Frost Hazard and Pattern of Minimum Daily Temperature Changes in Northern Highlands of Jordan

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Abstract. Occurrence of frost phenomena is a common agricultural hazard within the northern Jordan that has led to economic losses for farmers due to crop damage. This is aggravated by lack of adequate information on frost to cushion farmers and decision makers against losses. The purpose of this paper is to investigate the recent trends of minimum daily temperature and frost recurrence during the period from 1979 to 2014 in Jordan. Data on minimum daily temperature and nighttime frost during the winter season are examined for four climatic stations representing the northern and central regions of Jordan. A statistical analysis approach including t-test, linear regression, moving averages and CUSUM charts have been used to test the main hypothesis of this research. The results illustrate that the minimum daily winter temperature in northern Jordan shows a statistically significant increasing trend, and accordingly caused a decreasing trend for frost recurrence. Results of this research agree well with the findings of previous research for different regions in Jordan. The study proposes adoption of resilient crop cultivars, use of manual protective measures as well as site selection based on crop susceptibility as well as land surface curvature in order to avert the losses and ensure maximum crop production hence sufficient food supplies.

Keywords: Frost, t-test, regression line, moving averages, CUSUM charts, Jordan.

1. Introduction
Frost is the occurrence of an air temperature of 0°C or lower, measured at a height of between 1.25 and 2.0 m above ground, inside an appropriate weather shelter (FAO, 2005). The frost is formed when surface temperature drops below 0°C and water vapor in the atmosphere condenses and freezes (Cornel Cooperative Extension 1995). Agricultural sector still dominate the economies of many regions in Jordan including the highland. It is an important sector of the Jordanian economy supporting over 20% of the total population (DOS, 2014). Recent advances in agricultural technologies may not avail much if agricultural production still depends on weather and climate (Geerts, et al., 2006). This is because climatic variability is now playing a greater role in limiting production of sufficient food supplies to match the present
population growth rates. In the recent past, Jordan has suffered from frost cases that led to huge losses most of which was borne by farmers in the highlands regions (DOM, 2014). The rate of global temperature increase since the middle of the last century, due to the worldwide climate change, seems to be faster than any changes that occurred over the past 10,000 years (1). Eleven of the twelve warmest years since 1850 have occurred between 1995 and 2006, the last two decades of the 20th century have been hottest in the last 400 years. In the Northern Hemisphere, 1983–2012 was likely the warmest 30-year period of the last 1400 years (2). Over the past century the Earth has warmed by 0.8°C (2). More than half of this increase has happened in the last 25 years. The regions most affected by the temperature increase are the cold regions of the northern hemisphere. According to the multinational Arctic Climate Impact Assessment Report compiled between 2000 and 2004, the average temperature in Alaska, Western Canada and Russia has risen at twice the global average (2). All general circulation models (GCMs) that simulate the impact of the greenhouse upon the world temperature, predict worldwide accelerating increase in average temperature. If current trends in emissions of greenhouse gases continue, global temperatures are expected to rise faster over the 21st century than over any time during the last 10,000 years (3). Most recent climate general circulation models (GEC) predict 2.5°C increase in average temperature by (2050) and a total increase of 4°C by the end of the century in response to a doubling of carbon dioxide (2). The Mediterranean region is one of the areas mostly affected by the temperature increase. It is considered by several studies as a "hot spot" of climate change (4). According to a climate model developed by the International Center for Theoretical Physics at Trieste, Italy, the average temperature over the Mediterranean region has increased by (1.5 – 4) °C in the last 100 years and is expected to increase by about (4 – 6) °C by the end of this century (5). Intergovernmental Panel on Climate Change (IPCC) states that temperature in the Levant and North Africa has increased between (2-3) °C in the last century, faster than the global average of about 1°C (6). The net increase in temperature during the last thirty years of the past century exceeds 2.0 °C (7). One of the main results of the temperature increase in the Middle East is the northward shift of the location of the Mediterranean front and the tracks of Mediterranean depressions. Another result is that polar air masses that invade the region during the winter season became less cold (7). The most affected regions by this change are the south eastern corner of the Mediterranean region. The Eastern Mediterranean region became warmer, especially during the summer, with an increase in the recurrence and intensity of heat waves. Eighteen global climate models predict an overall temperature increase in the Middle East of ~1.4 °K by mid-century, increasing to almost 4.0 °K by late-century (8). GEC projections of temperature change suggested that there have been significant trends in temperature extremes, (9). The most affected area by this change is the coastal areas of North Africa and the South Eastern corner of the Mediterranean region where Jordan is located.

Many previous studies on the impact of climate change upon the increase of global temperature indicated that the increase was not limited to maximum daily temperature, but was more pronounced on minimum daily temperature. Analyzing monthly mean maximum and minimum temperatures for 37% of the global landmass found that the rise of minimum temperature has occurred at a rate three times that of the maximum temperature during the period 1951-90 (0.84 °C versus
0.28 °C) (10). Therefore, the curve of increase in maximum and minimum daily temperature is asymmetrical. The increase in minimum daily temperature causes a pronounced decrease in frost recurrence and a slight decrease in daily temperature range. Lobell, et al. (2007) compared projections of T_{min} and T_{max} changes by 2046–2065 for 12 climate models under an A2 emission scenario. The average modeled changes in T_{min} were similar to those for T_{max}, with slightly greater increases in T_{min} consistent with historical trends exhibiting a reduction in diurnal temperature ranges (11). The Eastern Mediterranean region became warmer, especially during the summer, with an increase in the recurrence and intensity of heat waves. In the Arab Gulf region, the results show that there is a significant increase in temperature for all studied regions (Alhusban 2013a, 2013b; Almazroui et al. 2012). In Kuwait, studies show an increase in nighttime temperature that is more than double the increase in daytime temperature (Ramadan 2008). In Saudi Arabia studies show an increase in temperature (Al-Zawad 2008), as well as an increase in frost severity (Alhusban 2013a).

Analysis of the mean annual minimum and maximum temperature records in Jordan for the period 1964 - 1999 show that there are a warming trends Ben Domi (2005) (12). Also there are increasing trends of minimum temperature exist, especially, in summer and spring months in Jordan (12). In the northeastern part of the Badia region in Jordan, the risk of frost has been increased as a result of decrease of minimum daily temperature during the period from 1980 to 2010 (Alhusban and Makhamreh). Previous study by Ben-Gai et al. (2008) revealed that the warming trend in Israel is confined to the central and northern regions of the country, which are parallel to the northern and central parts of Jordan, with a cooling trend in the south (13). Currently, there is need to limit losses that occur in the high agricultural potential areas as a result of frost risk, and cushion farmers through proper agricultural planning. Therefore, up-to-date information on crop management and protection against natural agricultural hazards such as frost among others are required. The purpose of this research is to investigate the effect of climate change on the trend of daily minimum temperature and frost hazards during the period 1980 – 2014 in the highland regions in Jordan.

2. Study Area

Jordan is a relatively small country located in the southeastern corner of the Mediterranean region as shown in figure (1). The climate is transitional between the Mediterranean in the north and west parts, and arid climate in the south and east parts.
The rainy season in Jordan extends from October until May. About 90% of Jordan is arid and semi-arid climate with less than 200 mm of rainfall, most of it evaporates back to the atmosphere. The study area covers the northern and central parts of Jordan from Amman to the Syrian border in the north. This is the area where an increase of minimum temperature is anticipated.

The region of north and central Jordan is the main agricultural region in the country. An increase in minimum temperature in that region means less frost nights, and less damage to agriculture sector. The farming system is the backbone of Jordan agricultural economy sector; an estimated 28% of the GDP is considered as agriculture-dependent. This sector provides livelihoods for about 20% of the total population of 9.7 million by the end of 2015 and employs about 7% of the labor force.

### 3. Method of Analysis

The climatic data on the minimum and maximum daily temperature for the period from 1980 to 2014 were collected from publication of the Jordanian Meteorological Department. The available data for the frost event recurrence is from 1979 to 2010. Table (1) show the climatic data for the three climatic stations that were used in the study.

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irbid</td>
<td>32° 32´</td>
<td>35° 51´</td>
<td>555</td>
</tr>
<tr>
<td>Ras Muneef</td>
<td>32° 22´</td>
<td>35° 45´</td>
<td>1150</td>
</tr>
<tr>
<td>Amman Airport</td>
<td>31° 59´</td>
<td>35° 59´</td>
<td>790</td>
</tr>
</tbody>
</table>

The main statistical techniques that used in this research in order to test the research hypothesis are: t-test, Moving averages, linear regression and CUMSUM Charts. The
following sections gives detailed description of the methodology that used in this research.

3.1: t-test

Minimum 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

\[ t = \frac{X_1 - X_2}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}} \]

S= Standard Deviation
N= Number of Data Points
\( \bar{Y} \) = Average Rainfall

The same technique is used for testing the decrease in the number of frost days.

3.2: Moving Averages

The moving average is usually computed as follows; given a series of numbers and a fixed subset size, the first element of the moving average is obtained by taking the average of the initial fixed subset of the number series. Then the subset is modified by "shifting forward", that is excluding the first number of the series and including the next number following the original subset in the series. This creates a new subset of numbers, which is averaged. This process is repeated over the entire data series.

3.3: 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 as shown in 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 minimum temperature.

\[ Y = a + bx + e \]  
\[ a = (\Sigma Y - b (\Sigma X)) / N \]
\[ b = (n \Sigma XY - \Sigma X \Sigma Y) / (n \Sigma X^2 - (\Sigma X)^2) \]

3.4: CUSUM Charts

CUSUM CHARTS are widely used in statistical studies to detect small changes in the main trend of the time series. A CUSUM chart is computed in order to detect the cumulative sum of minimum temperature deviations from the mean process shifts; in this case if a trend develops in the chart, it means that the process has shifted. The CUSUM function is used in this paper to compute the cumulative...
deviations (d) of the minimum temperature values from the mean recorded values as shown in equation (2).

A segment of the CUSUM chart with an upward slope indicates that the minimum temperature values are increasing. Likewise, a segment with a downward slope indicates that the minimum 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.

4. Results and Discussion

The discussion of the results will concentrate on two issues, the first is the minimum trend and the second is the forest occurrence.

4.1 Minimum Temperature

Figure (2) shows an overall slight increase in average seasonal temperature for all of the three meteorological stations of Irbed, Ras Muneif and Amman Airport during the period 1980 – 2014. The rapid increase during the last five years is clearly shown.

Figure (2): Mean seasonal temperature in the Highland regions during the period 1980- 2014.

Figure (3) show the linear regression of minimum daily temperature in Irbed station during the time period from 1980 to 2014. The results shows presence a positive coefficient of the linear regression trend line in all the winter months at the 0.05 significance level, which are shown in table (2). These results show there are increase in the minimum temperature value of the winter season months particularly in January to march. Table (2) the linear regression of the minimum temperature at Irbed station during the winter season during the period from 1980- 2014.

<table>
<thead>
<tr>
<th>Month</th>
<th>(B) value</th>
<th>Significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>December</td>
<td>0.017</td>
<td>0.537</td>
</tr>
<tr>
<td>January</td>
<td>0.040</td>
<td>**0.086</td>
</tr>
<tr>
<td>February</td>
<td>0.044</td>
<td>*0.030</td>
</tr>
<tr>
<td>March</td>
<td>0.073</td>
<td>*0.009</td>
</tr>
</tbody>
</table>
Table (3) shows that average minimum temperature during the first and second half of the study period. The average minimum temperature has increased from 5.96 °C during the first half of the study period to 6.72 during the second half. The absolute difference in temperature between the two period is 0.76 °C, and the difference between the two means is highly significant (α = 0.008).

<table>
<thead>
<tr>
<th>Period</th>
<th>Average Minimum Temperature</th>
<th>T</th>
<th>α</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980-1994</td>
<td>5.96</td>
<td></td>
<td>-2.82</td>
</tr>
<tr>
<td>1995-2014</td>
<td>6.72</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure (4) represents the CUSUM chart of minimum seasonal temperature. The results show continues increase in the minimum seasonal temperature since 1996. The continuous increase in minimum temperature is also shown in figure (5) of the moving averages window.
Figure (4): CUMSUM chart for minimum seasonal temperature in the Highland regions during the period 1980-2014.

Figure (5): Moving averages of minimum seasonal temperature in the Highland regions during the period 1980-2010.
4.2 Frost Recurrence
During the time period from 1979 to 2010 the frost event occurred 160 times, it is mostly concentrated in the three winter months of December, January and February, beside the first month of the spring season - March. The average number of frost events that happened per month is about two times, but with great variance from one year to another as shown in figure (6). The year 1995 is distinguished from other years in terms of the number of frost cases which reached about 20.

Figure (6): Number of Frosts Occurring Annually in northern Jordan, represented by Irbed station during the period 1979-2010.

About half of the frost incidences occurred in January with 48% as shown in figure (7), and followed by month of February with 26%. The month of March has the lowest number of frost recurrences of about 16 cases only.

Figure (7): Frequency of frost recurrence in northern Jordan, represented by Irbed station during the period 1979-2010
Figure (8) show the type of frost affecting Jordan, the analysis show that about 46% of frost occurrence is associated with the invasion of the Siberian High which is usually associated with clear skies and calm winds, this favoring the occurrence of radiation frost. The second type of frost which hit Jordan it occurs more frequently during the winter season with about 34%, this frost is related to advection type which is usually associated with cold polar fronts in winter. The third type of frost is usually associated with cold upper troughs with about 20%.

![Pie Chart](image)

Figure (8): Synoptic conditions responsible for frost recurrence in northern Jordan, represented by Irbed station, during the period 1979-2010.

The monthly distribution of frost recurrence in the study area are shown in figure (9). Almost more than 90% of the frost recurrence are in the winter months December, January and February, and about 7% of the frost recurrence is registered in spring season mainly March. However, as expected for a transitional region located between the Mediterranean climate in the west and arid climates in the east and south, the degree of variation from one year to another is very high according to the coefficient of variation which is almost about 100%. The monthly distribution of frost recurrence, as illustrated before shows great concentration in January with 48%, followed by February with 26%.

![Bar Chart](image)

Figure (9): Distribution of the monthly frost recurrence in the winter months during the period from 1979 – 2010.
The steady decrease in frost recurrence since 1993 is clearly shown in all of the three stations as shown in figure (11), which illustrate the CUSUM chart of monthly frost recurrence during winter months in the three previously mentioned stations.

Figure (10): CUSUM chart of monthly frost recurrence during winter season

The steady decrease in frost recurrence since 1991 is also shown in figure (12), which illustrates five year moving averages for seasonal frost recurrence in the three stations.

Figure (11): Moving averages of monthly frost recurrence during winter season

Figure (12) illustrates a steady decreasing linear regression line for seasonal frost recurrence in Irbed station during the study period. As shown in table (4), the rate of annual decrease (b) for the winter months of January, February and March is statistically significant at the level of significance (α) 0.03.
Comparing the difference between the average number of frost recurrence in the first half of the study period and the second half using the t-test revealed that there are a significant difference at ($\alpha \leq 0.00$) level, as clearly shown in table (4).

Table 4: Significance of the regression lines of minimum daily temperature

<table>
<thead>
<tr>
<th>Month</th>
<th>b</th>
<th>$\alpha$</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>-.026</td>
<td>0.029</td>
</tr>
<tr>
<td>February</td>
<td>-.052</td>
<td>0.036</td>
</tr>
<tr>
<td>March</td>
<td>-.073</td>
<td>0.004</td>
</tr>
</tbody>
</table>

**Conclusions**

Impact of the climate change upon atmospheric temperature in Jordan is not limited to maximum temperature and heat waves frequency and intensity, but is evident in raising minimum temperature and decreasing frost recurrence. The impact is evident in the northern and central regions of the country that have semi humid Mediterranean climate which is more influenced by climate change than the southern and eastern arid regions as revealed by other studies. The increase in minimum temperature is a positive sign for potential decreasing the risk of frost reoccurrence on plant growth and agricultural production, but detailed investigations should be done on the existing land use types and their growth cycle in the region. Also, these effects coupled with other climate change impact upon other climatic elements such as decreasing rainfall and heat waves effects demands more mitigation and adaptation methods from the farmers and the government.
References


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Abstract

Frost is a common phenomenon in Jordan, especially in the northern highlands. It poses a significant threat to agriculture and can lead to economic losses for farmers due to crop damage. This study aims to explore the recent trends in minimum daily temperature and frost frequency from 1979 to 2014 in the northern agricultural region of Jordan. The study was conducted by analyzing daily temperature and frost data from four meteorological stations representing the northern and central regions of Jordan. The data was analyzed using linear regression, moving averages, and statistical tests to examine the trends and test the research hypotheses.

The statistical results indicated a significant rise in the minimum daily winter temperature, which has led to a decline in the overall frequency of frost events. These results are consistent with previous studies in different areas of Jordan.

Based on these findings, the study recommends the adoption of improved crop varieties and the use of manual preventive measures while selecting locations based on the sensitivity of the crops and considering the shape of the terrain to minimize losses and ensure maximum crop production and food supply for the population in the study area.