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Changes in Observed Air Temperature in Kuwait from 2001 to 2016

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I. INTRODUCTION

Industrial Revolution during the 18th century gave rise to increased use of and dependence on fossil fuels. As a result, there is an observed increase in greenhouse gases and aerosols in the atmosphere. According to Intergovernmental Panel on Climate Change (IPCC) AR5, average global temperature increased by 0.85°C from 1880 to 2012 (IPCC 37). This warming is pointed out as a result of increased anthropogenic greenhouse gas emissions.

The Arab region is among the world's most vulnerable to the effects of climate change. The region is challenged by scarce water resources, very low precipitation and extreme events. Very high temperatures were observed recently, together with the increased strength of typhoons, high ocean water temperatures, more frequent heat waves, less but more intense rainfall, prolonged droughts, sea-level rise, more intense cyclones and changing rainfall and temperature patterns (Verner 11).

Temperature is one of the parameters assessed in the study of climate. Agencies, such as U.S.' National Aeronautics and Space Administration (NASA), look at the increasing average temperature as one of the evidence for climate change ("NASA Facts - Evidence"). Changes in temperature impact many sectors. Thus, it is important for up-to-date climatic information in any country for climate studies – to see patterns and assess whether the changes in climate factors are really occurring.

The analysis of trends is important in different sectors in the Arab region, especially agriculture, power generation, biodiversity, among others. In a study done by Abdirashid and Hassan regarding the trends in ambient air temperatures and its effect on soil temperature in Kuwait, the result showed that environmental conditions are not favorable to farming because of high temperatures, water scarcity and severity of land degradation. Generally, analyses of surface air temperatures use mean values; however, analysis of extreme events have been highlighted in the study of climate patterns. The study of extreme events involves minimum and maximum temperatures in which time series analysis usually attribute to microclimate at the site, among others (Lin and Hubbard 283).

Studies in the climatic trends are done in the Middle East (Zhang et al. 1; Nasrallah and Balling *Climate Change* 153), the Arabian Peninsula (Senafi and Anis 1; Nasrallah and Balling *Theoretical and Applied Climatology 245;* Almazroui et al. *Atmospheric Research* 29; AlSarmi and Washington 1329) and the countries in the region: Saudi Arabia (Athar 244; Almazroui et al. *International Journal of Climatology* 953), Iraq (Muslih and Blazejczyk 583), Bahrain (Elagib and Addin Abdu 269), Qatar (Cheng, Saleem and Sadr 193), Oman (Mohammed, John and Martin. 1), Sudan (Elagib 413), and Kuwait (Masrallah, Nieplova and Ramadan 357; Martin, Abdirashid and Hassan 1). These studies look at the trends in climate variables to find out whether climate change is already occurring. The studies conducted deal with spatio-temporal data, results of which are going to be discussed.

Studies on Temperature Trends in the Middle East

Zhang et al. studied the trends in 15 countries in the Middle East using a Kendall's tau-based slope estimator (4). Its significance was also determined using Kendall's test. Results showed that the increasing trends in temperature are statistically significant (5-11). The results of the temperature indices were also spatially coherent and related to the increases.

Nasrallah and Balling investigated the temperature records in the Middle East region from the period 1950-1990. The 40-year data showed high variance with statistically significant linear trend (*Climate Change* 156). The linear trend using a simple linear regression model revealed that the warming and cooling trends did not statistically increase the variance (157). The greatest warming occurred in the spring season, and the least amount was in winter (160). The results support the observations that the region is warming as greenhouse gas concentrations in the atmosphere increase as the increasing trends in the temperature in the region is statistically significant.

Studies on Temperature Trends in the Arabian Peninsula

Senafi and Anis studied the surface meteorology in the Northern Arabian/Persian Gulf using a 40-year period data (1973-2012). The study aims to: describe the climate variabilities in the Northern Gulf region based on the 40-year datasets of three countries and Shamal events and their effects on various meteorological parameters. Analysis suggested that the temperature in the area increased in the past 40 years and may continue to increase (4514). The variability observed in the parameters measured was suggested to be in response to natural convection patterns in the area (4524).

Nasrallah and Balling conducted a study in the Arabian Peninsula to determine the kinds of climate changes that are occurring in the desert zone using 40-year datasets. The results showed that temperature in the peninsula has increased by 0.63°C (250); however, the analysis of maximum and minimum temperatures in three stations revealed that there were no statistically significant trends in either maximum or minimum temperature recorded (251).

Almazroui et al. analyzed rainfall and temperature over the Arabian Peninsula using gridded data sets in the absence of on ground measurements (953). The researchers used regression trend analysis to discuss the temporal distribution of rainfall and temperature over Saudi Arabia (959, 961). The results showed that the observed temperature in the country is increasing. Mean, maximum and minimum temperatures are increasing at a rate of 0.60°C, 0.71°C and 0.48°C per decade, respectively. Inter-annual variability is found to be small, opposite of the decadal variations which are relatively large (965).

AlSarmi and Washington evaluated the trends in indices of daily temperature and precipitation recorded by the stations in the Arabian Peninsula. Results indicated that from 1970 to 2008, temperature trends revealed significant increase in warming extremes while cold extremes decrease (1335). The warming trend was also observed to be greater for daytime indices than for night-time indices. Minimum temperature also increased significantly over the region, same with the mean temperature (1338). The Diurnal Temperature Range was also found to be low and insignificant over the region.

Studies on Temperature Trends of Countries in the Middle East

Athar conducted a study on the variability in the observed temperature for the 30-year period from 1979 to 2008 recorded by 19 stations across Saudi Arabia. Results indicated that the increase in the daily maximum temperature is prominent that the increase of the daily mean and minimum temperature (248). Almazroui et al. conducted another investigation on the status of the climate in the Arabian Peninsula for a 32-year period from 1978 to 2009. Results showed that the mean, maximum and minimum temperatures increased (961); inter-annual variations are found to be relatively small, but the analysis of the decadal variations are the opposite (965).

Muslih and Blazejczyk analyzed the inter-annual variations and the long-term trends of monthly air temperatures in Iraq from 1941 to 2013. The study used monthly annual averages of mean, maximum and minimum air temperatures of seven stations across Iraq. The dataset covers a period of 73 years. Using a linear regression model, a general warming trend was observed across the stations. The correlation result suggested a strong positive relationship between the inter-annual variations and global temperature anomalies (588). The correlation was also statistically significant. The warmest year was recorded on 2010, which also corresponds to one of the warmest years recorded on a regional and global scale. The results pointed out a general trend of warming in minimum and mean temperatures (593); however, non-significant trends were also observed in the case of maximum temperature (591).

Elagib and Addin Abdu studied the temperature trends in the Kingdom of Bahrain from 1947 to 2005 using a linear regression to indicate the trend while a non-parametric test of Kendall tau was used to measure the correlations between the variables. Upwards trends were observed since the early 1990s (271). The wet season plays a larger part in the inter-annual variation, and this is consistent with the value of correlation by Kendall tau test. The annual and seasonal time series also showed positive trends with statistical significance for the warming during summer (272).

Cheng, Saleem, and Sadr investigated the long-term warming trend in the coastal region of Qatar using hourly data for a 30-year period from 1983 to 2012. Significant warming trends were observed, and this warming is reflected in the occurrence of warm days and nights, reduced number of cool days and nights, higher minimum temperatures during wet season, and increased frequency of hot days and nights during dry season (203-204).

Mohammed, John, and Martin analyzed the recent changes in temperature and precipitation for the Sultanate of Oman using a 34-year record of monthly minimum, maximum and mean temperatures for 1979 to 2012. Statistically significant increase in mean temperatures were observed, and minimum temperature coincided with the decrease in precipitation (4).

Masrallah, Nieplova, and Ramadan studied the warm season extreme temperature events in Kuwait from 1958 to 2000. The circulation pattern was examined, and a statistical analysis of incidence, including their duration and temporal variability was provided. The results showed that the highest numbers of both hot days and heat

waves were experienced during the last decade of the 20th century (366). During these periods, there were extremely high seasonal average of maximum temperatures observed.
Abdirashid and Hassan investigated soil temperatures under arid agro-ecosystem in Kuwait and included in their discussion air temperature analysis. The data during the study period showed that 2010 was the driest year and a sharp warming trend from 2012 to 2014 was also observed (2).

Objectives
The objective of this study is to examine air temperature trends in Kuwait based on 2001 to 2016 measurements from the synoptic station at Kuwait International Airport.

II. DATA AND METHODOLOGY

Kuwait lies in the northeast of the Arabian Peninsula, surrounded by Syrian and Arabian desert, and northwest of the Persian Gulf (MERI 3; Marcella and Eltahir 1097) (Figure 1). It has a semiarid desert climate with occasional winter rains (MERI 3; Marcella and Eltahir 1095). The country has four seasons: winter from December to February, characterized by great decrease in temperature, with clouds and rains and very cold Northwesterly wind; spring from middle of February to May characterized by moderate temperature with rains and thunderclouds and hot southerly winds; summer from June to November characterized by increased temperature and humidity and autumn from November to December characterized by moderate temperature with clouds and rains ("Climate of Kuwait").

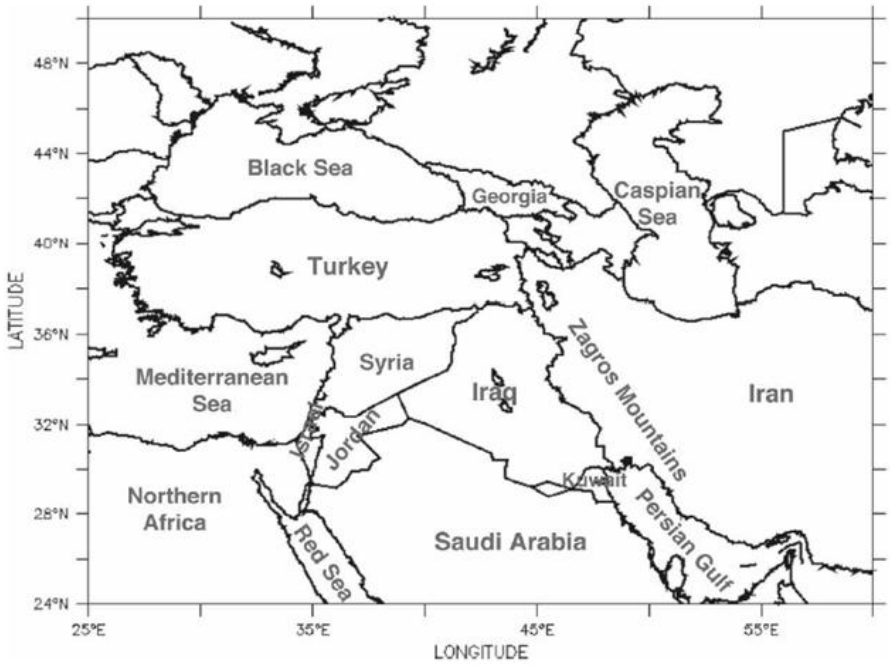

Figure 1. Middle Eastern countries and major bodies of water surrounding Kuwait (Marcella and Eltahir 1096)

Temperature data have been collected from 2001 to 2016 from the meteorological station located at Kuwait International Airport. The Kuwait International Airport, World Meteorological Organization Identifier 40582, is located in urban area (elevation = 55masl, latitude = 29.52N, longitude = 47.98E) ("Kuwait International Airport"). The Kuwait International Airport keeps continuous records of daily temperature, pressure, and precipitation since 1961 (Marcella and Eltahir 1097). Data obtained were summarized into mean, minimum and maximum monthly temperatures. Daily Temperature Range was also analyzed. It was calculated as the difference of average minimum and maximum temperatures measured.
Time trends were analyzed for annual and seasonal time series. Months were grouped according to the seasons based on the study of Almazroui et al.: winter from December to February (DJF), spring from March to May (MAM), summer from June to August (JJA), and autumn from September to November (SON) (16). Least squares linear regression together with non-parametric methods of Mann-Kendall test was used to establish the trend in time series to determine whether increasing or decreasing trends existed. The Mann-Kendall test does not have any presumption on the probability distribution of the data analyzed. This approach has been applied in statistical analysis of meteorological studies.

III. RESULTS

Monthly mean temperature per year is shown in Table 1. Monthly maximum temperature per year is shown in Table 2. Monthly minimum temperature per year is shown in Table 3.

Table 1. Mean Temperature at Kuwait International Airport, 2001-2016

YEARS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
2001	12.4	14.9	21.3	27.6	33.5	37.4	38.3	38.3	34.4	28.4	19.8	17.5
2002	12.9	15.3	21.1	25.5	33.3	37	39.4	38.9	35.5	29.2	20	15.1
2003	14.1	16.4	19.2	26.8	33.6	37.7	39	38.1	34.8	29.3	20.2	15
2004	15.2	15.9	22.2	24.6	32.2	37.6	38.9	38.5	33.6	29.3	21.7	12.1
2005	12.7	14.7	20	26.3	31.9	37.5	39.7	38.5	34.4	28.1	20.1	16.5
2006	13.5	15.9	21.2	26.3	34.2	38.5	40	39.1	34.2	29.9	19	11.1
2007	10.8	15.9	19.4	26.1	33.5	37.8	38.6	39.1	35.5	28.8	21.1	14.6
2008	10.4	14.5	23.6	28.1	33.2	37.8	39.2	38.4	34.9	28.5	19.7	13.6
2009	11.1	17.1	19.8	24.7	33.2	37.7	39	38.4	34.9	28.9	20.9	16.2
2010	15.9	17.7	23.1	27.3	33	38.5	39.6	38.1	35.5	30.2	20.3	15.3
2011	13.3	15	19.5	26.5	33.4	38.3	39.2	38.9	35.5	27.9	18.4	12.6
2012	12.8	14.9	18.5	26.3	34.3	38.6	40	39.6	35	29.5	21.3	15.8
2013	14	17.3	21.7	26.2	31	37.4	39.7	37.9	34.3	26.2	20.9	14
2014	12.9	14.4	20.9	27.8	33.2	37.7	39.7	38.5	35.6	29.3	19.5	15.8
2015	13.6	17.1	20.7	27.3	33.8	38.3	40.1	39.8	35.8	30.5	19.9	13.2
2016	13	16.8	22	26.2	33.8	38	39.8	39.6	35.3	28	19.9	14.8

Table 2. Maximum Temperature at Kuwait International Airport, 2001-2016

YEARS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
2001	22.5	27.3	37	39.4	45.5	47.6	48.3	50.5	47.5	41	37.5	28.1
2002	23.6	25.9	36	45.6	45.8	47.6	50.3	50	47	42.5	31.2	26.2
2003	25.7	27.5	30.1	44	44.9	47.1	49	49.5	48.5	44	33.8	25.5
2004	23.9	30.7	37.1	38.7	43.5	47.9	49.6	48.2	48	42.5	35.5	23
2005	25.2	24.9	31.2	42.9	47	49.4	50.5	49.2	47	41.7	33.1	28
2006	24	28.6	35.5	38.6	45.8	48.8	49.5	49.4	46.8	42.3	38.6	24.4
2007	22.6	31.3	32.5	43.5	46	47.8	50.2	49.3	47.5	41.2	35.3	29.4
2008	23	27.2	41.2	43.7	46.9	49.3	50.8	49.2	47	41.7	30.4	27.2
2009	22.5	28.4	34.4	42.4	48.1	49	47.7	49.5	45.9	40.5	35.5	24.4
2010	27	34.1	40.7	39.4	45.9	51	50.8	49.5	48.2	43.7	35.2	29.4
2011	26.1	27	35.2	38.5	48.3	49	51.1	50.4	46.2	41.5	35	24.3
2012	24.2	25.1	33.9	40.9	46.3	49	51.5	50.3	45.2	42.8	37.1	26.9
2013	25	29.2	36.6	38.6	45.2	47.2	50.5	48.6	47.5	43.2	31.1	28.6
2014	22.1	27.8	33	40.3	44.8	49.9	49	50.4	47.7	41.9	33.2	28
2015	30	33	33.5	41.4	46.8	49	50.9	49.5	46.5	44.7	29.3	29.8
2016	24.7	33.8	35.6	43	46.2	50.7	51.5	51.3	48.9	40.1	39.5	29

Table 3. Minimum Temperature at Kuwait International Airport, 2001-2016

YEARS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
2001	1.9	2.5	9.7	14.3	19	25	25.9	24.8	19.4	16.8	1.7	7.1
2002	2	3.7	7.8	13.9	20.1	23.3	27	26.7	21.9	16.5	8.8	4
2003	3.3	6	2.8	13.1	21.6	26	25.3	25.4	21.5	16	4.5	4.6
2004	4.3	5.6	6.4	12.3	19	24.2	23.8	22.5	19.9	18.5	4.5	2.1
2005	3	3	9.9	12.4	16.2	23.1	25.6	25.6	21.6	13.6	8	2.8
2006	2.5	6.3	7.4	14.5	22.5	22.3	27.9	27.6	20	18.6	4.2	1.8
2007	-0.4	4.9	8.1	14.7	21.6	25.3	26.3	25.5	19.8	15.7	3.7	0.2
2008	-1.5	1.2	8.6	14	20.2	25.7	24.1	25.2	22.8	15.1	9.8	-0.2
2009	-1.6	4.5	6.5	12.2	20	24.6	27.3	26.5	21.1	17.2	7	7.9
2010	2.6	1.5	9.3	14.5	20.1	24.5	27.9	27.1	22.8	16.5	6.3	2.1
2011	1	1.2	6	13.2	18.8	26.2	26.3	26.3	22.6	13.6	4.4	0.6
2012	-1.2	3.4	4.6	12.1	24.4	27	27.1	26.5	20.4	14.8	11.1	5.6
2013	1.1	7	7.1	13.3	19.1	26.3	26.6	26.5	17.2	11.2	11.8	1.6
2014	4.2	1.6	9.1	8.9	18.6	23.7	26.7	27.4	22.2	14.8	6.1	2.3
2015	1	2.4	6.6	10.4	21.7	25.5	27.4	28.5	21.8	18.2	9.1	2.5
2016	-0.1	1.5	10.3	10.9	17.2	20.6	26.6	28.2	22.3	17.1	6.2	1.3

The annual mean, minimum and maximum temperatures measured at the meteorological station in Kuwait is presented in Figure 1. The average temperature recorded was 51.5°C during 2012 (Figure 1a). Average yearly temperature ranged from 10.4°C to 40.1°C (Figure 1b). The lowest average temperature recorded was -1.6°C in 2006 (Figure 1c). The 16-year mean annual maximum and minimum temperatures are 39.6°C and 14.1°C, respectively.

Figure 2 shows the average monthly temperatures at the Kuwait International Airport from 2001-2016. The observed temperatures reflect the seasons – the lowest temperatures were observed during winter (December to February) while the highest temperatures were observed during summer (June to August). Table 4 shows the seasonal average temperature at the study site, which corresponds to the characteristics of the seasons suggested by Almazroui et al.

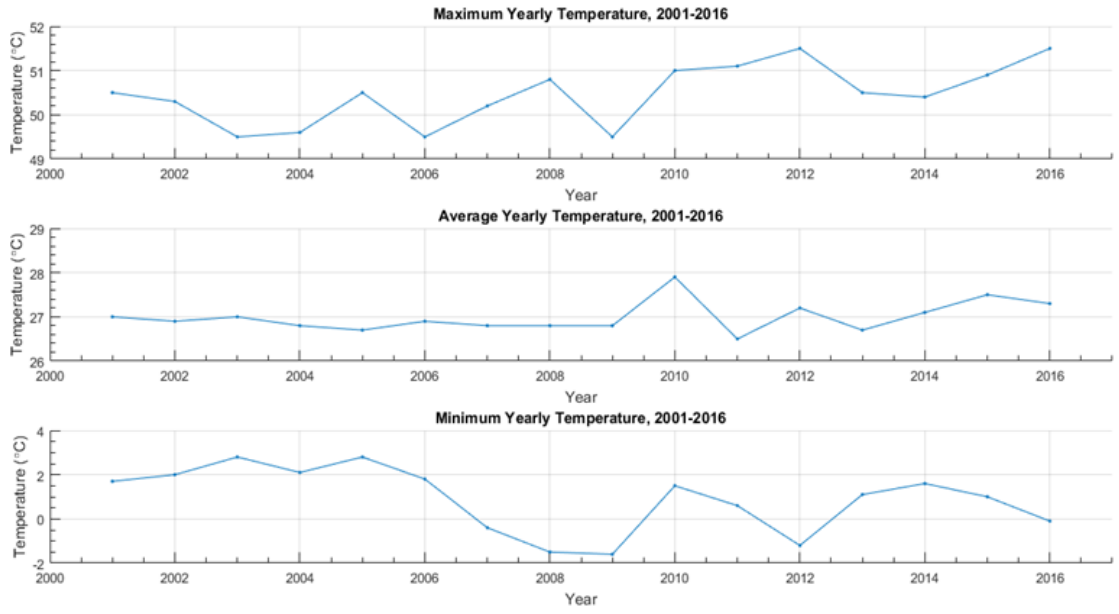

Figure 1. Observed temperatures over Kuwait from 2001 to 2016.

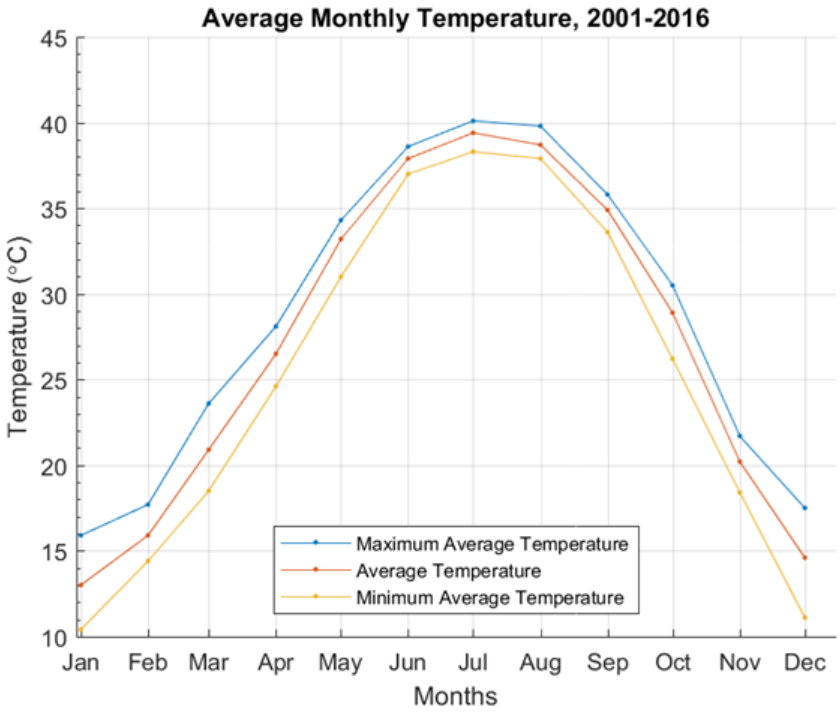

Figure 2. Average monthly temperatures in Kuwait from 2001-2016

Table 4. Seasonal average temperatures in Kuwait from 2001-2016

Months	T_{Min}	T_{Ave}	T_{Max}
DJF	-0.2	14.5	31.3
MAM	9.3	26.9	44.4
JJA	22.3	38.7	51.27
SON	10	28	44.37

The average Diurnal Temperature Range is from 17.9°C to 32.6°C. The average of the whole dataset is 25.53°C. Figure 3 shows the yearly average of Diurnal Temperature Range. The highest of which is observed in 2016 followed by 2010 while the lowest is 2009. Decreases in DTR mean that the maximum temperature has not increased or increased slightly whereas the minimum temperature increased faster.

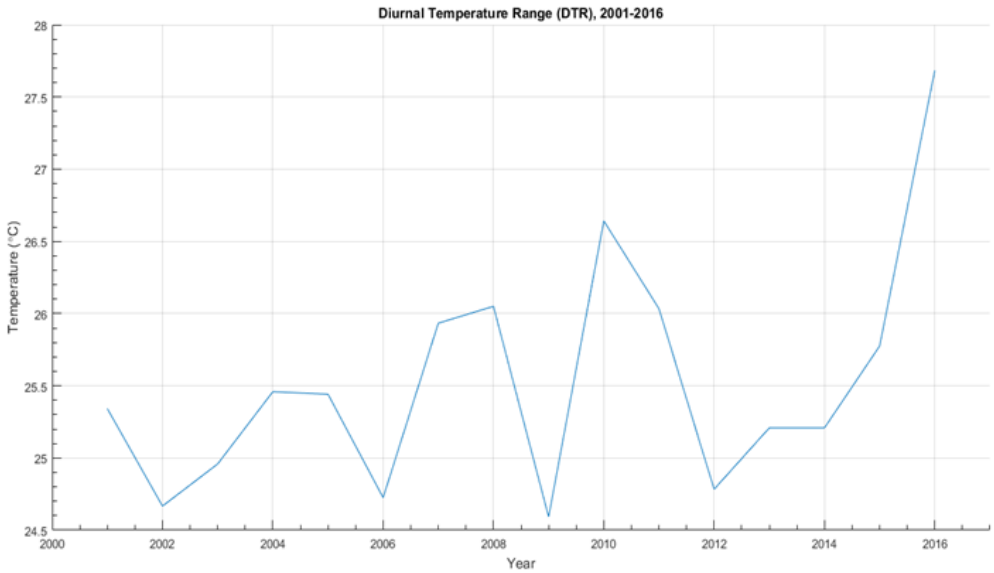

Figure 4. Diurnal Temperature Range in Kuwait from 2001-2016

Results of the statistical analysis is shown in Table 2. Results of simple linear regression reveal that there is a statistically low warming trend for minimum (R^2=0.19), mean (R^2=0.12) and maximum temperatures (R^2=0.35). Almazroui et al. used the combination of standard deviation and R^2 to look at the inter-annual variability of the trend (*International Journal of Climatology* 961). According to the study, relatively small standard deviation values and higher $R^2$is indicative of lower inter-annual variability in the temperature. In this case, relatively big standard deviation and low R^2 might have high inter-annual temperature variability.
Results of Mann-Kendall Test also reveals that the warming trends observed are statistically insignificant with p values greater than 0.05, except mean temperatures. Mean temperatures are found to be statistically significant with p value greater than 0.05.
Statistical analysis for Diurnal Temperature Trend is shown in Table 5. Diurnal Temperature Trend is also observed to have a low positive trend (R^2=0.20) with low standard deviation. Mann-Kendall Test shows that the warming trend observed is statistically insignificant.

Table 5. Statistical Analysis of Observed Temperature

	T_{Min}	T_{Ave}	T_{Max}	DTR
Standard Deviation	±9.32	±9.14	±9.53	±3.31
RMSE	25.4	1.589	4.4	8.0
R^2	0.19	0.12	0.35	0.20
Mann-Kendall Coefficient	0.16	0.43	0.09	0.09
p value	0.41	0.02	0.65	0.65
Z	0.81	2.31	0.45	0.45
Sen's slope	0.19	0.48	0.32	0.21

IV. DISCUSSION

In the maximum temperature presented in Figure 1, the highest temperature was in 2016. According to NOAA's "Global Climate Report", Kuwait recorded one of the highest temperatures in the Asian region. In 2016, Kuwait set a new recorded for the hottest temperature reaching 54°C for the Eastern Hemisphere and Asia on 21 July 2016 ("WMO examines reported record temperature of 54°C in Kuwait"). Heatwaves occurred in Middle East during this period. The next hottest year was 2012. According to NOAA, 2012 was one of the ten warmest years on record globally ("2012 was one of the 10 warmest years on record globally"). The recorded global high temperature coincides with one of the maximum temperatures recorded in Kuwait.
Studies on changes in temperature trends generally use long-term data sets to look at the climate variabilities. The trends, which include the seasonal, inter-annual and decadal trends, are included in the analysis. Literature cited in the preceding sections look at temporal averages using more than 40-year datasets. The results of the linear regression analysis and Mann-Kendall Tests reveal a statistically weak and insignificant warming trend for minimum and maximum temperatures while significant trend for average temperatures. This result coincides with the result of the study made Liebmann et al. (1490). Analysis of trends shorter than a few decades are not statistically significant. It is important to note, however, that the models may not reflect the true behavior of the system.

V. CONCLUSION

This study looks at the trends in recorded temperature in Kuwait International Airport. The mean, minimum, maximum temperatures of the 16-year data were used in the analysis. Annual trends were investigated using simple linear regression test and non-parametric Mann-Kendall Test.
Average yearly temperature ranged from 10.4°C to 40.1°C. Average minimum temperature in Kuwait can reach up to -1.6°C while the average maximum temperature can go up to 51°C. The 16-year mean annual maximum and minimum temperatures are 39.6°C and 14.1°C, respectively. The measured temperatures reflect the seasons – the lowest temperatures were observed during winter (December to February) while the highest temperatures were observed during summer (June to August). The average Diurnal Temperature Range is from 17.9°C to 32.6°C. The average of the whole dataset is 25.53°C. The highest of which is observed in 2016 followed by 2010 while the lowest is 2009.
Results of simple linear regression reveal that there is a statistically low warming trend for minimum (R^2=0.19), mean (R^2=0.12) and maximum temperatures (R^2=0.35). The relatively big standard deviation and low R^2 might have high inter-annual temperature variability. Results of Mann-Kendall Test also reveals that the warming trends observed are statistically insignificant with p values greater than 0.05, except mean temperatures. Mean temperatures are found to be statistically significant with p value greater than 0.05. Diurnal Temperature Trend

is also observed to have a low positive trend (R^2=0.20) with low standard deviation. Mann-Kendall Test shows that the warming trend observed is statistically insignificant.

The use of 16-year recent data may not have revealed the underlying warming trends observed in the different countries in the region. Studies on changes in temperature trends generally use long-term data sets to look at the climate variabilities. The results of the linear regression analysis and Mann-Kendall Tests reveal a statistically weak and insignificant warming trend for minimum and maximum temperatures while significant trend for average temperatures; however, it is important to note that the results of the study for the recent decade is not indicative of the true status of the climate in Kuwait. For further analysis, it is recommended that spatio-temporal analysis will be done. Using measured datasets from different stations and longer periods of more than 30 years, statistical analysis must be done. In the absence of on ground observations, the use of gridded datasets or satellite measurements are suggested to capture the warming trends described in other studies truly. As the measurements are only reflective of the site where it was located, using one site as basis for analysis will not be conclusive. Further studies on other climate variables are also encouraged. Air temperature is just one of the indicators of a changing climate. Looking at the relationship of air temperature and other variables, such as precipitation, humidity, cloud cover, solar intensity, among others, can give a better understanding of the climate trends in the country. Using other variables can also give a more holistic view on warming and climate change.

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