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# Evolution of the rainfall regime in the United Arab Emirates

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SUMMARY

Arid and semiarid climates occupy more than 1/4 of the land surface of our planet, and are characterized by a strongly intermittent hydrologic regime, posing a major threat to the development of these regions. Despite this fact, a limited number of studies have focused on the climatic dynamics of precipitation in desert environments, assuming the rainfall input – and their temporal trends – as marginal compared with the evaporative component. Rainfall series at four meteorological stations in the United Arab Emirates (UAE) were analyzed for assessment of trends and detection of change points. The considered variables were total annual, seasonal and monthly rainfall; annual, seasonal and monthly maximum rainfall; and the number of rainy days per year, season and month. For the assessment of the significance of trends, the modified Mann–Kendall test and Theil-Sen's test were applied. Results show that most annual series present decreasing trends, although not statistically significant at the 5% level. The analysis of monthly time series reveals strong decreasing trends mainly occurring in February and March. Many trends for these months are statistically significant at the 10% level and some trends are significant at the 5% level. These two months account for most of the total annual rainfall in the UAE. To investigate the presence of sudden changes in rainfall time-series, the cumulative sum method and a Bayesian multiple change point detection procedure were applied to annual rainfall series. Results indicate that a change point happened around 1999 at all stations. Analyses were performed to evaluate the evolution of characteristics before and after 1999. Student's *t*-test and Levene's test were applied to determine if a change in the mean and/or in the variance occurred at the change point. Results show that a decreasing shift in the mean has occurred in the total annual rainfall and the number of rainy days at all four stations, and that the variance has decreased for the total annual rainfall at two stations. Frequency analysis was also performed on data before and after the change point. Results show that rainfall quantile values are significantly lower after 1999. The change point around the year 1999 is linked to various global climate indices. It is observed that the change of phase of the Southern Oscillation Index (SOI) has strong impact over the UAE precipitation. A brief discussion is presented on dynamical basis, the teleconnections connecting the SOI and the change in precipitation regime in the UAE around the year 1999.



## 1. Introduction

The United Arab Emirates (UAE) is located in the arid southeast part of the Arabian Peninsula. This region is characterized by very scarce and variable rainfall. Without permanent surface water resources, groundwater resources were extensively used for water supply. Recently, strong economic and demographic growth in UAE has put even more stress on water resources. The deficit in water availability between the increasing demand and water resources availability has been met by non-conventional sources such as desalinated water. Groundwater aquifers rely on recharge from rainfall. For this purpose, a large number of small recharge dams were built to capture rainfall water from infrequent but usually intense events. For optimal water resources management, it is important to understand the temporal evolution of rainfall. The main objective of the present study is to analyze rainfall trends in the arid region of the UAE. The variables analyzed in this study are: the total annual, seasonal and monthly rainfall; the annual, seasonal and monthly maximum rainfall, and the number of rainy days per year, season and month.

A relatively limited number of studies dealing with rainfall trend analysis in arid and semi-arid regions have been conducted, with very few dealing with desert environments and the Arabian

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Peninsula. Modarres and Sarhadi (2009) found that, in Iran, annual rainfall is decreasing at 67% of 145 stations studied while annual maximum rainfall is decreasing at only 50% of the stations. However, only 24 stations exhibit significantly negative trends. Törnros (2010) reported a statistically significant decreasing trend at 5 stations among a total of 37 stations in the southeastern Mediterranean region. Decreasing but non-significant trends in rainfall characteristics were found in the region of Oman by Kwarteng et al. (2009). Gong et al. (2004) observed slightly decreasing trends in rainfall amounts in the semi-arid region of northern China. However, other rainfall characteristics, such as number of rainy days, maximum daily rainfall, precipitation intensity, persistence of daily precipitation and dry spell duration, experienced significant changes.

Hess et al. (1995) found significant decreasing trends in annual rainfalls and in the number of rainy days per year in the arid Northeast part of Nigeria. Neither trends nor abrupt changes in rainfall characteristics were found by Lazaro et al. (2001) at a station located in the semi-arid southeastern part of Spain. Batisani and Yarnal (2010) found significant decreasing trends for rainfall amounts, associated with a decrease in the number of rainy days throughout semi-arid Botswana. In general, most studies conducted in arid or semi-arid regions found decreasing trends in the rainfall regime of these areas. Outputs of global and regional climate models indicate also an anticipated decrease in rainfall amounts in most arid and semi-arid regions of the globe, although predicted scenarios for arid areas present a high degree of variability (Black et al., 2010; Chenoweth et al., 2011; Hemming et al., 2010).

In this study, a modified version of the original Mann–Kendall (MK) test, to account for serial correlation, was used for the assessment of trends in rainfall time series. The MK test is one of the most commonly used statistical tests for trend detection in hydrological and climatological time series (Türkeş, 1996; Gan, 1998; Fu et al., 2004; Lana et al., 2004; Khaliq et al., 2008, 2009a,b; Modarres and Sarhadi, 2009; Fiala et al., 2010). The main advantage of using a non-parametric statistical test is that it is more suitable for non-normally distributed and censored data, which are frequently encountered in hydro-meteorological time series (Yue et al., 2002a). The presence of sudden changes in rainfall time series was also investigated. For this, two methods were used. The first one is the cumulative sums method (Cusum). It is a simple graphical method that allows detecting changes in the mean by identification of linear trends in the plot of the cumulative values of deviations. The second one is a Bayesian multiple change point detection procedure. It can be used to detect changes in the relation of the response variable with explanatory variables. When time is used as explanatory variable, the procedure allows detecting temporal changes in the time-series. Changes in the mean and the variance are also investigated in this study. An analysis and a discussion of the physical causes of any observed changes are also presented in the present work.

The present paper is organized as follows: Section 2 presents the data used in this study. In Section 3, the methods used are summarized. Results are presented and discussed in Section 4, and conclusions are presented in Section 5.

## 2. Data

The UAE is located in the Southeastern part of the Arabian Peninsula. It is bordered by the Gulf in the north, Oman in the east and Saudi Arabia in the south. It lies approximately between 22°40′N and 26°N and between 51°E and 56°E. The total area of the UAE is about 83,600 km$^2$ and 90% of the land is classified as hot desert. The rest is mainly represented by the mountainous region in the Northeastern part of the country. The climate of the UAE is arid. Rainfall is scarce and shows a high temporal and spatial variability. The mean annual rainfall in the UAE is about 78 mm and ranges from 40 mm in the southern desert region to 160 mm in the northeastern mountains (FAO, 1997).

The data used in this study comes from 4 meteorological stations located in the international airports of the UAE. Total rainfall is recorded on a daily basis. The map in Fig. 1 gives the spatial

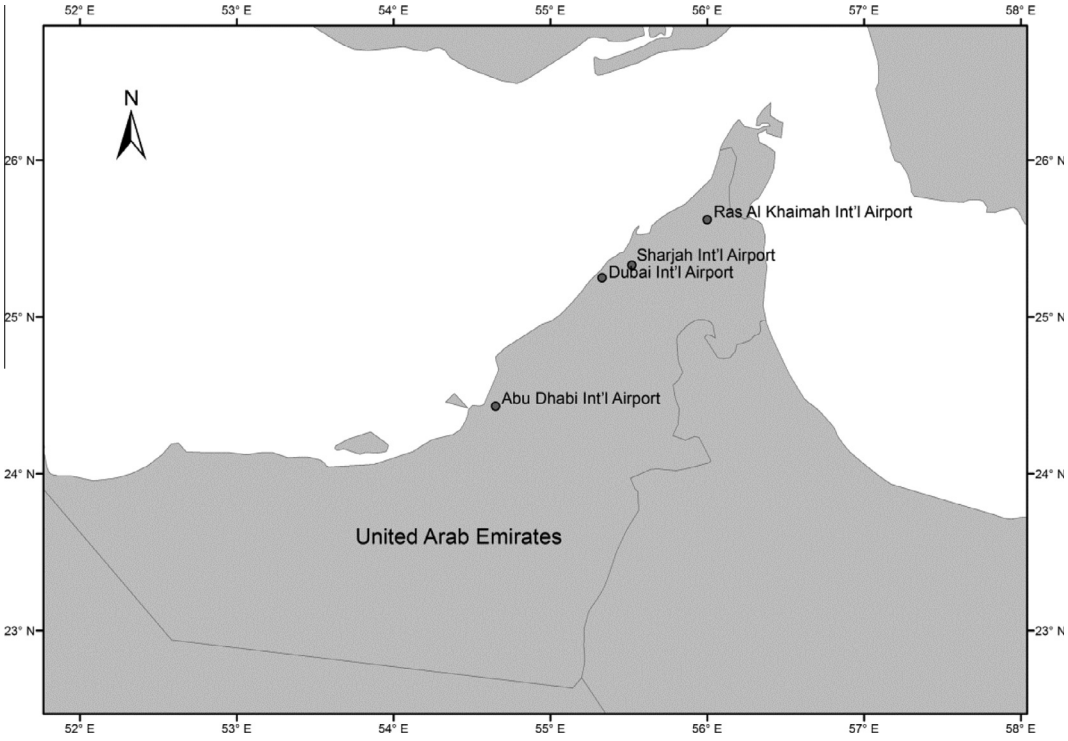


**Fig. 1.** Spatial distribution of the meteorological stations.