrologic time series data are not normally distributed. There exist a number of parametric and nonparametric methods for detection of trend (e.g. McBean and Motiee, 2006). Few methods among them are Mann-Kendall (non-parametric), Spearman's Rho (non-parametric), and Linear Regression (parametric). In the present study, three methods viz. regression, MK test and Sen's estimator were used. These are described in the following sections. The methodology adopted in the study is schematically shown in figure 1.

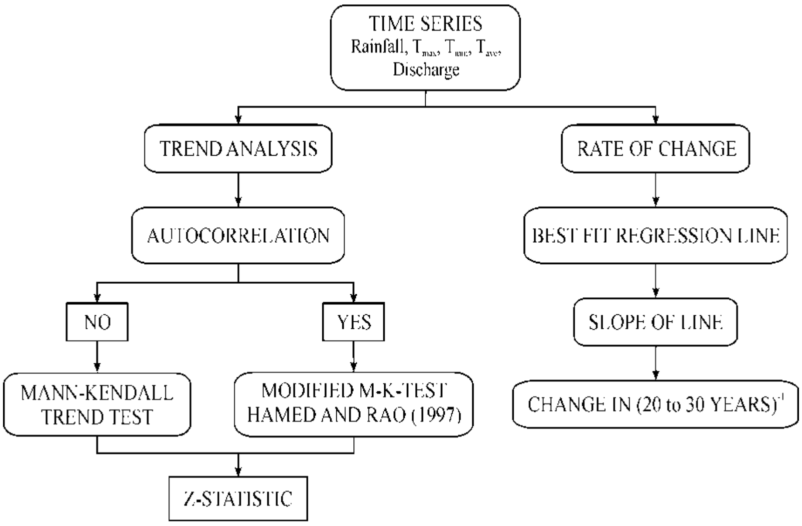

Fig. 1: Flow Chart of the Methodology

2. Regression model

One of the most useful parametric models to detect the trend is the "Simple Linear Regression" model. The method of linear regression requires the assumptions of normality of residuals, constant variance, and true linearity of relationship (Helsel and Hirsch, 1992). The model for Y (e.g. precipitation) can be described by an equation of the form:

$$Y = at + b \tag{2.1}$$

Where, t = time (year)
a = slope coefficient; and
b = least-squares estimate of the intercept

The slope coefficient indicates the annual average rate of change in the hydrologic characteristic. If the slope is significantly different from zero statistically, it is entirely reasonable to interpret that there is a real change occurring over time. The sign of the slope defines the direction of the trend of the variable: increasing if the sign is positive, and decreasing if the sign is negative.

Mann Kendall model

Simple linear regression analysis may provide a primary indication of the presence of trend in the time-series data. Other methods, such as the non-parametric Mann- Kendall (MK) test, which is commonly used for hydrologic data analysis, can be used to detect trends that are monotonic but not necessarily linear. The MK test does not require the assumption of normality, and only indicates the direction but not the magnitude of significant trends (USGS, 2005; Helsel and Hirsch, 1992).

The trend in the data was quantified using Mann-Kendall's S-statistic (Mann, 1945; Kendall, 1955). The MK method assumes that the time series under research are stable, independent and random with equal probability distribution (Zhang et al., 2005). The MK test is applied to uncorrelated data because it was reported that the presence of serial correlation might lead to an erroneous rejection of the null hypothesis (Helsel and Hirsch, 1992; Kulkarni and von Storch, 1995; Yue et al., 2002; Yue and Wang, 2002; Yue and Pilon, 2003).

The computational procedure for the MK test is described in Adamowski and Bougadis (2003). Let the time series consist of n data points and Ti and Tj be two sub –sets of data where i = 1,2,3…….., n-1 and j = i+1, i+2, i+3,…………n. Each data point T is used as a reference point and is compared with all the Tj data points such that:

$$\text{Sign}(T) = \begin{cases} 1 \text{ for } T_j > T_i \\ 0 \text{ for } T_j = T_i \\ 1 \text{for } T_j < T_i \end{cases} \tag{2.2}$$

The MK test used in the present study is based on the test statistic, *S*, defined as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sign}(Tj - Ti) \qquad (2.3)$$

The variance for the S-statistic is defined by:

$$\sigma^2 = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n} t_i(i)(i-1)(2i+5)}{18} \qquad (2.4)$$

In which t_i denotes the number of ties to extent i. The summation term in Eq. (2.4) is only used if data series contains the “tied” values. The test statistic, *Zs*, can be calculated as

$$Z_s = \begin{cases} (S-1)/\sigma \ \text{for} \ S > 0 \\ 0 \ \text{for} \ S = 0 \\ (S+1)/\sigma \ \text{for} \ S < 0 \end{cases} \qquad (2.5)$$

In which Z_s follows a standard normal distribution. Equation 2.5 is useful for record lengths greater than 10 and if the number of tied data is low (Kendall, 1955). The test statistic, Z_s is used as a measure of significance of trend. In fact, this test statistic is used to test the null hypothesis, H_0: There is no monotonic trend in the data. If $|Z_s|$ is greater than $Z_{\alpha/2}$ where α represents the chosen significance level (usually 5%, with $Z_{0.025}$=1.96), then the null hypothesis is rejected, meaning that the trend is significant. For this study, the simple regression analysis technique was used to test the slopes of the trend lines for statistical significance at 5% level. The Mann-Kendall trend test procedure is applied to further verify the outcomes of regression analysis for the hydrological variables considered

MK test holds well in the case of non-auto correlated time series data. For auto-correlated data, modified Mann-Kendall test proposed by Hamed and Rao (1997) was used, which is robust in presence of autocorrelation. It is based on the modified variance of *S given* by Eq. (2.5).

$$V^*(S) = \mathrm{var}(S)\frac{n}{n_s^*} = \frac{n(n-1)(2n+5)}{18}\frac{n}{n_S^*} \qquad (2.6)$$

The recommended approximate value of n/n_s^* *n*/*n*₂ is given by the equation (2.7)

$$\frac{n}{n_S^*} = 1 + \frac{2}{n(n-1)(n-2)} \sum_{i=1}^{n-1} (n-1)(n-i-1)(n-1-2)\rho_S(i) \qquad (2.7)$$

Where *n* is the actual number of observations and $\rho_S(i)$ is the autocorrelation function of the ranks of the observations. The accuracy of the approximation given by the Eq. 2.6 was found to improve as *n* increases. The autocorrelation between ranks of observations $\rho_S(i)$ is first evaluated. The value of ranks of observations $\rho_S(i)$, however, must be calculated after subtracting a suitable non-parametric trend estimator. Due to the nature of calculation in Eq. 2.5, which involves large number of terms, it was found that insignificant value of $\rho_S(i)$ will have an adverse effect on the accuracy of the estimated variance of *S*. Therefore, only significant values of $\rho_S(i)$ are used. This is achieved by requiring a suitable pre-set significance level for the autocorrelation to be included in the calculations, which can be taken equal to that of the rest.

In the present study, non-parametric Mann-Kendall trend test and modified Mann-Kendall test as proposed by Hamed and Rao (1997) were applied to study the trend in rainfall, temperature and stream flow and described in the following sections.

Sen's Estimator

The magnitude of trend in a time series can be determined using non-parametric method known as Sen's estimator. Sen's estimator method assumes a linear trend in the time series. In this method, the slopes (Ti) of all data pairs are calculated first by

For i = 1, 2,…….., N $$T_i = \frac{x_j - x_k}{j - k}$$

Where xj and xk are data values at time j and k (j>k) respectively.

The median of these N values of Ti gives the Sen's estimator of slope (β). A positive value of β indicates an upward trend and a negative value indicates a downward trend in the time series.

RESULTS AND DISCUSSION

ASSESSMENT OF HISTORICAL TRENDS

Gangwar (2006) has reported that the trend of climate change in India has shown a sudden acceleration in pace after 1971. The 1990s was reported to be the warmest decade since the beginning of the record in 1860 (Jones et al., 1998; Hulme, 1999). Eleven of the warmest years were recorded since 1990, with 2005 as the warmest on record (ICIMOD, 2007). The present study is a step further to understand the behaviour of climate since late 70s in part of Himalayan terrain of India. For the present study, Daily Gridded Temperature Data (maximum, minimum, and mean) of 1X1 diglatitude and longitude for eight stations (grid points) has been used.

The details of availability of the above data are given in the Table 1

Table 1: Summary of stations for which daily maximum, mean and minimum air temperature data were available

GRIDS/STATION	PERIOD OF DATA AVAILABILITY
Daily Maximum Temperature	
G1	1969-2005
G2	1969-2005
G3	1969-2005
G4	1969-2005
G5	1969-2005
G6	1969-2005
G7	1969-2005
G8	1969-2005
Daily Minimum Temperature	
G1	1969-2005
G2	1969-2005
G3	1969-2005
G4	1969-1999
G5	1969-1999
G6	1969-1999
G7	1969-1999
G8	1969-1999
Daily Mean Temperature	
G1	1969-2005
G2	1969-2005
G3	1969-2005
G4	1969-1999
G5	1969-1999
G6	1969-1999
G7	1969-1999
G8	1969-1999

DATA PREPARATION

The data has been analysed in following categories

1 **Annual**: Using the daily data, series of average annual data has been prepared for trend analysis for all the variables and for all the grids/stations

2 **Seasonal**: Four types seasonal data preparation has been carried out. Data were divided into four seasons, namely pre-monsoon (March-May), monsoon (June-August), post-monsoon (September-November) and winter (December-February) based on the prevailing climate of India.

3 **Monthly:** Using the daily data, series of average monthly data has been prepared for trend analysis for all the variables and for all the grids/stations

TEMPERATURE TRENDS

For better understanding of the observed trends, linear regression analysis was also performed with the data. The magnitude of the change in the variables namely rainfall, temperature, water level, sediment concentration and discharge were represented by the slope of the regression line.

For trend analysis at 5% significance level, at first, the time series were checked for randomness, autocorrelation and long-term persistence before conducting the Mann-Kendall test. Time series having no autocorrelation are analysed with Mann-Kendall's Test for the detection of trend and if significant autocorrelation is found in the data, the time series is tested with modified Mann-Kendall test as suggested by Hamed and Rao (1997). The amount of trend was estimated using the sen's estimator. The results have been summarised in Tables. Graphical presentation is shown in figures for max, minimum, mean and diurnal temperature data at the end of this chapter. The results are discussed in the following sections.

Table 2: Trend in Maximum Temperature

MAX	Grid	Auto-correlation	Mk-z Statistic	Sen's value	Dominant Trend
JANUARY	T1	NO	-1.84	-0.02	No
	T2	NO	-1.19	-0.01	NO
	T3	NO	-0.72	-0.01	NO
	T4	NO	-0.14	0.00	NO
	T5	NO	-1.71	-0.02	NO
	T6	NO	-1.48	-0.02	NO
	T7	NO	-0.43	-0.01	NO
	T8	NO	-0.17	0.00	NO
FEBUARY	T1	NO	-0.59	-0.01	NO
	T2	NO	-0.20	0.00	NO
	T3	NO	0.09	0.00	NO
	T4	NO	0.25	0.00	NO
	T5	NO	-0.77	-0.01	NO
	T6	NO	-0.59	-0.01	NO
	T7	NO	0.22	0.00	NO
	T8	NO	0.25	0.01	NO
MARCH	T1	NO	-2.52	-0.05	Decreasing
	T2	NO	-2.24	-0.04	Decreasing
	T3	NO	-2.18	-0.04	Decreasing
	T4	NO	-2.08	-0.04	Decreasing
	T5	NO	-2.37	-0.05	Decreasing
	T6	NO	-2.37	-0.05	Decreasing
	T7	NO	-2.16	-0.04	Decreasing
	T8	NO	-2.11	-0.04	Decreasing
APRIL	T1	NO	-2.08	-0.05	Decreasing
	T2	NO	-1.77	-0.04	NO
	T3	NO	-1.71	-0.03	NO
	T4	NO	-1.22	-0.03	NO
	T5	NO	-1.84	-0.05	NO
	T6	NO	-1.78	-0.04	NO
	T7	NO	-1.61	-0.03	NO
	T8	NO	-1.40	-0.03	NO
MAY	T1	NO	-0.80	-0.01	NO
	T2	NO	-0.75	-0.01	NO
	T3	NO	-0.46	-0.01	NO
	T4	NO	-0.75	-0.01	NO
	T5	NO	-0.88	-0.01	NO
	T6	NO	-0.64	-0.01	NO
	T7	NO	-0.67	-0.01	NO
	T8	NO	-0.84	-0.01	NO
JUNE	T1	NO	0.90	0.01	NO
	T2	NO	0.61	0.01	NO
	T3	NO	0.35	0.00	NO
	T4	NO	0.33	0.00	NO
	T5	NO	0.61	0.01	NO
	T6	NO	0.33	0.01	NO
	T7	NO	0.17	0.00	NO
	T8	NO	0.33	0.00	NO
JULY	T1	NO	-0.77	-0.01	NO
	T2	NO	-0.61	-0.01	NO
	T3	NO	-0.43	0.00	NO
	T4	NO	-0.22	0.00	NO
	T5	NO	-1.03	-0.01	NO
	T6	NO	-0.82	-0.01	NO
	T7	NO	-0.27	0.00	NO

	T8	NO	-0.12	0.00	NO
AUGUST	T1	NO	0.39	0.00	NO
	T2	NO	0.56	0.00	NO
	T3	NO	0.64	0.01	NO
	T4	NO	0.51	0.01	NO
	T5	NO	0.07	0.00	NO
	T6	NO	0.13	0.00	NO
	T7	NO	0.51	0.01	NO
	T8	NO	0.41	0.00	NO
September	T1	NO	-0.46	0.00	NO
	T2	NO	-0.09	0.00	NO
	T3	NO	0.09	0.00	NO
	T4	NO	0.30	0.00	NO
	T5	NO	-0.46	0.00	NO
	T6	NO	-0.43	-0.01	NO
	T7	NO	0.12	0.00	NO
	T8	NO	0.20	0.00	NO
OCTOBER	T1	NO	-0.59	0.00	NO
	T2	NO	-0.60	-0.01	NO
	T3	NO	-0.46	0.00	NO
	T4	NO	-0.07	0.00	NO
	T5	NO	-1.26	-0.01	NO
	T6	NO	-0.72	-0.01	NO
	T7	NO	-0.09	0.00	NO
	T8	NO	-0.04	0.00	NO
NOVEMBER	T1	NO	0.59	0.01	NO
	T2	NO	0.93	0.01	NO
	T3	NO	0.95	0.01	NO
	T4	NO	1.19	0.01	NO
	T5	NO	0.27	0.00	NO
	T6	NO	0.30	0.00	NO
	T7	NO	1.01	0.01	NO
	T8	NO	0.98	0.01	NO
DECEMBER	T1	NO	0.77	0.01	NO
	T2	NO	1.32	0.02	NO
	T3	NO	1.43	0.02	NO
	T4	NO	1.65	0.02	NO
	T5	NO	0.43	0.01	NO
	T6	NO	1.09	0.01	NO
	T7	NO	1.56	0.02	NO
	T8	NO	1.53	0.02	NO
MEAN	TREND	Auto-Correlation	MK-Z STATISTIC	SEN'VALU	TREND
JANUARY	T1	NO	0.35	0.00	NO
	T2	NO	1.11	0.01	NO
	T3	NO	1.22	0.01	NO
	T4	NO	1.56	0.02	NO
	T5	NO	0.20	0.00	NO
	T6	NO	0.85	0.01	NO
	T7	NO	1.56	0.02	NO
	T8	NO	1.40	0.02	NO
FEBUARY	T1	NO	0.39	0.01	NO
	T2	NO	1.05	0.02	NO
	T3	NO	1.05	0.02	NO
	T4	NO	1.10	0.02	NO
	T5	NO	0.58	0.01	NO
	T6	NO	0.78	0.01	NO
	T7	NO	1.05	0.02	NO
	T8	NO	1.05	0.02	NO
MARCH	T1	NO	0.75	0.01	NO
	T2	NO	0.25	0.00	NO
	T3	NO	0.14	0.00	NO
	T4	NO	0.00	0.00	NO
	T5	NO	0.61	0.01	NO
	T6	NO	0.85	0.01	NO
	T7	NO	0.22	0.00	NO
	T8	NO	0.61	0.01	NO
APRIL	T1	NO	-0.73	-0.02	NO
	T2	NO	-0.78	-0.02	NO
	T3	NO	-1.01	-0.02	NO
	T4	NO	-0.99	-0.02	NO
	T5	NO	-0.78	-0.02	NO
	T6	NO	-1.05	-0.02	NO
	T7	NO	-0.34	-0.01	NO
	T8	NO	-0.24	-0.01	NO

MAY	T1	NO	0.75	0.01	NO
	T2	NO	0.25	0.00	NO
	T3	NO	0.14	0.00	NO
	T4	NO	0.00	0.00	NO
	T5	NO	0.61	0.01	NO
	T6	NO	0.85	0.01	NO
	T7	NO	0.22	0.00	NO
	T8	NO	0.61	0.01	NO
JUNE	T1	NO	1.46	0.02	NO
	T2	NO	1.63	0.01	NO
	T3	NO	1.32	0.01	NO
	T4	NO	1.28	0.01	NO
	T5	NO	2.18	0.02	Increasing
	T6	NO	1.63	0.01	NO
	T7	NO	1.90	0.02	NO
	T8	NO	1.31	0.05	NO
JULY	T1	NO	0.44	0.00	NO
	T2	NO	0.47	0.00	NO
	T3	NO	0.50	0.00	NO
	T4	Yes	2.47	0.03	Increasing
	T5	Yes	2.39	0.05	Increasing
	T6	Yes	0.79	0.01	NO
	T7	Yes	2.36	2.36	Increasing
	T8	Yes	2.31	0.03	Increasing
AUGUST	T1	NO	1.87	0.01	NO
	T2	NO	1.56	0.01	NO
	T3	NO	0.77	0.00	NO
	T4	Yes	1.87	0.03	NO
	T5	Yes	1.81	0.02	NO
	T6	Yes	0.19	0.01	NO
	T7	Yes	1.98	0.03	Increasing
	T8	Yes	2.01	0.03	Increasing
September	T1	NO	0.86	0.01	NO
	T2	NO	1.18	0.01	NO
	T3	NO	1.07	0.01	NO
	T4	Yes	2.69	0.04	Increasing
	T5	Yes	2.58	0.04	Increasing
	T6	Yes	1.28	0.02	NO
	T7	Yes	2.71	0.04	Increasing
	T8	Yes	2.77	0.04	Increasing
OCTOBER	T1	NO	0.51	0.00	NO
	T2	NO	0.72	0.01	NO
	T3	NO	0.59	0.01	NO
	T4	Yes	2.39	0.06	Increasing
	T5	Yes	2.39	0.05	Increasing
	T6	Yes	0.68	0.02	NO
	T7	Yes	0.06	0.06	NO
	T8	Yes	0.06	0.06	NO
NOVEMBER	T1	NO	1.32	0.01	NO
	T2	NO	1.71	0.02	NO
	T3	NO	1.69	0.02	NO
	T4	NO	1.53	0.01	NO
	T5	NO	1.03	0.01	NO
	T6	NO	1.69	0.01	NO
	T7	NO	1.66	0.02	NO
	T8	NO	1.58	0.02	NO
DECEMBER	T1	NO	2.11	0.03	Increasing
	T2	NO	2.68	0.03	Increasing
	T3	NO	2.71	0.03	Increasing
	T4	Yes	2.00	0.04	Increasing
	T5	NO	1.97	0.02	No
	T6	NO	2.58	0.03	Increasing
	T7	NO	3.00	0.03	Increasing
	T8	Yes	2.22	0.04	Increasing
Minimum	Grid	Auto-correlation	Mk-z Statistic	Sen’s value	Trend
JANUARY	T1	NO	2.35	0.03	Increasing
	T2	NO	2.54	0.03	Increasing
	T3	NO	2.49	0.03	Increasing
	T4	NO	2.30	0.03	Increasing
	T5	NO	2.59	0.03	Increasing
	T6	NO	2.67	0.03	Increasing
	T7	NO	2.59	0.03	Increasing
	T8	NO	2.20	0.03	Increasing
FEBUARY	T1	NO	1.86	0.03	NO
	T2	NO	2.15	0.04	Increasing
	T3	NO	2.17	0.04	Increasing
	T4	NO	2.09	0.03	Increasing
	T5	NO	2.22	0.04	Increasing
	T6	NO	1.78	0.04	NO
	T7	NO	2.15	0.03	NO

	T8	NO	2.01	0.03	Increasing
MARCH	T1	NO	1.96	0.02	Increasing
	T2	NO	1.36	0.02	NO
	T3	NO	1.23	0.01	NO
	T4	NO	0.99	0.01	NO
	T5	NO	2.25	0.03	Increasing
	T6	NO	2.07	0.02	Increasing
	T7	NO	1.18	0.02	NO
	T8	NO	1.18	0.01	NO
APRIL	T1	NO	1.05	0.01	NO
	T2	NO	1.10	0.01	NO
	T3	NO	0.50	0.01	NO
	T4	NO	0.55	0.00	NO
	T5	NO	0.94	0.01	NO
	T6	NO	1.10	0.01	NO
	T7	NO	0.81	0.01	NO
	T8	NO	1.28	0.01	NO
MAY	T1	yes	1.57	0.02	NO
	T2	NO	1.52	0.02	NO
	T3	NO	1.20	0.01	NO
	T4	NO	1.12	0.01	NO
	T5	yes	1.38	0.02	NO
	T6	yes	1.78	0.02	NO
	T7	yes	1.13	0.01	NO
	T8	NO	1.23	0.01	NO
JUNE	T1	Yes	2.87	0.03	Increasing
	T2	Yes	2.52	0.02	Increasing
	T3	Yes	1.92	0.02	NO
	T4	Yes	2.19	0.02	Increasing
	T5	Yes	2.52	0.03	Increasing
	T6	Yes	1.98	0.02	Increasing
	T7	NO	3.32	0.02	Increasing
	T8	Yes	2.56	0.04	Increasing
JULY	T1	Yes	2.03	0.02	Increasing
	T2	No	2.59	0.02	Increasing
	T3	Yes	1.84	0.01	NO
	T4	Yes	2.64	0.04	Increasing
	T5	Yes	2.30	0.04	Increasing
	T6	Yes	1.51	0.03	NO
	T7	Yes	1.95	0.03	NO
	T8	Yes	2.11	0.03	Increasing
AUGUST	T1	Yes	1.92	0.03	NO
	T2	Yes	1.62	0.02	NO
	T3	Yes	1.40	0.02	NO
	T4	Yes	2.63	0.04	Increasing
	T5	Yes	1.98	0.04	Increasing
	T6	Yes	0.38	0.02	NO
	T7	Yes	0.86	0.02	NO
	T8	Yes	0.94	0.02	NO
September	T1	No	3.13	0.02	Increasing
	T2	No	3.39	0.02	Increasing
	T3	No	2.84	0.02	Increasing
	T4	Yes	2.50	0.04	Increasing
	T5	No	2.13	0.03	Increasing
	T6	Yes	2.93	0.02	Increasing
	T7	No	2.40	0.03	Increasing
	T8	No	2.42	0.02	Increasing
OCTOBER	T1	No	1.05	0.01	NO
	T2	No	1.41	0.02	NO
	T3	No	1.33	0.02	NO
	T4	Yes	1.99	0.07	Increasing
	T5	Yes	0.98	0.04	NO
	T6	Yes	-0.79	0.00	NO
	T7	Yes	0.01	0.02	NO
	T8	Yes	0.01	0.01	NO
NOVEMBER	T1	Yes	1.10	0.02	NO
	T2	Yes	1.46	0.02	NO
	T3	No	1.31	0.02	NO
	T4	Yes	1.10	0.01	NO
	T5	Yes	1.38	0.02	NO
	T6	No	1.52	0.02	NO
	T7	No	1.33	0.02	NO
	T8	No	1.15	0.02	NO
DECEMBER	T1	No	2.83	0.04	Increasing
	T2	No	2.93	0.04	Increasing
	T3	No	2.83	0.04	Increasing
	T4	Yes	1.73	0.05	NO
	T5	No	3.06	0.04	Increasing
	T6	No	2.80	0.04	Increasing
	T7	No	2.77	0.04	Increasing
	T8	Yes	1.89	0.04	NO

Trend of Diurnal Temp					
Monthly	Grid	Auto-correlation	MK-z statistic	Sen's value	Trend
JANUARY	T1	No	-3.24	-0.06	Decreasing
	T2	No	-2.81	-0.05	Decreasing
	T3	No	-2.38	-0.04	Decreasing
	T4	No	-1.69	-0.04	No
	T5	No	-3.70	-0.06	Decreasing
	T6	No	-3.18	-0.06	Decreasing
	T7	No	-2.21	-0.04	Decreasing
	T8	No	-1.82	-0.03	No
FEBUARY	T1	No	-2.21	-0.04	Decreasing
	T2	No	-1.92	-0.03	NO
	T3	No	-1.53	-0.03	NO
	T4	No	-1.53	-0.02	NO
	T5	No	-2.76	-0.05	Decreasing
	T6	No	-2.21	-0.04	Decreasing
	T7	No	-1.48	-0.02	NO
	T8	No	-1.58	-0.03	NO
MARCH	T1	No	-3.23	-0.06	Decreasing
	T2	No	-2.81	-0.06	Decreasing
	T3	No	-2.71	-0.05	Decreasing
	T4	No	-2.03	-0.05	Decreasing
	T5	No	-3.73	-0.07	Decreasing
	T6	No	-3.39	-0.07	Decreasing
	T7	No	-2.58	-0.05	Decreasing
	T8	No	-2.37	-0.05	Decreasing
APRIL	T1	Yes	-2.11	0.07	Decreasing
	T2	Yes	-2.25	-0.06	Decreasing
	T3	Yes	-2.36	-0.06	Decreasing
	T4	Yes	-2.44	-0.05	Decreasing
	T5	Yes	-2.00	-0.07	Decreasing
	T6	Yes	-2.19	-0.07	Decreasing
	T7	Yes	-2.11	-0.06	Decreasing
	T8	Yes	-2.71	-0.06	Decreasing
MAY	T1	Yes	-1.68	-0.03	NO
	T2	No	-2.68	-0.03	Decreasing
	T3	No	-2.39	-0.03	Decreasing
	T4	No	-1.84	-0.02	NO
	T5	No	-2.89	-0.04	Decreasing
	T6	No	-2.94	-0.03	Decreasing
	T7	No	-2.39	-0.03	Decreasing
	T8	No	-1.95	-0.03	NO
JUNE	T1	No	-1.43	-0.01	NO
	T2	No	-1.45	-0.01	NO
	T3	No	-1.22	-0.01	NO
	T4	No	-0.82	-0.01	NO
	T5	No	-1.61	-0.02	NO
	T6	No	-1.48	-0.02	NO
	T7	No	-1.82	-0.02	NO
	T8	Yes	-1.16	-0.06	NO
JULY	T1	No	-3.07	-0.02	Decreasing
	T2	No	-2.08	-0.04	Decreasing
	T3	No	-2.05	-0.02	Decreasing
	T4	Yes	-2.08	-0.04	Decreasing
	T5	Yes	-1.59	-0.04	NO
	T6	Yes	-3.64	-0.03	Decreasing
	T7	Yes	-1.68	-0.04	NO
	T8	Yes	-1.40	-0.03	NO
AUGUST	T1	No	-2.34	-0.02	Decreasing
	T2	No	-2.26	-0.01	Decreasing
	T3	No	-1.66	-0.01	NO
	T4	Yes	-2.71	-0.06	Decreasing
	T5	Yes	-1.13	-0.02	NO
	T6	Yes	-0.26	-0.01	NO
	T7	Yes	-0.75	-0.02	NO
	T8	Yes	-0.69	-0.02	NO
September	T1	No	-2.55	-0.02	Decreasing
	T2	No	-2.29	-0.02	Decreasing
	T3	No	-1.96	-0.01	NO
	T4	Yes	-2.08	-0.05	Decreasing
	T5	Yes	-0.83	-0.02	NO
	T6	Yes	0.53	-0.02	NO
	T7	Yes	-0.20	-0.02	NO
	T8	Yes	-0.26	-0.02	NO
OCTOBER	T1	No	-1.19	-0.01	NO
	T2	No	-1.63	-0.02	NO
	T3	No	-1.66	-0.02	NO
	T4	Yes	-2.06	-0.06	Decreasing
	T5	Yes	0.18	-0.01	NO
	T6	Yes	0.83	-0.01	NO
	T7	Yes	0.10	-0.01	NO

	T8	Yes	0.04	0.00	NO
NOVEMBER	T1	No	-0.59	-0.01	NO
	T2	No	0.59	0.01	NO
	T3	No	-1.19	-0.02	NO
	T4	No	-0.31	0.00	NO
	T5	No	0.35	0.01	NO
	T6	No	0.22	0.01	NO
	T7	No	0.25	0.01	NO
	T8	No	0.41	0.01	NO
DECEMBER	T1	No	-0.98	-0.02	NO
	T2	No	-0.54	-0.1	NO
	T3	No	-0.43	-0.01	NO
	T4	No	-0.27	0.00	NO
	T5	No	-1.09	-0.02	NO
	T6	No	-0.90	-0.01	NO
	T7	No	-0.25	0.00	NO
	T8	No	-0.14	0.00	NO
Season	Grid	Auto-correlation	Mk-z statistic	Sen's value	Trend
Monsoon	T1	No	-2.63	-0.02	Decreasing
	T2	No	-2.86	-0.02	Decreasing
	T3	No	-2.45	-0.01	Decreasing
	T4	Yes	-2.55	-0.05	Decreasing
	T5	Yes	-0.86	-0.02	NO
	T6	No	-1.95	-0.02	NO
	T7	Yes	-1.57	-0.02	NO
	T8	Yes	-2.03	-0.04	Decreasing
Pre-monsoon	T1	No	-4.25	-0.05	Decreasing
	T2	No	-4.02	-0.05	Decreasing
	T3	No	-3.73	-0.05	Decreasing
	T4	No	-3.26	-0.04	Decreasing
	T5	No	-4.33	-0.05	Decreasing
	T6	No	-4.43	-0.06	Decreasing
	T7	No	-3.83	-0.05	Decreasing
	T8	No	-3.73	-0.05	Decreasing
Post-Monsoon	T1	No	-0.51	-0.01	NO
	T2	No	-0.67	-0.01	NO
	T3	No	-0.88	-0.01	NO
	T4	Yes	-1.87	-0.04	NO
	T5	Yes	-0.12	0.01	NO
	T6	Yes	1.13	0.01	NO
	T7	Yes	0.42	0.01	NO
	T8	Yes	0.53	0.01	NO
Winter	T1	No	-3.28	-0.04	Decreasing
	T2	No	-2.63	-0.03	Decreasing
	T3	No	-2.60	-0.03	Decreasing
	T4	No	-2.13	-0.03	Decreasing
	T5	No	-3.88	-0.04	Decreasing
	T6	No	-3.52	-0.04	Decreasing
	T7	No	-2.81	0.03	Decreasing
	T8	No	-2.13	0.03	Decreasing
Annual	T1	Yes	-1.78	-0.04	NO
	T2	No	-3.86	-0.02	Decreasing
	T3	No	-3.49	-0.02	Decreasing
	T4	**Yes**	-1.78	-0.04	NO
	T5	**Yes**	-1.21	-0.02	NO
	T6	No	-2.00	-0.02	Decreasing
	T7	Yes	-0.56	-0.02	NO
	T8	**yes**	-0.94	-0.02	NO

The above Tables 2presents the results of temperature trend. The maximum and mean temperature does not show any significant trend at most of the grid locations. However, minimum temperature shows significant increasing trend at some grid locations but the diurnal temperature trends show a decreasing trend at almost all the grid locations. This conforms to the IPCC reports of global warming.

The following sections present the results of regression analysis of trend in graphical form for all the available data and it is found that there is close proximity between the results of graphical (regression) and Man-Kendall analysis results.

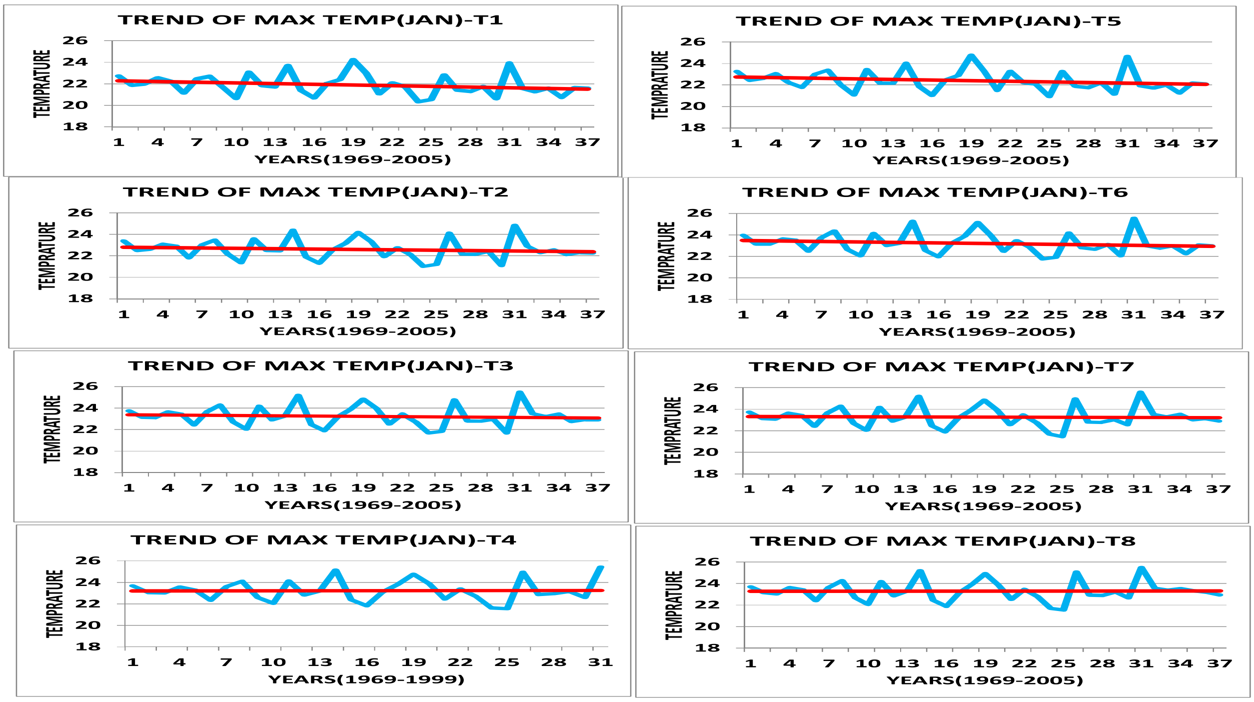

Fig. 2: TREND OF MAX TEMP (JANUARY)

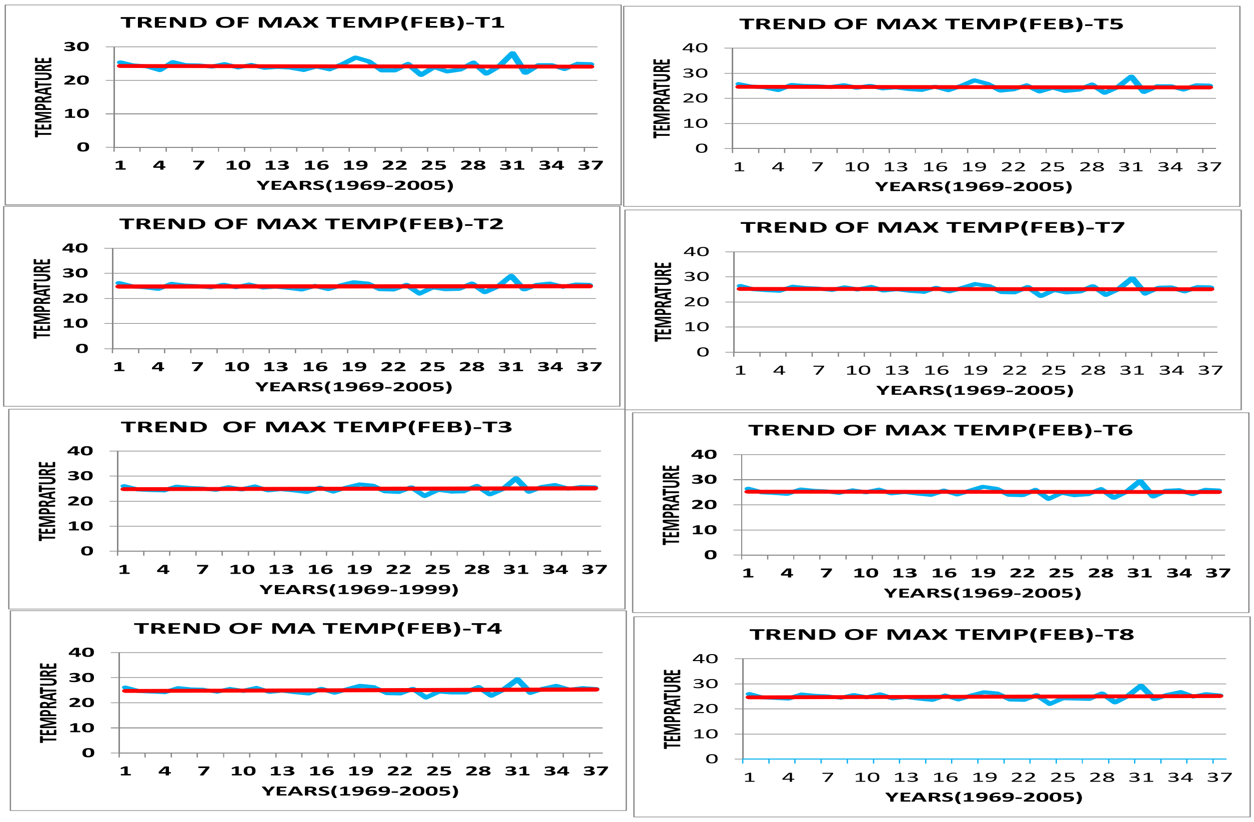

Fig.3: TREND OF MAX TEMP (FEBUARY)

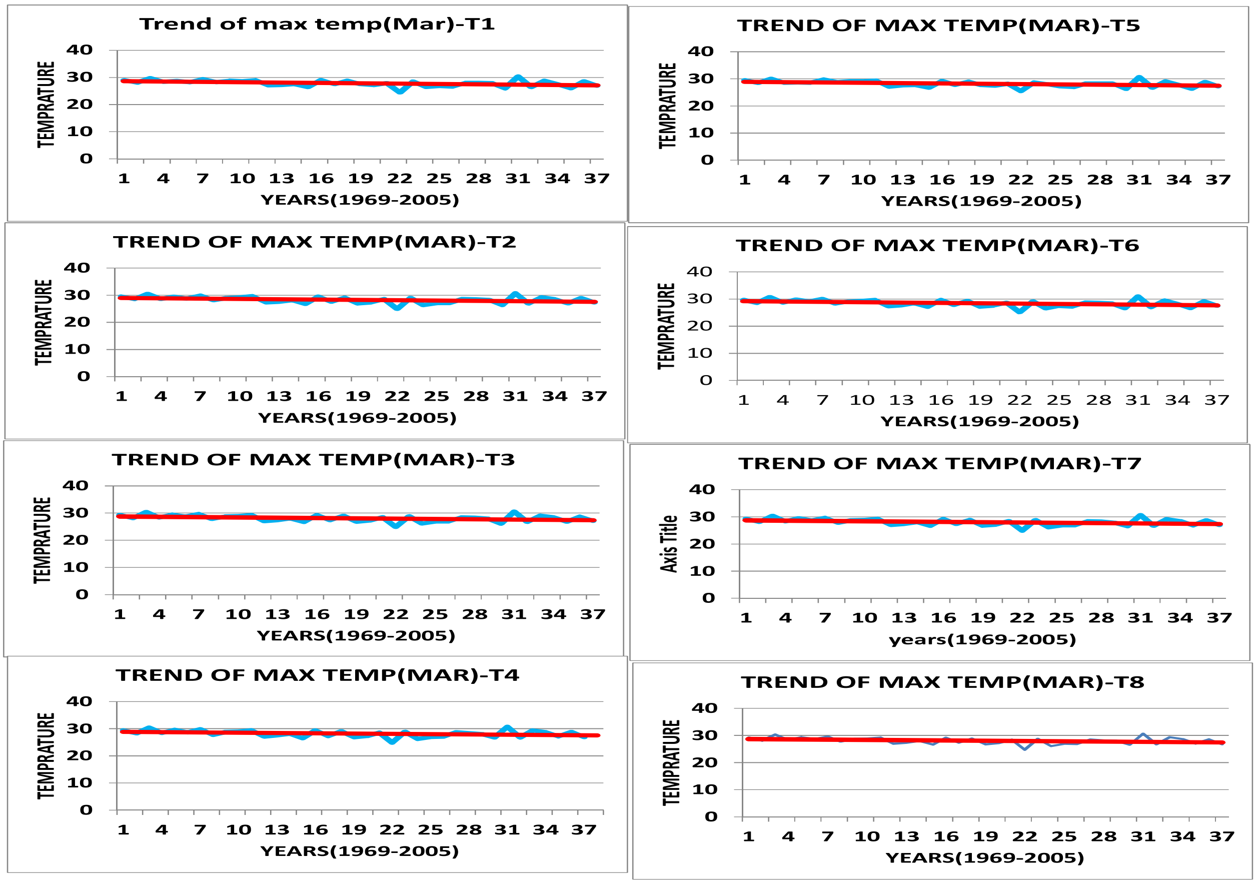

Fig.4: TREND OF MAX TEMP (MARCH)

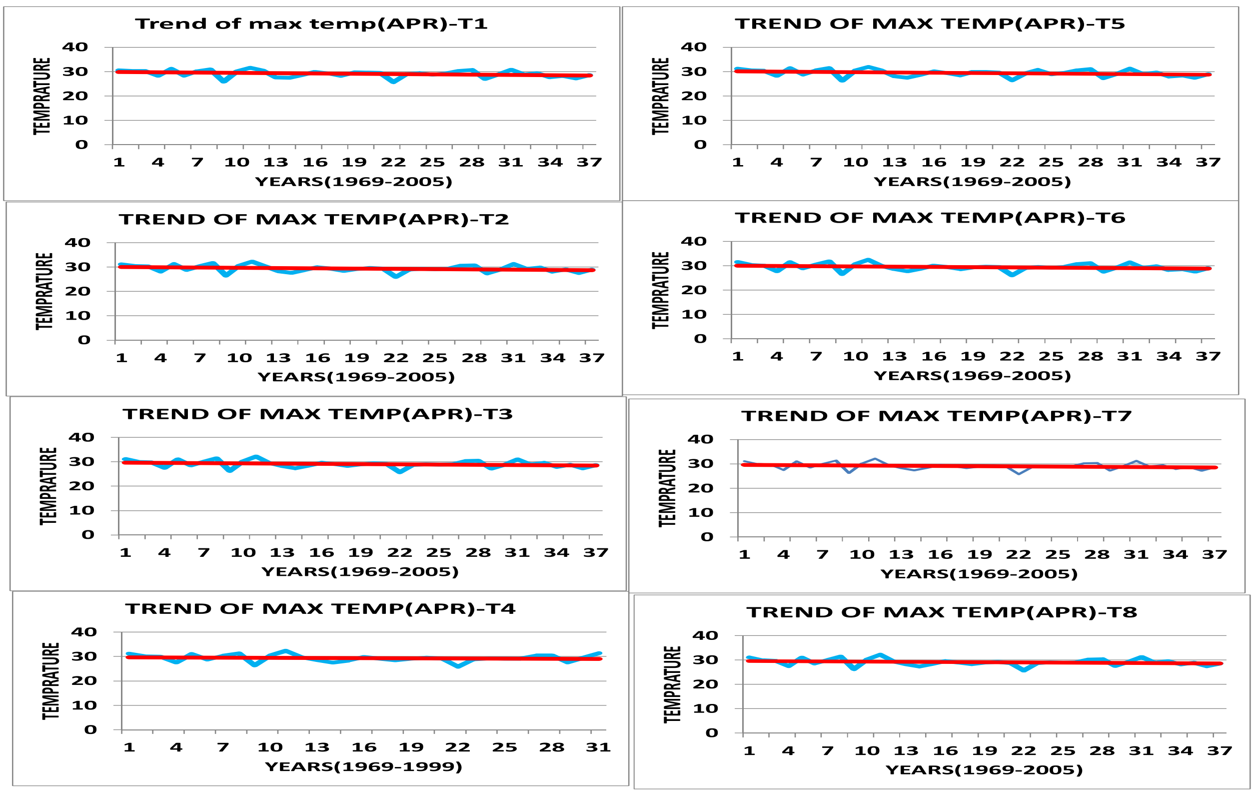

Fig.5: TREND OF MAX TEMP (APRIL)

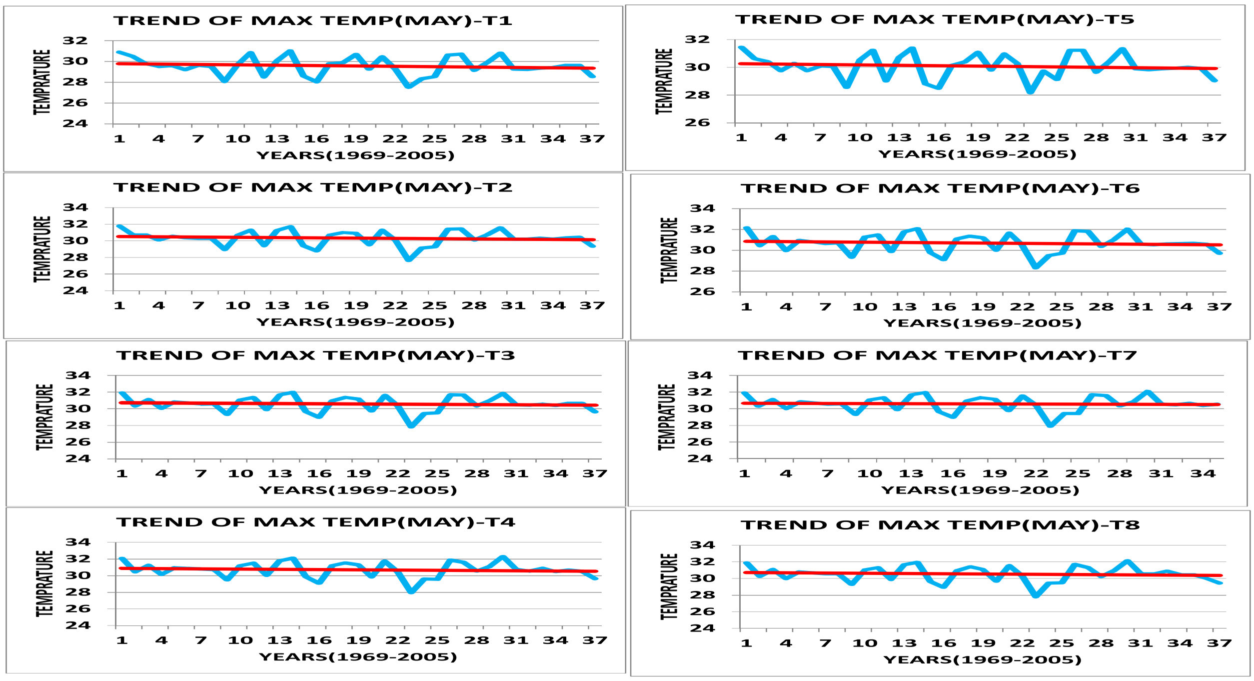

Fig.6: TREND OF MAX TEMP (MAY)

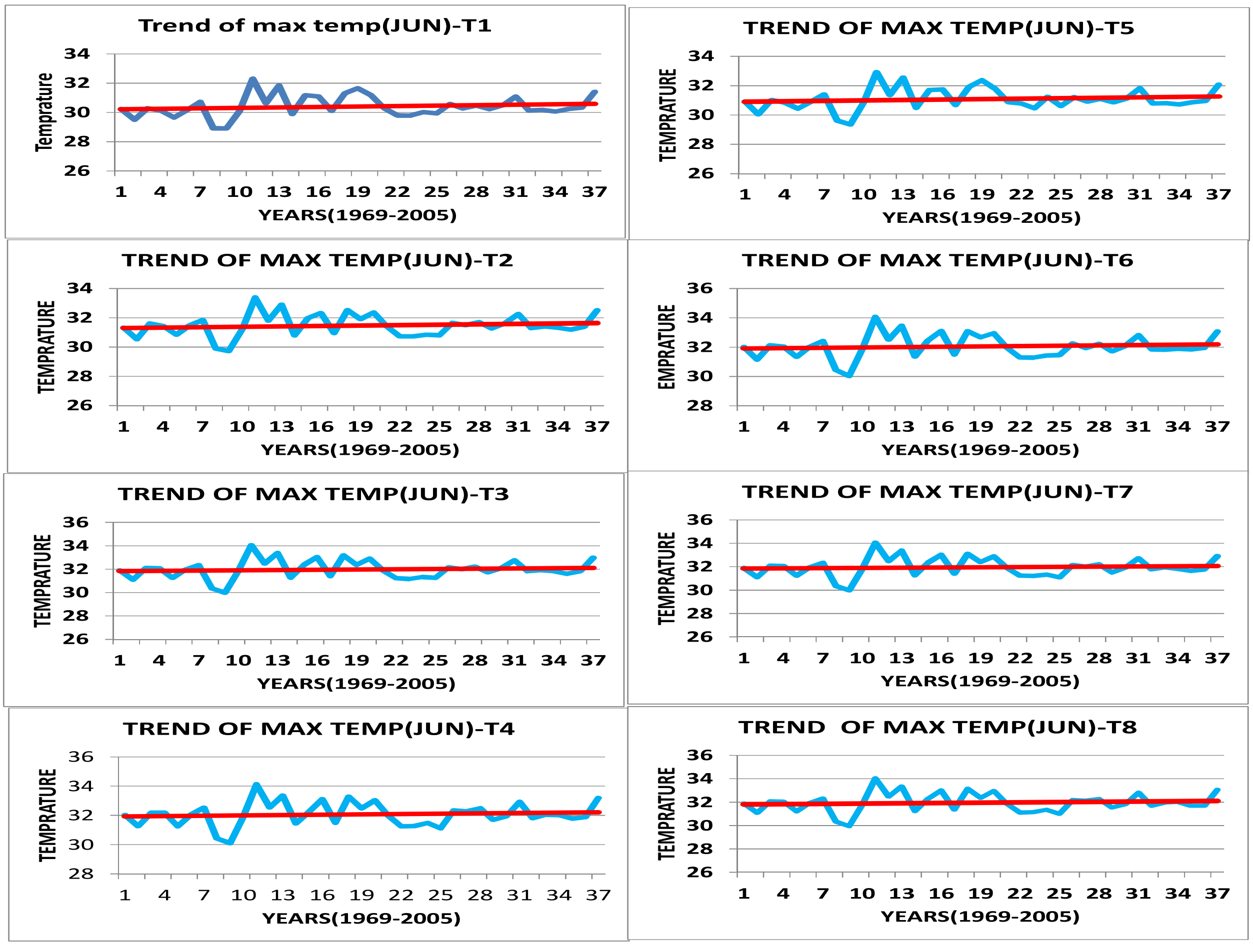

Fig.7: TREND OF MAX TEMP JUNE

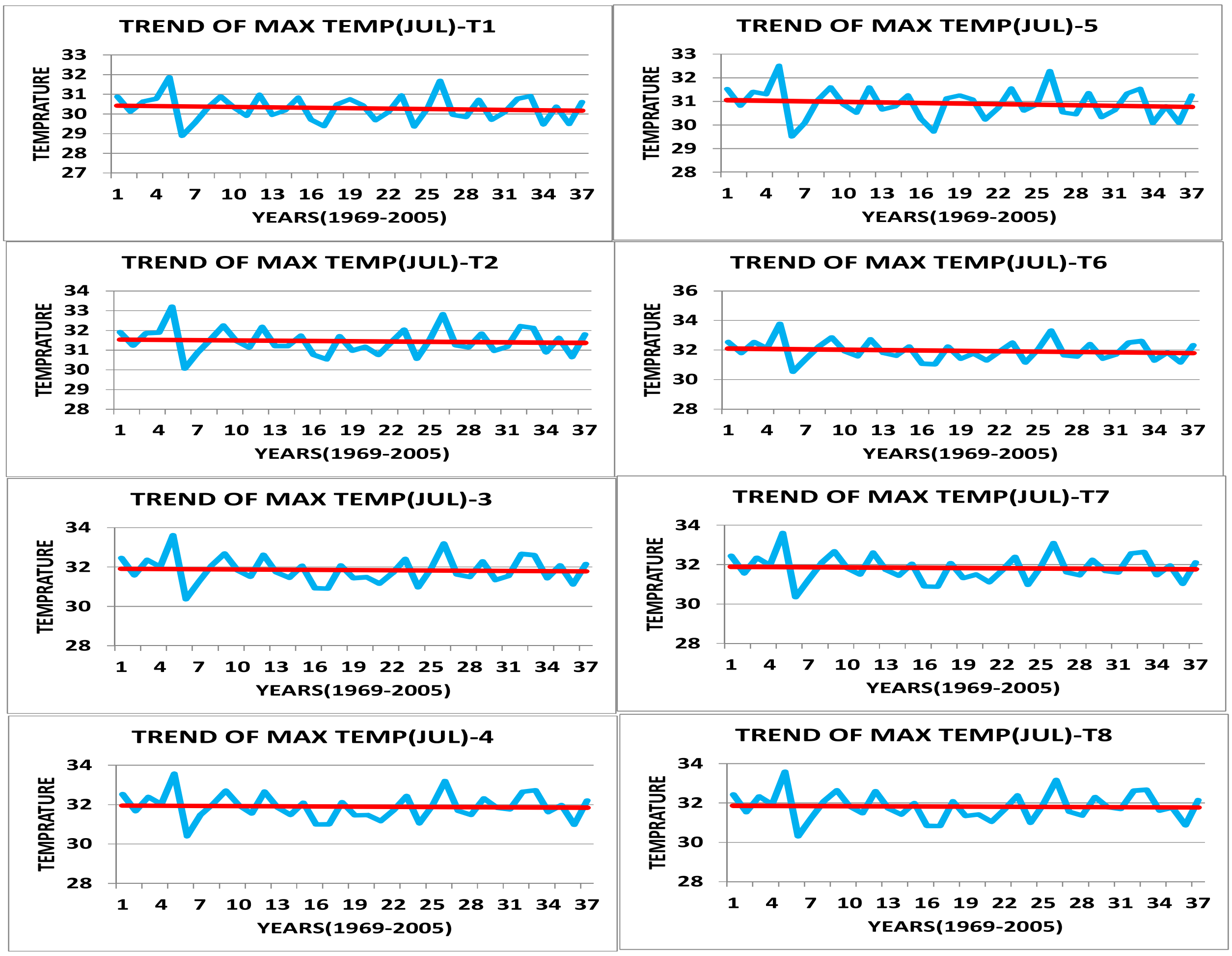

Fig.8: TREND OF MAX TEMP JULY

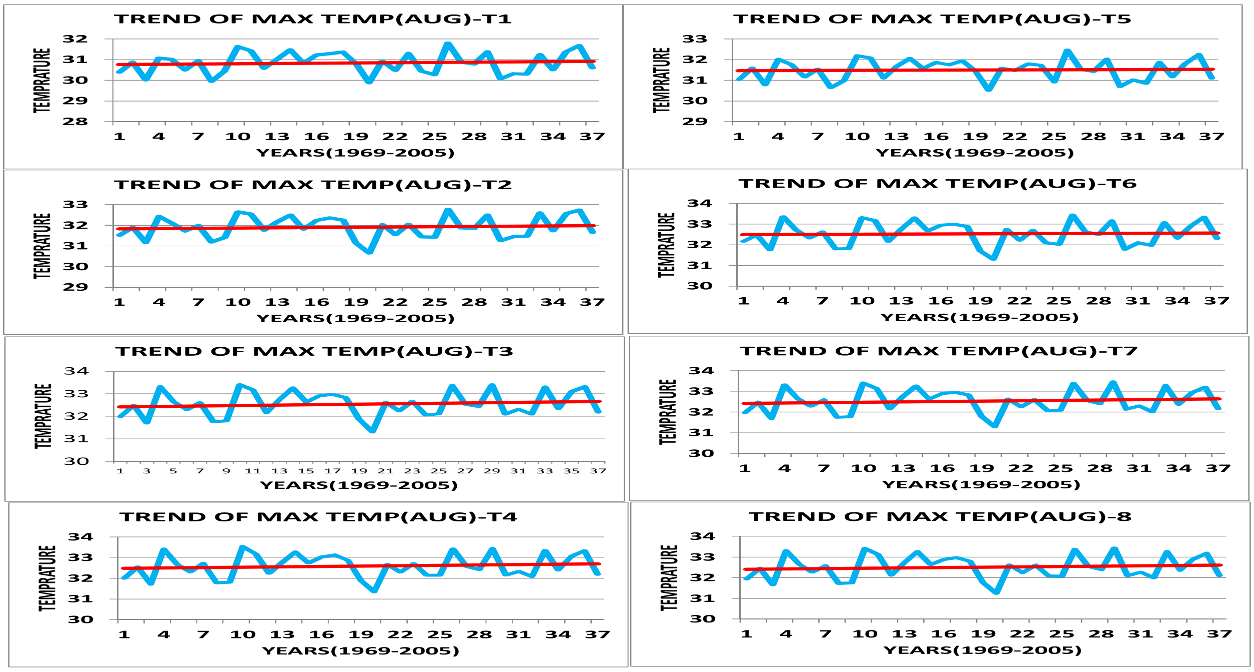

Fig.9: TREND OF MAX TEMP (AUGUST)

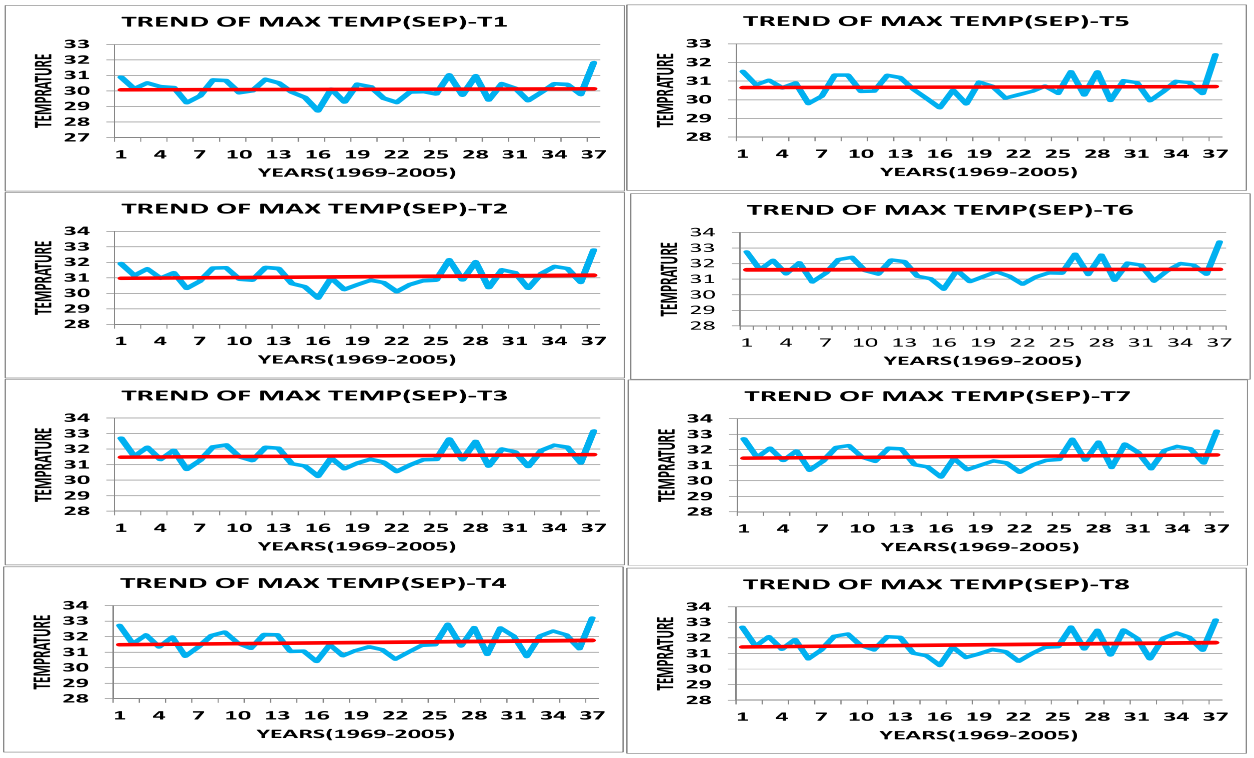

Fig.10: TREND OF MAX TEMP (SEPTEMBER)

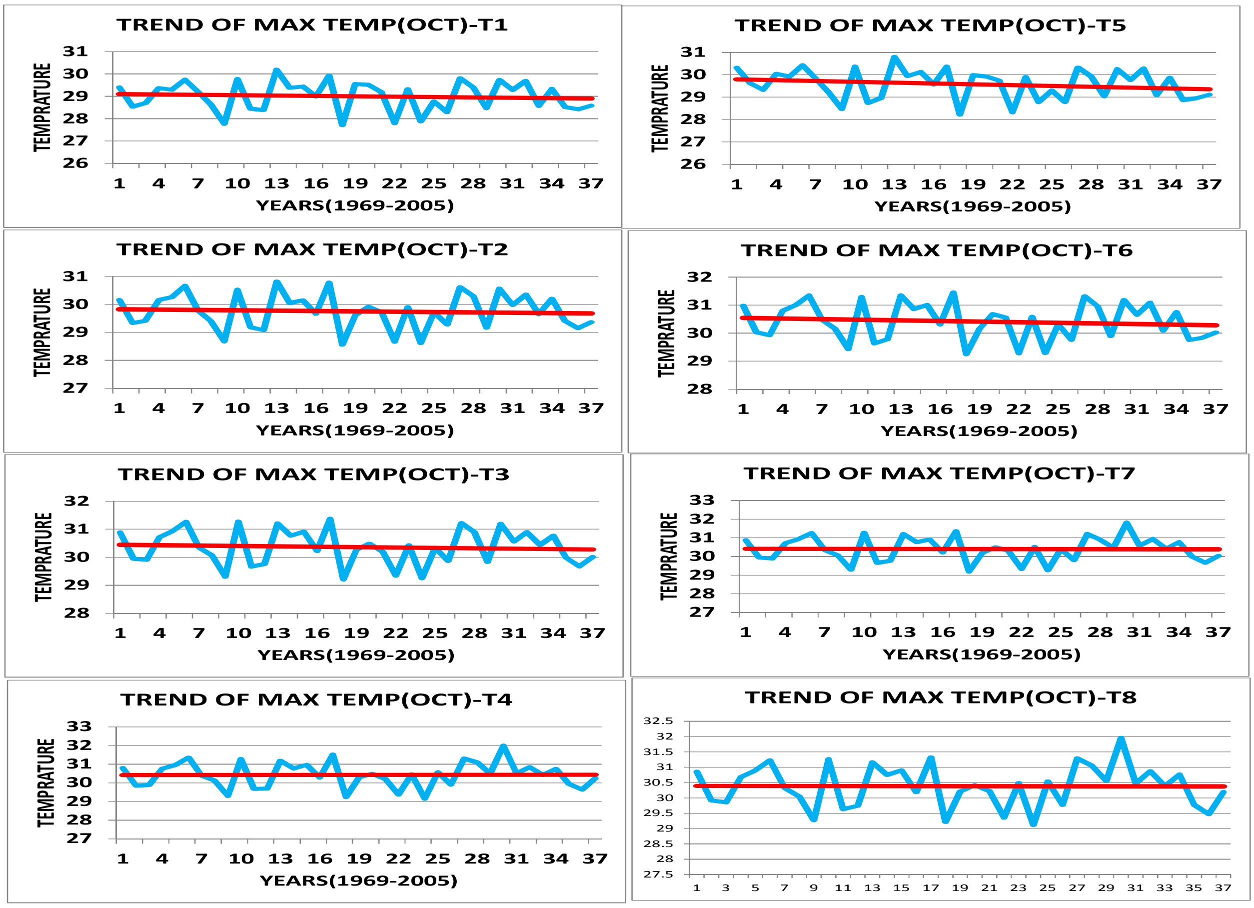

Fig.11: TREND OF MAX TEMP (OCTOBER)

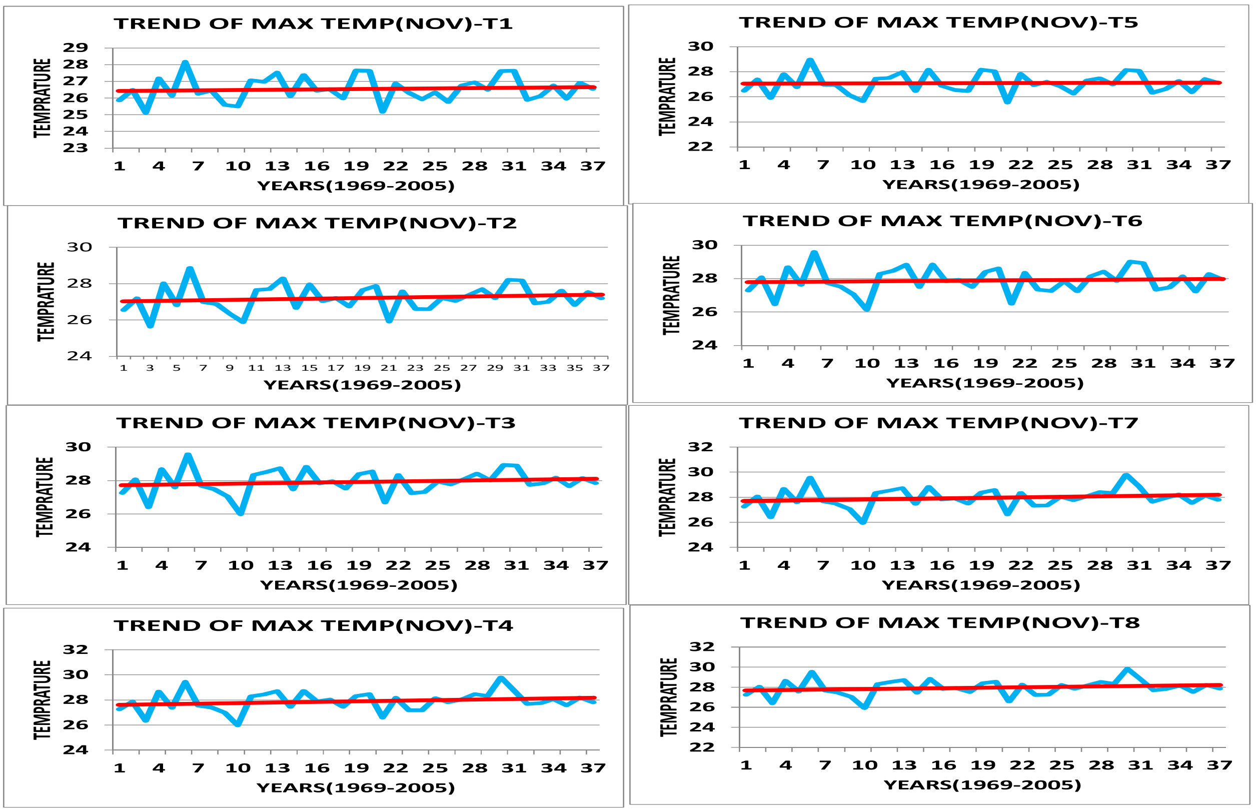

Fig.12: TREND OF MAX TEMP (NOVEMBER)

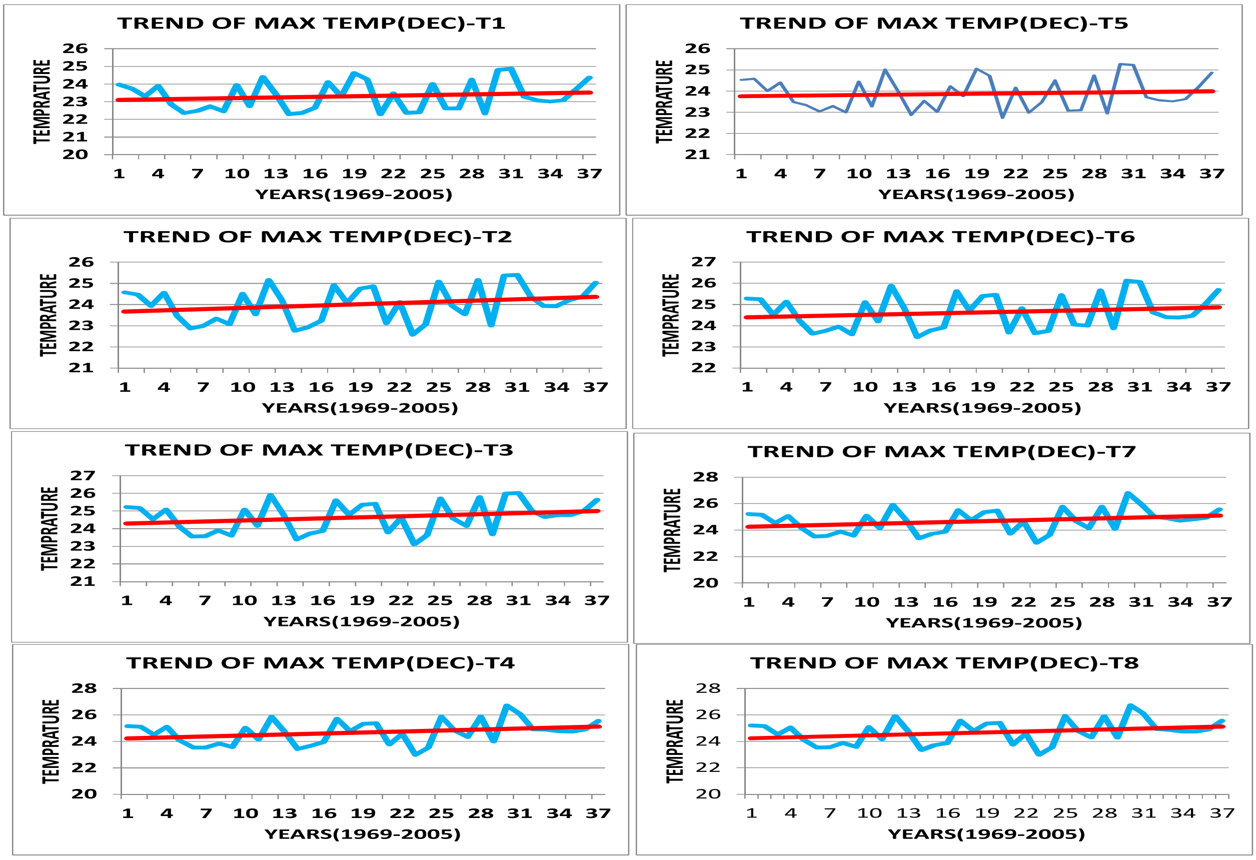

Fig. 13: TREND OF MAX TEMP (DECEMBER)

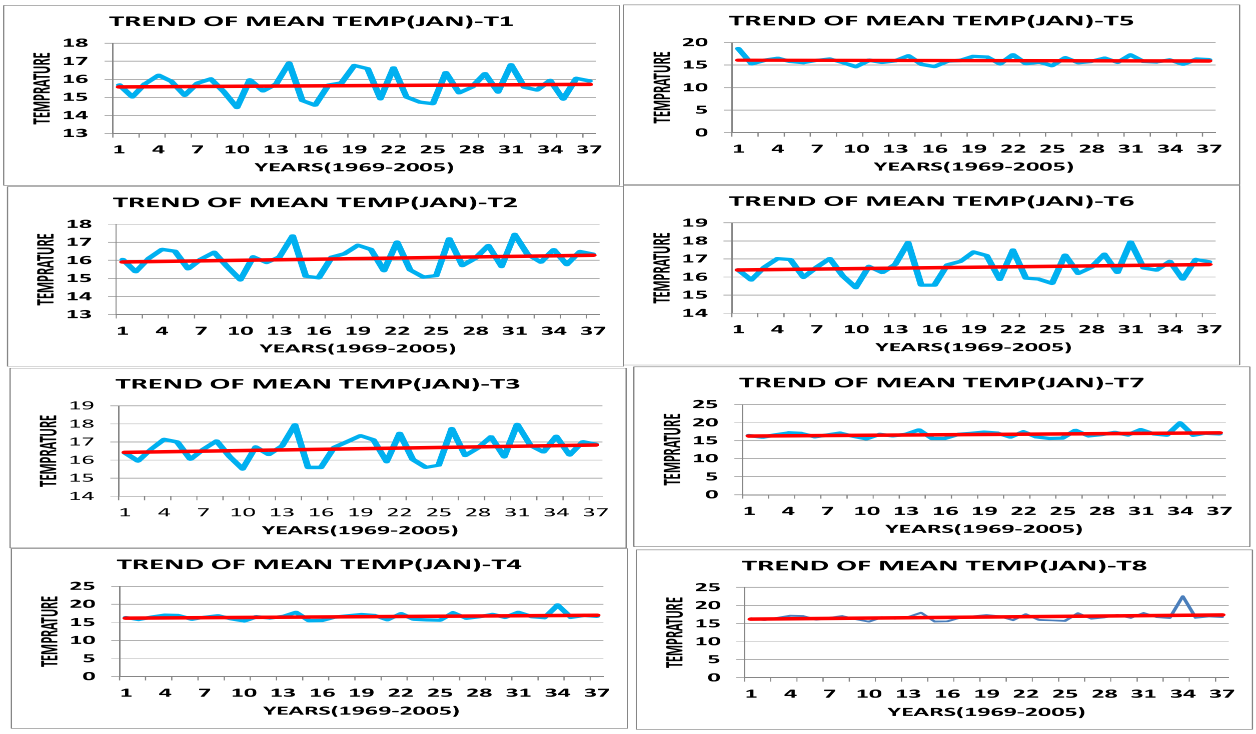

Fig.14: TREND OF MEAN TEMP (JANUARY)

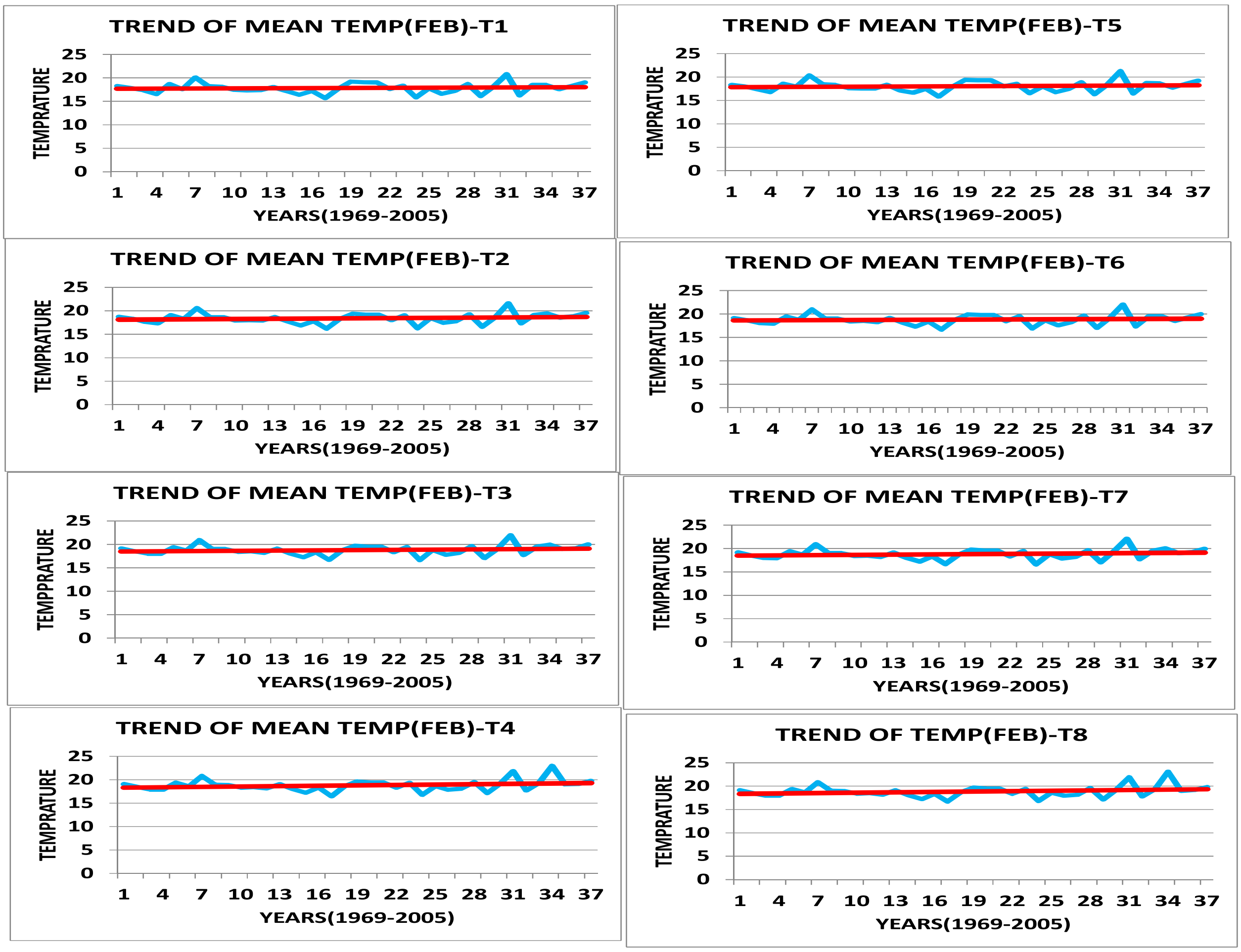

Fig.15: TREND OF MEAN TEMP (FEBUARY)

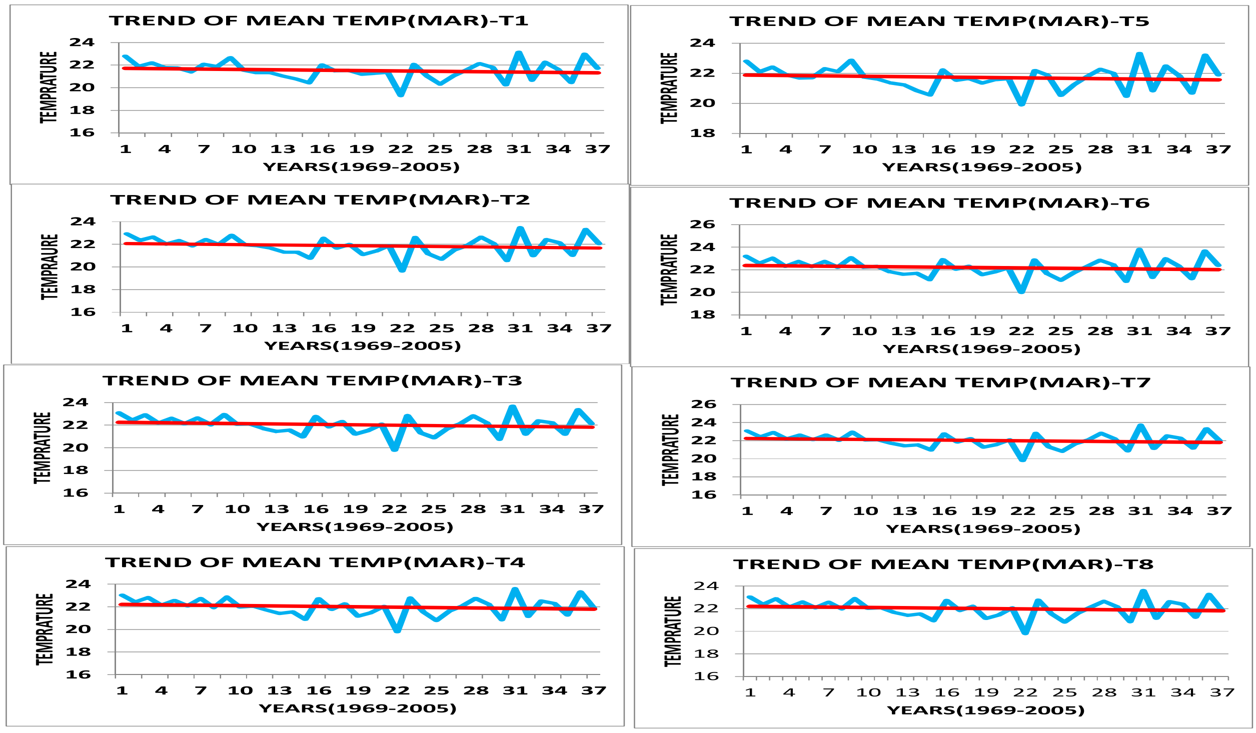

Fig.16: TREND OF MEAN TEMP (MARCH)

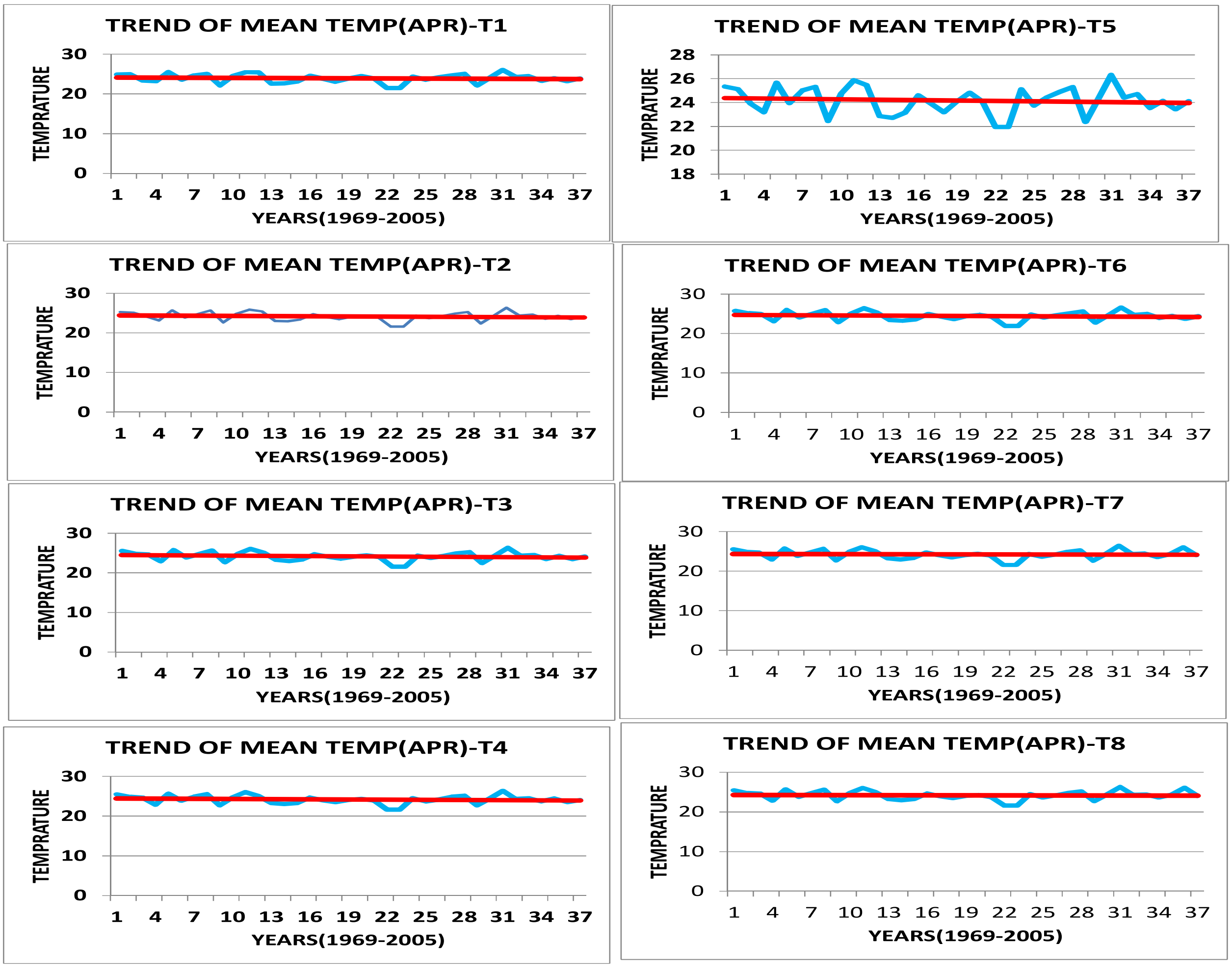

Fig.17: TREND OF MEAN TEMP (APRIL)

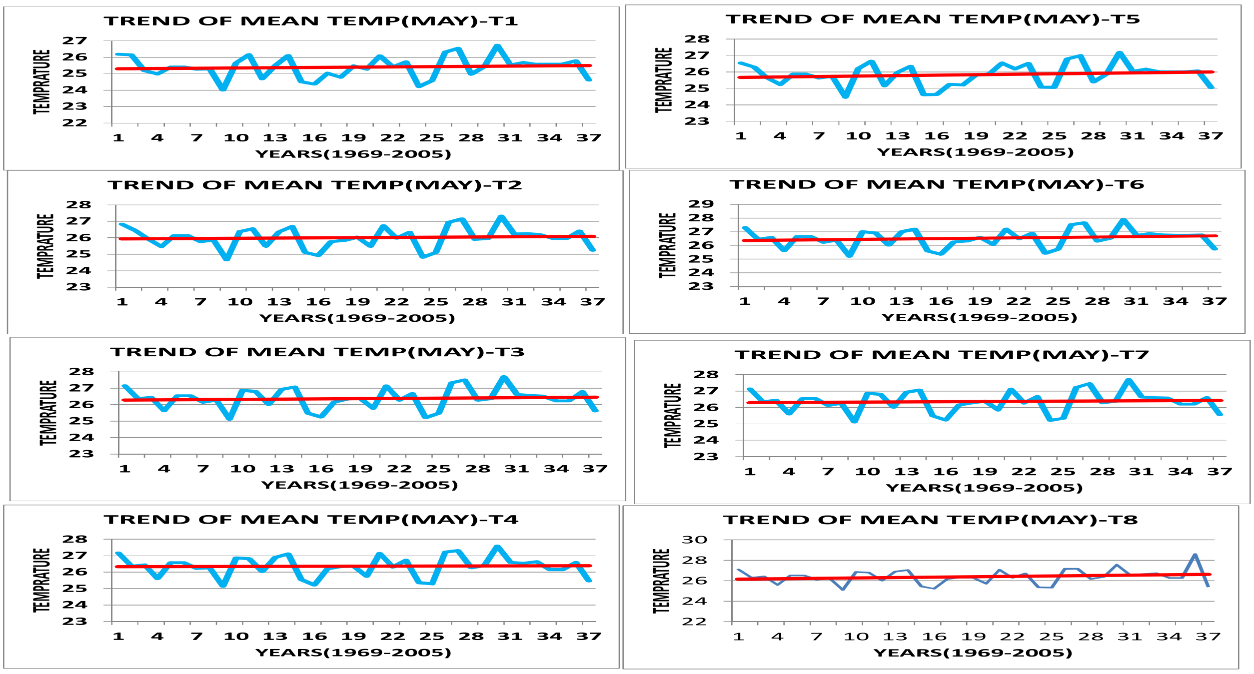

Fig.18: TREND OF MEAN TEMP (MAY)

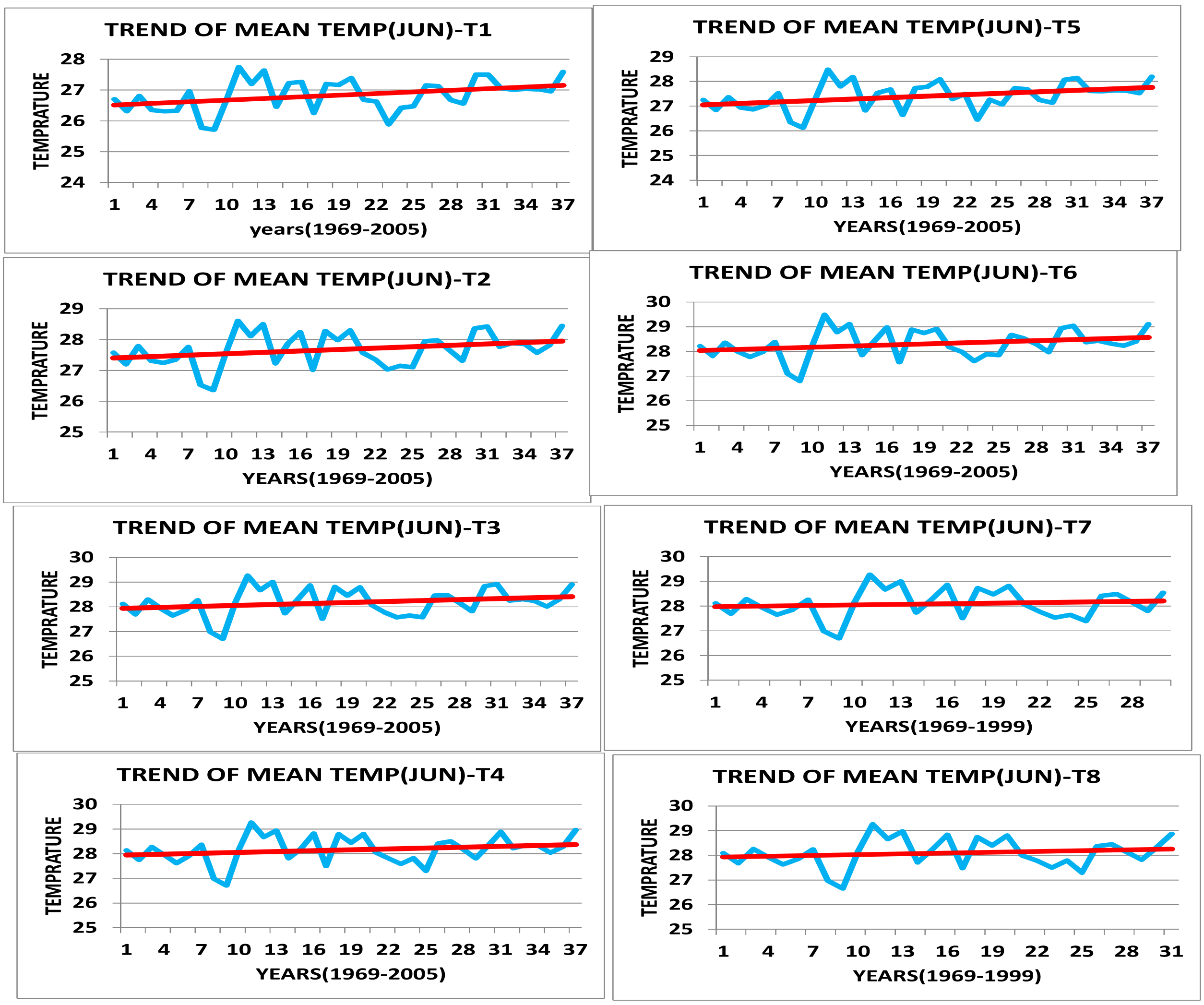

Fig.19: TREND OF MEAN TEMP (JUNE)

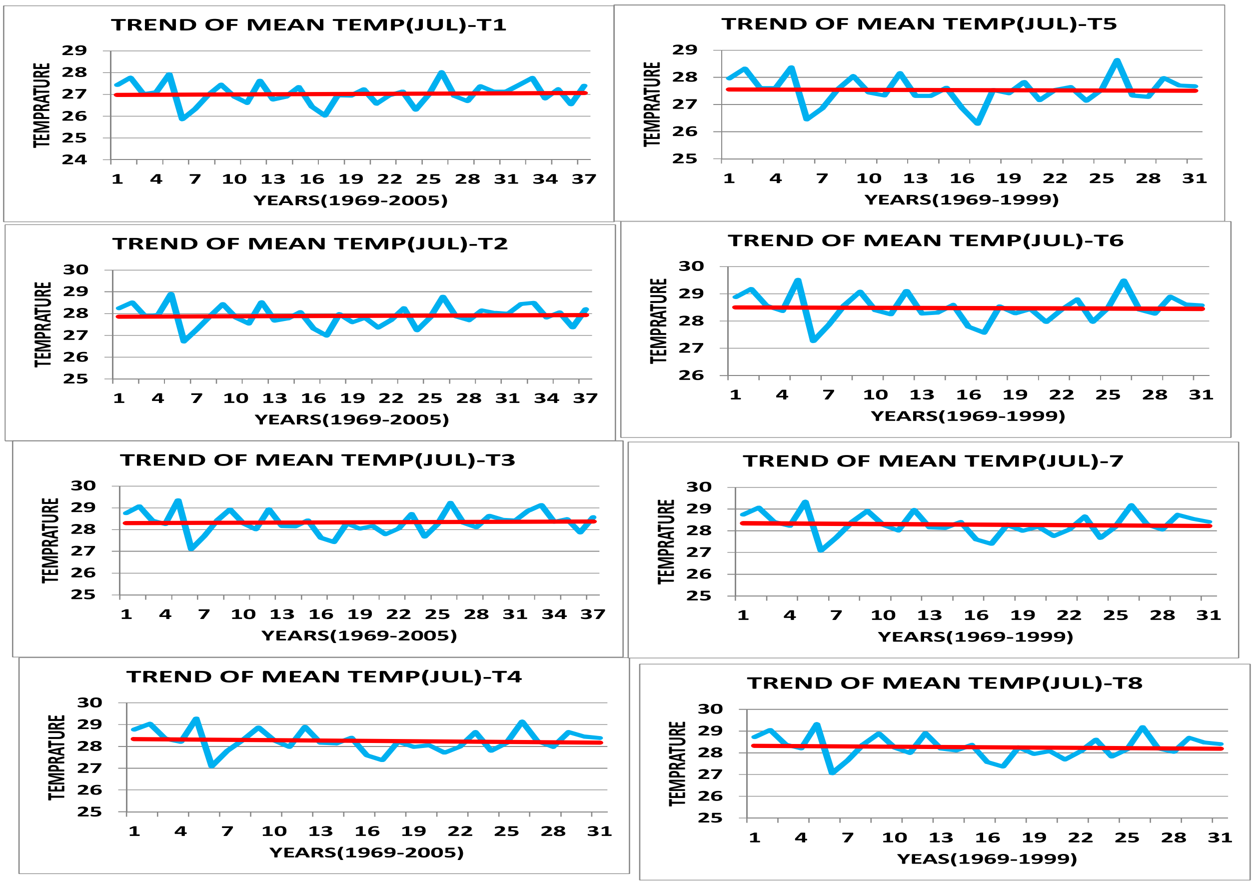

Fig.20: TREND OF MEAN TEMP (JULY)

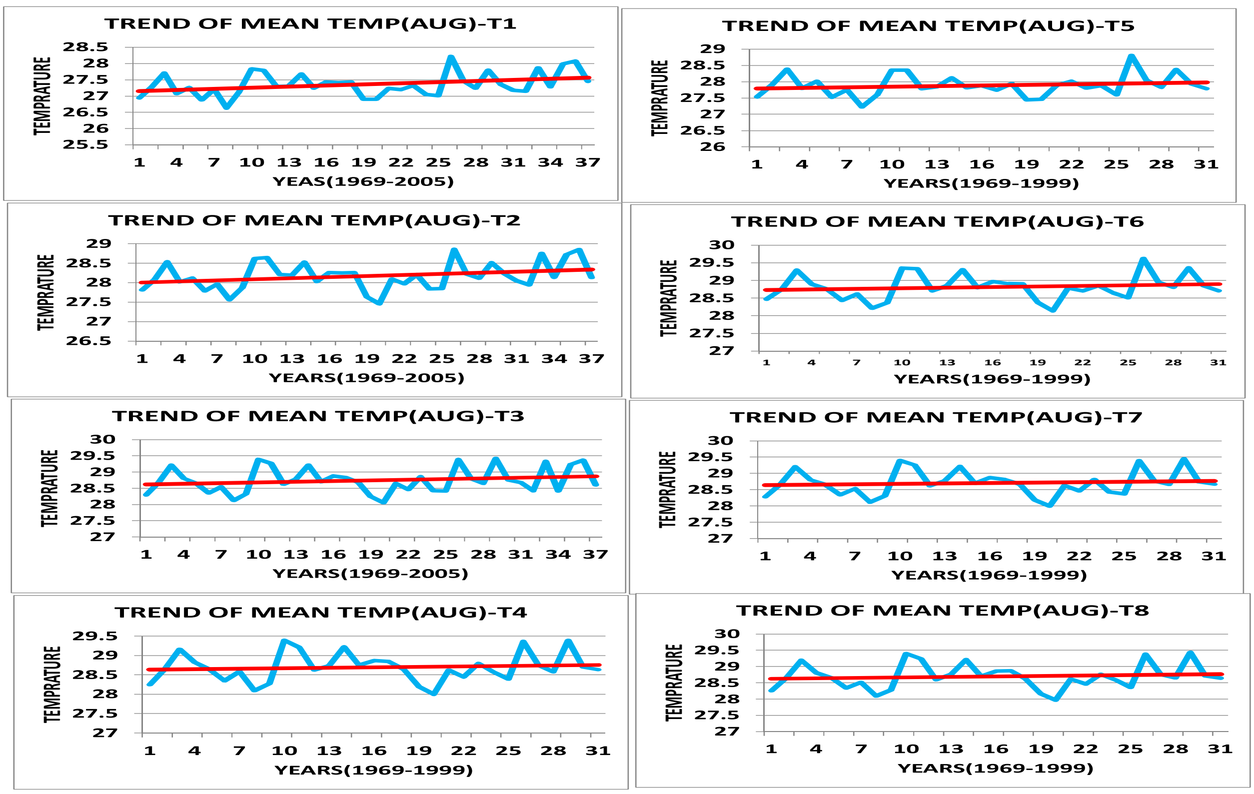

Fig.21: TREND OF MEAN TEMP (AUGUST)

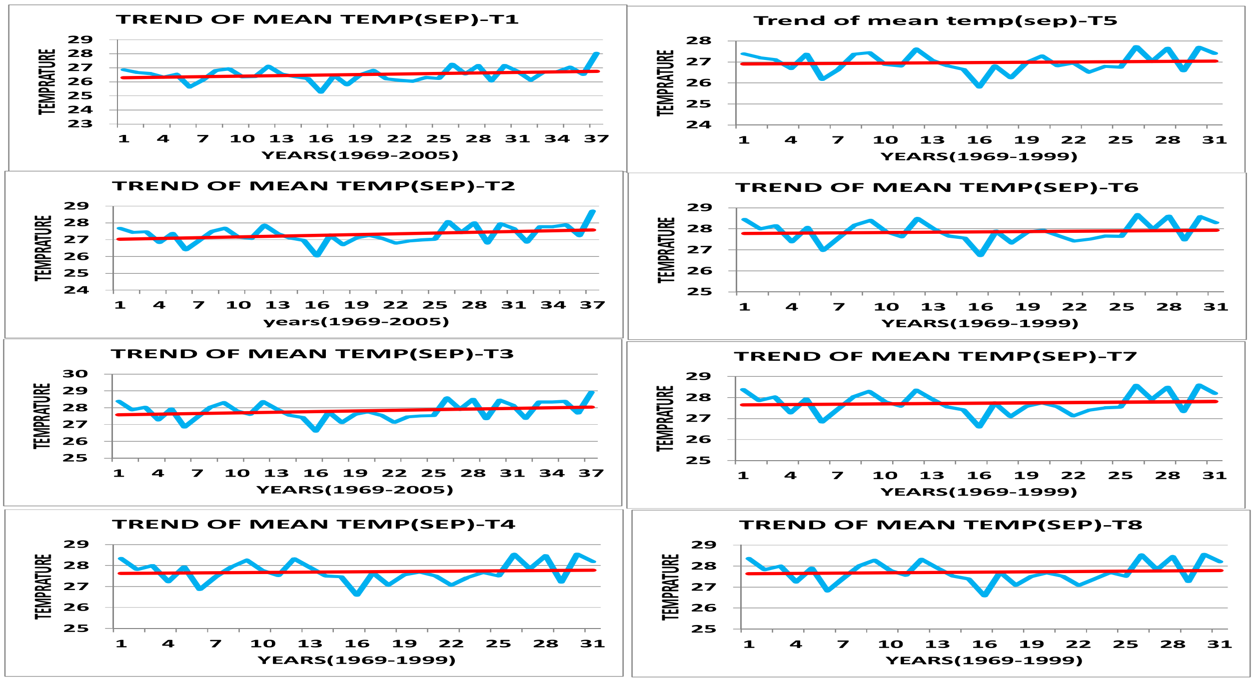

Fig.22: TREND OF MEAN TEMP (SEPTEMBER)

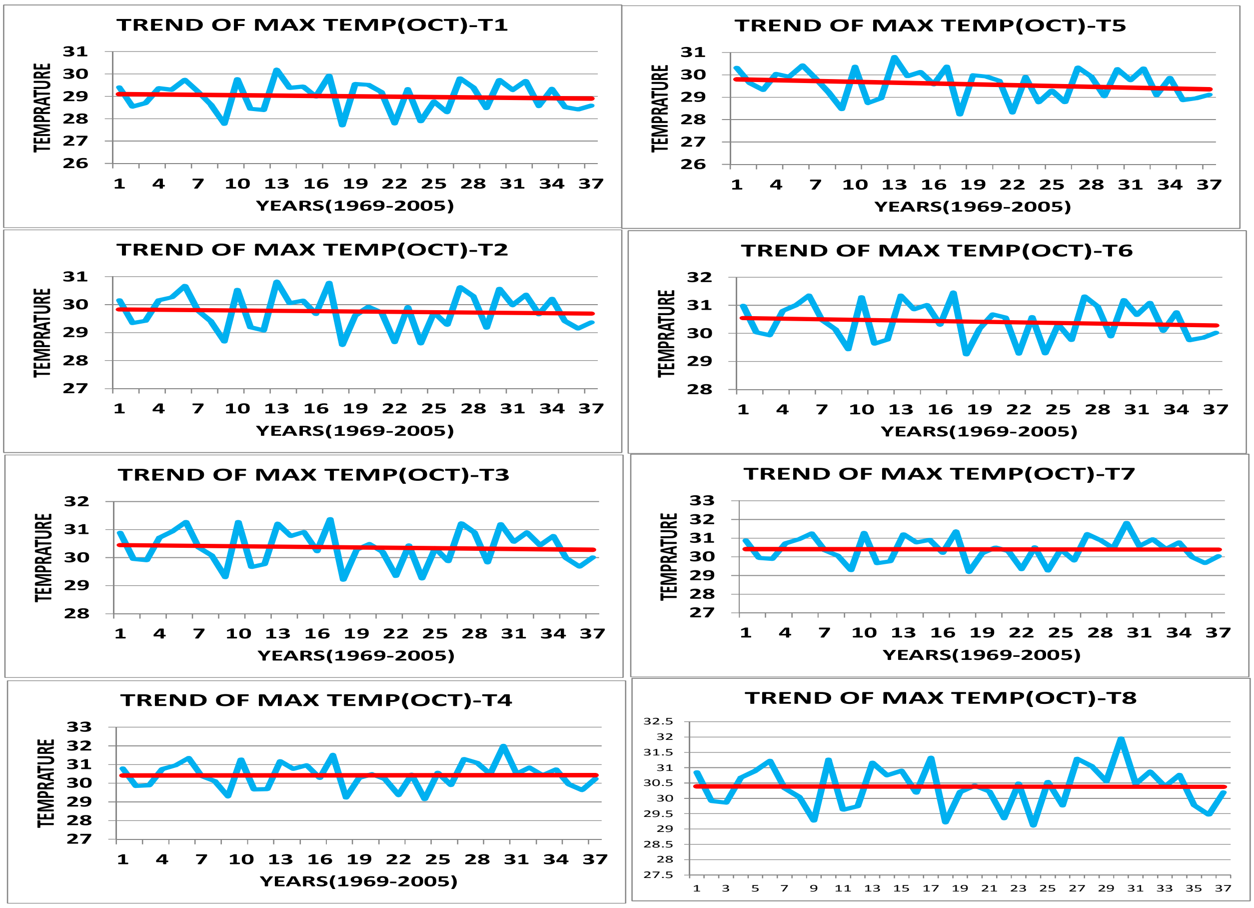

fig.23: TREND OF MEAN TEMP (OCTOBER)

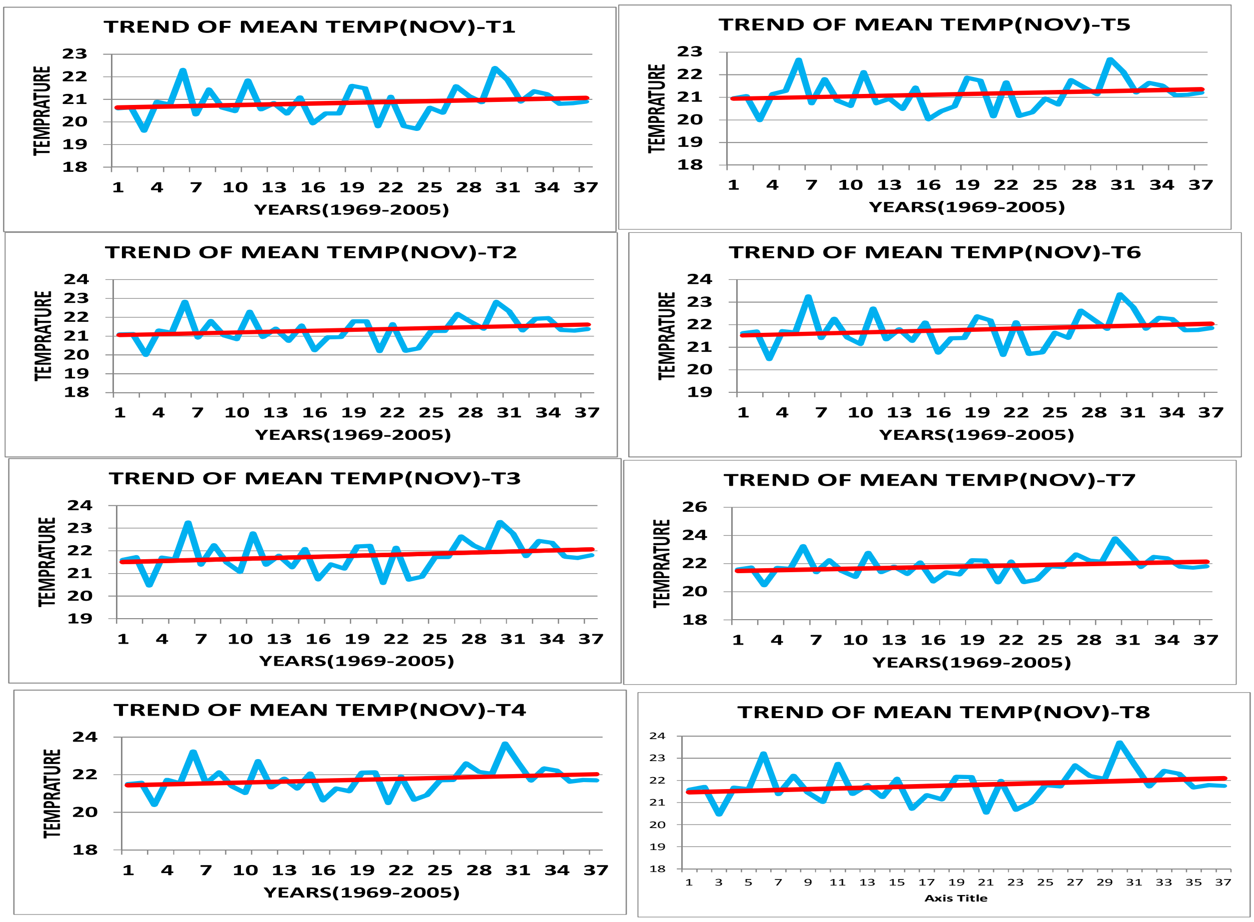

Fig.24: TREND OF MEAN TEMP (NOVEMBER)

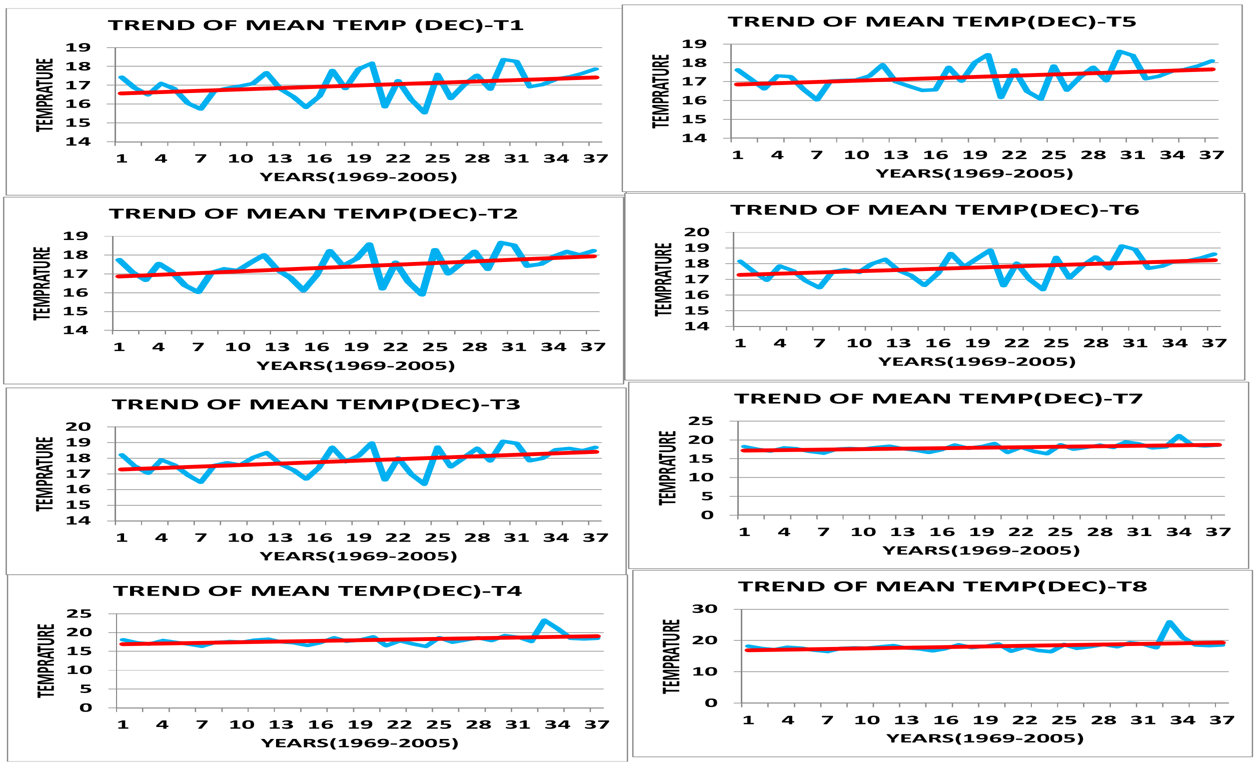

Fig.25: TREND OF MEAN TEMP (DECEMBER)

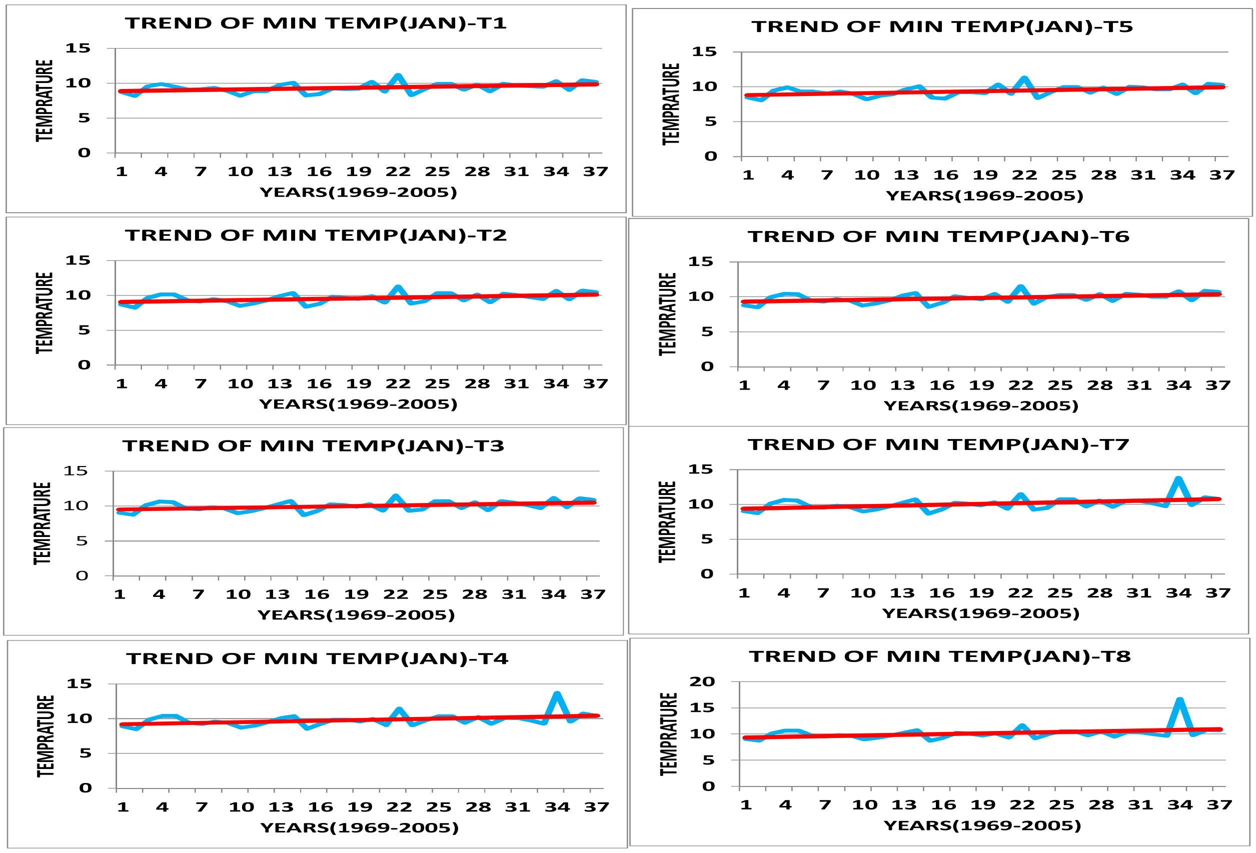

Fig.26: TREND OF MINIMUM TEMP (JANUARY)

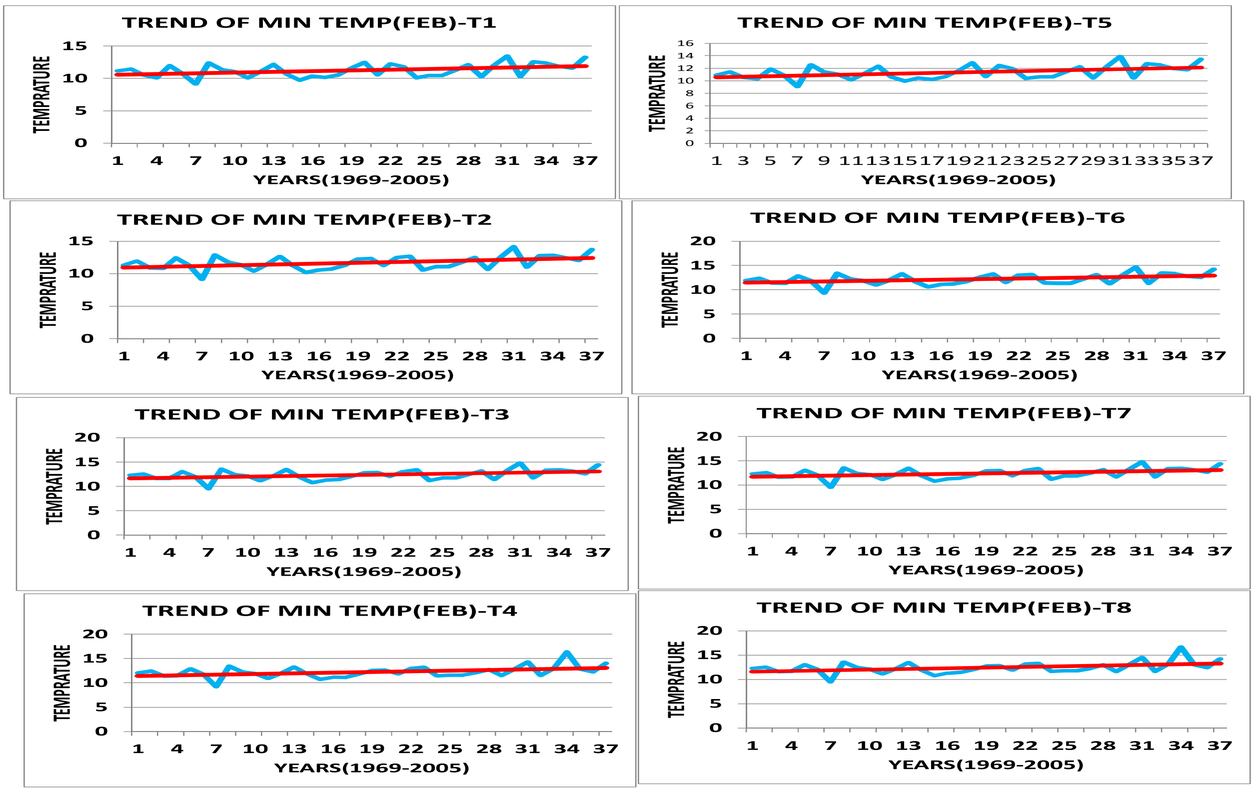

Fig.27: TREND OF MINIMUM TEMP (FEBUARY)

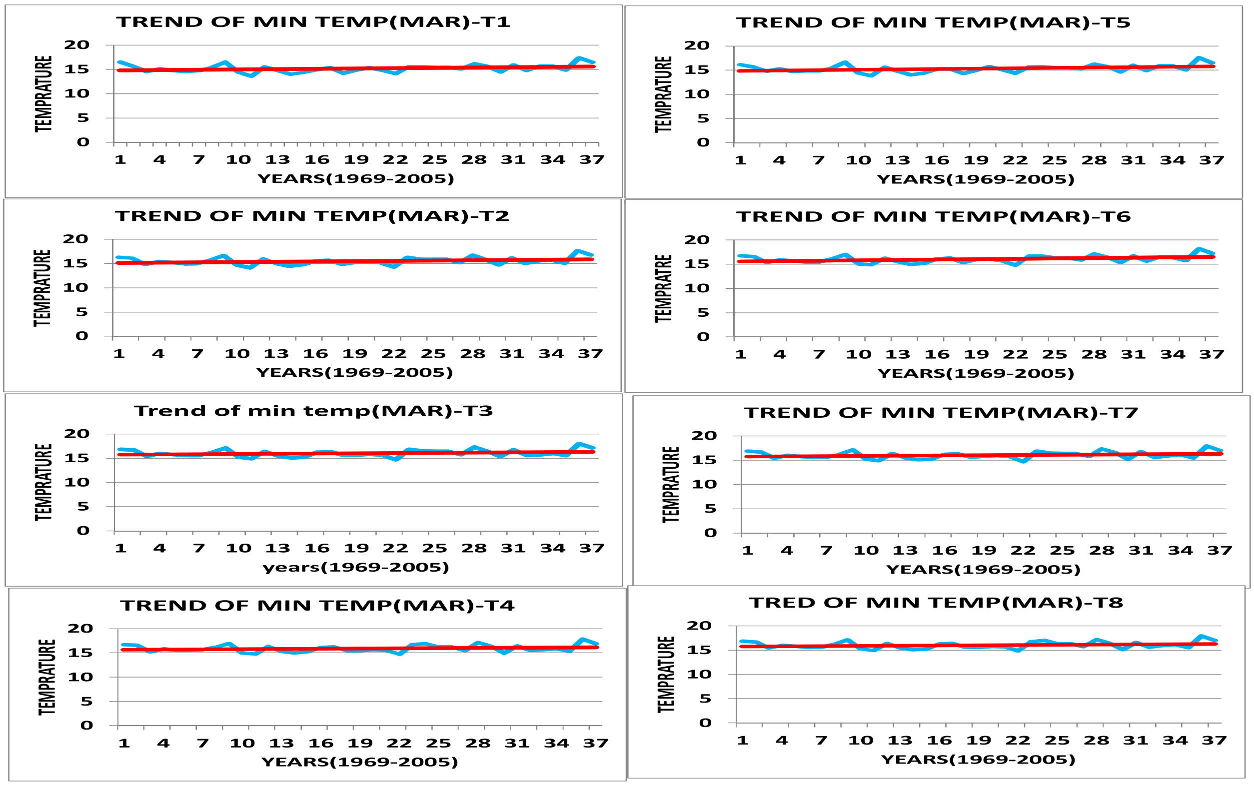

Fig.28: TREND OF MINIMUM TEMP (MARCH)

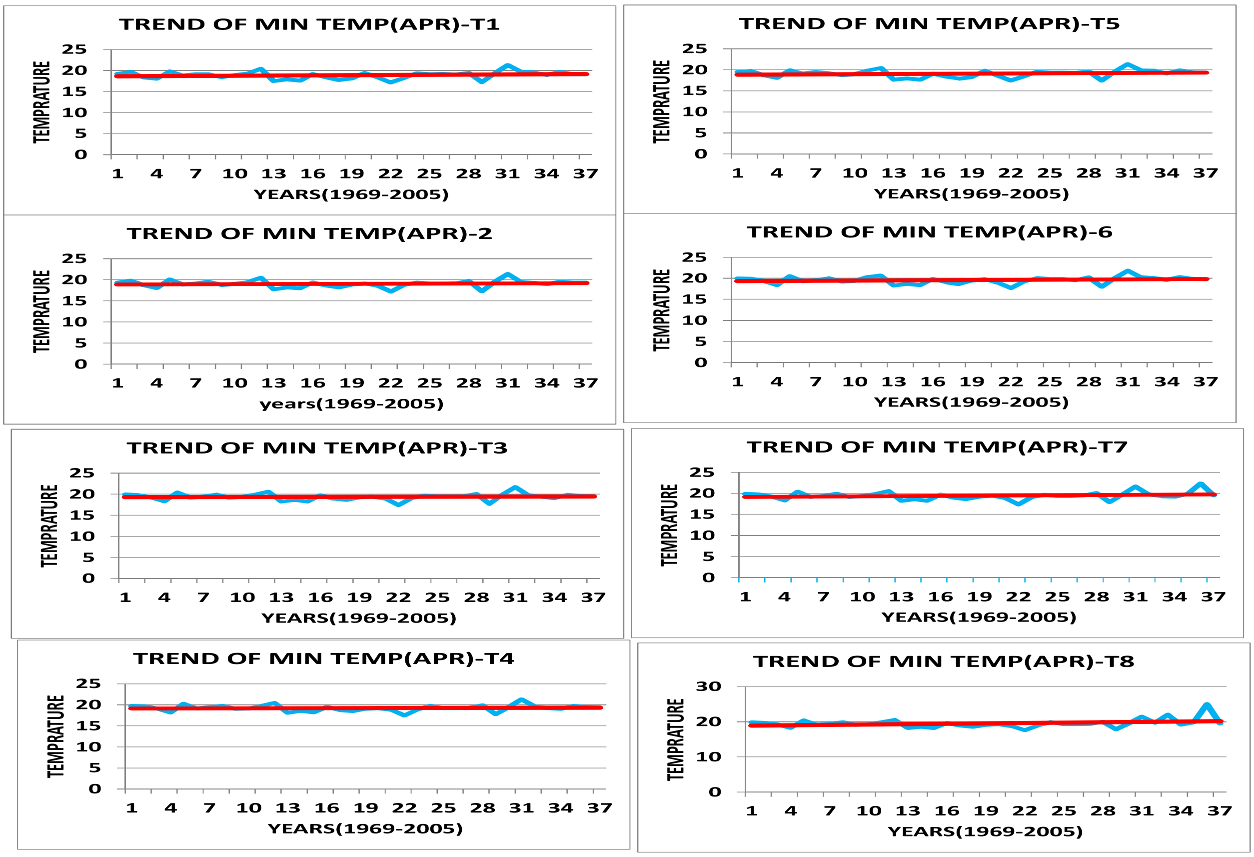

Fig.29: TREND OF MINIMUM TEMP (APRIL)

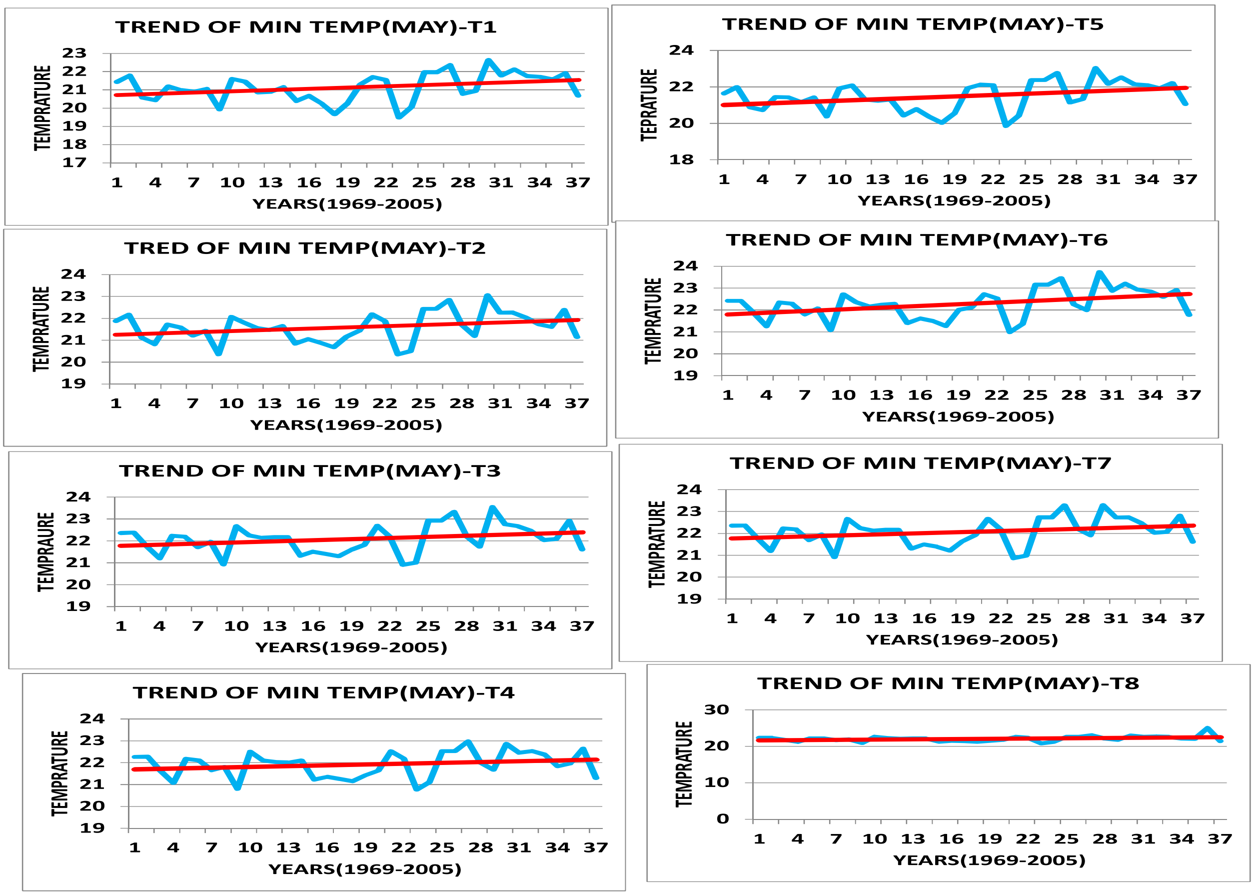

Fig.30: TREND OF MINIMUM TEMP (MAY)

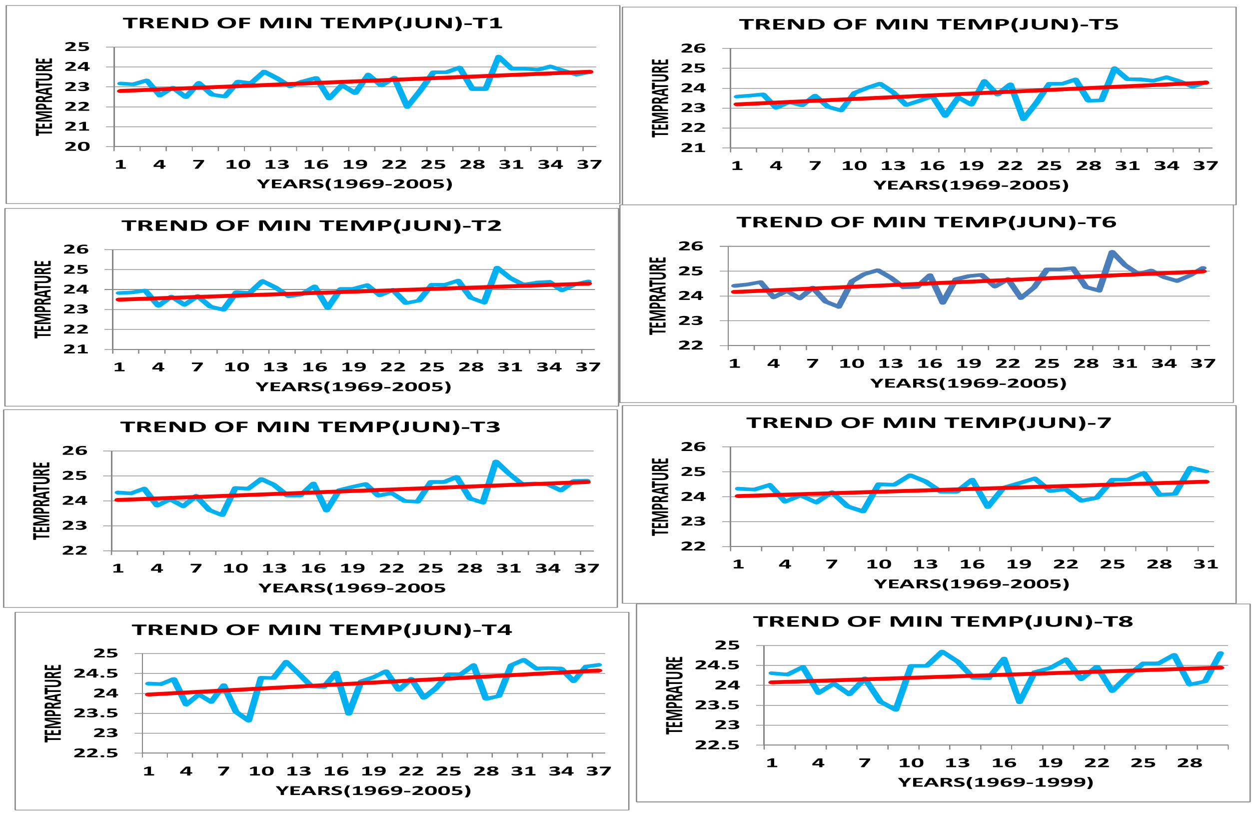

Fig.31: TREND OF MINIMUM TEMP (JUNE)

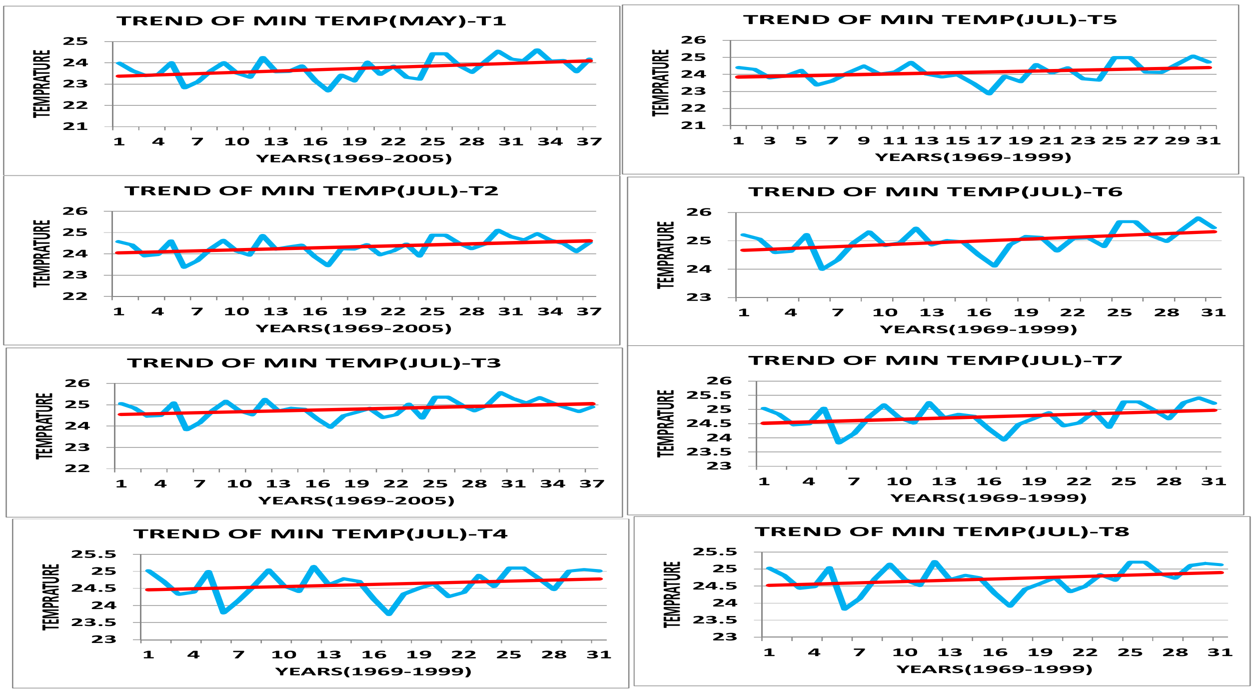

Fig.32: TREND OF MINIMUM TEMP(JULY)

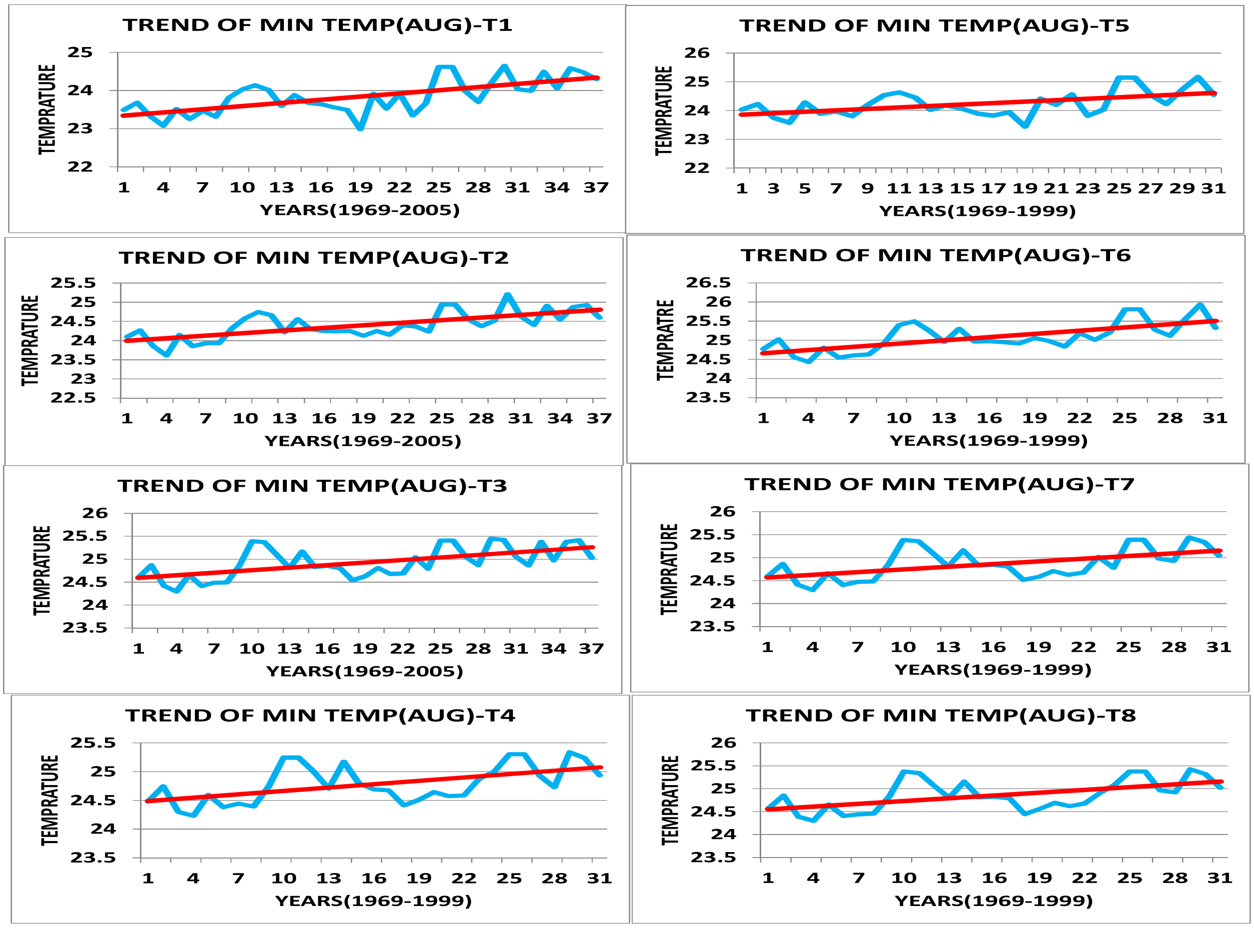

Fig.33: TREND OF MINIMUM TEMP(AUGUST)

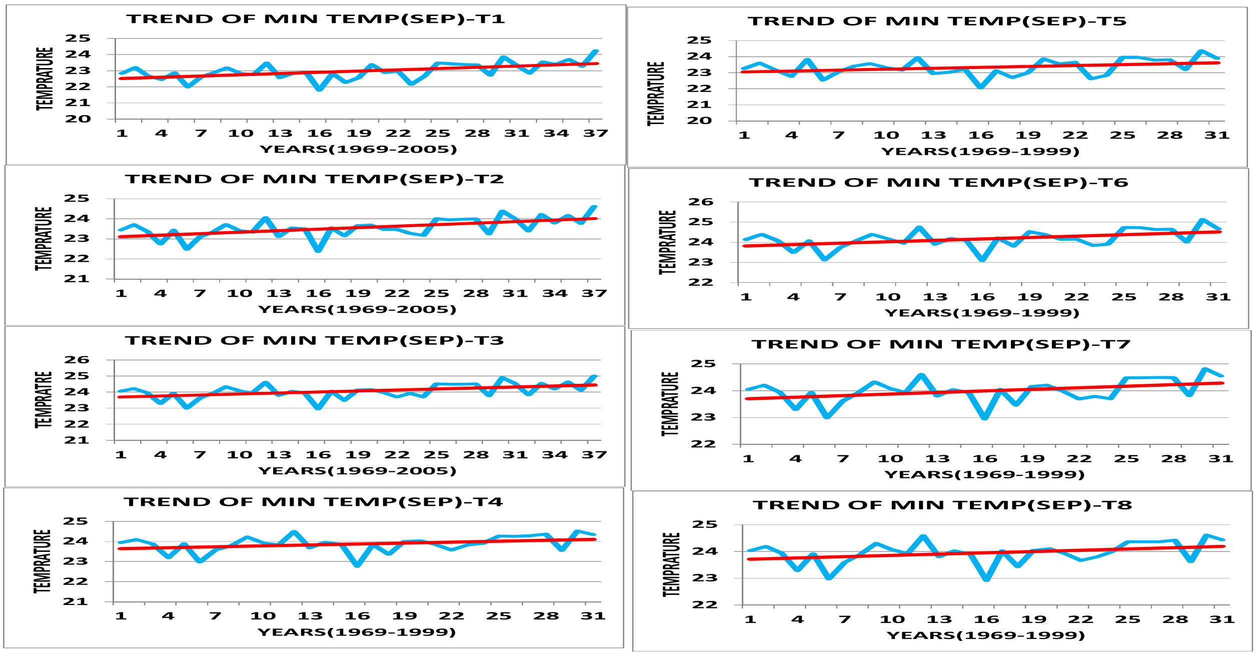

Fig.34: TREND OF MINIMUM TEMP (SEPTMBER)

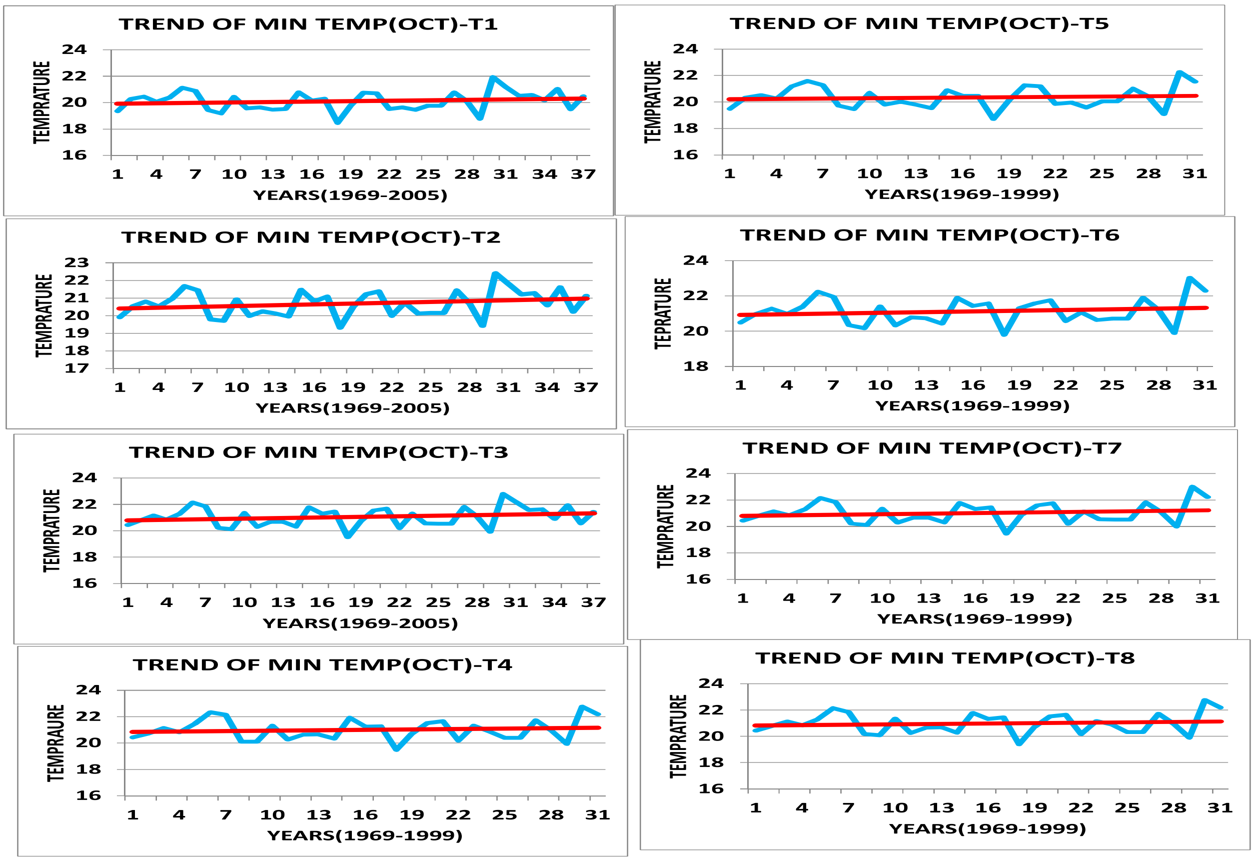

Fig.35: TREND OF MINIMUM TEMP (OCTOBER)

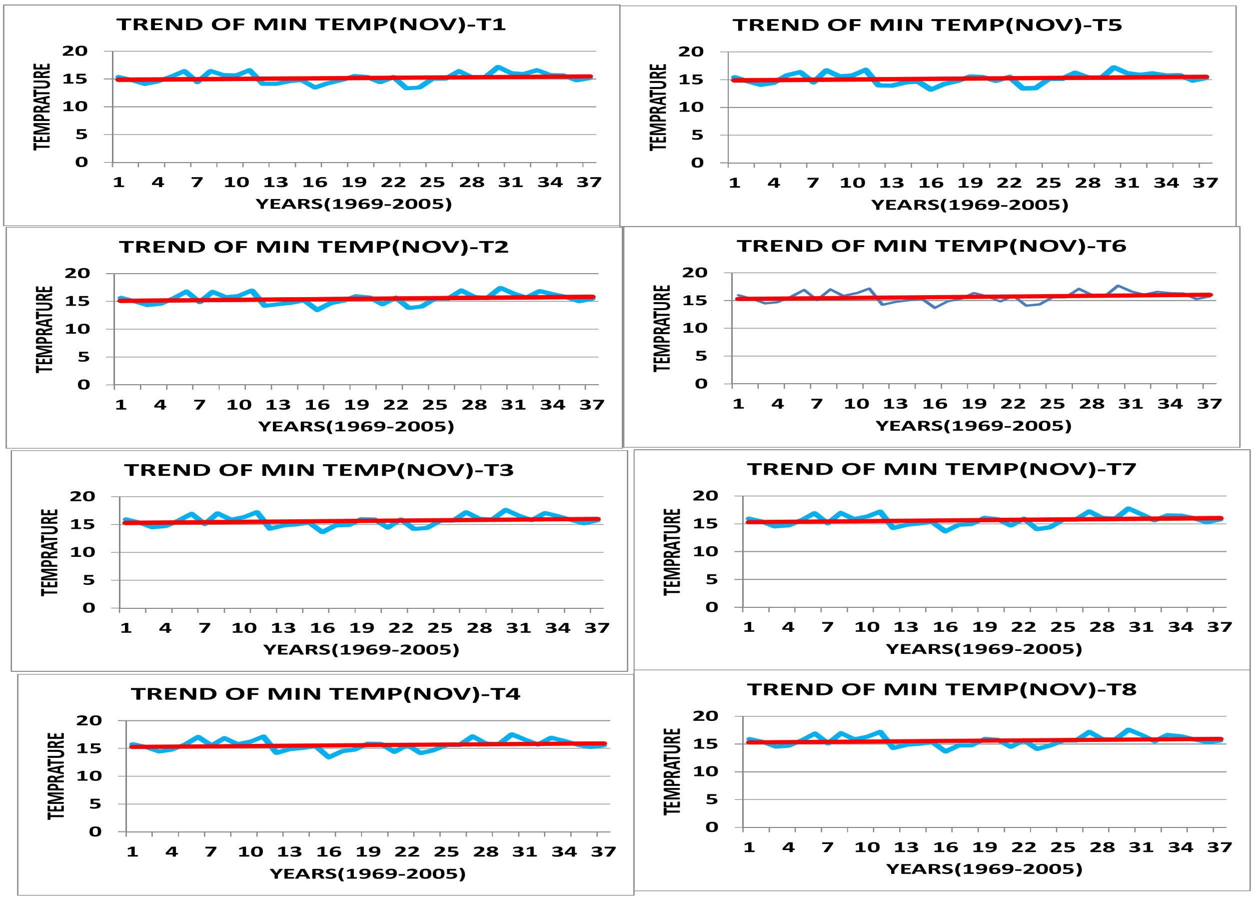

Fig.36: TREND OF MINIMUM TEMP (NOVEMBER)

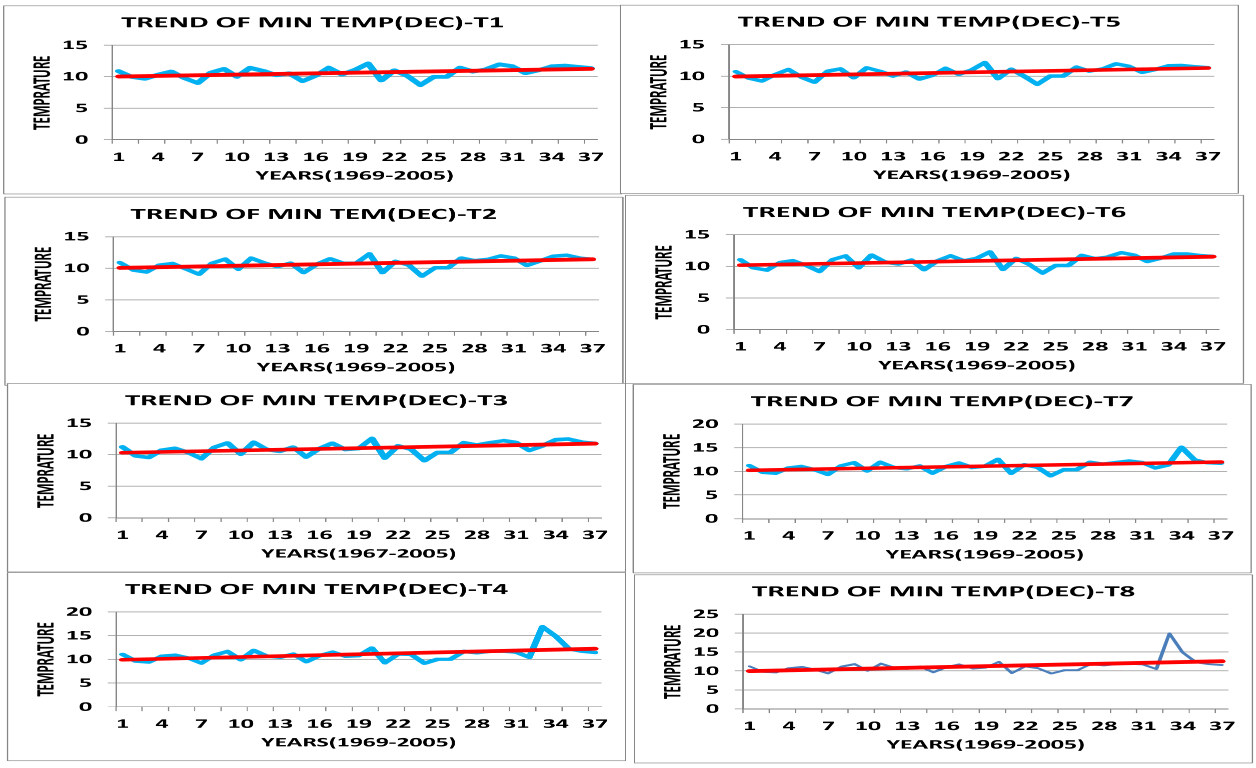

Fig.37: TREND OF MINIMUM TEMP (DECEMBER)

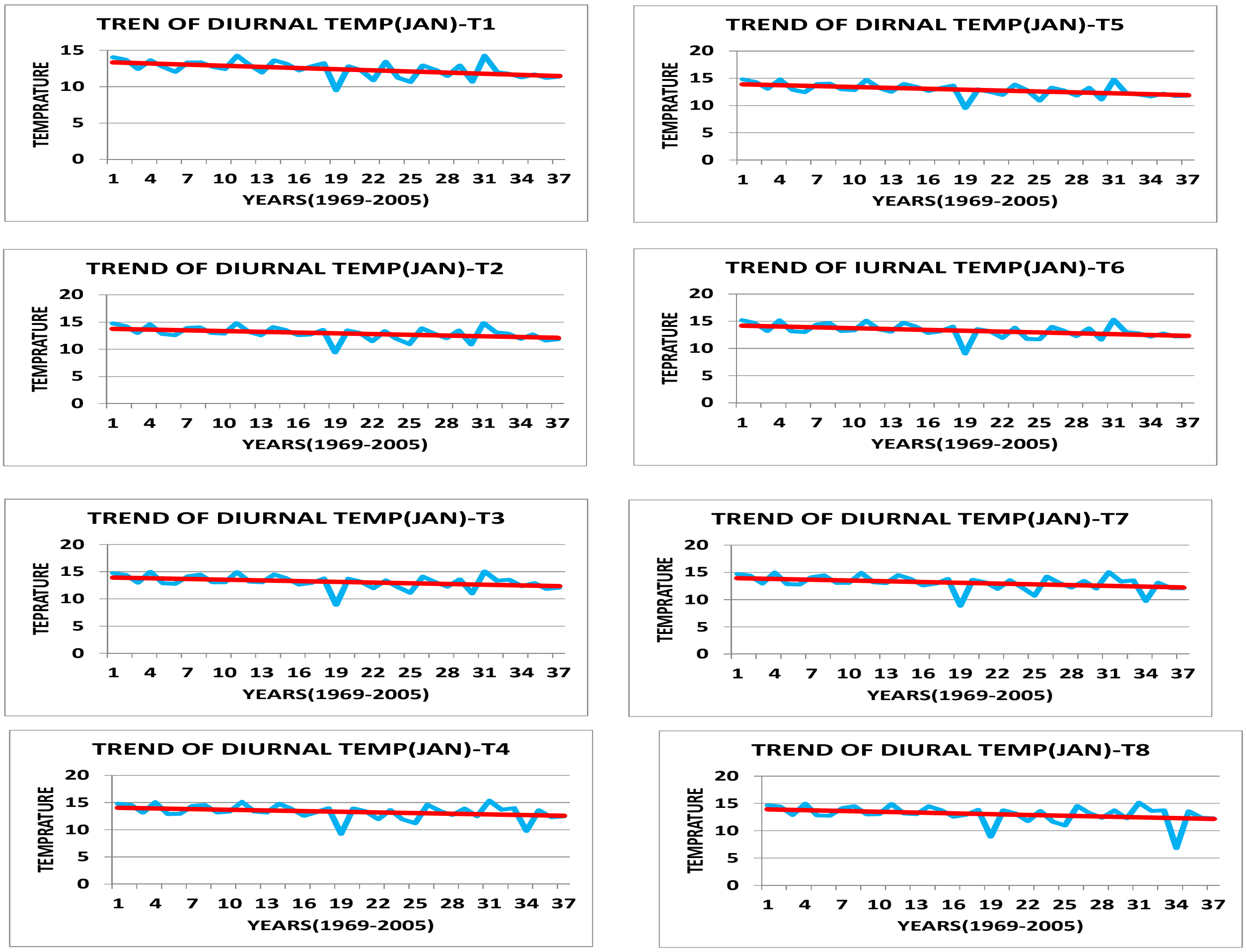

Fig. 38: TREND OF DIURNAL TEMP (JANUARY)

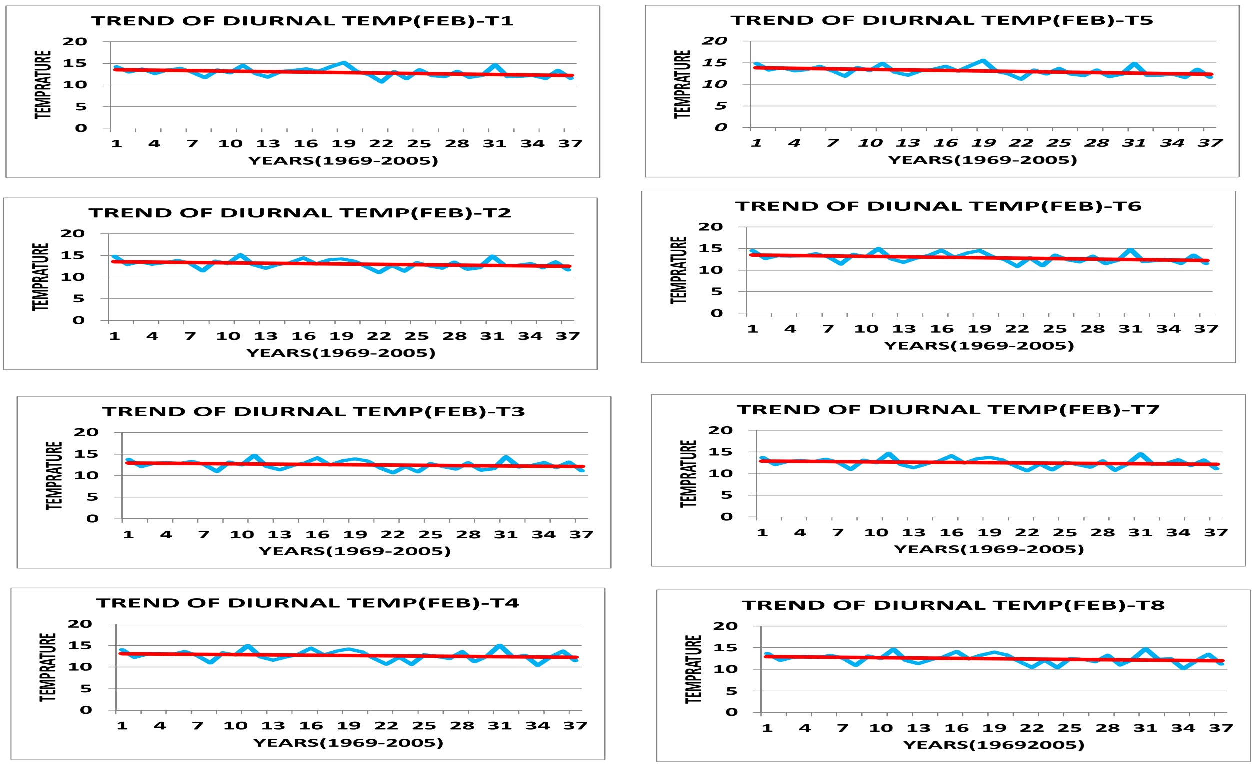

Fig.39: TREND OF DIURNAL TEMP (FEBUARY)

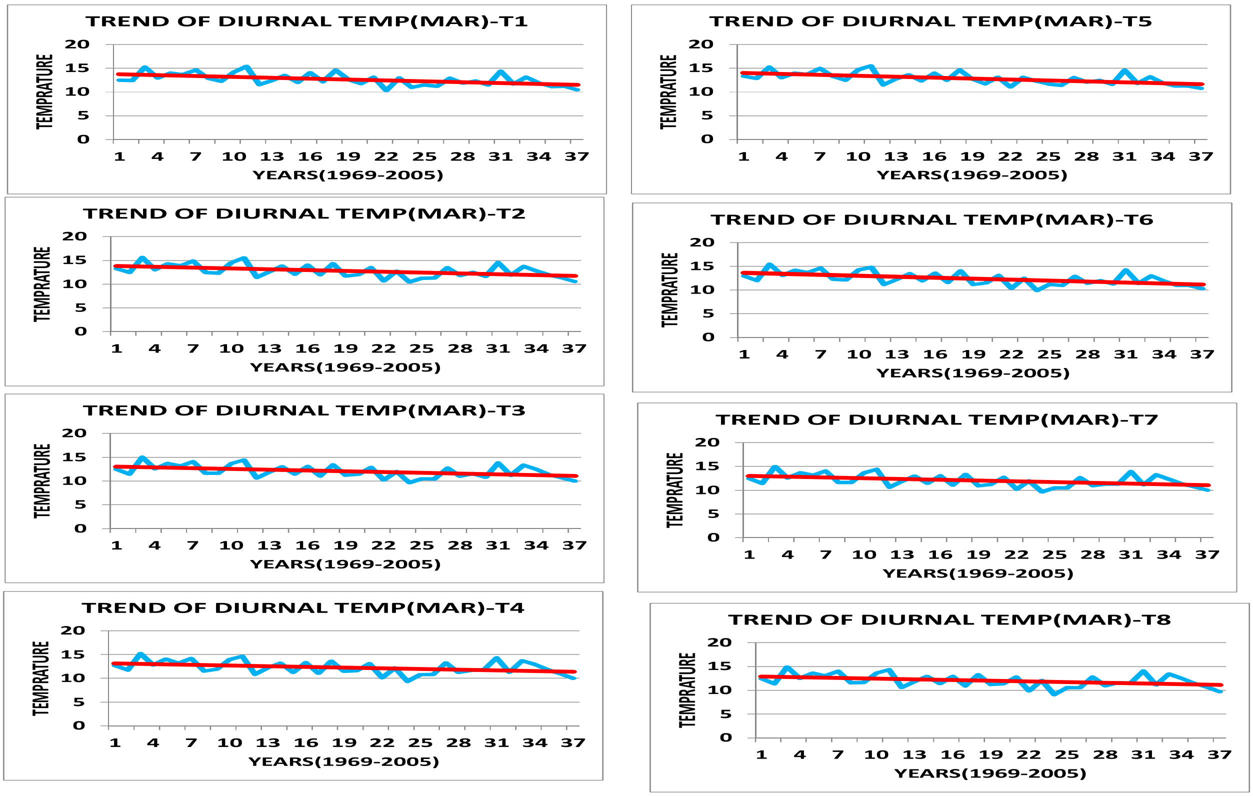

Fig.40: TREND OF DIURNAL TEMP (MARCH)

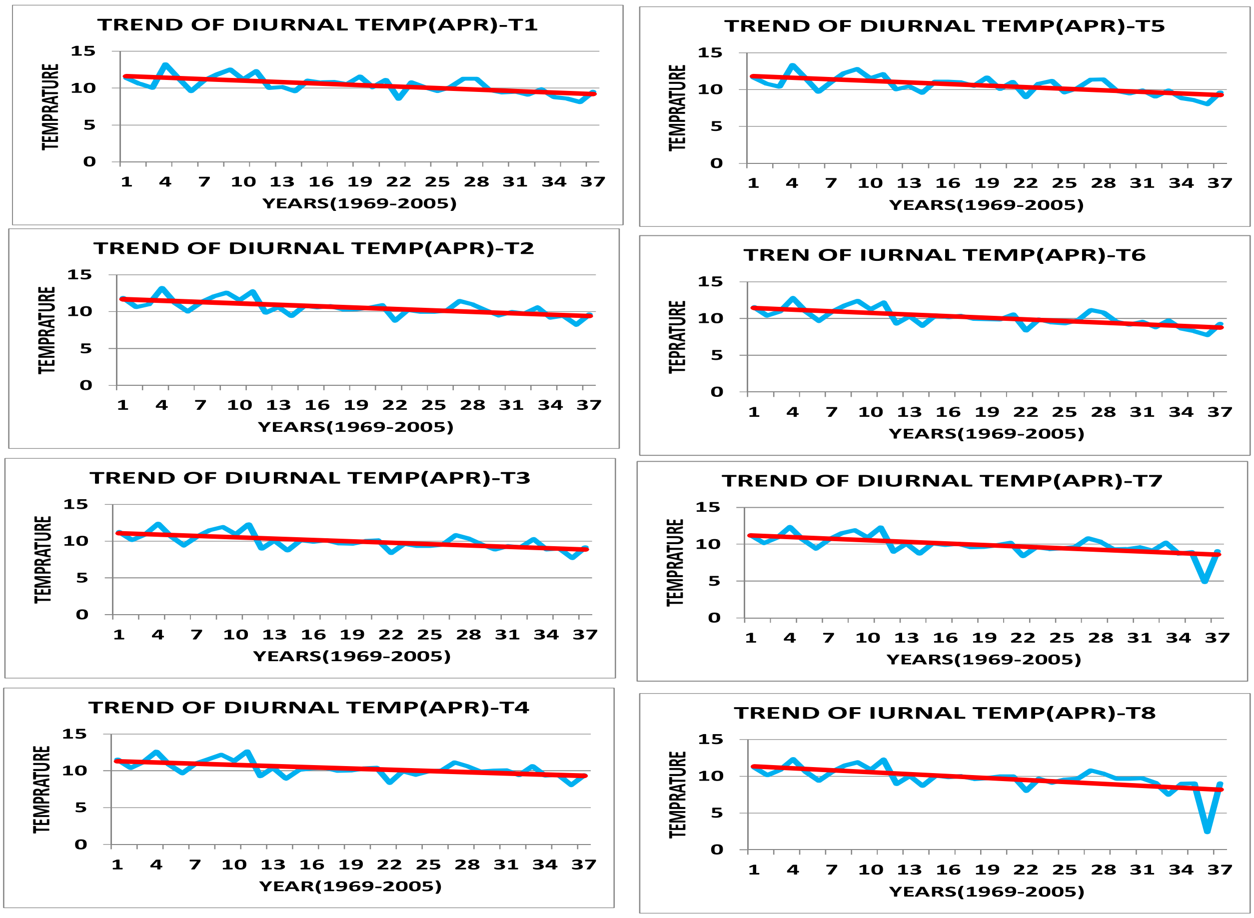

Fig.41: TREND OF DIURNAL TEMP (APRIL)

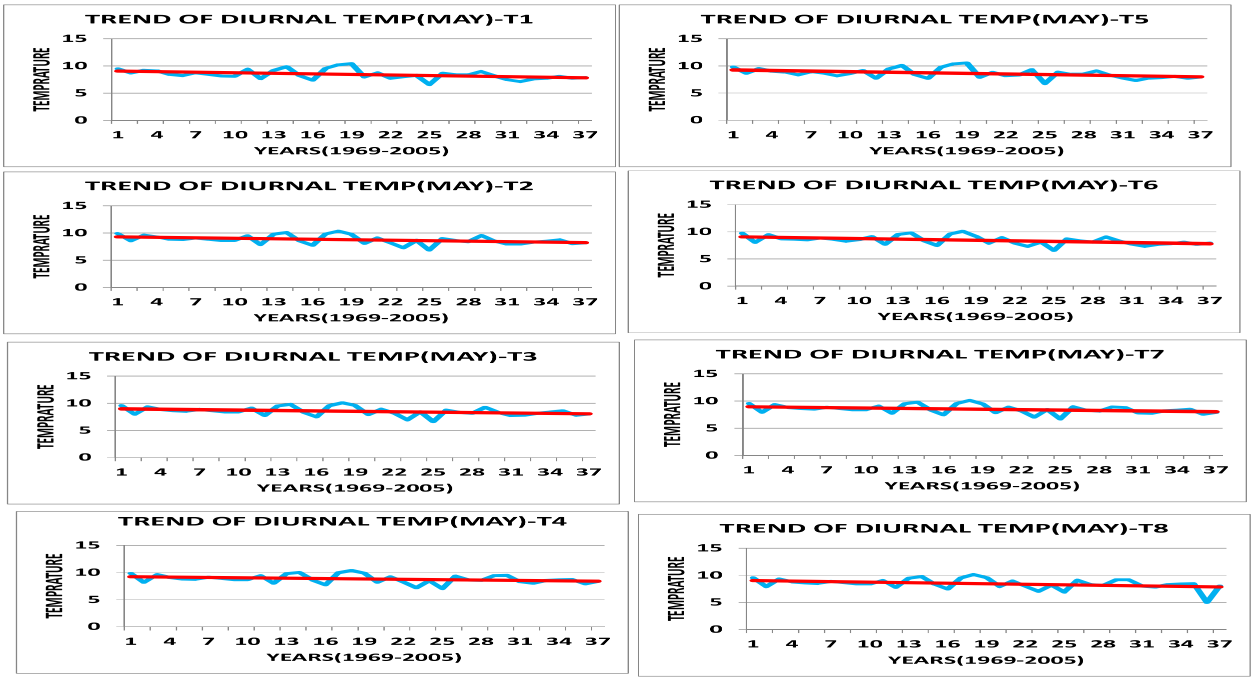

Fig.42: TREND OF DIURNAL TEMP (MAY)

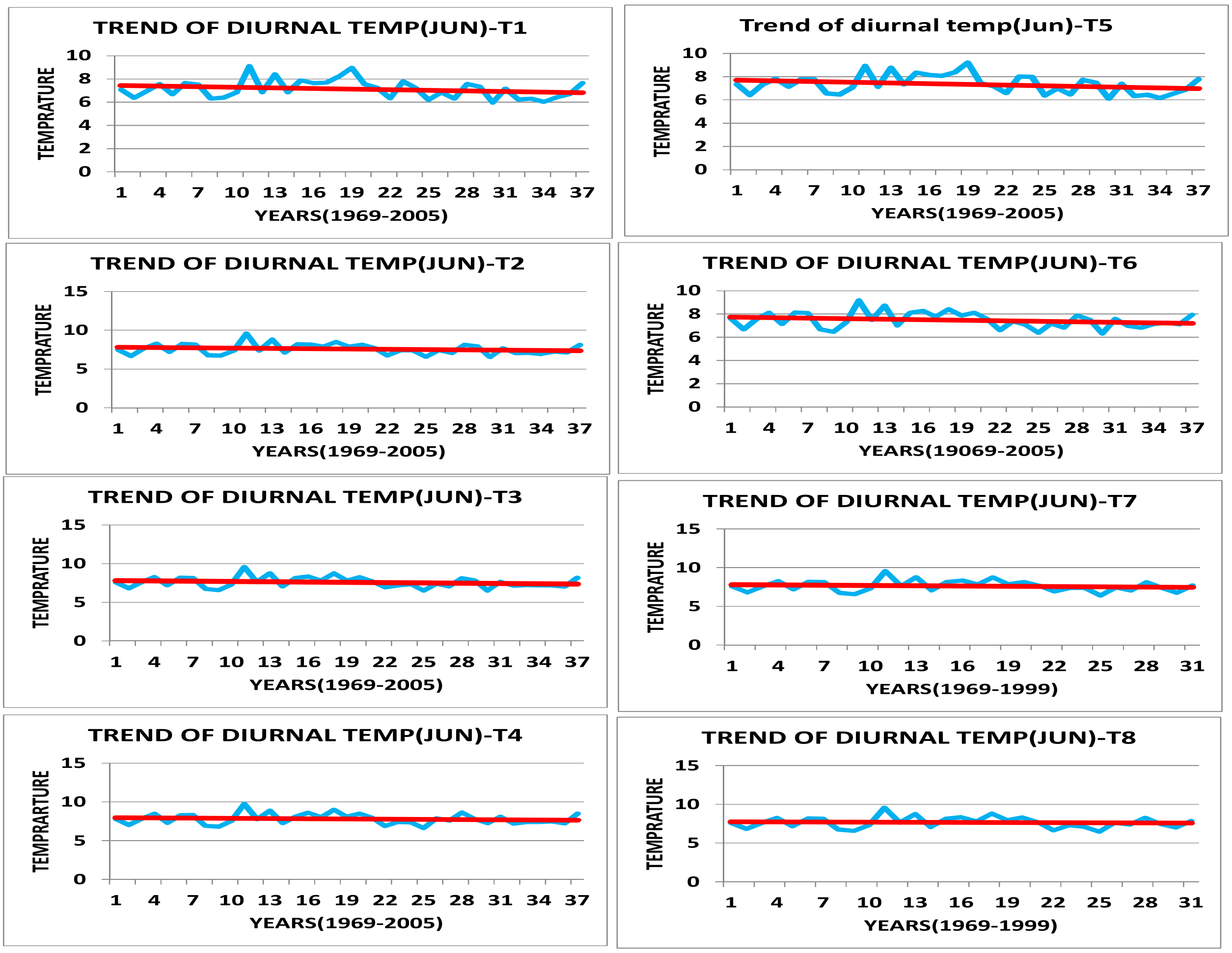

Fig.43: TREND OF DIURNAL TEMP (JUNE)

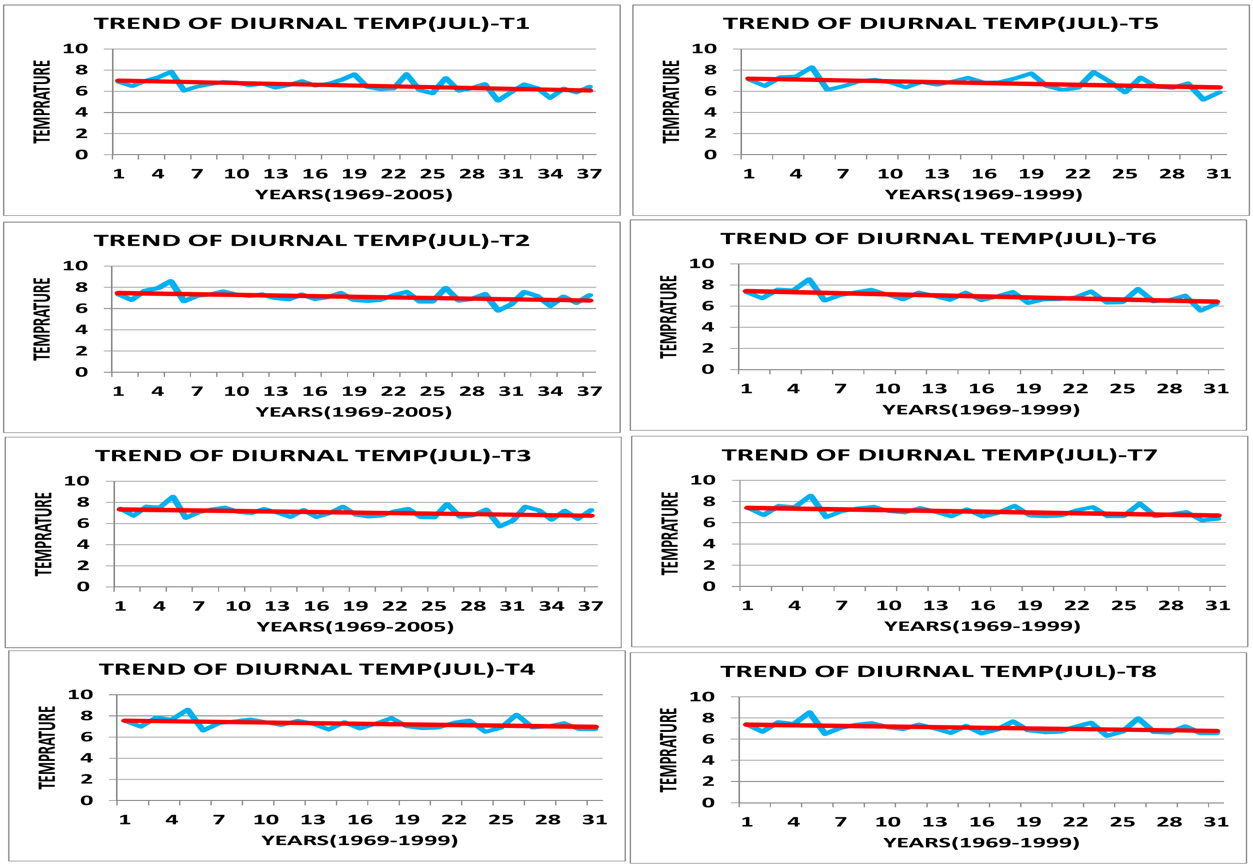

Fig.44: TREND OF DIURNAL TEMP (JULY)

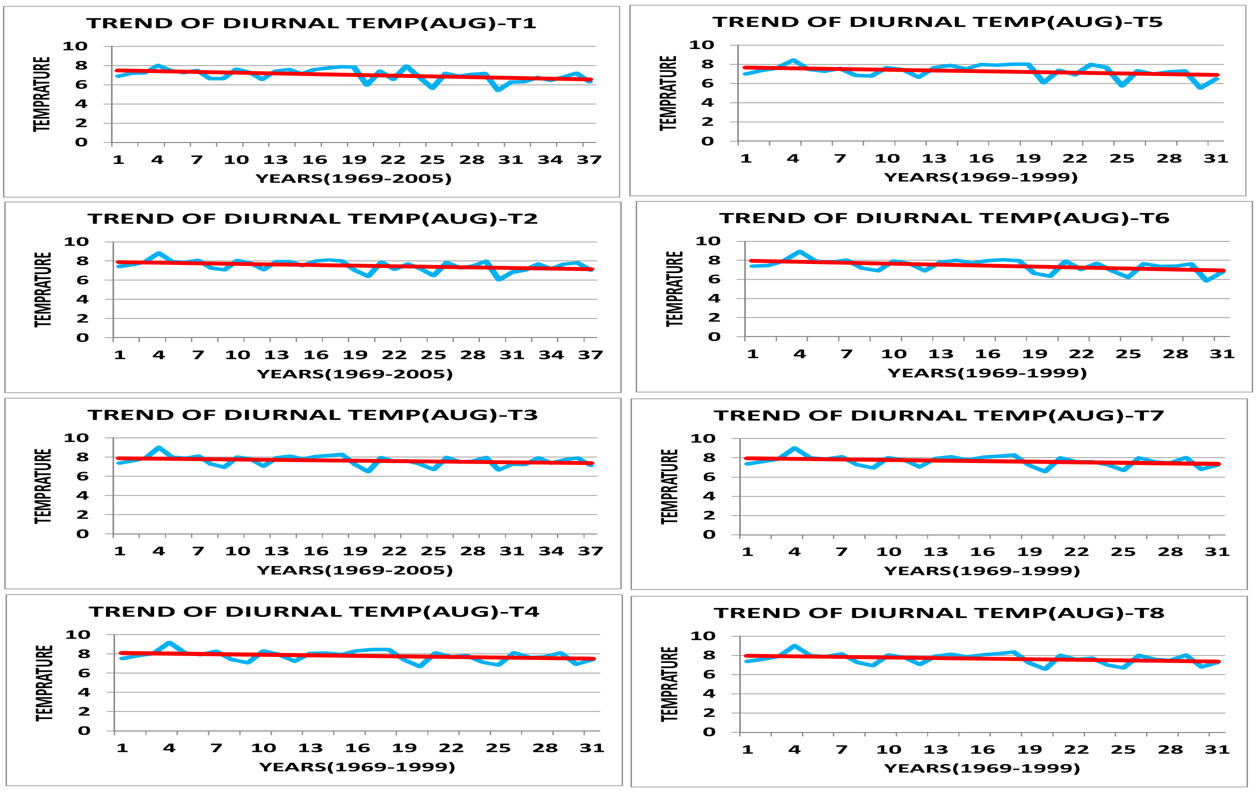

Fig.45: TREND OF DIURNAL TEMP (AUGUST)

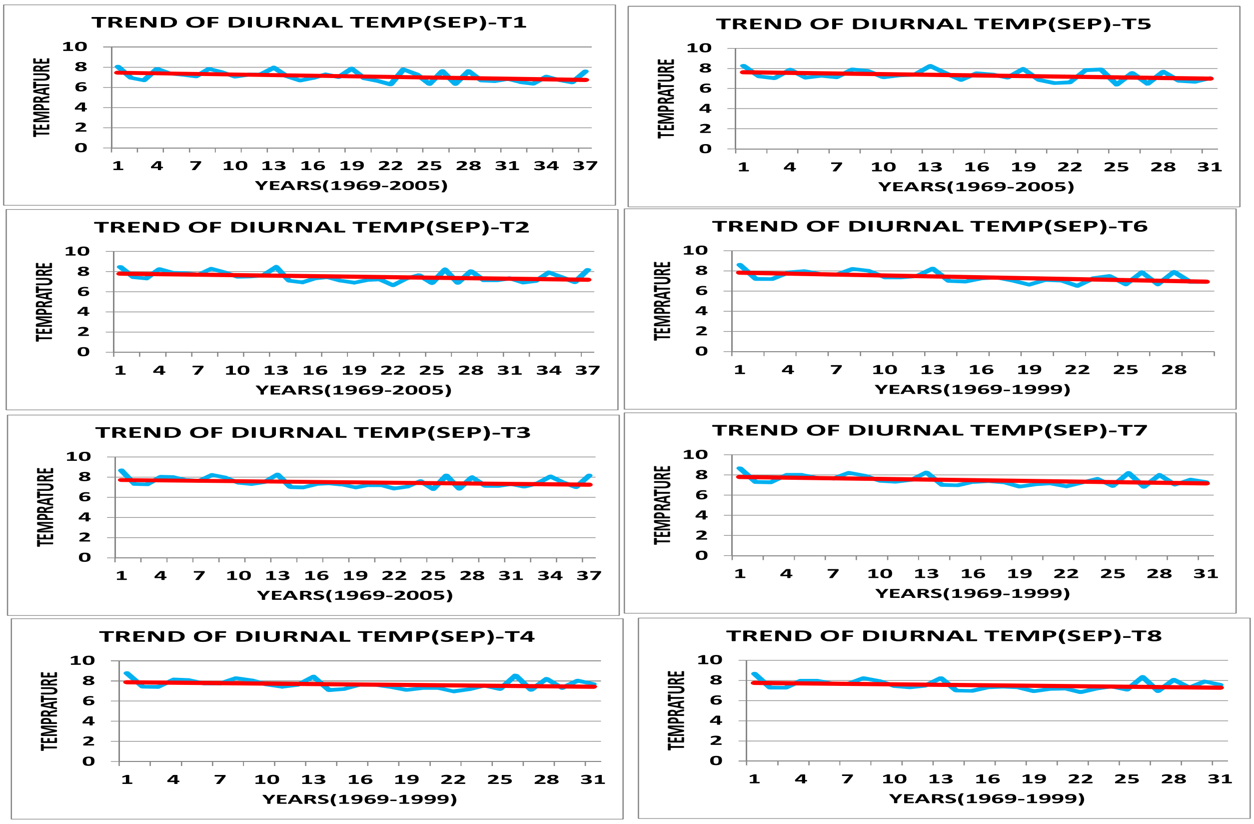

Fig.46: TREND OF DIURNAL TEMP (SEPTEMBER)

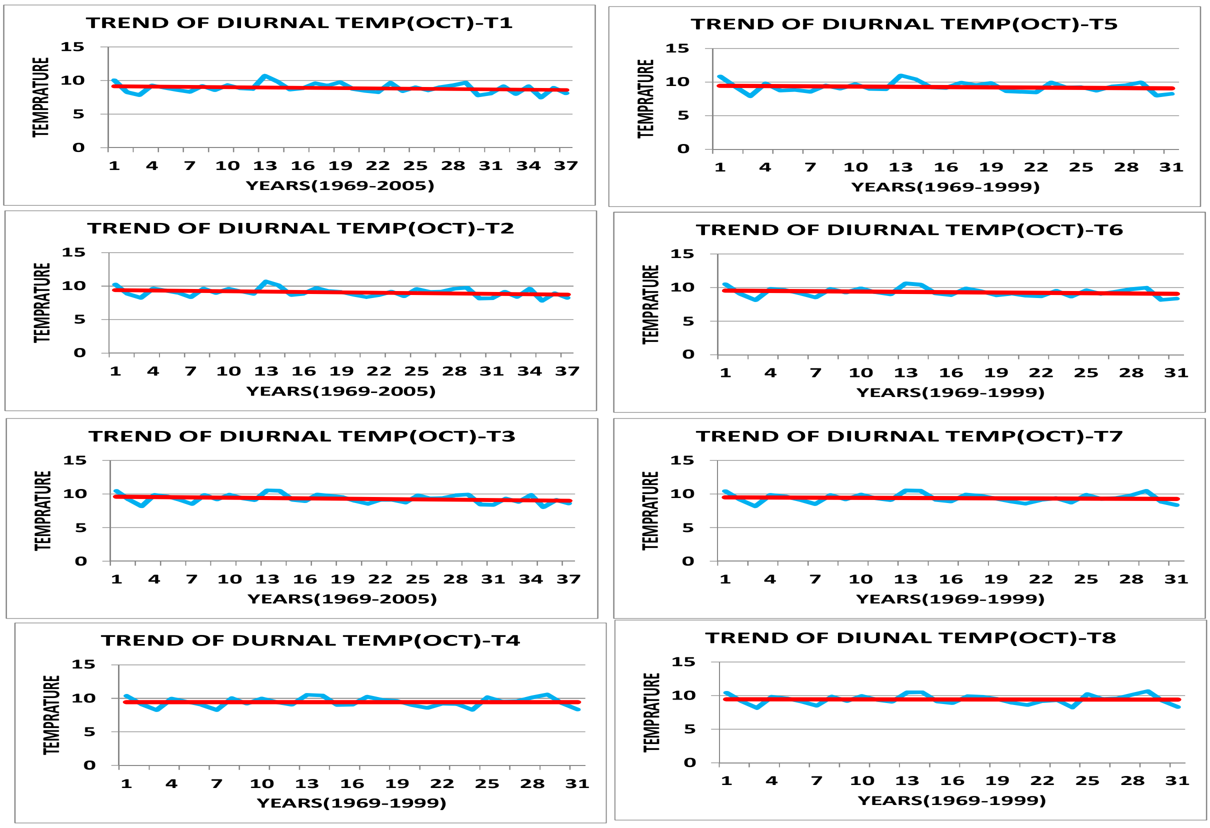

Fig.47: TREND OF DIURNAL TEMP (OCTOBER)

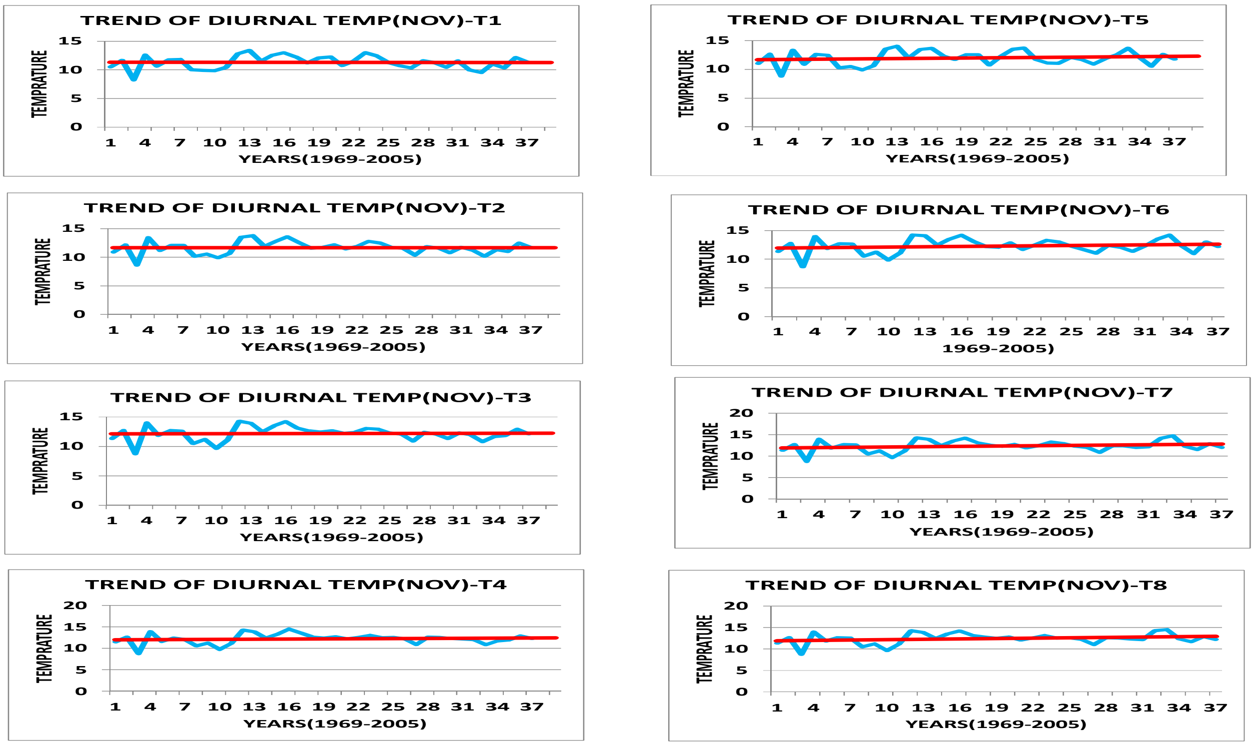

Fig.48: TREND OF DIURNAL TEMP (NOVEMBER)

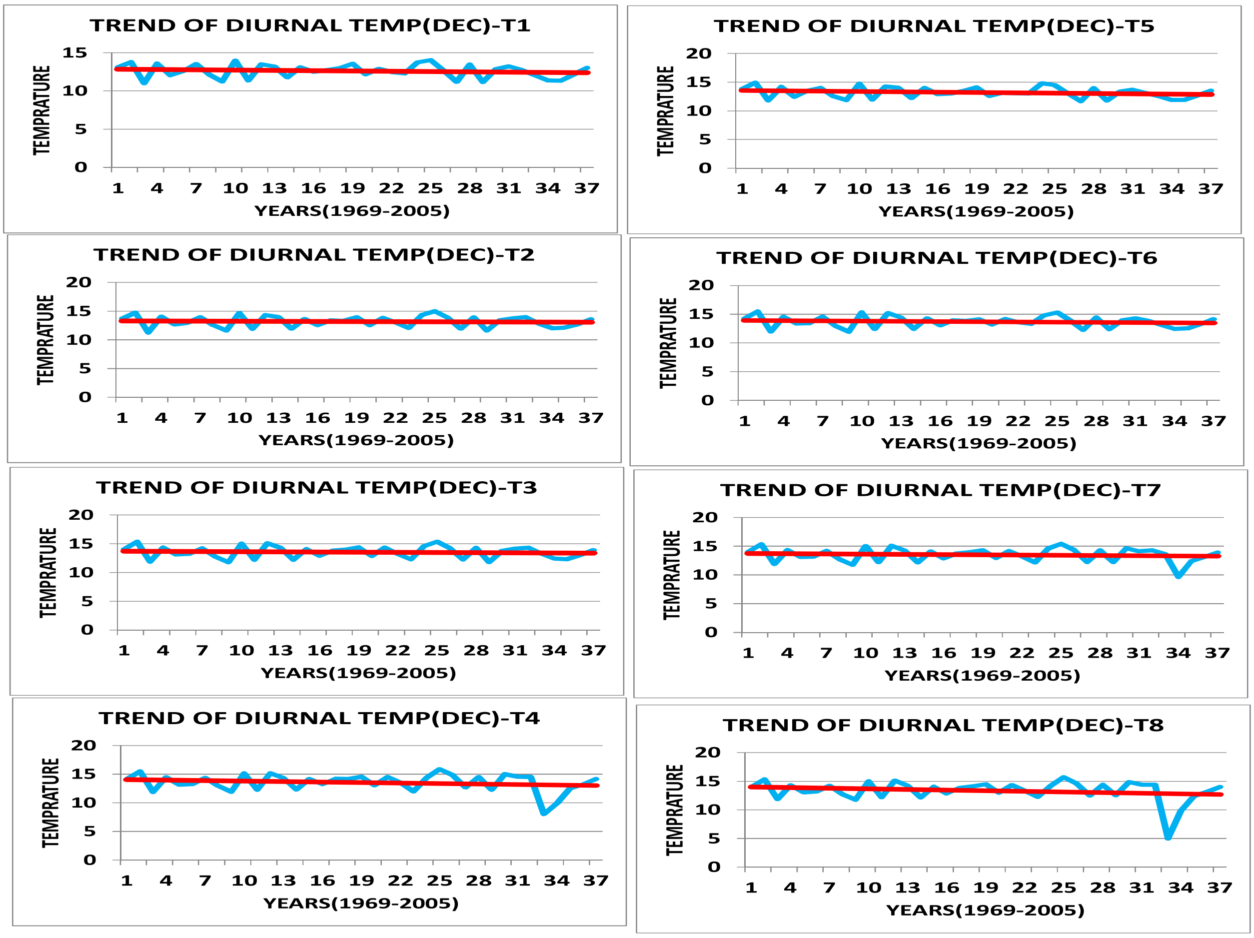

Fig.49: TREND OF DIURNAL TEMP (DECEMBER)

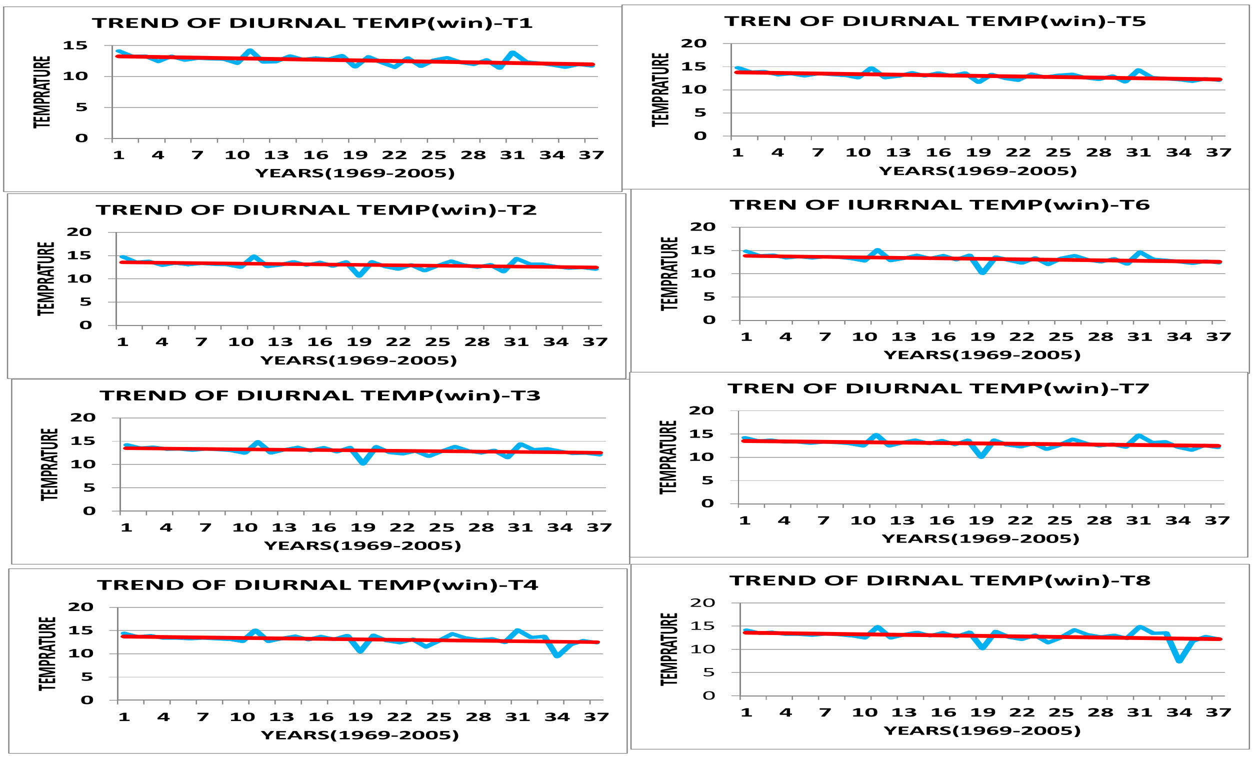

Fig.50: TREND OF DIURNAL TEMP (WINTER)

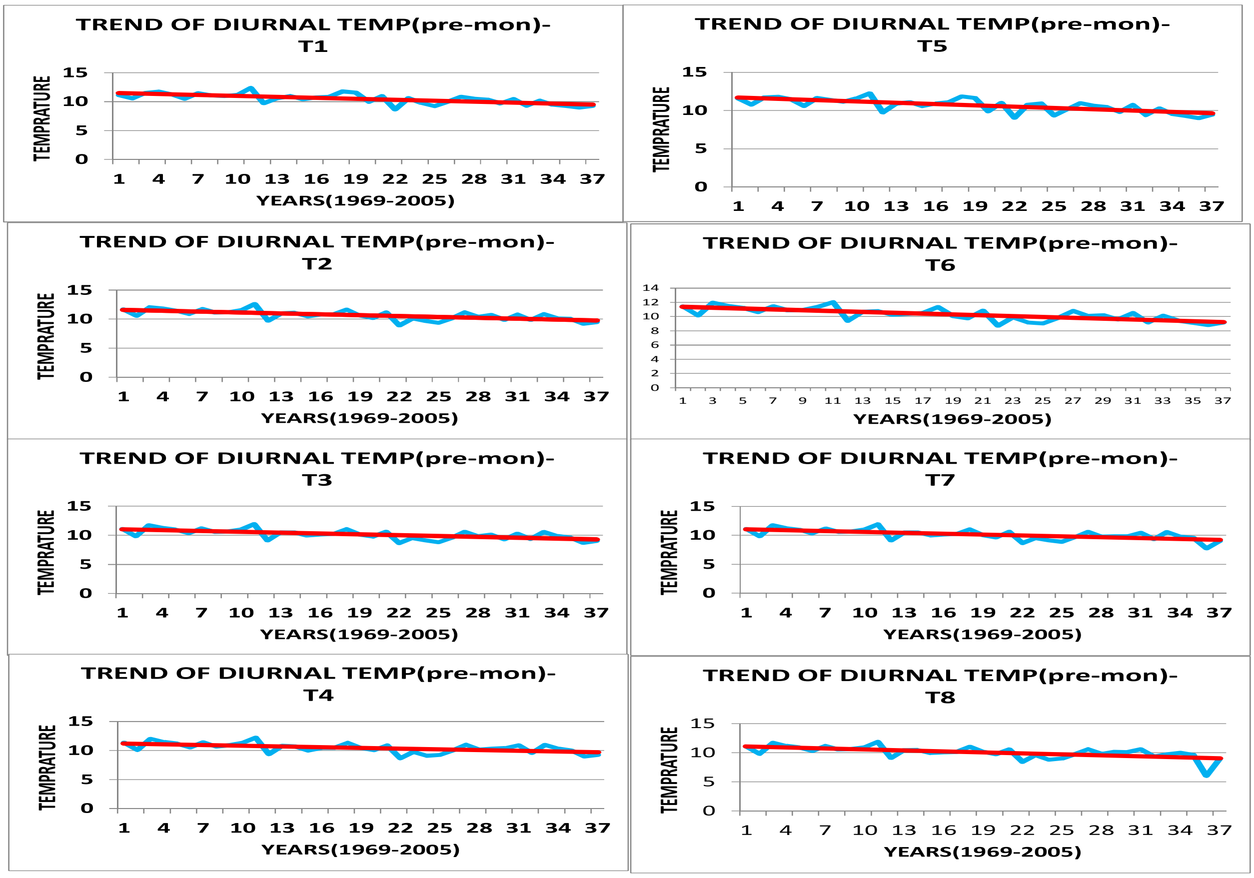

Fig.51: TREND OF DIURNAL TEMP (PRE-MONSOON)

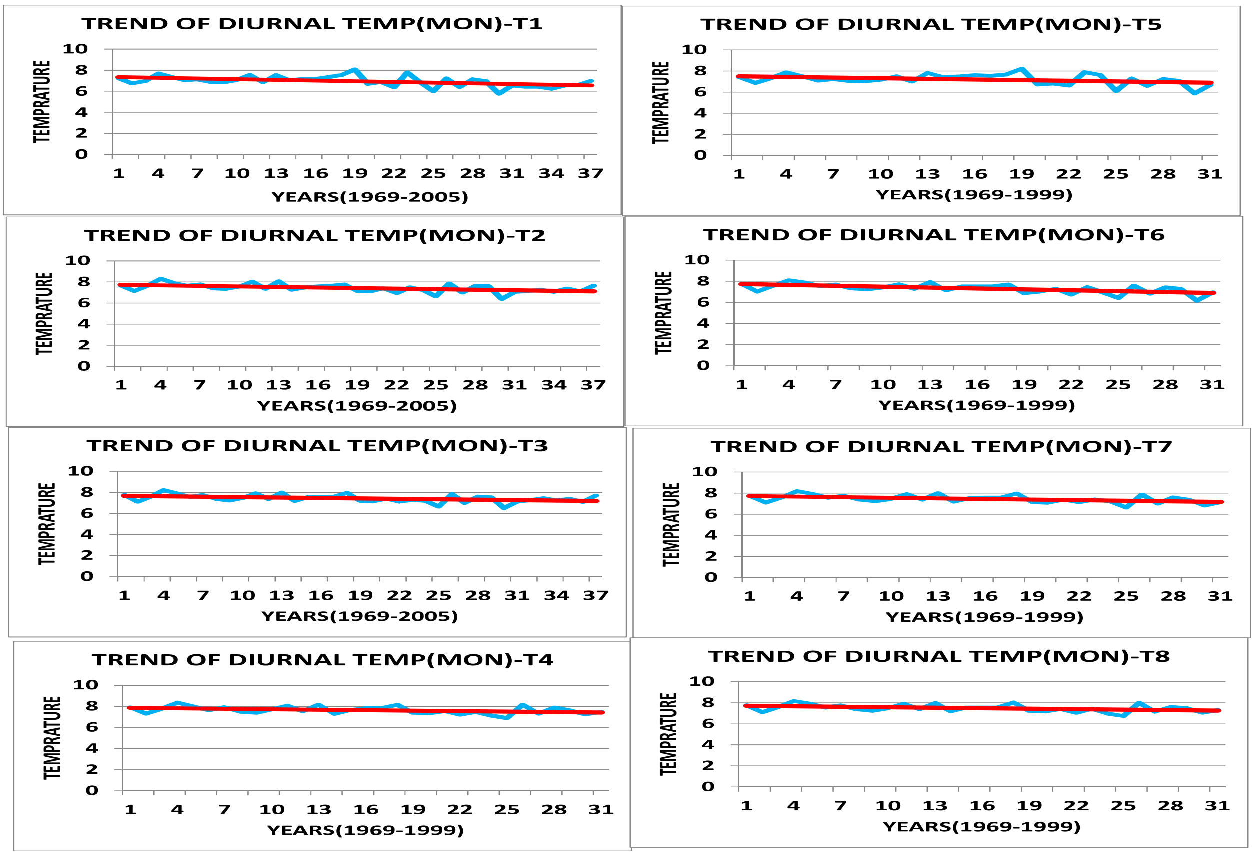

Fig.52: TREND OF DIURNAL TEMP MONSOON

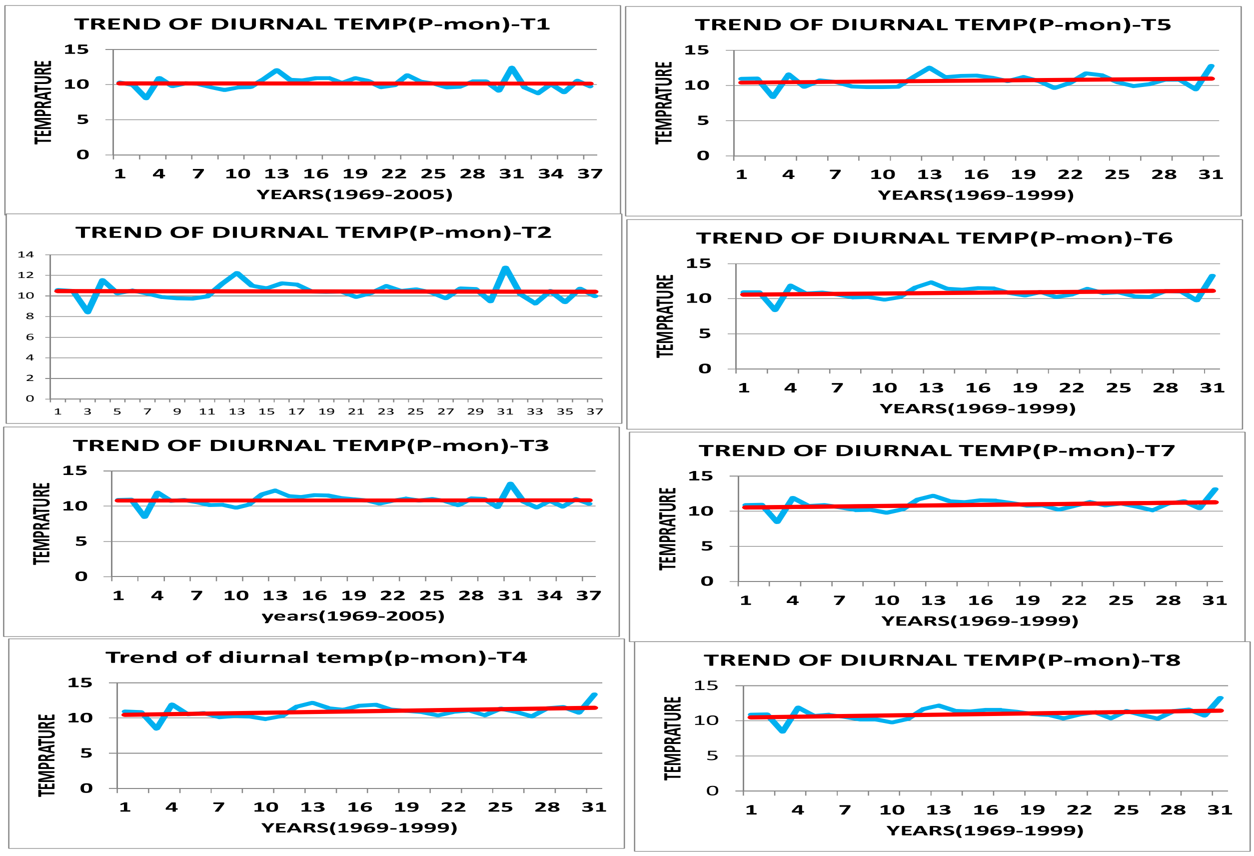

Fig.53: TREND OF DIURNAL TEMP POST-MONSOON

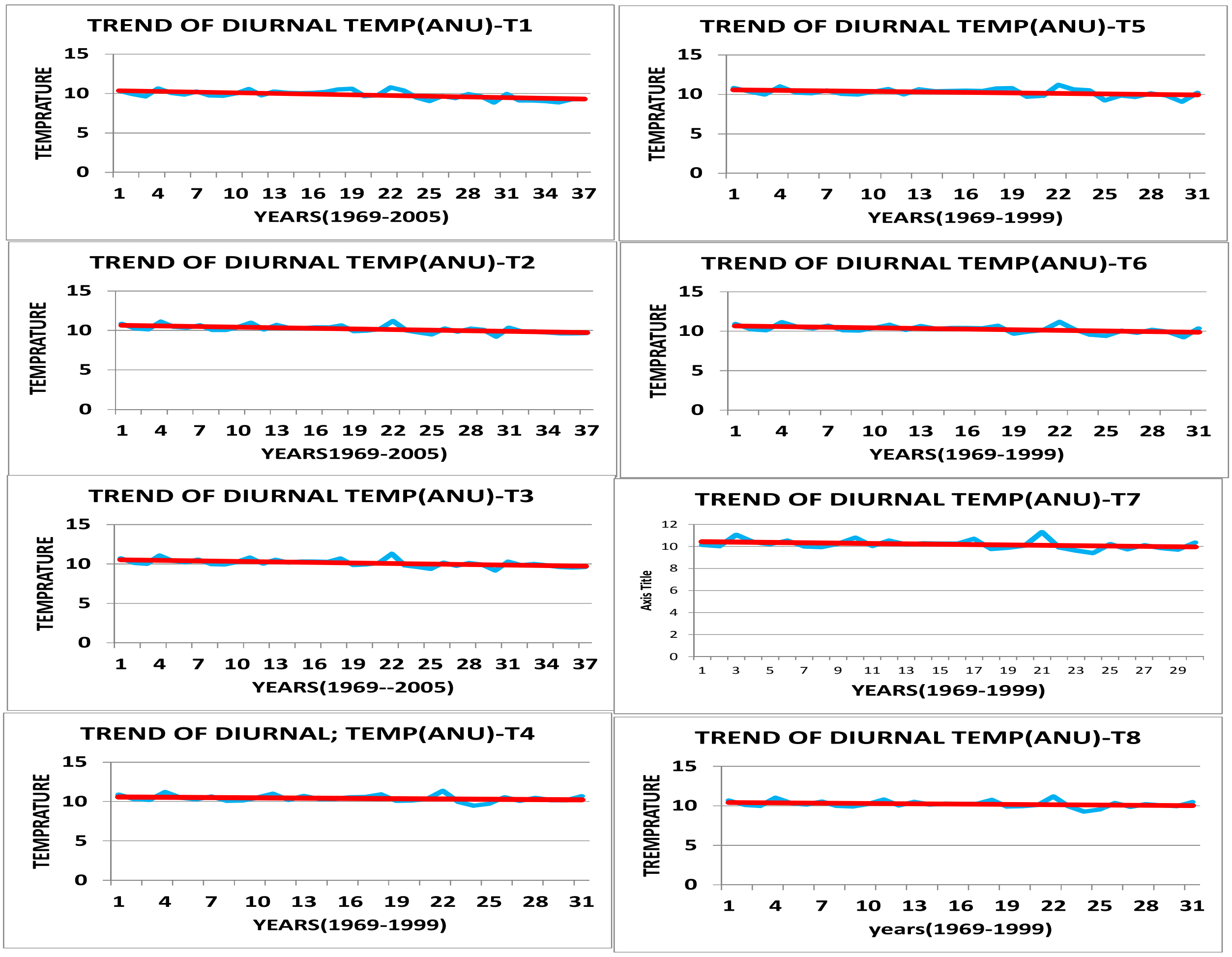

Fig.54: TREND OF DIURNAL TEMP ANNUAL

CONCLUSION

The study of trends in maximum, mean, minimum and diurnal temperature data are critically important for a country like India whose food security and economy are dependent on the timely availability of water. In this work, monthly, seasonal and annual trends of temperature data have been studied using daily data series of 30-35 years for 8 stations/grids in India. More than half of the grids showed a decreasing trend in diurnal temperature, but other variables do not show a significant trend at most stations/grids.

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