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Variability of Extreme Hydro-Climate Parameters in the North-Eastern Region of United Arab Emirates

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Abstract

The hydro-climate information is absolutely important for the management of water and environmental resources. However, in many cases, information for extreme hydro-climate variables are neglected. It is acknowledged that the climate change scenarios will affect the variability of extreme hydro-climate variables. In this study, several robust statistical tests were applied to identify the variability of several hydro-climate parameters in the northeastern region of the United Arab Emirates (UAE). The variables are annual maximum daily mean, maximum and minimum temperature; annual maximum daily rainfall; annual maximum mean humidity, wind speed, sea level pressure and solar radiation. Historical trends and step changes were identified. Five climate stations located in Al Ain, Abu Dhabi, Dubai, Fujairah and Ras Al Khaima were considered. Statistically significant increasing trends were observed in extreme temperature and rainfall parameters in all locations except the Al Ain region. The UAE is located in the arid climate region with an average annual rainfall of less than 100 mm. Increase of extreme rainfall might increase the risk of flash floods in the mountainous eastern region. Possible impacts of changes of extreme temperature and rainfall in the region are delineated in the study.

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Keywords: climate change; extreme; trend; step change

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1. Introduction

An increase in greenhouse gas emissions is raising the earth's average temperatures and resulting climate change around the world. This has changed the frequency, magnitude and persistence of extreme events of various climatic variables, which has already been identified in observational records [1, 2]. According to the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report [3] climate change has started to affect the frequency, intensity and duration of extreme temperature, rainfall and drought almost everywhere around the world over the late 20th century and this will continue in future. Projections of future changes in climate extremes are of particular interest due to their adverse effects on society and ecosystems.

Hydro-climate variables such as annual maximum daily rainfall, annual maximum and minimum daily temperature, humidity, etc., are the key inputs in regional water resources planning and management. The spatial temporal distribution of these variables is significantly important to understand the hydrological processes of a particular region. The IPCC [3] reported that the middle eastern region is expected to get warmer across all seasons by the middle of the 21st century. A warming of about 0.2^{o}C/decade is projected for a range of SRES (Special Report Emissions Scenarios) emissions scenarios for the next two decades. The IPCC also mentioned that even if the GHGs emissions had been kept constant at the year 2000 levels, a warming of about 0.1^{o}C/decade would be expected in this region. Hemming et al. [4] predicted an increase of temperature from 2.5 to 3.7^{o}C in summer, and 2.0 to 3.1^{o}C in winter in the region. The expected higher temperatures will increase the vapor pressure. Changes in vapor pressure along with the changes in atmospheric circulation patterns will likely have a considerable effect on the precipitation intensity, frequency and spatial variability [5]. Tolba and Saab [6] mentioned that the weather in the region is likely to become more unpredictable, experiencing an increase in extreme rainfall events. A general warming pattern of mean annual temperature at the rate of 0.81^{o}C/decade in the Dubai region was identified by AlSarmi and Washington [7]. Very recently, Elhakeem et al. [5] predicted an increase of annual mean maximum temperature in the range between 2.79 and 3.8^{o}C and a decrease of annual precipitation from 16.8 to 37% by 2080 in the UAE.

The UAE is located in a water scarce arid region where the water deficit increases every year. Managing water resources under the natural stresses of very low rainfall, high evaporation rate and limited non-renewable groundwater is an acknowledged challenge in the region. There are about 60 wadi (creek) catchments with an average ephemeral flow from 23 to 138 million m^3/year [5]. The flow occurs from localized storms, and contribute to the groundwater recharge to the shallow alluvial aquifers. Climate conditions play an important role in defining the hydraulic response of the watersheds. The most important factor affecting the hydraulic behavior of the wadi catchments is rainfall. Flash flood is one of the catastrophic phenomena, fairly common in arid regions and present a potential hazard to life, personal property, and structures. The occurrence of flash flood is complex since they depend on geological and morphological characteristics of the wadi basin, including rock types, elevation, slope, sediment transports and flood plain area [8]. Extreme rainfall creates an inundation problem in the urban area of UAE which is exacerbated by sand clogging of storm drainage systems. The statistics of extremes have played an important role in engineering the water resource design and management [9].

The characterization of extreme hydro-climate variables in the UAE region has not yet been investigated comprehensively. While few studies were conducted on the UAE rainfall characterization, most of these were spatially extended to a few wadi catchments [10]. Recently, Sherif et al. [11] explored the rainfall characteristics in the UAE. However, trends and jumps of extreme rainfall were not investigated. Considering the importance of extremes in the context of the potential climate change situation, this study investigated the statistical characteristics of extreme (annual maximum series) of hydro-climate variables in the eastern zone of UAE.

2. Data and Study Area

The UAE is located in the southeastern part of the Arabian Peninsula. The total area of the UAE is about 83,600 km^2. Its geomorphologic features include mountains, gravel plains, sand dunes, costal zones and drainage basins

[12]. More than 75% of the area is covered by the desert. The climate of the UAE is arid. The entire region is mostly dry throughout the year, but surface runoff generates during rainy seasons. Runoff generation differs from the wadi to wadi based on their topography, hydrogeology and headwater catchments. Sherif et al. [11] divided the UAE into four hydro-climatic zones. These are the east coast, mountains, gravel plain and desert foreland regions. The study area is located in the northeastern part of the UAE, covering the east coast, mountains, gravel plain and eastern part of the desert foreland zone (Figure 1). In the mountain region, heavy rainfall causes flash floods which are fairly common in arid regions [8]. Most of annual rainfalls reach the gravel plain region which, in some cases, corresponds to a relatively high annual runoff [11].

Hydro-climate daily data were collected from five climate stations located in the northeastern part of the UAE. The Fujairah Port station is located in the east coast region, the Ras Al Khaimah and the Al Ain stations are located in the gravel plain zone, the Dubai and Abu Dhabi stations are located in the desert foreland zone. Table 1 shows the details of collected data. Spatial locations of the selected stations are shown in Fig 1. The percentage of missing data are shown in Table 1. The missing values were filled using the linear interpolation method. The outliers were not identified in the data series.

Nine hydro-climate parameters were considered. These are annual daily maximum mean (Tmean), daily maximum of maximum (Tmax), daily maximum of minimum (Tmin) temperature; annual daily maximum mean sea level pressure (MSLP), annual daily maximum mean relative humidity (Hmean), annual daily maximum rainfall (Rainfall), annual daily maximum mean visibility (Vmean), annual daily maximum mean wind speed (WSmean) and annual daily maximum of maximum sustained wind speed (MSWS). The measurement unit of these parameters is shown in Table 1.

Table 1. Details of hydro-climate data

Climate parameter	Climate Station				
	Abu Dhabi	Al Ain	Fujairah Port	Dubai	Ras Al Khaimah
	Coordinates				
	24 28 38 N 54 19 40 E	24 12 57 N 55 47 37 E	25 10 21 N 56 21 40 E	25 11 56 N 55 16 23 E	25 58 37N 56 03 24 E
	Data Length (From – To)				
	2/1/1983-31/7/2014	23/3/1994-1/7/2014	1/1/1996-31/7/2014	1/1/1983-31/7/2014	1/1/1983-31/7/2014
	Missing Data (%)				
Tmean (°C)	0.53	1.01	1.34	0.34	1.15
Tmax (°C)	0.53	1.01	1.37	0.34	1.15
Tmin (°C)	0.58	1.12	1.39	0.34	1.16
MSLP (hPa)	2.87	5.22	3.67	8.45	5.37
Hmean (%)	0.53	1.05	1.34	0.34	1.15
Rainfall (mm)	1.92	2.97	3.42	1.73	2.63
Vmean (Km)	0.53	1.07	1.34	0.36	1.16
WSmean (Km/hr)	0.53	1.01	1.34	0.34	1.20
MSWS (Km/hr)	0.72	1.11	1.71	0.62	1.59

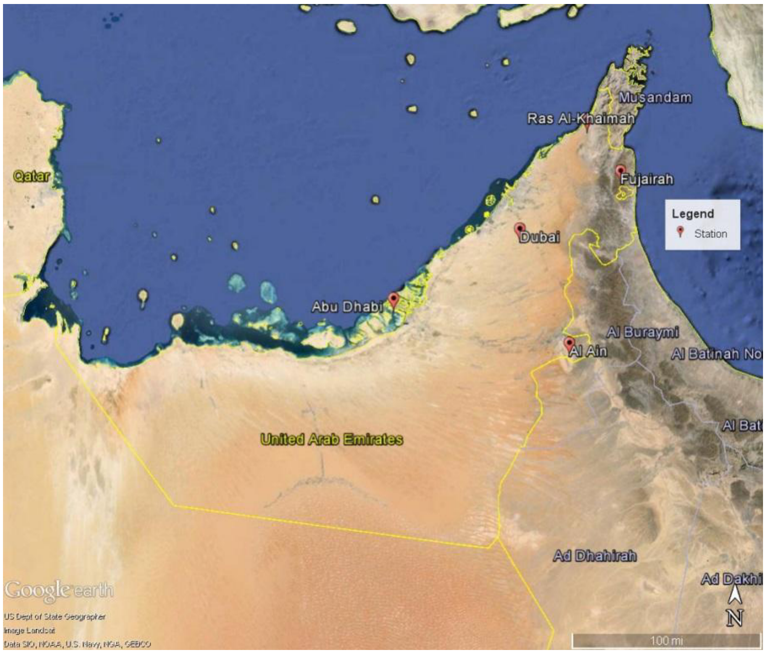

Fig 1. Location of selected five stations in the north eastern part of UAE

3. Methodology

Several statistical tests for trend and step changes in extreme hydro-climate variables were performed. The bootstrapping technique provided in [13] has been used in this study. The permutation and bootstrap techniques are generally used for resampling analysis. In resampling analysis, the original time series is resampled to generate replicates of time series data of equal length as the original data. Data for each replicate is obtained from randomly selected data from any year in the original time series. A description of resampling methods is available in [14]. The test statistic value of the original time series data has been compared with the replicates' test statistic values in order to estimate the significance level. The number of replicates used in this study was 1000. Generally there is no specific guideline for selection of the number of replicates; however the larger the number of replicates, the more accurate the estimate of the significance [14]. If the test statistic value of the original data is greater than the 950^{th} highest test statistic value from 1000 replicates, the H0 has been rejected at a significance level $\alpha = 0.05$. The critical test statistic values at $\alpha = 0.1$, $\alpha = 0.05$ and $\alpha = 0.01$ are the 90th, 95th and 99th percentile values, respectively of the test statistic values from the generated replicates.

Hydro-climate data may exhibit serial correlation as the data are collected over time. This can be checked by estimating the autocorrelation function (ACF) for the time series. The autocorrelation function is a measure of correlation between two values xt and xt+k for a lag k, which can be defined as:

$$R = \frac{\frac{1}{n}\sum_{t=1}^{n-k}\left(x_t - \bar{x}\right)\left(x_{t+k} - \bar{x}\right)}{\frac{1}{1-n}\sum_{t=1}^{n}\left(x_t - \bar{x}\right)^2} \quad (1)$$

$$\left(-1-1.645\sqrt{n}-2\right)/(n-1) \leq R \leq \left(-1+1.645\sqrt{n}-2\right)/(n-1) \tag{2}$$

where, R is the ACF for any lag k and is the mean of the time series. If the value of R for any lag, lies outside the interval defined by Eq. 2, then the time series has significant serial correlation at that lag at the 95% confidence limit. If the lag 1 ACF is outside of this interval, it is assumed that the time series is not composed of random observations.

The linear regression (LR) test is a parametric test that identifies whether there is a significant linear trend existing between two variables. The LR test assumes that the time series data follow a normal distribution. The test has been recommended for trend analysis by [13] and [14]. The Mann-Kendall (MK) test is a ranked based non-parametric test. It is widely used for trend analysis and a description is available in [15]. The Spearman's rho (SR) test [15] identifies whether there is significant correlation existing between two variables. The SR is also a ranked based non-parametric test.

The cumulative summation (CUSUM) test identifies whether the mean values in two parts of a time series are different for an unknown time of change. It is a non-parametric test and a description is available in [15]. The Rank Sum (RS) test identifies whether the medians in two different periods are different. It is also a non-parametric test.

4. Results and Discussion

Table 2 shows the results of statistical tests performed on hydro-climate variables for five stations in the north-eastern part of the UAE. It shows that the annual maximum daily mean, daily maximum and daily minimum temperature exhibit an increasing trend and step changes in the Abu Dhabi, Dubai and Ras Al Khaimah stations. The annual maximum daily mean sea level pressure (MSLP) exhibits an increasing trend and step changes in the Fujairah Port station. The annual maximum daily mean humidity has a decreasing trend and exhibits a step change towards lower value in the Dubai and Abu Dhabi stations. Except the Al Ain station, the annual maximum daily rainfall exhibits an increasing trend in all other stations. This is a clear indication of an increase of more extreme rain storms in the region. The annual maximum of mean visibility exhibits a decreasing trend in all stations, except the Fujairah Port station. The annual maximum mean wind speed possesses a decreasing trend in the Al Ain station. The annual maximum of mean sustained wind speed exhibits an increasing and a decreasing trend in the Fujairah Port and Ras Al Khaimah station, respectively. The selected hydro-climate variables in the Ras Al Khaimah station does not possess serial correlation. Interestingly, the annual maximum daily rainfall data in all stations do not exhibit serial correlation.

The spatial and temporal variability of hydro-climate parameters play an important role in defining the hydraulic response of the watersheds. The most important factor affecting the hydraulic behavior of the wadi catchments is rainfall. It is observed from Table 2 that the extreme rainfall exhibits an increasing trend in the north-eastern part of the UAE. The flash flood is one of the catastrophic phenomena, fairly common in arid regions and present a potential hazard to life, personal property, and structures. It is likely expected that an increased occurrence of extreme rainfall increases the frequency of flash floods in the region and creates an inundation problem in the urban area. The storm water drainage systems will possibly be affected by the increased extreme rainfall events. The increasing trend of extreme temperature in Abu Dhabi, Dubai and Ras Al Khaimah may affect the local weather pattern, as well as may increase heat stress in the region.

5. Conclusion

The observed trends in hydro-climate variables, particularly to rainfall and temperature, have brought significant challenges to the water sector. The detected trends might have been as a result of natural or anthropogenic forcing, but the existence of a trend in climatic variables over that region cannot be simply attributed only to climate change. It is important to identify whether these observed trends are because of climate change or this is just a climate variability in space and time. The IPCC projected more extreme events to increase in the UAE, and the results also suggested the increasing trends of extreme temperature and rainfall. It has been expected that challenges will become more likely and even inevitable in the future. Therefore, a thorough analysis from statistical as well as dynamic perspectives in order to see how regional climate has been changed will be of substantial importance.

Table 2: Statistically significant (95% significance level) trends, step change and auto-correlation in the observed hydro-climate extremes

Hydro-climate Parameter	Climate Station														
	Abu Dhabi			Al Ain			Dubai			Fujairah Port			Ras Al Khaimah		
	AC	TR	SC	AC	TR	SC	AC	TR	SC	AC	TR	SC	AC	TR	SC
Tmean	o	+	+	Y	o	+	Y	+	+	o	o	o	o	+	+
Tmax	Y	+	+	Y	o	o	o	o	+	o	o	o	o	+	+
Tmin	o	+	+	o	o	o	Y	+	+	o	o	o	o	+	+
MSLP	Y	o	+	Y	o	+	Y	o	o	Y	+	+	o	o	o
Hmean	o	-	-	o	o	+	Y	-	-	Y	o	o	o	o	o
Rainfall	o	+	+	o	o	+	o	+	+	o	+	+	o	+	+
Vmean	Y	-	-	o	-	o	Y	-	-	o	o	o	o	-	-
WSmean	o	o	o	o	-	o	o	o	o	o	o	o	o	o	o
MSWS	o	o	o	o	o	o	o	o	o	Y	+	+	o	-	o

AC = lag 1 auto correlation; TR = trend; SC = step change; Y (yes); + (increasing trend or jump to higher value); - (decreasing trend or jump to lower value); o (no trend, step change and auto-correlation)

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References

[1] L. V. Alexander, J. M. Arblaster, Assessing trends in observed and modelled climate extremes over Australia in relation to future projections, International Journal of Climatology. 29 (2009) 417 - 435.
[2] A. D. Evans, J. M. Bennett, C. M. Ewenz, South Australian rainfall variability and climate extremes. Climate Dynamics. 33 (2009) 477-493.
[3] IPCC, Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY USA, 2007
[4] D. Hemming, R. Betts, D. Ryall, Environmental stresses from detailed climate model simulations for the Middle East and Gulf region. Rep. MOEN/04/04/02/02b, Met Office Hadley Centre, UK, 2007.
[5] A. Elhakeem, W. E. Elshorbagy, H. AlNaser, F. Dominguez, Downscaling global circulation model projections of climate change for the United Arab Emirates, J. Water Resour. Plann. Manage. 141(2015) 04015007.
[6] M. K. Tolba, N. W. Saab, Impact of climate change on Arab countries. Rep. of the Arab Forum for Environment and Development (AFED), Technical Publications, Beirut, Lebanon, 181, 2009.
[7] S. AlSarmi, R. Washington, Recent observed climate change over the Arabean Peninsula. J. Geophys. Res. Atmos. 116(2011) 4 -10.
[8] A. M. Subyani, Hydrologic behavior and flood probability for selected arid basins in Makkah area, western Saudi Arabia, Arab. J. Geosci. 4 (2011) 817-824.
[9] R. W. Katz, M. B. Parlange, P. Naveau, Statistics of extremes in hydrology, Av. Water. Resour. 25 (2002) 1287-1304.
[10] M. Sherif, M. M. Mohamed, A. Shetty, M. Almulla, Rainfall-runoff modeling of three Wadis in the northern area of UAE, Journal of Hydrologic Engineering. 16(2011) 10–20.
[11] M. Sherif, A. Mohamed, A. Shetty, R. K. Chowdhury, Analysis of rainfall, PMP and drought in United Arab Emirates, International Journal of Climatology. 34 (2014) 1318–1328.
[12] B. Boer, An introduction to the climate of the United Arab Emirates. Journal of Arid Environments. 35 (1997) 3–16.
[13] F. H. S. Chiew, L. W. Siriwardena, Probabilistic seasonal streamflow forecasting methods. Proc. 29th Hydrology and Water Resources Symposium, Engineers Australia, Canberra, Australia, 2005.
[14] Z. W. Kundzewicz, A. J. Robson, Change detection in hydrological records – a review of the methodology, Hydrological Sciences. 49(2004) 7-19.
[15] R. K. Chowdhury, S. Beecham, Australian rainfall trends and their relation to the southern oscillation index, Hydrological Processes. 24(2010) 504-514.