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

Variation of Surface Temperature over AL-Madinah Al-Munawarah, Saudi Arabia, (1978 -2013)

Abdellatif Esawy A. Abdou, Turki M. Habeebullah

Environment and Health Researches Department, the Custodian of the Two Holy Mosques Institute for Hajj and Umrah Research, Umm Al-Qura University, Makkah, Saudi Arabia

Abstract: *The temperature variation and distribution over 36 year's period (1978 to 2013) in AL-Madinah Almunawarah, the second holiest city for all Muslims, have 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. The results showed that:*

- *The number of hot days and hot nights increased annually by 0.6216day and 0.6122 night, respectively, while the number of cold days and cold nights decreased annually by 0.1368 day and 0.5275 night. 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.*
- *The monthly mean of daily mean temperature (Tmmean) have increased annually with 0.0223℃, 0.0704℃, 0.0505℃, 0.0267℃, 0.0327℃, 0.0303℃, 0.0549℃, 0.0762℃, 0.0315℃, 0.0449℃, 0.0325℃ while the total increases during the entire period were 0.8028℃, 2.5344℃, 1.8252℃, 0.9612℃, 1.1772℃, 1.0908℃, 1.9764℃, 2.7432℃, 1.134℃, 1.6164℃, 1.17℃ and 1.1556℃ in January to December respectively*
- *The monthly mean of daily maximum temperature (Tmmax) have increased annually with 0.0243℃, 0.0768℃, 0.0679℃, 0.0332℃, 0.0366℃, 0.0296℃, 0.0476℃, 0.0817℃, 0.0312℃, 0.048℃, 0.0292℃ and 0.0382℃ while the total increases during the entire period are 0.8748℃, 2.7648℃, 2.444℃, 1.1952℃, 1.3176℃, 1.0656℃, 1.7136℃, 2.941℃, 1.1232℃, 1.728℃, 1.0512℃ and 1.3752℃ in January to December respectively.*
- *The monthly mean of daily minimum temperature (Tmmin) have increased annually with 0.0133℃, 0.0644℃, 0.0275℃, 0.0207℃, 0.0208℃, 0.0408℃, 0.0701℃, 0.0938℃, 0.0437℃, 0.0412℃, 0.0328℃ and 0.0265℃ while the total increases during the entire period are 0.4788℃, 2.3184℃, 0.99℃, 0.7452℃, 0.7488℃, 2.5236℃, 3.3768℃, 1.5732℃, 1.4832℃, 1.1808℃ and 0.954℃ in January to December respectively.*
- *The annual mean of daily mean temperature (Tamean), daily maximum temperature (Tamax) and daily minimum temperature (Tamin) have increased by 0.0421℃, 0.0454℃ and 0.0413℃ per year, and 1.5156℃, 1.6344℃, 1.4868℃ respectively during the full period*

Both Regression analysis and Theil-Sen test demonstrated positive trends in mean, minimum and maximum temperature levels. Trends are determined for various sub-annuals (months and seasons) and annual basis of the entire period and showed that AL-Madinah Almunawarah is suffering from a 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-Madinah Almunawarah, Saudi Arabia

1. Introduction

One of the largest challenges since couple of decades on all geographical scales and across all economic sectors is the climate change and climate variability[1]. The earth's surface temperature and sea surface temperature have been increasing since the mid-19th century[2] with manifestations in national and local scales[3],[4],[5]. Two periods of pronounced warming have occurred: 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 [6],[7].

A long-term temperature study on different scales [8], [9]showed that the rate of annual warming for global land areas over the 1901– 2000 period was 0.078°C per decade, Another study [10] showed that the surface temperature of the Earth increased by 0.6°C – 0.8°C during the 20th century.

The recent global trends in maximum temperature, minimum temperature, and the diurnal temperature range (DTR) have been studied [11] and demonstrated that the minimum and maximum temperature increased in almost all parts of the globe.

The lower Tropospheric air temperatures have increased by 0.13°C to 0.22°C per decade since 1979[12]. A positive trend in summer mean temperature, increase in temperature and the number of hot days at Belgrade have been concluded by [5]. 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 [13]

In a study on the climate extremes over Europe using 750 temperature sites cover the period 1960–2000 [14] showed that the European average trend in annual DTR was 0.09 °C decade−1. In a study over the west, south and south west of Iran [15], 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).
Over turkey, the mean annual temperature records have a warming trend over the 1939 to 1989 period [16] while the

Licensed Under Creative Commons Attribution CC BY

summer temperatures have increased during the last 3 decades of the 20th century over the south Mediterranean[17].

In a study over Jordan, a significant warming trend after the years 1957 and 1967 for the minimum and maximum temperatures have been detected[18] and over Kuwait, the maximum yearly temperature is persistently exceeding its mean value during the last two decades[19]. Another study over Kuwait[20], showed that there is a statistically significant temperature increase of 0.07°C/decade over Kuwait during the period 1950-1990.

A study of the annual mean temperature in the Korean Peninsula 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[21]

Utilizing the minimum and maximum daily temperature from 49 meteorological stations during the period from 1961 to 2004 to study the annual series of mean temperature anomalies over Italy[22] 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 whole period

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[23]

Chaouche et al. [24] 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. [25] 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) [26]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/year.

Another study showed that 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].

Also, 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 Jeddah, 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].

Recent study for 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.

A study of the temperature data on 19 meteorological stations distributed through the Saudi Arabia [31] during the period of 1978–2013 demonstrated that there is a negative temperature trend (cooling) with 0.03 °C/year for all stations during the first period (1978–1997) followed by a positive trend(warming) 0.06°C/year in the second period (1998–2013) with reference to the entire period of analysis.

The main aim of this study is to contribute to the knowledge of the behavior of mean, maximum and minimum temperatures occurring over AL-Madinah Almunawarah, Saudi Arabia, over the period (1978 to 2013) on a monthly, seasonal and annual timescale. Since the extreme temperatures can affect many areas of the society. It raises the power demand for air conditioning, increase water consumptions, and create dangerous conditions for human health in terms of protection from heat waves [32], [33]. So this study may help the decision makers to put the right policy to avoid any medical dangerous or shortages or scarcity of energy. The temperature issue in Al-Madinah Al-Munawarah has special importance since several millions of people of more than80 different nationalities come to Al-visit it annually and increased drastically year by year.

2. Site Description, Data and Methodology

Al-Madinah Al-Munawarah is the capital the Al-Madinah Province and located in the Hejaz region of western part of Saudi Arabia. It is the second holiest city of Islam and the burial place of the Prophet Muhammad, Peace Be upon Him (PBUH), and historically significant city for being the home of the prophet after the Hijrah (the prophet emigration from Makkah to Al-Madinah Al-Munawarah). Also, it comprises the second Holy Mosque (Al-Masjid Al-Nabawy). All Muslims, visit it during their hajj and Umrah performance

AL-Madinah Almunawarah is the second very famous Islamic holy city, located around 470 km away from Makkah Al-Mukarramah, 150km to the east of the Red Sea, the first holy Islamic city, and the capital of AL-Madinah Almunawarah Province **Figure 1.**

Licensed Under Creative Commons Attribution CC BY

Figure 1: Location of Al-Madinah Al-Munawarah on Saudi Arabia Map

AL-Madinah Al-Munawarah located on the country's west side, along the Red Sea coast. (Latitude: 24.55 degree North, longitude: 39.7 degree East) and has an area of 589 km² among 151,990km² of Al-Madinah Provence, and the city's population is 1,100,093 people among 1,962,600 population of the full region[34]

In the modern times, AL-Madinah Almunawarah has seen tremendous expansion in size and infrastructure, since more than 10 million Muslims visit AL-Madinah Almunawarah annually, including several millions during the Hajj period. As a result of that, AL-Madinah Almunawarah has become one of the most cosmopolitan and diverse cities in the Muslim world. The study incorporates daily mean, daily maximum and daily minimum values of temperature in the current analysis. **Figure 1** shows the geographical location of Al-Madinah Al-Munawarah city on the map of Saudi Arabia.

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.

2.1 Quality of the dataset

Before utilizing the data, it has been gone under several quality control checks (QC) to detect and remove or reduce errors, loss, 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 [36].

Following [36], [37] and [38], the applied QC procedures were:-

Check of plausibility: to reject those values which never can exist; for example; the negative values of temperature in Al-Madinah Al-Munawarah; 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 **Figure 2 to Figure 4**. In these figures, the x-axis represents the temperature (°C) and the y-axis represents the frequency.

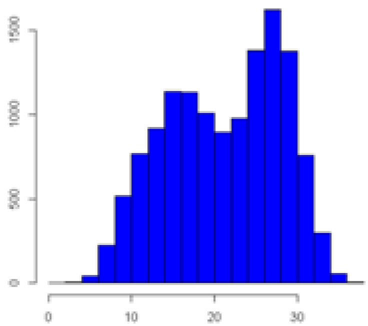

Figure 2: Histogram of the Daily Minimum Temperature (°C)

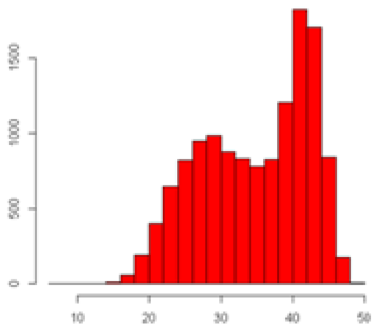

Figure 3: Histogram of the Daily Maximum Temperature (°C)

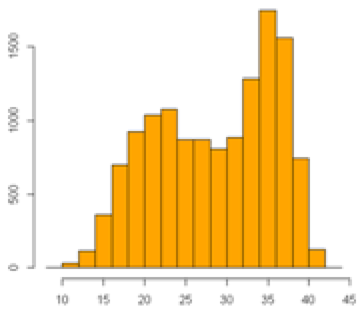

Figure 4: Histogram of the Daily Mean Temperature (°C)

Figure 2 to Figure 4 Represent 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. The bimodality is due to the fact that Tdmin, Tdmax and Tdmean dataset are heterogeneous.

Figure 2 shows that the probability of finding minimum temperatures less than 5°C is very low and most of minimum temperatures lie between 12 °C and 30 °C. Also the probability of finding minimum temperatures more than 35 °C is also low.

Figure 3 shows that the probability of finding maximum temperatures less than 17°C is very low and most of maximum temperatures lie between 27°C and 45°C and there is a probability of finding maximum temperatures greater than 45°C.

Figure 4 shows that the probability of finding mean temperatures less than 12°C is very low and most of mean temperatures lie between 17°C and 37°C. Also there is a probability of finding mean temperatures greater than 38°C.

Licensed Under Creative Commons Attribution CC BY

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[39], [40] statistical approach which is commonly used for trend quantification [41]. 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].

Figure 5 shows the daily minimum (blue), the daily maximum (red) and the daily mean (yellow) temperatures and demonstrated that daily maximum temperatures range between 6.5°C and 48.4°C, the daily minimum temperatures range between 1.8°C and 37°C and the daily mean temperatures range between 9.4°C and 41.9°C

Table 1 show that the daily maximum temperature has increased by 0.0002°C/day and the daily minimum temperature has increased by 0.0001°C/day, while the daily mean temperature has increased by 0.0001°C/day during the whole period (1978-2013).

The number of hot and cold nights and days were estimated using daily maximum and minimum temperatures recorded during different year. Days are considered hot if the maximum daily temperature exceed 35°C (Tdmax≥ 35°C), nights are defined hot when daily min temperature reaches 20°C (Tdmin ≥ 20°C), the days are defined as cold when Tdmax ≤20°C and finally nights are classified as cold when Tdmin ≤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.

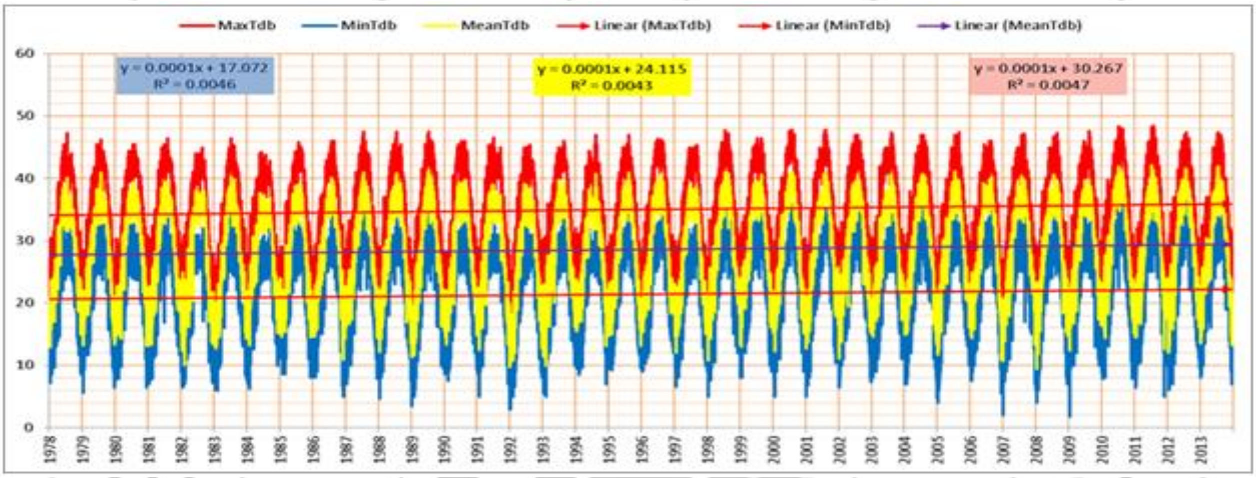

Figure 5: Daily maximum, minimum and mean Temperatures during the period (1978-2013) over Al-Madinah Al-Munawarah

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

Temperature (°C)	Regression line	R^2
Daily maximum (Tdmax)	y = 0.0001x + 30.267	0.0047
Daily minimum (Tdmin)	y = 0.0001x + 17.072	0.0046
Daily mean (Tdmean)	y = 0.0001x + 24.115	0.0043

3. Results and Discussion

The data of daily maximum (Tdmax), daily mean (Tdmean) and daily minimum (Tdmin) levels of temperature, monthly mean of maximum (Tmmax), monthly mean of daily mean (Tmmean) and monthly mean of minimum (Tmmin) values of temperatures and 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

The overall variations of maximum, mean and minimum levels of daily maximum, mean and minimum temperature during 1978-2013 are summarized, **Table 2.**

.

The maximum, mean and minimum of daily maximum temperature (Tdmax) were 48.4°C, 35.01°C and 14°C, respectively with standard deviation of 7.52°C. Similarly the maximum, mean and minimum of daily mean temperature (Tdmean) were 41.9°C, 28.51 °C and 9.4°C with standard deviation of 7.92°C and daily minimum temperature (Tdmin) varied between 37°C and 1.8°C while the overall mean was 21.39°C with standard deviation of 6.93°C as given in **Table 2**..

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

Label	*Max(°C)*	*Min(°C)*	*Mean(°C)*	*Std. Dev. (°C)*
Tdmax	48.5	14	35.01	7.52
Tdmean	41.9	9.4	28.51	7.92
Tdmin	37	1.8	21.39	6.93

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

Licensed Under Creative Commons Attribution CC BY

nights (Tdmin ≤15°C) during the period of study (1978-2013) were calculated and depicted in **Figure 6.** 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 the frequency of the hot nights and the hot days increased by 0.6122 nights and 0.6261 days each year respectively, The number of cold nights and cold days showed negative trends and the regression lines of best fit show that the frequency of the cold nights decreased by 0.5275 nights and 0.1368 days per year.

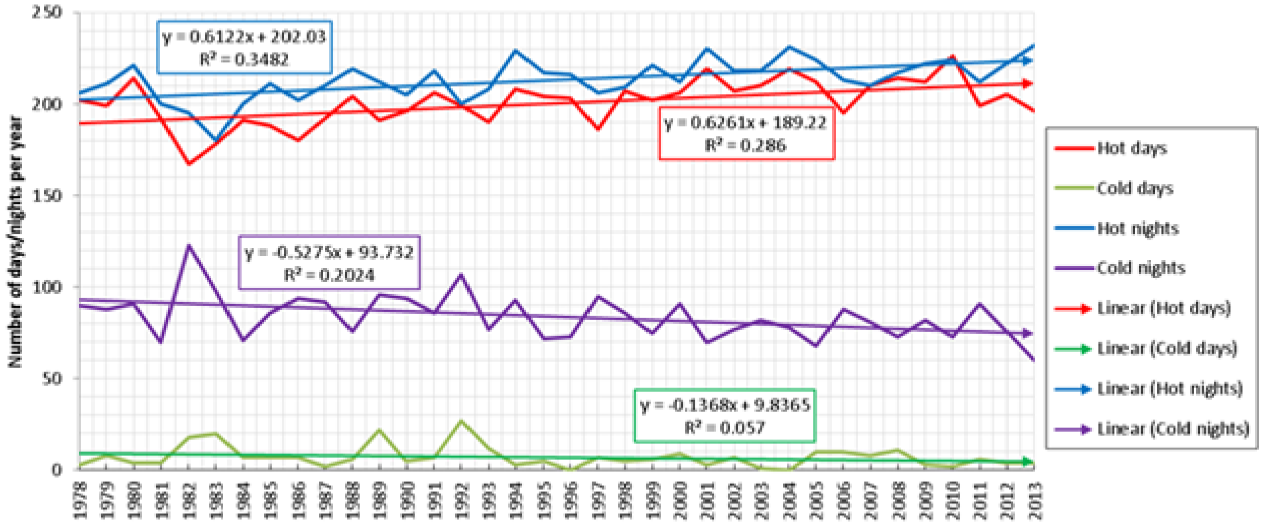

Figure 6: Annual frequency of hot days and nights and cold days and nights

3.3 Daily Mean Temperature (Tdmean) Variation

The long term monthly mean temperature (Tmmean) is calculated using the Tdmean of the entire period and the minimum, maximum and mean values has been depicted in **Figure 7**. As shown, The minimum, maximum and mean of (Tmmean) mean values recorded 18.014°C and 36.78°C in January, August, while the minimum, maximum and mean of (Tmmin) minimum values recorded 13.9°C and 35.02°C in January, June respectively. The minimum, maximum and mean of (Tmmean) maximum recorded 20.52°C, and 39.54°C also in January, August.

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 **Table 3.** From this table, it is clear that the higher values of covariance correspond to higher standard deviations (SD) and smaller values of covariance to smaller standard deviations.

Higher values of COV and SD were observed for the winter months. The COV varied between 2.47 % and 8.45% corresponding to January and August during the year. This shows that the temperature is most stable in August and least in January.

Table 3: Statistical summary of Tmmean

Mon.	*Mean (℃)*	*Std. Dev (℃)*	*Mean Dev. (℃)*	*Range (℃)*	*COV. (%)*
Jan	18.01417	1.352776	0.980167	6.62	2.477286
Feb	20.30639	1.926061	1.537722	8.68	7.817
Mar	23.84417	1.386188	1.071278	5.56	5.623571
Apr	28.4675	1.165954	0.961778	4.22	2.961857
May	32.97833	1.203631	0.992889	4.47	3.625714
Jun	36.23833	0.644114	0.521667	2.76	3.364571
Jul	36.52667	1.213978	0.989333	4.57	6.089714
Aug	36.78139	1.268077	0.975222	5.79	8.453
Sep	35.35194	0.80283	0.629611	3.26	3.495571
Oct	30.235	0.76700	0.617222	3.24	4.988286
Nov	23.96667	1.183267	1.470078	5.24	3.610286
Dec	19.62528	1.470078	1.156944	5.89	3.568143

Licensed Under Creative Commons Attribution CC BY

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-i)** 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)

Mon.	*Regression line*	*R^2*	*Mon.*	*Regression line*	*R^2*
Jan	y = 0.0223x – 26.52	0.0302	**Jul**	y = 0.0549x –77.25	0.175
Feb	y = 0.0704x - 120.2	0.1484	**Aug**	y = 0.0762x –115.2	0.399
Mar	y = 0.0507x - 77.25	0.1483	**Sep**	y = 0.0315x –27.49	0.179
Apr	y = 0.0267x –24.77	0.0581	**Oct**	y = 0.0449x – 59.44	0.292
May	y = 0.0327x– 32.20	0.0817	**Nov**	y = 0.0325x –40.93	0.083
Jun	y = 0.0303x –24.24	0.2454	**Dec**	y = 0.0321x –44.52	0.053

The monthly mean of daily mean temperature (Tmmean) have increased during the entire period **Figure 9** the recorded increases were, 0.0223, 0.0704, 0.0505, 0.0267,

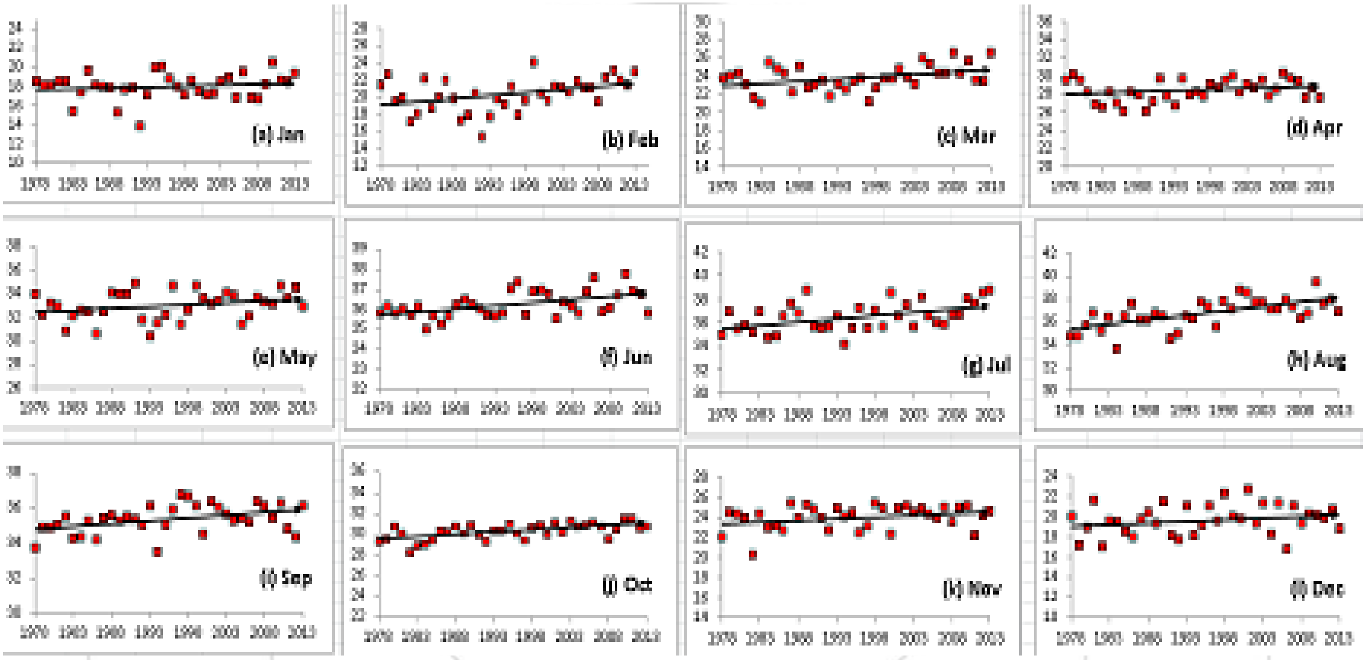

Figure 8: Linear regression trends of monthly mean of daily mean temperatures

0.0327, 0.0303, 0.0549, 0.0762, 0.0315, 0.0449, 0.0325 and0.0321in January to December respectively with major increases in August, February and July. The monthly total increases in the entire period were 0.8028, 2.5344, 1.8252, 0.9612, 1.1772, 1.0908, 1.9764, 2.7432, 1.134, 1.6164, 1.17 and 1.1556in January to December respectively **Figure 9**.

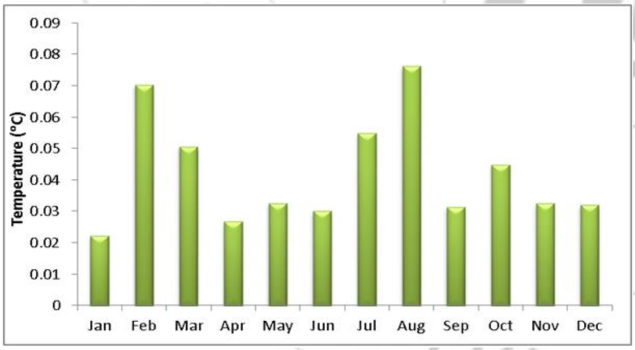

Figure 9: Tmmean Annual Increase

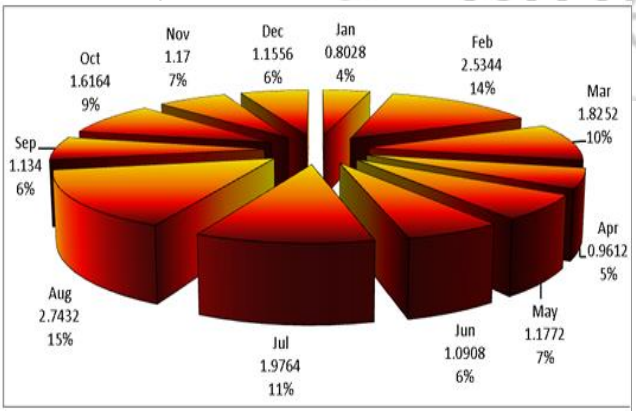

Figure 10: Tmmean total increase in the last 36 years

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

The annual mean of Tdmean is increasing by 0.0421°C per year. This implies that over the last 36 years the annual mean temperature of Al-Madinah Al-Munawarah has increased by 1.1516°C as shown in **Figure 11**.

Figure 12 shows that the annual deviations from overall mean temperature show major decreasing trends during the period (1978 to 1997) and major increasing trends during the period (1998 to 2013).

Licensed Under Creative Commons Attribution CC BY

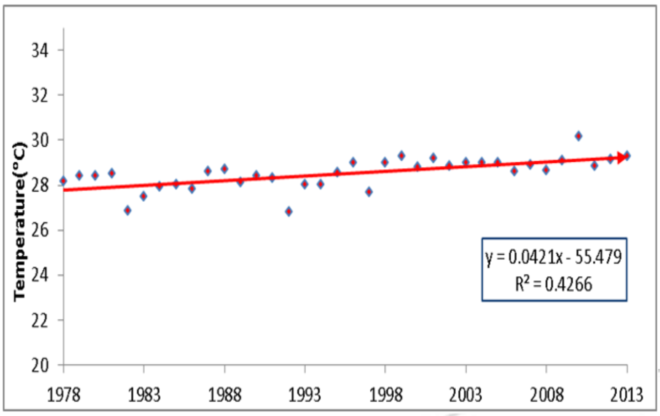

Figure 11: Trend of annual mean of daily mean temperature (Tamean)

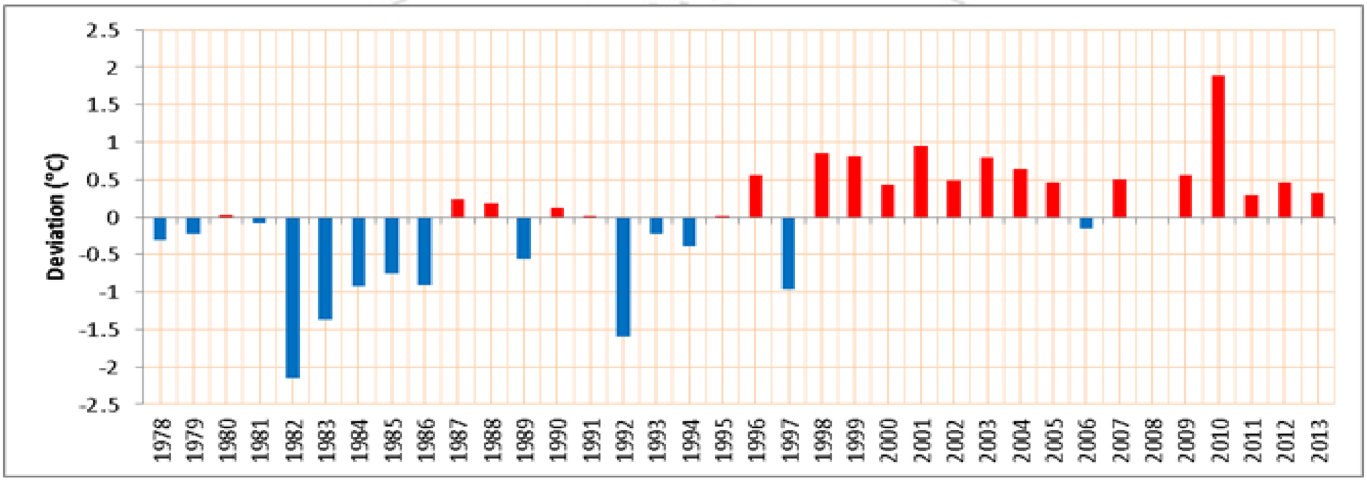

Figure 12: Trend of annual deviation from overall mean (Tamean)

3.6 Variation of Daily Maximum Temperature (Tdmax)

The long term monthly mean (Tmmax) of the daily maximum temperatures (Tdmax) were calculated during the period of study, **Figure 12**, and show that the maximum of Tmmax of 46.5°C was found in August while a minimum of 19.96°C in January.

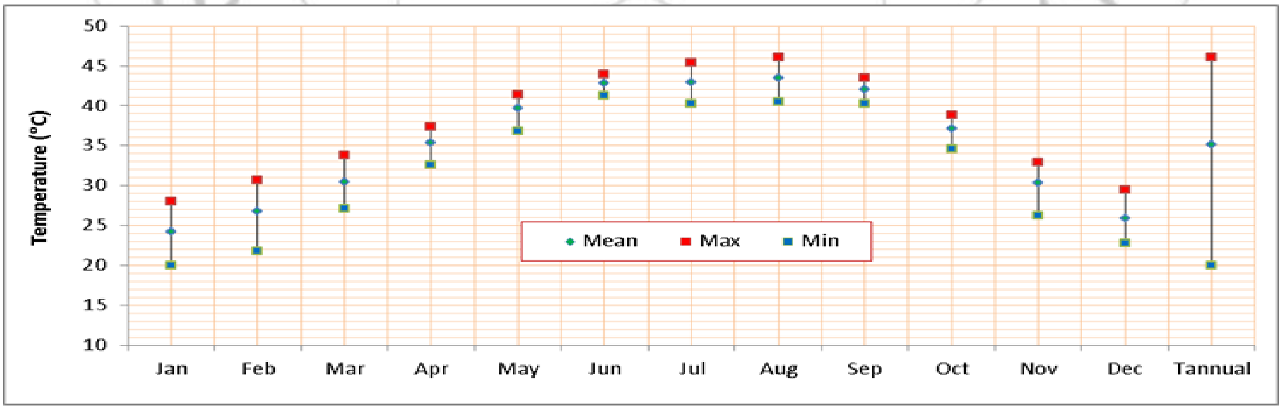

Figure 13: Variation of monthly mean, maximum and minimum temperature of daily maximum values

Figure 14 shows the daily maximum temperatures which exceed 44°C which affect the Humidex value and hence the human activities and health[42]. The best fit regression line shows an increase of 0.0146 day per year for the temperature that exceeds 44°C per year. It is well known that the extreme heat is well connected to the cause of Heat Stroke, Sun Stroke, Heat Syncope, Heat Cramps, Cardiovascular Diseases, Epilepsy, Diabetes, Breathing Disorders, Dehydration, Sunburn, Blisters, Syncope, Viral Infection, Bacterial Infections, Gastrointestinal Diseases, Respiratory Diseases, Falls-Sprains/Strains, Cuts and Abrasions, Burns, Crush Injuries, Bone Fractures[43] and exacerbates many pre-existing health conditions. The extreme heat specially with increasing humidity conditions are more stressful to human health more than isolated hot days [44, 45].

Licensed Under Creative Commons Attribution CC BY

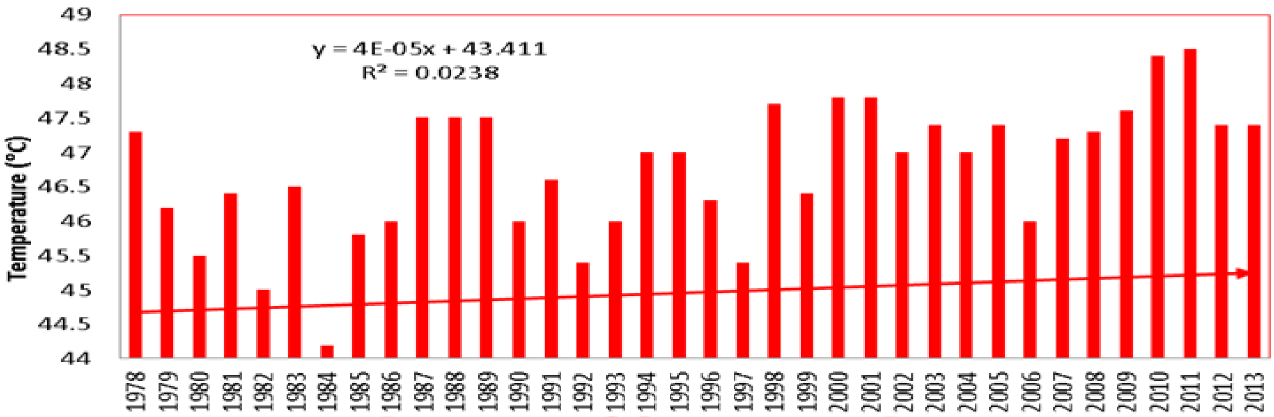

Figure 14: Daily Maximum Temperature greater the 44°C

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 were observed for winter months (January, February and December). This indicated that the temperature in the other months is relatively more stable.

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

Mon.	Mean (°C)	Std. Dev. (°C)	Mean Dev. (°C)	Range (°C)	COV. (%)
Jan	24.15889	1.541505	1.107283	8.07	2.699429
Feb	26.70056	2.067412	1.645556	8.84	8.519429
Mar	30.34306	1.588805	1.213389	6.69	7.540429
Apr	35.24389	1.320018	1.068889	4.75	3.680286
May	39.55528	1.257761	1.065278	4.6	4.067857
Jun	42.74444	0.689349	0.545778	2.66	3.289429
Jul	42.88306	1.19903	0.9925	5.13	5.288143
Aug	43.3425	1.361613	1.043611	5.61	9.063571
Sep	41.98889	0.775878	0.611778	3.22	3.462286
Oct	37.04389	0.934529	0.722	4.28	5.322571
Nov	30.27222	1.467453	1.190333	6.77	3.239429
Dec	25.77722	1.727379	1.388722	6.69	4.235429

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

Figure 15(a-l) show the linear regression trends of monthly mean of daily maximum temperature (Tmmax) from January to December and demonstrated that Tmmax have increased in all months with annual increase of, 0.0243°C, 0.0768°C, 0.0679°C, 0.0332°C, 0.0366°C, 0.0296°C, 0.0476°C, 0.0817°C, 0.0312°C, 0.048°C, 0.0292°C and 0.0382°C for the months January to December, **Figure 16**, respectively.

This implies that the monthly mean of daily maximum temperature have increased by 0.8748°C, 2.7648°C, 2.4444°C, 1.1952°C, 1.3176°C, 1.0656°C, 1.7136°C, 2.9412°C, 1.1232°C, 1.728°C, 1.0512°C and 1.3752°C during the last 36 years **Figure 17**.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**.

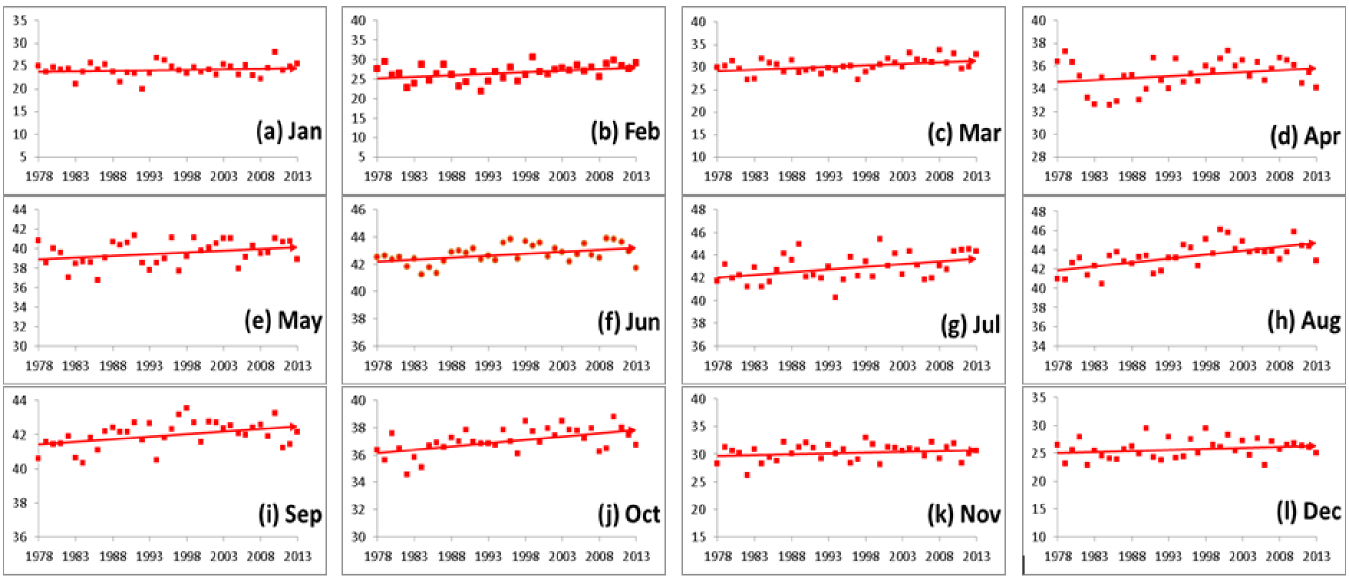

Figure 15: Linear regression trends of monthly mean of daily maximum temperature

Licensed Under Creative Commons Attribution CC BY

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

Mon.	*Regression line*	*R^2*	*Mon.*	*Regression line*	*R^2*
Jan	y = 0.0243x - 24.37	0.027	**Jul**	y = 0.0476x - 52.18	0.175
Feb	y = 0.0768x - 126.4	0.153	**Aug**	y = 0.0817x - 119.6	0.399
Mar	y = 0.0679x - 105.2	0.202	**Sep**	y = 0.0312x - 20.25	0.179
Apr	y = 0.0332x - 30.91	0.07	**Oct**	y = 0.048x - 58.64	0.292
May	y = 0.0366x - 33.57	0.094	**Nov**	y = 0.0292x - 27.96	0.043
Jun	y = 0.0296x s- 16.39	0.205	**Dec**	y = 0.0382x - 50.36	0.054

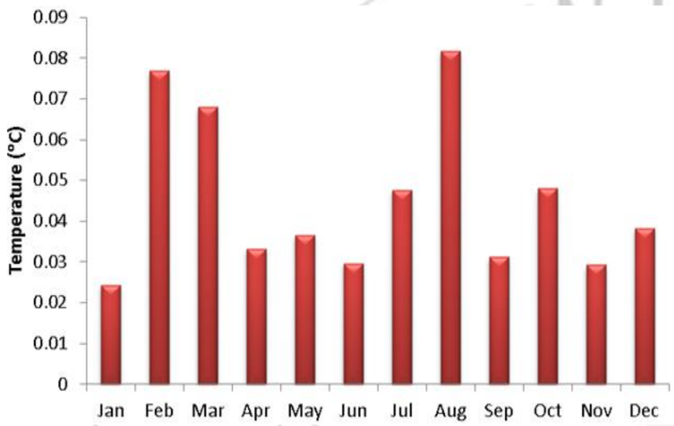

Figure 16: Annual increment in the mean of monthly mean of daily maximum temperature (Tmmax)

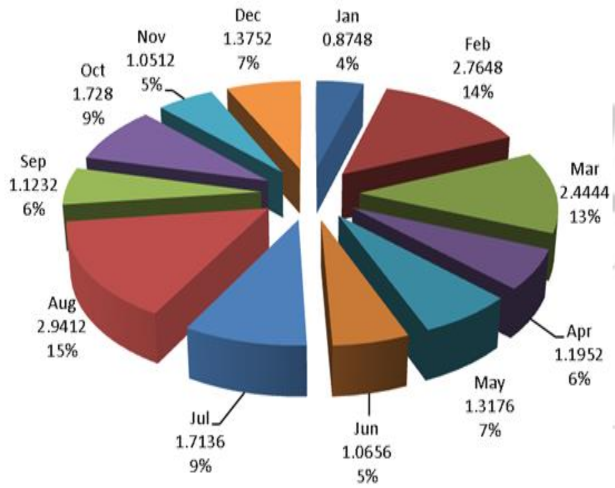

Figure 17: Tmmax total increase in the last 36 years

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

The annual mean of daily maximum temperature (Tamax) show an increasing trend with an annual rise of 0.0454°C, which implies that over the last 36 years the annual mean of daily maximum temperature of Al-Madinah Al-Munawarah has increased by 1.6344°C as shown in **Figure 18**

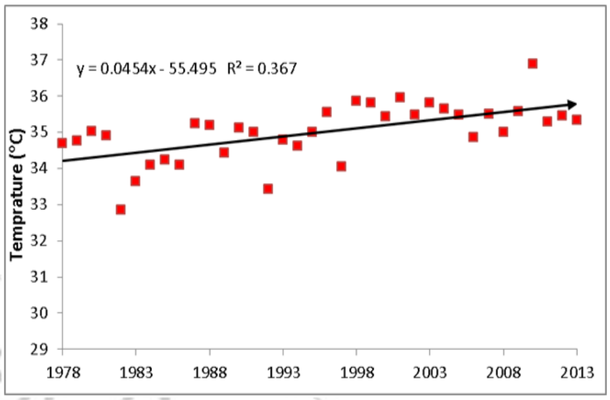

Figure 18: Trend of annual mean of daily mean temperature (Tamax)

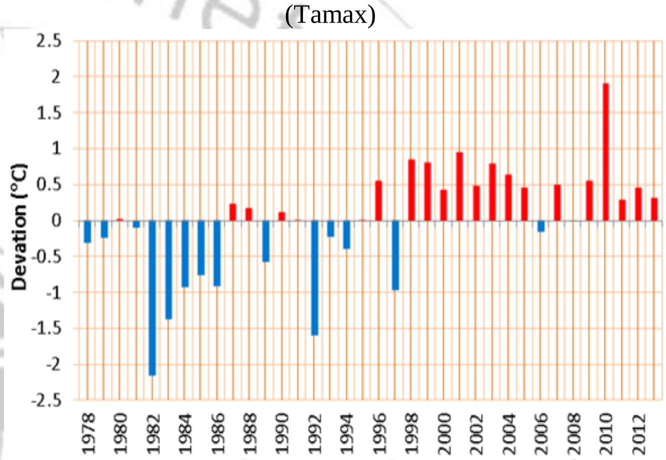

Figure 19: Trend of annual deviation from overall mean (Tamax)

The annual deviation from overall mean temperature show major negative trends during the interval (1978 to 1997) and during the period (1998 to 2013) it shows major positive trends, **Figure 19**. The maximum cooling was found in the year 1982, -2.2°C, while the maximum warming was recorded in the year 2010.

3.9 Variation of Daily Minimum Temperature (Tdmin)

Figure 20 shows the long term monthly mean temperatures along with the monthly maximum and minimum of daily minimum (Tmmin) values during the period 1978 to 2013. The Tmmin varied between a minimum of 7.99°C in January and a maximum of 32.56°C in August. This means that the ratio between the hottest to the coldest Tmmin is 4.07.

Licensed Under Creative Commons Attribution CC BY

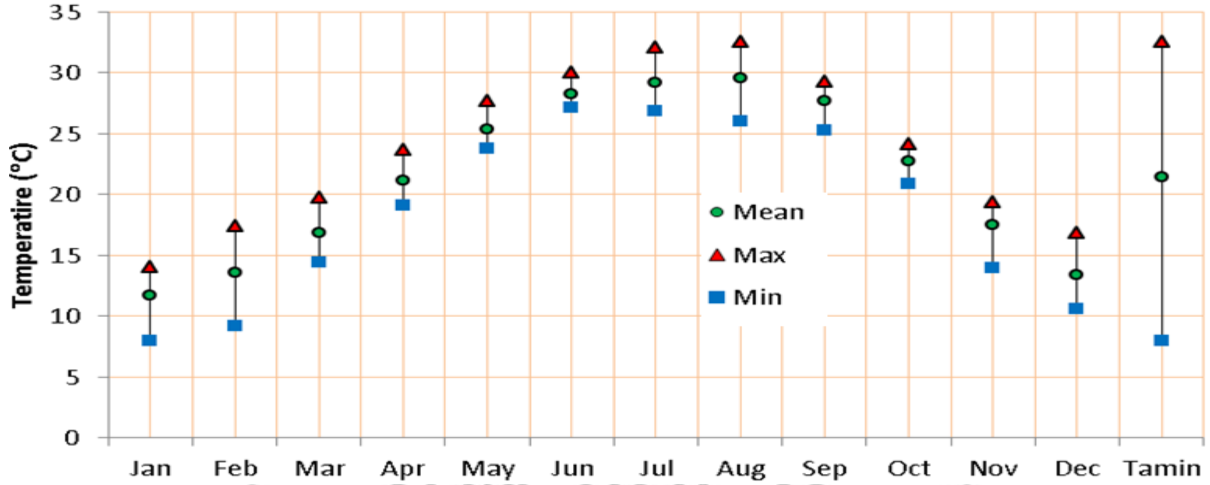

Figure 20: Variation of monthly mean, maximum and minimum temperature of daily minimum values

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.**

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

Month	*Mean (°C)*	*Std. Dev. (°C)*	*Mean Dev. (°C)*	*Range (°C)*	*COV (%)*
Jan	11.70667	1.402555	1.085333	6.07	1.48
Feb	13.57694	1.748704	1.379167	8.26	0.966018
Mar	16.82056	1.16247	0.929472	5.37	0.808467
Apr	21.15889	1.065237	0.854939	4.51	0.256689
May	25.385	0.97759	0.762222	3.94	0.186049
Jun	28.27333	0.800518	0.616056	2.98	0.154534
Jul	29.16556	1.271021	0.985864	5.26	0.453261
Aug	29.53083	1.478407	1.191944	6.54	1.076061
Sep	27.63639	1.006772	0.798966	4.07	0.377263
Oct	22.74694	0.828251	0.634367	3.29	0.19044
Nov	17.48778	1.026949	0.71	5.41	0.301696
Dec	13.38639	1.450449	1.168994	6.32	0.376517

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

The linear regression trends of monthly mean of daily minimum temperatures (Tmmin) from January to December are shown in **Figure 21 (a-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, **Figure 22,** with an annual increase, 0.0133°C, 0.0644°C, 0.0275°C, 0.0207°C, 0.0208°C, 0.0408°C, 0.0701°C, 0.0938°C, 0.0437°C, 0.0412°C, 0.0328°C and 0.0265°C for January to December which implies that the Tmmin has increased during the last 36 years with 0.4788°C, 2.3184°C, 0.99°C, 0.7452°C, 0.7488°C, 1..4688°C, 2.5236°C, 3.3768°C, 1.5732°C, 1.4832°C, 1.1808°C and 0.954°C for January to December in Al-Madinah Al-Munawarah respectively as shown in **Figure 23**

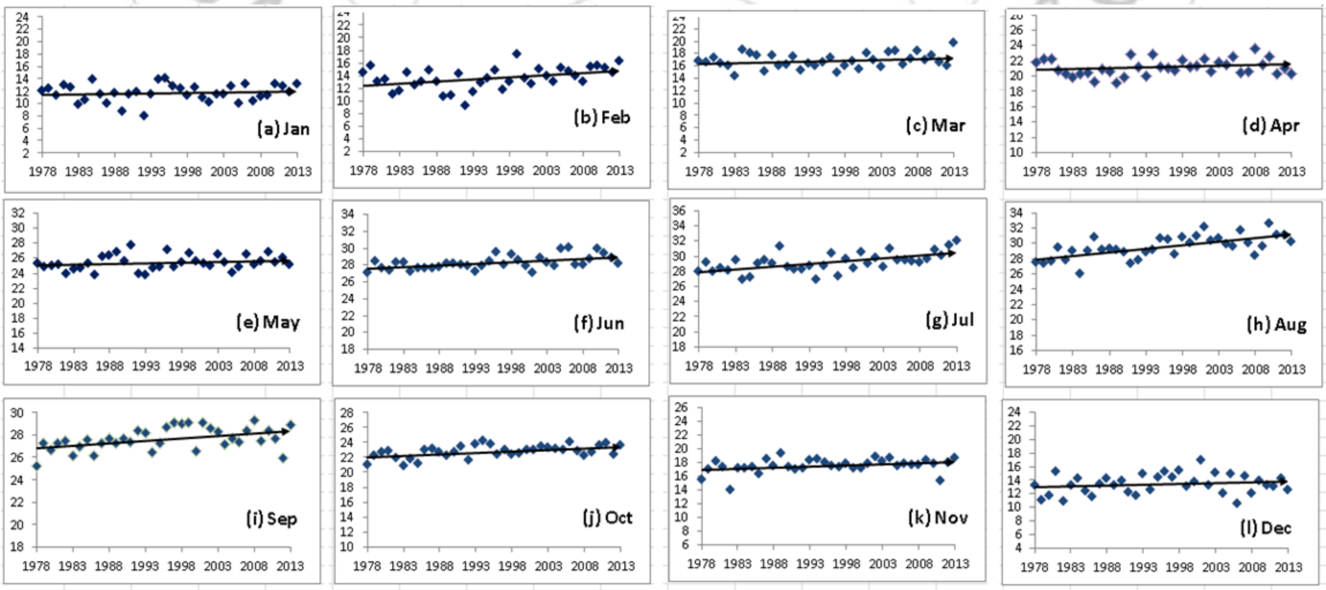

Figure 21: Linear regression trends of monthly mean of daily minimum temperature

Licensed Under Creative Commons Attribution CC BY

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

Month	Regression line	R^2	Month	Regression line	R^2
Jan	y = 0.0133x - 14.9	R^2 = 0.01	Jul	y = 0.0701x - 110.67	R^2 = 0.3374
Feb	y = 0.0644x - 114.88	R^2 = 0.1504	Aug	y = 0.0938x - 157.73	R^2 = 0.4472
Mar	y = 0.0275x - 38.098	R^2 = 0.0622	Sep	y = 0.0437x - 59.567	R^2 = 0.2091
Apr	y = 0.0207x - 20.117	R^2 = 0.0419	Oct	y = 0.0412x - 59.459	R^2 = 0.2746
May	y = 0.0208x - 16.174	R^2 = 0.0504	Nov	y = 0.0328x - 47.899	R^2 = 0.113
Jun	y = 0.0408x - 53.134	R^2 = 0.2883	Dec	y = 0.0265x - 39.521	R^2 = 0.0371

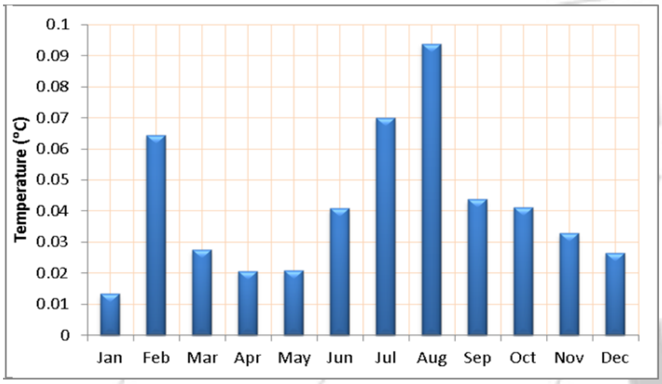

Figure 22: Annual increment in the monthly mean of daily minimum temperature (Tmmin)

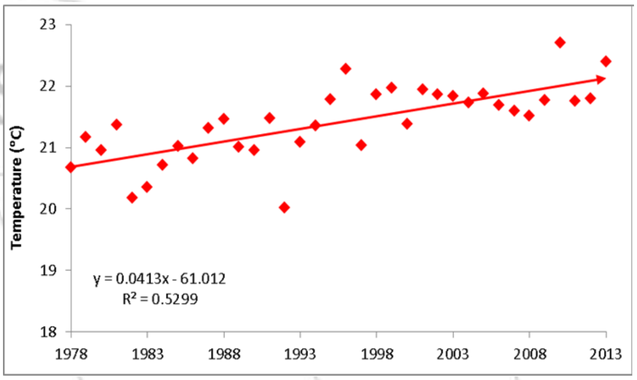

Figure 24: Trend of annual mean of daily maximum temperature(Tamin)

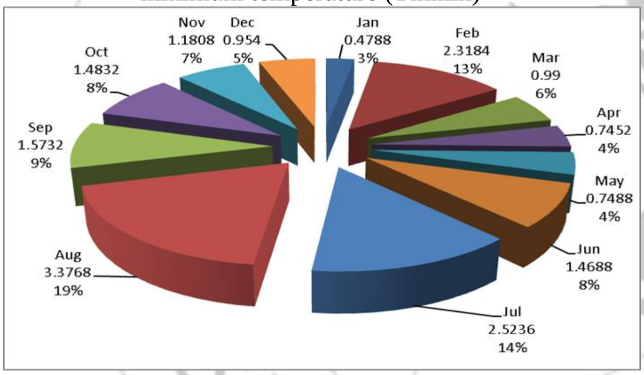

Figure 23: Tmmin total increase in the last 36 years

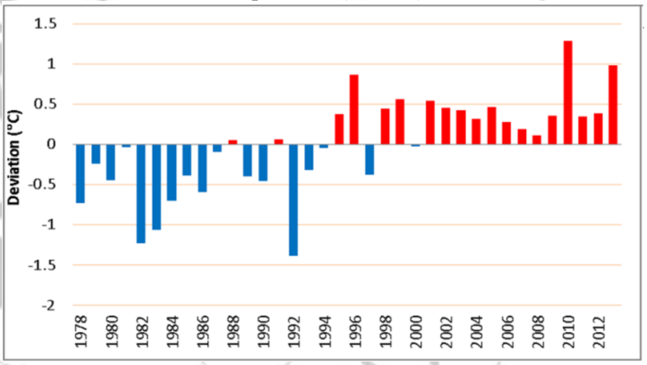

Figure 25: Trend of annual deviation from overall mean (Tamin)

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 0.0413°C which implies that over the last 36 years the annual mean of daily minimum temperature of Al-Madinah Al-Munawarah has increased by 1.4868°C, **Figure 24.**

Figure 25 shows the annual deviations from overall mean of (Tamin) show major negative trends during the periods (1978 to 1994) and positive trends in the period (1995 to 2013).

3.12 Using the Theil-Sen nonparametric statistical approach

Temporal trends of the observed daily minimum, maximum and mean temperature in Al-Madinah Al-Munawarah have been analyzed for the recent36 years (1978-2013) to determine how they are changed over the time using the Theil-Sen nonparametric statistical approach. The advantage of using the Theil-Sen estimator 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 [46]. All trends expressed in (°C)/year.

3.12.1 Annual trend in daily mean temperature

Figure 26 shows the annual trend in the daily mean temperature in Al-Madinah Al-Munawarah, 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 0.04

Licensed Under Creative Commons Attribution CC BY

(°C) per year and the 95 % confidence intervals in the slope from 0.04–0.05°C/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.

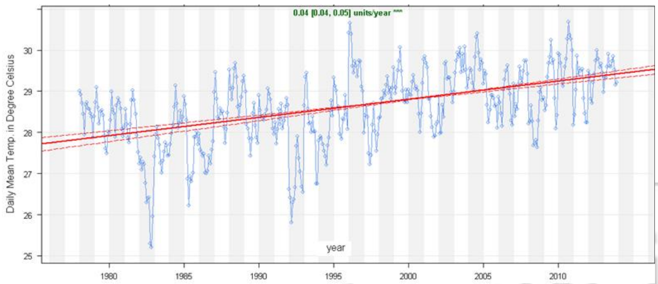

Figure 26: Annual Trend in daily mean temperature

3.12.2 Seasonal trend in daily mean temperature

Figure 27 Shows four panels for the seasonal trend of the daily mean temperature at Al-Madinah Al-Munawarah. 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 (left panel) trend is 0.04 (°C) per year and the 95 % confidence intervals in the slope from 0.02–0.05°C/year.

The summer (JJA) season (second left panel) trend is 0.06(°C) per year and the 95 % confidence intervals in the slope from 0.04–0.08°C/year. The autumn (SON) season (third left panel) trend is 0.05(°C) per year and the 95 % confidence intervals in the slope from 0.04–0.07°C/year[30]. The winter (DJF) season (first right panel) trend is 0.04(°C) per year and the 95 % confidence intervals in the slope from 0.02–0.05°C/year. In all panels, 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.

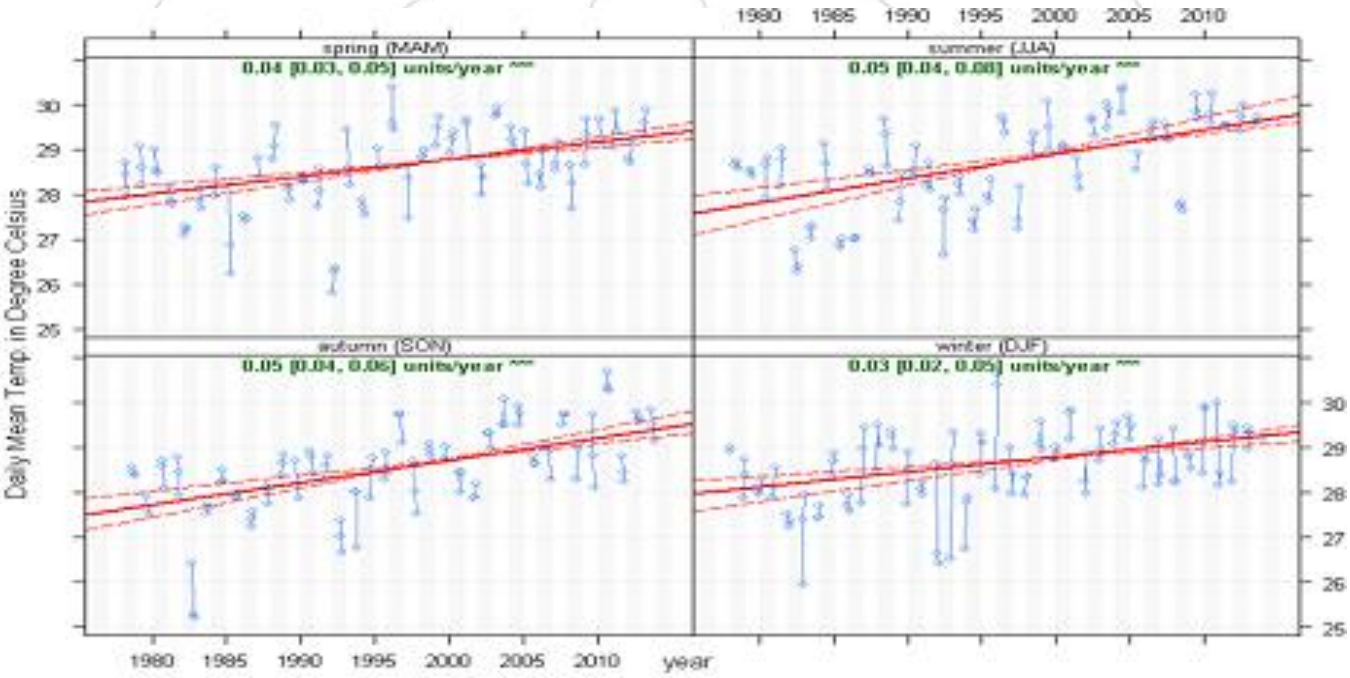

Figure 27: Seasonal Trend in daily mean temperature

3.12.3 Monthly trend in daily mean temperature

Figure 28 shows that the monthly trends increase in the daily mean temperature at Al-Madinah Al-Munawarah with the values; 0.04°C, 0.03°C, 0.03°C, 0.04°C, 0.04°C, 0.06°C, 0.05°C, 0.06°C, 0.06°C, 0.05°C, 0.05°C, 0.05°C for Jan., Feb., Mar., Apr., May., Jun., Jul., Aug., Sep., Oct., Nov. and Dec. during the period 1978-2013 and the trend is:

Significant to the 0.001 level (***) providing very strong evidence that the mean temperature increased as in May, Jun., Sep., Oct., Nov. and Dec.,

Significant to the 0.01 level (**) providing strong evidence that the mean temperature increased as in Jan, Apr., Jul. and Aug.

Significant to the 0.05 level (*) providing good evidence that the mean temperature increased as in Mar.

Significant to the 0.1 level (+) providing 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.

Licensed Under Creative Commons Attribution CC BY

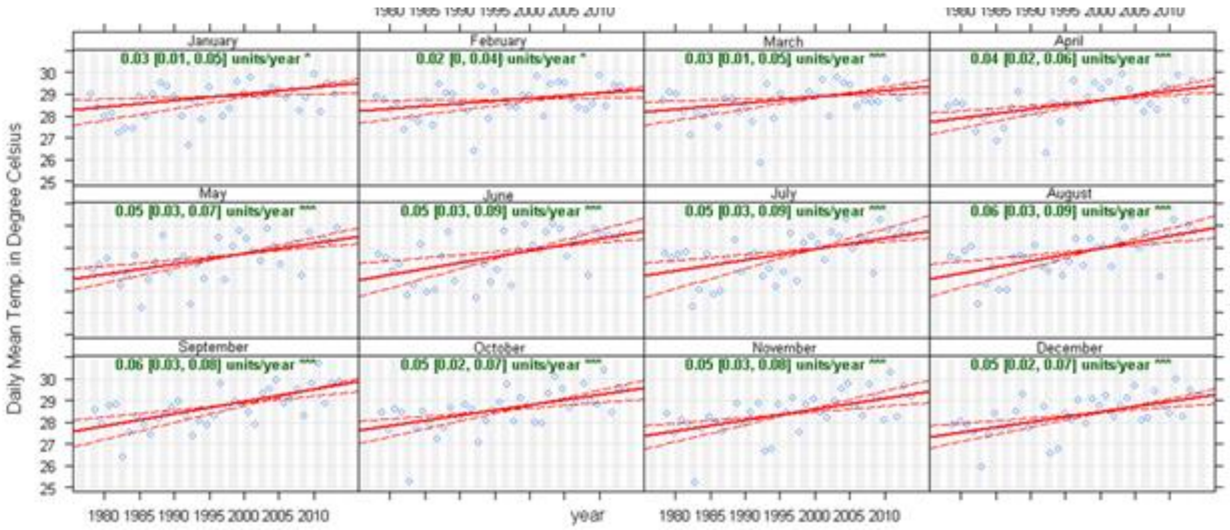

Figure 28: Monthly Trend in daily mean temperature

3.12.4 Annual trend in daily maximum temperature

Figure 29 shows the annual trend in the daily maximum temperature at Al-Madinah Al-Munawarah. 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 as 0.05 (°C) per year and the 95 % confidence intervals in the slope from 0.04–0.06°C/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.

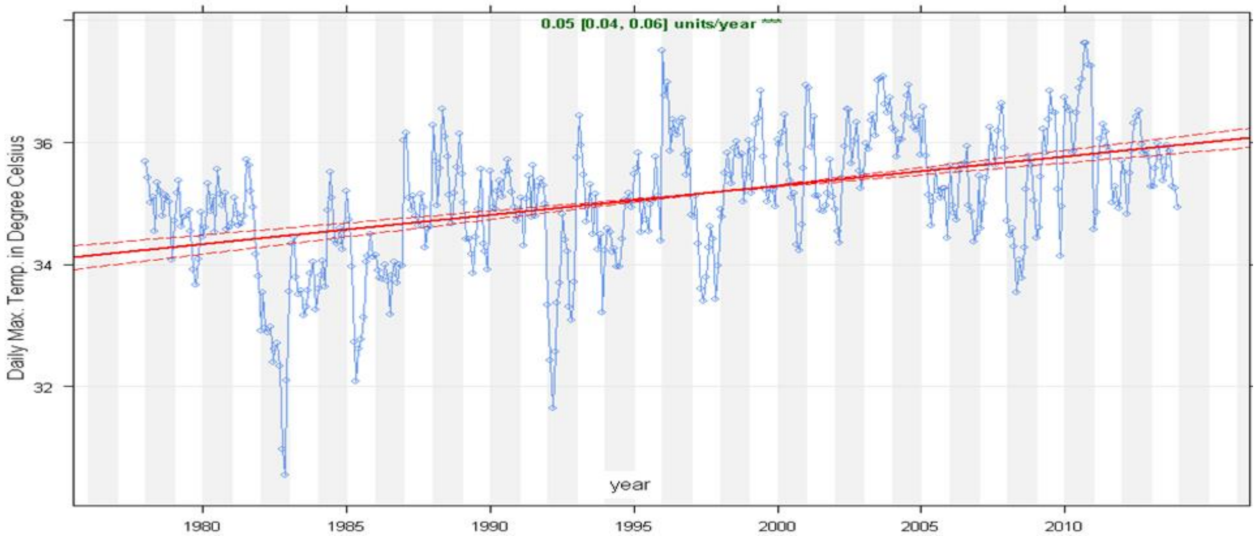

Figure 29: Annual Trend in daily maximum temperature

3.12.5 Seasonal trend in daily maximum temperature

Figure 30 shows four panels for the seasonal trend in the daily maximum temperature as follows: 0.05°C, 0.06°C, 0.06°C and 0.04°C per year for the spring (MAM) season (top left panel), the summer (JJA) season (second left panel), the autumn (SON) season (third left panel) and the winter (DJF) season (first right 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.

3.12.6 Monthly trend in daily maximum temperature.

Figure 31 shows that the monthly trends increase in the daily mean temperature at Al-Madinah Al-Munawarah with the values 0.05°C, 0.03°C, 0.04°C, 0.06°C, 0.05°C, 0.06°C, 0.06°C, 0.06°C, 0.06°C, 0.07°C, 0.06°C and 0.06°C for Jan., Feb., Mar., Apr., May., Jun., Jul., Aug., Sep., Oct., Nov. and Dec. during the period 1978-2013 and the trend is significant to the 0.001 level (***), the 0.01 level (**), the 0.05 level (*) and the 0.1 level (+) providing very strong evidence for increasing the maximum temperature as in Apr., May, Jun., Sep., Oct., Nov. and Dec. and strong as in Jul. and Aug. and good as in Mar. and fair as in Jan. evidence that the maximum temperature increased over the period. This

Licensed Under Creative Commons Attribution CC BY

confirms the increasing trend obtained from regression in **Figure 13.**

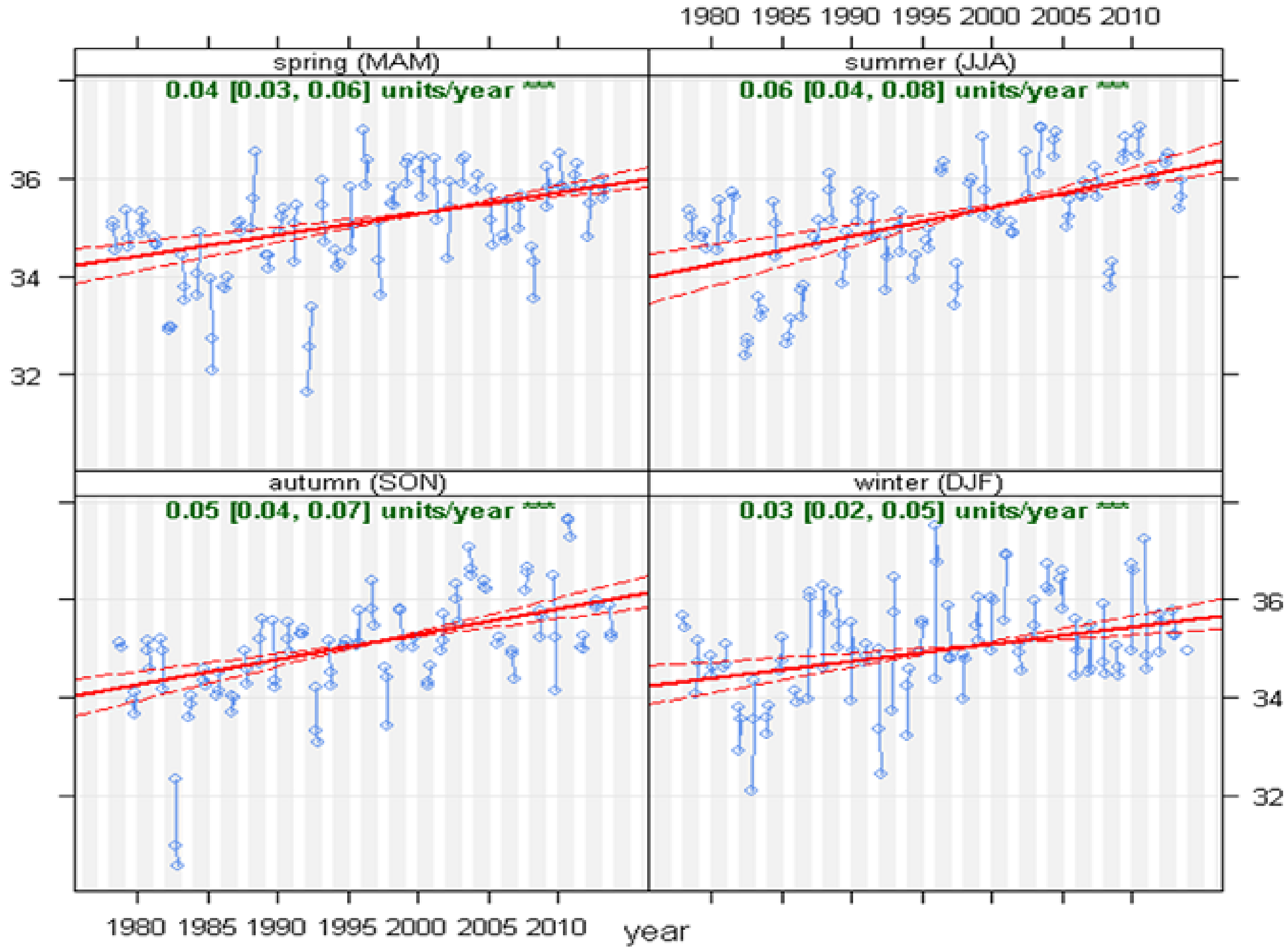

Figure 30: Seasonal trend in daily maximum temperature

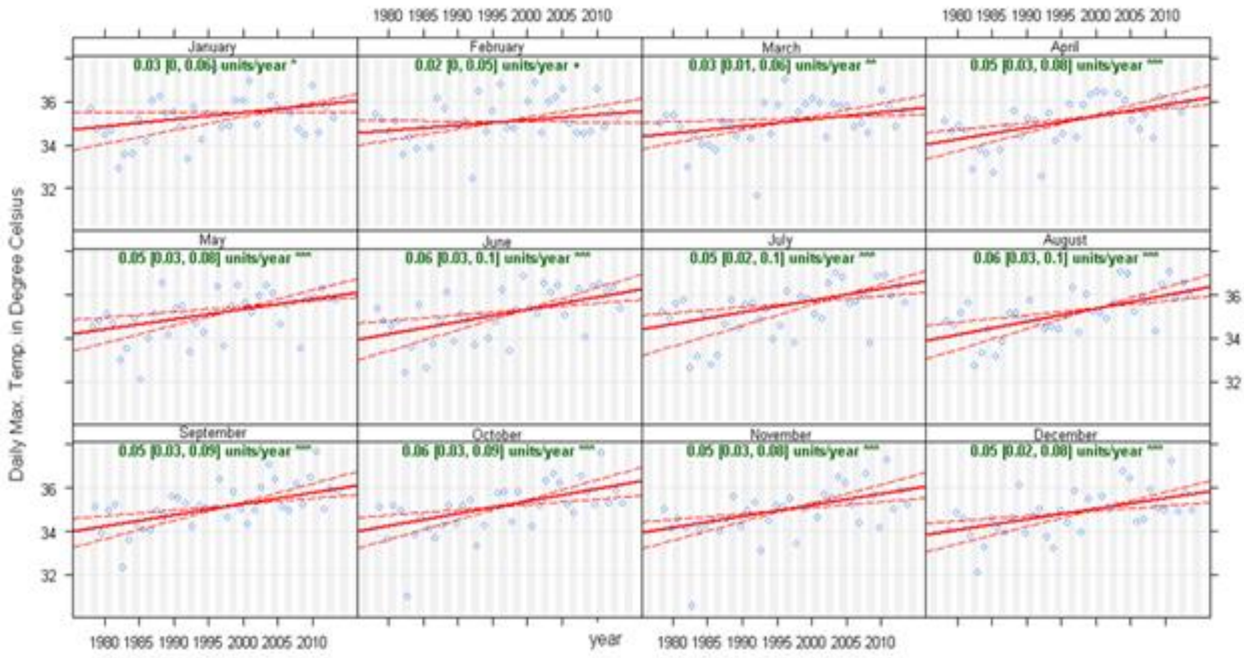

Figure 31: Monthly trend in daily maximum temperature

3.12.7 Annual trend in daily minimum temperature.

The annual trend in the daily minimum temperature at Al-Madinah Al-Munawarah is shown in **Figure 32**. The solid red line shows the trend estimate and the dashed red lines

Licensed Under Creative Commons Attribution CC BY

show the 95 % confidence intervals for the trend based on re-sampling methods. The overall trend is shown at the top-center as 0.04°C per year and the 95 % confidence intervals in the slope from 0.04–0.05°C/year. The trend is significant to the 0.001level which indicated by *** in the top right. The significance level in this case is very high providing very strong evidence that the minimum temperature increased over the entire period.

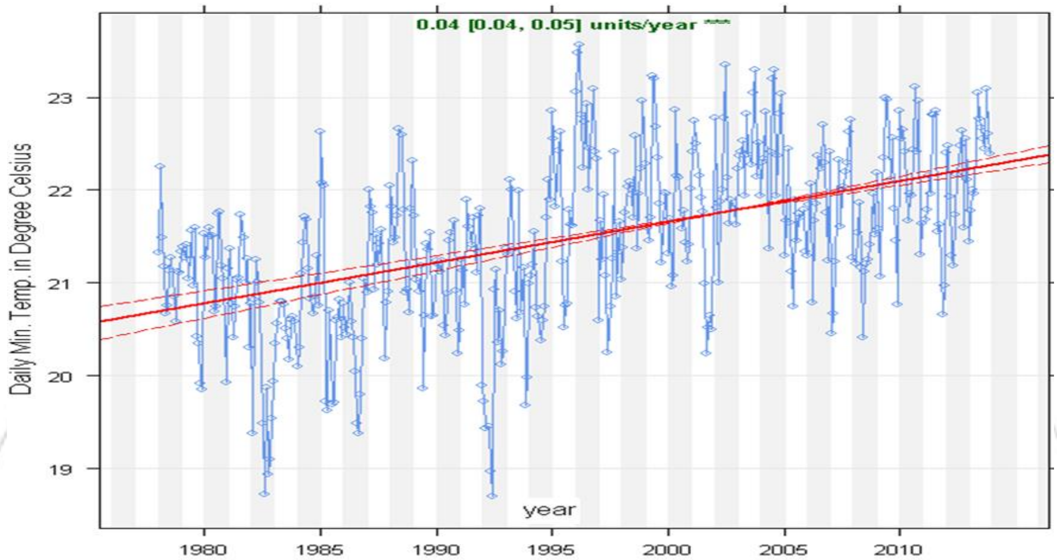

Figure 32: Annual trend in daily minimum temperature

3.12.8 Seasonal trend in daily minimum temperature.

Figure 33 shows four panels for the seasonal trend in the daily minimum temperature (Tdmin) have increased by 0.03°C, 0.05°C, 0.06°C and 0.04°C per year for the spring (MAM) season (top left panel), the summer (JJA) season (top left panel), the autumn (SON) season (bottom left panel) and for the winter (DJF) season (bottom right 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.

This implies that the seasonal Tdmin has increased in the last 36 years with 1.08°C, 1.8°C, 2.16°C and 1.44°C for spring, summer, autumn and winter respectively.

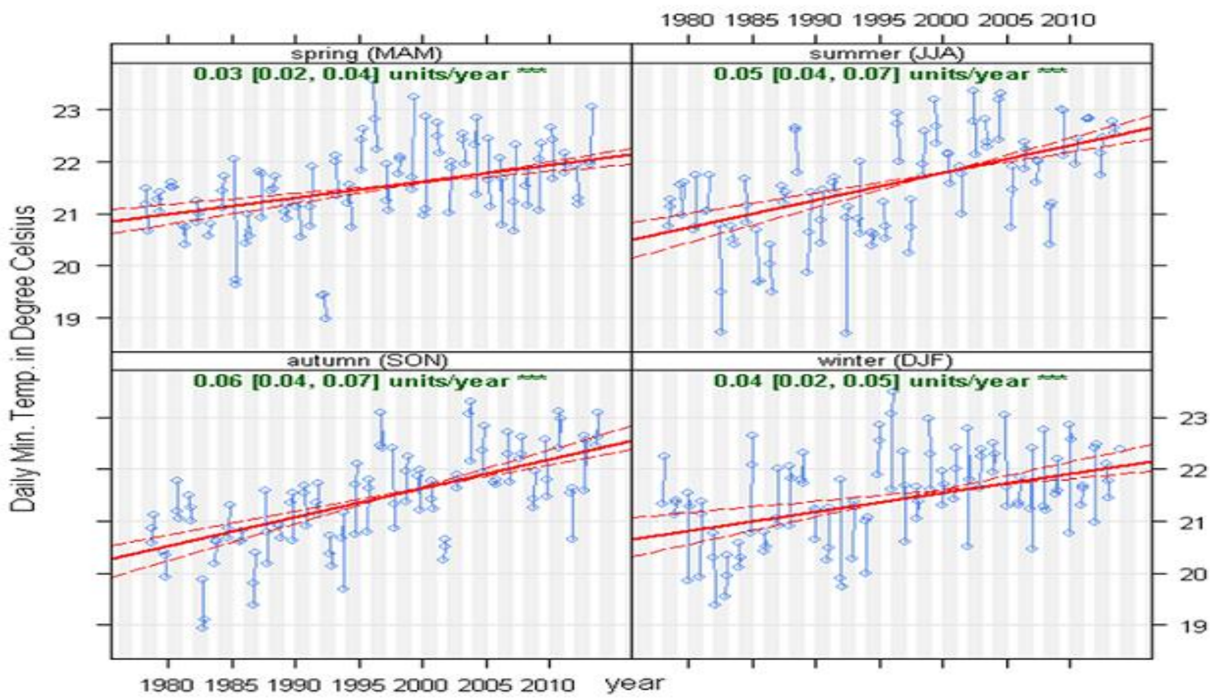

Figure 33: Seasonal trend in daily minimum temperature

Licensed Under Creative Commons Attribution CC BY

3.12.9 Monthly trend in daily minimum temperature

The monthly trends in the daily minimum temperature at Al-Madinah Al-Munawarah have increased with values; 0.03°C, 0.02°C, 0.03°C, 0.3°C, 0.3°C, 0.5°C, 0.06°C, 0.05°C, 0.06°C, 0.05°C, 0.06°C and 0.05°C for Jan., Feb., Mar., Apr., May., Jun., Jul., Aug., Sep., Oct., Nov. and Dec. respectively during the period 1978-2013 **Figure 34**. The trend is significant to the 0.001level (***) providing very strong evidence that the Tdmin temperature increased over the entire period and confirms the results obtained from regression in for Tdmin

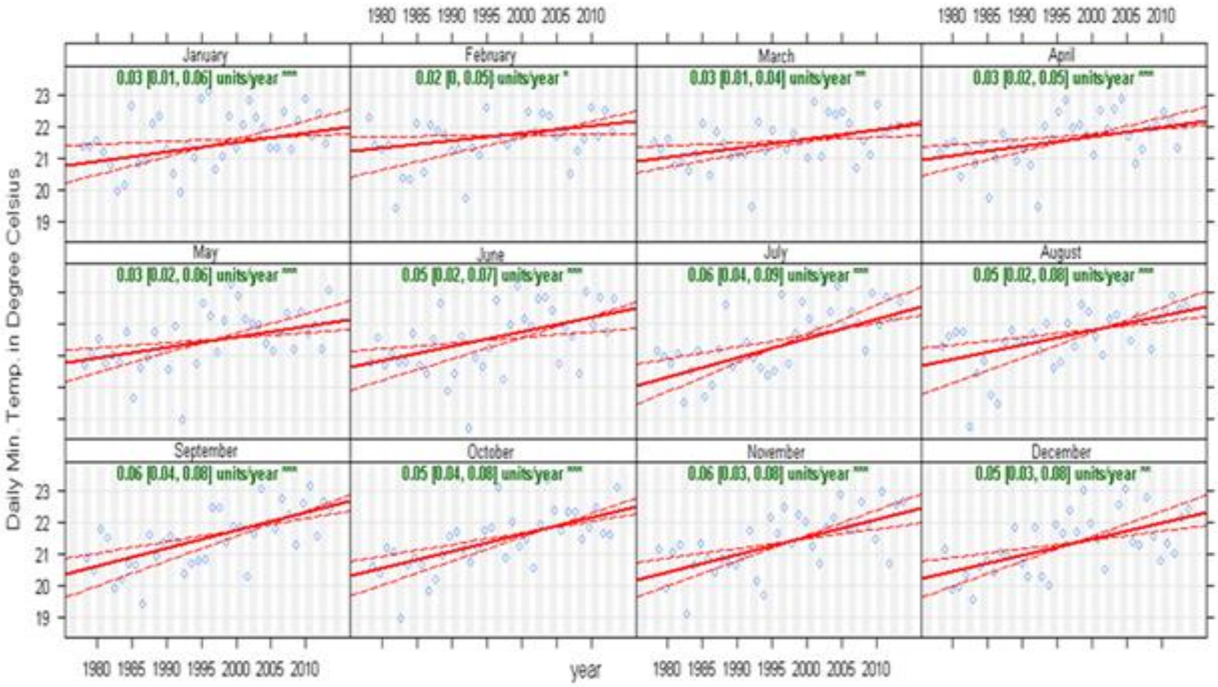

Figure 34: Monthly trend in daily minimum temperature

3. Results Summary

The main findings of this study could be summarized in the following points:
By analyzing the daily mean, minimum and maximum temperature during the last 36 years (1987-2013) it is shown that

- The number of hot days and hot nights increased annually by 0.6216 day and 0.6122 night, respectively, while the number of cold days and cold nights decreased annually by 0.1368 day and 0.5275 night. 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.
- The monthly mean of daily mean temperature (Tmmean) have increased annually with 0.0223°C, 0.0704°C, 0.0505°C, 0.0267°C, 0.0327°C, 0.0303°C, 0.0549°C, 0.0762°C, 0.0315°C, 0.0449°C, 0.0325°C while the total increases during the entire period were 0.8028°C, 2.5344°C, 1.8252°C, 0.9612°C, 1.1772°C, 1.0908°C, 1.9764°C, 2.7432°C, 1.134°C, 1.6164°C, 1.17°C and 1.1556°C in January to December respectively
- The monthly mean of daily maximum temperature (Tmmax) have increased annually with 0.0243°C, 0.0768°C, 0.0679°C, 0.0332°C, 0.0366°C, 0.0296°C, 0.0476°C, 0.0817°C, 0.0312°C, 0.048°C, 0.0292°C and 0.0382°C while the total increases during the entire period are 0.8748°C, 2.7648°C, 2.444°C, 1.1952°C, 1.3176°C, 1.0656°C, 1.7136°C, 2.941°C, 1.1232°C, 1.728°C, 1.0512°C and 1.3752°C in January to December respectively.
- The monthly mean of daily minimum temperature (Tmmin) have increased annually with 0.0133°C, 0.0644°C, 0.0275°C, 0.0207°C, 0.0208°C, 0.0408°C, 0.0701°C, 0.0938°C, 0.0437°C, 0.0412°C, 0.0328°C and 0.0265°C while the total increases during the entire period are 0.4788°C, 2.3184°C, 0.99°C, 0.7452°C, 0.7488°C, 2.5236°C, 3.3768°C, 1.5732°C, 1.4832°C, 1.1808°C and 0.954°C in January to December respectively.
- The annual mean of daily mean temperature (Tamean), daily maximum temperature (Tamax) and daily minimum temperature (Tamin) have increased by 0.0421°C, 0.0454°C and 0.0413°C per year, and 1.5156°C, 1.6344°C, 1.4868°C respectively during the full period
- 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.

Licensed Under Creative Commons Attribution CC BY

- The increasing trend of the annual mean of minimum, maximum and mean temperature is confirmed by both [28] and [47] with slight difference in the rate.

4. Conclusion

The analysis of the hot and cold days/nights based on temperature thresholds reveals that summers are expanding and winters are shrinking in Al-Madinah Al-Munawarah, resulting in more pressure on water and energy sectors. The increasing trend of intense heat may cause health problems for the visitors.. The results indicate the vulnerability of the Holly City. The results would be helpful for the policy makers to reduce the future risks associated with rapidly changing climate of Al-Madinah Al-Munawarah."

5. Acknowledgments

Thanks are expressed to the Presidency of Meteorology and Environment in Saudi Arabia for providing the observation dataset. Dr. Yasser Khalaf, PME for his cooperation and great help in dataset preparation and availability, Dr. Sayed Munir for his help and advice, the ICTP center for the scientific support. The author greatly appreciates the contribution of the anonymous reviewers, as a result of which the manuscript has considerably improved.

References

[1] Aerts, J. and Droogers P, Climate change in contrasting river basins: adaptation strategies for water, food, and environment. 2004: Biddles Ltd, King's Lynn, UK, p 30.
[2] IPCC, Climate change 2007: synthesis report. Valencia, Spain. 200
[3] Brunetti, M., et al., Trends of Minimum and Maximum Daily Temperatures in Italy from 1865 to 1996. Theor. Appl. Climatol., 2000. 66: p. 49-60.
[4] Domroes, M. and A. El-Tantawi, Recent temporal and spatial temperature changes in Egypt. International Journal of Climatology, 2005. 25(1): p. 51-63.
[5] Unkasˇevic´, M., D. Vujovic´, and I. Tosˇic, Trends in extreme summer temperatures at Belgrade. Theor. Appl. Climatol., 2005. 82: p. 199-205.
[6] Arndt, D.S., et al., State of the climate in 2009. Bull. Am. Meteorol Soc, 2010. 91(6): p. S1–S224.
[7] Arnfield, A.J., Two decades of urban climate research: a review of turbulence, exchanges of energy and water, and the urban heat island. International Journal of Climatology, 2003. 23(1): p. 1-26.
[8] Brohan, P., et al., Uncertainty estimates in regional and global observed temperature changes: A new data set from 1850. Journal of Geophysical Research: Atmospheres, 2006. 111(D12): p. D12106.
[9] Jones, P.D. and A. Moberg, Hemispheric and Large-Scale Surface Air Temperature Variations: An Extensive Revision and an Update to 2001. Journal of Climate, 2003. 16(2): p. 206-223.
[10] Soon, W., et al., Variations of solar coronal hole area and terrestrial lower tropospheric air temperature from 1979 to mid-1998: astronomical forcings of change in earth's climate? New Astronomy, 2000. 4(8): p. 563-579.
[11] Vose, R.S., D.R. Easterling, and Byron Gleason, Maximum and minimum temperature trends for the globe: An update through 2004. 2005.
[12] Vinnikov, K.Y. and N.C. Grody, Global Warming Trend of Mean Tropospheric Temperature Observed by Satellites. Science, 2003. 302(5643): p. 269-272.
[13] Bavani, A.M., E. Goodarzi, and Narges Zohrab, Detection of climatic variables trend by using parametric and non-parametric statistical tests. (A case study of West Azerbaijan, Iran). Technical Journal of Engineering and Applied Sciences, 2012. 2: p. 557-564
[14] Klok, E.J. and A.M.G. Klein Tank, Updated and extended European dataset of daily climate observations. International Journal of Climatology, 2009. 29(8): p. 1182-1191.
[15] Tabari, H., B.S. Somee, and M.R. Zadeh, Testing for long-term trends in climatic variables in Iran. Atmospheric Research, 2011. 100(1): p. 132-140.
[16] LU, M.K.K., Trends in Surface Air Temperature Data over Turkey. International J. of Climatology, 1997. 17: p. 511–520
[17] Aesawy, A.M. and H.M. Hasanean, Annual and Seasonal Climatic Analysis of Surface Air Temperature Variations at Six Southern Mediterranean Stations. Theoretical and Applied Climatology, 1998. 61(1-2): p. 55-68.
[18] Smadi, M., Observed abrupt changes in minimum and maximum temperatures in Jordan in the 20th century. Am. J. Environ. Sci., 2006. 2(3): p. 114-120.
[19] Al-Fahed, S., O. Al-Hawaj, and W. Chakroun, The recent air temperature rise in Kuwait. Renewable Energy, 1997. 12(1): p. 83-90.
[20] Nasrallah, H. and R. Balling, Jr., Impact of desertification on temperature trends in the Middle East. Environmental Monitoring and Assessment, 1995. 37(1-3): p. 265-271.
[21] Chung, Y.S. and M. B. Yoon, Interpretation of recent temperature and precipitation trends observed in Korea. Theor. Appl. Climatol. , 2000. 67: p. 171-180.
[22] Toreti, A. and F. Desiato, Temperature trend over Italy from 1961 to 2004. Theoretical and Applied Climatology, 2008. 91(1-4): p. 51-58.
[23] Brunetti, M., et al., Temperature, precipitation and extreme events during the last century in Italy. 2012. p. 8.
[24] Chaouche, K., et al., Analyses of precipitation, temperature and evapotranspiration in a French Mediterranean region in the context of climate change. CR Geosci, 2010. 342: p. 234-243.
[25] Río, S., et al., Recent trends in mean maximum and minimum air temperatures over Spain (1961-2006). Theoretical & Applied Climatology, 2012. 109(1/2): p. 605-626.
[26] H. Hasanean and A. AL-Khalaf, Variability of Wintertime Surface Air Temperature over the Kingdom of Saudi Arabia. Atmospheric and Climate Sciences, 2012. V.2 No.3: p. 307-321.
[27] ElNesr, M.N., M.M. Abu-Zreig, and Abdurrahman A. Alazba, Temperature Trends and Distribution in the

Licensed Under Creative Commons Attribution CC BY

Arabian Peninsula. American Journal of Environmental Sciences, 2010. 6(2): p. 191-203.
[28] Almazroui, M., et al., Recent climate change in the Arabian Peninsula: Seasonal rainfall and temperature climatology of Saudi Arabia for 1979–2009. Atmospheric Research, 2012. 111(0): p. 29-45.
[29] S. Rehman and L. Al-Hadhrami, Extreme Temperature Trends on the West Coast of Saudi Arabia. Atmospheric and Climate Science, 2012. 2 No. 3: p. 351-361.
[30] Abdou, A.E.A., Temperature Trend on Makkah, Saudi Arabia. Atmospheric and Climate Science, 2014. 4(3): p. 457-481.
[31] Almazroui, M., et al., Detecting climate change signals in Saudi Arabia using mean annual surface air temperatures. Theoretical and Applied Climatology, 2013. 113(3-4): p. 585-598.
[32] C, P., Heatwave. Weatherwise, 1980. 33: p. 112-116.
[33] Mearns, L.O., R.W. Katz, and S.H. Schneider, Extreme High-Temperature Events: Changes in their probabilities with Changes in Mean Temperature. Journal of Climate and Applied Meteorology, 1984. 23(12): p. 1601-1613.
[34] CityPopulation. Saudi Arabia. http://www.citypopulation.de/SaudiArabia.html 2013.
[35] Almazroui, M., M.N. Islam, and P.D. Jones, Urbanization effects on the air temperature rise in Saudi Arabia. Climatic Change, 2013. 120(1-2): p. 109-122.
[36] Abdou, A.E.A., Studying the effect of internal consistency on the objective analysis. 2000, Cairo University: Cairo. p. 118.
[37] Athar, H., Decadal variability of the observed daily temperature in Saudi Arabia during 1979–2008. Atmospheric Science Letters, 2012. 13(4): p. 244-249.
[38] Zhang, X., et al., Trends in Middle East climate extreme indices from 1950 to 2003. Journal of Geophysical Research: Atmospheres, 2005. 110(D22): p. D22104.
[39] H. Theil, A rank invariant method of linear and polynomial regression analysis, i, ii, iii. Proceedings of the Koninklijke Nederlandse Akademie Wetenschappen,. Series A. Mathematical Sciences, 1950. 53: p. 386-392, 521-525, 1397-1412.
[40] Sen, P.K., Estimates of regression coefficient based on kendall's tau. American Statistical Association. Vol. 63. 1968. 324.
[41] Munir, S., et al., Quantifying temporal trends of atmospheric pollutants in Makkah (1997e2012). Atmospheric Environment, 2013. 77: p. 647-655.
[42] Thermal Comfort and Heat Stress Guideline. 2010; Available from: http://www.uottawa.ca/services/ehss/documents/heatstress_final_060810_000.pdf.
[43] Knowledge Economic City, A study on the risks associated with the concurrently with the next pilgrimage seasons summers and propose alternatives to deal with. 2014, Knowledge Economic City. p. 88.
[44] Smoyer-Tomic, K.E., and Rainham, D.G.C. Beating the heat: Development and evaluation of a Canadian hot weather-health response plan. Environmental Health Perspectives, 2001. 109: p. 1241-48.
[45] Kalkstein, L.S. and K.E. Smoyer, The impact of climate change on human health: some international implications. Experientia 1993; 49: 969-79., 1993. 49: p. 969-979.
[46] Carslaw, D. and K. Ropkins, Openair - an R package for air quality data analysis. Environmental Modelling & Software 2012: p. 27-28, 52-61.
[47] Almazroui, M., et al., Recent climate change in the Arabian Peninsula: annual rainfall and temperature analysis of Saudi Arabia for 1978–2009. Int. J. Climatol., 2012. 32: p. 953–966.

Author Profile

Dr. Abdellatif Esawy A. Abdou has completed his B.Sc. from Zagazig University – Banha Branch (Currently Banha University), Banha, Egypt 1987, and M.Sc. in Meteorology from Cairo University, Cairo 2000 and Ph.D. in Meteorology from Cairo University, Cairo 2005. He published any researches in Weather and Climate. He worked as a Researcher in the Scientific Research Department, Egyptian Meteorological Authority (1994-2009), Assistant Professor of Meteorology in the Department of Meteorology, Meteorology, Environment and Agriculture of arid Land Faculty, king Abdulaziz University (from 2009 to 2012). He is currently working as an Assistant Professor of Meteorology in the Department of Health and Environment, the Custodian of the Two holy Mosques Institute for Hajj and Umrah Research, Um Al-Qura University, Makkah, Saudi Arabia. He was a regular associate (2005-2012) with The International Center for theoretical Physics (ICTP) and has attended many conferences and workshops in the field of Climate and Climate and published many papers in the Climate Science.

Dr. Turki M. A. Habeebullah has completed his B. SC. In Metrology, from King Abdulaziz University, Jeddah, Saudi Arabia, his M.SC. Metrology, King Abdulaziz University, Saudi Arabia and PhD. Air Pollution Meteorology, University of East Anglia, United Kingdom. He worked as a Technician (1999 – 2001), Meteorologist, (2001-2004), Lecturer (2004-2010), Assistant Professor (2010-2014) and Associate Professor (2014 -present) in the Climatology Research Unit, Environmental and Health Department, The Custodian of the Two Holy Mosques Institute of Hajj Research, Umm Al Qura University, Makkah, Saudi Arabia.
He has attended many conferences and workshops in the field of specialist and published many papers in Climate, Air pollution and Biometeorology Sciences.

Licensed Under Creative Commons Attribution CC BY