

Statistical Analysis of Recent Changes in Relative Humidity in Jordan

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Abstract: This study examines recent changes in annual and seasonal relative humidity variations in Jordan. The analysis indicates an increasing trend in relative humidity at different stations. The analysis shows a significant increasing trend at Amman Airport Meteorological (AAM) station with a rate of increase 0.13% per year. These increasing trends are statistically significant during summer and autumn seasons. Finally, a major change point in the annual relative humidity occurred in 1979 at AAM station.

Key words: Jordan, abrupt changes, trends, humidity

INTRODUCTION

Humidity is defined as the amount of water vapor in an air sample. The main sources of water vapor in the lower atmosphere are evaporation from the Earth's surface and transpiration by plants. In the stratosphere, the breakdown of methane by sunlight is another source. The main sink is precipitation. Atmospheric water vapor accounts for only about 1/10,000th of the total amount of water in the global hydrological cycle. Nevertheless, atmospheric water vapor is one of the most important factors in determining Earth's weather and climate, because of its role as a greenhouse gas and because of the large amounts of energy involved as water changes between the gaseous (vapor) phase and liquid and solid phases.

World-wide interest in global warming and climate changes has led to numerous trend detection studies^[1]. Studies in Jordan showed significant abrupt changes and trends in air temperature and precipitation time series data^[2,3]. Most of climate changes studies focus on changes on temperature and precipitation, However, Humidity is very important as an environmental condition which influences the growth of the plants, health, pollution etc. For example, plants also respond to changes in humidity. The transpiration rate is determined by a balance between the amount of energy available to convert water from the liquid to vapor phase and the moisture gradient.

In the absence of significant changes in weather, the variations in humidity over the course of the day can be easily understood. The specific humidity remains relatively constant from day to night and so,

therefore, does the dew point temperature. However, as the temperature cools at night, the saturation vapor pressure decreases and so relative humidity increases. The highest values usually occur at the time of lowest temperature, near dawn. Seasonal humidity variations depend on two factors: seasonal changes in temperature and seasonal changes in atmospheric circulation. In temperate climates, the warmer air in summer has a higher saturation vapor pressure than the cooler winter air. Average summer and winter relative humidity values tend not to differ much, so the specific humidity tends to be much larger in summer. In monsoon climates, relative and specific humidity tend to increase dramatically during the monsoon season, when onshore winds carry moisture-laden air from the ocean to land areas.

This study aims to characterize the occurrence of abrupt changes and trends in relative humidity records in Jordan. The analysis in this work focuses on AAM station. The relative humidity data obtained for the AAM station covers a period of 83 years; from 1923 to 2005. Humidity data from other stations in Jordan were also selected and analyzed. Cumulative sum charts (CUSUM) and bootstrapping were used to detect and locate any abrupt changes. The rank test was used to demonstrate existence of any possible trends.

Data used: The Amman Airport Meteorological (AAM) station was the main station in Jordan and was established in 1922. The station lies in the eastern part of the capital city (Amman).

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Table 1: Statistical Results of Seasonal Relative Humidity for AAM Station

Season	Mean	C.V	Minimum	Maximum	Slope	Rank
Annual	53.58	9.46	42.80	73.70	0.13	2.02**
Winter	69.93	8.66	59.67	87.33	0.12	1.41
Spring	50.49	12.51	35.33	68.67	0.10	1.07
Summer	42.18	14.61	32.00	66.67	0.14	1.66**
Autumn	52.13	12.57	32.00	72.33	0.16	1.67***

Table 2: Statistical Results of Relative Humidity Records for Different Stations

Station	Period	Mean	C.V	Minimum	Maximum	Slope	Rank
AAM	1923-2005	53.58	9.46	42.80	73.70	0.13	2.02**
Ma'raq	1960-2005	58.11	7.65	49.30	67.40	0.21	1.37
Deir Alla	1961-2005	52.52	9.41	44.50	66.38	0.14	0.457
Er-Rabbah	1963-2005	55.91	8.42	49.40	67.08	0.23	1.27
Ma'an	1960-2005	47.00	16.09	32.09	66.30	0.32	1.17

Table 3: Results of Change-Point Analysis on Relative Humidity at AAM Station

Year	Conf. Interval	Conf. Level	From	To	Level
1929	(1926, 1929)	99%	53.033	46.362	3
1937	(1936, 1940)	99%	46.362	52.064	2
1979	(1973, 1981)	96%	52.064	56.155	1
1990	(1988, 1005)	90%	56.155	59.614	2

The station elevation is 780 m, above sea level (a. s. l.) (With Latitude N 31° 59' and longitude E 35° 59'). The mean annual rainfall and temperature are 275 mm and 12.3°C, respectively, while the mean monthly evaporation is 51 mm. Different meteorological stations are scattered all over the country. We examine humidity records from other four stations in the country.

MATERIALS AND METHODS

Rank test: The Mann-Kendall rank test has proven to be useful for detecting trends in climate and environmental sciences^[4,5]. Assuming x_1, x_2, \dots, x_n be the time series data. Define P, the number of pairs (i, j) where $x_j > x_i, j > i; j=1, \dots, n$ and $i=1, \dots, n-1$. The mean and variance of P are given by Brockwell and Davis^[6].

$$\text{Mean} = \frac{n(n-1)}{4},$$

$$\text{Variance} = \frac{n(n-1)(2n+5)}{8}$$

Critical values are determined by normal approximation.

Cumulative sum charts (CUSUM) and bootstrapping: This procedure was used by Taylor^[7] devised a procedure for performing change point analysis using cumulative sum charts (CUSUM) and bootstrapping. Let X_1, X_2, \dots, X_n represent the n data points. The cumulative sums S_0, S_1, \dots, S_n are calculated iteratively as follows:

1. Calculate the average

$$\bar{X} = \frac{X_1 + X_2 + \dots + X_n}{n} \tag{1}$$

2. Let $S_0 = 0$.

3. Calculate S_i recursively:

$$S_i = S_{i-1} + (X_i - \bar{X}), \quad i = 1, 2, \dots, n. \tag{2}$$

A segment of the CUSUM chart with an increasing slope indicates a period where the values tend to be above the overall average. Likewise, a segment with a decreasing slope indicates a period of time where the values tend to be below the overall average. A sudden change in direction of the CUSUM indicates a sudden shift in the average. A period where the CUSUM chart follows a relatively horizontal path indicates a period where there is no change in the average. The confidence level can be determined by performing bootstrap analysis^[8]. In this work, the software *Change Point Analyzer* was used and performs the change point analysis of the humidity records at AAM station.

RESULTS AND DISCUSSION

Analyses of fluctuations in long term annual and seasonal relative humidity are presented. Analysis of seasonal data was performed only for AAM station. A season is defined as 3-month period, winter (December-February), spring (March-May), summer (June-August) and autumn (September-November). The following asterisks will be frequently used in the result tables to denote statistical significance at different levels (α): * for $\alpha = 0.1$, ** for $\alpha = 0.05$ and *** for $\alpha = 0.01$.

The time series plot of the relative humidity data for AAM station is shown in Fig. 1. Table 1 displays summary statistics, slope estimates and rank test statistics for the annual and the seasonal mean relative

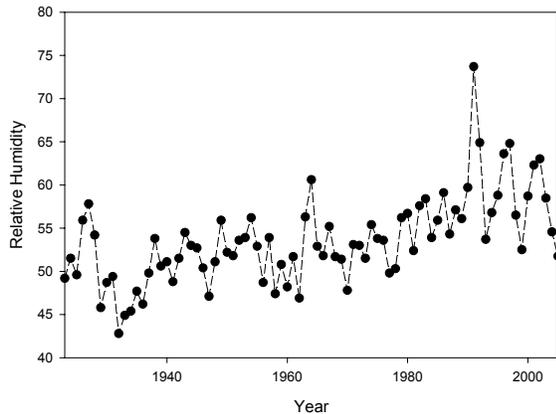


Fig. 1: The time series of relative humidity from 1923 to 2006 for AAM station

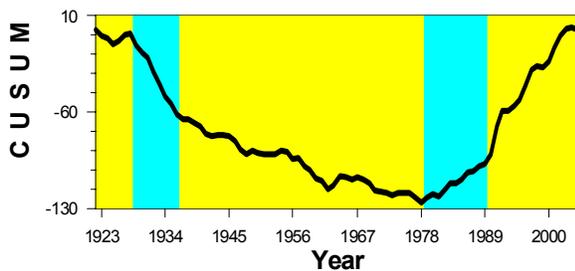


Fig. 2: CUSUM chart for the relative humidity of AAM station

humidity for the entire period (1923-2005). The rank test shows a significant increasing trend of annual relative humidity at the level of significance 0.05, The relative humidity has increased by a rate of 0.13%/year. These increasing trends are statistically significant during summer and autumn seasons. The results of annual relative humidity for five stations are shown in Table 2. It can be observed that there is an increasing trend in the relative humidity, where none of them are statistically significant, except that of AAM station.

Table 3 shows the results of a change-point analysis for the annual relative humidity for AAM. The table gives a level associated with each change; the level is an indication of the importance of the change. Using the *Change Point Analyzer*^[9] no departure from the independent error structure and no outlier's assumptions were found. This analysis detects four changes which occurred in the years 1929, 1937, 1979 and 1990. The first and most important change is estimated to have occurred around 1979 with 100% confidence level.

The increase in relative humidity might be due to the increase of evaporation from land and the Mediterranean Sea which lies about 100 km from

Jordan and may also be due to stable weather conditions in the vicinity of extension of subtropical high belt over the area (east of the Mediterranean Sea). This neighboring causes high frequency of high pressure belt with an association of wide spread inversion over the study area and this high frequency of high pressure belt reduces the amount of the annual rainfall.

CONCLUSION

The analysis indicates an increasing trend in relative humidity at different stations. The analysis shows a significant increasing trend at AAM station with a rate of increase 0.13% per year. These increasing trends are statistically significant during summer and autumn seasons. Finally, a major change point in the annual relative humidity occurred in 1979 at AAM station.

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