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Analysis of monthly, seasonal and annual air temperature variability trends in Junagadh (Saurashtra region) of Gujarat

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■ **ABSTRACT :** Climatic change is one of the most important issues of present times, therefore, world-wide interest in global warming and climate change has led to numerous trend detection studies. Anthropogenic interference in the environment is one of the greatest causes of the process of climatic change in several regions of the world. This study focuses on the variability and trends of the mean annual, seasonal and monthly surface air temperature in Junagadh (Saurashtra region) of Gujarat, during the period 1980-2011. This study investigated monthly, seasonal and annual climatic variability in Junagadh (Saurashtra region) of Gujarat based on mean maximum, mean minimum and mean air temperatures. One of the main results of this study was the confirmation of a significant warming trend in average temperatures in Junagadh (Saurashtra region) of Gujarat. Analysis of maximum and minimum temperatures revealed a warming trend for the annual and all seasonal series. The warming trend for the summer and winter seasons was statistically significant at $P < 0.01$ level with a rate of increase of 0.006 C/year and less 0.055C/year. The air temperature time series were analyzed, so that the variability and trends can be described.

■ **KEY WORDS :** Air temperature, Climate change, Mann-Kendall test, Trends

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Climate change over the last century is a subject of great topical interest. This problem worries the scientific community, as it could have a major impact on natural and social systems at local, regional and national scales. Numerous climatologists (Jones *et al.*, 1999 and Parker and Horton, 1999); Intergovernmental Panel on Climate Change (IPCC), (IPCC, 2001; Jones and Moberg, 2003; Vinnikov and Grody, 2003) agree that there has been a large-scale warming of the earth's surface over the last hundred years or so. This warming up of the earth during the 20th century brought with it a decrease in the area of the world affected by exceptionally cool temperatures and to a lesser extent, an increase in the area affected by exceptionally warm temperatures (Jones *et al.*, 1999). Some analyses of long time-series of temperatures on a hemispheric and global scale (Anonymous, 2001) have indicated a warming rate of 0.3-0.6ºC since the mid-19th century, due to either anthropogenic causes (Anonymous, 2001) or astronomic causes (Soon *et al.*, 2000 and Landscheidt, 2000). The third assessment report projections for the present century are that average temperature rises by 2100 would be in the range of 1.4-5.8ºC (IPCC, 2001 and IPCC, 2001). Records show that global temperatures, averaged world-wide over the land and sea, rose 0.6 ± 0.2ºC during the 20th century. A number of recent studies have been devoted to global, hemispherical, or regional long-term temperature variations. On a global scale, climatologically studies indicate an increase of 0.3-0.6ºC of the surface air temperature 0.5-0.7ºC for the Northern Hemisphere since, 1860 (Jones *et al.*, 1999 and Jones *et al.*, 1986 and Jones, 1988), while the eighth warmest years ever recorded were observed after (Brasseur and Roeckner, 2005). A broad consensus of scientists has concluded that, the earth's surface air temperature increased by about 0.6ºC during the 20th century, that most of the warming during the latter half of the century is attributable to human emissions of greenhouse gases, and that temperature increases were greatest during the 1990s (Anonymous, 2001). Numerous other factors such as variations in solar radiation and pollutant aerosols also contribute to climate change (Scafetta and West, 2005; Pielke, 2005). The IPCC panel further concluded that global temperature increases are likely to persist in the 21st century and will probably be accompanied by changes in precipitation and runoff amounts. Future climate change is more difficult to predict with great certainty at the regional scale due to spatial resolution limitations of current climate models and to the likely influence of unaccounted for factors such as regional land use change (Savelieva *et al.*, 2000).

The dominating climatic feature in the region is the summer Southwest Asian Monsoon, which influences the climatology of the nations within the sub-region to varying degrees and in diverse ways (Anonymous, 2001). Climate trends and variability in Asia are generally characterized by increasing surface air temperature which is more pronounced during winter than in summer. The observed increases in some parts of Asia during recent decades ranged between less than 1ºC to 3ºC per century. Increases in surface temperature are most pronounced in north Asia (climate change in Russia, 2003); climate change in Russia (Gruza and Rankova, 2004; Lal *et al.*, 2001). The third assessment report predicted that the area-averaged annual mean warming would be about 3ºC in the decade of the 2050s and about 5ºC in the decade of the 2080s over the land regions of Asia as a result of future increases in atmospheric concentration of greenhouse gases (Balling and Brazel, 1987). The rise in surface air temperature was projected to be most pronounced over boreal Asia in all seasons. Many investigators have studied climatic changes in various regions of the world including: United States (Comrie and Broyles, 2002; Folland *et al.*, 1997; Easterling *et al.*, 1999; Karl and Easterling, 1999; Jose *et al.*, 1996); Philippines (Arnell, 1999); Europe (Kipkorir, 2002 and Al-Fahed *et al.*, 1997); Kenya (Elagib and Abdu, 1997); Arab region (Abahussain, 2002; Mahmoud, 2006; Chang, 2002 and Yu *et al.*, 2002); Taiwan (Yu *et al.*, 2002 and Cohen *et al.*, 2002); Israel (Moonen, 2002) and Italy (Mann, 1945). Thus, given the relevance of the climate change in the world, the present paper aimed to ascertain the occurrence of climatic variability in Junagadh (Saurashtra region) of Gujarat. Generally there are two seasons; summer and winter. During summers the climate is hot with high humidity dominating in the coastal area. In winter the climate in the coastal area is relatively moderate. Occasional rains in the summer are caused by the monsoon coming from the Indian Ocean. These rains decrease the high temperatures in the coastal area during the summer. The weather in the mountain area is moderate in summer and relatively cold in winter. During winter it becomes especially cold in the night and in the early morning, with pleasant sunny days.

In this study, the variability and trends of the monthly mean, mean annual and seasonal surface air temperature in Junagadh (Saurashtra region) of Gujarat are examined. The climatic data used concern mean monthly values of air temperature meteorological service, for the period 1980-2011. The air temperature time series are analyzed, so that the variability and trends be described. The monthly, seasonal and annual temperature trends of mean, mean maximum, and mean minimum air temperature are discussed. The work then focuses on the statistics of the annual, seasonal and monthly maximum, minimum and mean temperatures (Al-Buhairi, 2010).

■ METHODOLOGY

Study area :

The Junagadh city is located between latitudes 21º 31'N and 70º 49' E in Fig. A. The city is a gate way to famous Gir forest which is the natural habitat for the last existing population of Asiatic lion in the wild. Apart from Gir, there is Girnar ranges, Barda hills and extensive grasslands known as Vidis, which also support a variety of wildlife especially avifauna. Junagadh has a tropical wet and dry climate, with three distinct seasons observed, a mild winter from November to February, a hot summer from March to June, and a monsoon from July to October. Junagadh faces adverse climatic conditions in the summer months with the temperature ranging from 28°C to 38°C. In the winter months, the temperature ranges from 10°C to 25°C. Various factors such as its close proximity to the sea influence the weather of Junagadh. The latent winds from the sea affect the climatic conditions in the region. For the purpose of this study, the uninterrupted temperature series from 1980-2011 (32 years) has been used, consisting of maximum and minimum air temperatures measured with thermometers. The readings, maximum and minimum, are averaged for the calculation of monthly, seasonal and annual temperatures.

Fig. A : Location map of study area

Daily air temperature data were first calculated as monthly maximum, minimum and mean temperature. Monthly temperature values were averaged to obtain seasonal and annual values. Trends were determined using the computer's program template. This template uses a nonparametric Mann-Kendall test to assess the probability that there is a trend statistically different from zero, and evaluate increasing or decreasing slope of trends in the climate variables.

Trend detection :

Trends were detected in the time series of all the indices analysed by means of the Mann–Kendall test (Burn and Elnur, 2002; Hirsh *et al.*, 1982). This is a rank correlation statistic test based on the comparison of the observed number of discordances and the value of the same quantity expected from a random series. The Mann–Kendall method has been suggested by the World Meteorological Organization to assess the trend in environmental data time-series (Cohen *et al.*, 2002). This test consists of comparing each value of the time-series with the others remaining, always in sequential order. The number of times that the remaining terms are greater than that under analysis is counted (Lettenmaier *et al.*, 1994; Burn and Elnur, 2002). The Mann–Kendall statistic is given by:

$$S = \sum^{n}\sum^{i=1} \mathrm{Sign}(x_t - x_j) \qquad ......(1)$$

where, n is the length of the data set, $i\ x$ and $j\ x$ are two generic sequential data values, and the function sign $(x_i - x_j)$ assumes the following values :

$$\mathrm{Sign}(x_i - x_j) = \begin{cases} 1, \text{if } (x_i - x_j) > 0, \\ 0, \text{if } (x_i - x_j) = 0, \\ -1, \text{if } (x_i - x_j) < 0. \end{cases} \qquad ......(2)$$

The S statistic, therefore, represents the number of positive differences minus the number of negative differences found in analyzed time series. Under the Null of that there is no trend in the data no correlation between considered variable and time, each ordering of the data set is equally likely. Under this hypothesis the statistic S is approximately normally distributed with the mean E(S) and the variance var (S) as follows :

$$E.S. = 0 \qquad ......(3)$$

$$\mathrm{Var}(S) = \frac{1}{18}\left[n(n-1)(2n = 5) - \sum_{p=1}^{q} t_p (t_p - 1)(2t_p + 5)\right] ......(4)$$

where, n is the length of the times-series, tp is the number of ties for the pth value and q is the number of tied values *i.e.*, equals values. The second term represents an adjustment for tied or censored data. The standardized test statistic Z is given by :

$$Z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var}(S)}} \text{ if } S > 0, \\ 0 \quad \text{if } S = 0, \\ \frac{S-1}{\sqrt{\mathrm{Var}(S)}} \text{ if } S < 0. \end{cases} \qquad ......(5)$$

The presence of a statistically significant trend is evaluated using the Z value. This statistic is used to test the Null hypothesis such that no trend exists. A positive Z indicates an increasing trend in the time-series, while a negative Z indicates a decreasing trend. To test for either increasing or decreasing monotonic trend at p significance level, the Null hypothesis is rejected if the absolute value of Z is greater than

$$Z\left[\frac{1-p}{2}\right];$$

where, $Z\left[\frac{1-p}{2}\right]$

is obtained from the standard normal cumulative distribution tables. In this work, the significance levels of 0.01, 0.05 and 0.1were applied, and the significant level p-value was obtained for each analyzed time-series. It is also possible to obtain a non-parametric estimate for the magnitude of the slope of trend (Hirsch *et al.*, 1982).

$$b = \text{Median}\left[\frac{(X_j - X_i)}{(j-i)}\right], \text{for all } i < j \qquad ......(6)$$

where, is the slope between data points j X and i X; measured at times j and i; respectively.

RESULTS AND DISCUSSION

The standard deviation, mean and co-efficient of variation of the maximum (T*max*), minimum (T*min*) and mean (T*mean*) temperatures are specified in Table 1. From the basic temperature data, (T*max*), (T*min*) and (T*mean*) temperature, along with their standard deviation have been statistically computed for each month, year and the three seasons; summer, monsoon and winter. These means are depicted in Table 1. Seasons were defined using the standard meteorological definition: winter = December, January and February, summer = March, April and May; monsoon = June, July, August and Septmber.

Table 1 reports the temperature characteristics in Junagadh (Saurashtra region), Gujarat India. It is clear from the table that, the mean monthly temperature was highest in June 34.5ºC (June) and lowest in January 22.5ºC (January).

However, the mean maximum temperature for June is 34.5ºC. On the average, January is the coldest month of the year and June is the warmest (only slightly warmer than May and July). The temperature variability between the different years and the average annual temperature is 31.3ºC, while the annual mean maximum temperature reached 37.8˚C and the annual mean minimum temperature was 16.7ºC. The Mann–Kendall test statistics of the T*max*, T*min*, and T*mean* are given in Table 2. The statistically significant levels, high 0.01, medium 0.05 and low 0.1 were used in this paper (Jones *et al.*, 1999). The nonparametric estimate for the magnitude of the slope, b, was computed for the significant trends, which certify all the trends in ºC /year.

Table 1 reports the temperature characteristics in Junagadh (Saurashtra region), Gujarat India. It is clear from the table that, the mean monthly temperature is highest in June 34.5ºC and lowest in January 22.5ºC. However, the mean maximum temperature for June is 43ºC. On the average, January is the coldest month of

Table 1 : Statistics of the monthly, seasonal and annual temperature means and standard deviation, co-efficient of variation

Month	Tmax. (C)			Tmin. (C)			Tmean (C)		
	Mean Tmax	S.D.	C.V.	Mean Tmin	S.D.	C.V.	Mean Tmean	S.D.	C.V.
January	33.6	2.28	6.79	11.5	1.32	11.55	22.5	1.38	6.12
February	36.7	1.88	5.13	14.0	1.66	11.90	25.3	1.31	5.17
March	40.5	1.78	4.41	18.9	1.69	8.91	29.7	1.41	4.76
April	42.6	1.47	3.44	23.0	1.75	7.62	32.8	1.21	3.68
May	43.0	1.96	4.56	25.3	1.28	5.06	34.2	1.30	3.81
June	43.0	1.92	4.47	26.0	1.25	4.82	34.5	1.36	3.94
July	35.4	1.68	4.73	25.1	1.23	4.88	30.3	1.17	3.86
August	33.1	1.67	5.04	24.6	0.95	3.87	28.8	1.18	4.08
September	36.1	1.53	4.25	23.6	0.85	3.62	29.9	0.97	3.24
October	38.4	1.36	3.54	21.2	1.40	6.61	29.8	1.16	3.89
November	36.4	1.61	4.42	16.7	1.71	10.25	26.6	1.44	5.42
December	34.4	1.92	5.57	12.2	1.65	13.51	23.3	1.50	6.41
Annual	37.8	1.09	2.88	16.7	1.14	6.83	31.3	0.92	2.94
Winter	34.9	1.45	4.15	12.6	1.29	10.27	23.7	1.15	4.87
Summer	42.0	1.25	2.98	22.4	1.06	4.73	32.2	1.02	3.17
Monsoon	34.9	1.26	3.62	24.4	0.90	3.70	29.7	0.97	3.28

the year and June is the warmest (only slightly warmer than May and July). The temperature variability between the different years and the average annual temperature is 31.3ºC, while the annual mean maximum temperature reached 37.8°C and the annual mean minimum temperature was 16.7°C. The Mann–Kendall test statistics of the T*max*, T*min*, and T*mean* are given in Table 2. The statistically significant levels, high 0.01, medium 0.05 and low 0.1 were used in this paper. The non-parametric estimate for the magnitude of the slope b was computed for the significant trends, which certify all the trends in ºC/year. Behaviour of the T*max*, *Tmin* and T*mean* was studied for individual months, seasons and annually by subjecting them to the Mann–Kendall test. The results of the standardized test statistics Z, significance level *p*-value and the slope b; corresponding to the temperature variables trend analysed in this study are presented in Table 2. It is to be noted have that the T*max* and T*mean* shows a significant trend in the majority of the months, while T*min* shows a significant trend in nearly half the number of the months.

Annual temperature trends :

The annual mean, annual maximum and annual minimum temperatures and trend line are presented in Fig. 1. The Mann–Kendall test confirmed that the positive trend observed is statistically significant (Table 2). The mean annual temperature and the mean annual maximum temperature show an increasing trend, which is statistically significant at $P < 0.01$ level, while the mean annual minimum temperature is significant at 0.1 level. A linear fit to the ensemble averaged annual means of mean, minimum and maximum temperature anomalies confirms significant and quite large trends of 0.030ºC/

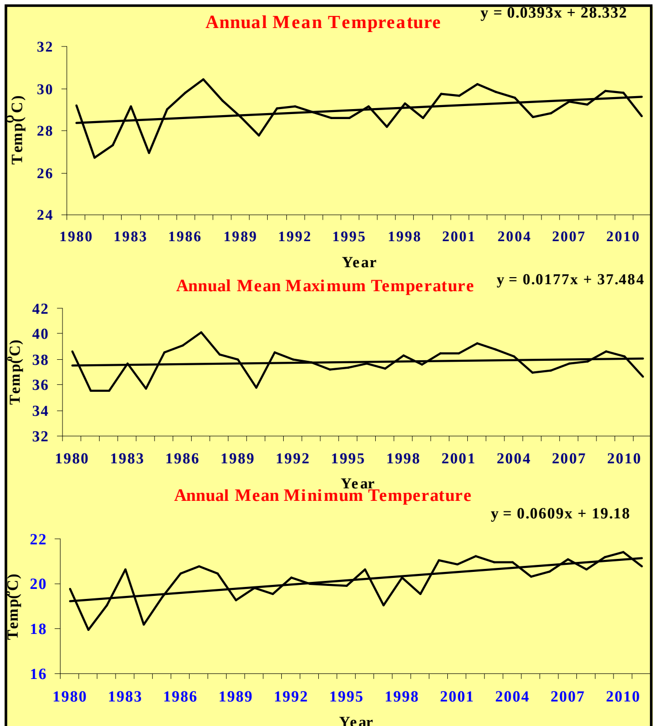

Fig. 1 : Annual temperature trends in Junagadh (Saurashtra region) Gujarat, India.

Table 2 : Mann-Kendall trend test results (Z and p-value) and the slope b

Month	Tmax(ºC)			Tmin(ºC)			Tmean(ºC)		
	Z	P-value	b(C/year)	Z	P-value	b(C/year)	Z	P-value	b(C/year)
January	0.23	0.986	0.009	2.59	0.008	0.073	1.43	0.191	0.037
February	0.70	0.323	0.030	3.86	0.000	0.122	2.92	0.002	0.078
March	1.54	0.098	0.038	2.76	0.004	0.080	2.24	0.017	0.060
April	0.58	0.315	0.028	1.69	0.047	0.041	0.86	0.221	0.023
May	0.54	0.586	0.025	2.34	0.026	0.037	1.27	0.169	0.029
June	0.70	0.485	0.027	3.11	0.003	0.056	1.56	0.139	0.045
July	0.06	0.551	0.000	1.52	0.241	0.025	0.32	0.465	0.008
August	0.67	0.323	0.019	1.07	0.386	0.010	0.75	0.386	0.012
September	-1.15	0.324	-0.034	2.64	0.011	0.043	-0.08	1.000	0.000
October	-0.86	0.657	-0.024	1.41	0.153	0.035	0.75	0.269	0.009
November	1.63	0.054	0.060	2.90	0.001	0.096	2.97	0.001	0.082
December	-0.15	0.973	-0.008	3.20	0.003	0.100	1.18	0.262	0.042
Annual	0.29	0.507	0.006	3.99	0.0001	0.055	2.01	0.028	0.030
Winter	0.15	0.812	0.004	4.05	0.0001	0.096	2.24	0.034	0.052
Summer	0.79	0.308	0.026	2.59	0.007	0.054	1.75	0.055	0.039
Monsoon	-0.80	0.708	-0.010	2.34	0.037	0.029	0.45	0.575	0.004

year for mean temperatures. The annual mean maximum air temperatures trend is that of 0.006ºC/year. Annual mean minimum temperature trend was a little less 0.055ºC/year

Seasonal temperature trends :

In the climatic seasons we observe a different tendency of changes in air temperature. The mean temperature, *Tmax* and T*min* for spring, summer, autumn and winter seasons during the period 1980-2011 are presented in Fig. 2. The parameters analysed show a positive trend practically for all seasons (Table 2). The air temperature time-series in Junagadh (Saurashtra region) of Gujarat for the whole period analysed showed an increasing trend statistically significant at $P < 0.01$, $P < 0.05$ and $P < 0.1$ in practically all the months and seasons. However, some months showed a declining trend February, October and December. The winter mean temperature shows an increasing trend, which is statistically significant at $P < 0.01$ level (Table 2). T*min* also shows warming. However, this warming trend of T*min* is not statistically significant. The T*max* during winter shows an increasing trend, which is statistically significant at $P < 0.01$. In spring the Mann–Kendall test indicates that the mean temperature shows an increasing trend, significant at $P < 0.01$ level. T*max* also shows an increasing trend, significant at $P < 0.01$ level and T*min* shows an increasing trend, which is statistically significant at $P < 0.05$ level. The summer mean temperature, T*max* and T*min* also shows an increasing trend, significant at $P < 0.01$ level.

Monthly temperature trends :

The mean minimum and maximum temperature was also studied for individual months by subjecting them to the Mann–Kendall test. The results are presented also in Table 2. The mean temperature shows a significant

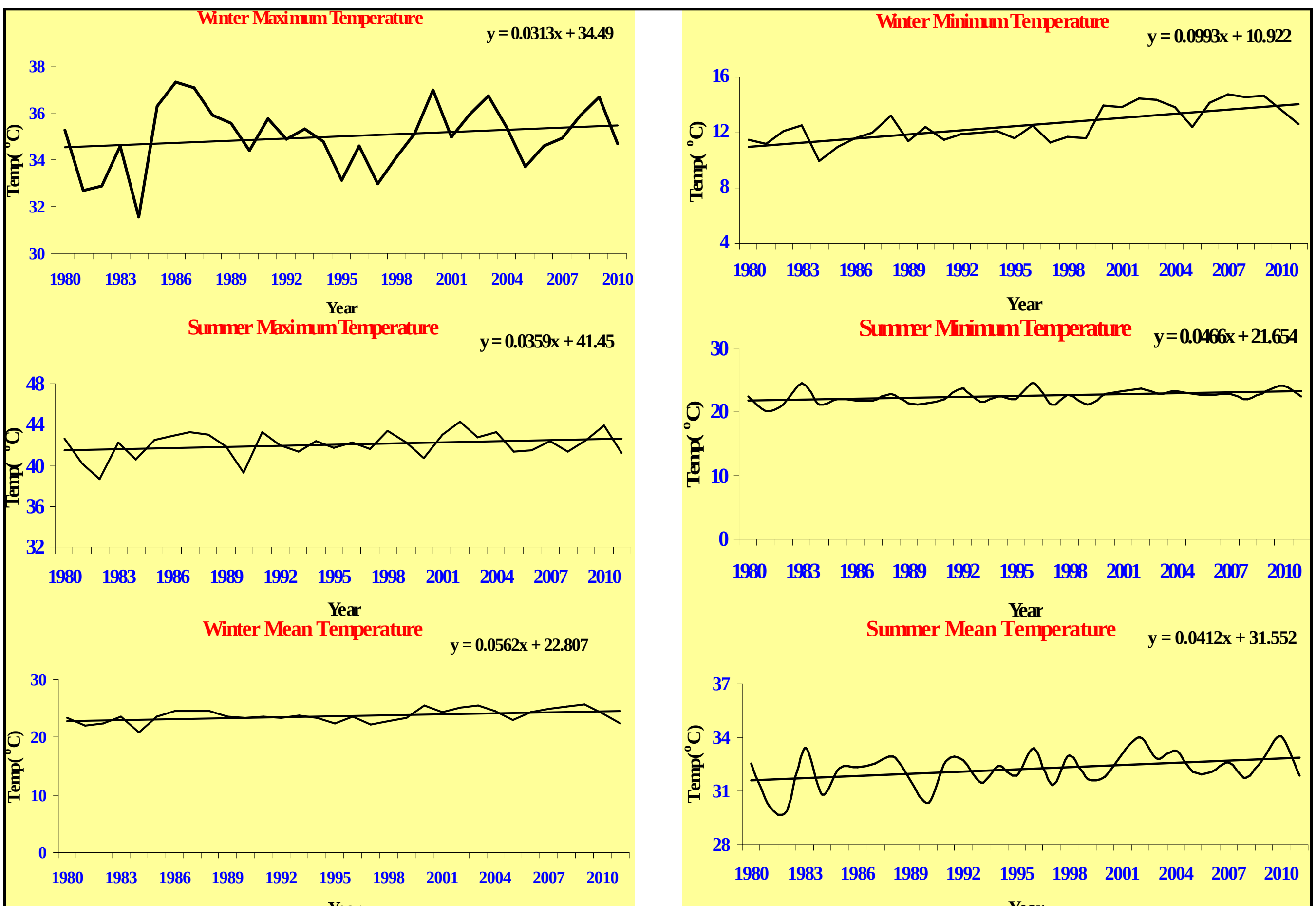

Fig. 2 : Temperature trends for summer, winter in Junagadh (Saurashtra region) of Gujarat

trend practically for all months except September, October and December. Statistically significant at the $P < 0.05$ level increases in mean air temperature were noted for January, February, March, April, and August. However, this increase is significant for May, June, July and November at $P < 0.01$ level and December at 0.1 level. T*max* shows a significant trend practically for all months except September, October and December. Statistically significant at the level 0.01 increases in maximum air temperature were noted for February, March, May, June, July, November. However, this increase is significant for January, April, and August. at 0.05 level. April, May and July showed the greatest increasing trend in the mean maximum air temperature in the whole period analysed. T*min* also shows a significant trend in the majority of the months. The trend analysis of winter months shows a slightly increasing trend in minimum temperature, which is not statistically significant. The trend of T*min* during the summer months shows an increasing trend significant for June at 0.05 level, July at 0.01 level and August are not statistically significant. This increase in temperature is attributed to the green house gases emissions, especially CO_2, from the different motor vehicles used in the city.

Conclusion :

This study investigated monthly, seasonal and annual climatic variability in Junagadh (Saurashtra region) of Gujarat based on mean maximum, mean minimum and mean air temperatures. One of the main results of this study is the confirmation of a significant warming trend in average temperatures in Junagadh (Saurashtra region) of Gujarat. Analysis of maximum and minimum temperatures reveals a warming trend for the annual and all seasonal series. The warming trend for the summer and winter seasons is statistically significant at $P < 0.01$ level. With a rate of increase of 0.006ºC/year and less 0.055ºC/year.

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