TREND ANALYSIS OF CLIMATE VARIABLES FOR THE ABU DHABI EMIRATE

BY

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DECEMBER 2016

1. INTRODUCTION

This study aims to analyze temporal trends in maximum and minimum temperature, rainfall and relative humidity within the Abu Dhabi Emirates. Given indication that groundwater levels are declining at an alarming rate, and with estimates that water demand is likely to double over the next two decades, understanding climatic variables is of significant importance in the uncovering of improved management options of ground water resources.

Rising amount of greenhouse gases (GHG) in the atmosphere, as a result of anthropogenic activities can alter radiative balances and this may lead to changes in climate variables such as temperature and rainfall (George et al. 2011). Such changes in meteorological variables is of growing concern to hydrologists as it can impact major components of the hydrological cycle and ultimately water resources availability (Ahmed et al. 2014; Thomas et al. 2014). An analysis of historical trends in meteorological variables is, therefore, of significant use in water resource planning and management. There is also a need to analyse temperature regimes over long periods and changes in general rainfall patterns at local levels for better understanding regional situations (Varghese et al. 2017).

A number of studies have been undertaken worldwide to assess the variability and trends in temperature and rainfall across the globe to understand the impact of climate change. IPCC AR5 assessment report reported that the globally averaged combined land and ocean surface temperature data showed an increase of 0.85°C (0.65 to 1.06) over the period 1880 to 2012 (IPCC, 2014). The last three decades has been successively warmer than any other decades since 1850 (IPCC, 2014). Abeysingha et al. 2014 undertook a trend analysis of rainfall, temperature and stream flow for the Gomti river basin in India using the Mann-Kendall and Sen's slope estimator. The analysis concluded that there is an increase in both pre-monsoon rainfall and temperature and a decrease in streamflow. Zarenistanak et al. 2014 concluded that rainfall change is insignificant and that temperature change is positive through trend analysis conducted in southwest Iran and change point detection of annual and seasonal precipitation and temperature.

In this study, magnitudes of trend in rainfall, temperature and humidity patterns were determined using Mann-Kendall test, Spearman's Rho test (non-parametric methods) and regression analysis (parametric test). These methods assume a linear trend in variables of interest. For regression analysis, time is taken as the independent variable and rainfall/temperature as the dependent variable. The linear trend value represented by the slope of the simple least-square regression line provided the rate of increase/decrease in the variable. Trend analyses was undertaken for temperature (maximum and minimum), rainfall and humidity data using the Mann-Kendall, Spearman's Rho, linear regression and the t-test.

2. METHODOLOGY

Mann-Kendall Trend Test

The non-parametric statistical test Mann-Kendall (MK) is well suited for the assessment of trends in data over long time periods (Mann 1945; Kendall 1975; Thomas *et al*., 2015; Varghese et al. 2017). This test analyses the presence of a tendency of long period in meteorological data. The Mann-Kendall statistic S measures the trend in the data and is given mathematically as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(Xj - Xi) \qquad (1)$$

Where Xi and Xj represents data points at time i and j respectively The positive values of 'S' indicate an increasing trend, whereas negative values indicate a decrease in value over time. The strength of trend is proportional to the magnitude of S (i.e., larger the S value, stronger the trend). The sign of the difference between the consecutive sample sets is given by the following equations.

$Sgn(x_j-x_i) = +1$, if $x_j-x_i>0$ (2)

$Sgn(x_j-x_i) = 0$, if $x_j-x_i=0$ (3)

$Sgn(x_j-x_i) = -1$, if $x_j-x_i<0$ (4)

$Sgn(x_j-x_i)$ is an indicator function that results in the values 1, 0, -1 according to the sign of x_j-x_i where $j>i$.

The null hypothesis (H_0) is that the data are a sample of 'n' independent and identically distributed random variables without any trend in the time series. Using the Kendall probability table and by assessing the S result along with the number of samples 'n' we obtain the probability of rejecting the null hypothesis for a given level of significance, z which is given as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} \text{ for } S > 0 \\ 0 \qquad\qquad S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} \text{ for } S < 0 \end{cases} \qquad (5)$$

Z follows a normal probability distribution and it can be related to a p value using cumulative normal distribution tables to test the level of significance. When Z is positive and the computed probability is greater than the level of significance, there is an increasing trend. When Z is negative and the computed probability is greater than the level of significance, there is a decreasing trend.

$$Var\ (S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \qquad (6)$$

Where m is the number of groups with tied data in month; t_i is the number of tied data points of month i, n is the number of data points over the years for month i.

Spearman's Rho Test

This is a rank-based non-parametric test that determines the statistical dependence between the ranking of two variables. It assesses how well the relationship between two variables can be described using a monotonic function and is a rank-based version of the Pearson's correlation coefficient. The estimate is obtained in the same way as the Pearson correlation coefficient, but using ranks:

$$\gamma s = \frac{\sum_{i=1}^{n}\left[\left(Rank\ (x\mathrm{i}) - \overline{\mathrm{Rank(x)}}\right)\left(Rank\ (y\mathrm{i}) - \overline{\mathrm{Rank(y)}}\right)\right]}{\sqrt{\sum_{i=1}^{n}\left(Rank\ (x\mathrm{i}) - \overline{\mathrm{Rank(x)}}\right)^2 \sum_{i=1}^{n}\left(Rank\ (y\mathrm{i}) - \overline{\mathrm{Rank(y)}}\right)^2}} \qquad (7)$$

where rank(xi) and rank(yi) are the ranks of the observation in the sample.

Linear Regression Test

Linear regression test is a parametric test that assumes that the variables are normally distributed. It tests whether there is a linear trend by examining the relationship between time (x) and the other variable (y).

Student 't' test

This method tests whether the means in two different periods are different. The test assumes that the data are normally distributed. The whole time series of data is divided into two equal groups and then analysis is conducted to test the hypothesis.

The 't' statistic is calculated as

$$t = \frac{\bar{x} - \bar{y}}{s\sqrt{\frac{2}{n}}} \qquad (8)$$

Where $\bar{x}$ and $\bar{y}$ are the means of the first and second periods, n is the number of observations and s is the standard deviation of the sample.

3. DATA

Weather data (rainfall, temperature and relative humidity) reported by the National Centres for Environmental Prediction Climate Forecast System Reanalysis for a 31-year period from 1979 to 2010 have been utilized in this study. Data were available at varying resolutions, and 0.5 degree by 0.5-degree resolution chosen for analysis.

The monthly gridded reanalysis data for the Al Ain and Western area was obtained from NCEP (Figure 1) and a comparison was made based on the coefficient of determination (R^2) between the reanalysis and observed data. The National Center of Meteorology and Seismology of the Ministry of Presidential Affairs, UAE, publishes daily weather records for some 79 stations distributed over the UAE on its website (http://www.ncms.ae). The centre also publishes climate related data based on averages from 2003 to 2015 for air temperature, relative humidity, rainfall, wind speed and solar radiation for the locations shown on the following map (Figure 2).

Figure 1. Grid Locations (Source: Obtained from NCAR website)

The average monthly observed data for the same region was obtained from the National Centre of Meteorology and Seismology web site (http://www.ncms.ae/), with comparison only possible for monthly averages. The range of R^2 values obtained was 0.71-0.85 which indicates a strong linear relationship between the observed and reanalysis data. The R^2 values obtained for maximum temperature, minimum temperature and relative humidity was 0.77, 0.85 and 0.76 for Al Ain station. The R^2 values for the Western Region for maximum temperature, minimum temperature and relative humidity was estimated as 0.74, 0.82 and 0.71 respectively.

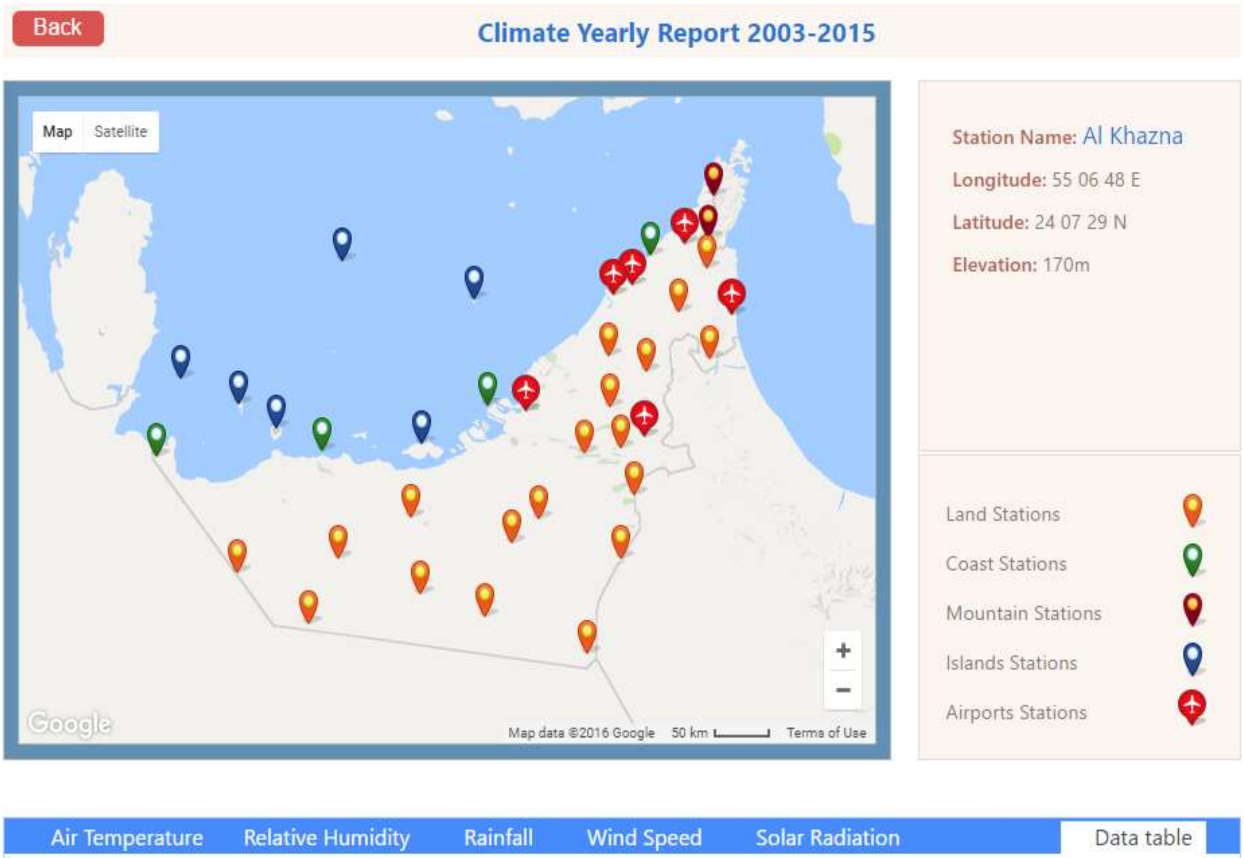

Figure 2: Weather station locations of the National Center of Meteorology and Seismology (Source: http://www.ncms.ae)

4. RESULTS AND DISCUSSION

Temperature

Changes in temperature affect water availability and demand and is therefore of critical importance in climate change studies. Over the period 1979-2010, the mean maximum air temperature was in the range of 30.2 to 32.5°C, with an average value of 31.5°C. The mean minimum air temperature ranged between 22.1 and 24.6 with an average value of 23.3 °C. The mean air temperature for the entire period was estimated as 27.4 °C (ranging between 26.4 and 28.5 °C).

Statistical characteristics of the mean, maximum and minimum monthly mean temperature obtained from the reanalysis data of NCEP for the period 1979-2010 are presented in Table 1. The region experiences maximum temperatures during July-August and minimum temperatures during January-February (Figure 3). Within the study region, temperature starts rising from March to

August. The mean monthly maximum temperature varies between 20.5 °C in February to 39.93 °C in August. The mean monthly minimum temperature varies between 14.6 °C in February to 30.65 °C in September (Figure 3).

Table 1. Statistical summary of monthly averages of maximum temperature, and minimum temperature

Month	Max Temperature (Degree Celsius)			Minimum Temperature (Degree Celsius)		
	Mean	Median	SD	Mean	Median	SD
January	22.36	22.56	1.25	15.92	16.04	1.11
February	20.50	20.11	1.12	14.56	14.40	1.03
March	23.03	22.84	1.48	16.60	16.70	1.39
April	27.12	27.30	1.59	20.04	19.95	1.19
May	32.46	32.85	1.44	24.19	24.06	0.98
June	37.07	37.29	0.87	27.31	27.36	1.13
July	39.18	39.09	0.78	28.66	28.47	1.13
August	39.93	40.15	0.70	30.55	30.44	0.84
September	39.45	39.60	0.63	30.65	30.63	1.02
October	36.79	36.69	0.56	27.85	27.85	0.62
November	32.59	32.73	0.74	23.88	23.92	0.79
December	27.02	27.02	0.78	19.24	19.26	0.90

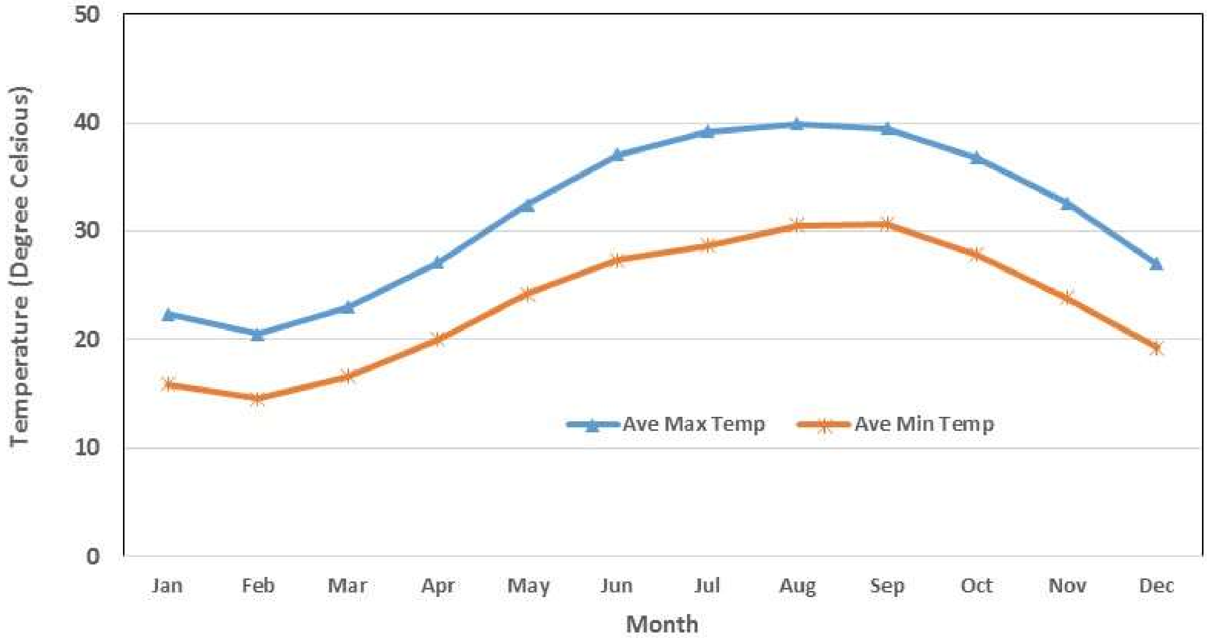

Figure 3: Average monthly maximum and minimum temperature in Al Ain

The maximum temperature trend analysis for the study period indicated a positive linear relationship between annual averages of maximum temperature and time (Figure 4), with a rate of increase of 0.04°C/year (0.4 degrees per decade). These results were confirmed using the Mann-Kendall test with a statistic value of 3.45, Spearman's Rho and the t-test. A sudden shift in trend was observed as of 1995. Average maximum temperature increased by 0.7°C between 1979-94 (31.1°C) and 1994-2010 (31.8°C). Temperature means between the two time periods were statistically different at $a < 0.05$ and reflect an increasing trend of 0.04°C/year. Average minimum temperature between 1979-94 was 22.9 and rose to 23.7°C between 1994-2010. The Mann-Kendal test yielded z-values of 3.45 and 3.68 for maximum and minimum temperatures, respectively, which indicates that variation is statistically significant at the 0.01 level. The Spearman's Rho test also yielded similar results.

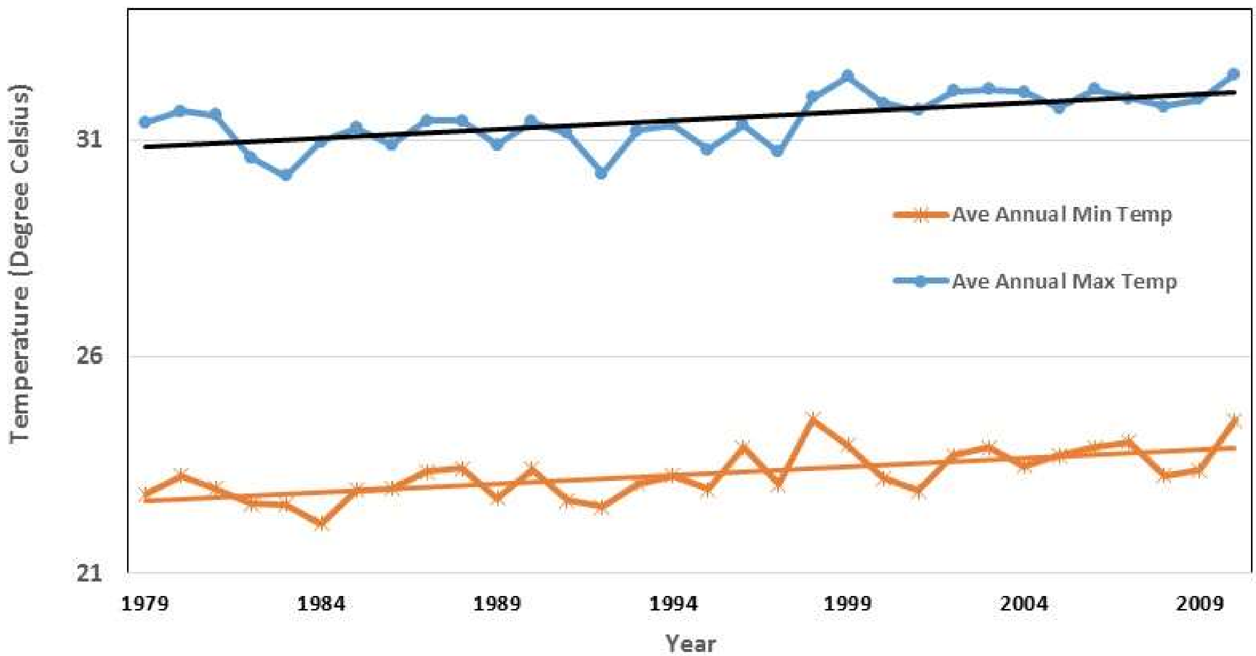

Figure 4. Trend detection of average annual maximum and minimum temperature

An analysis of average monthly maximum temperature indicates a statistically significant increasing trend for the months of January, March, April, June, July, Sept, Oct, Nov and Dec (Table 2). The analysis further indicates that trends in monthly maximum temperature are not statistically significant for February, May and August. Average monthly minimum temperature is statistically significant and increasing for the months of January, March, July, Sept, Oct, Nov and Dec (Table 3). Mann-Kendall statistic value varies between 0.56 in February to 3.84 in November. Maximum rate of increase in monthly maximum temperature was observed during the month of Jan (0.6°C per decade) and March (0.7°C per decade). Maximum rate of increase of monthly minimum temperature was observed during the month of March (0.6°C per decade). Mann-Kendall statistic value varies between 0.94 in February to 3.78 in December.

Table 2. Trend statistics of maximum monthly temperature at Al Ain

Months	**Mann-Kendall Z**	**Slope Q**	**Spearman's Rho Z**	**Linear regression t statistic**	**Student's t test**
Jan	2.676*	0.06	2.596*	2.766*	S*

Feb	0.568	0.01	0.753	0.464	NS
Mar	2.789*	0.07	2.582*	3.097*	S*
Apr	2.173**	0.06	2.172**	2.217**	NS
May	1.184	0.04	1.18	1.482	S**
Jun	2.741*	0.04	2.774*	2.451**	S**
Jul	1.8***	0.03	1.812***	1.873***	S***
Aug	0.908	0.04	0.855	0.741	NS
Sep	2.724*	0.03	2.774*	3.344*	S***
Oct	2.335**	0.03	2.486**	2.836*	NS
Nov	3.843*	0.05	3.829*	4.729*	S**
Dec	3.535*	0.05	3.515*	3.906*	S***

Table 3. Trend statistics of minimum monthly temperature at Al Ain

Months	**Mann-Kendall Z**	**Slope Q**	**Spearman's Rho z**	**Linear regression t statistic**	**Student's t test**
Jan	2.757*	0.06	2.69*	2.946*	S**
Feb	0.941	0.02	1	0.914	NS
Mar	2.497**	0.07	2.514**	2.584**	S*
Apr	1.378	0.04	1.635	1.693	S**
May	1.314	0.03	1.4	1.689	NS
Jun	1.249	0.02	1.137	1.047	NS
Jul	2.238**	0.05	2.276**	2.647**	S*
Aug	0.827	0.01	0.81	0.98	NS

Sep	2.416**	0.04	2.39**	2.504**	S***
Oct	2.043**	0.02	2.17**	2.255**	S***
Nov	3.422*	0.05	3.37*	3.926*	S**
Dec	3.778*	0.06	3.674*	4.475*	S**

Western Region

Over the period of 1979-2010 the mean annual maximum air temperature range was between 30.8 and 33.5°C with an average value of 32.3°C. The mean annual minimum air temperature range was 23.3 and 25.7 with an average value of 24.5 °C. The mean air temperature for the whole period was estimated as 28.4 °C (ranging from 27.2 and 29.5 °C).

Mean monthly maximum temperature varies between 21.0°C in February to 41.2°C in August. The mean monthly minimum temperature varies between 15.3°C in February to 32.1°C in August (Figure 5).

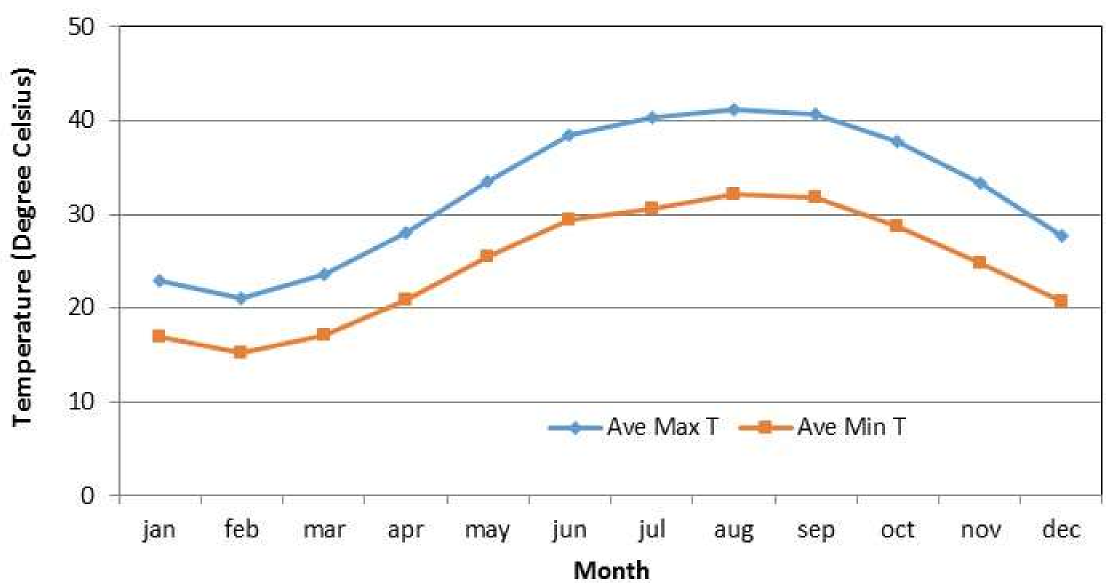

Figure 5. Average monthly maximum and minimum temperature in Western Region

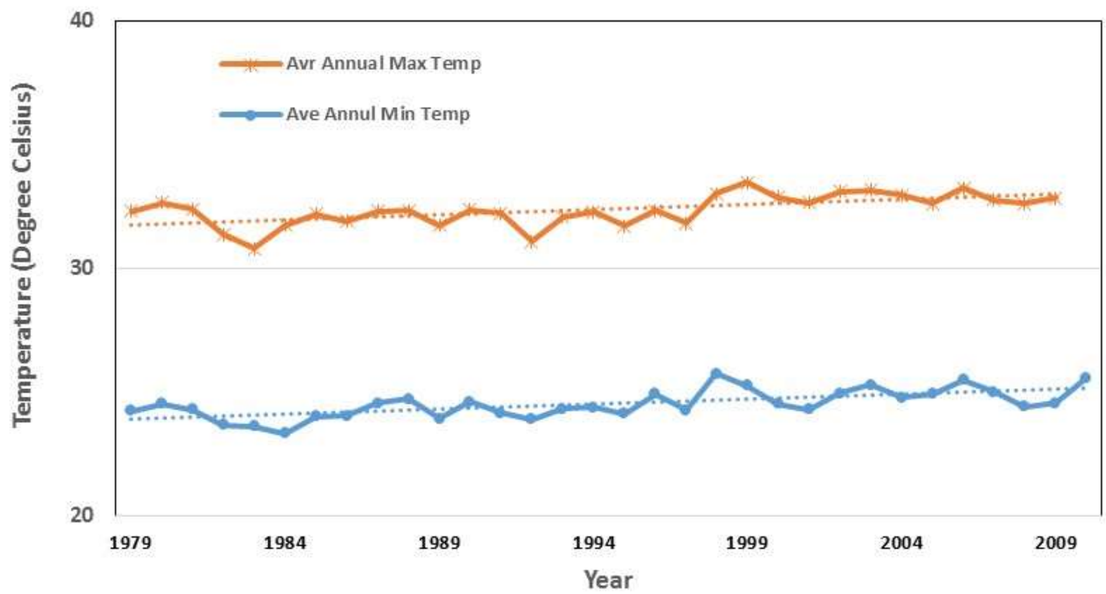

Figure 6. Trend detection of average annual maximum and minimum temperature – Western Region

The maximum temperature trend analysis for the study period indicates a positive linear relationship between annual averages of maximum temperature and time (Figure 5), with the rate of increase at 0.04°C/year (0.4 degrees per decade). The analysis showed significant positive trend at $a < 0.01$ with the MK statistic value of 3.58. Minimum temperature also showed a positive relationship with a rate of increase of 0.04°C/year and is statistically significant with the MK test statistic value of 3.88 at $a < 0.01$. Similar to the results in Al Ain, a sudden shift in the trend was observed since 1995 with average maximum temperature from 1979-94 of 32.0°C and from 1994-2010, 32.8°C – an increase of 0.8°C between the two periods and statistically significant differences in mean values at $a < 0.05$. Similar results were obtained for the t-test on average minimum temperature where the mean from 1979-94 was 24.1 and from 1994-2010, 24.9°C, with statistically significant differences at $a < 0.05$.

Table 4. Trend statistics of maximum monthly temperature within Western Region

Months	**Mann-Kendall z**	**Slope Q**	**Spearman's Rho Z**	**Linear regression t statistic**	**Student's t test**

Jan	1.962**	0.05	2.155**	2.127**	S**
Feb	0.47	0.01	0.543	0.505	NS
Mar	2.611**	0.08	2.423*	2.956**	S**
Apr	2.238**	0.06	2.253**	2.316**	NS
May	1.93***	0.05	1.949***	1.97***	S**
Jun	2.854*	0.04	2.894*	3.039*	S**
Jul	2.757*	0.04	2.847*	2.938*	S**
Aug	1.687***	0.02	1.825***	1.614	NS
Sep	3.892*	0.05	3.866*	4.516*	S**
Oct	3.065*	0.03	3.217*	3.631*	S**
Nov	3.519*	0.04	3.594*	4.155*	S**
Dec	3.681*	0.05	3.584*	4.016*	S***

Separate analyses were carried out for summer and winter seasons. Analysis of average maximum temperature during the summer season (June to September) revealed a rate of increase of 0.04 °C. These results were confirmed using the Mann-Kendall test, Spearman's Rho and the t-test. The results were similar for the summer season average minimum temperature. During the winter season, average maximum temperature showed a rate of increase of 0.05°C/year and the t-test results showed that the mean from 1979-94 was 27.3°C and from 1994-2010 was 28.2°C. With a difference of 0.9°C, both means were statistically different. Average minimum temperature showed a rate of increase of 0.4°C with a mean difference of 0.9°C between the two periods and statistically significant differences.

Table 5. Trend statistics of minimum monthly temperature at Western Area

Months	**Mann-Kendall z**	**Slope Q**	**Spearman's Rho z**	**Linear regression t statistic**	**Student's t test**
Jan	1.849*	0.04	1.904*	1.907*	S***

Feb	0.795	0.02	0.88	0.926	NS
Mar	2.157**	0.06	2.182**	2.316**	S*
Apr	1.2	0.03	1.476	1.547	S***
May	2.076**	0.04	2.157**	2.469**	S***
Jun	2.497**	0.03	2.386**	2.212**	NS
Jul	2.432**	0.04	2.374**	2.42**	S**
Aug	1.654***	0.03	1.914***	1.992***	S***
Sep	2.805*	0.06	2.992*	3.455*	S**
Oct	2.838*	0.03	2.786*	2.633**	NS
Nov	2.708*	0.04	2.798*	3.107*	S***
Dec	3.989*	0.07	3.866*	5.202*	S*

Rainfall

Annual rainfall trends between 1979 and 2010 for the Al Ain and Western Region are presented in Figure 7 and Figure 8. Historical data of rainfall indicates that the mean annual rainfall is 43 mm in the Al Ain region and there is high inter annual variability (between 2 mm and 162 mm) where as in the Western Region average annual rainfall was 32 mm and varies between 0 and 106 mm. In both locations annual rainfall data shows a declining trend, but one which is not significant at 95% level of confidence (MK statistic of -0.28 for Al Ain and -0.34 for Western Region). A maximum decrease of -4.5 mm/decade is observed at both Al Ain and Western Region. All four statistical tests suggest that the trend is not statistically significant.

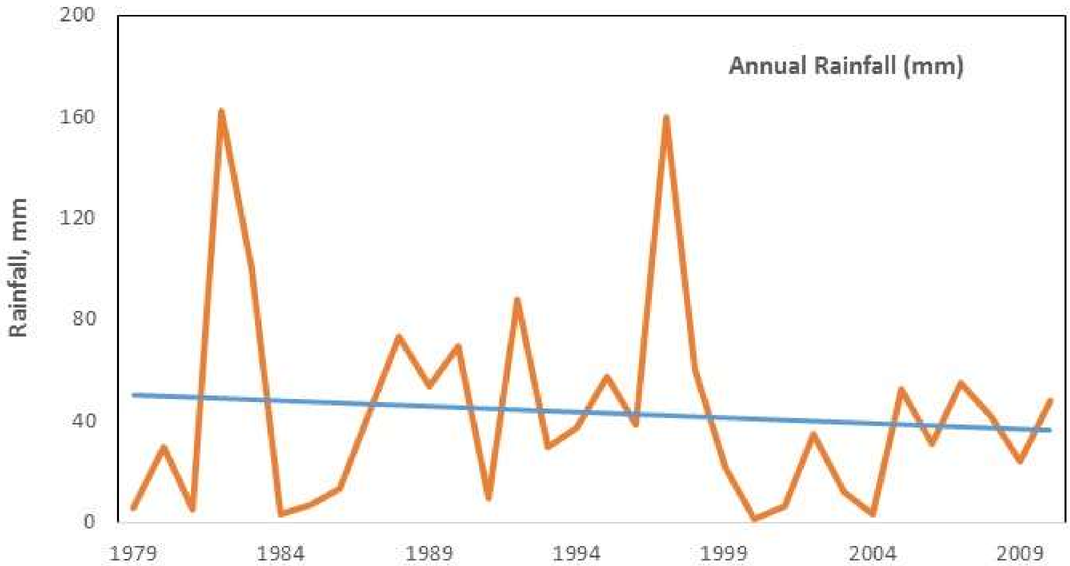

Figure 7. Annual rainfall trend in Al Ain

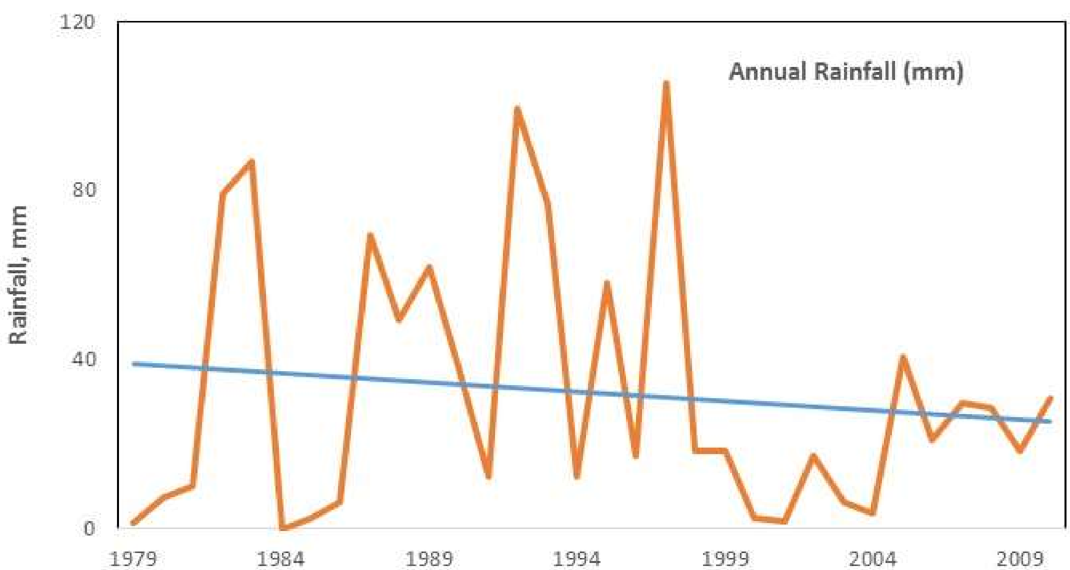

Figure 8. Annual rainfall trend in the Western Region

Humidity

Trend analysis was carried out for relative humidity for the two stations (Al Ain and Western Region), with a declining (not statistically significant at $a < 0.05$) annual trend over the entire period observed at both. Analysis of monthly data of Al Ain however showed a statistically significant declining trend during the months of March, April and August. Similar analysis in Western Region shows statistically significant declining trend during the months February, March, April, June, October and December.

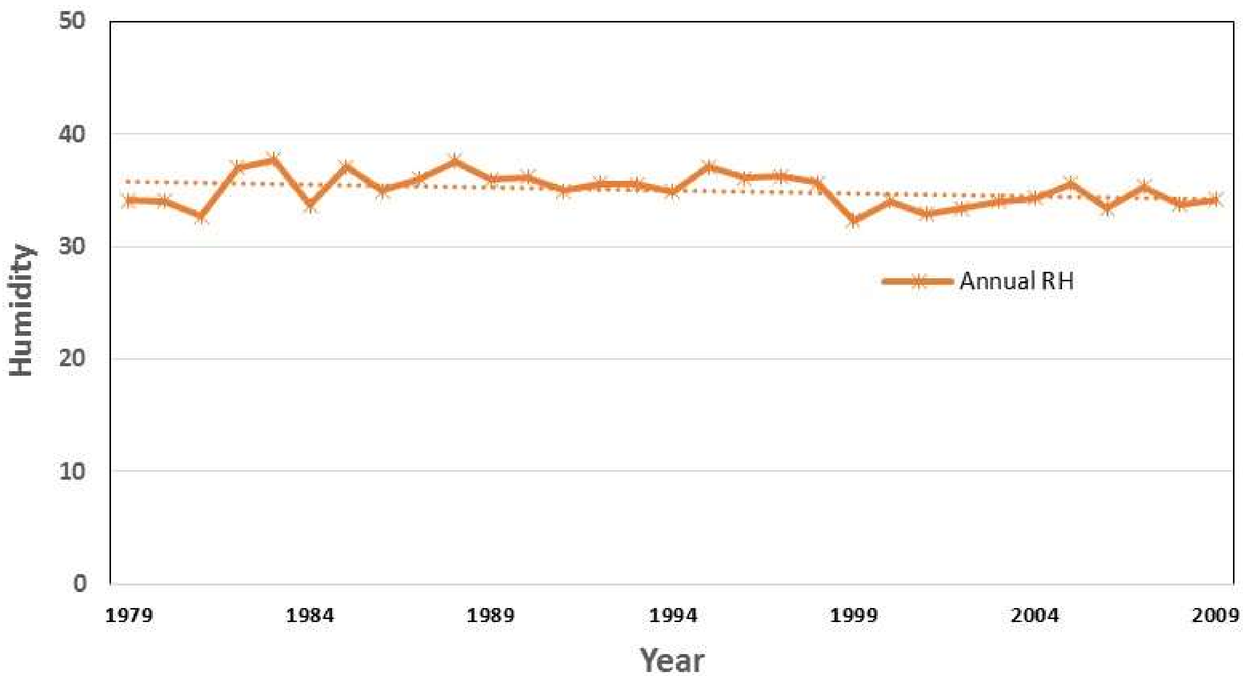

Figure 9. Average annual RH in the Western Region

Conclusions

The present study aimed to analyse the temporal trends in climate variables within the Abu Dhabi Emirates. Climate variables analysed were annual, seasonal and monthly maximum and minimum temperature, annual rainfall and annual and annual and monthly relative humidity. The non-parametric Mann-Kendall test and Spearman's Rho test and parametric linear regression and

Student's t tests were applied to each time series. Results shows that annual maximum and minimum temperature indicated a positive trend for both locations (Al Ain and Western Region) and is statistically significant, which were confirmed using the Mann-Kendall test. Seasonal analysis for Al Ain reveals that more significant trends happen in winter season than summer season. Similar results were obtained for Western Region.

An analysis of average monthly maximum temperature for Al Ain indicates a statistically significant increasing trend for the months of January, March, April, June, July, Sept, Oct, Nov and Dec whereas the minimum temperature is statistically significant and increasing for the months of January, March, July, Sept, Oct, Nov and Dec. Similar analysis of average monthly maximum temperature for Western Region indicates a statistically significant increasing trend for all the months except February whereas the minimum temperature is statistically significant and increasing for all the months except February and April.

The analysis of annual rainfall series present decreasing trends for both stations but not statistically significant. Seasonal trends were also not statistically significant. Trend analysis of annual average relative humidity for the two stations showed a declining (not statistically significant at $a < 0.05$) annual trend. The analysis was carried out using limited data that was available for the region. More detailed analysis on annual, seasonal and monthly maximum rainfalls, rainy days and wind speed is essential to draw more conclusions on climate change. The results also suggest further investigations using point measurements of meteorological variables could be useful in knowing the impacts of climate change in the Abu Dhabi Emirates.

References

Abeysingha N S, Singh M, Seghal V K, Khanna M and Pathak H. 2014. Analysis of rainfall and temperature trends in Gomti River Basin. Journal of Agricultural Physics. 14(1):56-66.

Ahmed W, Fatima A, Awan U A, Anwar A. 2014. Analysis of long term meteorological trends in the middle, lower Indus basin of Pakistan – A non-parametric statistical approach. Global planetary change 122 (2014): 282-291.

CRC for catchment hydrology, Australia, http://www.toolkit.net.au/

George BA, Davidson B, Nawarathna B, Ryu D, Malano H, Kulkarni A, Patwardhan A, Deshpande N, Pavelic P, Anshuman J, Kumar K. 2011. A modelling framework to evaluate climate change and watershed development impacts on water security. Proceedings of 19th International Congress on Modelling and Simulation (MODSIM), Perth, Australia.

IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Kendall MG (1975) Rank Correlation Methods. 4th edn. Charles Griffin, London.

Mann HB (1945) Nonparametric tests against trend. Econometrica 13:245-259.

NCEP Climate Reanalysis (CFSR) Monthly Products, January 1979 to December 2010 (ds093.2).

Thomas T, Gunthe, SS and Sudheer KP (2014) Analysis of monsoon rainfall variability over Narmada basin in central India: Implication of climate change. Journal of Water and Climate Change.

Varghese A, Hajilal M S, George B A. 2017. Analysis of temperature and rainfall trends in the Bharathapuzha basin, India. Nature, Environment and Pollution Technology (Accepted).

Zarenistanak M, Dhorde AG, Kripalini RH. 2014. Trend analysis and climate change point detection of annual precipitation and temperature series over southwest Iran. J. Earth Syst. Sci. 123 (2): 281-295.

APPENDICES

Table 1. Trend analysis of monthly relative humidity at Al Ain

Months	Mann-Kendall	Spearman's Rho	Linear Regression	Student t test
January	NS	NS	NS	NS
Feb	NS	NS	NS	NS
March	S*	S***	S**	S**
April	S**	S***	S***	NS
May	NS	NS	NS	NS
June	NS	NS	NS	S***
July	NS	NS	S***	S**
August	S***	S***	NS	NS
Sept	NS	NS	NS	NS
Oct	NS	NS	NS	NS
Nov	NS	NS	S***	NS
Dec	NS	S***	S*	S**

Table 2. Trend analysis of monthly relative humidity at the Western Region

Months	Mann-Kendall	Spearman's Rho	Linear Regression	Student t test
January	NS	NS	NS	NS
Feb	S**	S***	NS	NS
March	S**	S***	S***	NS
April	S**	S**	S**	NS
May	NS	NS	NS	S***
June	S*	S*	S*	S*
July	NS	NS	NS	NS
August	NS	NS	NS	NS
Sept	NS	NS	NS	S**
Oct	S**	S**	S**	S***
Nov	NS	NS	NS	S**
Dec	S**	S***	S**	S***

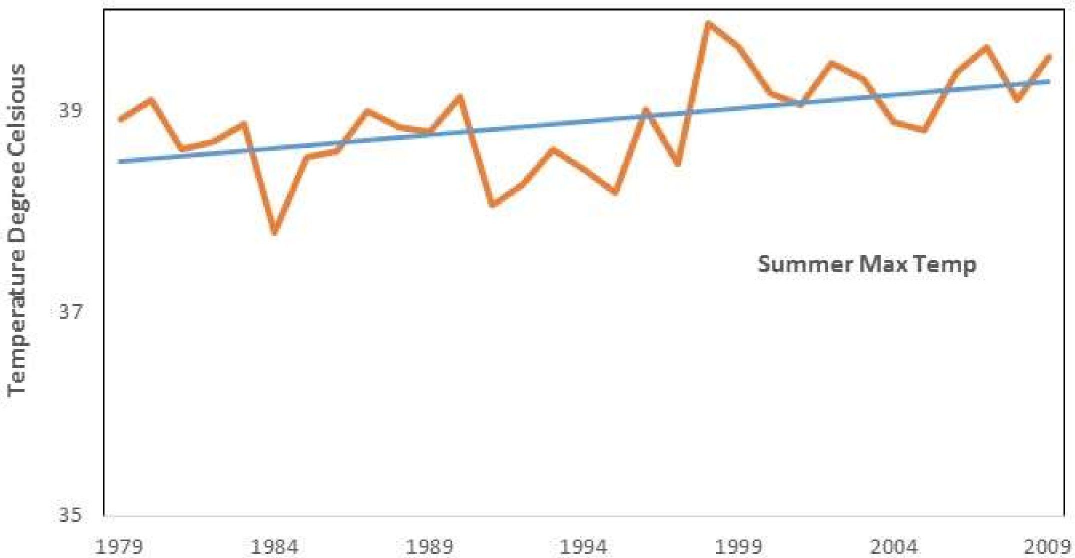

Figure 1: Trends of average summer maximum temperature in Al Ain

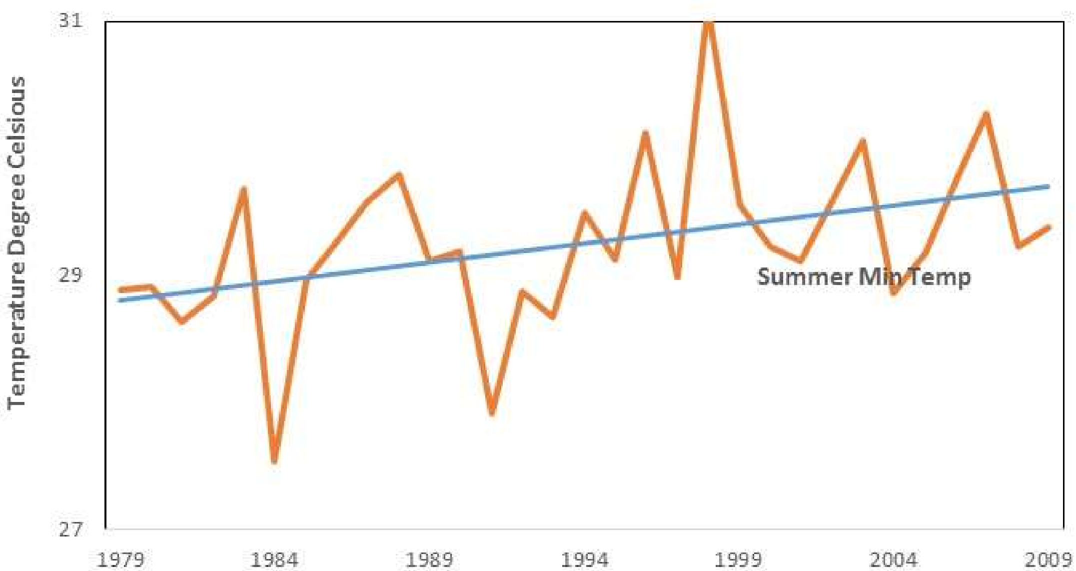

Figure 2: Trends of average summer minimum temperature in Al Ain

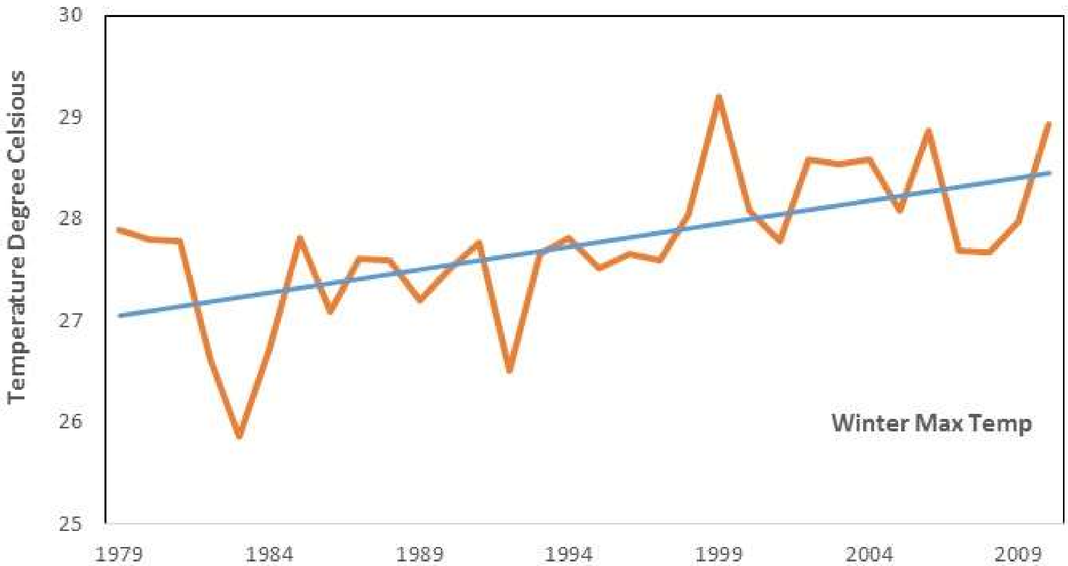

Figure 3: Trends of average winter maximum temperature in Al Ain

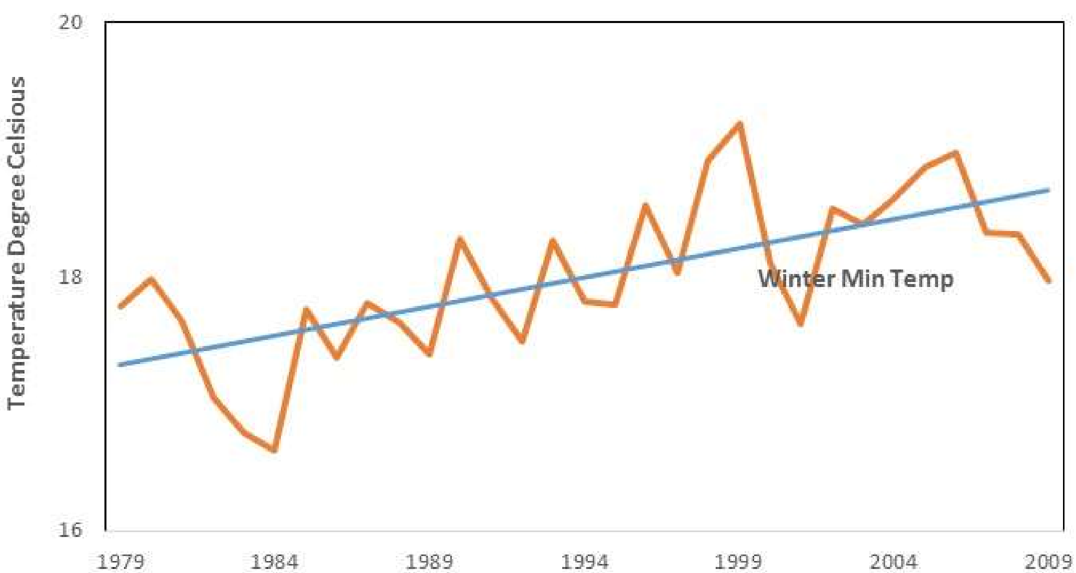

Figure 4: Trends of average winter minimum temperature in Al Ain

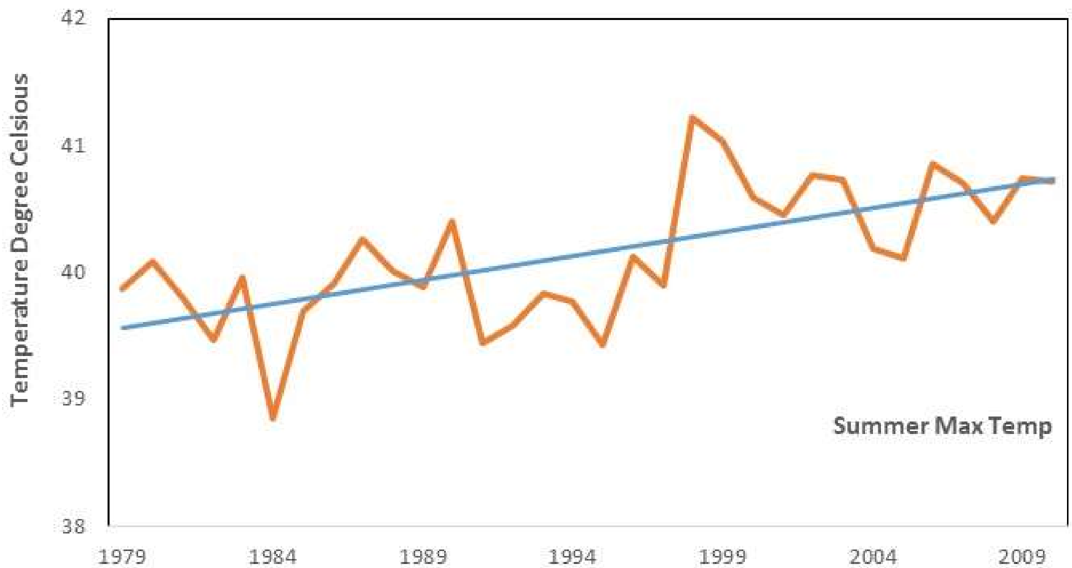

Figure 5: Trends of average summer maximum temperature in the Western Region

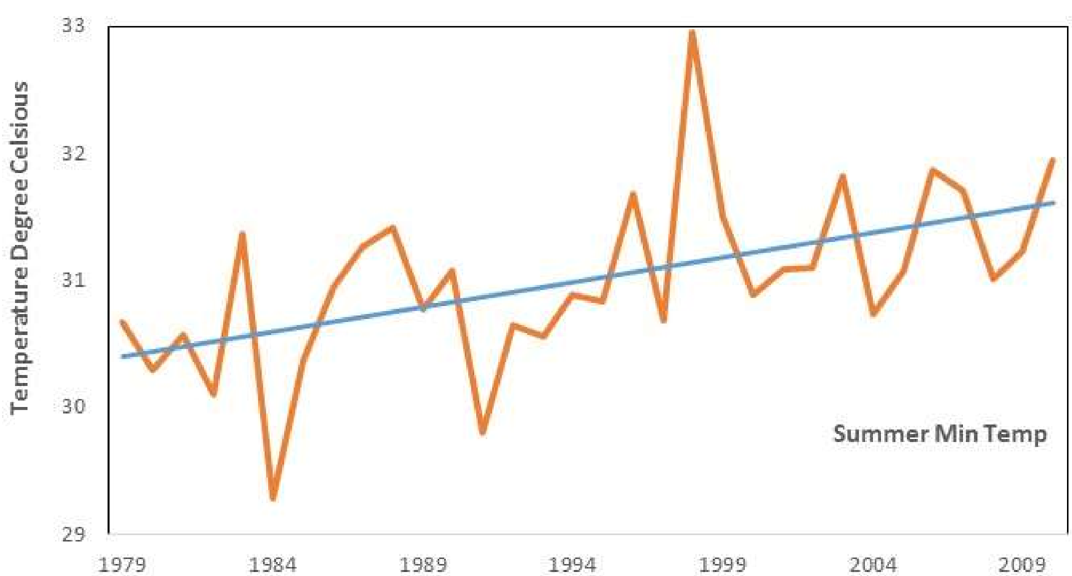

Figure 6: Trends of average summer minimum temperature in the Western Region

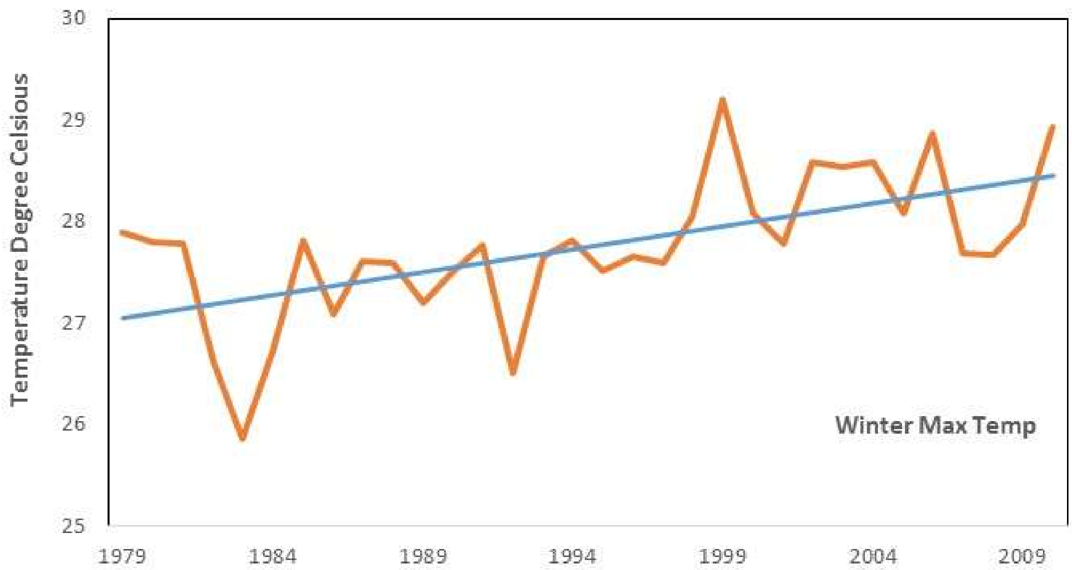

Figure 7: Trends of average winter maximum temperature in Western Region

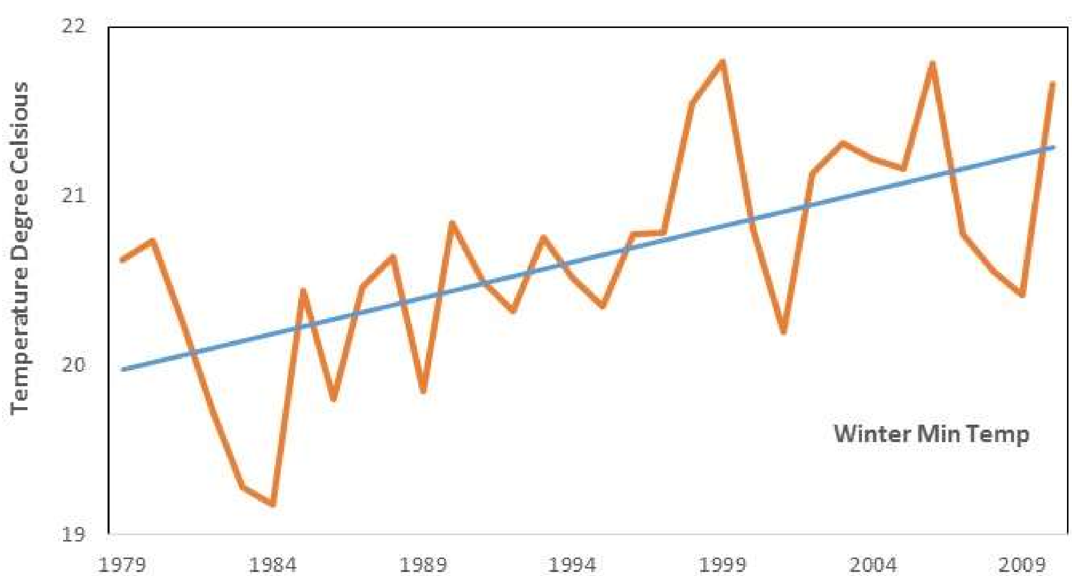

Figure 8: Trends of average winter minimum temperature in Western Region