Trends in crop reference evapotranspiration and climatological variables across Ceará state: Brazil.

PAULINO, V.E.N., STUDART, T.M.C., CAMPOS, J.N.B., PESTANA, C.J., LUNA, R.M., ALVES, J.M.B.

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Article

Trends in Crop Reference Evapotranspiration and Climatological Variables Across Ceará State − Brazil

Virginia Ellen do Nascimento Paulino[1], Ticiana Marinho de Carvalho Studart[1] ,
José Nilson B. Campos[1], Carlos J. Pestana[1], Renata Mendes Luna[1], José Maria Brabo Alves[2]

*[1]Departamento de Engenharia Hidráulica e Ambiental, Universidade Federal do Ceará,
Fortaleza, CE, Brasil.*
[2]Departamento de Física, Universidade Estadual do Ceará, Fortaleza, CE, Brasil.

Abstract

Irrigation has a substantial share in total world water demand. At the global level, the withdrawal ratio for agriculture is 69 percent. Irrigation is necessary to compensate evapotranspiration (ET) deficit due to insufficient precipitation. Knowing the impacts of climatic changes on meteorological variables that directly affect the ET is important for successful climate adaptation. This paper analyzes annual trends in measured meteorological variables and in the crop reference evapotranspiration (ET_0), at eight climatological stations in Ceará State, Brazil. Two statistical tests for trend analysis were used - Mann-Kendall and linear regression. The results indicate positive trend, statistically significant, in the maximum air temperature in five of eight stations. Minimum air temperature showed positive trend in three stations. Wind speed, sunshine hours and relative humidity presented positive and negative trends. These irregular patterns directly impacted ET_0 in three stations. It seems that the increasing trend in ET_0 was probably due to a significant increase detected in maximum temperature and minimum air temperature, not fully offset by the decrease in wind speed and relative humidity. The warning from these results is that water demand for irrigation is expected to significantly increase over the next decades on in Jaguaribe River Basin.

Keywords: Mann-Kendall, linear regression, semi-arid.

Análise de Tendências na Evapotranspiração de Referência e nas Variáveis Climatológicas do Estado do Ceará-Brasil

Resumo

A irrigação representa uma parte substancial na demanda de água mundial. Em âmbito global, a retirada para a agricultura é de 69%. A irrigação é necessária para compensar o déficit em evapotranspiração (ET) devido à precipitação insuficiente. O conhecimento dos impactos das mudanças climáticas em variáveis meteorológicas que afetam a ET é importante para adaptação às mudanças no clima. Este artigo analisa tendências em variáveis meteorológicas e na evapotranspiração de referência (ET_0), em oito estações climatológicos no estado do Ceará, Brasil. Foram aplicados os testes de Mann-Kendall e regressão linear. Os resultados indicam tendência positiva, estatisticamente significativa, na temperatura máxima do ar, em cinco de oito estações. A temperatura mínima do ar mostrou tendência positiva em três estações. A velocidade do vento, as horas de insolação e a umidade relativa apresentaram tendências positivas e negativas. Estes padrões impactaram a ET_0 em três estações. A tendência crescente em ET_0 decorre do aumento detectado na temperatura máxima e na temperatura mínima do ar, não totalmente compensado pela diminuição na velocidade do vento e na umidade relativa. Estes resultados apontam para aumento da demanda para irrigação nas próximas décadas sobre na bacia do rio de Jaguaribe.

Palavras-chave: Mann-Kendall, regressão linear, semiárido.

Autor de Correspondência: Ticiana Marinho de Carvalho Studart, ticianastudart2010@gmail.com.

1. Introduction

Irrigation is an essential driving force in the water use management and has a substantial share in total world water demand. At global level, the withdrawal ratios are 69% agricultural (including irrigation, livestock and aquaculture), 12% municipal (including domestic) and 19% industrial (FAO, 2016). In arid and semiarid climates or during extended dry seasons, irrigation is necessary to compensate evapotranspiration (ET) deficit due to insufficient precipitation.

ET is one of the critical components of the hydrological cycle, given its importance for local water availability estimation. A report of the Intergovernmental Panel on Climate Change (IPCC, 2014) shows that, in recent decades, the near-surface air temperature has increased significantly. This results in higher evaporation rates, which enables higher amounts of water vapor to be transported by the atmosphere. The main warning from these results is that water demand for irrigation is expected to significantly increase over the next decades due higher ET rates.

Measuring ET directly is a complicated task due to the varied factors that influence it, one must consider parameters that affect the plant (crop type, variety, density and phase culture), the soil (salinity, fertility, presence/absence of disease and the local weather). Thus, surrogate measurements obtained from meteorological variables (air temperature, wind speed, humidity and solar radiation) are used to indirectly compute the reference evapotranspiration or reference crop evapotranspiration, denoted as ET_0 (Temesgen et al., 2005).

According to Shan et al. (2015), ET_0 is one of the best indicators of hydrological processes changes. From the results of IPCC (2014), it can be expected that the water cycle has accelerated in many parts of the world (Lv et al., 2016). Despite some recent studies confirming the expectation of ET_0 increase is associated to average temperature elevation (Dinpashoh et al., 2011; Tabari et al., 2012), other studies point in the opposite direction (Xu et al., 2006; Kousari et al., 2013; Huo et al., 2013; Li et al., 2013; Shan et al., 2015), possibly due to atmospheric changes in other variables. Peterson et al. (1995) linked the decrease in ET_0 in the US and in the former Soviet Union to increases in cloud cover, which influenced the radiation balance; Bandyopadhyay et al. (2009) related the decrease in ET_0 in India to increases in the relative humidity, coupled with decreases in solar radiation and wind speeds.

Several studies have also analyzed the ET_0 in Brazil. A large majority, however, were based on Climatological Standard Normal (1961-1990), published by the National Institute of Meteorology - INMET. In 2016, INMET released a new historical database of all Brazilian meteorological stations, including 1990 - 2015 period.

In this context, the objective of this paper is to analyze spatial and temporal variations in five meteorological variables that directly affect the ET_0: maximum and minimum temperature, wind speed, insolation, and relative humidity. Additionally, changes in the ET_0 itself have been estimated using the Pemann-Montheith (PM) method. The dataset used covers the period from 1961 to 2015, identifying possible trends in these variables and in ET_0 across Ceará State, Brazil, a region of semiarid climate, frequently plagued by droughts. Knowing the impacts of climatic changes on water demand for irrigation and high-water consumption activity is very important for successful climate adaptation. This is especially true for semi-arid regions (Alves et al., 2009).

2. Materials and Methods

2.1. Study area

The State of Ceará, in the semi-arid Northeast of Brazil, has a short rainy season. The three large-scale precipitation mechanisms - Intertropical Convergence Zone (ITCZ), cold fronts, and upper air vortices - create a certain rainfall pattern over the state during different months. The rainfall varies from 400 mm in inland to l,200 mm on the coast, while the annual potential evaporation varies from 2,400 mm in the coast, to 3,000 mm inland; 80% of the precipitation on the state is centered around March to May, when it's main rainfall system (ITCZ) reaches the southernmost position. The dominant climate is Köppen Aw' in the coast and inland. In the mountains of Baturité, where is located the Guaramiranga station, the climate is Köppen Amw' (Funceme, 2014).

Since there are no perennial rivers in Ceará, the only way to provide water for all needs, is from the stock of water accumulated in surface reservoirs (Campos; Studart; Costa, 2000), which are highly vulnerable to the effects of evaporation. Despite the chronic water scarcity, the demand for irrigation follows worldwide standards and represents around 62% of the total water demand in the state (ANA, 2012).

2.2. Data collection

There are 12 weather stations belonging to INMET in the state of Ceará which continuously record the meteorological parameters from January 1961 to December 2015. Of these 12 stations, only eight had monthly (mean daily data for each month) records of the required parameters to estimate ET_0, namely: [1] T_{max}: maximum average temperature (°C); [2] T_{min}: minimum average temperature (°C); [3] U: wind speed at 10 m height (m s^{-1});
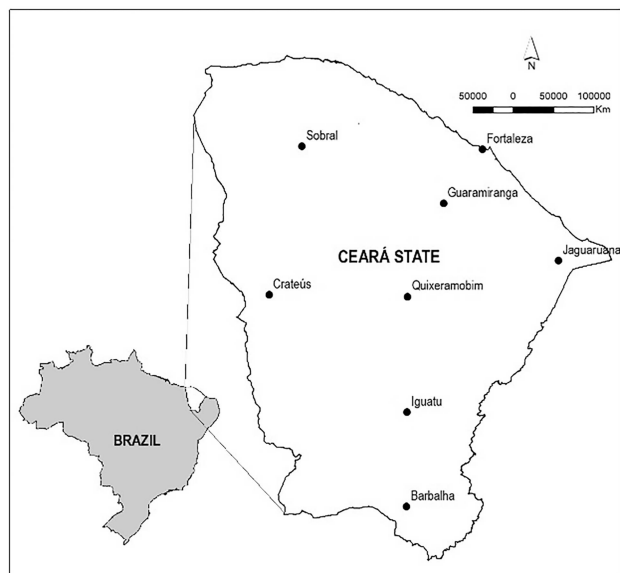
Figure 1 - Location of the study area and spatial distribution of meteorological stations in Ceará State map.

[4] S: sunshine hours (h) and [5] RH: relative humidity (%) (Figure 1; Table 1) (INMET, 2016).

Even though the historical data covers 55 years of measurements (1961 - 2015), there are many gaps in the data for some of the climatic variables. To be able to estimate the ET_0, it is necessary to have data for all climatic variables affecting ET_0. For this reason, the length of the data set was reduced. Depending on the station, the time span observed was from 15 to 31 years. For each station the percent availability of each meteorological variable was determined (Table 2). It may be noted that in Crateus, for instance, only 29% of the time series can be used (16 years). For Fortaleza however, 56% of the data collected could be used (31 years).

2.3. ET_0 estimation

The annual ET_0 was calculated using the standard Penman-Monteith Method (PM) as recommended by the United Nations Food and Agriculture Organization (FAO) (Allen *et al.*, 1998). PM has been applied successfully in many arid and semi-arid regions (Shadmani; Marofi; Rokinian, 2012), and is considered the most reliable method for various climates, once it is physically based on and explicitly incorporates both physiological and aerodynamic parameters (Xu *et al.*, 2006).

The software SEVAP (Silva *et al.*, 2005) was employed for the estimation of the PM reference evapotranspiration. Non-available meteorological variables in routine observations in conventional stations (necessary in PM Method) is estimated by SEVAP using maximum and minimum temperatures, wind speed, sunshine hours and relative humidity.

Table 1 - Geographic and climatic characteristics of the climatology (annual mean) stations used in the study (adapted from INMET, 2016).

Code	Station	Latitude (°)	Longitude (°)	Elevation (m)	T_{max} (°C)	T_{min} (°C)	U (ms⁻¹)	S (h)	RH (%)
82784	Barbalha	-7.3	-39.3	409.0	32.2	20.7	1.8	8.0	67.7
82583	Crateus	-5.2	-40.7	296.8	32.2	22.0	2.9	7.5	60.7
82397	Fortaleza	-3.8	-38.5	26.5	30.6	23.6	3.3	7.9	78.2
82487	Guaramiranga	-4.3	-39.0	870.7	25.7	18.1	2.7	5.1	86.6
82686	Iguatu	-6.4	-39.3	217.7	33.2	22.2	2.4	8.3	62.9
82493	Jaguaruana	-4.8	-37.8	11.7	33.4	22.9	3.6	8.3	71.1
82586	Quixeramobim	-5.2	-39.3	79.5	33.2	22.7	3.3	8.0	65.1
82392	Sobral	-3.7	-40.3	109.6	34.0	22.2	2.0	7.4	69.2

Table 2 - Availability of data from meteorological stations and variables of the amount of calculated ET_0.

Code	Station	T_{max}	T_{min}	U	S	RH	ET_0	Years Available	N° years
82784	Barbalha	55%	49%	51%	44%	47%	35%	1974, 1976, 1978, 1981, 1984, 1996, 1997, 1999, 2003-2007, 2009-2014	19
82583	Crateus	47%	49%	47%	38%	44%	29%	1970, 1973, 1975, 1977-1978, 1996, 1998-1999, 2006-2008, 2011-2012	16
82397	Fortaleza	56%	56%	56%	64%	56%	56%	1961-1962, 1965-1970, 1973-1978, 1982, 1994, 1996-1997, 1999, 2003-2014	31
82487	Guaramiranga	64%	64%	53%	53%	60%	35%	1961-1962, 1969, 1976, 1978, 1997-1998, 2002-2007, 2009-2014	19
82686	Iguatu	60%	62%	49%	55%	53%	42%	1963-1971, 1973, 1978, 1997, 2001, 2005-2014	23
82493	Jaguaruana	60%	56%	47%	55%	49%	42%	1995-1997, 2003-2014	15
82586	Quixeramobim	62%	64%	62%	47%	64%	36%	1961-1963, 1968-1970, 1974, 1978, 1996, 1999, 2006-2015	20
82392	Sobral	64%	64%	49%	58%	55%	35%	1961-1962, 1969-1970, 1973-1975, 1978, 2004-2014	19

2.4.   Trend analysis

To detect trends, two statistical tests were applied in this investigation: Mann-Kendall and regression analysis. The Mann-Kendall test is a nonparametric test, highly recommended by the World Meteorological Organization (WMO) for the analysis of hydro-meteorological time series, because assumptions about the underlying probability distribution function of the data are not necessary (Wang, 2011). Regression analysis is a classical statistical test for the detection of trends in time data sets that provides an estimative for the trend value.

2.4.1.   Linear regression analysis

Linear regression analysis is applied for detecting trends in the climate variables time series. The main statistical parameter drawn from the regression analysis, the slope, shows temporal trends in the average of the climate variable. For a time series of a climate variable Y, the Eq. (1):

$$Y_i = a + bt_i + \varepsilon_i \qquad (1)$$

where Y_i is the value of climate variable at time t; a is the value of Y for $t = 0$; b is the slope, t_i is the time and ε is white noise. To verify the limits of confidence and test of significance is applied the test for b as a random variable with a t of Student distribution (Storch *et al.*, 1999).

2.4.2.   Mann-Kendall Test

This statistic test was originally developed by Mann (1945) as a non-parametric test for trends. The test was later modified by Kendall (1975). The Mann-Kendall test (MK) has been used since then and is considered an effective tool for identifying trends in hydrologic variables. The method offers many advantages because missing values are allowed, and the data is not required to conform to any particular distribution (Salmi *et al.*, 2002), furthermore it is less sensitive to outliers (Hamed, 2008). MK, based on S statistics, compares each value of the time series with its own future values, always in sequential order (Eq. (2)). Autocorrelation in time series can affect the sensitivity of this method, and so, it must be verified (Silva, 2015).

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(X_j - X_i) \qquad (2)$$

where x_j - the sequential data values; n - the length of the data set; sgn - equal to 1, 0 or -1, if $(x_j - x_i)$ is greater than, equal to or less than zero, respectively.

The null hypothesis (H_0) is that the data ($x_1, \ldots x_n$) is identically distributed with random variables (i.e. no existing trend in the data set). The alternative hypothesis (H_1) is that there is a trend.

It can be shown that S is normally distributed, i.e., $S \sim N(\mu, \sigma^2)$. For several observations greater than ten ($n > 10$) the test statistic is calculated (Eq. (3)) (Önöz; Bayazit, 2003):

$$Z = \begin{cases} S - 1/\sigma_s & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ S + 1/\sigma_s & \text{if } S < 0 \end{cases} \qquad (3)$$

were $\sigma_s = \sqrt{\dfrac{n(n-1)(2n+5)}{18}}$

The null hypothesis, no trend, is rejected when the computed Z value is greater than $Z_{\alpha/2}$ in absolute numbers. The Z statistic signal indicates whether the trend is increasing (Z > 0) or descending (Z < 0). The significance level was set to 0.05, which is widely used in the literature (Wang, 2011; Li *et al.*, 2013; Gocic; Trajkovic, 2013; Zhang *et al.*, 2015).

3.   Results and Discussion

The autocorrelation of the time series was checked for each variable. Only Guaramiranga station presented negative significance, at 5% significance level, an autocorrelation on lag 1. For a better discussion and understanding of the spatial and temporal trends in the five intervening variables, as well as in the ET_0, tables and graphics containing the results of MK tests (Tables 3 to 6) and of the linear regression (β) were applicable (hatched lines).

3.1.   Maximum (T_{max}) and minimum (T_{min}) temperature

A significant increasing trend (Z) was observed in T_{max} for six stations - Barbalha, Crateus, Fortaleza, Iguatu, Quixeramobim, and Sobral (Table 3) For T_{min} a significant increasing trend in three stations was observed - Crateus, Fortaleza, and Guaramiranga. No significant decreasing trend for these variables was detected in any station. These results are consistent to rising surface air temperature recently found in urban and nearby areas (Ren, 2015).

Table 3 - MK results and linear regression of T_{max} and T_{min}.

Station	Maximum temperature (T_{max})			Minimum temperature (T_{min})		
	Z	Trend	β (ºC year⁻¹)	Z	Trend	β (ºC year⁻¹)
Barbalha	4.07	S+	0.042	1.17	NS	0.024
Crateus	2.47	S+	0.026	3.13	S+	0.025
Fortaleza	5.20	S+	0.029	2.99	S+	0.012
Guaramiranga	0.48	NS	0.004	4.99	S+	0.030
Iguatu	2.22	S+	0.016	1.19	NS	0.004
Jaguaruana	1.10	NS	0.020	1.48	NS	0.015
Quixeramobim	1.85	S+	0.022	1.27	NS	0.004
Sobral	2.36	S+	0.026	-1.59	NS	-0.005

NS = not significant trend; S+ = positive significant trend (5 %); S- = significant negative trend (5 %). Z = M-K significance; β = linear regression coefficient. The gray-shaded lines signify a significant positive trend.

The linear regression coefficient (β) revealed, at 5% significance level, increases in T_{max}, ranging from 0.16 °C per decade in Iguatu to 0.42 °C per decade in Barbalha. These values are much smaller than those found in Serbia, which are around 6 °C per decade (Gocic and Trajkovic, 2013), but are in the same range of those detected in the Brazilian Amazon region, around 0.15 °C per decade (Gocic and Trajkovic, 2013) and Iran, around 0.7 °C per decade (Tabari and Marofi, 2011).

For T_{min}, the lowest increase was in Fortaleza (0.12 ° C per decade) and the largest was in Guaramiranga (0.30 ° C per decade). These values are lower than those found in Iran, around 1.2 °C per decade (Tabari and Marofi, 2011) and Serbia, around almost 4 °C per decade (Gocic and Trajkovic, 2013), but are in the same range of those detected in the Brazilian Amazon region, between 0.41 and 0.72 °C per decade (Silva, 2015). Davis and Hanna (2016) also detected a tendency of increase in the maximum and minimum temperatures in Australia. All these authors linked these growing trends to global warming, increase in urban areas, and changes in atmospheric circulation.

3.2.   Wind speed (U) and sunshine hours (S)

In the data for the annual wind speed and sunshine hours for the 1961 to 2015 period there is a significant increasing trend in wind speed in three stations - Crateus, Iguatu and Quixeramobim and a significant downward trend in Barbalha and Fortaleza. There is a significant increasing trend in sunshine hours in two stations - Iguatu and Sobral; as well as a significant declining trend in Guaramiranga (Table 4).

The coefficient β revealed, at the level of significance of 5 %, an increase in U, ranging from 0.10 m s^{-1} per decade in Crateus to 0.25 m s^{-1} per decade in Quixeramobim. A decrease of 0.11 and 0.13 m s^{-1} per decade is

Table 4 - MK results and linear regression of wind speed and sunshine. The gray-shaded lines correspond to positive significant trend.

Station	Wind speed (U)			Sunshine hours (S)		
	Z	Trend	β (m s^{-1} year^{-1})	Z	Trend	β (h year^{-1})
Barbalha	-3.73	S-	-0.013	0.77	NS	0.012
Crateus	2.89	S+	0.010	0.21	NS	0.000
Fortaleza	-2.28	S-	-0.011	0.00	NS	0.000
Guaramiranga	0.66	NS	0.040	-2.64	S-	-0.019
Iguatu	2.34	S+	0.017	2.69	S+	0.011
Jaguaruana	-1.59	NS	-0.009	0.68	NS	0.012
Quixeramobim	3.47	S+	0.025	1.14	NS	0.006
Sobral	0.58	NS	-0.006	3.68	S+	0.024

NS = not significant trend; S+ = positive significant trend (5 %); S- = significant negative trend (5 %). Z = MK significance; β = linear regression coefficient.

observed in Fortaleza and Barbalha. These values are close to those found in China, around 0.1 m s^{-1} per decade (Liu *et al.*, 2011) and Serbia, around 1.2 m s^{-1} per decade (Gocic and Trajkovic, 2013), and lower than those detected in China by Ye *et al.* (2014), around 0.2 m s^{-1} per decade.

For the sunshine hours (S), the coefficient β revealed, for the same level of significance, an increase of 0.11 h per decade in Iguatu station and 0.24 h per decade in Sobral. A decrease of 0.19 h was observed in Guaramiranga. These values are similar to those detected in China, around -0.2 h per decade (Ye *et al.*, 2014), and the Brazilian Amazon region, between 0.2 and 0.5 h per decade (Silva, 2015).

3.3.   Relative humidity (RH)

The annual trends in the relative humidity (RH) for the 1961 to 2015 period demonstrate a significant downward trend in two stations - Crateus and Iguatu and only a significant increasing trend in Barbalha (Table 5).

The linear regression coefficient revealed, at the level of significance of 5%, a decrease in relative humidity (RH) of 0.86% per decade in Crateus and 0.85% per decade in Iguatu; an increase of 2.11% per decade is observed in Barbalha. These values are higher than those found in China, between -0.3 and 0.5% per decade (Huo *et al.*, 2013; Ye *et al.*, 2014), but similar to those reported in the Brazilian Amazon region, around 2.2% per decade by Silva (2015).

The trends on maximum average temperature, minimum average temperature, wind speed, sunshine hours and relative humidity for Iguatu station are presented in Figure 2.

3.4.   Evapotranspiration (ET$_0$)

For annual trends in evapotranspiration (ET$_0$) for the 1961 to 2015 period there is a significant increasing trend

Table 5 - MK results and linear regression for humidity.

Climatology Station	Relative humidity		
	Z	Trend	β (% year^{-1})
Barbalha	2.56	S+	0.211
Crateus	-1.81	S-	-0.086
Fortaleza	-1.29	NS	-0.038
Guaramiranga	-1.35	NS	-0.027
Iguatu	-2.31	S-	-0.085
Jaguaruana	-0.77	NS	-0.025
Quixeramobim	0.68	NS	0.017
Sobral	-1.57	NS	-0.056

NS = not significant trend; S+ = positive significant trend (5 %) ; S- = significant negative trend (5 %). Z = MK significance; β = linear regression coefficient. The gray-shaded lines correspond to positive significant trend.

in three stations - Crateus, Fortaleza, and Iguatu (Table 6). No station showed a significant downward trend for ET_0. The MK test was not applied to Guaramiranga station, since it presented a negative correlation on lag -1. Thus, the other tests were not performed.

The coefficient β revealed, at the level of significance of 5 %, an increase in ET_0 of 37.9 mm per decade in Crateus, 47.4 mm per decade in Iguatu and 5.5 mm per decade in Fortaleza. These values are higher than those found in the Brazilian Amazon region, between 0.06 and 0.15 mm per decade (Silva *et al.*, 2015) and in China, around -30.9 mm per decade (Huo *et al.*, 2013), but similar to those detected in some stations of Iran by Kousari *et al.* (2013). The trend on ET_0 for Iguatu Station is presented in Figure 3.

Table 6 - MK results and linear regression of evapotranspiration.

Climatology Station	Evapotranspiration		
	Z	Trend	β (mm year^{-1})
Barbalha	-1.40	NS	-1.31
Crateus	1.94	S+	3.79
Fortaleza	1.80	S+	0.55
Guaramiranga	*	*	*
Iguatu	3.49	S+	4.74
Jaguaruana	0.10	NS	0.27
Quixeramobim	1.59	NS	2.78
Sobral	1.19	NS	1.79

NS = not significant trend; S+ = positive significant trend (5 %); S - = significant negative trend (5 %). Z = MK significance; β = linear regression coefficient. The gray-shaded lines correspond to positive significant trend.
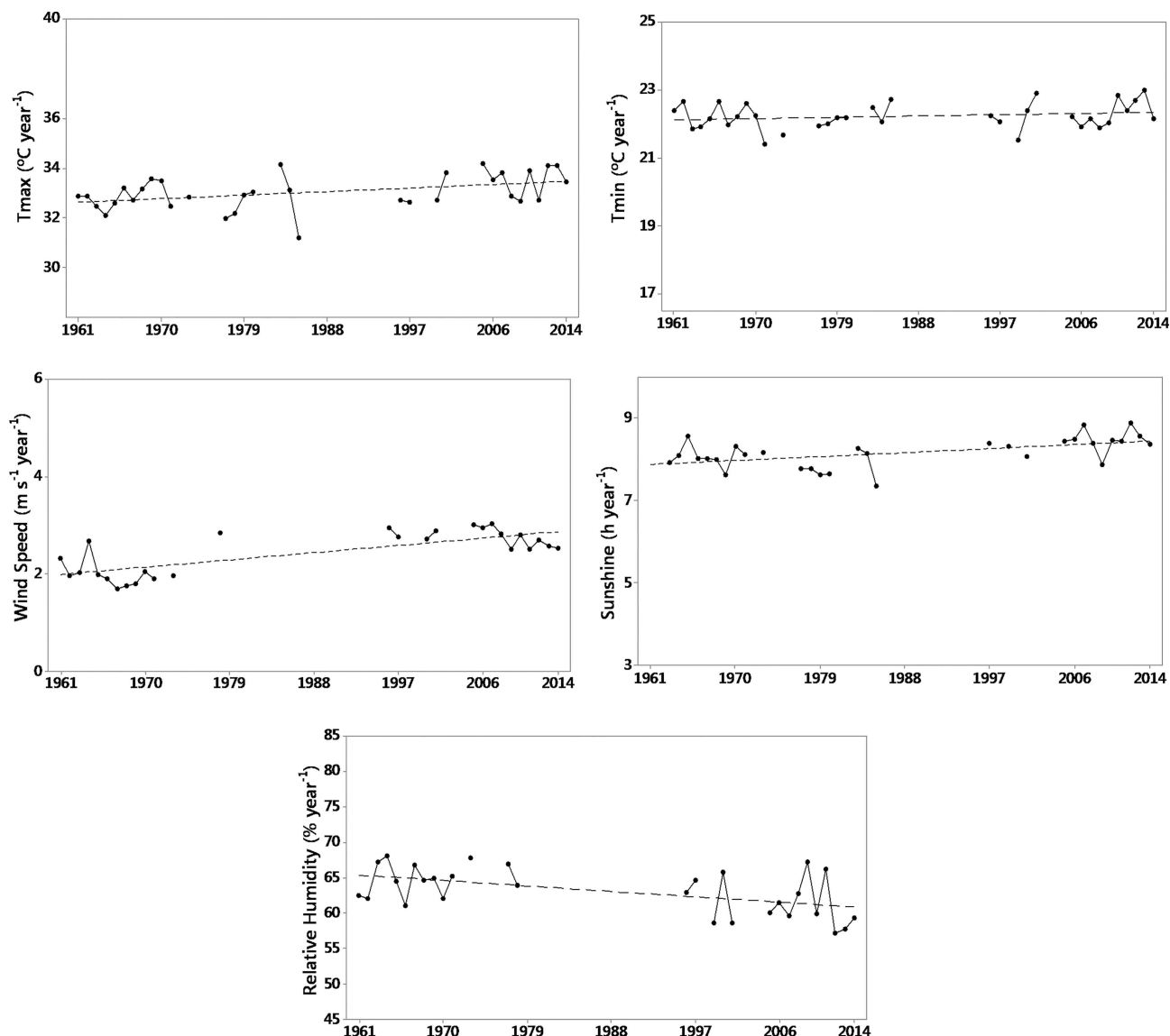
Figure 2 - Average annual climatological variables (round dotted line) over time with the linear regression line of the Iguatu station.

The Table 7 shows a summary of the trends behavior (increasing or decreasing) in regard to ET_0, as well as in the defining variables (air temperature, wind speed, relative humidity and sunshine hours). It demonstrates that the variables display predominantly positive trends. However, only in three stations the increase in ET_0 period was directly affected by them.

Some increasing trends observed in the meteorological records may express more local effects than global change (Back, 2001). The heat due to urbanization produces the warming of the atmosphere that affects the temperature, since most of the meteorological stations are close to the urban areas. Figure 4 shows the growth of urban areas in Iguatu for the period 1984 to 2011 (area passing from 375 ha to 1,162 ha). However, Crateus and Iguatu still have some rural characteristics (few concrete and asphalt pavements) and displayed an increasing trend in T_{max} and T_{min}, variables that respond strongly to global warming (Tang *et al.*, 2010). Increased T_{min} results in a decrease in daily temperature range and warmer nights, a fact already observed in various regions of the world that are not affected by mega cities, since concrete and asphalt pavements directly influence the diurnal temperature variation

(Marengo; Rusticucci; Penalba, 2010). In the Fortaleza station, vertical urbanization on the north-northeast coast of the city influenced the negative trend of the wind variable, a fact not observed in the other regions of the State.

It is difficult to establish the real cause of these increasing trends - climate change, urbanization or both). However, the main warning from these results is that ET_0 is increasing in the inland (Iguatu and Crateus stations). This means that water demand for irrigation is expected to significantly increase over the next decades due higher ET_0 rates. It is also important to point out the relative importance of irrigation in Jaguaribe River Basin (where Iguatu station is located), which corresponds to 83% of its total water demand - 37% (private irrigation) and 46% (public irrigation projects) (Studart *et al.*, 2000).

4. Conclusion

Trend analyses of ET_0 and of its underlying meteorological variables were conducted for eight meteorological stations in Ceará State, located in semi-arid Northeast Brazil, using the Mann-Kendall test and linear regression analysis. The trends found in some climate variables were aggregated in the annual average
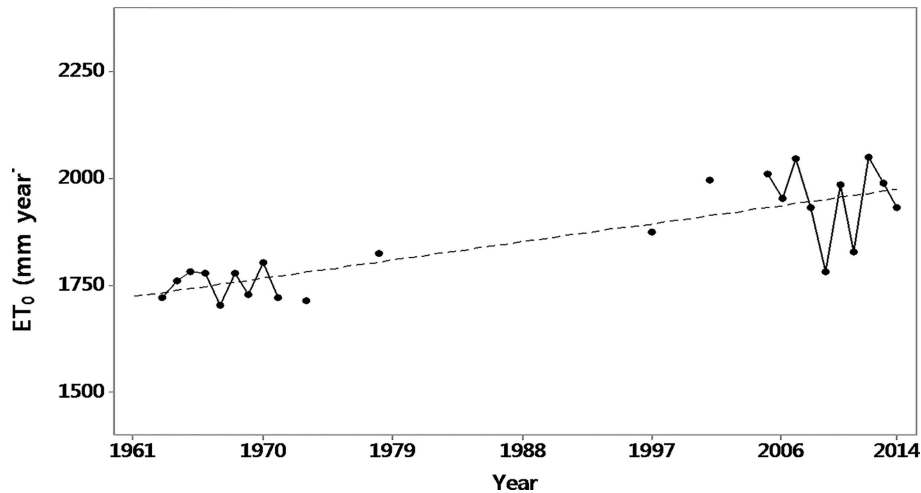
Figure 3 - Average annual evapotranspiration (round dotted line) over time with the linear regression line of the Iguatu station.
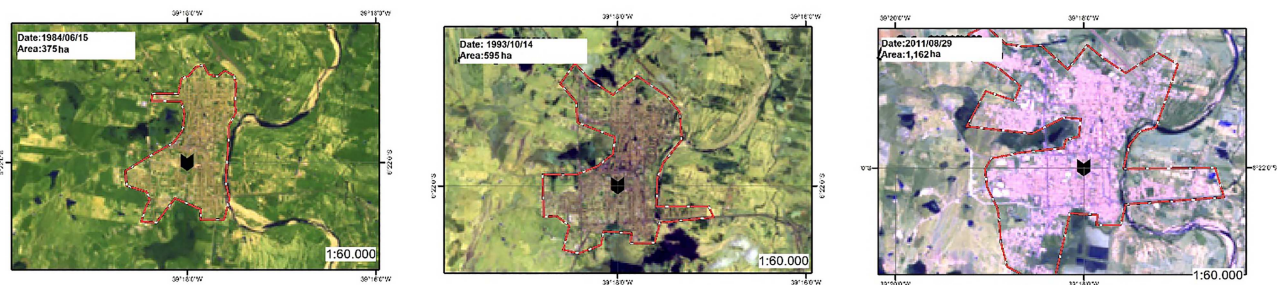
Figure 4 - Urban area evolution in Iguatu (1984 to 2011).

Table 7 - Synthesis of trend analysis of ET_0 and defining variables.

Station	T_{max}		T_{min}		U		S		RH		ET_0	
	Trend	β (°C year^{-1})	Trend	β (°C year^{-1})	Trend	β (m s^{-1} year^{-1})	Trend	β (h year^{-1})	Trend	β (% year^{-1})	Trend	β (mm year^{-1})
Barbalha	S+	0.042	NS	0.024	S-	-0.013	NS	0.012	S+	0.211	NS	-1.310
Crateus	S+	0.026	S+	0.025	S+	0.010	NS	0.000	S-	-0.086	S+	3.790
Fortaleza	S+	0.029	S+	0.012	S-	-0.011	NS	0.000	NS	-0.038	S+	0.550
Guaramiranga	NS	0.004	S+	0.030	NS	0.040	S-	-0.019	NS	-0.027	*	*
Iguatu	S+	0.016	NS	0.004	S+	0.017	S+	0.011	S-	-0.085	S+	4.745
Jaguaruana	NS	0.020	NS	0.015	NS	-0.009	NS	0.012	NS	-0.025	NS	0.270
Quixeramobim	S+	0.022	NS	0.004	S+	0.025	NS	0.006	NS	0.017	NS	2.780
Sobral	S+	0.026	NS	-0.005	NS	-0.006	S+	0.024	NS	-0.056	NS	1.790

NS = not significant trend; S+ = positive significant trend; S- = significant negative trend (5 %); S− = significant negative trend (5 %); Z = MK significance; β = linear regression coefficient. The gray-shaded lines correspond to positive significant trend.

evapotranspiration ET_0, which is variable most related to the water demand for irrigation.

The most relevant results were the positive trends in ET_0 in three of the eight stations: 47.4 mm per decade in Iguatu; 37.9 mm per decade in Crateus, and 5.5 mm decade in Fortaleza. These upward trends point out increases in annual ET_0 of 2.6%, 2.0% and 0.3% per decade, respectively. It should be observed that the higher increases in evapotranspiration happens in the interior of the state, Crateus and Iguatu, places frequently impacted by severe droughts. Iguatu station, which presented the highest ET_0 rate is in the Jaguaribe River Basin, where the irrigation demand is greater than 80% of its total water demand.

Other studies that compare changes in water demand with changes in water availability are still necessary for the development of better climate adaptation policies. Nevertheless, climatic data should warn and alarm society that new practices that increase sustainability are necessary and urgently required.

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