

Analysis of Monthly, Seasonal and Annual Air Temperature Variability and Trends in Taiz City - Republic of Yemen

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ABSTRACT

Climate change is one of the most important issues of today's World. Climate scientists have concluded that the earth's surface air temperature warmed by $0.6 \pm 0.2^\circ\text{C}$ during the 20th century, accompanied by changes in the hydrologic cycle. Of all the climate elements, temperature plays a major role in detecting climate change brought about by urbanization and industrialization. This study focuses on the variability and trends of the mean annual, seasonal and monthly surface air temperature in Taiz city, Republic of Yemen, during the period 1979-2006. The results of the analysis of the whole period reveal a statistically significant increasing trend in practically all the months and seasons. A tendency has also been observed towards warmer years, with significantly warmer summer and spring periods and slightly warmer autumn and winter, an increase of 1.79°C and 1.18°C has been observed in the mean summer and mean winter temperature, respectively. Positive trends of about 1.5°C in the annual mean temperature were found for the whole period. The air temperature time series are analyzed, so that the variability and trends can be described.

Keywords: Air Temperature, Climate Change, Republic of Yemen, Taiz City, Mann-Kendall Test, Trends

1. Introduction

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 complex phenomenon, which includes natural and human processes, depends on a multiplicity of factors and is an almost irreversible scenario [1]. The Earth's atmosphere is warming and that human activities that release greenhouse gases are an important cause. Warming of the atmosphere affects the temperature of air, land, and water, which in turn affects patterns of precipitation, evaporation, and wind, as well as ocean temperature and currents. Greenhouse gases are atmospheric gases such as carbon dioxide, methane, and nitrous oxide. The concentration of CO₂, one of the major greenhouse gases, in the atmosphere has increased significantly. They trap solar energy, warming the atmosphere and the surface of the Earth, and play a critical role in maintaining the tem-

perature of the Earth within a range suitable for life. However, as the levels of these gases build up in the atmosphere, they act like the transparent roof of a greenhouse, which allows in sunlight while trapping the heat energy.

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 [2,3]; Intergovernmental Panel on Climate Change (IPCC), [4-6] 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 [2]. Some analyses of long time-series of temperatures on a hemispheric and global scale [4] have indicated a warming rate of $0.3\text{-}0.6^\circ\text{C}$ since the mid-19th century, due to either anthropogenic causes [4] or astronomic causes [7,8]. The Third Assessment Report projections for the

present century are that average temperature rises by 2100 would be in the range of 1.4-5.8°C [4,9]. Records show that global temperatures, averaged world-wide over the land and sea, rose $0.6 \pm 0.2^\circ\text{C}$ 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, climatological studies indicate an increase of 0.3-0.6°C of the surface air temperature (0.5-0.7°C for the Northern Hemisphere) since 1860 [2, 10,11], while the eighth warmest years ever recorded were observed after [12].

A broad consensus of scientists has concluded that, the earth's surface air temperature increased by about 0.6°C 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 [4]. Numerous other factors such as variations in solar radiation and pollutant aerosols also contribute to climate change [13,14]. 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 [15].

The Republic of Yemen lies in the South of The Arabian Peninsula, south-west of Asia. South-West Asia (the Middle East), is a relatively data sparse region of the world. Rapid population growth and water scarcity are common throughout the area, rendering it sensitive to changes in climate. This emphasizes the importance of meteorological data and climatic knowledge to the region. In the Middle East, investigations of long-term variations and trends in temperature data are not receiving enough attention even though, these countries suffer serious environmental, agricultural and water resources problems. The dominating climatic feature in the region is the summer Southwest Asian Monsoon, which influences the climatology of the nations within the subregion to varying degrees and in diverse ways [4]. 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 1°C to 3°C per century. Increases in surface temperature are most pronounced in North Asia [16]; Climate Change in Russia [17,18].

The Third Assessment Report predicted that the area-averaged annual mean warming would be about 3°C in the decade of the 2050s and about 5°C in the dec-

ade of the 2080s over the land regions of Asia as a result of future increases in atmospheric concentration of greenhouse gases [19]. 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 [20-24]; Philippines [25]; Europe [26,27]; Kenya [28]; Arab Region [29-33]; Taiwan [34,35]; Israel [36]; and Italy [37]. Thus, given the relevance of the climate change in the world, the present paper aimed to ascertain the occurrence of climatic variability in Taiz City, which is considered one of the largest cities in Yemen, which lies to the north west of the Yemeni Republic. The climate in Yemen is various and depends on the different altitudes of the regions. There are no distinctive limits between the seasons. Generally there are two main seasons; summer and winter. During summer 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 Taiz are examined. The climatic data used concern mean monthly values of air temperature Meteorological Service, for the period 1979-2006. 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.

2. Methods

2.1. Study Area

Taiz city is one of the largest cities in Yemen located in the southwest of Yemen (located at 13°35' N and 44°01' E). Its average height from sea level is 1311 m.

Daily air temperature data during the period 1979-2006, were obtained from agro meteorological station of the Agricultural Research and Extension Authority (AREA) in Taiz. The station elevation is 1200 m above sea level with latitude N 13°42' and longitude E 44°55'. The mean annual rainfall and temperature is 588 mm and 24°C, respectively, while the mean monthly evaporation is 140 mm. The geographical location of Yemen and the

Osiefera station in Taiz City provide a sign and indication about temperature changes and trends in the region.

For the purpose of this study, the uninterrupted temperature series from 1979 to 2006 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.

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.

2.2. Trend Detection

Trends were detected in the time series of all the indices analysed by means of the Mann–Kendall test [38,39]. 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 [35]. 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 [40,41]. The Mann–Kendall statistic is given by:

$$S = \sum_{i=2}^n \sum_{j=1}^{i-1} sign(x_i - x_j) \tag{1}$$

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

$$sign(x_i - x_j) = \begin{cases} 1, & \text{if } (x_i - x_j) > 0, \\ 0, & \text{if } (x_i - x_j) = 0, \\ -1, & \text{if } (x_i - x_j) < 0. \end{cases} \tag{2}$$

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:

$$E(S) = 0 \tag{3}$$

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

where n is the length of the times-series, t_p is the number of ties for the p^{th} 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:

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

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 $Z_{(1-p/2)}$; where $Z_{(1-p/2)}$ is obtained from the standard normal cumulative distribution tables. In this work, the significance levels of 0.01, 0.05 and 0.1 were 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 [42].

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

where b is the slope between data points X_j and X_i ; measured at times j and i ; respectively.

3. Results and Discussion

The standard deviation (σ) and mean (μ) 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 (σ) have been statistically computed for each month, year and the four seasons; spring, summer, autumn, and winter. These means are depicted in **Table 1**. Seasons were defined using the standard meteorological definition: winter = December, January and February, spring = March, April and May; summer = June, July and August and autumn = September, October and November.

Table 1 reports the temperature characteristics in Taiz city. It is clear from the Table that, the mean monthly temperature is highest in June 26.6°C and lowest

Table 1. Statistics of the monthly, seasonal and annual temperature means (μ) and standard deviation (σ).

Month	T_{max} (°C)		T_{min} (°C)		T_{mean} (°C)	
	μ	σ	μ	σ	μ	σ
January	27.3	0.88	14.1	2.02	20.7	1.15
February	28.4	1.28	15.3	2.02	21.8	1.19
March	29.9	1.10	17.3	1.61	23.6	1.08
April	31.3	1.42	18.8	1.67	25.1	1.28
May	32.9	1.23	19.5	2.03	26.2	1.36
June	33.3	0.80	19.9	1.45	26.6	0.98
July	32.5	0.82	20.2	1.91	26.3	1.16
August	32.0	0.56	19.1	2.13	25.6	1.14
September	31.8	1.15	17.8	2.06	24.8	1.36
October	31.1	0.92	16.9	1.81	23.9	1.13
November	29.6	0.90	15.7	1.50	22.7	0.89
December	28.1	0.97	14.9	1.90	21.5	0.83
Annual	30.7	0.58	17.5	1.44	24.1	0.84
Spring	31.4	1.07	18.6	1.61	25	1.12
Summer	32.6	0.75	19.8	1.74	26.2	1.00
Autumn	30.8	0.8	16.8	1.50	23.8	0.95
Winter	27.9	0.81	14.8	1.67	21.3	0.81

in January 20.7°C. However, the mean maximum temperature for June is 33.3°C. On the average, January is the coldest month of the year and June is the warmest (only slightly warmer than May and July). The lowest mean monthly temperature occurred in January 1987 (8.7°C) and the warmest month ever recorded was May 1999 (35.2°C). The temperature variability between the different years and the average annual temperature is 24.1°C, while the annual mean maximum temperature reached 30.7°C and the annual mean minimum temperature was 17.5°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 [1]. The nonparametric estimate for the magnitude of the slope, b , was computed for the significant trends, which certify all the trends in °C/year. **Table 1** reports the temperature characteristics in Taiz city. It is clear from the Table that, the mean monthly temperature is highest in June 26.6°C and lowest in January 20.7°C. However, the mean maximum temperature for June is 33.3°C. On the average, January is the coldest month of the year and June is the warmest (only slightly warmer

than May and July). The lowest mean monthly temperature occurred in January 1987 (8.7°C) and the warmest month ever recorded was May 1999 (35.2°C). The temperature variability between the different years and the average annual temperature is 24.1°C, while the annual mean maximum temperature reached 30.7°C and the annual mean minimum temperature was 17.5°C.

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Behavior of the T_{max} , T_{min} , 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.

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

Month	<i>Tmax</i>			<i>Tmin</i>			<i>Tmean</i>		
	Z	P-value	b (°C/Year)	Z	P-value	b (°C/Year)	Z	P-value	b (°C/Year)
January	1.73	0.084	0.037	0.97	0.33	0.026	2.14	0.033	0.038
February	2.43	0.014	0.074	0.00	1	0.00	2.26	0.024	0.073
March	2.99	0.003	0.071	0.98	0.84	0.009	2.20	0.03	0.041
April	2.14	0.03	0.075	1.48	0.14	0.043	2.04	0.042	0.066
May	3.43	0.001	0.105	2.08	0.04	0.067	2.87	0.004	0.088
June	2.98	0.003	0.056	2.24	0.025	0.071	2.53	0.011	0.064
July	2.99	0.003	0.06	3.19	0.0014	0.097	4.01	0.0001	0.092
August	1.89	0.059	0.029	0.83	0.41	0.032	2.23	0.026	0.031
September	1.68	0.092	0.033	1.99	0.046	0.091	2.10	0.038	0.057
October	1.19	0.23	0.026	-0.099	0.92	0.00	0.97	0.33	0.021
November	2.73	0.006	0.06	1.54	0.12	0.05	2.57	0.01	0.058
December	2.42	0.015	0.05	-0.06	0.95	0.00	1.84	0.066	0.031
Annual	8.32	0.000	0.05	4.19	0.11	0.042	8.07	0.000	0.053
Spring	4.96	0.0002	0.084	2.19	0.03	0.04	4.12	0.000	0.064
Summer	4.56	0.0002	0.044	3.63	0.0003	0.067	5.10	0.000	0.064
Autumn	3.26	0.014	0.04	1.99	0.05	0.047	3.27	0.001	0.045
Winter	3.82	0.003	0.05	0.53	0.60	0.0098	3.62	0.0003	0.042

3.1. Annual Temperature Trends

The annual mean, annual maximum and annual minimum temperatures and trend line are presented in **Figure 1**. The Mann-Kendall test confirmed that the positive trend observed is statistically significant see **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 $0.053^{\circ}\text{C}/\text{year}$ for mean temperatures. This trend corresponds to an increase of 1.5°C in the total period analysed (1979-2006) of mean temperature. The annual mean maximum air temperatures trend is that of $0.05^{\circ}\text{C}/\text{year}$. This trend corresponds to an increase of 1.4°C in the total period analyzed of mean maximum temperature. Annual mean minimum temperature trend was a little less $0.042^{\circ}\text{C}/\text{year}$. The temperature increase corresponding to the total period was 1.2°C of annual mean minimum temperature.

3.2. Seasonal Temperature Trends

In the climatic seasons we observe a different tendency of changes in air temperature. The mean temperature, *Tmax* and *Tmin* for spring, summer, autumn and winter seasons during the period 1979-2006 are presented in **Figure 2**. The parameters analysed show a positive trend practically for all seasons and is most important for maximum temperatures **Table 2**. The air temperature time-series in Taiz 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**. *Tmin* also shows warming. However, this warming trend of *Tmin* is not statistically significant. The *Tmax* 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. *Tmax* also shows an increasing trend, significant at $P < 0.01$

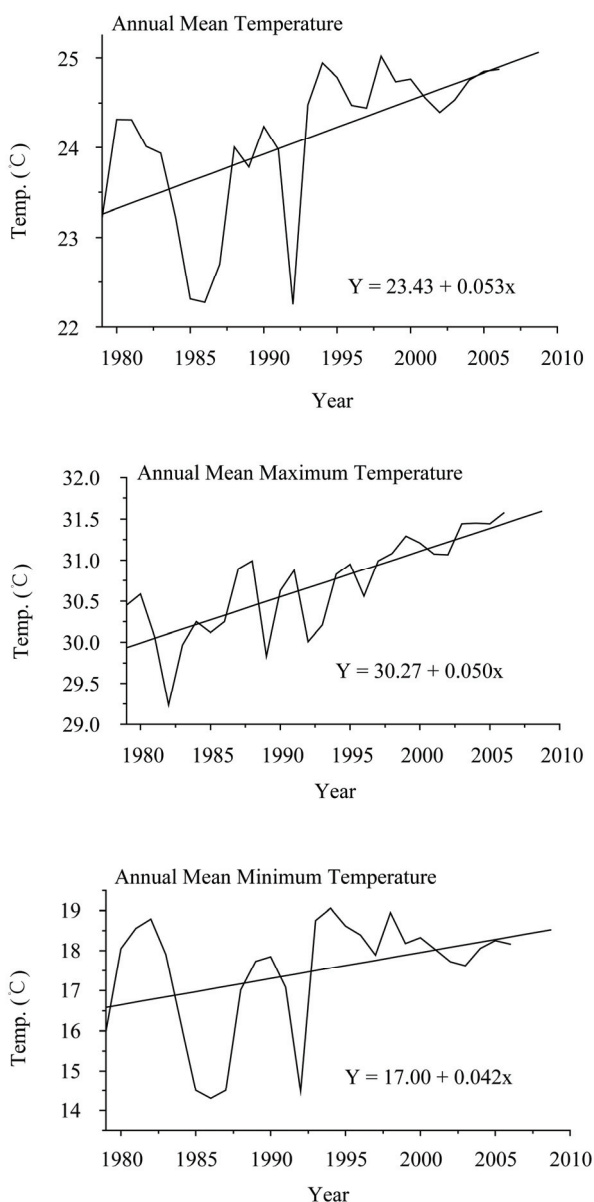


Figure 1. Annual temperature trends in Taiz.

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. Autumn is characterized by a significant increase in temperature. The mean and mean maximum temperature show an increasing trend, which is statistically significant at $P < 0.01$ level. The mean minimum also shows an increasing trend, significant at $P < 0.05$ level.

3.3. Monthly Temperature Trends

Behavior of mean, mean minimum and mean maximum temperature was also studied for individual months by

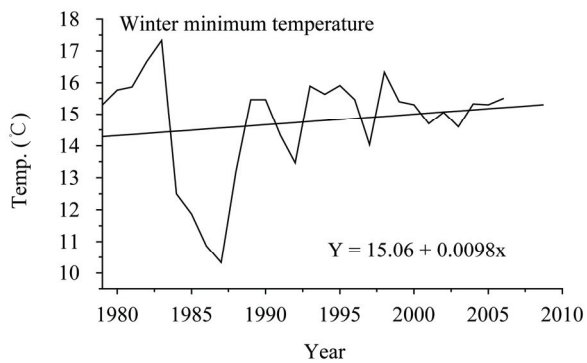
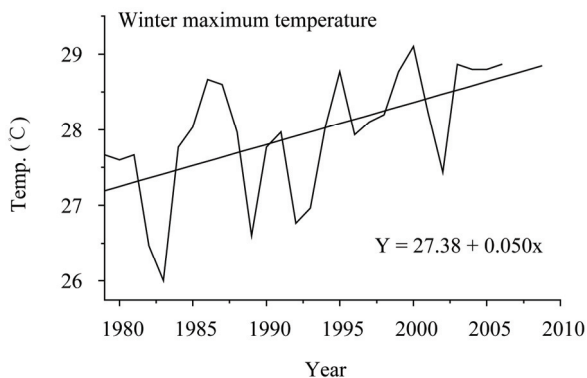
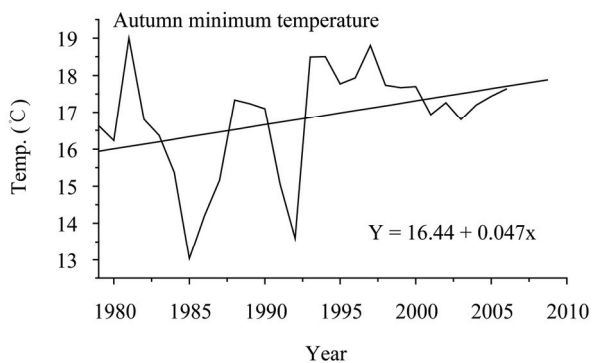
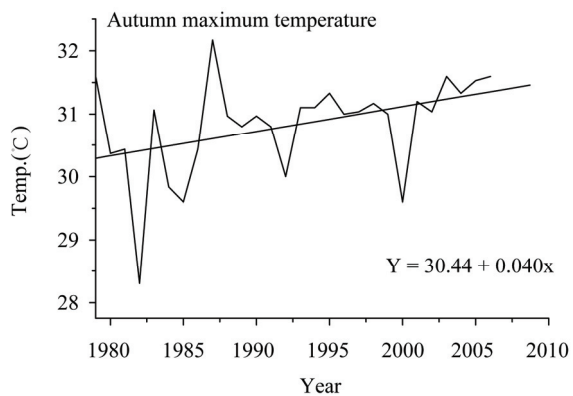
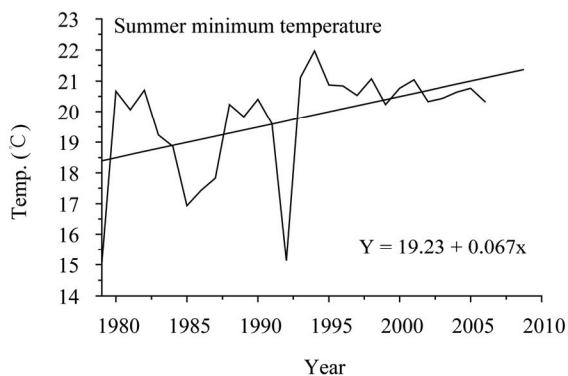
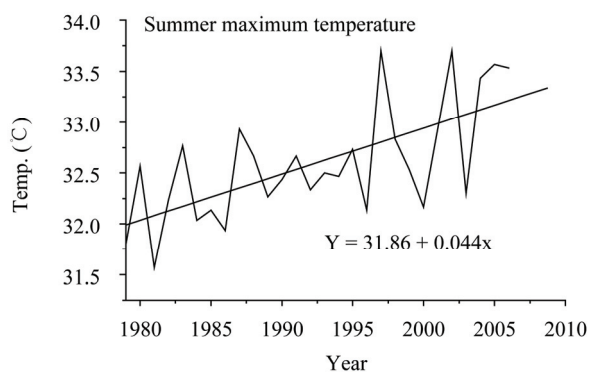
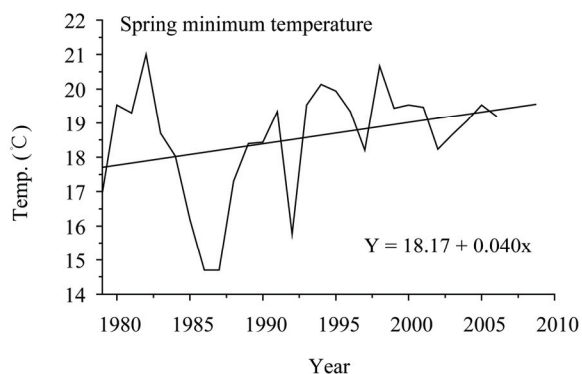
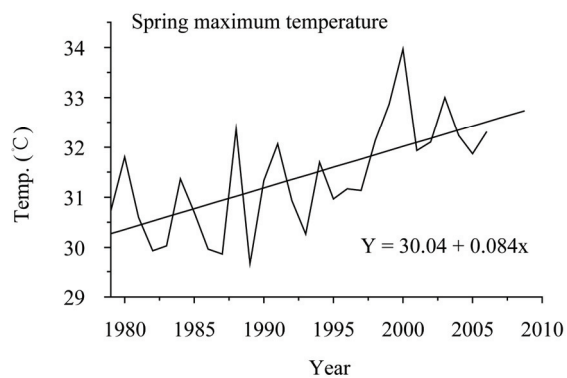
subjecting them to the Mann–Kendall test. The results are presented also in **Table 2**. The mean temperature shows a significant trend practically for all months except October. Statistically significant at the $P < 0.05$ level increases in mean air temperature were noted for January, February, March, April, August and September. 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 October. Statistically significant at the level 0.01 increases in maximum air temperature were noted for February, March, May, June, July, November and December. However, this increase is significant for January, April, August and September 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 an increasing trend in minimum temperature, which is not statistically significant. The T_{min} at the beginning of spring, though it shows an increasing trend in minimum temperature, is not statistically significant. The later part of spring, particularly April and May, shows an increasing trend significant for April at 0.1 level and May at 0.05 level. 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. The mean minimum temperature during the autumn months shows an increasing trend significant for November at 0.1 level, while October and December 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. The rough terrain of the city, as the city is an area that is shaped ridges, depressions and dissecting wadis, leads to only partial combustion of the fuel which, in its turn, leads to an increase in the effort of the engine. The factories situated around the city as well the increase in human activities and the dearth of green areas and parks in the city also contribute to the warming of the city. Moreover, the mountains which surround the city, especially Saber Mountain which is about 3100 meters above sea level, act like natural wind shields preventing smooth circulation of air and leading to an increase in the warming of the city.

4. Conclusions

This study investigated monthly, seasonal and annual climatic variability in Taiz City 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



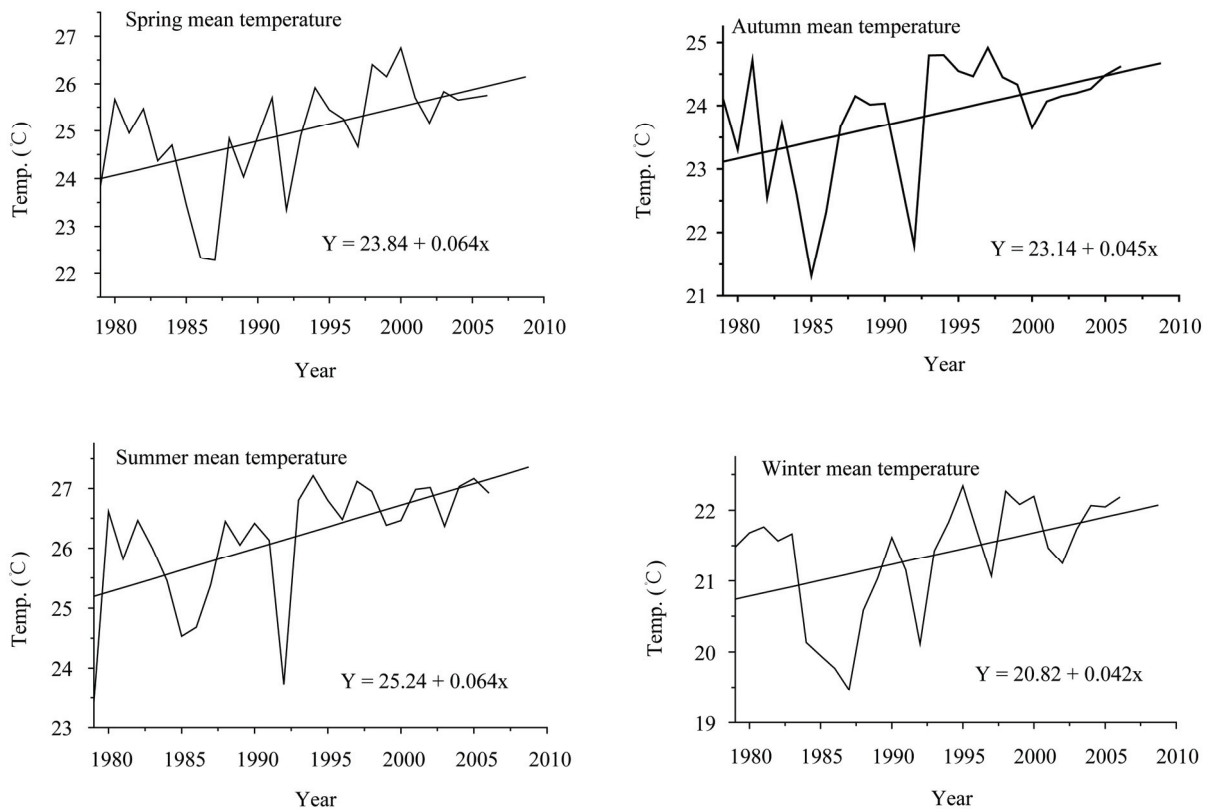


Figure 2. Temperature trends for spring, summer, autumn and winter in Taiz.

Taiz city, of about 1.5°C in the past 30 years, concentrated in spring and summer months. 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 0.064°C/year, 0.042°C/year, respectively.

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