

# Long Term Temperature Trends in Four Different Climatic Zones of Saudi Arabia

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## Abstract

*Climate change and its variation studies is a hot topic in global climatic research. The warming trend has been characterized by a decrease in the Diurnal Temperature Range (DTR) as a result of an increase in minimum temperatures experienced during night time. Many factors have been identified as possible reasons for this decrease in DTR like the cloud cover, increase in greenhouse gases, increased urbanization etc. This study aims to find out trends in the maximum and minimum temperatures observed in 4 different climatic zones of Saudi Arabia. Meteorological data for 4 cities representing separate climatic zones was collected from the Presidency of Meteorology and Environment for the period 1984-2013. The results indicate a significant rise in temperature in all the stations. However the distribution of warming trends was not uniform. The minimum temperature is generally found to increase at a higher rate compared to the maximum temperature. The decreasing trend in DTR is found to be maximum for the capital city of Riyadh followed by the new industrial city of Tabuk.*

**Keywords:** Diurnal Temperature Range, Temperature trends, Saudi Arabia

## 1. Introduction

Recent years have seen a rising interest on global climatic changes and its study. This could be the result of fluctuating climatic events like droughts, floods, and hurricanes etc. happening worldwide, signaling changes in climatic parameters. Accurate predictions of its variability are especially necessary due to our dependence on climate for health, food supply, and habitats. Considering the fact that human intervention is the root of this entire anomaly, due to urbanization, rapid population growth, industrialization and other human activities, it is our responsibility to monitor climatic patterns and take preventive steps to reduce the fluctuation.

### 1.1 Global Climate Variations

Most of the studies related to climatic pattern at global and local scales are based on temperature and precipitation data. Studies using temperature records have shown that the annual global combined land and ocean surface temperature was  $0.62^{\circ}\text{C}$  above the 20<sup>th</sup> century average of  $13.9$ . The Global Climate reports show that the year 2013 was the 4<sup>th</sup> warmest year globally since 1880. Currently the warmest year on record is 2010 which was  $0.66^{\circ}\text{C}$  above average. The 1<sup>st</sup> decade of the 21<sup>st</sup> century also includes 9 years out of the top 10 warmest years in the 134 years of data on record. The global annual mean temperature that has shown an increase of  $0.06^{\circ}\text{C}$  /decade since 1880 has now increased to  $0.16^{\circ}\text{C}$  /decade after 1970.

The impact from global climate change may depend more on changes in daily mean maximum and minimum temperature rather than on their average. The daily temperature range generally known as the Diurnal Temperature Range (DTR) is also an important indicator of climatic changes. It is the difference between the daily maximum and minimum temperature. Changes in DTR have multiple possible causes including cloud cover, urbanization, change in land usage, aerosols, greenhouse gases etc. This change in DTR is assumed to be an evidence of climate change by many researchers.

The first report that there can be important large scale characteristics due to changes in the DTR was by Karl et.al (1984). They indicated a significant decrease in DTR across many rural stations in United States. Later on, the Intergovernmental Panel on Climate Change also reported a significant decrease in DTR in Southeastern Australia and China. Further a study by Karl et.al (1991) on temperature data of the United States, the then Soviet Union and China showed that most of the warming that has occurred in these regions in the past 4 decades could be attributed to an increase in the mean minimum temperature while the mean maximum temperature showed no increase.

Karl et.al (1993) using data around the globe has reported strong evidence for a widespread decrease in DTR in many regions of the globe. Easterling et.al (1997) while examining the data for the period 1950-1993 over the globe identified the decrease in the difference between the maximum and minimum temperatures as one of the reasons for the increase of global mean surface air temperature. This continuous increase in minimum temperature with no significant change in the maximum temperature has resulted in a decrease of DTR. Jones et.al (1999) while analyzing the surface air temperature and its changes reported that over the years 1950-1993, the DTR had decreased by  $0.088^{\circ}\text{C}/\text{decade}$ . These variations in the maximum and minimum temperatures has been studied locally also by many researchers ( M.Turkes et.al (2002), S Del Rio et.al (2007), NA Elagib and SA Abdu (1997), Rehman S and Luai M Al Hadhrami (2012), Hossein Tabari and Parisa Hosseninzadeh Talace (2011)).

Turkes and Sumer (2004) while studying the patterns in the maximum and minimum trends in Turkey for the period 1929-1999, reported weak warming and cooling in the maximum temperature in comparison with a significant warming in the minimum temperature. Gadgil and Dhorde (2005) had reported significant decrease in the mean annual and maximum temperature during the period 1901-2000 over Pune city, India. Su et.al (2006) had shown that both the maximum and minimum temperature over Yangtze river basin, China, during the period 1960-2002 show a positive trend and the strongest trend was found in the winter mean minimum temperature. Del Rio et.al (2007) detected similar patterns in the monthly, seasonal and annual trends of mean maximum and minimum temperature over North West Spain during 1961-1997. However the maximum temperature was found to increase at a higher rate than the minimum temperature.

Such changing pattern in the trend of maximum and minimum temperatures over the Kingdom of Saudi Arabia has also been reported by many researchers. Rehman S and Luai M Al-Hadhrami (2012) reported the extreme temperature events over the western coastal city of Jeddah. They reported that the monthly and annual variations in the maximum temperature were more than the mean and mean minimum temperatures. H Athar (2014) also had reported the increase in extreme temperature events over different stations in Saudi Arabia during a 30 year period from 1979-2008. He had shown that the southwest coastal stations experience more warming compared to the inland stations. He also reported that the frequency of extreme warm temperatures is larger than the increase in frequency of extreme cold temperatures.

## 1.2 Climate of Saudi Arabia

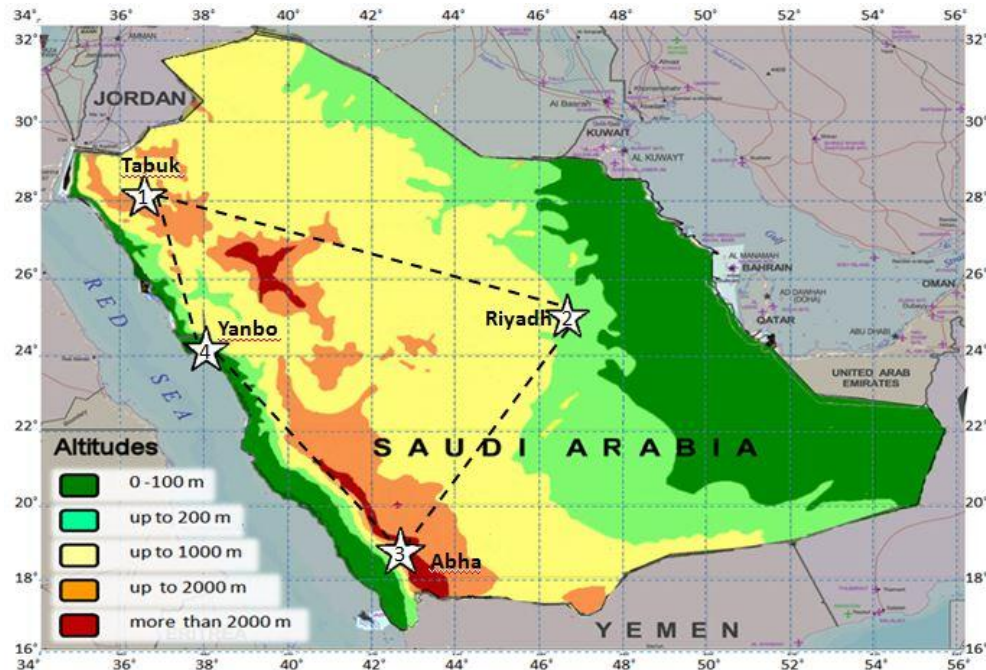
Saudi Arabia lies in the tropics between  $16^{\circ}\text{N}$  and  $32^{\circ}\text{N}$  latitudes and  $37-52^{\circ}\text{E}$  longitude. It is a large peninsula that lies between the vast continental land masses of Africa and Asia. These factors make Saudi Arabia one of the hottest countries in the world with low humidity except in summer along the coastal regions. The climate of Saudi Arabia is composed of extreme aridity and heat. It is among a few countries in the world where temperature during summer reaches above  $50^{\circ}\text{C}$ . During summer, the average temperature ranges from  $27^{\circ}\text{C}$ -  $43^{\circ}\text{C}$  in inland regions while the coastal regions experience  $27-38^{\circ}\text{C}$ . Except for the mountainous regions in the south west, Saudi Arabia is known for its desert weather and climate. It is characterized by an extreme amount of heat during daytime and a sudden drop in temperature during night time. The country as such does not receive much rain. The yearly precipitation will be around 100 mm.

The climate of Saudi Arabia varies from province to province. High temperatures are experienced in the regions of Saudi Arabia to the north of the Tropic of cancer ( $23^{\circ}26'\text{N}$ ,  $38^{\circ}38'\text{E}$ ) and also in the extreme north and inland areas. The southwestern highlands on the other hand experience moderate temperatures. The rainfall though very little on the average, also shows a spatial variation with the south western high lands showing a higher amount of precipitation. Apart from topographical factors, Saudi Arabia's climate is also affected by the tropical winds, latitude, proximity to sea, altitude etc. Ahmed Badraddin Yusuf Mohammed (1997) made an extensive study using factor cluster analysis technique to obtain the different climatic regions of Saudi Arabia. Starting with 14 climatic elements from 56 stations, a factor analysis was done in the first stage and the final output is used as an input for a further cluster analysis. The stations were finally classified into 9 groups taking into account the internal climatic differences. The stations were then regrouped into a group of 5 in the second stage. In the 3<sup>rd</sup> state, the stations shrinks to a group of 4 regions and finally into 3 regions.

## 2. Data and Selection of Stations

The present study incorporates the long term variations of the mean (T-Mean), maximum (T-Max) and minimum (T-Min) temperatures in 4 different climatic zones of Saudi Arabia during the period 1984-2013. Based on the analysis of Ahmed (1997), 4 stations are selected, each representing a specific climatic zone.

They are Riyadh, Tabuk, Yanbu and Abha. The location of the stations in Saudi Arabia is shown (Fig.2.1). Riyadh is the capital city located at 24.7°N, 46.71°E at an elevation of 635 m above sea level and is a typical station experiencing the hot and dry climate of central Saudi Arabia and is a representative of the Region 1 in the 9 groups. This region experiences the highest average maximum summer temperature. Tabuk representing Region 4, with coordinates of 28.28°N and 36.63°E lies at an altitude of 778 m and represents the temperate and dry climate of northern Saudi Arabia. This region records the lowest winter temperature averages and is under the northerly cooling influences. Yanbu lies at 24.15°N and 38.06°E and is representative of climate of the Red Sea coast (Region 6) with hot and dry conditions with high relative humidity in all seasons. Abha is a hill station representing the south western high lands with moist mild temperature (Region 8). The coordinates are 18.23°N and 42.65°E and is at an elevation of 2090 m. In the 5 group of climatic regions, Riyadh represents Group 1, Tabuk group 2, Yanbu group 3 and Abha Group 5.



**Fig 2.1: Geographical locations of the 4 stations for study in Saudi Arabia**

### 3. Data Analysis

The monthly and annual means and the standard deviations are calculated using the standard statistical methods. The least square technique was used to develop a linear regression equation and the trends are evaluated. Trend analysis examines the existence of any significant trends in the inter-annual patterns of the mean, maximum and minimum temperatures in the 4 stations. The main statistical parameter derived from the regression analysis is the slope which indicates the temporal changes of the parameter. Positive values of the slope represent an increasing trend while negative values indicate a decreasing trend. The deviation in temperature for each year is also calculated with respect to a base year average during 1984-2013. The meteorological data during the period 1984-2013 from the Presidency of Meteorology and Environment is used in this study.

### 4. Results

#### 4.1 Trend Analysis of the Annual Mean Temperature (T-Mean)

The annual mean temperature (T-Mean) of all the 4 stations is shown along with the trend lines (Figs. 4.1(a-d)). The trend lines show an increase in the annual mean temperature over the 30 years in all the stations. Yanbu showed an increase of 0.0687°C per year in its mean temperature while Abha showed an increase of 0.0668°/yr. Tabuk experienced an increase of 0.0643°C per year during the same period while T-Mean at Riyadh showed an average increase of 0.0521°C/year. In short while the stations of Yanbu, Tabuk and Abha showed an almost similar warming trend, Riyadh had showed a slightly less warming trend. The annual decadal mean temperature also showed an increase.

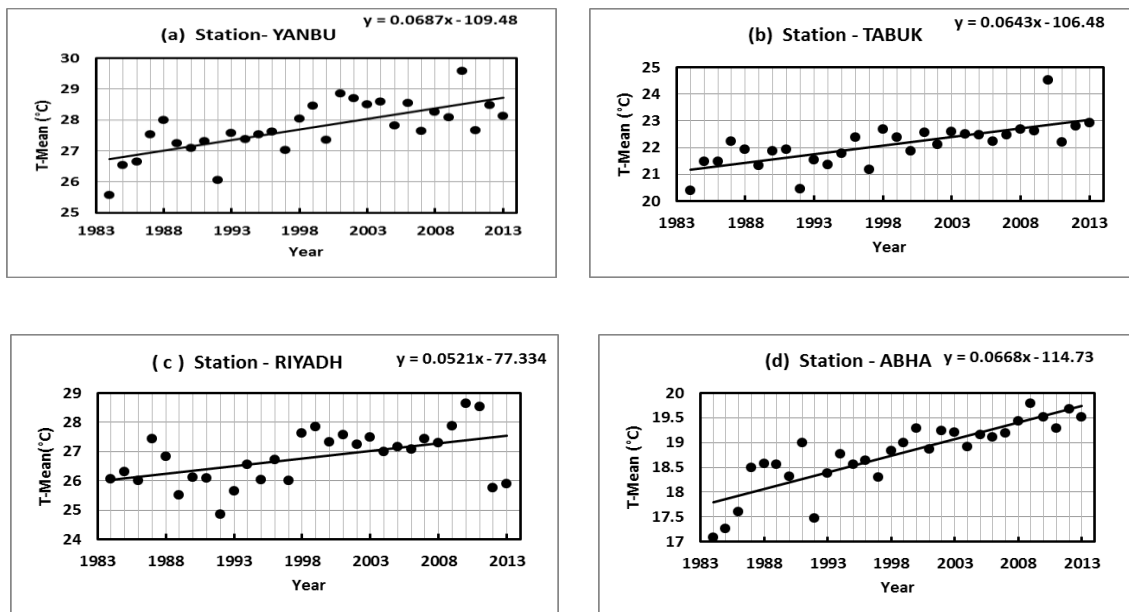


Fig 4. 1: (a-d) The Annual mean of T-Mean for the Period 1984-2013 in the 4 stations

#### 4.2 Trend Analysis of the Annual Mean Maximum Temperature (T-Max)

The time series of the annual mean maximum temperature (T-Max) in the 4 stations is shown (Figs. 4.2 (a–d)). All the stations showed a positive trend over the time period. Among all the 4 stations, Tabuk has recorded the minimum increase in T-Max with a value of  $0.0307^{\circ}\text{C}/\text{yr}$ . Riyadh which has shown an increase of  $0.038^{\circ}\text{C}/\text{yr}$  comes the next highest while Yanbu and Abha has shown  $0.0539^{\circ}\text{C}/\text{yr}$  and  $0.0617^{\circ}\text{C}/\text{yr}$  respectively. It is interesting to note that Abha which is basically a moderate temperature zone has shown the maximum increase in the T-Max during the period 1984-2013.

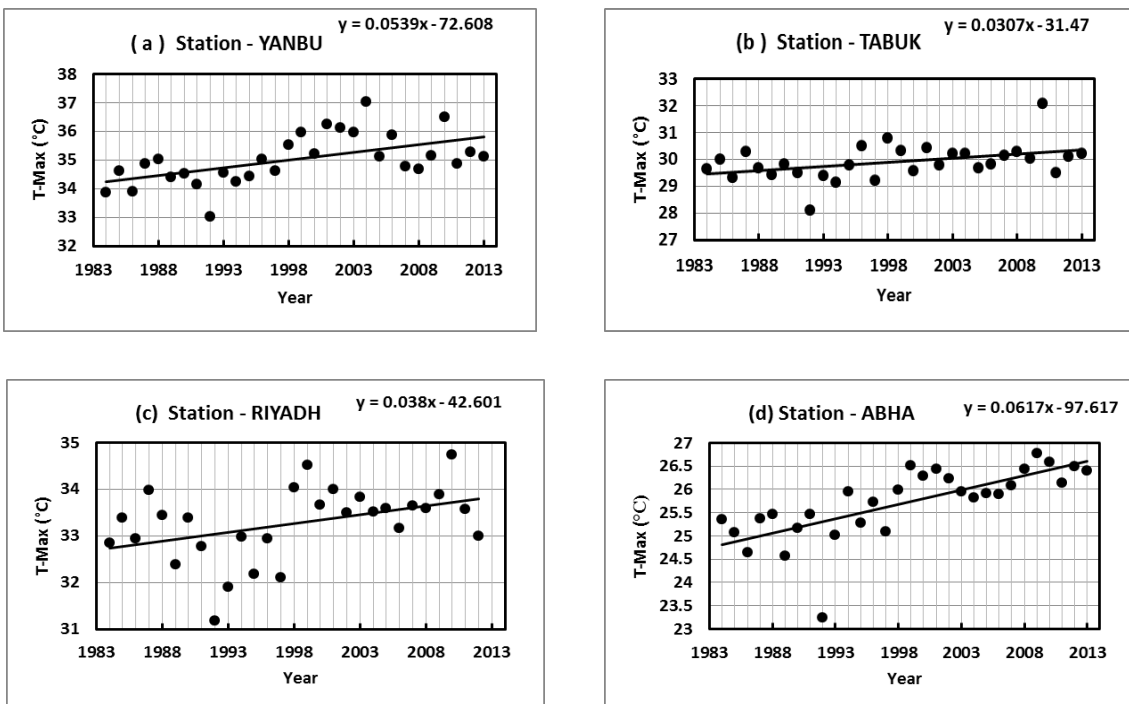


Fig 4.2: (a-d) The Annual Mean of T-Max for the Period 1984-2013 in the 4 Stations

### 4.3 Trend Analysis of the Annual Mean Minimum Temperature (T-Min)

The annual mean minimum temperature T-Min also showed an increasing trend over the years with Tabuk recording the lowest increment of 0.0476°C/yr followed by Yanbu with 0.0507°C/yr, Riyadh 0.0562°C/yr and Abha with a value of 0.0708°C/yr (Figs.4.3(a– d)).

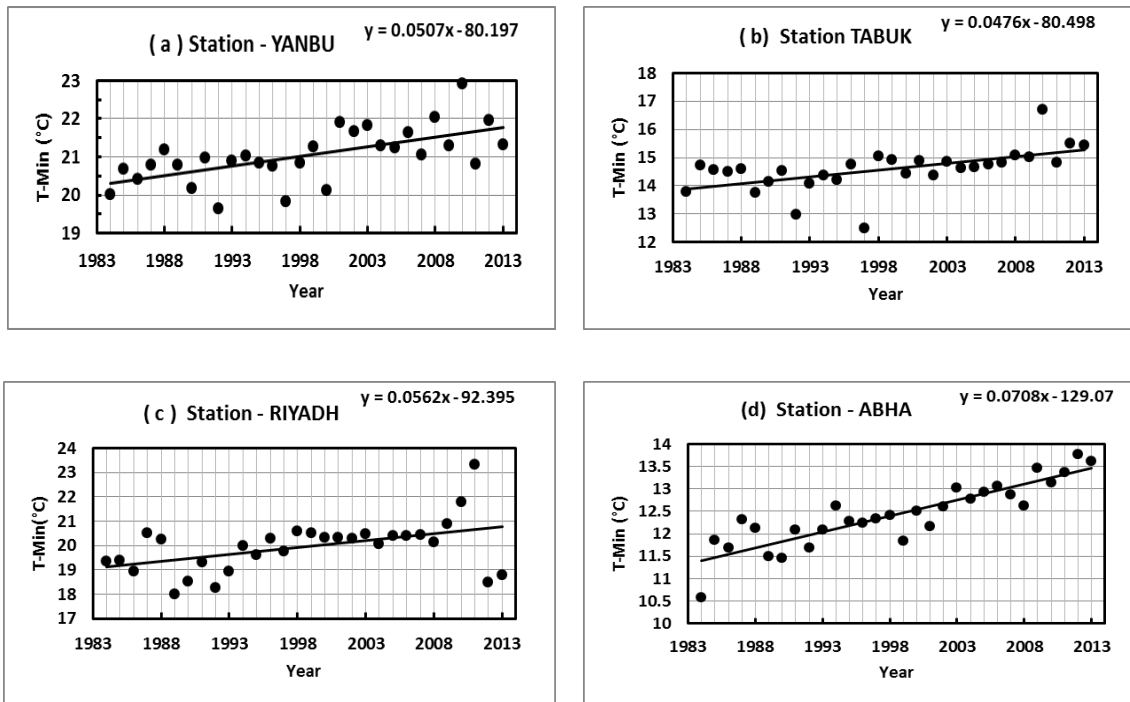


Fig 4.3: (a-d) The Annual Mean of T-Min for the Period 1984-2013 in the 4 Stations

### 4.4 Deviations in the Mean Temperature

The deviations in the annual mean temperature from the overall mean temperature during the reported period are shown (Figs. 4.4 (a-d)). The mean temperature in Yanbu showed a significant minimum in 1984 and 1992 and a maximum during 2010. Tabuk also showed significantly lower temperatures during 1984 and 1992 and a well defined maximum during 2010. The inland station Riyadh has shown a cooling trend during 1992 and a warming during 2010. The cooling trend of 1984 and 1992 to some extent is also reflected in Abha. However, the 2010 maximum is not clearly seen.

The deviations in annual temperature above the long term mean showed a decreasing trend from 1984-1997 in all the 4 stations. However the years 1988 in Yanbu, 1987 in Tabuk and Riyadh and 1991 in Abha were above the long term mean. After 1998, the trend was positive in all the 4 stations with an exception of 2002 and 2008 in Yanbu, 2000 in Tabuk and 2011-13 in Riyadh. The hill station ABHA however is showing a complete warming since 1998.

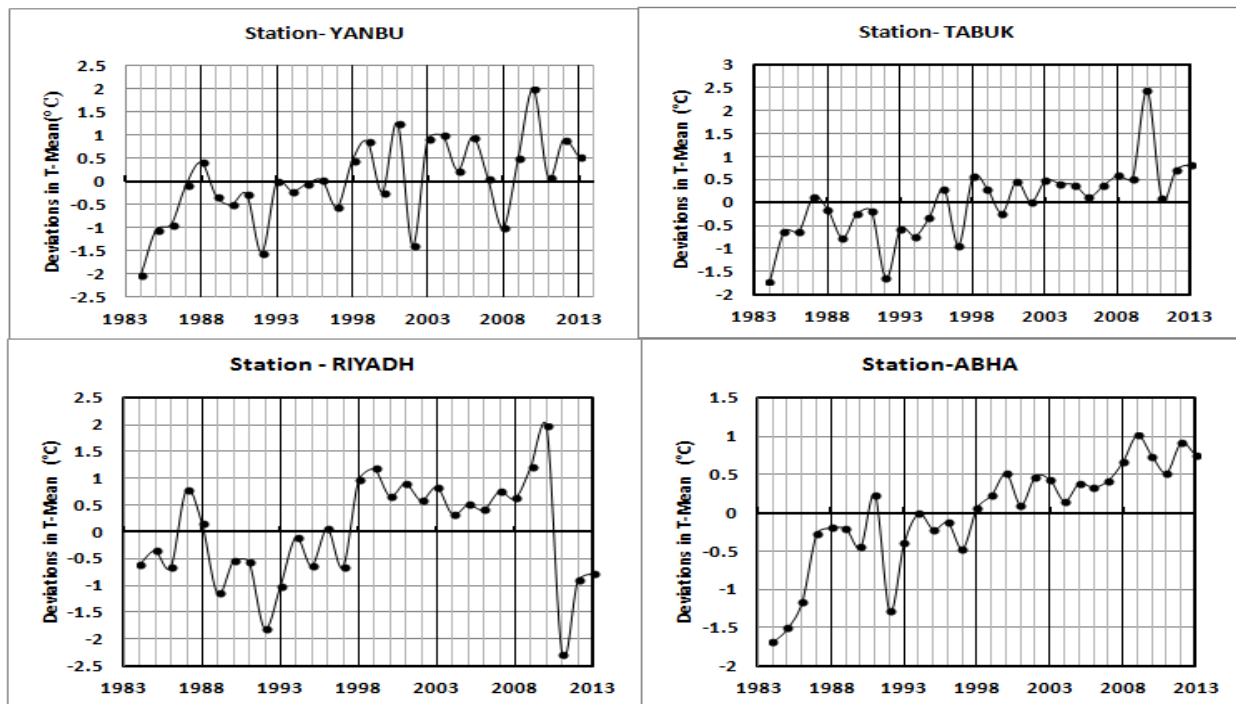


Fig 4.4 (a-d): Deviations in T –Mean from the Overall Mean for 1984-2013 in the 4 Stations

**4.5 Observed Trends in the Diurnal Temperature Range (DTR)**

The annual diurnal temperature range for all the stations is shown (Fig. 4.5). It is seen that the temporal variations in DTR shows a decreasing trend in Tabuk, Riyadh and Abha whereas the coastal station of Yanbu shows no significant variations over the years. This decrease in DTR has already been reported from different parts of the world. However this decrease in DTR rate was on the higher side in the Capital city Riyadh ( $-0.0236^{\circ}\text{C}/\text{yr}$ ) followed by the developing province of Tabuk ( $-0.0169^{\circ}\text{C}/\text{yr}$ ) and then the hill station Abha ( $-0.0091^{\circ}\text{C}/\text{yr}$ ). The coastal station Yanbu was showing a slight increase in the DTR value in the 30 years ( $0.0032^{\circ}\text{C}/\text{yr}$ ).

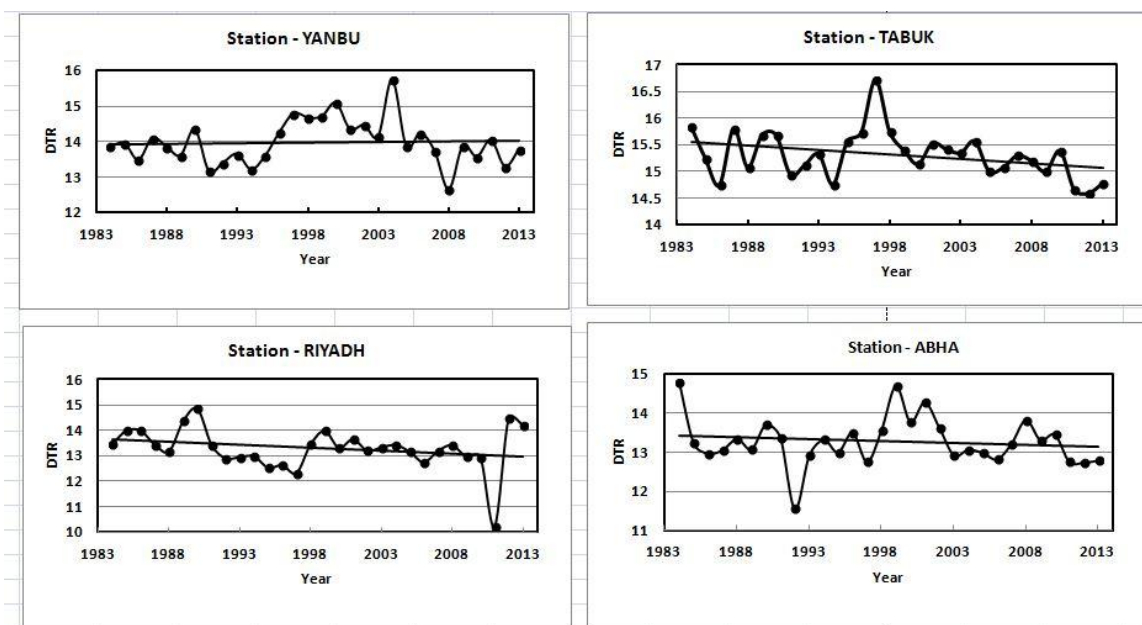
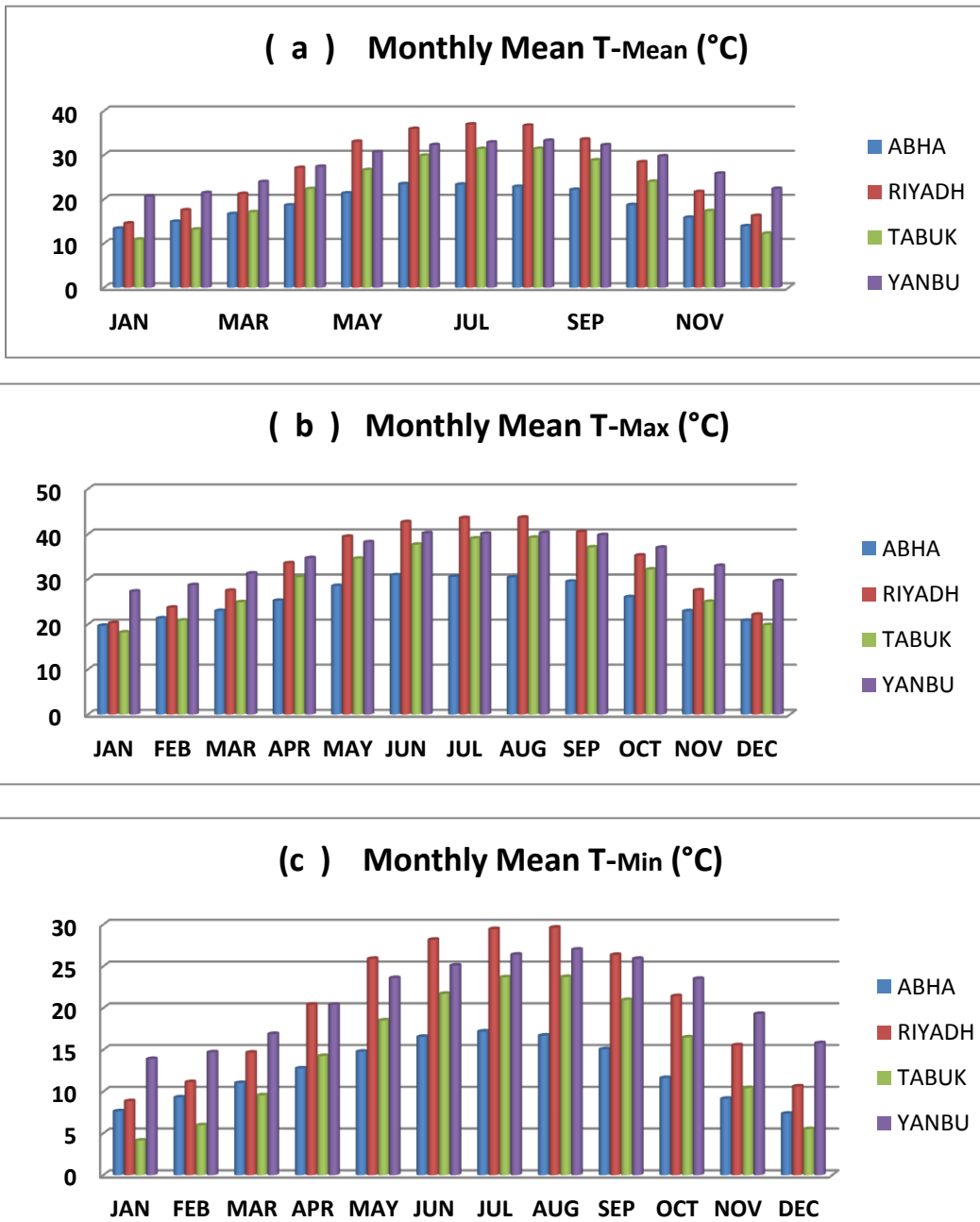


Fig 4. 5: Trends in the Diurnal Temperature Range for the 4 Stations

**4.6 Variations in the Monthly Mean of T-mean, T-max and T-min**

The monthly absolute maximum, minimum and the mean temperatures are calculated over the 30 year period and are shown (Figs. 4.6 (a-c)). The standard deviations of the monthly mean are also calculated for the 30 years. The inland station Riyadh records the maximum mean temperature during July month, while Yanbu and Tabuk have the hottest time during August and Abha during June. The corresponding maximum values recorded are  $36.96 \pm 1.11^{\circ}\text{C}$  in Riyadh,  $33.26 \pm 1.37^{\circ}\text{C}$  in Yanbu,  $31.42 \pm 1.23^{\circ}\text{C}$  in Tabuk and  $23.45 \pm 0.92$  in Abha ( Fig 4.6a).

January records the minimum value for T-mean for all the stations. The recorded minimum temperatures are  $14.55 \pm 1.44^{\circ}\text{C}$  for Riyadh,  $20.63 \pm 1.24^{\circ}\text{C}$  for Yanbu,  $10.88 \pm 1.59^{\circ}\text{C}$  for Tabuk and  $13.37 \pm 0.84^{\circ}\text{C}$  for Abha.



**Fig 4.6 – The monthly mean of T-Mean (a) , T-Max (b) and T-Min (c) for the 30 year period for the 4 stations**

During summer months of May-September, the average mean temperature in Riyadh shows a maximum of 35.22°C while Yanbu comes next with 32.27°C. Tabuk records a summer average of 29.63°C and Abha 22.63°C. The winter months average on the other hand shows the highest in Yanbu (21.48°C) followed by Riyadh with 16.10°C. Unlike the summer months, Tabuk shows the minimum mean temperature during winter time with an average of 12.09°C and Abha with 14.07°C.

The monthly mean of the maximum temperature T-Max show variations between a maximum of  $43.65 \pm 0.92^\circ\text{C}$  during August and a minimum of  $20.25 \pm 1.82^\circ\text{C}$  in Riyadh. The corresponding variations in T-Max for the other 3 stations are between  $40.27 \pm 1.33^\circ\text{C}$  in August to  $27.25 \pm 1.27^\circ\text{C}$  for Yanbu,  $39.2 \pm 1.14$  during August and  $18.19 \pm 2.01$  for Tabuk and  $30.86 \pm 0.8^\circ\text{C}$  in June to  $19.65 \pm 1.35^\circ\text{C}$  for Abha. It has to be noted that the minimum in T-Max occurs during January for all the stations (Fig 4.6 b).

Tabuk shows the minimum temperature T-Min recorded among the 4 stations with a value of  $4.14 \pm 1.62^\circ\text{C}$ , while Abha recorded a temperature of  $7.64 \pm 1.35$ , Yanbu  $13.9 \pm 1.54^\circ\text{C}$  and Riyadh  $8.85 \pm 1.5^\circ\text{C}$ . The standard deviations in Tabuk, Riyadh and Abha remained lowest during the summer months than in winter showing more consistent temperature during summer months than in winter. However the low elevation station Yanbu showed no significant variations in the year to year variations of temperature throughout the months (Fig 4.6 c).

## 5. Discussion

All the stations covered in this study are representative of the different climatic zones of Saudi Arabia. The overall variations of the T-Mean, T-max and T-min values during the period of study can be summarized as follows.

The overall mean temperature T-Mean is found to be a maximum in the coastal region of Yanbu. The temperature here has shown a maximum of 36.1 and a minimum of 17.1°C averaging out to a mean of 27.72°C. The standard deviation is 4.7 and represents an almost consistent and stable temperature over the period of 30 years. This region comes under the tropical Red sea coast which is characterized by the highest relative humidity in all the seasons. The region normally registers high annual and winter time maximum and minimum temperatures.

Riyadh which stands next to Yanbu in experiencing a high temperature shows an average of 26.8°C mean temperature that varies between 38.8°C maximum and 10.8°C minimum. However the calculated standard deviations are slightly on the higher side indicating variability over the period. Riyadh being an inland station experiences a hot desert climate with maximum temperatures during summer months.

Tabuk which is a northern city has a continental climate that experiences the lowest winter temperature average. It receives the northerly cooling influences and experiences the lowest winter average in T-max and T-min also. The mean temperature observed during the period of study is 22.29°C with a standard deviation of 7.56.

Abha is located in the southwest highlands of the country and is a hill station. It receives reasonably good rainfall during late winter and spring. It has recorded the lowest annual and summer temperature averages. During the period of study a very consistent average of 18.77°C was recorded with a standard deviation of 3.76.

The surface air temperature in all the stations is found to increase during the 30 years of study. The annual average of the mean, maximum and minimum temperatures reveals a general rise of temperature during the period of study in all the 4 stations. This increase in the mean temperature is in line with the increase in temperature around the globe. These results are expected considering the factors that affect the variations of surface air temperature based on latitude, elevation and proximity to large water surfaces. However, it is interesting to note the differential rate of increasing T-Max and T-Min. All the 3 stations except the coastal station Yanbu, showed a higher rate of increase in T-min compared to T-max. Tabuk has observed the least increase in T-Max and T-Min while the high elevation station Abha has shown the maximum increase per year in both T-max and T-min. According to Soltani & Soltani (2008), these positive trends in temperature might be due to the greenhouse effect, along with other reasons like the increased cloud formation, haze from factories and burning forests and fields that could happen due to increased urbanization.

Analysis of global air temperature data has shown that this global warming has resulted, in part, from the daily minimum temperature increasing at a faster rate or decreasing at a slower rate than the daily maximum, resulting in a decrease in the DTR for many parts of the world.



Decreases in the DTR were first identified in the United States, where large-area trends show that maximum temperatures have remained constant or have increased only slightly, whereas minimum temperatures have increased at a faster rate. Similar changes have been found for other parts of the world as data have become available.

The Global Temperature Anomaly Report of 2013 also shows these positive trends in the mean temperature during the time 2000-2013 except during the year 2008 and 2000 which has shown a cooling trend. This global report was based on a 30 year average from 1981-2010. The period 1983-1997 was also showing a negative anomaly globally with exceptions of positive anomalies during 1987, 1988, 1991, and 1995. However compared to 1998, which ranked 1<sup>st</sup> globally among the warmest years, 2010 warming is more prominent in the Saudi Arabian cities. The inland station Riyadh is showing a cooling during the period 2011-2013 whereas all the other stations show a warming trend.

This differential warming rate between the maximum and minimum temperatures is reflected in the decrease of the diurnal temperature range in the Kingdom also. All the stations except Yanbu has shown a higher rate of increase in the T-Min values compared to T-Max. While the station Riyadh has shown the maximum difference in this rate of increase between T-Max and T-Min. Even though Abha recorded the maximum rate of increase in T-Max and T-Min among all the stations, it has shown the minimum decrease in DTR due to the approximately equal rate of increase in both parameters. For Yanbu, the rate of increase of T-Max was found to be slightly more than that for T-Min and hence the nominal change in DTR. The low variations in DTR in Yanbu can be due to its low lying humid nature.

While considering the decadal changes in the DTR values, it is found that Riyadh has shown a decreasing trend during the 2<sup>nd</sup> and 3<sup>rd</sup> decade of the observation period. However, the decrease was more prominent during the second decade. Tabuk on the other hand started showing this decreasing trend of DTR only in the 21<sup>st</sup> century. Abha infact has shown an increase in the DTR during the second decade. However, during the last decade, a substantial decrease in DTR is observed in this fast developing hill station. All these changes can be due to the rapid growth of urbanization and the related changes it brings about in the atmospheric conditions.

The average monthly mean variations over the 30 year period were also studied. It is found that the relatively stable temperature pattern is followed during the summer months compared to winter. The standard deviations also show a negative correlation with temperature.

## **6. Conclusion**

In this study, the trends of annual, seasonal and monthly T-Mean, T-Max and T-Min time series were examined for 30 years from 1984-2013 for 4 different stations. The results indicate a significant rise in temperature in all the stations. However the distribution of warming trends was not uniform. T-Min is generally found to increase at a higher rate compared to T-Max. The annual T-Mean values showed a positive trend in all the four stations. This trend was found to be a minimum in the inland station Riyadh with a warming of 1.563°C over the 30 years. Tabuk, Yanbu, and Abha also showed similar warming trends with an increase of 1.929°C, 2.061°C and 2.004°C during the same period.

Another important observation is the differential rates in the increase of T-Max and T-Min which had led to a decrease in the diurnal temperature range in 3 cities of Riyadh, Tabuk and Abha. The rate of increase in T-Min is found to be faster than that in T-Max in these 3 cities. A seasonal comparison between summer and winter months have shown that during summer months, Riyadh and Yanbu had shown the maximum temperatures while during winter months Tabuk records the minimum temperature among the 4 stations.

This study only intends to bring out the variations in temperature in different regions of Saudi Arabia. By using the linear regression analysis, it has been shown that mean annual trends in near surface air temperature exist at all stations under study. The rate of change of surface temperature over a period of 30 years indicates a warming trend. The observed features are very important in the context of the global warming trends observed during the late 20<sup>th</sup> and 21<sup>st</sup> century. New industrial zones have come up in hitherto green and open areas, leading to increased air pollution within the urban environment. The ever increasing number of motor vehicles is also points to more pollution.

Rising greenhouse gases and changes in the reflective properties of the earth's surface are predicted to raise global temperatures. The much-reported decrease in the diurnal temperature range has been said to be one of the "fingerprints" of human-induced global warming. Detailed studies are required to arrive at a comprehensive conclusion on the real phenomenon leading to these warming trends in temperature and a decrease in the DTR which is considered as an indicator of climate change. This information leads to the importance of considering the environmental implications of such urban temperature modification for human comforts, while designing the expansion of urban planning programs of cities. The physical and socioeconomic changes occurring within the urban environment could lead to the long-term modification of the temperature conditions.

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