Impact of Climate Change upon SummerHeat waves in Jordan

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Abstract: Summer heat waves in Jordan are analyzed for the period 1960- 2010. Meteorological data for six main climatic stations distributed throughout the country and representing the main climatic regions of Jordan are used. Various statistical techniques including t- test, regression lines, moving averages and CUSUM charts are used to test the main hypothesis of this paper regarding recent trends of monthly maximum temperature, heat wave frequency, length and intensity. Findings of this paper illustrate that, due to the impact of climate change in the Eastern Mediterranean, summer heat waves in Jordan are becoming more frequent, longer and more intense. The coefficients of variation of those characteristics during the period 1995- 2010 are greater than the coefficients of variation for the period 1980-1994. Monthly average maximum temperature shows increasing trends for all stations and for all of the three summer months.
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Key Words: Heat Wave, Thermal Discomfort, Atmospheric Trough, Air mass.

1. Introduction

A heat wave is a prolonged period of excessively hot weather. However, the definition of heat wave varies from one region to another depending on the main characteristics of the region's climate. Defining ofa heat wave and estimating thresholds for its beginning and end has been discussed by several studies (Karl and Knight, 1997). The definition of a heat wave recommended by the World Meteorological Organization,

The **World Meteorological Organization** is an intergovernmental organization with a membership of 188 Member States and Territories. It originated from the International Meteorological Organization , which was founded in 1873 is when the daily maximum temperature of a minimum of five consecutive days exceeds the average maximum temperature by 5 °C (9 °F). However, the definitions adopted by various countries and recommended by several authors differ from the definition adopted by the WMO. The definition adopted for a heat wave, in this research, is when daily maximum temperature for three consecutive days exceeds the average maximum temperature for that period of the year by 5 °C at least. This definition was found more appropriate for Jordan, because more than 68% of heat waves that strike Jordan during the three summer months are 3-4 days long.

Since human activities related mainly to industry, transportation and other human activities are responsible for the change in the chemical composition of the atmosphere**,** and that these activities show increasing trends, the artificially induced climatic trends are becoming one of the most widely speculated aspects of climate during the twentieth century (Karl, T., op. cit). Various trend-detection studies have been carried out in different parts of the world, mostly for identification of global warming. Some of these cases have shown significant increasing trends, especially during the last 40-year period (Meehl, 2004).

The Mediterranean region is one of the most susceptible places to climate change. It is considered by several authors as a "hot spot" of climate change (Kuglitsch, et. al., 2010). During the last six decades, summers in the Eastern Mediterranean became warmer with an increase in the recurrence and intensity of heat waves.

A regional climate model developed by the International Center for Theoretical Physics at Trieste, Italy, revealed that the average temperature over the Mediterranean region has increased by 1.5 – 4^{o}C in the last 100 years and is expected to increase by about 4^{o}C to 6^{o}C by the end of this century (Alpert, et.al., 2008). As Evans states that 18 global climate models participating in the Intergovernmental Panel on Climate Change Fourth Assessment Report predict an overall temperature increase in the Middle East of 1.4 K by mid-century, increasing to almost 4 K by late-century.The temperature increase in the Mediterranean is predicted to be greater in summer than in winter and will reach 5^{o}C at the end of this century (Alpert, et. al., 2008).

Bani Domi (2005) has found, when analyzing mean annual minimum and maximum temperature records in Jordan for the period 1964 – 1999, that all these records showed warming trends(Bani Domi, 2005).

Heat waves have been affectedby global warming, and are expected to be affected more in the future. Projections of most recent global climatic models reveal that there is a distinct geographic pattern to future changes in heat waves. Those models, also, predict that, due to the warming trend, heat waves will become more intense, longer lasting, and more frequent in the 21 century. (Meehl,,et. al., op. cit., IPCC, 2007)

Some regions of the world like inland deserts and Mediterranean-type climates

Earth is the third planet from the Sun. Earth is the largest of the terrestrial planets in the Solar System in diameter, mass and density. It is also referred to as *the World* and *Wiktionary:Terra*.Note that by International Astronomical Union convention, the term "Terra" is used for naming extensive land masses, rather will are expected to become more susceptible to heat waves than others. The Mediterranean area is also expected to experience a large number of extremely hot temperature events, an increase of summer heat wave frequency and duration, and increasing summer temperatures (Türkeş et al., 2002, Kostopoulou and Jones, 2005, Giorgi, F. 2006Della et al., 2007.

Kuglitsch found by analyzing maximum daily temperature for 246 stations, located in the Eastern Mediterranean, during the period 1960- 2006 that heat waves in the area have increased by 8%. He also, found that heat wave intensity has increased by a factor of 7.6% (Kuglitsch. et al., 2010).

Since Jordan has two main types of climate; the Mediterranean climate in the central and northern regions and the desert or semi- desert in the east and south, summer heat wave frequency and intensity are expected to increase. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), issued in 2007, has pointed out that heat waves are very likely to become more frequent in subtropical areas (IPCC, 2007).

2.Experimental

1.1 Synoptic Conditions Leading to Heat Waves in Jordan

Synoptic conditions leading to the occurrence of heat waves in Jordan have been studied before by several authors (Shehadeh, N.A., 1990, 1991, Sabri, A., 2001). One of the major studies that analyze heat wave changes in the Mediterranean area for the period 1960-2006 is that of Kuglitsch, F.G.,*et al.,*. alop.cit.,).

The synoptic conditions leading to heat waves that invade Jordan are classified into three main categories.

a. The Saudi thermal depression which forms during the summer over the northern region of the Arab Peninsula, especially when that depression deepens and merges with the Arabian Gulf depression and extend northward. More than 54% of the heat waves that invade Jordan during the summer season are attributed to this factor (Alpert et al.,2008).
b. The upper atmospheric ridges that form in the upper atmosphere over northern Africa, especially when these ridges extend northward. 40% of the heat waves that invade Jordan during the summer season are attributed to this factor (Bani- Domi,M., 2005).
c. The Khamasini depressions that travel eastward along the northern African shore, especially when Jordan comes under the influence of the warm front of the depression. This factor is responsible for heat waves that occur in late Spring and early Fall seasons.

1.2 Study Importance

Jordan is considered one of the four most arid countries in the world. Therefore, droughts, heat waves, lack of rain and water scarcity are no new phenomena. Heat waves and lateness or sheer absence of rain have become normal phenomena during the last three or four decades.

Most previous studies on expected temperature change in the Mediterranean region, including Jordan focus either on changes in mean monthly maximum temperatures, diurnal temperature ranges, temperature percentiles, count series above absolute or percentile based thresholds, and do not specifically focus on changes in heat wave number, length and intensity (Türkeş et al.,op. cit., Founda et al., op. cit., Kostopoulou and Jones, 2005; Della Marta et al., 2007). With the projected increase of temperature, whether on global or regional scale, it is reasonable to suppose that heat waves in the eastern Mediterranean generally and in Jordan particularly will increase in frequency, severity, duration, or areal extent in the future (Meehl, G.A., &Tebaldi, C., 2004).

1.3 Research Problem

The research problem of this paper could be summarized in the following questions:

1. Is their a significant positive trend of average maximum monthly temperature during the period 1980 - 2010?
2. Did the climate change cause a significant increase in the total number of summer heat waves in Jordan during the period 1980 - 2010?
3. Did the climate change enhance significantly the intensity of summer heat waves during the period 1980 - 2010?
4. Did the climate change cause a significant increase in the length of heat waves during the period 1980 - 2010?

1.4 Research Hypothesis

The four alternative hypothesis of this study are:

1. There has been a significant increase in the total number of summer heat waves in Jordan during the period 1980 – 2010.

2. There has been a significant increase in the intensity of summer heat waves in Jordan during the period 1980 – 2010.
3. There has been a significant increase in the length of heat waves in Jordan during the period 1980 – 2010.
4. Average maximum monthly temperature during the period 1980 – 2010 shows a significant positive trend?

1.5 Study Area

Jordan is located in Southwest Asia, south of Syria, west of Iraq northwest of Saudi Arabia and east of Israel and the West Bank. The country consists mainly of a plateau between 700 and 1,200 meters high, and a few mountainous areas .

1.6 Climate

Most of Jordan, especially the central and northern regions, has Mediterranean climate characterized by considerable contrast between hot, dry summers and cool winters during which practically all of the precipitation occurs. In general, the farther inland from the Mediterranean Sea a given part of the country lies, the greater are the seasonal contrasts in temperature and the less rainfall. Atmospheric pressures during the summer months are relatively uniform, whereas the winter months bring a succession of Mediterranean cyclones. These cyclones generally moving eastward over the Mediterranean result in sporadic precipitation. The country's long summer reaches a peak during August.

1.7 Temperature Regime

The country's long summer reaches a peak during August. January is usually the coolest month. The fairly wide ranges of temperature during a twenty-four-hour period are greatest during the summer months and have a tendency to increase with distance from the Mediterranean seacoast. Daytime temperatures during the summer months frequently exceed 36 °C (96.8 °F) and average about 32°C. In contrast, the winter months—November to April bring moderately cool and sometimes cold weather, averaging about 13 °C.

1.8 Data Collection

Climatic data for six main climatic stations that represent all the geographic regions of Jordan and far from being affected by heat island are used in this study. The data include maximum and average daily temperature, as well as mean monthly temperature for the period 1980- 2010. The main sources of the data are the Meteorological Service of Jordan and the following electronic site: http://www.tutiempo.net/en/Climate/Jordan,Asia.

2. Methods of Analysis

Different techniques, such as parametric and non-parametric tests, are used for testing whether there have been statistically significant trends. The statistical techniques used in this research to study trends are:

1. t- test
2. Moving averages
3. Linear regression
4. CUMSUM Charts

2. 1 t- test:

Temperature record for each station is divided into two equal parts, and the average temperature for each part is computed and compared to the average of the other part. The t- test is used to test the significance of the difference between the two means at the level of 0.05**.**

2.2 Moving Averages

A moving average (MA), also called a rolling average or rolling mean, is usually used in time series analysis to smooth out short-term fluctuations and emphasize the direction of a trend line. A simple moving average is a set of numbers, each of which is the average of the corresponding subset of a larger set of data points.The plot line connecting all the averages is the moving average. Moving averages display a smoothed out line of the overall trend. The longer the term of the moving average, the smoother the line will be. The time period used for computing the moving averages in this paper is seven years.

2. 3 Linear Regression

Linear regression is used in time series analysis to model the relationship between two variables by fitting a least square linear equation to the observed data (Equation 1). One variable is considered to be an explanatory or independent variable (X), and the other is considered to be a dependent variable (Y). In this research, the explanatory variable is the time unit used in the analysis and the dependent variable is temperature. Significance of the trend line is tested at 0.05 level.

2. 4 Cusum:

CUSUM charts, introduced by Page in 1954, are widely used in statistical studies to detect small changes in the main trend the temperature record .The CUSUM technique is used in this paper by computing cumulative sum charts for temperature deviations from the mean. A CUSUM chart is drawn for each station to detect process shifts; If a trend develops in the chart, it shows that the process has shifted. As used in this paper, the CUSUM function is used to compute cumulative deviations (d) of temperature records (Xi) from the record mean.

A segment of the CUSUM chart with an upward slopeindicates that temperature values are increasing. Likewise, a segment with a downward slope indicates that temperature is decreasing. A period where the CUSUM chart follows a relatively horizontal path indicates a period where there is no change in the

average. One standard and two standard deviations are used to judge the significance of the shifts

3. Analysis of Results

3.1 Results of The T- Test

3.1.1 Maximum Temperature

The t-test is used in this research to compare the averages of daily maximum temperature for the two periods (1980 – 1984) and (1995-2010). As shown in table (1), averages for the second period for the month of July are higher than averages of the first period and the differences between the two periods are significant at less than .05 for all the stations.

Table (1) Comparing Means of July Maximum Daily Temperaturefor the Periods (1980 – 1994 and 1995-2010)

STATION	X1	X2	t	ά
Amman Airport	30.87 °C	31.88 °C	-2.99	0.006
Aqaba Airport	38.72 °C	40.35 °C	- 5.29	0.000
Irbed	30.36°C	31.73°C	-7.15	0.000
Maan	33.40°C	34.1°C	-2.39	0.020
Irewaished	37.08	38.41	-2.88	0.003
Safawi	36.27	37.81	-3.48	0.002

3.1. 2 Heat Waves

The t-test is also used, in this research, to test the differences in summer heat wave characteristics (frequency, length and intensity) between the two periods (1980 – 1997 and 1998- 2010). Table (2) summarizes the results for Amman Airport which show an increase in the; number, intensity and length of heat waves. However, none of the results is statistically significant, which could be partly attributed, to the bias of temperature readings in the first period towards higher temperatures.

Table (2) Comparing Means of summer heat wave characteristics in Amman Airport for the Periods (1980 – 1994 and 1995-2010)

Heat wave characteristics	1st Period	2nd Period	t	Ά
Frequency	4.31	5.00	-1.17	.328
Length	4.0	4.17	-. 565	.977
Intensity	5.29	5.41	-.350	0.14

The difference between the two periods was not limited to the averages of heat waves length and intensity, but in the coefficients of variation of these characteristics (Table 3). This result agrees well with findings of previous research emphasizing the impact of climate change upon the increase in climatic extremes (Christopher, B.F., 2012).

Table (3) Comparing the coefficients of variation of summer heat waves in Amman Airport for the Periods (1980 – 1994 and 1995-2010)

Heat wave characteristics	1st Period	2nd Period
Frequency	33%	36%
Length	14%	15%
Intensity	14%	21%

3.2 Results of Moving Averages

3.2.2 Moving Averages of Maximum Temperature

Increasing moving averages exist in all stations for all of the three summer months. Figures (1) illustrate the increasing moving average of maximum temperature in Amman Air Port for the summer season during the period 1980- 2010. The rate of increase accelerates after the year 1994. Taking into consideration that temperature measurements at the first half of the study period were biased toward higher temperatures, the rate of increase of the real trend could be greater than what is already shown.

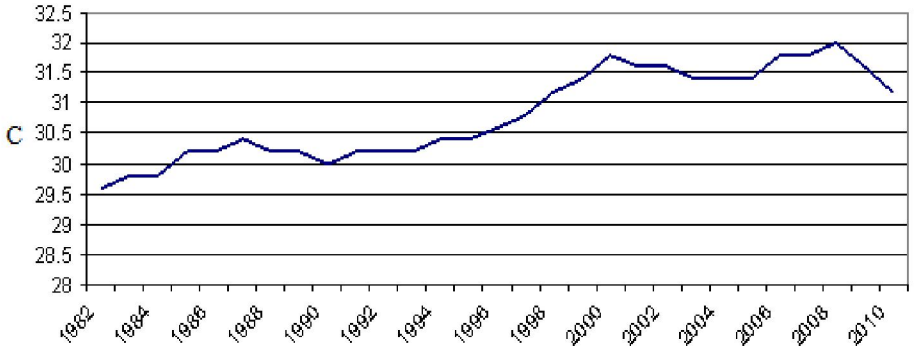

Figure (1) Five Years Moving Average for Maximum SummerTemperature for Amman Airport during the Period (1980- 2010)

3.2.3 Moving Averages ofHeat Waves

Curves of moving averages for heat wave characteristics (number, length and intensity) for the period 1980-2010 are shown for Amman Airport (Figures 2&3). As clearly shown in these figures the two moving averages are all generally increasing especially after 2004.

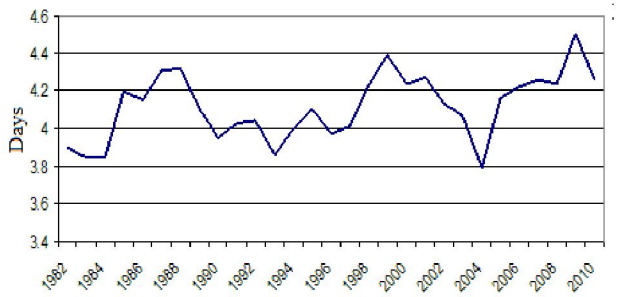

Fig. (2) Moving Averages for Summer Heat Wave Length in Amman

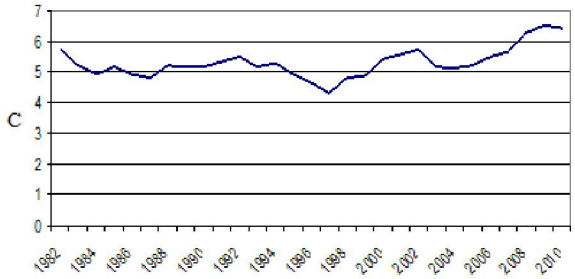

Fig. (3) Moving Average for Summer Heat Wave Intensity in Amman

3.4 Results of Linear Regression

3.4.1 Linear Trends of Maximum Temperature

Significant increasing temperature trends exist in average monthly maximum temperature in all months and for all stations (Table 4).

Table (4) Statistical Significance of Temperature Trends

STATION	b	t	ά	R^2
Maan	0.068	4.164	0.000	0.374
Ruaished	0.077	3.792	0.000	0.332
Irbid	0.084	4.401	0.000	0.400
Aqaba Air Port	0.060	4.220	0.000	0.380
Amman Air Port	0.070	4.706	0.000	0.433
Safawi	0.076	4.045	0.000	0.366

3.4.2 Linear Trends Of Heat Waves

Increasing Trends of heat wave frequency, intensity and duration are also found in all stations. Table (5) illustrates that such trend is statistically insignificant. Even though, the spatial predominance of increasing trends in all stations is a reasonable evidence of the significance of such trend.

Table (5) Statistical Significance of the Frequency of Heat wave Trends

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.948	.597		6.609	.000
	YEAR	.044	.033	.241	1.336	.192

3.5. Results of Cumulative Sum

3.5.1 Cumulative Sum of Monthly Maximum Temperature

Figure (4) represents a cusum chart for the average of daily maximum temperature of the summer season in Amman Airport. A decreasing trend extends to 1998, and an increasing trend since then. The increasing trend is highly significant because it exceeds the two standard deviations limit. Similar trends exist in the cusum charts of other stations which agree very well with the results of other analysis.

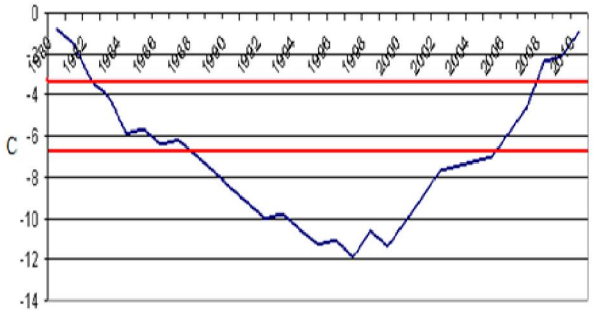

Figure (4) A CUSUM Chart for Summer Average Daily Temperatureat Amman Airport

3.5.2 Cumulative Sum of Heat Wave Characteristics

Figures (5, 6&7) represent three cusum charts for the three summer months of June, July and August at Amman Airport. Decreasing trends exist in all curves up to the mid of the last decade of the twentieth century. An increasing trend predominates since then. Both decreasing and increasing trends are statistically significant because they both cross the two standard deviations limit.

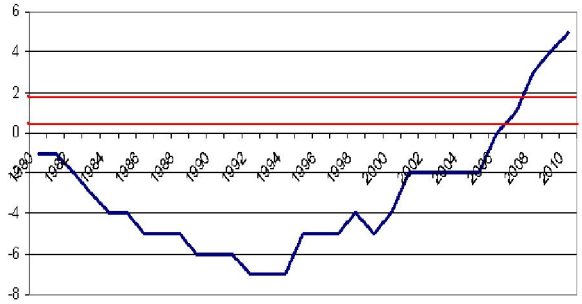

Figure (5) CUSUM Curve for June Heat Wave Frequencyin Amman Air Port

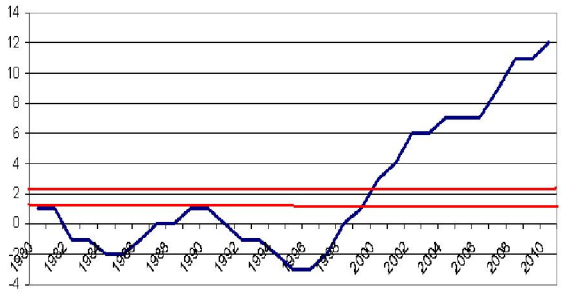

Figure (6) CUSUM Curve for June Heat Wave Duration in Amman Air Port

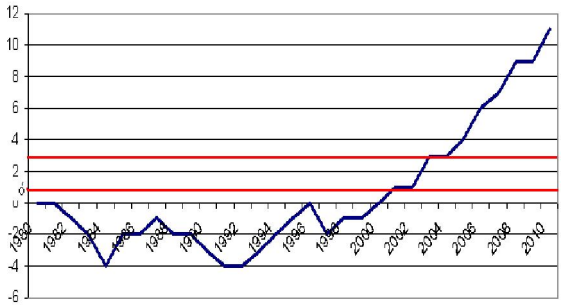

Figure (7) CUSUM Curve for June Heat Wave Intensity in Amman Air Port

4.Conclusions

Analysis of average monthly temperature records for six climatological stations representing various climatic regions in Jordan for the period 1980-2010 revealed a statistically significant increasing trend. Analysis of maximum daily temperature for the three summer months (June, July, August) for two climatic stations revealed a statistically significant trend in the length, Recurrence and intensity of heat waves. Various statistical techniques were used in the analysis including t- test, simple regression, moving averages and cumulative sums.

References

1. Alpert, P., 2008, Krichak, S.O, Shafir, D., et.al Climatic trends to extremes employing regional modeling and statistical interpretation over the E. Mediterranean, Global and Planetary Change 63 , 163–170
2. Bani-Domi, M,2005. Trend Analysis of Temperatures and Precipitation in Jordan, Dept, of Geography Yarmouk University Irbid , Jordan . Um Alqura University, v.1, no.17, pp.16-35.
3. Beniston, M,2004. The 2003 heat wave in Europe: A shape of things to come? An analysis based on Swiss climatologically data and model simulations. Geophysical Research Letters,Lett. 31, L020022.

4. Christopher, B. F., et.al, 2012. Managing the Risks of Extreme Events and disasters to advance climate Change Adoptation, IPCC,
5. Della - Marta, P. M., M. R. Haylock, J. Luterbacher, and H. Wanner ,2007. Doubled length of western European summer heat waves since 1880, J. Geophys. Res., 112,
6. Deffenbaugh, N. S., J. S. Pal, F. Giorgi, and G. Xuejie 2007. Heat stress intensification in the Mediterranean climate change hotspot, Geophys. Res. Lett., 34, L11706, doi:10.1029/2007GL030000
7. Evans.J.P.,2008. 21st century climate change in the Middle East, Climatic Change 2009. 92:417–432.
8. Giorgi, F. 2006.Climate change hot spots, Geophys. Res. Lett., 33, L08707.
9. Giorgi, F., & Lionello, P. 2007. Climate Change Projections for the Mediterranean, Global and Planetary Change, 63, issues 2-3, 90- 104.
10. Intergovernmental Panel on Climate Change 2007. Climate Change 2007: The Physical Basis. Contribution of Working Group I to the Fourth, Assessment Report of the Intergovernmental Panel on Climate Change, edited by S. Solomon et al., Cambridge Univ. Press, New York.
11. Kafle. H,& Bruins. H.J,2009, Climatic trends in Israel 1970–2002: warmer and increasing aridity inland , International Journal of Climatology, 22: 1327-1337
12. Karl, T., and R. Knight,1997, The 1995 Chicago heat wave: How likely is a recurrence?, Bull. Am. Meteorol.Soc.,78,1107–1119.
13. Kostopoulou, E.& Jones P. D. 2005. Assessment of climate extremes in the Eastern Mediterranean, Meteorology and Atmospheric Sciences, v. 89, no. 1-4,pp. 69- 85.
14. Kuglitsch.,Toreti, Xoplaki. *et al.,* 2010. Heat wave changes in the eastern Mediterranean since 1960.Geophysical Research Letters,VOL,37.5 PP.
15. Marta.P,*et al.,*2007. European Heat Waves Double In Length Since 1880, the Journal of Geophysical Research-Atmospheres.
16. Meehl, G. A., and Tebaldi,C. : 2004, More Intense, More Frequent, and Longer Lasting Heat waves in the 21st Century, Science 305, 994. Available online,
17. Sabri, A., 2001. Heat Waves in Jordan, PH.D., dissertation, University of Amman, Jordan.
18. Shehadeh, N, A., 1990, The Climate of Jordan, Dar Albasheer, Amman, Jordan.
19. 1990, Heat Waves in Jordan, Kuwait Geographical Journal, no. 138, Kuwait.
20. .,1978. General and Recent Temperature Trends in the Levant, Dirasat, V.5, no,2, Amman, Jordan.
21. Tebaldi.G. A., 2004. More Intense, More Frequent, and Longer Lasting Heat Waves in the 21st Century, Vol. 305 no. 5686 pp. 994-997
22. Türkeş, M., U. M. Sümer, and I. Demir 2002. Re-evaluation of trends and changes in mean, maximum and minimum temperatures of Turkey for the period 1929–1999, Int. J. Climatology., 22, 947–977, doi:10.1002/joc.77
23. WMO Report 2008. World Meteorological Organization, Commission for Basic Systems , Management Group Ninth Session Geneva .

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