Original Research Article

Time Series Trend Analysis of Temperature and Rainfall Using Mann-Kendall Method: A Study of Vadodara City, Gujarat

ABSTRACT

Aims:
This study aimed to quantify the variability of monthly temperature and precipitation patterns on a local scale within Vadodara city, Gujarat, India.

Study Design and Data
A retrospective analysis was employed, utilizing historical weather data encompassing a 37-year period from 1981 to 2017 for Vadodara city. The data included monthly minimum and maximum temperatures (T_{MIN} and T_{MAX}) alongside monthly precipitation totals.

Methodology
Non-parametric statistical techniques were implemented to analyze the trends within the temperature and precipitation data. The Mann-Kendall (MK) test was employed to identify statistically significant trends, while Sen's slope estimator was utilized to quantify the magnitude of any trends detected.

Results
The analysis revealed a possible increasing trend in minimum temperature records over the study period, with a positive correlation coefficient (R^2) of 0.04. Regarding precipitation, a trend towards increasing rainfall was observed in the month of July (R^2 = 0.03), while June exhibited a trend towards decreasing rainfall (R^2 = 0.008).

Keywords: Time Series, Trend, Mann-Kendall, Sen’s Slope, temperature and Rainfall

1. INTRODUCTION

Climate plays an important role in the development and sustainable growth of the region. The fluctuations at local, regional, and global rainfall have been observed at different time scales over the past years, leading to changes in climate and variability.

A temperature and precipitation trend analysis, on different spatial and temporal scales, has been of great concern during the past century because of the attention given to global climate change from the scientific community, indicate a small positive global trend, even though large areas are instead characterized by negative trends [1]

Analyzing long-term trends in climatic parameters is an essential challenge in climate change monitoring research. The rainfall and temperatures [2] are the most important fundamental physical parameters among the climate as these parameters determine the environmental condition of the particular region which affects the agricultural productivity [3]; [4]. A trend analysis is ordinarily used in climatology to know how the temperature for example, changes with time. It is also useful in predicting the future behavior of climate parameters. [5] The rainfall received in an area is an important factor in determining the amount of water available to meet various demands such as agricultural, industrial, domestic water supply and for hydroelectric power generation. The pattern and amount of the rainfall [6].

For the management and planning at regional or local scale it has been found that continental or global scale studies of climate variables are not very much useful [7], [8]. Therefore, the regional and local level climatic variables studies are required for the same. The temperature regimes are now making micro climatic zones.

Changes in precipitation showed a significant impact on society; therefore it's up-to-date [9]

information is needed to estimate the spatial distribution and variability at all points of the territory [10]. The drastic change in precipitation trend would lead to hazardous events like flood and drought. [11]. The built-up area is increasing and the resource demand such as land and water will also see a rise. Several studies are indicating this pressures, also in Vadodara region expansion is found.[12]

The trend test conducts an investigation to detect changes in temperature and precipitation in the urban watershed with the use of the Mann- Kendall trend test. Mann-Kendall test had been formulated by Mann (1945) as a non-parametric test for trend detection and the test statistic distribution had been given by Kendall (1975) for testing non-linear trend and turning point. The benefit of this test is that data need not confirm any particular distribution. In this test, each data value in the time series is compared with all subsequent values.

The rank-based Mann-Kendall test (MK) has been widely used throughout the world to detect trends in agro-meteorological as well as hydrological time series. [13]

For a trend analysis, non-parametric tests are widely used compared to their parametric counterparts. When comparing their strength, i.e., their ability to distinguish between the null hypothesis and an alternative hypothesis, the Mann-Kendall (M-K) tests [14]. Sen's non-parametric estimator of slope has been frequently used to estimate the magnitude of trend, whose statistical significance was assessed by the Mann–Kendall test.

Analyzing 40 years of data, Ray et al. [15] observed an increase in rainfall extremes over south Gujarat and Saurashtra and no change in north Gujarat and Kutch. A study for the past 115 years rainfall trend is done using the Mann-Kendall trend, Sen's slope and variability at five districts of south Gujarat[16].

2. MATERIAL AND METHODS

Daily maximum and minimum temperature and normal daily rainfall data were collected from Indian Meteorological Department (IMD) for Vadodara station for the period 1981-2017. The annual average of the minimum and maximum temperature were calculated. The seasonal rainfall data used for the month of June –September from 1981-2017 basis on the availability of rainfall data. Rainfall contribution during the remaining months was less than one percent.

The Mann- Kendall trend test Mann-Kendall (Mann, 1945; Kendall, 1975) was applied to all the independent weather parameters. (Maximum & minimum temperature and rainfall) were statistically examined in two phases. . Man-Kendall test is a non-parametric test for finding trends in time series. This test compares the relative magnitudes of data rather than data values themselves. The benefit of this test is that data need not to confirm any particular distribution. The test procedure using the normal approximation test is described by Kendall (1975) [14]

First one is the using of non-parametric Mann-Kendall test and the second one is the non-parametric Sen's slope estimator. The increasing or decreasing trend was tested based on normalized test statistics (Z), Sen's slope use to estimate the true slope of an existing trend. When Z is positive, the trend is said to be increasing and when Z is negative, it is said to be decreasing. The trend's slope gives the annual rate and direction of change (Kendall M G, 1995)

Mann –Kendall Test: This test is found to be an excellent tool for trend detection by other researchers in similar application. [17], [18], [19],[20]. The non-parametric Mann-Kendall test is commonly employed to detect monotonic trends in a series of environmental data, climate data or hydrological data. The null hypothesis, H0, is that the data come from a population with independent realizations and are identically distributed. The alternative hypothesis, HA, is that the data follow a monotonic trend. The Mann-Kendall test statistic(S) is calculated according to:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(\, x_{j-}\, x_k)$$

With

$$sgn(x)\begin{cases}1 \; if & x > 0\\ 0 \; if & x = 0\\ -1 \; if & x < 0\end{cases}$$

A positive value of S indicates an increasing trend, and a negative value indicates a decreasing trend. However, it is necessary to perform the statistical analysis for the significance of the trend.

$$\mathrm{Var\ (S)} = \frac{\mathrm{n(n-1)(2n+5)} - \sum_{j=1}^{p} t_j\,(t_j - 1)(2t_j\ + 5)}{18}$$

Where, n is the number of data points, p is the number of tied groups and tj is the number of data points in the j th group The statistic S is approximately normal distributed provided that the following Z transformation is employed:

$$Z = \begin{cases}\dfrac{S-1}{\sqrt{Var(S)}}, & if\ S > 0\\ 0 & if\ S = 0\\ \dfrac{S+1}{\sqrt{Var(S)}}, & if\ S < 0\end{cases}$$

The significance of the trend is assessed using a Z value, where negative and positive scores of Z denote downward and upward trends.

Sen's method

The Theil-Sen approach (TSA), a commonly-used method to quantify the significant linear trends in time series, was used in this study. To estimate the true slope of an existing trend the Sen's nonparametric method is used. The TSA is considered more robust than the least-squares method due to its relative insensitivity to extreme values and better performance even for normally distributed data.[16] [21]

The magnitude of the trend is estimated by Sen's slope method. Which is proceeds by calculating the slope as a change in measurement per change in time. To get the slope estimate Q in equation calculate the slopes of all data value Pairs.

$$Q_i = \frac{x_j\ - x_k}{\mathrm{j-k}}$$

Where, Q_i is the slope between data points x_j and x_k, x_j is the data measurement at time j and x_k is the data measurement at time k.

For a time series x having n observations, there are a possible N = n (n-1)/2 values of Q_i that can be calculated. According to Sen's method, the overall estimator of Sen's slope is simply given by the median of these N values of Q_i. (S Chattopadhyay and D. R. Edwards, 2016).

The overall slope estimator Q is thus:

$$Q = \begin{cases}Q_i(N+1)/2, & if\ N\ is\ odd\\ \dfrac{Q_iN/2 +\ Q_i(N+2)/2}{2}, & if\ N\ is\ Evan\end{cases}$$

Positive Sen's slope indicates a rising trend while negative Sen's slope indicates a falling trend.

The procedure in Mann-Kendall and Sen's Slope computes the confidence interval at two different confidence levels; □α= 0.01 and α= 0.05, resulting in two different confidence intervals.

It is computed as:

$$C\alpha = Z_{1-\alpha/2}\sqrt{Var(S)}$$

Where, Var (S) has been defined in equation above, and $Z_{1-\alpha/2}$ is obtained from the standard normal distribution.

The smallest significance level α with which the test shows that the null hypothesis of no trend should be rejected. If n is 9 or less, the test is based to the S statistic and if n is at least 10, the test is based to the Z statistic (normal approximation).

3. RESULTS

Trend analysis of temperature for the period of 1981-2017 (37 years) Vadodara station has been done in the present study. Seasonal average and annual average of the maximum, minimum temperature and rainfall weather factor were calculated. The mean and standard deviation measured for this parameter. Finally, Mann-Kendall and Sen's Slope Estimator have been used for the determination of the temperature and rainfall trend detection (Fig.1).

3.1. Monthly And Seasonal Variability

The variation in seasonal average temperature measured by the three major period as pre-monsoon, monsoon and post-monsoon and rainfall measured for monsoon season (June-sept).

Table: 1 Monthly and Seasonal Variability Temperature (T MAX and TMIN) and Rainfall

Season	Maximum Temperature		Minimum Temperature		Rainfall	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Pre-Monsoon	36.84	0.84	21.61	0.74	-	-
Monsoon	33.43	0.78	25.98	0.44	918	100.06
Post-Monsoon	34.11	0.67	16.89	1.13	-	-

Highest average temperature has been detected in pre-monsoon season and it gradually decrease in monsoon. It is seen, winter seasonal average maximum temperature was 33.43°C with SD 0.78 this is gradually increased in post monsoon season with 34.11° and SD change with 0.67. The most important changed attributed in the seasonal mean minimum temperature, the mean was 25.98 °C with SD 0.44 in monsoon season compare to the pre and post monsoon. Seasonal normal rainfall mean was 918 mm in 37 years.

The graphs show variation between the monthly average of the maximum and minimum temperature over the 37 years. From month of March to June maximum temperature was high, the highest mean maximum temperature was 40 ℃ in month of May. The minimum temperature gradually increased from the month of April to September. Lowest minimum temperature found in December month.

Month-wise mean temperature shows the increasing and decreasing trend. The normal linear regression trend line shows the maximum temperature was decreasing very less toward the post-monsoon months, whereas minimum temperature was gradually increased in the same period.

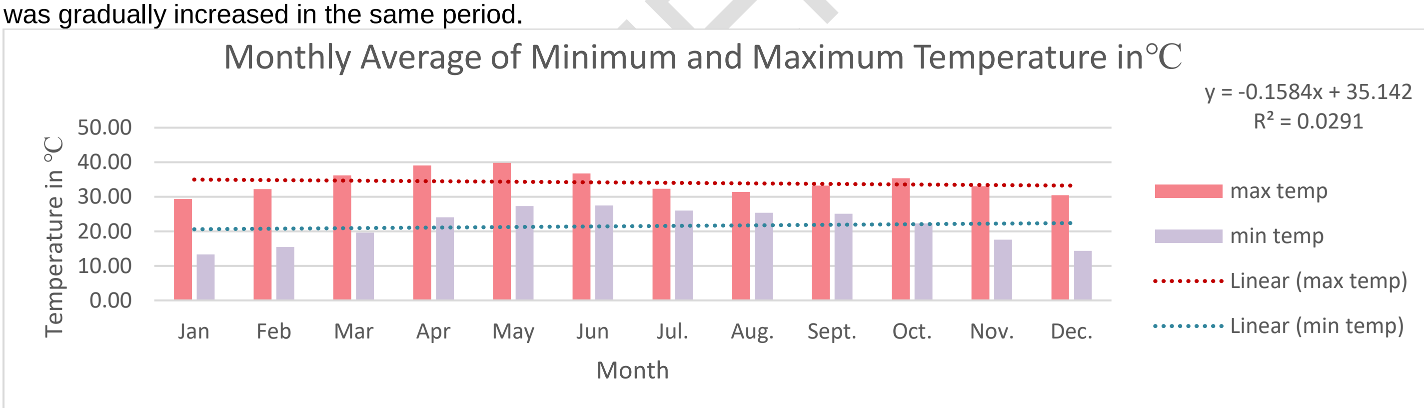

Fig:1. Monthly average temperature during the period (1981-2017) for Vadodara Station.

3.1.1. Annual Variability

The annual average maximum temperature show least decreasing trend same as above mention monthly climatic change. It is observed highest maximum temperature in 1987 with more than 35 ℃., then it was decreased in 1990 and 1997. The maximum temperature dramatically increased in 2000, 2001 and 2002 again it fall down in years 2008 and 2013 with 32℃. Besides, May was the years of high deviation of temperature occurrence. Using a linear regression model, the rate of change is defined by the slope of regression line which in this case is about $R^2 = 0.04$ with negative trend. It indicates the mean maximum temperature reduction.

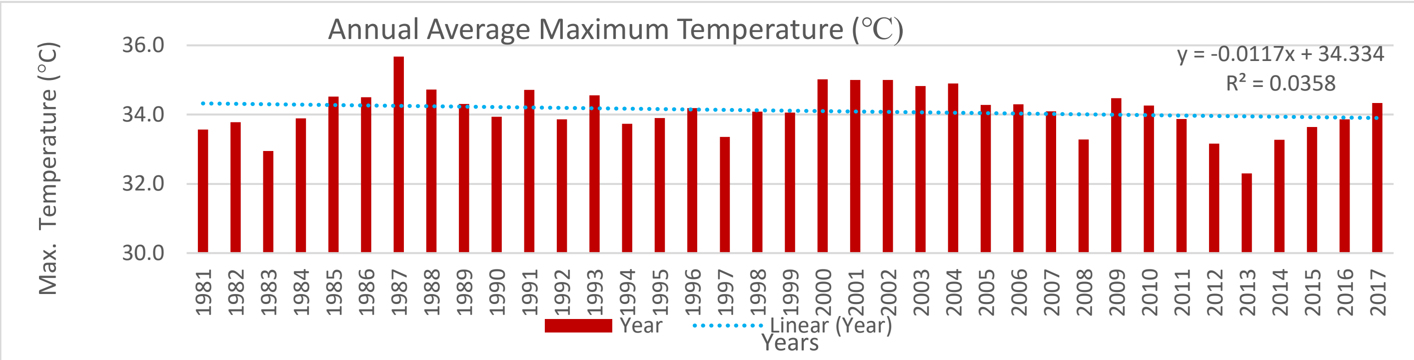

Fig 2: Annual Average Maximum Temperature

To investigate the observed spatial variability of the minimum temperature trend, the regression line for climatic period explained the increasing trend of the temperature. There is a positive correlation between the minimum temperature record and the time period. Highest minimum temperature exhibited in 2009 to 2011 with more than 22℃. This might be the case that temperature is increasing from time to time in the area as a result of global climate change.

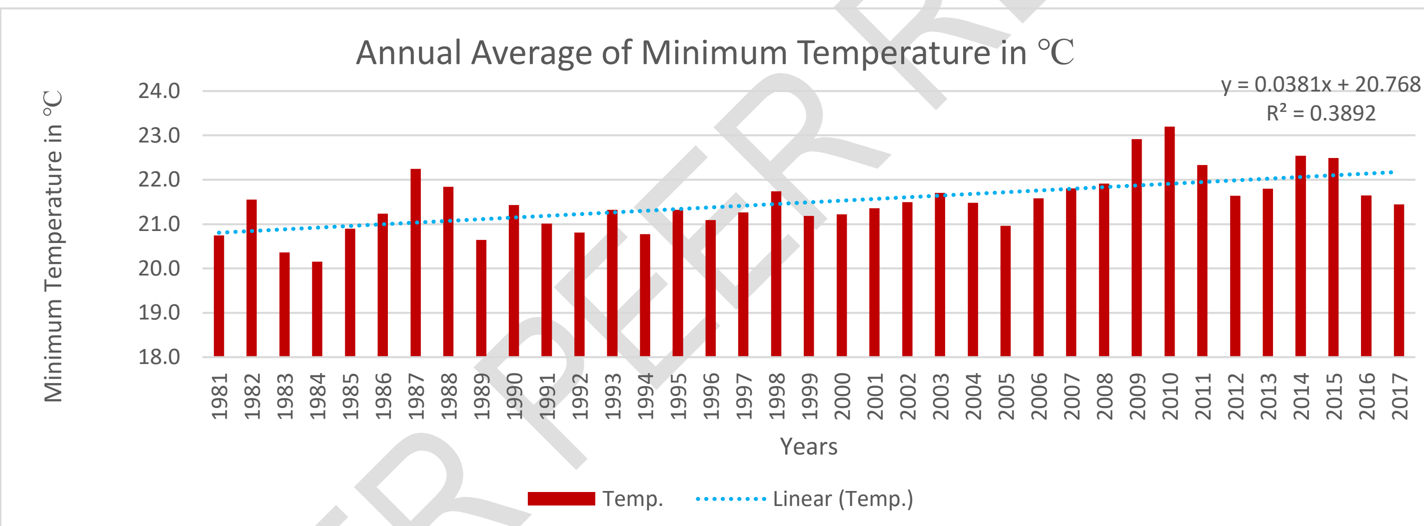

Fig 3: Annual Average Minimum Temperature

3.2. Rainfall Seasonal Variability

The figure 4 shows seasonal rainfall for month of June, July, August and September, especially for monsoon period of Vadodara station. The years wise (1981-2017) sum of rainfall were calculated for monsoon season. Increasing of precipitation was observed in month of July in all years, the linear regression line shows the increasing trend (R^2= 0.03) of rainfall. The precipitation increased with high trend in the September month from 1981 to 2017 periods (R^2 =0.09). The highest precipitation observed in 2005 and 2006 in all month of monsoon (fig)

A dramatic decreasing of precipitation was observed in 2008 to 2012 in month of June and all rainy months observed in 1998, 1999 and 2000. The decreasing trend observed in month of June over the 37 years. (R^2 = 0.008). Long term climatic change with decreasing trend of precipitation in monsoon month of June expressed conversion of the wet month into dry month. Monthly rainfall trends, even small, were also identified to be both increasing and decreasing in the region.

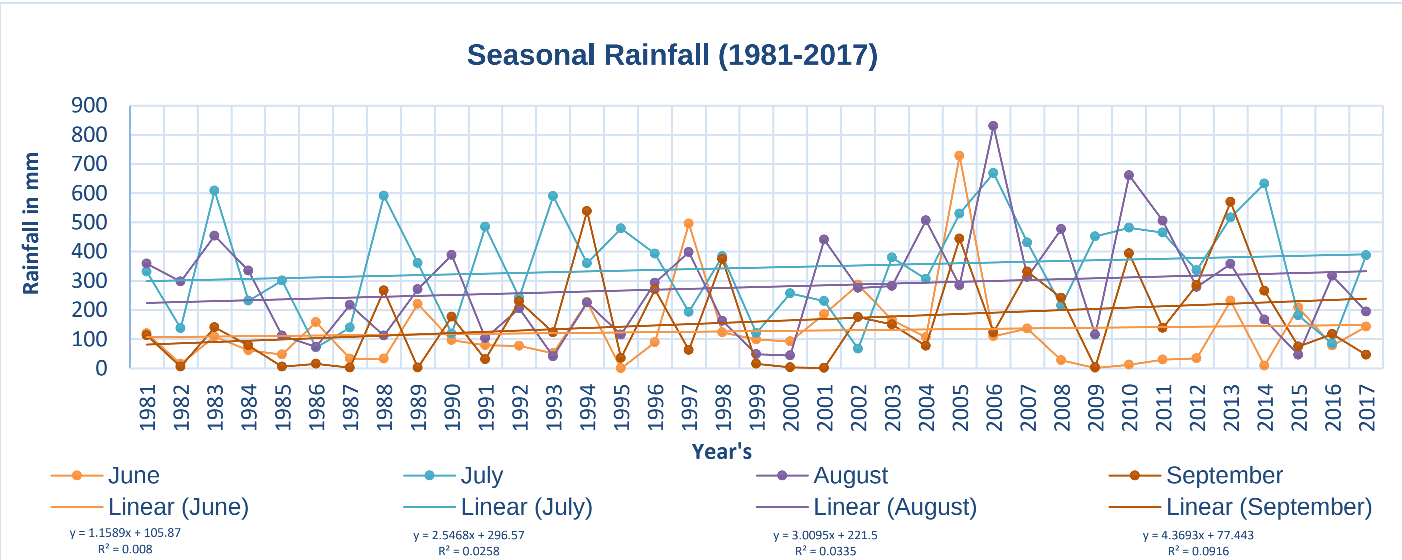

Fig. 4. Annual Variability of Rainfall

3.3. Trend Analysis

In the non-parametric Mann-Kendall test, trend of maximum temperature for 37 years from January to December has been calculated for each month individually together with the Sen's magnitude of slope. In the Mann-Kendall test describes the trend of the series for individual 12 months from January to December as well as seasonal variation trend. (Table 2)

For January, May, June, September ,October, November and December there is an evidence of falling trend, especially negative trend at 95% found in September month with Z= -2.12 test statistic. January month has a Sen's Slope of -0.024, indicating a slight decreasing trend in maximum temperatures over the years. While test value is showing least positive trend in February, March, April, and July, no trend found in august month. Thus from negative trend shows test values for four months representing almost non-significant condition. 0.05 Level of significance found in September, whereas the cell is blank, significance level is greater than 0.1.

Table 2: Trend Analysis: Maximum Temperature

Non-Parametric Test (Sen's Slope and Mann Kendall)				
Maximum Temperature (1981-2017)				
Month	**S**	**Sen's Slope**	**Z**	**Level of Significance**
January	-72	-0.024	-0.78	
February	7	0.001	0.09	
March	33	0.007	0.42	
April	73	0.02	0.94	
May	-20	-0.003	0.25	
June	-12	-0.002	-0.14	
July	3	0	0.03	
August	-1	-0.001	0	
September	-163	**-0.05**	**2.12**	*
October	-37	-0.014	0.48	
November	-74	-0.018	0.72	
December	-108	-0.029	1.46	
Summer	26	0.007	0.59	
Rainy	-82	-0.013	1.03	
Winter	-62	-0.01	0.85	
Avg.of all month	-62	-0.01	0.85	
	Negative trend at 95%			
	Remaining Z values no trend at 95%			

*α = 0.05 level of significance

The fig 5. shows Sen's slope falling from September to December, it explained, the maximum temperature fall in month of September, October, November and December in climatic period with less than – 0.02 slope. It is noticeable that, maximum temperature rising slope found in month of April with 0.02 Sen's slope, rest of the month found with no slope or less than 0 (zero) slope magnitude values. Overall figure represent the maximum temperature trend reduction towards the post monsoon period.

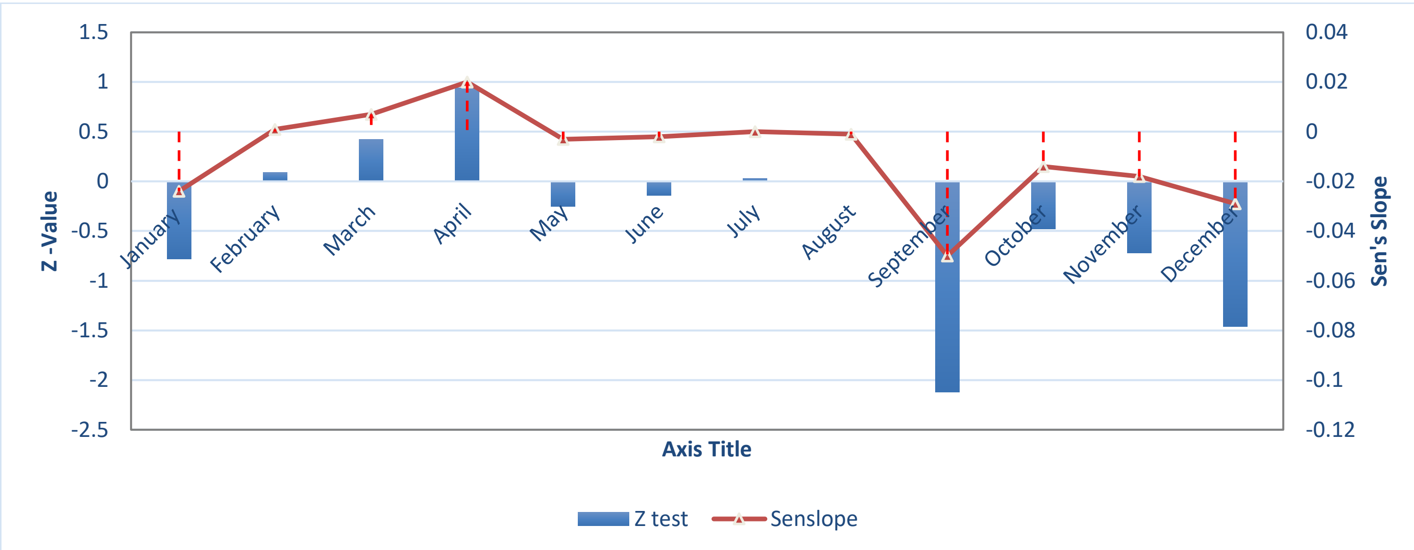

Fig. 5. Trend Test: Maximum Temperature

The trend test shows rising trend for minimum temperature. The slope of the whole months indicates that a positive value inferring rise in the mean minimum temperature. The normal positive trend indicates in month of February, March and April, there is Z statistic more than 2 with high value of Mann- Kendall statistic (S). Besides, the positive trend found in post monsoon season especially in month of October with 3.6 Z value and 0.079 Sen's slope magnitude. Level of significance found vary, the 0.05 level of significance shows in august, September and November month 0.001 level of significance exhibited with high S Values as well as Z statistics. The July and December month seen as 0.01 level of significant with least trend. Seasonal period also indicate the positive trend. Thus, result seems the minimum temperature were increased with long period of time.

Table 3: Non- Parametric Test- Minimum Temperature

Non-Parametric Test (Sen's Slope and Mann Kendall)				
Minimum Temperature (1981-2017)				
Month	**S**	**Sen's Slope**	**Z**	**Level of Significance**
January	91	0.02	1.18	
February	212	0.06	2.76	**
March	130	0.039	3.05	**
April	148	0.052	3.57	***
May	81	0.01	1.05	
June	102	0.016	1.32	
July	132	0.013	1.71	+
August	180	0.024	2.37	*
September	186	0.021	2.42	*
October	192	0.079	3.6	***
November	156	0.071	2.03	*
December	96	0.049	1.92	+
Summer	116	0.044	3.86	***
Rainy	203	0.017	2.68	**
Winter	136	0.062	3.26	**
Avg.of all month	86	0.04	4.12	***

	Positive Trend at 95%
	Remaining Z values no trend at 95%

***α = 0.001 level of significance, **α = 0.01 level of significance *α = 0.05 level of significance,
+ α = 0.1 level of significance. Cell is blank, the significance level is greater than 0.1.

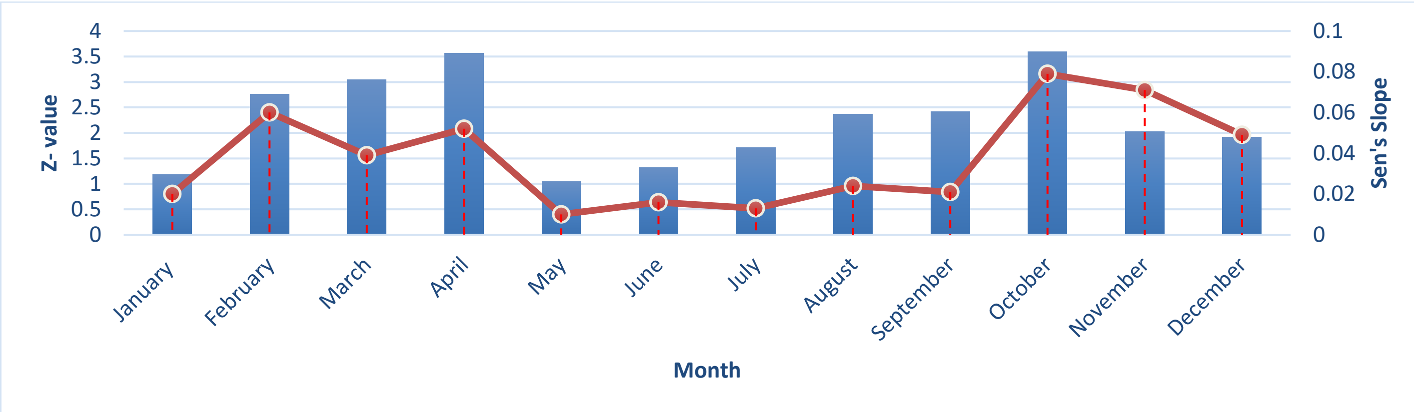

Fig. 6. Trend Test: Minimum Temperature

For seasonal rainfall, magnitude of the trends are significant in particular time intervals of the reference period, as indicated in corresponding Z test and Mann–Kendall test. The period from 1981–2017 shows a generalized positive trend for seasonal rainfall in July and September, significant trends coming of during the September month season (α = 0.05) with high value of S statistics and Sen's slope magnitude (3.417). The other months indicates the least trend of rainfall with 0.1 level of significance and Z value with less than 1. The positive trend in the September month indicates the high rainfall month over the 37 years.

Table 4: Non-Parametric Test -Rainfall (Sen's Slope and Mann Kendall)

Non-Parametric Test (Sen's Slope and Mann Kendall)				
Rainfall (1981-2017)				
Month	**S**	**Sen' S Slope**	**Z**	**Level of Significance**
June	34	0.62	0.43	
July	76	3.701	0.98	
August	68	2.402	0.88	
September	129	3.417	1.67	*
Avg.of Rainy	88	2.47	1.63	

*α = 0.05 level of significance

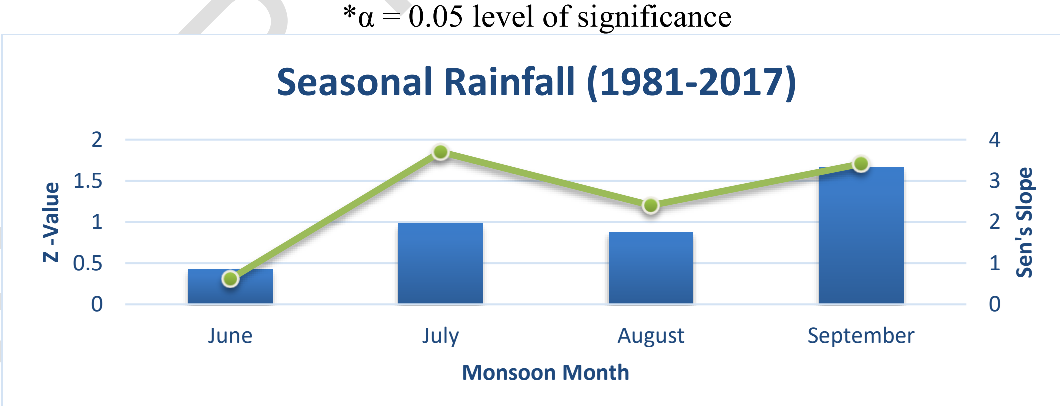

Fig. 7. Seasonal Rainfall

4. DISCUSSION:

The air temperature and precipitation behavior is important for short-term planning and the prediction of future climate conditions. Trends in precipitation and temperature at annual, seasonal and monthly time scales for the periods of 1981-2017 have been analyzed using IMD data for Vadodara station.

The seasonal characteristics of rainfall measures for the month of June –September. The non-parametric Mann-Kendall test and Sen's slope was applied to detect trends and to assess the significance of the trends in the time series.

Three major period as pre-monsoon, monsoon and post-monsoon and rainfall measured for monsoon season. The most important change attributed in the seasonal mean minimum temperature gradually increased as trend regression line, the mean was 25.98 ˚C with SD 0.44 in monsoon season compare to the pre and post monsoon. The annual average maximum temperature show least decreasing trend, the rate of change is defined by the slope of regression line which in this case is about $R^2 = 0.04$ with negative trend. There is a positive correlation between the minimum temperature record and the time period with positive trend ($R^2 = 0.04$).
Increasing and decreasing trend of precipitation was observed in month of July ($R^2= 0.03$) and June. 0.008) respectively over the 37 years. This study was done to find the monotonic trend (annual) for temperature time series, which was found to be increasing (positive) with level of least-significance trend.

Mann-Kendall test describes the trend of the series for individual 12 months for maximum temperature, especially negative trend at 95% found in September month with Z= -2. 12 test statistic almost level of significant condition with 0.05, rising slope found in month of April with 0.02 Sen's slope, rest of the month found with no slope or less than 0 (zero) slope magnitude values. The slope of the whole months indicates that a positive value inferring rise in the mean minimum temperature, the positive trend found in post monsoon season especially in month of October with 3.6 Z value and 0.079 Sen's slope magnitude, minimum temperature were increased with long period of time. A generalized positive trend for seasonal rainfall in July and September, significant trends coming of during the September month season ($\alpha = 0.05$) with high value of S statistics and Sen's slope magnitude (3.417).

5. CONCLUSION:

The Mann-Kendall test results reveal insightful trends in both maximum and minimum temperatures as well as seasonal rainfall, offering valuable implications for landscape and water resource management in the Vadodara city region. Notably, a significant negative trend in maximum temperature is observed in September, indicating a potential cooling trend during this month. Conversely, a rising slope in April suggests a warming trend during this period. While most months exhibit no or negligible slope magnitudes in temperature, the overall trend suggests a gradual increase in mean minimum temperatures over time.
Moreover, the post-monsoon season, particularly in October, exhibits a pronounced positive trend in minimum temperatures, reflecting a consistent long-term warming trend. This finding underscores the importance of adaptive strategies to mitigate the impacts of rising temperatures on the local environment and human activities.
In terms of precipitation patterns, a generalized positive trend is noted in seasonal rainfall, notably in July and September. Of particular significance is the marked increase in precipitation during September, suggesting a potentially heightened risk of wet spells during this period. This trend underscores the necessity for robust water resource management strategies, including flood prevention measures and infrastructure development to mitigate the impacts of heavy rainfall events.
These findings hold significant implications for decision-makers involved in landscape management, water resource management, and urban planning in Vadodara and similar regions. Consistent protection of water and soil, coupled with sustainable management practices, is imperative to ensure the resilience of communities in the face of fluctuating climatic conditions throughout the year. By integrating these insights into policy frameworks and management strategies, stakeholders can effectively address the dynamic challenges posed by climate variability and enhance the long-term sustainability of water and land resources in the region.

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