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Reference Evapotranspiration in the State of Paraíba, Brazil: Climatic Trends and Influencing Factors

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ABSTRACT

Reference evapotranspiration (ET_0) plays an important role in the planning of irrigation and the water demand of crops, as well as in the planning of water uses in watersheds. The identification of trends in ET_0 under climate changes is important to understand its effects on agriculture, water balance and water resources planning. The goal of this work was verify whether there was or there was not an increasing/decreasing trend on ET_0 in dry and rainy periods, as well as in annual period, identifying the influencing climate variables on ET_0 in the state of Paraíba, Brazil. In order to determine the ET_0 trend in the series the Mann-Kendall nonparametric test was used, whereas the series slope was determined by applying Sen's estimator. To identify the most influencing climatic variable it was performed a multiple regression of normalized data. The data were obtained of six stations with monthly data from January 1961 to December 2015, a total period of 55 years. Results showed increasing on ET_0 in almost all stations during the study period, except for a single of them in which there was a decreasing. The most dominant variables influencing the trend on ET_0 was air temperature during annual time scale, while during the rainy and dry seasons there was an alternation between the most influencing variables (air temperature and sunshine duration).

Keywords: climate variables, Mann-Kendall test, climate change

Introduction

There is an urgent global necessity for elaborating policies to a rational use of hydric resources, inasmuch as there are 4 billion people in the world who face shortage of water at least a month per year (Mekonnen and Hoekstra, 2016) and projections indicate an increase in dry areas due to climate changes (Huang et al., 2016).

It is well known that climate changes have altered not only the magnitude of rainfall but also its seasonal distribution (Kang and Eltahir, 2019) and its interannual variability, thus affecting water availability and having direct impacts on agriculture and vegetation (Elouissi et al., 2017).

Evapotranspiration (ET) is the most important variable used to show both climate change and the space-time patterns of variables influencing ecohydrological processes which

control the evolution of surface ecosystems (Hao et al., 2018). Therefore, investigating the effects of climate changes on ET may be effective in order to determine strategies to mitigate the probable damages caused by such effects, because projections indicate an increase in ET in all scenarios studied (Gharbia et al., 2018). Furthermore, reference evapotranspiration (ET_0) plays an important role in the planning of irrigation (Feder et al., 2016) and in that of future hydric demands (Fisher et al., 2017).

ET_0 represents the evapotranspiration ability of a hypothetical reference crop with a specific height, surface resistance and albedo and without water stress, which is important to quantify agriculture water demand. To estimate ET_0 , the Penman-Monteith method considering a radiative term and aerodynamic term is used as a standard

method in many studies (Fan et al., 2016; Wang et al., 2017).

The identification of climate factors contributing to increases or decreases in ET_0 during a historical time series is important because it identifies which variable has contributed for such increases or decreases. Researches show that climate variables such as wind speed, amount of solar radiation, relative humidity, and maximum and minimum temperatures have been the ones contributing more to the trends in ET_0 (Li et al., 2017a; Wang et al. 2019).

The investigation to verify whether there have been changes in climate variables during a time series is carried out by analyzing the significance of trends in hydroclimatic time series with the use of tests classified as either parametric or nonparametric. Parametric tests are more potent, nevertheless, they require that data be more independent and have a normal distribution. In nonparametric tests, on their turn, data must also be independent, but outliers are more tolerated, and those tests are insensitive to the type of data distribution (Jinlin et al., 2018). In that sense, the Mann-Kendall (MK) test is an example of such nonparametric tests, and it is applied to detect trends in rainfall (Wu et al., 2016), in temperature (Martínez-Austria et al., 2016) as well as in other climate variables (Geng et al., 2016).

Evapotranspiration is very sensitive to changes in climatic variables that are decisive for its calculation. As the air temperature increased,

verified in practically the whole globe, including in the northeast region of Brazil, ET_0 certainly presented changes. However, the questions arise: did all stations present changes in evapotranspiration or part of them? Was the air temperature only presented changes or others climate variables caused changes? And what are the climatic variables that most contributed to these changes?

There are few studies on climate trends in the state of Paraíba, Brazil, and they only assess the rainfall trends as well as maximum and minimum temperatures (Nóbrega et al., 2014, Dantas et al., 2015). Due its semiarid climate, the State of Paraíba has been affected by droughts and El Niño, increasing the hydric crisis. In view of that, this work aims at: (1) verifying occurrences of increasing or decreasing trends in ET_0 in dry and rainy periods, as well as in annual ones, in six localities in the state of Paraíba, by using the MK test, (2) identifying, too, which climate variable has contributed to increase or decrease in ET_0 .

Data and Methodology

This study comprises six cities in the state of Paraíba, in Northeast Brazil, and the data used to calculate ET_0 have been obtained through the database of the National Institute of Meteorology (INMET). The data series range from January 1961 to December 2015, and the information about stations and climate are shown in Table 1.

Table 1 Climate classification for the stations in study

Station	Latitude (°)	Longitude (°)	Elevation (m)	Climate	Rainy	Dry
João Pessoa	-7.16	-34.81	34	As	APR-JUL	SEP-DEC
Areia	-6.97	-35.72	573	As	APR-JUL	SEP-DEC
Campina Grande	-7.22	-35.90	546	BSh	APR-JUL	SEP-DEC
Monteiro	-7.89	-37.12	606	BSh	FEB-MAY	AUG-NOV
Patos	-7.08	-37.27	264	BSh	JAN-APR	AUG-NOV
São Gonçalo	-6.83	-38.31	237	As	JAN-APR	AUG-NOV

The FAO-56 equation proposed by Allen et al. (1998) was used to calculate ET_0 . For the months missing data, the evapotranspiration was calculated through the Thornthwaite (1948) model, since the only input variable required is the temperature.

In order to detect significant (Z) trends in the series of ET_0 the MK test was used (Mann, 1945, Kendall, 1975). The MK test detects linear and nonlinear trends, and in that test the null hypothesis (H_0) and the alternative one (H_1) are

respectively equivalent to nonexistence and existence of a trend in the observational data series.

Sen's method (Sen, 1968), was also used to estimate the slope magnitude (β) in the trend series. The advantage of using that method is that it limits the influence of outliers on the slope.

The nonparametric test developed by Pettitt (1979) was another method used in this study. It detects a significant changing point in the mean value of a time series when such a precise point is unknown. The test uses a version of the Mann-Whitney statistic U_{bN} , which verifies

whether or not two samples sets $x_1, \dots, x_t$ and $x_{t+1}, \dots, x_N$ come from the same population. Such statistical test counts the number of times a member of the first sample exceeds another in the second sample. The null hypothesis of Pettitt test is the absence of a changing point and the test was applied only on the annual trend.

The tests were carried out at a level of significance of 5%, and they analyzed whether or not a trend occurred during rainy or dry periods, as well as in annual period.

It is important to verify whether the trends observed in the annual ET_0 have the same configuration in all seasons or if there are differences between them, as well as to check whether localities that do not show any trends in annual ET_0 present some trend during seasonal variations.

In Paraíba, because of its proximity to the equator, the seasons of the year (summer, fall, winter, and spring) are not well marked. As a result, only two are effectively noticed: a rainy period and a dry, which are appropriately referred to as rainy and dry periods, respectively. That is why trends of ET_0 for the rainy and dry periods are analyzed in this work. Rainy and dry periods were defined as the average of four consecutive rainiest and driest months, respectively, in the time series of precipitation. Thus, rainy and dry months for each location are shown in Table 1. It is important to mention that the stations are located in different climatic regions, for this they present particular characteristics of the region which belong.

The methodology proposed by Zang et al. (2011) and Ye et al. (2014), in which multiple linear regression is used to determine the relative contribution of each independent variable to explaining its dependent, was used in this work so

as to determine the percentage of contribution of such variables as air temperature, relative humidity, and wind speed to ET_0 . Before applying the method, however, it is necessary to normalize the original data concerning ET_0 and input variables. Such normalization is done accordingly to Equation 1:

$$X_{in} = \frac{x_i - x_{i \min}}{x_{i \max} - x_{i \min}} \quad (1)$$

in which, X_{in} is the normalized variable, x_i , $x_{i \max}$ and $x_{i \min}$ are sequences of values observed in the historical series (current value, maximum value and minimum value, respectively).

Based on the coefficients of regression, the relative rate (η %) of contribution of each variable (X_{in}) to explaining the values of ET_0 (Y_i) may be estimated from Equation 2.

$$\eta_{1,2,3,\dots,n} = \left(\frac{|a_{1,2,3,\dots,n}|}{|a_{1,2,3,\dots,n}| + |b_{1,2,3,\dots,n}| + |c_{1,2,3,\dots,n}| + |n|} \right) \cdot 100 \quad (2)$$

Thus, concerning their percentage of contribution to the increase or decrease of ET_0 , the variables analyzed were temperature (Temp), relative humidity (RH), sunshine duration (SD) and wind speed (W).

Results and Discussion

Annual Trend and Their Influencing Factors: - the annual trend of ET_0 was statistically significant for the stations located at João Pessoa, Monteiro and Patos, however, in Areia, Campina Grande and São Gonçalo were not statistically significant. Only João Pessoa and Patos localities showed an annual increase in the ET_0 , whereas Monteiro showed a decrease of it, as show the Tab. 2.

Table 2 Annual trend of reference evapotranspiration (ET_0) and weather data for six locations in the state of Paraíba, Brazil. Z: trend, β : Sen's estimator, Temp: air temperature, RH: relative humidity, SD: sunshine duration, W: wind speed at 2 m height

Station	ET_0		Temp		RH		SD		W	
	Z	β	Z	β	Z	β	Z	β	Z	β
João Pessoa	0.596*	8.3	0.692*	0.03	0.256*	-0.04	-0.062 ^{ns}	-	-0.107 ^{ns}	-
Areia	-0.055 ^{ns}	-	0.362*	0.03	0.029 ^{ns}	-	-0.036 ^{ns}	-	-0.113 ^{ns}	-
Campina Grande	-0.044 ^{ns}	-	0.618*	0.04	0.391*	-0.15	0.211*	0.31	0.182 ^{ns}	-
Monteiro	-0.414*	-10.24	-0.359*	-0.05	0.126 ^{ns}	-	0.037 ^{ns}	-	0.435*	0.02
Patos	0.453*	1.07	0.527*	0.04	0.14 ^{ns}	-	0.356*	0.71	-0.286*	-0.01
São Gonçalo	-0.033 ^{ns}	-	0.146 ^{ns}	-	0.052 ^{ns}	-	0.215*	0.34	0.017 ^{ns}	-

ns – no significant, * significant at 5%

The Sen's estimator showed a very sharp increase on the ET_0 in João Pessoa with a rate of increase of 8.3 mm year^{-1} . The decrease of air relative humidity implies that there was an increasing deficit of saturation due to the increment of air temperature, which caused a rise of ET_0 . Tests showed that the variable which had more influence on ET_0 was the temperature showing 65% of influence followed by the relative humidity with 20% of influence on the ET_0 . Sunshine duration and wind showed less influence on ET_0 as show the Figure 1(a). The urban sprawl of João Pessoa according to Sobreira et al. (2011) has contributed to an increase of air temperature, it has been a pattern in cities of Brazil as Recife - PE (Mendes et al., 2019), Santarém - PA (Oliveira et al., 2018) and Cuiabá-Várzea Grande - MT (Silva and Tarifa, 2017). The Pettitt's test showed that the first changing point in the series on ET_0 was in 1992, as from which a sharp increase of ET_0 is observed in Fig. 1(a). It is shown that from 1992 to

2015 the ET_0 values are oscillating around of 1750 mm, not varying in higher and lower values of ET_0 as occurred before of 1992. The lower value occurred in 1968 (1030 mm) and it was due a weak La Niña event. On the other hand, the higher value occurred in 1998 (1882 mm) and it was due a strong El Niño event. In El Niño event occurred decreasing in precipitation leading to higher values of evapotranspiration.

Patos presented a rate of increase of $1.07 \text{ mm year}^{-1}$ on the ET_0 . In Patos there was an increase of temperature and sunshine duration, as well as a decrease of wind speed, whereas relative humidity showed no trends. The first changing point on ET_0 in that time series, according to Pettitt's test was in 1980. The increase of air temperature and sunshine duration as well as the decrease of wind speed was due a local urban sprawl (Moreira et al., 2017).

Figure 1. Annual trend of ET_0 from localities significant statistically and contributing of the variables

However, the increase of ET_0 occurred mainly by air temperature that contributed with 99% of influence on the ET_0 (Fig. 1(b)). It is shown in Figure 1(b) that lower value occurred in 1976 (1454 mm) and it was due a moderate La Niña event. On the other hand, the higher value occurred in 1998 (2491 mm) and it was due a strong El Niño event.

Monteiro presented a more sharp decrease on the ET_0 , in that the rate of decrease is of $10.2 \text{ mm year}^{-1}$, as show the Figure 1(c). It was the one locality in wich occurred decrease in the ET_0 . The decrease of temperature as well as the increase of wind speed at the Monteiro meteorological station are probably associated with the substitution of the caatinga natural vegetation to pastures and agricultural fields. Changes in land cover types have had a substantial influence on evapotranspiration, especially when it comes to changing from natural vegetation to field crops (Li et al. 2017b), which facilitated the advection of colder and dry air from the Southeast into the area. However, the decrease of ET_0 occurred mainly by air temperature. The Pettitt's test showed that the first changing point in that series happened in 1987, but differently than occurred in the localities of João Pessoa and Patos, in Monteiro the higher and lower values occurred in neutral events of El Niño and La Niña.

It has been observed in Figure 1 that air temperature is the most dominant variable influencing ET_0 in annual time scale.

It was observed increasing in ET_0 due an increasing of air temperature, probably in decorrence to a local urban sprawl in the local studied. What reinforces the more local and

detailed analysis, because according to previous studies, other climatic variables can produce the same effect.

Kundu et al. (2016) observed similar behavior in India, where the increase of ET_0 was associated with air temperature always accordingly to the following pattern: the higher the temperature, the higher the ET_0 , the lower the temperature, the lower the ET_0 . However, Pandey and Khere (2018) founded only increasing on ET_0 over Narmada river basin (India). The differences occurred because the stydies were carried out in different areas. Liu et al. (2019) observed in North China Pain that the influence of precipitation on ET_0 produced positive trend, while the effects of air temperature, minimum temperature, relative humidity exhibited downward trends, with ET_0 being most sensitive to relative humidity, followed by air temperature. In a work carried out by Gao et al. (2017) and Li et al. (2018) to different basins in China, they observed a decreasement on ET_0 in annual time scale, but Gao et al. (2017) founded the solar radiation to be the most dominant variable influencing ET_0 . On the other hand, Li et al. (2018) founded the wind speed to be the most dominant variable.

Trends in the Rainy and Dry Seasons and Their Factors Influencing - the localities with statistically significant trends of ET_0 during the rainy period are João Pessoa, Campina Grande, Monteiro, and Patos. No statistically significant trends were noticed in Areia and São Gonçalo, as show Table 3.

Table 3 Trends of reference evapotranspiration (ET_0) and of climate variables for rainy season in the towns under study in the state of Paraíba, Brazil. Z: trend, β : Sen's estimator, Temp: air temperature, RH: relative humidity, SD: sunshine duration, W: wind speed at 2 m height

Station	ET_0		Temp		RU		SD		W	
	Z	β	Z	β	Z	β	Z	β	Z	β
João Pessoa	0.574*	3.2	0.621*	0.03	0.138 ^{ns}	-	-0.037 ^{ns}	-	-0.017 ^{ns}	-
Areia	-0.080 ^{ns}	-	0.400*	0.03	0.099 ^{ns}	-	-0.050 ^{ns}	-	-0.028 ^{ns}	-
Campina Grande	0.405*	0.31	0.678*	0.04	0.412*	-0.15	0.297*	0.68	0.248*	0.01
Monteiro	-0.333*	-2.42	-0.319*	-0.03	0.149 ^{ns}	-	-0.012 ^{ns}	-	0.398*	0.03
Patos	0.414*	0.63	0.448*	0.03	0.084 ^{ns}	-	0.33*	0.87	-0.159 ^{ns}	-
São Gonçalo	0.099 ^{ns}	-	0.129 ^{ns}	-	0.141 ^{ns}	-	0.353*	0.66	-0.031 ^{ns}	-

ns – no significant, * significant at 5%

João Pessoa shows trend for the rainy season only on ET_0 and air temperature, as show the Table 3, in that occurred an increase of 32 mm per decade in the ET_0 and 0.3 °C per decade in the

air temperature. Figure 2(a) shows that the air temperature has influenced 66 % on ET_0 followed of sunshine duration with 17%. Basically the values of the contribution of the air temperature for

the annual period and rainy season were the same, with a change in the second variable that most

Figure 2. ET_0 trend rainy season from localities significant statistically

contributed, where in the rainy season it was the sunshine duration, while in the annual period it was the relative humidity. The lowest and highest values of ET_0 occurred in neutral events of El Niño South Oscillation (ENSO). The changing point in the trend occurred in 1990.

In Campina Grande, ET_0 increased 3.1 mm per decade in rainy seasons, as show Tabel 3, due duration, on its turn, showed an increase of 6.8 h per decade. The changing point in the trend occurred in 1976. However, the most influencing variables to ET_0 were sunshine duration (37%) and wind (37%), as show the Figure 2. The increase in ET_0 in Campina Grande influenced by the insolation indicates less cloud cover for this period, and as shown in Table 3, there was an increase in the sunshine duration. The increase in ET_0 during the rainy season can bring changes in the water balance, with less storage for the dry season.

The Monteiro station, on its turn, showed a decrease of 24.2 mm per decade in ET_0 , as show Table 3, accompanied by decrease of air temperature which was of 0.3 °C per decade during rainy season. However, wind speed had an increase of 0.3 m s⁻¹ per decade. Changes in the natural vegetation contributed to increase wind speed and decrease air temperature causing a reduction in the ET_0 . Then, air temperature influenced 62% in the reduction of ET_0 , followed by sunshine duration that contributed with 32% to reduce ET_0 (Figure 2(c)). The changing point in the trend occurred in 1985.

In Patos, ET_0 increased 6.3 mm per decade in rainy season, Table 3, due an increase of temperature of 0.3 °C decade⁻¹ and sunshine duration of 8.7 h per decade in rainy season. The increase of sunshine duration in this study may be

an increase of temperature and sunshine duration and decreasing in the relative humidity, moreover, there was an increase of wind speed. The increase of air temperature was higher than registered by others stations, that was of 0.4 °C per decade, and relative humidity during rainy seasons was also significant only in this city, occurring a decrease equal to 1.5% per decade. Sunshine associated with the decrease or poor regularity of rainfall during the period analyzed influencing changes in relative humidity. Thus, air temperature (74%) and relative humidity (16%) were the most influencing variables on ET_0 .

In Areia and São Gonçalo, no statistically significant trends on ET_0 were observed in either rainy or dry seasons, although in Areia the air temperature had showed an increasing trend in both seasons (rainy and dry), whereas in São Gonçalo variables no showed any statistically significant trends, only sunshine duration.

Li et al. (2018) showed a significant decreasing trend on ET_0 in the upper-middle Huai River Basin and Yi-Shu-Si River Basin, especially in growing season and summer, while a generally increasing trend in ET_0 was detected in the lower Huai River Basin, and the significance only showed in spring. The dominant factor of the decreasing ET_0 was wind speed in spring, autumn, and winter in most sub-regions, except the lower Huai River Basin, which then shifted to solar radiation in the growing season and summer.

Trends in dry season to ET_0 and climatic variables are showed in Table 4, and the localities that presented statistically significant trends on ET_0 were João Pessoa, Monteiro and Patos.

Table 4 Trends of reference evapotranspiration (ET_0) and of climate variables concerning dry season in the cities analyzed in the state of Paraíba, Brazil. Z: trend, β : Sen's estimator, Temp: air temperature, RH: relative humidity, SD: sunshine duration, W: wind speed at 2 m height

Station	ET_0		Temp		RU		SD		W	
	Z	β	Z	β	Z	β	Z	β	Z	β
João Pessoa	0.349*	1.44	0.607*	0.03	0.304*	-0.07	-0.094 ^{ns}	-	-0.172 ^{ns}	-
Areia	0.017 ^{ns}	-	0.316*	0.02	0.063 ^{ns}	-	-0.049 ^{ns}	-	-0.200 ^{ns}	-
Campina Grande	-0.162 ^{ns}	-	0.545*	0.04	0.340*	-0.17	0.258*	0.55	-0.022 ^{ns}	-
Monteiro	-0.459*	-5.58	-0.342*	-0.06	0.288*	-0.14	0.029 ^{ns}	-	0.492*	0.02
Patos	0.380*	1.40	0.448*	0.04	0.125 ^{ns}	-	0.314*	0.68	-0.26*	-0.01
São Gonçalo	-0.075 ^{ns}	-	0.14 ^{ns}	-	0.067 ^{ns}	-	0.447*	0.64	-0.023 ^{ns}	-

ns – no significant, * significant at 5%

Figure 3. ET_0 trend dry season from localities significant statistically

João Pessoa presented an increase of 14.4 mm per decade in ET_0 , and the variables that more contributed to an increasing on ET_0 were sunshine duration, with 60%, and the temperature with 19%, Figure 3(a). During dry period the air temperature presented increasement, while the relative humidity presented decrease in the trend. The urban sprawl of João Pessoa according to Sobreira et al. (2011) has contributed to an increase of air temperature. In the present work, however, it was noticed that not only the temperature was affected but there was also a decrease of relative humidity in that city. The trends observed in these two variables caused an increase of ET_0 in João Pessoa.

Monteiro, according to Figure 3(b), showed a considerably sharp decrease of ET_0

during dry periods (about 56 mm per decade), which, according to Table 4, also showed a decrease of $0.6\text{ }^{\circ}\text{C decade}^{-1}$ in air temperature. Sunshine duration, on its turn, was not statistically significant, whereas wind speed showed an increase, but a decreasing in relative humidity during the period. Although others climatic variables had influenced ET_0 , they were insufficient to revert the sign of the ET_0 trend imposed by air temperature (72%) and sunshine duration (18%). Such as presented during rainy season, air temperature and sunshine duration were more influencing on ET_0 . The Brazilian Annual Land Use and Land Cover Mapping Project (Projeto MapBiomass, 2018) shows that in Monteiro, on its turn, near its meteorological station, old-growth stepps vegetation were turned

into field crops or pastures from 1985 to 2015, which may explain this results

In the station located in Patos occurred a increase of 14 mm decade⁻¹ in the ET₀ during dry season, Table 4, which increased 0.4 °C per decade in his air temperature, an increase of 6.8 h per decade in the sunshine duration and a decrease of 0.1 m s⁻¹ per decade in wind speed. Air temperature (65%) and relative humidity (21%) were the more influencing variables on ET₀, as show Fig. 3(c). In Patos there was a spread of the urban area toward the local station.

In Areia and São Gonçalo, few alterations in land cover were verified near their respective stations. In Campina Grande, on its turn, the meteorological station is located at a very urbanized area, and the city as a whole sprawled into neighboring regions between 1985 and 2015, nevertheless, according to results obtained in this research, such an alteration has probably had a climatic effect only during rainy season.

Gao et al. (2017) observed that in seasonal time scale, average air temperature, maximum air temperature, relative humidity were the most dominant factors in spring, summer and winter, and autumn, respectively. Wind speed was the second most significant factor in all seasons. She et al. (2017) observed middle reaches of Yellow River basin of China that annual ET₀ increases from the northwest to the southeast in space. Yet, in further analysis showed that solar radiation and wind speed are the two major contributing factors that control the change of ET₀ at most stations and during most subperiods.

Thus, it is observed in the papers cited that climatic factors have contributed differently and according to each region, not following a pattern for identifying the most influential variables on ET₀.

The air temperature was relevant in all stations where ET₀ showed a positive trend, corroborating the statements of the increase in air temperature in the last ten years. Therefore, it would be possible to model ET₀ in the temperature rise scenarios, to assess its impact on the water balance and to subsidize the analysis of use and allocation of water resources in Paraíba.

Conclusions

1) The stations in João Pessoa and Patos show increasing and Monteiro present decreasing trend on ET₀ during annual, rainy and dry periods. In all of them, the air temperature is the variable wich more is influencing with increase or decrease of ET₀ during annual period. But during rainy and dry periods was not followed this pattern. Specially

in Campina Grande and João Pessoa in that sunshine duration were the climatic variables most influencing on ET₀ during rainy and dry seasons.

2) We also have verify that the changes of land use of natural to pasture or buildings affect ET₀ values.

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