International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

Recent Trends in Surface Air Temperature over Al-Taif, Saudi Arabia

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Abstract: ***Variability 0f surface air temperature and distribution over 36 year's period (1978 to 2013) in Al-Taif, Saudi Arabia, has been studied using Regression Analysis and Theil-Sen nonparametric test. The monthly mean of mean (Tmmean), maximum (Tmmax) and minimum (Tmmin) temperatures levels and their trends have been investigated. The trends in deviations from the reference period (1978–2013) are analyzed and the results showed the following particular findings:***

- ***The number of hot days increased by 2.0088 days per year which means that there is 72.317 hot days increased during the last 36 years. The frequency of the hot nights increased by 0.3703 nights per year, this means that there are 13.3308 hot nights increased during the last 36 years. The number of cold nights increased by 0.0587 nights per year this implies that there is 2.113 nights has decreased during the entire period. The number of cold days decreased by -0.2241 day per year which implies that there is 8.064 cold days has decreased during the entire period.***
- ***The highest and lowest values of Tdmax are 40.79℃ in July 2011 and 31.96℃ in February 1999.***
- ***The highest and lowest values of Tdmin are 36.9℃ in July 2013 and 25.73℃ in January 1992.***
- ***The monthly mean of daily mean temperature (Tmmean) have increased during the entire period with annual increase 0.0155℃, 0.0636℃, 0.0202℃, 0.0192℃, 0.0333℃, 0.0271℃, 0.0308℃, 0.0497℃, 0.023℃, 0.0248℃, 0.0167℃ and -0.0007℃ for January to December with major increases in February, August, May and July.***
- ***The monthly mean of daily mean temperature (Tmmean) have increased with 0.558℃, 2.2896℃, 0.7272℃, 0.6912℃, 1.1988℃, 0.9756℃, 1.8088℃, 1.7892℃, 0.828℃, 0.8928℃, 0.6012℃ in January to November respectively while it decreases with -0.0252℃ in December during the full period.***
- ***The annual mean of Tdmean is increasing by 0.0269℃ per year which implies that over the last 36 years the annual mean temperature has increased by 0.9684℃.***
- ***The annual deviations of monthly mean temperature (Tmmean) from the overall mean temperature show major decreasing trends (cooling) in the period (1978 to 1997) and major increasing (warming) trends in the period (1998 to 2013).***
- ***The maximum of Tmmax was 37.59℃ in July while a minimum of 18.15℃ was found in December.***
- ***Tmmax have increased in all months with annual increase of, 0.0434℃, 0.1036℃, 0.0629℃, 0.0486℃, 0.0616℃, 0.0478℃, 0.0533℃, 0.0681℃, 0.047℃, 0.0583℃, 0.0416℃ and 0.0145℃ for the months January to December. The higher increases were in August and February and less increase were in January and November.***
- ***The annual mean of daily maximum temperature (Tamax) show an annual increasing trend of 0.0542℃ which implies that over the last 36 years the annual mean of daily maximum temperature of Al-Taif has increased by 1.9512℃.***
- ***The annual deviation of Tmmax from overall mean temperature show negative trends during the interval (1978 to 1997) and shows major positive trends in the period (1998 to 2013). The maximum cooling was found in the years 1982 and 1992 with 1.55℃ and 1.53℃ while the maximum warming was recorded in the year 1999 and 2010 with 1.389℃ and 1.12℃ respectively.***
- ***The Tmmin varied between a minimum of 5.63℃ in January and a maximum of 25.45℃ in July which means that the ratio between the hottest to the coldest Tmmin 4.52.***
- ***The increasing trends in the Tmmin values were observed in all months of the year with an annual decrease (cooling) of -0.0117℃, -0.0236℃, -9.00E-05℃, -0.0006℃, -0.0031℃, -0.0046℃ and -0.0125℃ for Jan., Mar., May, Oct., Nov. and Dec. and has increased (warming) with an annual value of 0.0307℃, 0.0161℃, 0.0201℃ and 0.0384℃ for Feb., Jun., Jul. and Sep. which implies that the Tmmin has decreased with the values of -0.4212℃, -0.8496℃, -0.0032℃, -0.0216℃, -0.1116℃, -0.1656℃ and -0.45℃ for Jan., Mar., May, Oct., Nov. and Dec. and has increased with 1.1052℃, 0.5796℃, 0.7236℃, 1.3824℃ and 0.126℃ for Feb., Jun., Jul. and Sep. during the last 36 years respectively.***
- ***The annual mean of daily minimum temperature (Tamin) showed significant increasing trend with an annual rise of 0.0044℃ which implies that over the last 36 years the annual mean of daily minimum temperature of Al-Taif has increased by 0.1584℃***
- ***The annual deviations from overall mean of (Tamin) show negative trends (cooling) during the periods (1982-1984, 1986, 1989, 1992, 1996-2002 and 2004) and positive trends (warming) in the periods (1978 to 1981, 1985, 1987-1988, 1990-1991, 1993-1995, 2003, and 2005-2013).***
- ***The increasing trend in the annual and the monthly mean of daily mean (Tdmean), daily maximum (Tdmax) and daily minimum (Tdmin) temperatures (Tmmin) determined by regression method have been confirmed by the nonparametric Theil-Sen method.***

This study showed that Al-Taif is vulnerable to the considerable warming temperature trend which requires specific attention towards the energy demands for extra cooling, medical preparedness and water resources.

Keywords: Extreme temperature, heat waves, temperature trends, Al-Taif, Saudi Arabia

1. Introduction

The changes in climatic variability continue to be major global issue [1] and be One of the largest challenges since couple of decades on all geographical scales and across all economic sectors is The climate and the climate variability[2]

The earth's surface temperature and sea surface temperature have been increasing since the mid-19th century[3] with manifestations in national and local scales[4],[5],[6]. Two periods of warming have detected: 1910-1945 and 1976-2000 and the 2000s were the warmest decade experienced, and 1998, 2005 and 2010 have been the warmest individual years in the instrumental record [7],[8].

A study [9] showed that the surface temperature of the Earth increased by 0.6°C – 0.8°C during the 20th century. Another long-term temperature study on different scales [10], [11]showed that the rate of annual warming for global land areas over the 1901– 2000 period was 0.078°C per decade.

Another study [12] to the global trends in maximum temperature, minimum temperature, and the diurnal temperature range (DTR) demonstrated that the minimum and maximum temperature increased in almost all parts of the globe. A positive trend in summer mean temperature, increase in temperature and the number of hot days at Belgrade have been concluded by [6].

The lower Tropospheric air temperatures have increased by 0.13°C to 0.22°C per decade since 1979[13]. In a study on the climate extremes over Europe using 750 temperature sites cover the period 1960–2000 [15] showed that the European average trend in annual DTR was 0.09 °C decade−1. Trends in annual temperature and precipitation series of six stations West Azarbaijan (Iran) were analyzed for 40 years period and showed that that there is an increasing tendency in temperature [14]

In a study over the west, south and south west of Iran [16], The Tmax, Tmin and Tmean showed a warming trend in the annual Tmax, Tmin and Tmean at the majority of the stations during the period (1970s). The mean annual temperature records Over turkeyhave a warming trend over the 1939 to 1989 period [17] while the summer temperatures have increased during the last 3 decades of the 20th century over the south Mediterranean[18].

Study over Kuwait, the maximum yearly temperature is persistently exceeding its mean value during the last two decades [20] and other over Jordan showed thata significant warming trend after the years 1957 and 1967 for the minimum and maximum temperatures have been detected [19]. Also, over Kuwait, a statistically significant temperature increase of 0.07°C/decade over Kuwait during the period 1950-1990[21],.

A study over the Korean Peninsula of the annual mean temperature during the period 1974-1997 showed an annual increase of 0.96°C (0.42°C per decade) and 1.5°C in the large cities and in the rural and coastal areas the increase was smaller. 0.58°C [22]

Over Italy, utilizing the minimum and maximum daily temperature from 49 meteorological stations during the period from 1961 to 2004 to study the annualseries of mean temperature anomalies [23] and found that there is a negative trend for the period 1961–1981, a more pronounced positive trend from 1981 to 2004, and an increase of the average daily temperature range for the wholeperiod

Brunetti et al. studied the Italian climate in the twentieth century and found that Italian climate is becoming warmer and drier with an increase of both heavy precipitation events and long dry spells[24]

Chaouche et al. [25] demonstrated an increasing monthly temperature trend in June and in the spring thought the western parts of the French Mediterranean areas.

S. del Rio et al. [26] have studied the mean, maximum, minimum temperature trends on a monthly, seasonal and annual timescale to 476 Spanish weather stations during the period between 1961 and 2006 and demonstrated that the temperature significantly increased in over 60% of the country in March, June, Spring and summer in case of maximum temperature and in March, May , June, August, Spring, and summer for minimum temperature. At the annual resolution, temperature significantly increased in over 90% of Spain with rise of around 0.3°C per decade.

The Variability of winter time surface air temperature of 24 observing sites in the KSA based on time series over thirty one years (1978-2008) [1]showed that there is a warming trend in winter temperature during the last 2 decades at most sites and there is significant warming trend after the year 1997 with a rate of 0.03°C per year.

A considerable warming temperature trend and the rainfall decrease were the main reasons of the aridity in the Middle East which should be considered for rural development and water resources management in KSA [27].

A recent seasonal climate study of temperature over Saudi Arabia[28]demonstrated that the temperature has increased significantly in the rate 0.72°C per decade in the dry season (June to September) against 0.51°C per decade in the wet season (November to April) during 1979-2009. Also, it showed that maximum (Tmax), mean (Tmean) and minimum temperature (Tmin) have increased by 0.67°C, 0.51°C and 0.34°C per decade in the wet season and by 0.8°C, 0.72°C and 0.63°C in the dry season.

The temperature over Al-Taif, Saudi Arabia, have been analyzed for 40 years (1970 to 2006) and showed that there is a significant increase in hot days per year and relatively smaller decrease in hot nights [29].

The temperature over Makkah, Saudi Arabia [30] during the period of (1985-2013) illustrated that the number of hot days and nights increased annually by 1.5966 and 1.832, respectively, while the number of cold nights decreased annually by 0.4054 nights and The annual mean of daily mean, maximum and minimum temperature have increased by 0.0398˚C, 0.0552˚C, 0.0398˚C per year.

The surface temperature variability over Al-Madinah Al-Munawarah [31]has studied and showed that This implies that during the entire period the numbers of hot days increased by 22.3776 days while the number of hot nights increased by 22.0392 nights and both the daily mean, daily maximum and daily minimum temperature have increased during the last 36 years.

More recent study on the recent Trends in Mean, Maximum and Minimum Surface Air Temperature over Jeddah, Saudi Arabia, (1978 -2013) [32] showed that during the period of study there are 29.1564 hot nights , 16.6464 hot days increased during the last 36 years.

The extreme temperature variability over Abha city, Saudi Arabia [33] has been studied and showed a warming trend of the local air during the period (1985 to 2005) and there is an increase in in the annual mean temperature of 0.048°C per year with overall increase of 1.01°C between 1985 and 2005, and also there is warming trends for both the daily maximum and the daily minimum with 0.068°C and 0.047°C per year.

A study[34] of the temperature data on 19 meteorological stations distributed through the Saudi Arabia during the period of 1978–2013 demonstrated that there is a negative temperature trend (cooling) with 0.03°C per year for all stations during the first period (1978–1997) followed by a positive trend(warming) 0.06°C per year in the second period (1998–2013) with reference to the entire period of analysis.

The air temperature rise as an effect of the urbanization has been investigated by Almazroui M. et al., [35] in Saudi Arabia and concluded that the rise in air temperature is not likely to be due to urbanization changes resulting from population increase.

The main objective of this study is to contribute to the knowledge of the behavior of mean, maximum and minimum temperatures occurring over Al-Taif, Saudi Arabia, over the period (1978 to 2013) on a monthly, seasonal and annual timescale. As it is known that the extreme temperatures can affect many areas of the society. It increase water consumptions, raises the power demand for air conditioning, and create dangerous conditions for human health in terms of protection from heat waves [36], [37]. So this study may help the decision makers to make the precautions to avoid any shortages or scarcity of energy or minimize the medical dangerous.

2. Site Description, Data and Methodology

Al-Taif is a Saudian city located in the Hijaz region on the

Figure1: Location of Al-Taif on Saudi Arabia Map

The town is about 100 km southeast of Makkah (Latitude: 21°26′ North, longitude: 40°21 East and at an elevation of 1,879 m)and has an area of 42750 km² among 153,128 km² of Makkah Provence, and the city's population is 885,000people among 7,688,600 population of the full region [38].Each summer the Saudian people moves from the heat of different places to Al-Taif. The city is the center of an agricultural area known for its grapes, pomegranate, figs, roses and honey.In the modern times, Al-Taif has seen tremendous expansion in size and infrastructure.

This study incorporates daily mean, daily maximum and daily minimum values of surface air. (**Figure1**) shows the geographical location of Al-Taif city on the map of Saudi Arabia.

2.2 Quality of the Dataset

Before analyzing the data, it has been gone under several quality control checks (QC) to detect and remove or reduce errors, losses, incompletion, redundancy, misidentification, misattribution and contamination in the data in the process of recording, manipulating, formatting, transmitting and archiving data to have higher quality, more efficiently and more consistently observation dataset [39].

Following [39], [40] and [41], the applied QC procedures includes checking of plausibility: to reject those values which never can exist; for example; the negative values of temperature in Al-Taif; the daily maximum temperature which is less than daily minimum temperature…etc

The probability distributions of the minimum, maximum and mean temperature are assessed using an R-based program and the results are summarized in (Error! Reference source not found.to**Figure4**). In these figures, the x-axis represents the temperature (°C) and the y-axis represents the frequency.

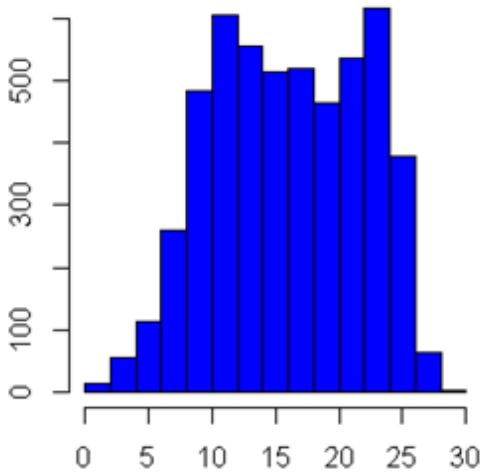

Figure 2: Histogram of the Daily Minimum Temperature (°C)

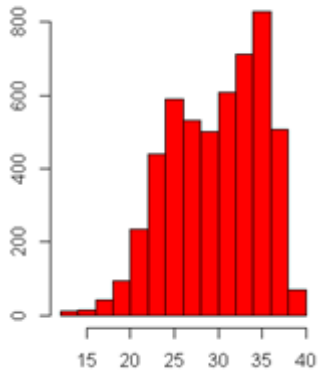

Figure 3: Histogram of the Daily Maximum Temperature (°C)

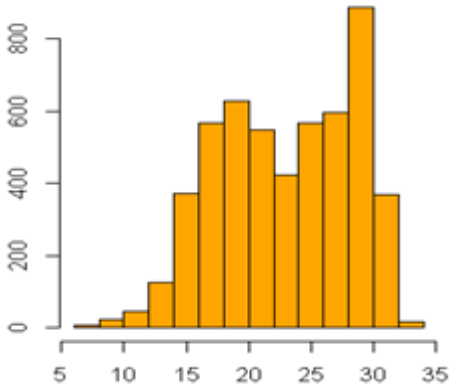

Figure 4: Histogram of the Daily Mean Temperature (°C)

(**Error! Reference source not found.** to **Error! Reference source not found.**) Represents Bimodal histograms for the daily minimum temperatures (Tdmin), the daily maximum temperatures (Tdmax) and the daily mean temperatures (Tdmean) observed in the period 1978-2013 which reflects the heterogeneity of the dataset. (**Error! Reference source not found.**) shows that the probability of finding minimum temperatures less than 0°C is very low and most of minimum temperatures lie between 8°C and 25°C. Also the probability of finding minimum temperatures more than 27°C is also low.

(**Error! Reference source not found.**) shows that the probability of finding maximum temperatures less than 10°C is very low and most of maximum temperatures lie between 22°C and 37°C and there is no probability of finding maximum temperatures greater than 40°C.

(**Error! Reference source not found.**) It shows that the probability of finding mean temperatures less than 7°C is very low and most of mean temperatures lie between 15°C and 32°C.

The magnitude of the trends of increasing or decreasing temperature were derived from the slopes of the regression line using the least square method and the nonparametric Theil-Sen[42], [43] statistical approach which is commonly used for trend quantification [44]. The Theil-Sen test calculates slopes between all pairs of points and the median of the slopes is selected as Theil-Sen estimate, which is taken as the trend of the Temperature for the given period. Furthermore, Theil-Sen test tends to yield accurate confidence intervals even with non-normal data and non-constant error variance (homoscedasticity) and is resistant to outliers, as it is based on the median of the slopes. Theil-Sen test was conducted in statistical software R, using package 'openair' [33].

(**Error! Reference source not found.**) shows that the daily maximum temperature have increased by 0.0002°C per day and the daily minimum and daily mean temperatures have increased by 0.00002°C and 0.00009°C per day during the entire period (1978-2013) respectively.

Using daily maximum and minimum temperatures, the number of hot and cold nights and days were estimated as follows: The days are considered hot if the daily maximum temperature (Tdmax) exceeds 35°C, the nights are defined hot when daily minimumtemperature (Tdmin) greater than or equal 20°C and the days are defined ascold when the daily maximum temperature (Tdmax) less than or equal 20°C and the nights are classified as cold when the daily minimum temperature (Tdmin) less than or equal 15°C [29]. The monthly and annual standard deviations were calculated. The temperature range has obtained by taking the difference between the maximum and minimum temperatures of the daily mean values.

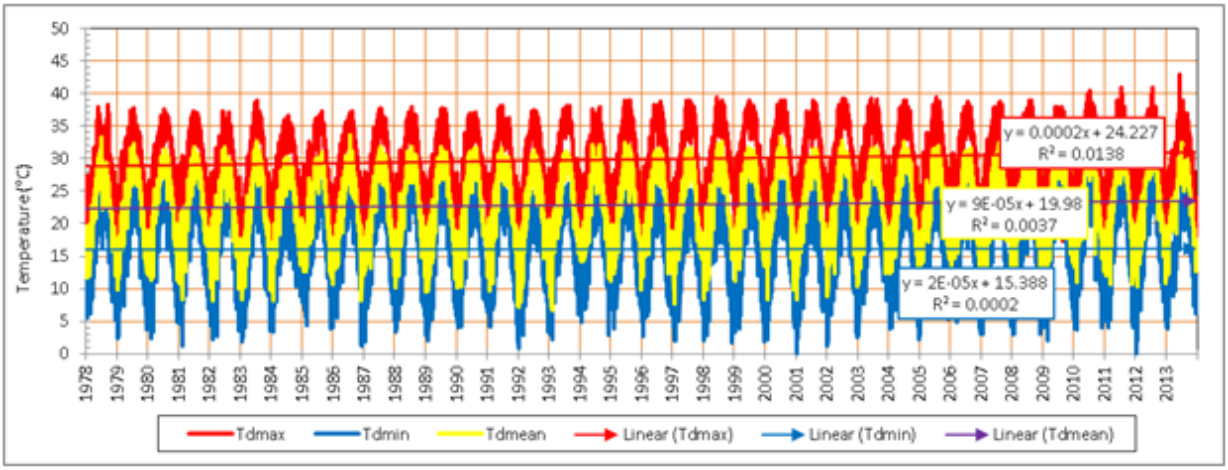

Figure 5: Daily maximum, minimum and mean Temperatures during the period (1978-2013) over Al-Taif

Table 1: Linear regression equation for the daily maximum, minimum and mean temperature

Temperature (℃)	*Regression line*	*R²*
Daily maximum (Tdmax)	y = 0.0002x + 2.227	0.0138
Daily minimum (Tdmin)	y = 2E-05x + 15.388	0.0002
Daily mean (Tdmean)	y = 9E-05x + 19.98	0.0037

Error! Reference source not found.) shows the daily minimum (blue), the daily maximum (red) and the daily mean (light blue) temperatures and demonstrated that daily maximum temperatures range between 12.4°C and 43°C, the daily minimum temperatures range between **0**°C and 28.6°C and the daily mean temperatures range between **6.7**°C and 33.7°C

3. Results and Discussion

The data of daily maximum (Tdmax), daily mean (Tdmean) and daily minimum (Tdmin) levels of temperature, monthly mean of daily maximum (Tmmax), monthly mean of daily mean (Tmmean) and monthly mean of daily minimum (Tmmin) values of temperatures and the annual mean of maximum (Tamax), mean (Tamean) and minimum (Tamin) values of temperatures are analyzed and discussed in the coming sections.

3.1 Temperature Data Summary

Table 2summarize the overall variations of maximum, mean and minimum levels of daily maximum, daily mean and daily minimum temperature during 1978-2013.

The maximum temperature varied between12.4 °C and 43°C with standard deviation of 5.12°C. The minimum temperature varied between 0°C and 28.6°C with standard deviation of 5.64°C and the mean temperature varied between 6.7°C and 33.7°C with standard deviation 5.3°C.

Table 2: Mean Temperature data Summary during the period (1978 to 2013)

	Tmax (°C)	Tmin (°C)	Tmean (°C)
Max. recorded	43	28.6	33.7
Min. recorded	12.4	0	6.7
Meanrecorded	29.088	16.196	22.596
St.Dev.	5.119	5.64	5.307
Range	30.6	28.6	27

3.2 Frequency of Hot/Cold Days and Nights

The number of hot days (Tdmax ≥ 35°C) and hot nights (Tdmin ≥ 20°C) and cold days (Tdmax ≤20°C) and cold nights (Tdmin ≤15°C) during the period of study (1978-2013) were calculated and depicted in (**Error! Reference source not found.**). It is shown that the number of hot nights and hot days per year have positive trends. The regression lines of best fit show that.

1. The frequency of the hot nights increased by 0.3703 nights per year, this means that there are13.3308 hot nights increased during the last 36 years.
2. The number of hot days increased by2.0088 days per year which means that there is72.317 hot days increased during the last 36 years.
3. The number of cold nights increased by 0.0587 nights per year this implies that there is 2.113 nights has decreased during the entire period.
4. The number of cold days decreased by -0.2241 dayper year which implies that there is 8.064cold days has decreased during the entire period.

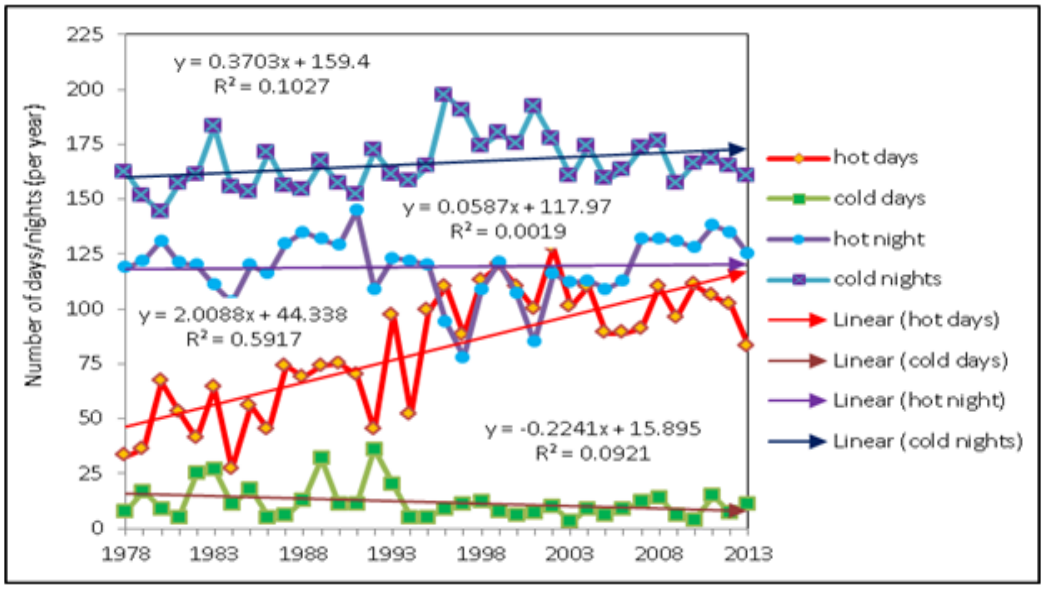

Figure 6: Annual frequency of hot days and nights and cold days and nights

3.3 Daily Mean Temperature (Tdmean) Variation

The long term monthly mean (Tmmean) of daily mean temperature (Tdmean) is calculated in the entire period (**Figure 7**) and show that:-

1. The higher and lower of the maximum of Tmean are30.9°C in June and17.3°C in January respectively.
2. The higher and lowerof the minimum of Tmean are 29.12°C in June and15.5°C in January respectively.

3. The higher and lower of the mean of Tmean are 27.82°C in Juneand 12.6°C in December.

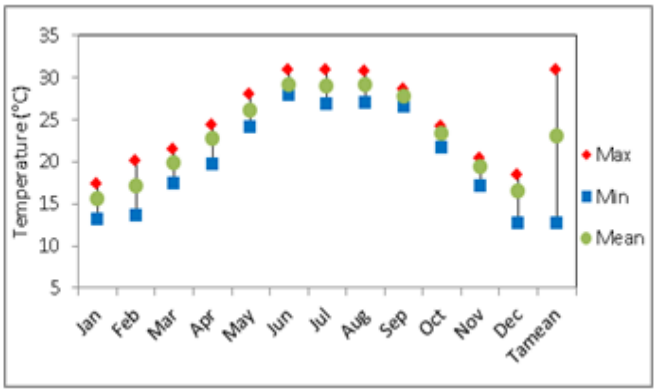

Figure 7: Variations of monthly mean, maximum and minimum of daily mean temperature

The average of (Tmmean), the corresponding standard deviations (SD), the mean deviation, the range, and the covariance are given in (**Table 3**). The higher values of covariance correspond to higher standard deviations (SD), higher values of COV and SD were observed in February, winter. The COV varied between 1.7% and 7.05% corresponding to January and February during the year. This shows that the temperature is most stable in these months.

Table 3: Statistical summary of Tmmean

Month	Max (°C)	Min (°C)	Mean (°C)	St.Dev. (°C)	MeanDev. (°C)	Range (°C)	Cov. (%)
Jan	17.32	13.08	15.49889	1.123158	0.897889	4.24	1.720286
Feb	20.08	13.53	17.15972	1.44684	1.114111	6.55	7.055571
Mar	21.49	17.36	19.78139	0.982301	0.794667	4.13	2.245857
Apr	24.44	19.68	22.77111	1.089922	0.869333	4.76	2.133714
May	28.07	24.08	26.15222	1.095357	0.903556	3.99	3.696286
Jun	30.9	27.83	29.11528	0.666837	0.531944	3.07	3.009857
Jul	30.89	26.77	29.03389	0.922014	0.725556	4.12	3.423143
Aug	30.73	27.03	29.07778	0.837572	0.627556	3.7	5.517429
Sep	28.67	26.48	27.8025	0.528531	0.406389	2.19	2.551286
Oct	24.29	21.6	23.40861	0.641877	0.502722	2.69	2.748714
Nov	20.42	17.09	19.35694	0.795652	0.594278	3.33	1.858429
Dec	18.52	12.68	16.42611	1.085229	0.795222	5.84	-0.07257

3.4 Trend analysis of Monthly Mean of Daily Mean Temperatures (Tmmean)

The trends of monthly mean values of daily mean temperature over different years were obtained using linear regression best fit lines. The linear regression trends for all the months from January to December are shown in **Figure 8(a) to Figure 8(l)** and the corresponding best fit equations along with coefficient of determination are summarized in (**Table 4**).

Table 4: Linear regression equation for all the months (Tmmean)

Month	Regression Line	R^2
Jan	y = 0.0155x - 15.428	R^2 = 0.0211
Feb	y = 0.0636x - 109.68	R^2 = 0.2142

Mar	y = 0.0202x - 20.593	R² = 0.0471
Apr	y = 0.0192x - 15.588	R² = 0.0345
May	y = 0.0333x - 40.298	R² = 0.1026
Jun	y = 0.0271x - 24.994	R² = 0.1835
Jul	y = 0.0308x - 32.506	R² = 0.1242
Aug	y = 0.0497x - 70.112	R² = 0.3909
Sep	y = 0.023x - 18.063	R² = 0.2099
Oct	y = 0.0248x - 26.006	R² = 0.1652
Nov	y = 0.0167x - 14.053	R² = 0.0491
Dec	y = -0.0007x + 17.731	R² = 4E-05

As shown in (Error! Reference source not found.),the monthly mean of daily mean temperature (Tmmean) have increased during the entire period with annual increase 0.0155°C, 0.0636°C, 0.0202°C, 0.0192°C, 0.0333°C, 0.0271°C, 0.0308°C, 0.0497°C, 0.023°C, 0.0248°C, 0.0167°C and -0.0007°C for January to December with major increases in February, August, May and July.

During the full period, the monthly mean of daily mean temperature (Tmmean) have increased with 0.558°C, 2.2896°C, 0.7272°C, 0.6912°C, 1.1988°C, 0.9756°C, 1.8088°C, 1.7892°C, 0.828°C, 0.8928°C, 0.6012°C inJanuary to November respectively while it decreases with-0.0252°C in December (**Figure 10**).

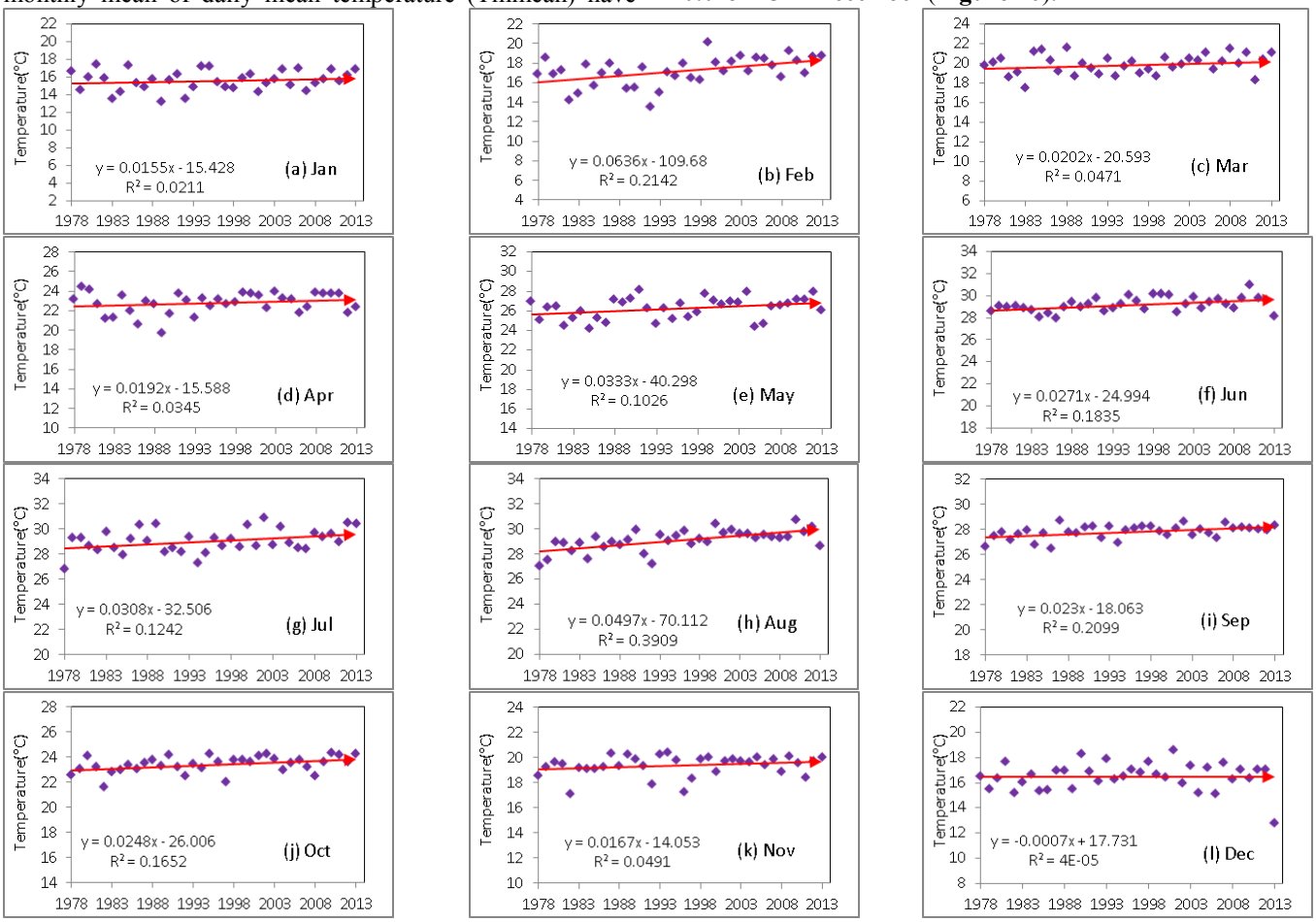

Figure 8: Linear regression trends of monthly mean of daily mean temperatures

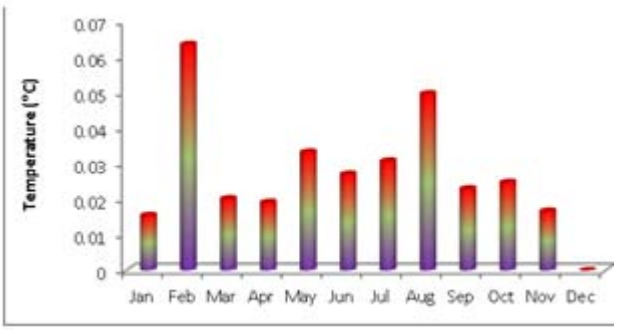

Figure 9: Tmmean Annual Increase

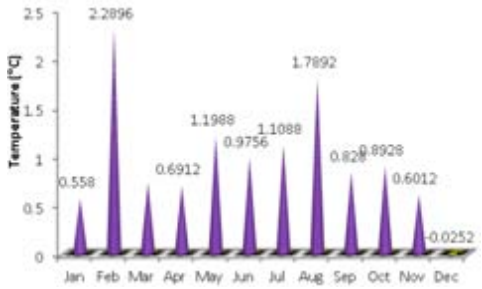

Figure 10: Tmmean total increase in the last 36 years

3.5 Trend analysis of Annual Mean of Daily Mean Temperatures (Tamean)

The annual mean of Tdmean is increasing by 0.0269°C per year. This implies that over the last 36 years the annual

mean temperature of Al-Taif has increased by 0.9684°C (Error! Reference source not found.).

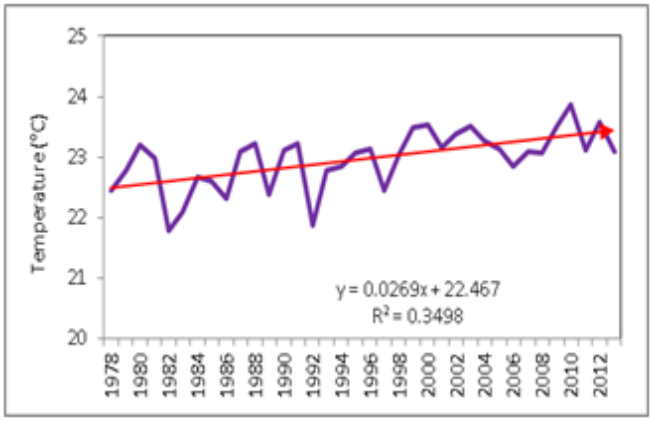

Figure11: Trend of annual mean of daily mean temperature (Tamean)

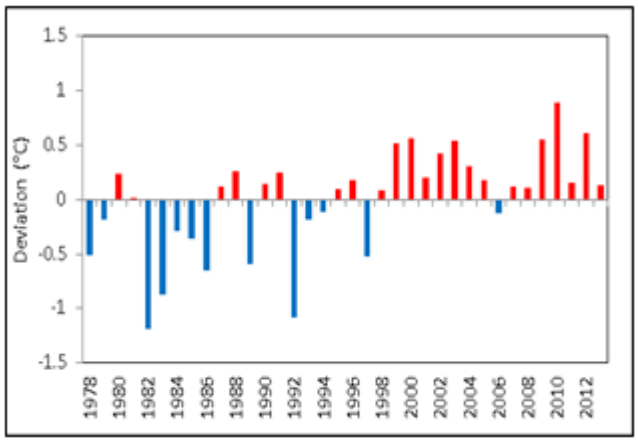

Figure 12: Trend of annual deviation from overall mean (Tamean)

As shown in (**Error! Reference source not found.**) the annual deviations of monthly mean temperature (Tmmean) from the overall mean temperature show major decreasing trends in the period (1978 to 1997) and major increasing trends in the period (1998 to 2013) which is consistent with both trends in Makkah [30], Al-Madinah Al-Munawarah [31] and Jeddah [32]

3.6 Variation of Daily Maximum Temperature (Tdmax)

The long term monthly mean (Tmmax) of the daily maximum temperature (Tdmax) was calculated for the period of study (**Error! Reference source not found.**) and show that the maximum of Tmmax was 37.59°C comparing to40.79°C in Jeddah [32], 45.42°C in Makkah [30]and 46.5°C inAl-Madinah Al-Munawarah [31]and found in July while a minimum of 18.15°Ccomparing to25.73°C in Jeddah [32], 27.43°C in Makkah [30] and 19.96°C in and Al-Madinah Al-Munawarah [31] and was found in December.

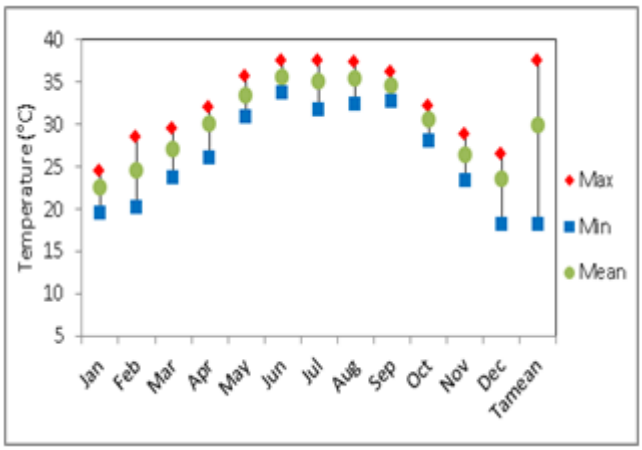

Figure 9: Variation of monthly mean, maximum and minimum temperature of Tdmax over Al-Taif

The monthly mean temperature (Tmmax), their corresponding standard deviations, mean deviations, range and COV are given in (**Table 5**). Higher mean values of COV and standard deviations are indications for stability.

Table 5: Statistical summary of monthly mean temperature of daily maximum values

Month	Max (°C)	Min (°C)	Mean (°C)	St.Dev (°C)	MeanDev. (°C)	Range (°C)	Cov. (%)
Jan	24.49	19.48	22.56028	1.340455	1.029722	5.01	4.821857
Feb	28.56	20.2	24.45306	1.855717	1.483056	8.36	11.49843
Mar	29.59	23.76	27.05889	1.295263	1.075667	5.83	6.980857
Apr	32.06	25.98	29.99611	1.386324	1.082667	6.08	5.397143
May	35.78	30.84	33.30667	1.226044	0.992	4.94	6.838
Jun	37.56	33.78	35.60194	0.997256	0.823278	3.78	5.311
Jul	37.59	31.75	35.10722	1.159898	0.899833	5.84	5.914857
Aug	37.35	32.38	35.36528	1.20677	0.978056	4.97	7.559571
Sep	36.21	32.66	34.57556	0.855237	0.701111	3.55	5.213429
Oct	32.2	27.99	30.54111	0.962526	0.787278	4.21	6.473143
Nov	28.82	23.36	26.4425	1.197787	0.955722	5.46	4.619571
Dec	26.59	18.15	23.59778	1.573531	1.131889	8.44	1.614571

3.7 Trend analysis of Monthly Mean of Daily Maximum Temperatures (Tmmax)

(**Figure 14(a) to Figure 14(l)**) show the linear regression trends of monthly mean of daily maximum temperature (Tmmax) from Jan. to Dec. demonstrated that Tmmax have increased in all months with annual increase of, 0.0434°C, 0.1036°C, 0.0629°C, 0.0486°C, 0.0616°C, 0.0478°C, 0.0533°C, 0.0681°C, 0.047°C, 0.0583°C, 0.0416°C and 0.0145°C for the months January to December Error! Reference source not found.**5**) respectively.

This implies that the monthly mean of daily maximum temperature have increased by 1.5624°C, 3.7296°C, 2.2644°C, 1.7496°C, 2.2176°C, 1.7208°C, 1.9188°C,

2.4516°C, 1.692°C, 2.0988°C, 1.4976°C and 0.522°C during the last 36 years (Error! Reference source not found.). The most significant increases were in August and February and less increase were in January and November. The corresponding best fit equation and the determination coefficient are mentioned in (**Table 6**).

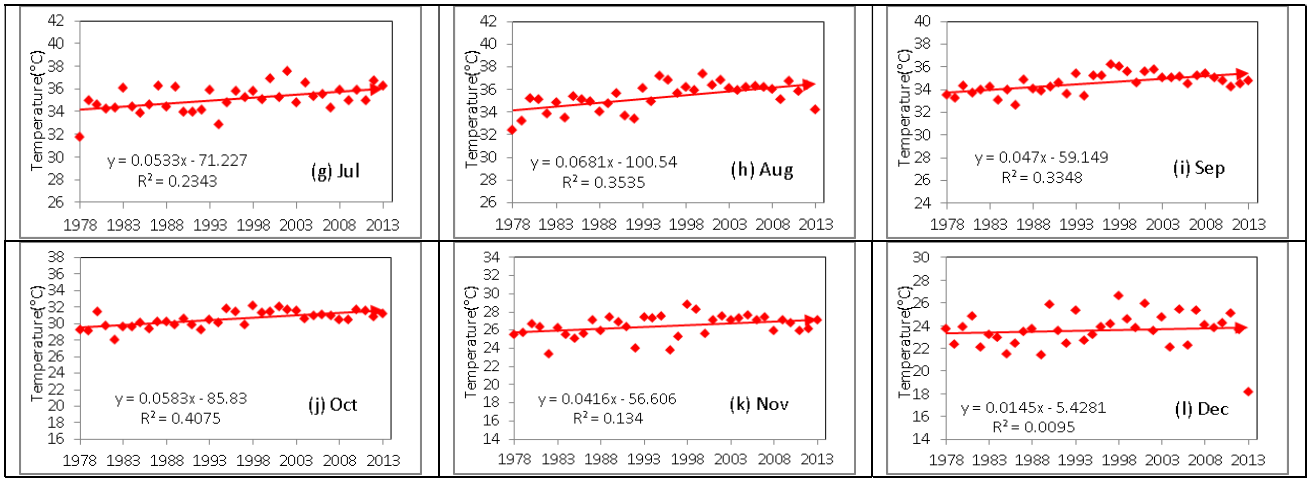

Figure10: Linear regression trends of monthly mean of daily maximum temperature

Table 6: Linear regression equation for all the months (Tmmax)

Month	Regression Line	R²
Jan	y = 0.0434x - 64.125	R² = 0.1166
Feb	y = 0.1036x - 182.26	R² = 0.3459
Mar	y = 0.0629x - 98.439	R² = 0.2617
Apr	y = 0.0486x - 67.031	R² = 0.1365
May	y = 0.0616x - 89.623	R² = 0.2802
Jun	y = 0.0478x - 59.876	R² = 0.2555
Jul	y = 0.0533x - 71.227	R² = 0.2343
Aug	y = 0.0681x - 100.54	R² = 0.3535
Sep	y = 0.047x - 59.149	R² = 0.3348
Oct	y = 0.0583x - 85.83	R² = 0.4075
Nov	y = 0.0416x - 56.606	R² = 0.134
Dec	y = 0.0145x - 5.4281	R² = 0.0095

Figure 12: Tmmax total increase in the last 36 years

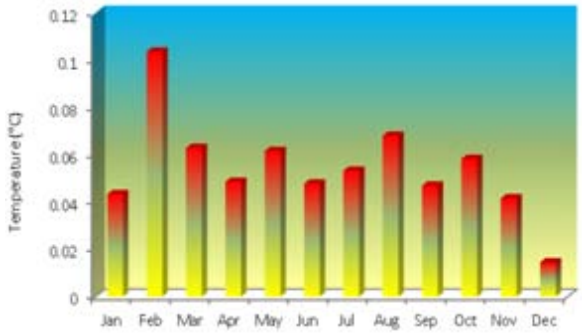

Figure 11: Annual increment in the mean of monthly mean of daily maximum temperature (Tmmax)

3.8 Trend analysis of Annual Mean of Daily Maximum Temperatures (Tamax)

The annual mean of daily maximum temperature (Tamax) show an annual increasing trend of 0.0542°C comparing to 0.0454°C of Almadinah Al-Munawarah [31], which implies that over the last 36 years the annual mean of daily maximum temperature of Al-Taif has increased by 1.9512°C (**Error! Reference source not found.**).

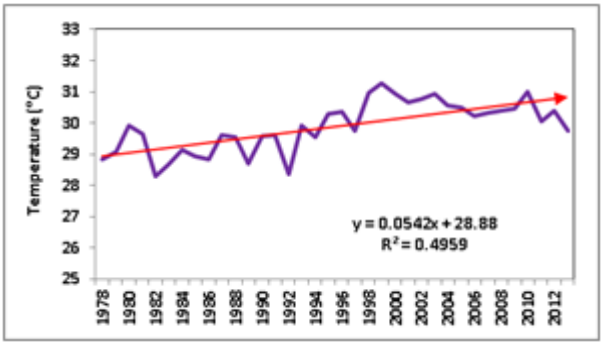

Figure 13: Trend of annual mean of daily mean temperature (Tamax)

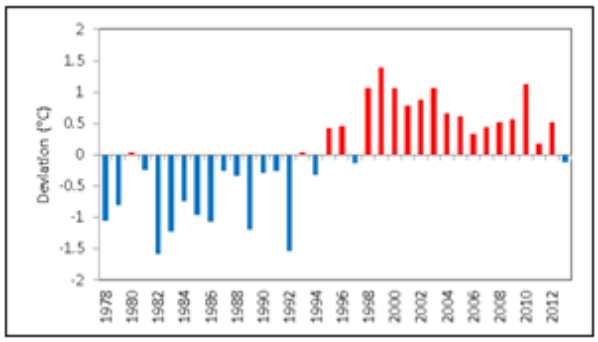

Figure 14: Trend of annual deviation from overall mean of Tdmax

The annual deviation from overall mean temperature show negative trends during the interval (1978 to 1997) and shows major positive trends in the period (1998 to 2013) (**Error! Reference source not found.**). The maximum cooling was found in the years 1982 and 1992with 1.55°C and 1.53°C below normal while the maximum warming was recorded in Table 7)

the year 1999 and 2010 with 1.389°C and 1.12°C respectively.

3.9 Variation of Daily Minimum Temperature (Tdmin)

(**Figure 19**) shows the long term monthly mean temperatures along with the monthly maximum and monthly minimum of daily minimum (Tmmin) during the study period. The Tmmin varied between a minimum of 5.63°C in January and a maximum of 25.45°C in July which means that the ratio between the hottest to the coldest Tmmin 4.52.

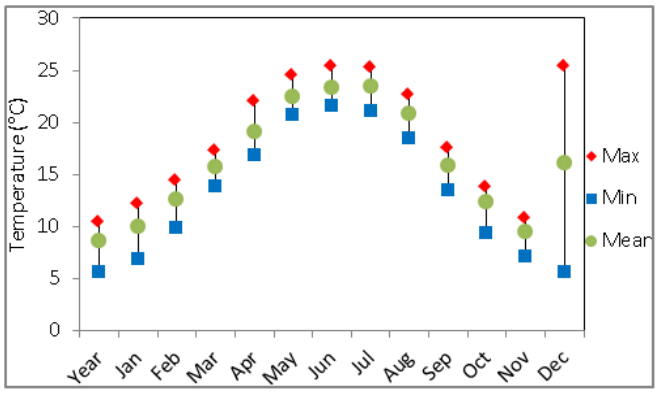

Figure 19: Variation of monthly mean, maximum and minimum temperature of daily minimum values

The monthly mean of daily minimum temperature (Tmmin), the corresponding standard deviations from overall mean, the mean deviation, the range, and the covariance (COV) are given in (

Table 7: Statistical summary of monthly mean temperature of daily minimum values

Month	Max (°C)	Min (°C)	Mean (°C)	St.Dev. (°C)	MeanDev. (°C)	Range (°C)	Cov. (%)
Jan	10.44	5.63	8.619444	1.202851	1.017889	4.81	-1.30343
Feb	12.21	6.92	10.00694	1.309861	1.099167	5.29	3.410714
Mar	14.49	9.84	12.60167	1.074607	0.835611	4.65	-2.62257
Apr	17.34	13.84	15.675	0.957388	0.7925	3.5	-0.01029
May	22.08	16.87	19.13389	1.017727	0.767167	5.21	-0.06114
Jun	24.59	20.68	22.43611	0.798217	0.616883	3.91	1.791429
Jul	25.45	21.52	23.35028	1.014291	0.810278	3.93	2.233857
Aug	25.33	21.05	23.46472	0.961051	0.704611	4.28	4.266429
Sep	22.7	18.52	20.79083	0.943626	0.750833	4.18	0.387857
Oct	17.59	13.52	15.85056	0.918247	0.765556	4.07	-0.344
Nov	13.87	9.41	12.29278	1.018973	0.780222	4.46	-0.50543
Dec	10.89	7.16	9.451389	0.893958	0.723056	3.73	-1.39243

3.10 Trend analysis of Monthly Mean of Daily Minimum Temperatures (Tmmin)

The linear regression trends of the monthly mean of daily minimum temperatures (Tmmin) from January to December are shown in (**Figure 20(a) to Figure 20(l)**) and the corresponding best fit equations in(**Table 8**). The increasing trends in the Tmmin values were observed in all months of the year (Error! Reference source not found.- Error! Reference source not found.) with an annual decrease of -**0.0117**°C, -**0.0236**°C, -**9.00E-05**°C, -**0.0006**°C, -**0.0031**°C, -**0.0046**°C and -**0.0125**°C for Jan., Mar., May, Oct., Nov. and Dec. and has increased with an annual value of **0.0307**°C, **0.0161**°C, **0.0201**°C and**0.0384**°C for Feb., Jun., Jul. and Sep. respectively.

This implies that the Tmmin has decreased during the last 36 years with -**0.4212**°C, -**0.8496**°C, -**0.0032**°C, -**0.0216**°C, -**0.1116**°C, -**0.1656**°C and -**0.45**°C for Jan., Mar., May, Oct.,

Nov. and Dec. and has increased with **1.1052**°C, **0.5796**°C, **0.7236**°C, **1.3824**°C and**0.126**°C for Feb., Jun., Jul. and Sep. during the last 36 years respectively(**Error! Reference source not found.**).

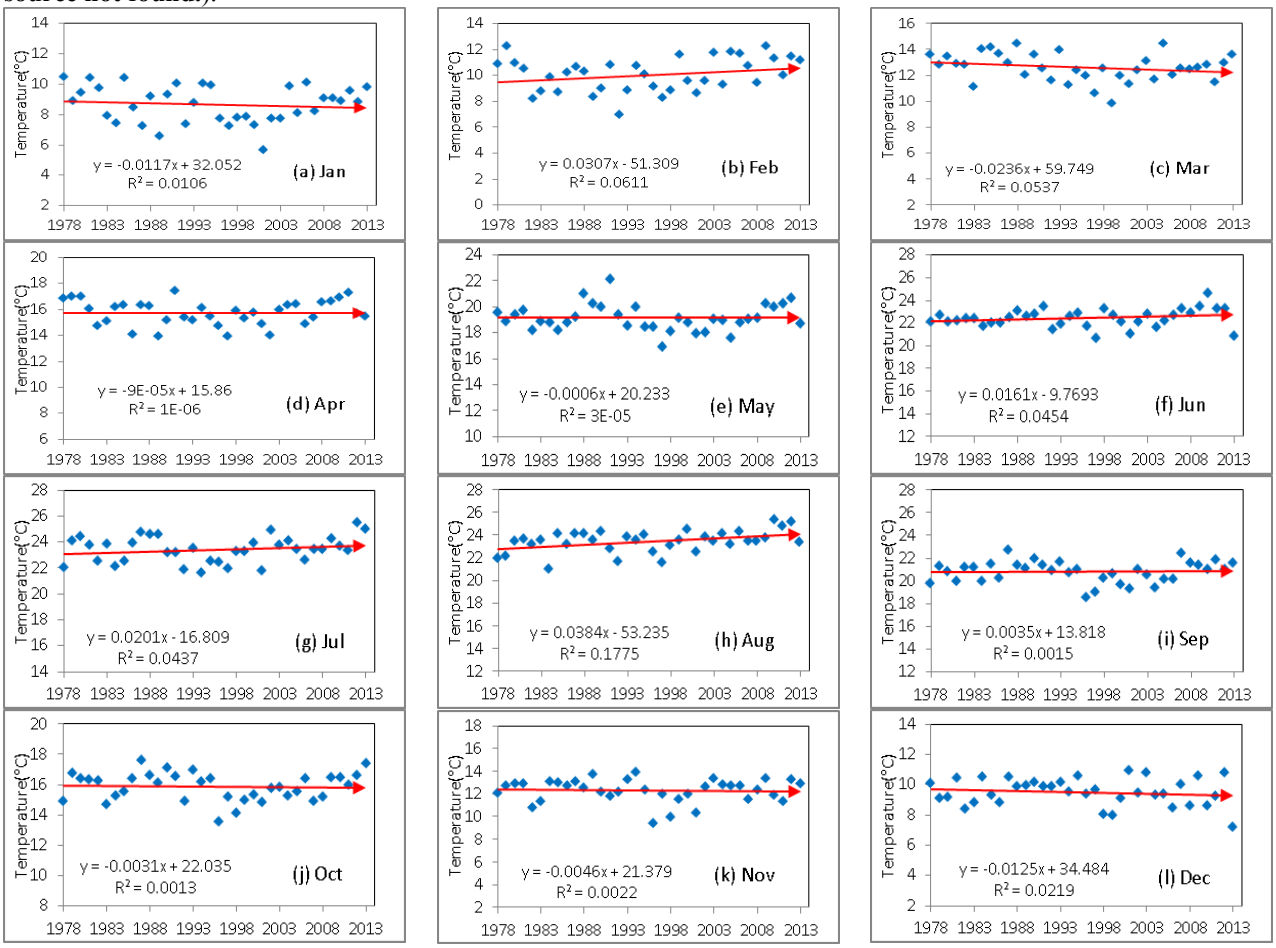

Figure150: Linear regression trends of monthly mean of daily minimum temperature

3.11 Trend analysis of Annual Mean of Daily Minimum Temperatures (Tamin)

The annual mean of daily minimum temperature(Tamin) showed significant increasing trend with an annual rise of 0.0044°C which implies that over the last 36 years the annual mean of daily minimum temperature of Al-Taif has increased by 0.1584°C (**Figure 23**).

(**Figure 24**) shows the annual deviations from overall mean of (Tamin) shownegative trends during the periods (1982-1984, 1986, 1989, 1992, 1996-2002 and 2004) andpositive trends in the periods (1978 to 1981, 1985, 1987-1988, 1990-1991, 1993-1995, 2003, and 2005- 2013). The full period could be classified into cold and hot cycles of hot positive and cold negative minor parts, 3, 1, 1, 1, 7, 1 years with major hot positive 4, 1, 2, 2, 3 , 1 , 8 years. This means that the overall trend is going to be positive.

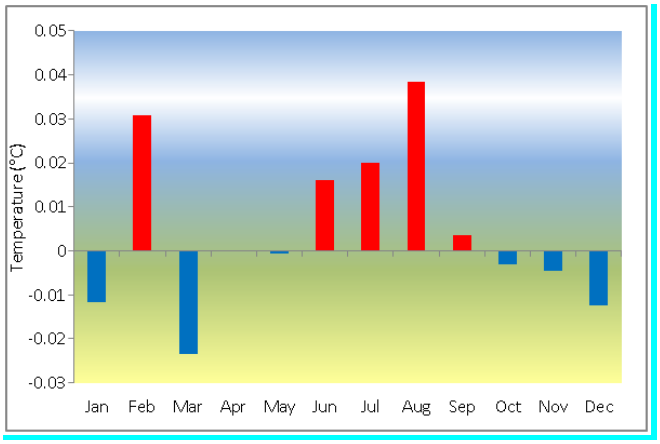

Figure 161: Annual increment in the monthly mean of daily minimum temperature (Tmmin)

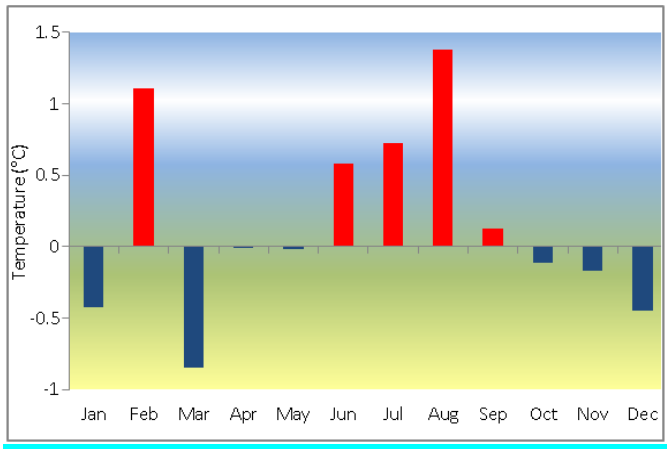

Figure22: Tmmin total increase in the last 36 years

Table 8: Linear regression equation for all the months (Tmmin)

Month	*Regression Line*	*R²*	*Month*	*Regression line*	*R²*
Jan	y = -0.0117x + 32.052	R² = 0.0106	Jul	y = 0.0201x - 16.809	R² = 0.0437
Feb	y = 0.0307x - 51.309	R² = 0.0611	Aug	y = 0.0384x - 53.235	R² = 0.1775
Mar	y = -0.0236x + 59.749	R² = 0.0537	Sep	y = 0.0035x + 13.818	R² = 0.0015
Apr	y = -9E-05x + 15.86	R² = 1E-06	Oct	y = -0.0031x + 22.035	R² = 0.0013
May	y = -0.0006x + 20.233	R² = 3E-05	Nov	y = -0.0046x + 21.379	R² = 0.0022
Jun	y = 0.0161x - 9.7693	R² = 0.0454	Dec	y = -0.0125x + 34.484	R² = 0.0219

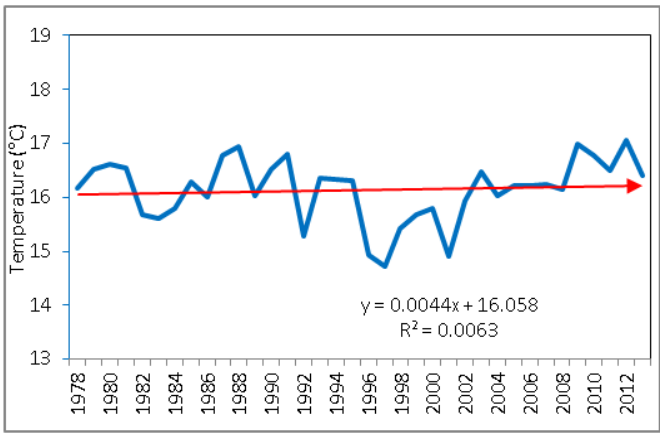

Figure 23: Trend of annual mean of daily minimum temperature (Tamin)

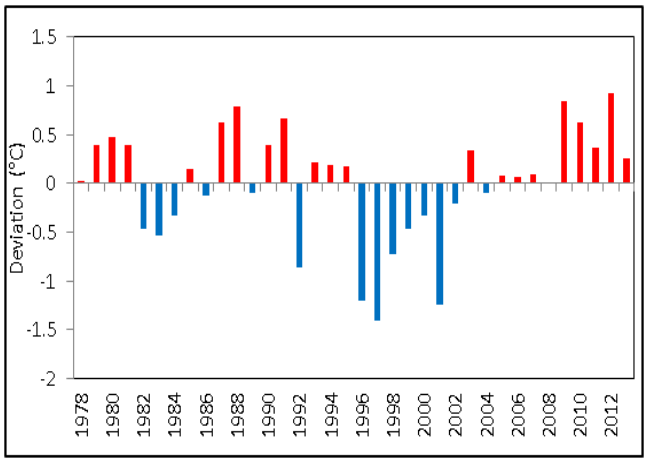

Figure 24: Trend of annual deviation from overall mean (Tamin)

3.12 Using the Theil-Sen nonparametric statistical approach

Using the Theil-Sen nonparametric statistical approach, the temporal trends of the observed daily minimum, maximum and mean temperature have been analyzed for the entire period (1978-2013) to determine the amount of changing over the time. The main advantage of using this method is that it tends to yield accurate confidence intervals even with non-normal data and heteroscedasticity (non-constant error variance). It is also resistant to outliers [45]. All trends expressed in (°C per year).

3.13 Annual Trend in Daily Mean Temperature (using Theil-Sen Method)

(Error! Reference source not found.) shows the annual trend in the daily mean temperature in Al-Taif, the solid redline shows the trend estimate and the dashed red lines show the 95 % confidence intervals for the trend based on resampling methods. The overall trend is shown at the top-left as 0.03°C per year and the 95 % confidence intervals in the slope from 0.02–0.03°C per year. The *** show that the trend is significant to the 0.001level. The significance level in this case is very high providing very strong evidence that the mean temperature increased over the period.

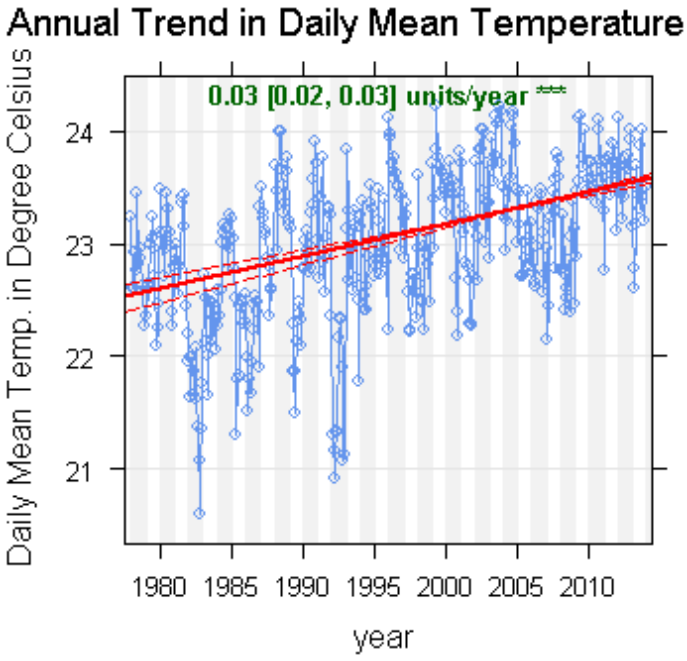

Figure 25: Annual Trend in daily mean temperature

(Error! Reference source not found.) Show four panels for the seasonal trend of the daily mean temperature. The solid red line shows the trend estimate and the dashed red lines show the 95 % confidence intervals for the trend based on resampling methods. The spring (MAM) season (top left panel) trend is 0.04°C per year and the 95 % confidence intervals in the slope from 0.03–0.06°C per year. The summer (JJA) season (top right panel) trend is 0.04°C per year and the 95 % confidence intervals in the slope from 0.03–0.06°C per year.

The autumn (SON) season (bottom left panel) trend is 0.04°C per year and the 95 % confidence intervals in the slope from 0.02–0.05 °C per year[30].

The winter (DJF) season (bottom right panel) trend is 0.03°C per year and the 95 % confidence intervals in the slope from 0.02–0.04°C per year. In all panels, the *** show that the trend is significant to the 0.001level. The significance level in this case is veryhigh providing very strong evidence that the mean temperature increased over the period.

3.14 Seasonal trend in daily mean temperature (using Theil-Sen Method)

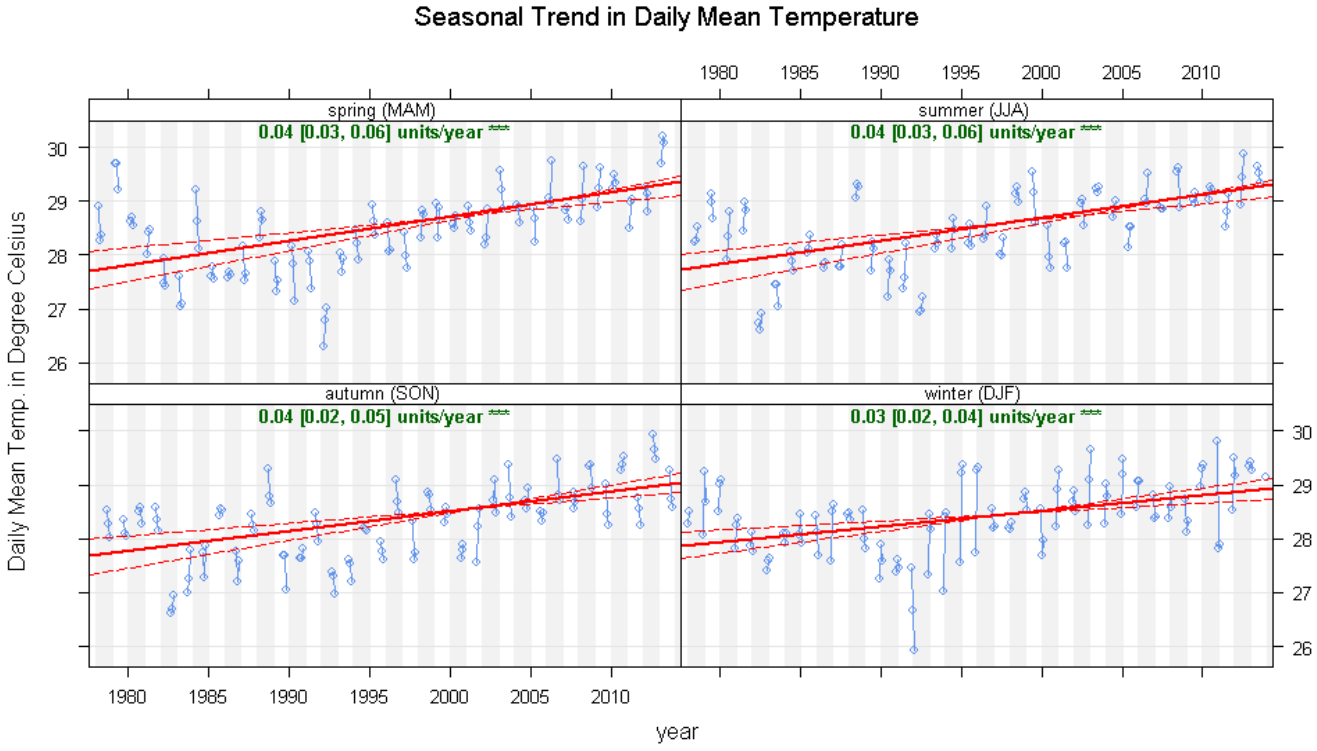

Figure 26: Seasonal Trend in daily mean temperature

3.15 Monthly trend in daily mean temperature

(**Error! Reference source not found.**) shows that the monthly trends increase in the daily mean temperature at Al-Taif with the values;
0.02°C, 0.01°C, 0.03°C, 0.03°C, 0.03°C, 0.03°C, 0.03°C, 0.03°C, 0.04°C, 0.03°C, 0.04°C, 0.04°C for Jan., Feb., Mar., Apr., May., Jun., Jul., Aug., Sep., Oct., Nov. and Dec. during the period 1978-2013 and the trend is:-

(i) Significant to the 0.001 level (***) providing very strong evidence that the mean temperature increased as in Apr., May, Sep., Oct., Nov. and Dec.,
(ii) Significant to the 0.01 level (**) providing strong evidence that the mean temperature increased as inMar. and Aug.
(iii) Significant to the 0.05 level (*) providing good evidence that the mean temperature increased as in Feb. and Jun.

(iv) Significant to the 0.1 level (+) providing fair evidence that the mean temperature increased as in Feb.

So, it is clear that the mean temperature increased during the whole months of the year.

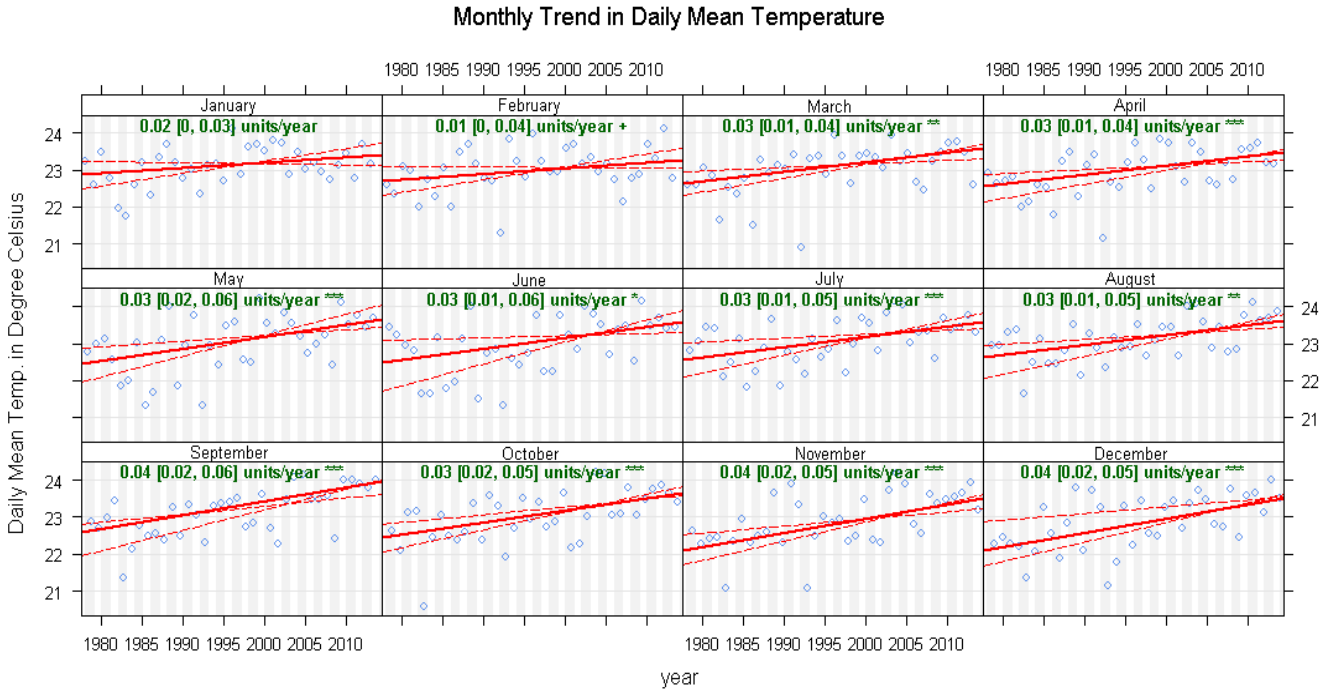

Figure 27: Monthly Trend in daily mean temperature

3.16 Annual trend in daily maximum temperature (using Theil-Sen Method)

(**Figure 28**) shows the annual trend in the daily maximum temperature. The solid red line shows the trend estimate and the dashed red lines show the 95 % confidence intervals for the trend based on resampling methods. The overall trend is shown at the top-left corner as 0.06°C per year and the 95 % confidence intervals in the slope from 0.05–0.06°C per year. The *** show that the trend is significant to the 0.001 level. The significance level in this case is very high providing very strong evidence that the mean temperature increased over the period.

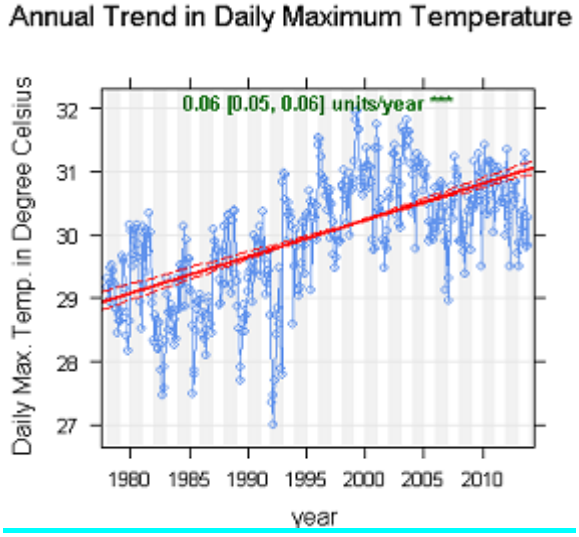

Figure 28: Annual Trend in daily maximum temperature

3.17 Seasonal trend in daily maximum temperature using Theil-Sen Method

(Error! Reference source not found.) shows four panels for the seasonal trend in the daily maximum temperature as follows: 0.06°C, 0.06°C, 0.07°Cand 0.05°C per year for the spring (MAM) season in top left panel, the summer (JJA) season in top right panel, the autumn (SON) season in bottom left panel and the winter (DJF) season in bottomright panel, respectively. All panels show that the trend level is significant to the 0.001 level (***) which providing very strong evidence that the mean temperature increased over the period.

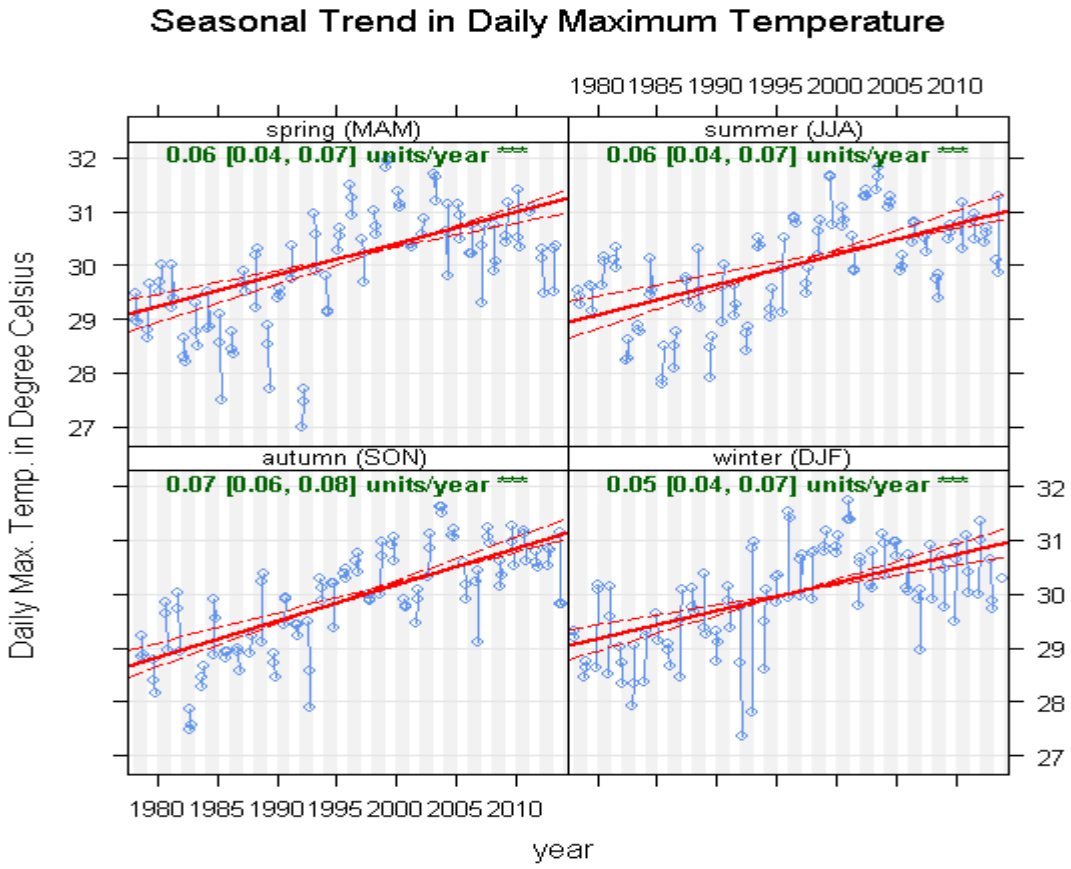

Figure 29: Seasonal trend in daily maximum temperature

3.18 Monthly trend in daily maximum temperature using Theil-Sen Method

(**Figure 30**) shows that the monthly trends increase in the daily mean temperature with the values 0.05°C, 0.04°C, 0.06°C, 0.05°C, 0.06°C, 0.05°C, 0.05°C, 0.06°C, 0.07°C, 0.07°C, 0.07°C and 0.06°C for Jan. to Dec. respectively during the period 1978-2013 and the trend is significant to the 0.001 level (***) providing very strong evidence for increasing the maximum temperature in the months Jan. to Jul. and Sep. to Dec. and Dec. and significant to the 0.01 level (**) providing strong evidence for increasing the maximum temperature inAug. This resultconfirms the increasing trend obtained from regression in (**Figure** 13).

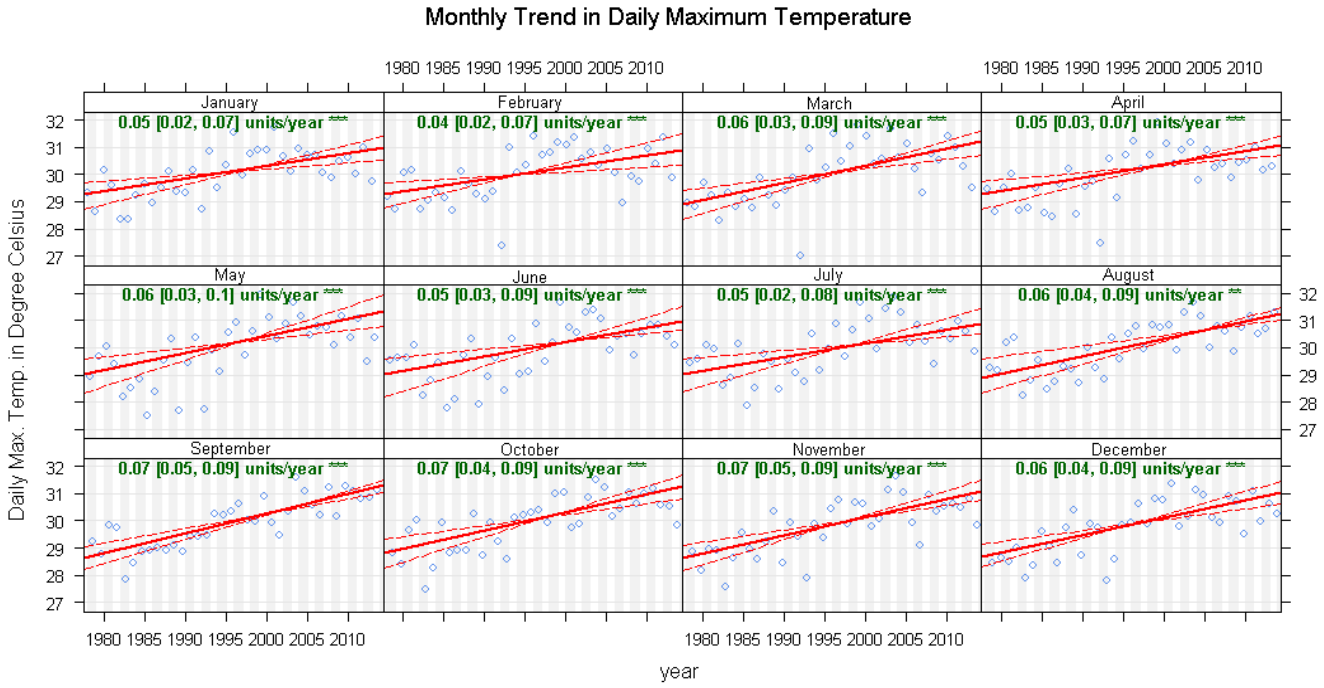

Figure 30: Monthly trend in daily maximum temperature

3.19 Annual trend in daily minimum temperature using Theil-Sen Method

The annual trend in the daily minimum temperature at Al-Taif is shown in (Error! Reference source not found.). The solid red line shows the trend estimate and the dashed red lines show the 95 % confidence intervals for the trend based on resampling methods. The overall trend is shown at the top-center as 0.01°C per year and the 95 % confidence intervals in the slope from 0.0–0.02°C per year. This trend is Significant to the 0.05 level (*) providing good evidence that the mean temperature increased.

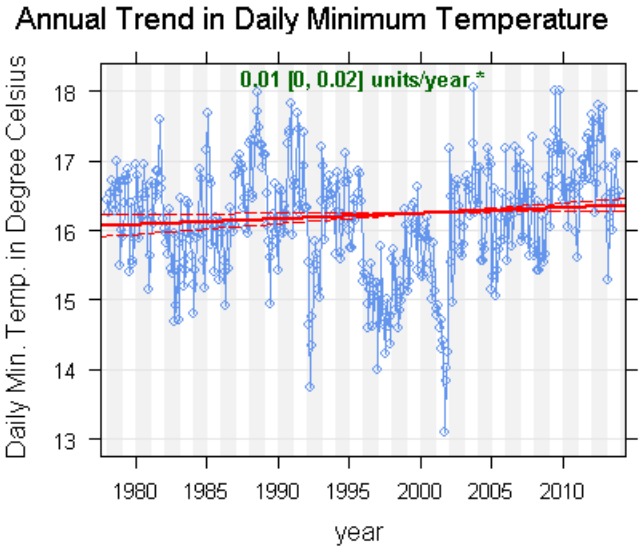

Figure 31: Annual trend in daily minimum temperature

3.20 Seasonal trend in daily minimum temperature using Theil-Sen Method

(Error! Reference source not found.) show four panels for the seasonal trend in the daily minimum temperature (Tdmin) have increased by 0.01°C, 0.02°C and 0.01°C per year for the summer (JJA) season (top right panel), the autumn (SON) season (bottom left panel) and for the winter (DJF) season (bottom right panel) respectively and 0°C in Spring season (MAM). The bottom right panel show that the trend level is significant to the 0.05 level (*) which providing an evidence that the mean temperature increased during the autumnseason while show slight increase evidence as in summer (JJA) and Winter (DJF)

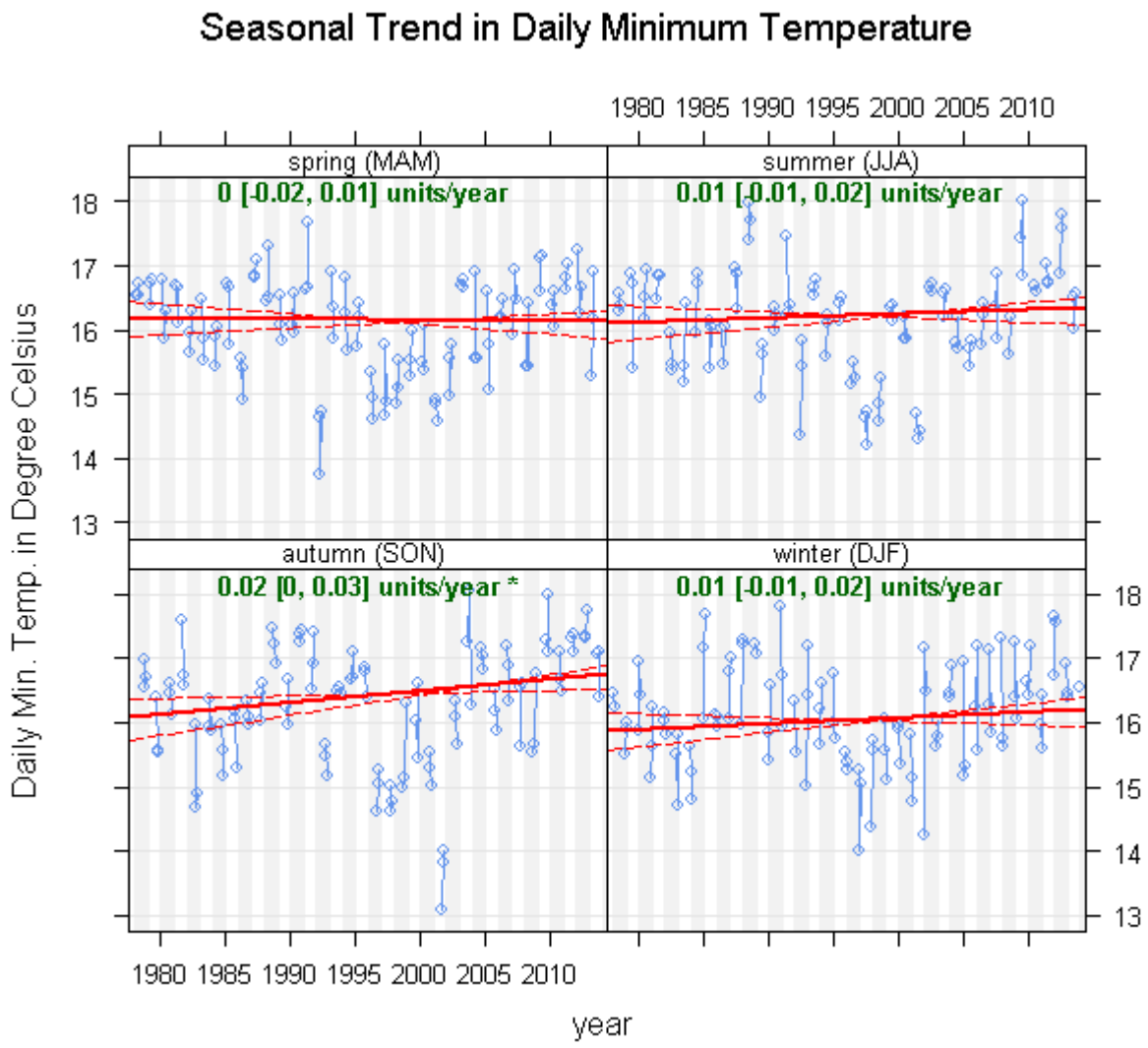

Figure 32: Seasonal trend in daily minimum temperature

3.21 Monthly trend in daily minimum temperature using Theil-Sen Method

The monthly trends in the daily minimum temperature at Al-Taif have increased with values; 0.01°C, 0.0°C, 0.0°C, 0.0°C, 0.0°C, 0.0°C, 0.01°C, 0.0°C, 0.01°C, 0.02°C, 0.02°C and 0.03°C for Jan. to Dec. respectively (Error! Reference source not found.).

The results show that the trend is:-

- Significant to the 0.05 level (*) providing good evidence that the mean temperature increased as in December.
- Indication of increase of the mean temperature as in Jan., Jul., Sep., Oct. and Nov.
- So, it is clear that most of the monthly mean of minimum temperature has increased during the year.

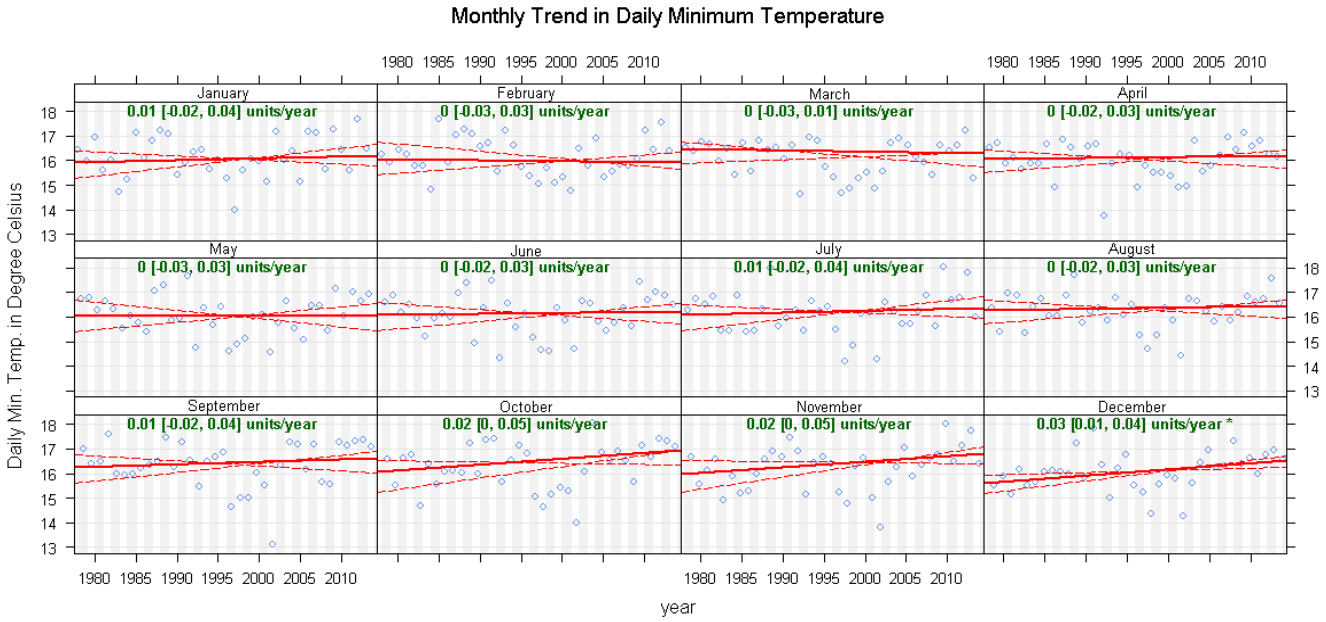

Figure 33: Monthly trend in daily minimum temperature

4. Results Summary

By analyzing the surface air temperature over Al-Taif city, the behaviour of the daily mean, minimum and maximum temperature during the last 36 years (1987-2013) yielded the following findings:-

- The number of hot days increased by 2.0088 days per year which means that there is 72.317 hot days increased during the last 36 years. The frequency of the hot nights increased by 0.3703 nights per year, this means that there are 13.3308 hot nights increased during the last 36 years. The number of cold nights increased by 0.0587 nights per year this implies that there is 2.113 nights has decreased during the entire period. The number of cold days decreased by -0.2241 day per year which implies that there is 8.064 cold days has decreased during the entire period.
- The highest and lowest values of Tdmax are 40.79°C in July 2011 and 31.96°C in February 1999.
- The highest and lowest values of Tdmin are 36.9°C in July 2013 and 25.73°C in January 1992.
- The monthly mean of daily mean temperature (Tmmean) have increased during the entire period with annual increase 0.0155°C, 0.0636°C, 0.0202°C, 0.0192°C, 0.0333°C, 0.0271°C, 0.0308°C, 0.0497°C, 0.023°C, 0.0248°C, 0.0167°C and -0.0007°C for January to December with major increases in February, August, May and July.
- The monthly mean of daily mean temperature (Tmmean) have increased with 0.558°C, 2.2896°C, 0.7272°C, 0.6912°C, 1.1988°C, 0.9756°C, 1.8088°C, 1.7892°C, 0.828°C, 0.8928°C, 0.6012°C in January to November respectively while it decreases with -0.0252°C in December during the full period.
- The annual mean of Tdmean is increasing by 0.0269°C per year which implies that over the last 36 years the annual mean temperature has increased by 0.9684°C.
- The annual deviations of monthly mean temperature (Tmmean) from the overall mean temperature show major decreasing trends (cooling) in the period (1978 to 1997) and major increasing (warming) trends in the period (1998 to 2013).
- The maximum of Tmmax was 37.59°C in July while a minimum of 18.15°C was found in December.
- Tmmax have increased in all months with annual increase of, 0.0434°C, 0.1036°C, 0.0629°C, 0.0486°C, 0.0616°C, 0.0478°C, 0.0533°C, 0.0681°C, 0.047°C, 0.0583°C, 0.0416°C and 0.0145°C for the months January to December. The higher increases were in August and February and less increase were in January and November.
- The annual mean of daily maximum temperature (Tamax) show an annual increasing trend of 0.0542°C which implies that over the last 36 years the annual mean of daily maximum temperature of Al-Taif has increased by 1.9512°C.
- The annual deviation of Tmmax from overall mean temperature show negative trends during the interval (1978 to 1997) and shows major positive trends in the period (1998 to 2013). The maximum cooling was found in the years 1982 and 1992 with 1.55°C and 1.53°C while the maximum warming was recorded in the year 1999 and 2010 with 1.389°C and 1.12°C respectively.
- The Tmmin varied between a minimum of 5.63°C in January and a maximum of 25.45°C in July which means that the ratio between the hottest to the coldest Tmmin 4.52.
- The increasing trends in the Tmmin values were observed in all months of the year with an annual decrease (cooling) of -0.0117°C, -0.0236°C, -9.00E-05°C, -0.0006°C, -0.0031°C, -0.0046°C and -0.0125°C for Jan., Mar., May, Oct., Nov. and Dec. and has increased (warming) with an annual value of 0.0307°C, 0.0161°C, 0.0201°C and 0.0384°C for Feb., Jun., Jul. and Sep. which implies that the Tmmin has decreased with the values of -0.4212°C, -0.8496°C,-0.0032°C, -0.0216°C, -0.1116°C, -0.1656°C and -0.45°C for Jan., Mar., May, Oct., Nov. and Dec. and has increased with

1.1052°C, 0.5796°C, 0.7236°C, 1.3824°C and 0.126°C for Feb., Jun., Jul. and Sep. during the last 36 years respectively.

- The annual mean of daily minimum temperature (Tamin) showed significant increasing trend with an annual rise of 0.0044°C which implies that over the last 36 years the annual mean of daily minimum temperature of Al-Taif has increased by 0.1584°C
- The annual deviations from overall mean of (Tamin) show negative trends (cooling) during the periods (1982-1984, 1986, 1989, 1992, 1996-2002 and 2004) and positive trends (warming) in the periods (1978 to 1981, 1985, 1987-1988, 1990-1991, 1993-1995, 2003, and 2005-2013).
- The increasing trend in the annual and the monthly mean of daily mean (Tdmean), daily maximum (Tdmax) and daily minimum (Tdmin) temperatures (Tmmin) determined by regression method have been confirmed by the nonparametric Theil-Sen method.

5. Conclusion

The analysis of the hot and cold days/nights based on temperature thresholds reveals that summers are expanding and winters are shrinking specially during the last decade in Al-Taif. The results indicate the vulnerability of the Al-Taif City with temperature increasing. The results would be helpful for the policy makers to reduce the future risks associated with rapidly changing climate of Al-Taif

6. Acknowledgments

Thanks are expressed to the Presidency of Meteorology and Environment in Saudi Arabia for providing the observation dataset. Also, the author would like to acknowledge Dr. Yasser Khalaf and Mr. Ali Al-Ahmary, PME for his cooperation and great help, the ICTP center for the scientific support during my association. The author greatly appreciates the contribution of the anonymous reviewers, as a result of which the manuscript has considerably improved.

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