

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

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.

"Tropical countries are vulnerable to the change of weather pattern the and variability due to the complicated reactions among land, oceans, and the atmosphere".[1] Also, studies indicate that India will be one of the most vulnerable countries to the impact of climate change[2], with its cities at the forefront. [3] "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". [4]

"Changing weather patterns and their impact on water resources are important climatic features that pose a challenge to society" [5].

"Analyzing long-term trends in climatic parameters is an essential challenge in climate change monitoring research. The rainfall and temperatures 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" [6,7]; [8]. "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". [9] "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

35 water supply and for hydroelectric power generation. The pattern and amount of the rainfall also determines the
36 occurrence of the drought”[10].

37 “For the management and planning at regional or local scale it has been found that continental or global scale studies of
38 climate variables are not very much useful” [11], [12]. “Therefore, the regional and local level climatic variables studies are
39 required for the same. Rainfall and temperature variability affects rain fed cereal crops production, but the effects vary
40 across crops”[13]. “The temperature regimes are now making micro climatic zones” [14] . Changes in precipitation showed
41 a significant impact on society; therefore it’s up-to-date

42 “Information is needed to estimate the spatial distribution and variability at all points of the territory” [15]. “The drastic
43 change in precipitation trend would lead to hazardous events like flood and drought”. [16]. “The built-up area is increasing
44 and the resource demand such as land and water will also see a rise. Several studies are indicating this pressures; also in
45 Vadodara region expansion is found”. [17]

46 “Numerous research on long-term rainfall variations and related severe occurrences have been documented in various
47 literatures”.[18-25]

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

53 “The rank-based Mann-Kendall test (MK) has been widely used throughout the world to detect trends in agro-
54 meteorological as well as hydrological time series”. [26]

55 “For a trend analysis, non-parametric tests are widely used compared to their parametric counterparts. When comparing
56 their strength, i.e., their ability to distinguish between the null hypothesis and an alternative hypothesis, the Mann-Kendall
57 (M-K) tests” [27]. Sen’s non-parametric estimator of slope has been frequently used to estimate the magnitude of trend,
58 whose statistical significance was assessed by the Mann–Kendall test.

59 Analyzing 40 years of data, Ray et al. [28] observed “an increase in rainfall extremes over south Gujarat and Saurashtra
60 and no change in north Gujarat and Kutch”. “A study for the past 115 years rainfall trend is done using the Mann-Kendall
61 trend, Sen’s slope and variability at five districts of south Gujarat”[29].

62 The present study attempts to statistically derive the trend the in the climatic change and rainfall variability in the last 37
63 years for the Vadodara city. This city is fastest growing city and depends on the rainfall for the water requirement, so
64 variability study is essential to understand the dynamics of the regions.

65 2. DATA

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

70 3. METHODS

71 The Mann- Kendall trend test Mann-Kendall (Mann, 1945; Kendall, 1975) was applied to all the independent weather
72 parameters. (Maximum & minimum temperature and rainfall) were statistically examined in two phases. . Man-Kendall test
73 is a non-parametric test for finding trends in time series. This test compares the relative magnitudes of data rather than
74 data values themselves. The benefit of this test is that data need not to confirm any particular distribution. The test
75 procedure using the normal approximation test is described by Kendall (1975) [30]

76 First one is the using of non-parametric Mann-Kendall test and the second one is the non-parametric Sen’s slope
77 estimator. The increasing or decreasing trend was tested based on normalized test statistics (Z), Sen’s slope use to
78 estimate the true slope of an existing trend. When Z is positive, the trend is said to be increasing and when Z is negative,
79 it is said to be decreasing. The trend’s slope gives the annual rate and direction of change [37]

80 Mann –Kendall Test: This test is found to be an excellent tool for trend detection by other researchers in similar
81 application. [31-34]. The non-parametric Mann-Kendall test is commonly employed to detect monotonic trends in a series
82 of environmental data, climate data or hydrological data. The null hypothesis, H₀, is that the data come from a population
83 with independent realizations and are identically distributed. The alternative hypothesis, H_A, is that the data follow a
84 monotonic trend. The Mann-Kendall test statistic(S) is calculated according to:[36][37]

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

85 With

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

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.

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

Where, n is the number of data points, p is the number of tied groups and t_j 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:

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

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

Trend Analysis (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.[29] [34]

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.

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

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 . [38]

The overall slope estimator Q is thus:

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

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; $\alpha = 0.01$ and $\alpha = 0.05$, resulting in two different confidence intervals.

It is computed as:

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

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).

4. 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).

4.1. 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 T_{MIN}) 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	-	-

The highest average temperature has been detected in the pre-monsoon season, gradually decreasing during the monsoon. It is observed that the winter seasonal average maximum temperature was 33.43°C with a standard deviation (SD) of 0.78. This gradually increased in the post-monsoon season to 34.11°C, with an SD change of 0.67. The most significant change is attributed to the seasonal mean minimum temperature, which was 25.98°C with an SD of 0.44 in the monsoon season compared to the pre and post-monsoon periods. The seasonal normal rainfall mean was 918 mm over 37 years.

Figure 1 illustrates the variation between the monthly averages of maximum and minimum temperatures over the 37-year period. From March to June, the maximum temperature was highest, with the highest mean maximum temperature recorded at 40°C in May. The minimum temperature gradually increased from April to September, with the lowest minimum temperature found in January at 13.3°C, while December averaged 14.3°C.

Month-wise mean temperature data indicates an increasing and decreasing trend. The normal linear regression trend line shows that the maximum temperature decreased only slightly towards the post-monsoon months, while the minimum temperature gradually increased during the same period.

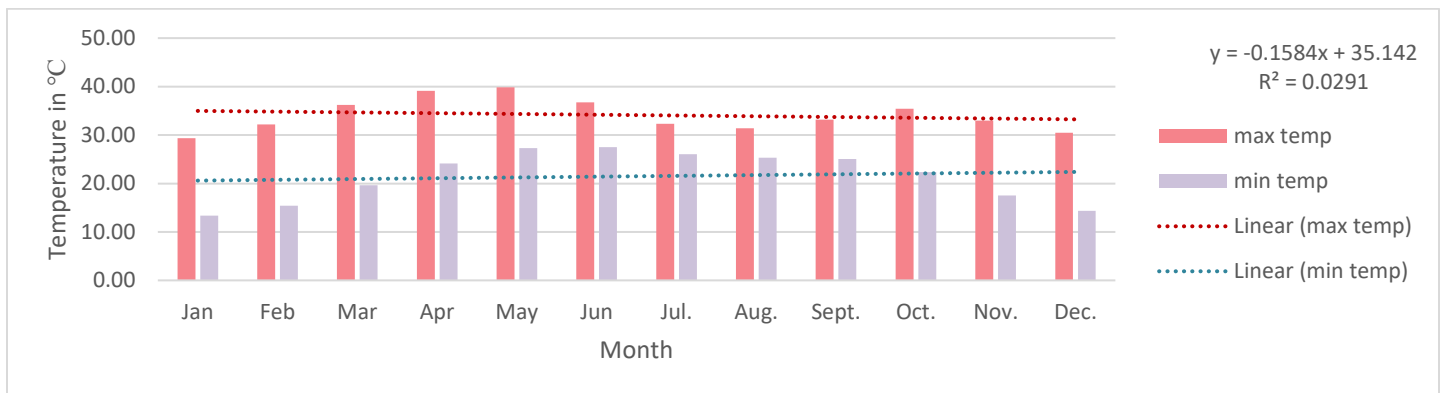


Fig: 1. Monthly average temperature (°C) during the period (1981-2017) for Vadodara Station.

4.1.1. 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 °C., 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°C. 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.

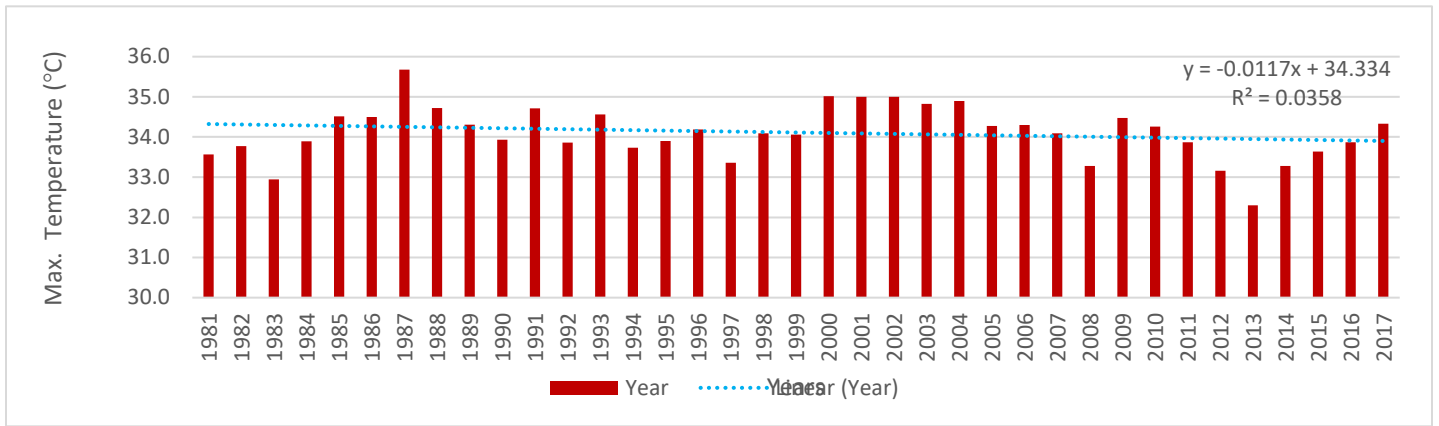


Fig 2: Annual Average Maximum Temperature (°C)

To investigate the observed spatial variability of the minimum temperature trend, regression analysis was conducted for the climatic period, revealing an increasing trend in temperature. A positive correlation between the minimum temperature record and the time period was observed. The highest minimum temperatures were exhibited from 2009 to 2011, exceeding 22°C. This suggests a possible trend of increasing temperatures over time in the area, potentially linked to global climate change.

The rise in temperature could also be associated with factors such as the increase in impervious surfaces, changes in land cover, higher heat retention on surfaces, and disturbances in atmospheric circulation due to urban canyon effects. Interestingly, the average minimum temperature has shown a rise in this urban city, which may be attributed to the increase in urban landforms.

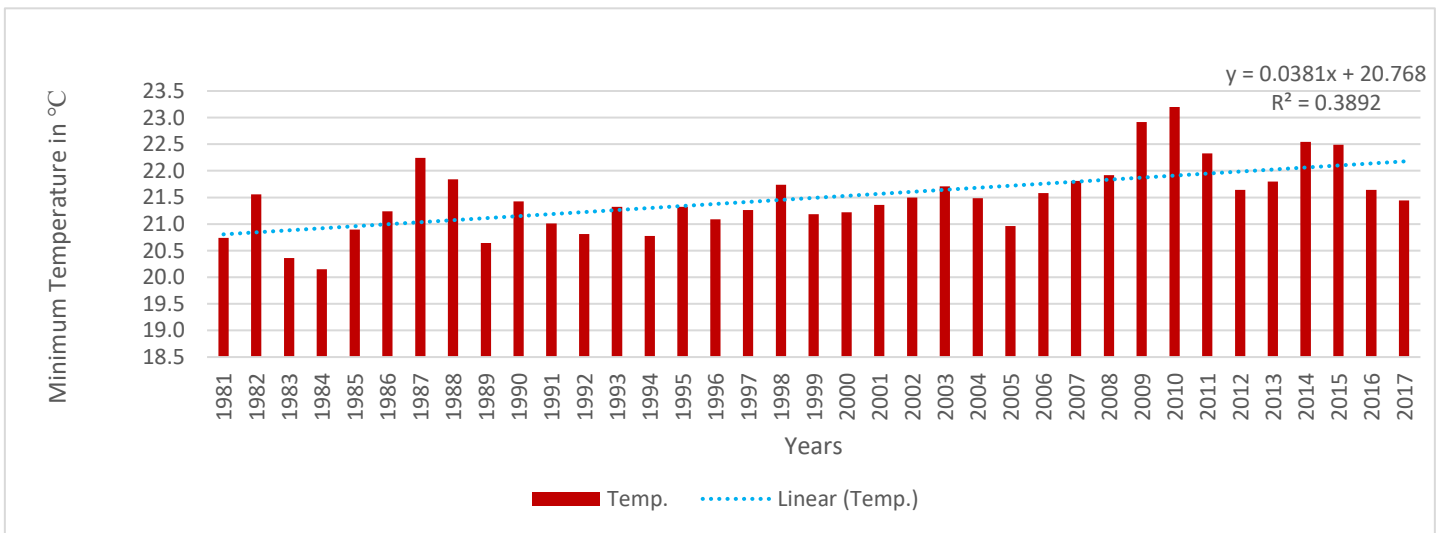


Fig 3: Annual Average Minimum Temperature (°C)

4.2. Rainfall Seasonal Variability

The Figure 4 illustrates seasonal rainfall for the months of June, July, August, and September, particularly focusing on the monsoon period of the Vadodara station. The cumulative rainfall for the monsoon season was calculated for each year from 1981 to 2017.

An increase in precipitation was observed in the month of July throughout the years, with the linear regression line indicating a rising trend ($R^2 = 0.03$). Furthermore, there was a notable increase in precipitation trends in September from 1981 to 2017 ($R^2 = 0.09$). The highest precipitation levels were recorded in 2005 and 2006 across all monsoon months.

196 A significant decrease in precipitation was observed from 2008 to 2012, particularly in the month of June, with similar
 197 decreases noted in 1998, 1999, and 2000. This decreasing trend in June's precipitation was consistent over the 37-year
 198 period ($R^2 = 0.008$). This suggests a long-term climatic change characterized by a decreasing trend in precipitation during
 199 the monsoon month of June, potentially indicating a shift from wet to dry conditions during this period.

200 Monthly rainfall trends, albeit small, were identified to exhibit both increasing and decreasing patterns in the region,
 201 reflecting the complexity of local climate dynamics.

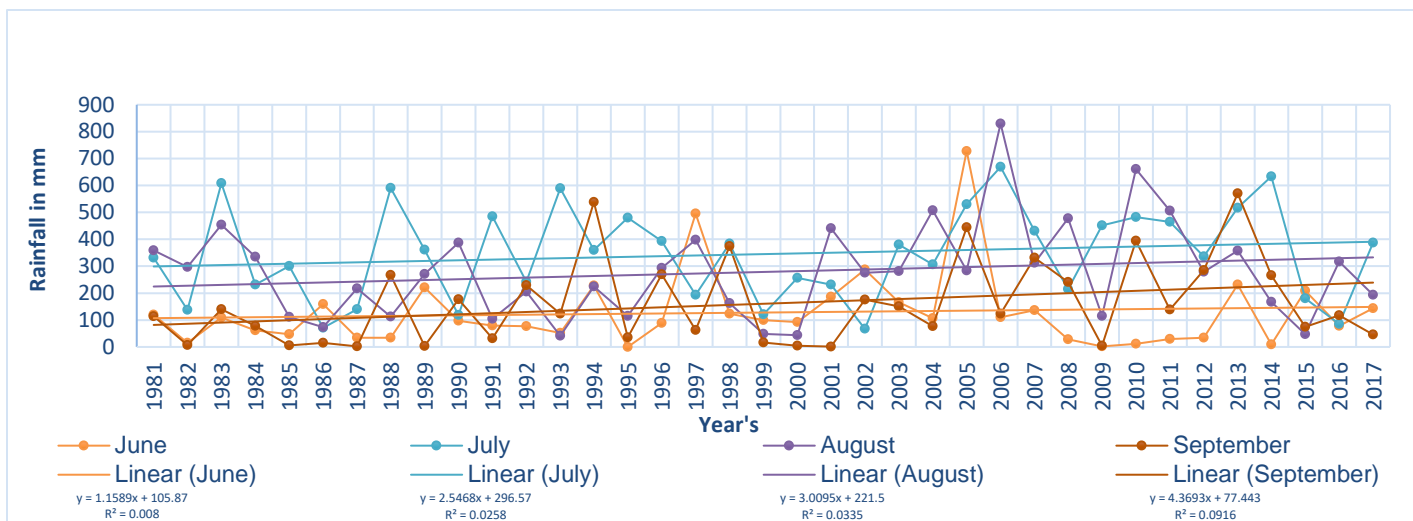


Fig. 4. Annual Variability of Rainfall (1981-2017)

4.3. Trend Analysis

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

206 For January, May, June, September, October, November and December there is an evidence of falling trend, especially
 207 negative trend at 95% found in September month with $Z = -2.12$ test statistic. January month has a Sen's Slope of -0.024 ,
 208 indicating a slight decreasing trend in maximum temperatures over the years. While test value is showing least positive
 209 trend in February, March, April, and July, no trend found in August month. Thus from negative trend shows test values for
 210 four months representing almost non-significant condition. 0.05 Level of significance found in September, whereas the cell
 211 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	

<i>Rainy</i>	-82	-0.013	1.03	
<i>Winter</i>	-62	-0.01	0.85	
<i>Avg. of all month</i>	-62	-0.01	0.85	
Negative trend at 95%				
Remaining Z values no trend at 95%				

* $\alpha = 0.05$ 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.

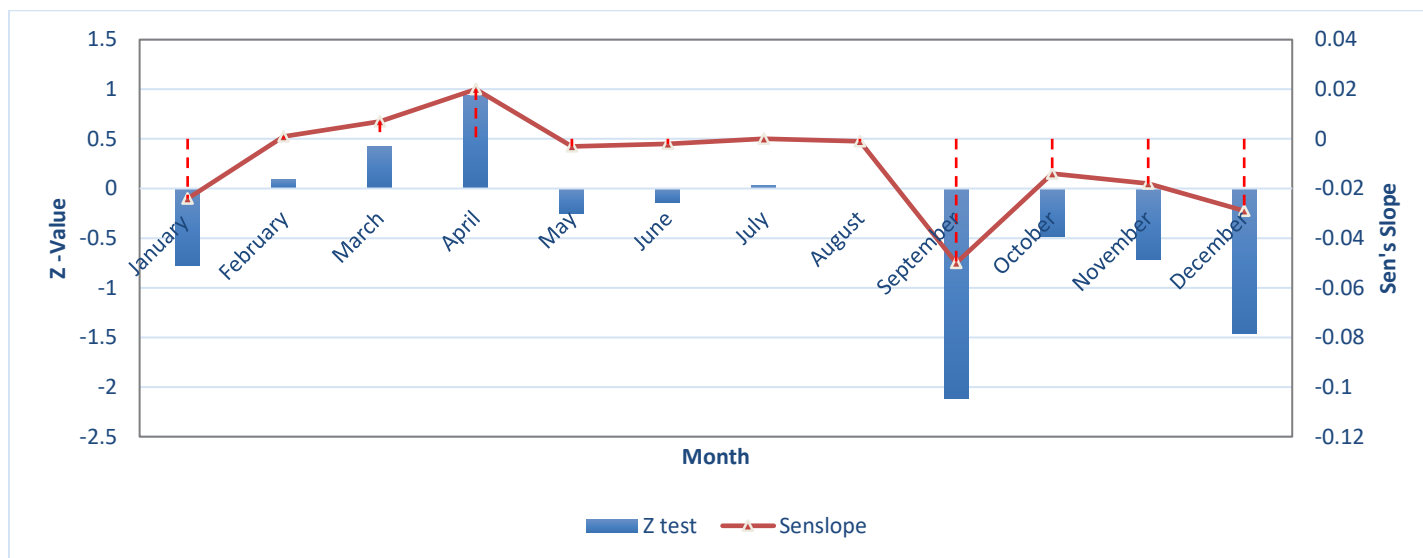


Fig. 5. Trend Test: Maximum Temperature

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	+
<i>Summer</i>	116	0.044	3.86	***

<i>Rainy</i>	203	0.017	2.68	**
<i>Winter</i>	136	0.062	3.26	**
<i>Avg. of all month</i>	86	0.04	4.12	***
Positive Trend at 95%				
Remaining Z values no trend at 95%				

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

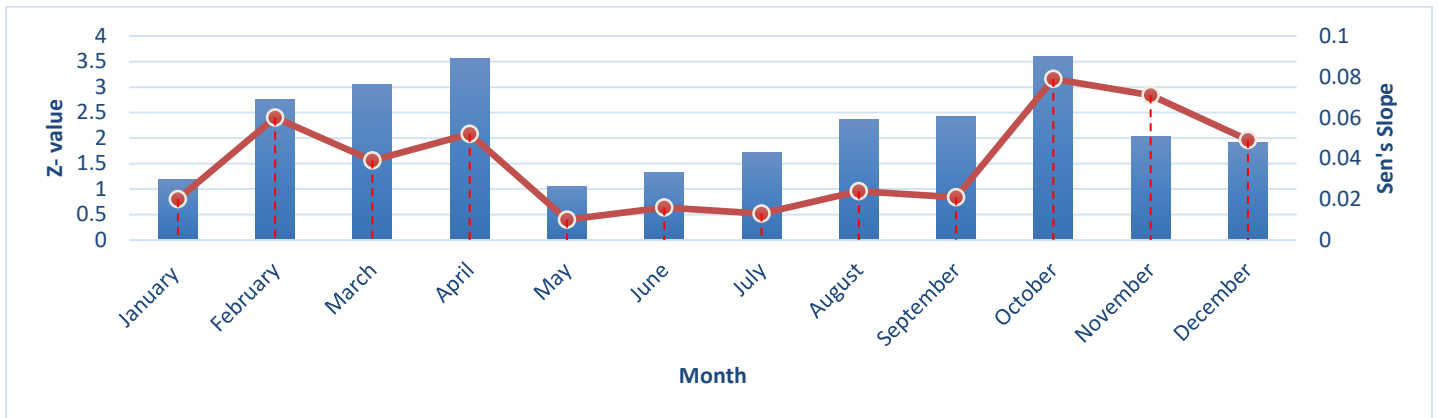


Fig. 6. Trend Test: Minimum Temperature

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 ($\alpha = 0.05$) 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	*
<i>Avg. of Rainy</i>	88	2.47	1.63	

* $\alpha = 0.05$ level of significance

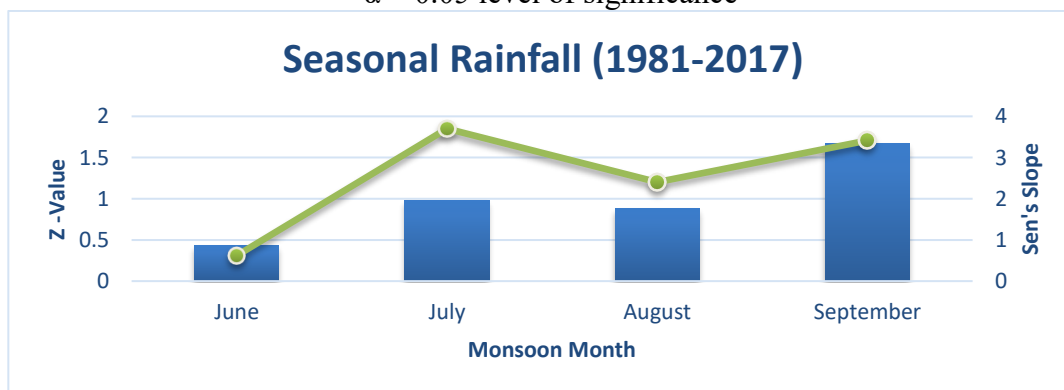


Fig. 7. Seasonal Rainfall (1981-2017)

5. DISCUSSION:

The study delves into the significance of understanding air temperature and precipitation patterns, crucial for short-term planning and predicting future climate conditions. Analyzing data from the Vadodara station spanning 1981 to 2017, trends in temperature and precipitation were assessed across annual, seasonal, and monthly scales using IMD data.

262 The focus lies on seasonal rainfall patterns, particularly during the monsoon months from June to September. Employing
263 the non-parametric Mann-Kendall test and Sen's slope, trends were detected and their significance evaluated in the time
264 series data.

265 Three distinct periods—pre-monsoon, monsoon, and post-monsoon—were delineated, with a primary emphasis on rainfall
266 during the monsoon season. Notably, the study reveals a gradual increase in the seasonal mean minimum temperature
267 during the monsoon season compared to pre and post-monsoon periods. This trend is supported by regression analysis,
268 indicating a positive correlation between minimum temperature and time period.

269 While the annual average maximum temperature displays a minor decreasing trend, the correlation analysis underscores
270 a positive trend in minimum temperature over time. July exhibits an increasing trend in precipitation, whereas June
271 experiences a decreasing trend over the 37-year span. The investigation aims to discern monotonic trends, revealing an
272 overall positive trend in temperature time series.

273 Further examination using the Mann-Kendall test reveals specific monthly trends. September shows a significant negative
274 trend in maximum temperature, while April indicates a rising slope. Post-monsoon months, notably October, exhibit a
275 positive trend in minimum temperature, signifying a long-term increase. July and September demonstrate generalized
276 positive trends in seasonal rainfall, with September exhibiting particularly significant trends.

277 In essence, this comprehensive analysis provides valuable insights into the temporal dynamics of temperature and
278 precipitation patterns, offering a nuanced understanding of climate variability in the region.

279 **6. CONCLUSION:**

280 The findings from the Mann-Kendall test offer critical insights into temperature and rainfall trends, with implications for
281 landscape and water resource management in Vadodara and its surroundings. Noteworthy is the significant negative
282 trend in maximum temperature observed in September, suggesting a potential cooling trend during this month.
283 Conversely, the rising slope in April indicates a warming trend, highlighting the seasonal variability in temperature
284 patterns. While most months exhibit minimal temperature trends, there is an overall gradual increase in mean minimum
285 temperatures over time.

286 The post-monsoon season, notably October, stands out with a pronounced positive trend in minimum temperatures,
287 indicative of a consistent long-term warming trend. This underscores the urgency of implementing adaptive measures to
288 counteract the impacts of rising temperatures on the local environment and human activities.

289 Regarding precipitation, a general positive trend is observed in seasonal rainfall, particularly in July and September. The
290 significant increase in September precipitation signals a heightened risk of wet spells during this period, emphasizing the
291 need for robust flood prevention measures and infrastructure development in the region.

292 These findings carry significant implications for decision-makers involved in landscape and water resource management,
293 as well as urban planning. It underscores the importance of prioritizing water and soil conservation efforts and adopting
294 sustainable management practices to enhance community resilience in the face of climatic variability. By integrating these
295 insights into policy frameworks and management strategies, stakeholders can effectively address the challenges posed by
296 climate change and ensure the long-term sustainability of water and land resources in Vadodara and similar regions
297

298 **COMPETING INTERESTS:** The authors declares no conflict of interests.

299 Disclaimer (Artificial intelligence)

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307 technology and as well as all input prompts provided to the generative AI technology

308 Details of the AI usage are given below:

309 1.

310 2.

311 3.

312

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