

DIFERENÇAS NA SOMA DA EVAPOTRANSPIRAÇÃO DE REFERÊNCIA HORÁRIA E DIÁRIA PARA A REGIÃO DO CARIRI CEARENSE

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RESUMO: A evapotranspiração (ET) é um processo essencial para o manejo hídrico, principalmente em regiões semiáridas. Portanto, este estudo teve como objetivo comparar as estimativas de evapotranspiração de referência (ET_o) diária e horária, utilizando o método FAO Penman-Monteith, com dados da estação meteorológica da UFCA de 2024. Os resultados mostraram que a ET_o horária foi superior à diária durante todo o ano, especialmente nos meses secos, indicando que o método diário pode subestimar a demanda real de água. A baixa correlação entre os métodos ($R^2 = 0,15$) e os valores do erro evidenciam essa diferença. A velocidade do vento foi a variável meteorológica que mais influenciou a variação entre as estimativas. Concluiu-se que a ET_o horária é mais precisa para representar as condições reais do ambiente, sendo mais adequada para o manejo da irrigação em regiões com alta variabilidade climática, como o Cariri cearense.

Palavras-chaves: Evaporação, Clima, Irrigação.

DIFFERENCES IN THE SUM OF HOURLY AND DAILY REFERENCE EVAPOTRANSPIRATION FOR THE CARIRI CEARENSE REGION

ABSTRACT: Evapotranspiration (ET) is an essential process for water management, especially in semiarid regions; therefore, this study aimed to compare daily and hourly reference evapotranspiration (ET_o) estimates using the FAO Penman–Monteith method with data from the UFCA meteorological station in 2024. The results revealed that the hourly ET_o was higher than the daily ET_o throughout the year, especially during dry months, indicating that the daily method may underestimate the real demand for water. The low correlation between the methods ($R^2 = 0.15$) and the error values highlight this difference. Wind speed was the meteorological variable that most influenced the variation between the estimates. It is concluded that the hourly ET_o is more accurate

at representing real environmental conditions and is more suitable for irrigation management in regions with high climate variability, such as Cariri in Ceará.

Keywords: Evaporation, Climate, Irrigation.

1 INTRODUCTION

Evapotranspiration (ET) is a fundamental process in the hydrological cycle, representing the transfer of water from the Earth's surface to the atmosphere through evaporation and transpiration from plants, and is widely used as a parameter for assessing water demand in various fields of knowledge, including ecology, meteorology, agronomy, and hydrology (Allen *et al.*, 1998; Awal. *et al.*, 2020; Xiang *et al.*, 2020). Quantifying evapotranspiration is essential for ensuring efficient water resource management, especially in dry regions such as semiarid regions (Vieira, 2003).

Estimating direct evapotranspiration is time-consuming and costly (Bakhtiari; Khanjani; Fadaei-Kermani, 2017); thus, other indirect methods are widely used with meteorological variables, but there is much discussion in the scientific literature about whether these variables are accurate and their effects on ET (Al Mamun). *et al.*, 2024). Different methods can be used to calculate evapotranspiration, mainly because of technological advances and the greater availability of automatic weather stations (Tomas *et al.*, 2021), making it feasible to obtain meteorological data with high temporal resolution, allowing for more detailed estimates of evapotranspiration at hourly intervals.

The Penman–Monteith equation, recommended by the Food and Agriculture Organization (FAO), is among the most widely used methods for estimating reference evapotranspiration (ET_o) (Lima *et al.*, 2021). Its application can be carried out at different time scales, such as monthly, daily, and hourly intervals. According to Ortega-Farias, Cuenca, and English (1995), determining ET_o calculated at hourly intervals can be more representative of real environmental conditions than monthly or daily ET_o, especially in locations where there is significant variation in

meteorological conditions throughout the day. Althoff *et al.* (2019) also highlight its improved data accuracy and provide more effective options for planning and managing water and soil resources. Santos, Souza and Rosa (2021) compared the hourly summation and daily ET_o, identifying average differences of 5.1% to 7.4% between the daily reference evapotranspiration (ET_o) and the sum of the hourly ET_o. On the basis of these results, they suggested that hourly summation has significant potential for application in engineering.

Given this context, this study aims to calculate, on the basis of meteorological station data, reference evapotranspiration estimates obtained at hourly intervals and analyze their differences and implications for water management in agriculture.

2 MATERIALS AND METHODS

The meteorological data used in this study were obtained from the Automatic Weather Station of the Federal University of Cariri (UFCA), located at coordinates 7°14' S and 39°22' W, at an altitude of approximately 423 meters above sea level. The region has a semiarid climate, characterized by an average annual rainfall of approximately 1090 mm, with a concentration of rain mainly in the months of January to May, which directly influences hydrological processes and local water availability. The average air temperature in the area varies between 24°C and 26°C throughout the year (Alcântara *et al.* 2025).

Daily and hourly reference evapotranspiration (ET_o) was calculated on the basis of the FAO 56 Penman–Monteith (PM) method, which is considered one of the most accurate and widely used procedures for estimating reference evapotranspiration because of its ability to integrate several relevant climatic factors (Allen *et al.*, 1998).

$$ET_{o,d} = \frac{0.408\Delta(R_n - G) + \gamma(37/(T_h + 273))u_2(e^{\circ}(T_h) - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

where $ET_{o,d}$ is the ET calculated daily; R_n is the net radiation at the crop surface ($MJ\ m^{-2}\ day^{-1}$); G is the soil heat flux density ($MJ\ m^{-2}\ day^{-1}$); T_a is the average daily air temperature at 2 m height ($^{\circ}C$); u_2 is the wind speed at 2 m height (ms^{-1}); e_s is the saturation vapor pressure (kPa); e_a is the actual vapor

pressure (kPa); $(e_s - e_a)$ is the saturation vapor pressure deficit (kPa); Δ is the slope of the vapor pressure curve ($kPa\ C^{-1}$); and γ is the psychrometric constant ($kPa\ C^{-1}$).

The FAO PM equation for hourly time intervals is as follows:

$$ET_{o,h} = \frac{0.408\Delta(R_n - G) + \gamma(37/(T_h + 273))u_2(e^{\circ}(T_h) - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (2)$$

where T_h is the average hourly air temperature ($^{\circ}C$) and $e^{\circ}(T_h)$ is the saturation vapor pressure at air temperature T_h (kPa). The steps involved in calculating daily and hourly reference evapotranspiration (ET_o) are provided in the supplementary material and were taken from the FAO-56 manual. The calculations were performed for the period from January 1 to December 31, 2024, using daily meteorological data collected by the station, including global solar radiation (R_s , $MJ\ m^{-2}\ day^{-1}$), average, maximum and minimum air temperatures (T_{med} , T_{max} and T_{min} , in $^{\circ}C$), relative air humidity (RH, in %) and wind speed (u , ms^{-1}).

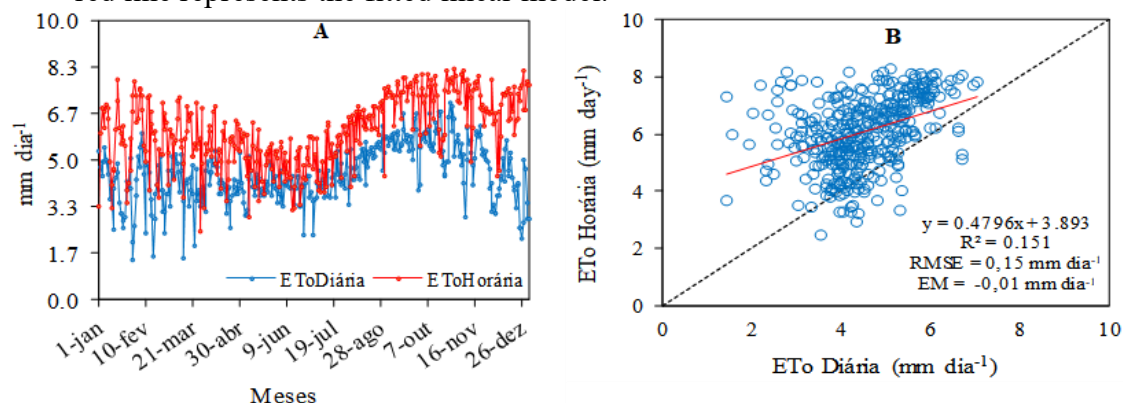
To evaluate the accuracy of evapotranspiration values estimated by different procedures, comparative statistical analyses were performed. Indicators such as the coefficient of determination (R^2), which measures the proportion of variability in the observed data; the root mean square error

(RMSE), which provides a measure of the dispersion of forecast errors; and the mean error (ME), which indicates the tendency to overestimate or underestimate the estimated values, were used.

3 RESULTS AND DISCUSSION

The temporal distributions of daily evapotranspiration ($ET_{oDiária}$) and the hourly sum ($ET_{oHorária}$) throughout the study period are shown in Figure 1. The ET_o estimates varied throughout the year, reflecting the seasonal and climatic variations typical of the region (Figure 1A). The ET_{oH} values were greater than the ET_{oD} values throughout the analyzed period, with more pronounced differences in the months with higher evaporative demand, especially between August and December.

Figure 1. Temporal distribution of daily evapotranspiration (EToDiária) and the hourly sum (EToHorária) (A) and dispersion between the EToDiária and EToHorária data (B). The red line represents the fitted linear model.



Source: Author

These variations can be attributed to the greater sensitivity of the hourly method in capturing diurnal fluctuations in climatic variables. According to studies such as that of Yetbarek, Vashishth, and Ojha (2024), this discrepancy occurs because EToH has the ability to capture more precise intraday variations since it considers hourly data, whereas EToD uses only daily average values, which can mask peaks in solar radiation, high temperatures, or strong winds that occur at certain times of the day. Thus, EToH tends to reflect more realistic evaporative demand, especially under more variable climate conditions, such as those observed in the studied region.

During the driest months, from August to December, this trend of increasing differences between estimates was quite evident. EToD frequently underestimated the actual evaporative demand of the environment, a finding that corroborates the results of Djaman *et al.* (2018), who reported that under hot and dry climate conditions, methods based on daily averages tend to underestimate evapotranspiration, as they do not adequately capture the peak solar radiation and high temperatures that occur throughout the day. This underestimation can significantly impact water management practices, leading to insufficient irrigation or poor assessment of crop water requirements.

The regression analysis between the ETo values estimated by the daily method

(EToD) and those estimated by the hourly method (EToH) is shown in Figure 1B, allowing a comparative evaluation between these two estimates throughout the study period. The regression line drawn, which is parallel to and above the 1:1 reference line (identity line), shows that, in general, the EToH values tend to be higher than those of EToD, indicating a tendency for underestimation by the daily method.

The coefficient of determination (R^2) of only 0.15 reinforces this low correlation between the two estimates, showing that there is a large dispersion of the data and a weak linear relationship between EToD and EToH. This low correlation suggests that the methods differ significantly in terms of their representation of evaporative demand over time, especially under conditions of greater climatic variability, such as dry periods with high temperatures.

Although the error indices, such as the root mean square error (RMSE) of 0.15 mm day^{-1} and the mean error (ME) of $-0.01 \text{ mm day}^{-1}$, do not present extremely high values, they still indicate a consistent tendency of underestimation by the daily method compared with the hourly estimate. The relatively low RMSE suggests that although the differences between the methods may not be extremely large in absolute terms, they are systematic and relevant from the point of view of accuracy. This underestimation behavior can be attributed to the variability in meteorological conditions

throughout the day, which are not well captured by daily averages.

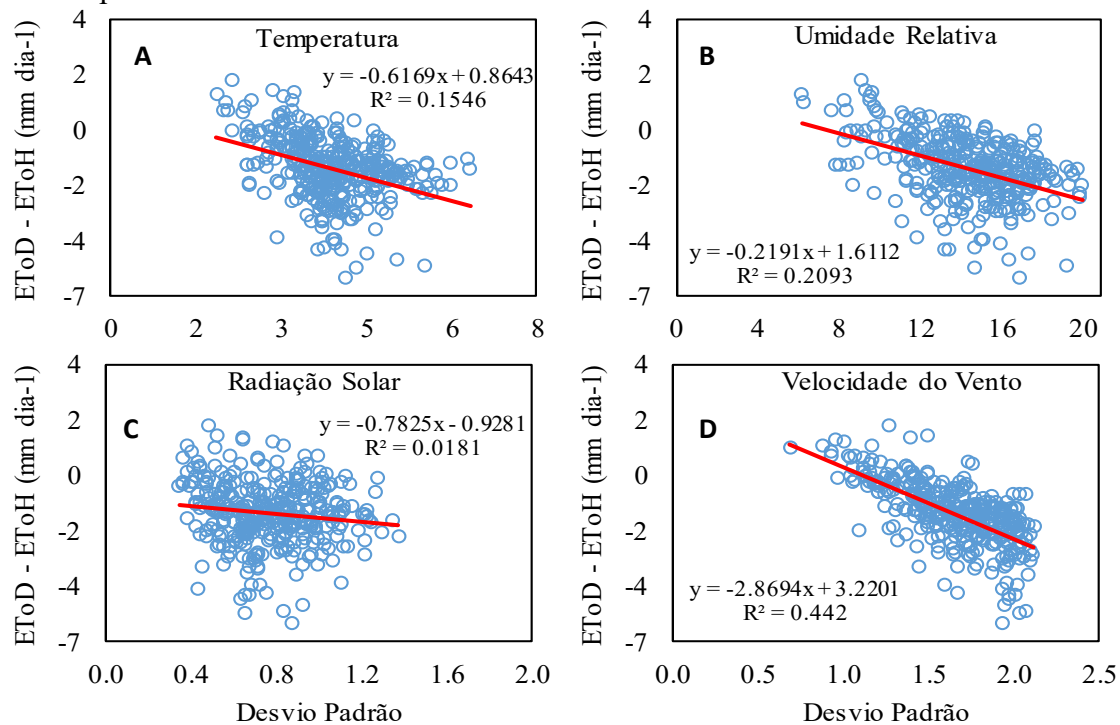
A detailed analysis of the influence of the daily standard deviation of the main meteorological variables, namely, temperature, relative humidity, solar radiation, and wind speed, on the difference between daily (EToD) and hourly (EToH) evapotranspiration estimates is presented in Figure 2. This approach aims to understand how daily variations in these variables influence the discrepancies observed between the two methods of evapotranspiration estimation, highlighting possible factors that may contribute to the underestimation or overestimation of values in each method. According to the coefficients of determination (R^2) presented, the variable that most influences this difference is the wind speed (Figure 2D), followed by the air humidity (Figure 2B), whereas the temperature (Figure 2A) and solar radiation (Figure 2C) have smaller, but still relevant, impacts. These results suggest that variations in wind speed play a predominant role in the difference between daily and hourly evapotranspiration estimates, possibly because of their direct effect on the evaporation rate and

the dispersion of water vapor in the environment.

The greatest influence of wind speed can be attributed to its impact on the evaporation rate, since stronger winds increase water loss through evapotranspiration by removing moisture from the air layer near the plant or soil surface, intensifying the evaporation process. Thus, daily variations in wind speed can generate significant changes in evaporative demand, which, if not adequately captured by daily methods, can lead to an underestimation of the real values, as the results suggest.

However, the results obtained thus far suggest the importance of deepening this analysis, considering the different climatic conditions throughout the year. For example, it would be interesting to divide the study period into rainy and dry seasons to verify whether the influence of each variable presents significant variations according to the time of the annual cycle. This approach revealed that during the dry season, factors such as wind speed and solar radiation have greater effects on the difference between the estimates, whereas during the rainy season, air humidity may have a greater influence.

Figure 2. Influence of the daily standard deviation of meteorological variables on the difference between the estimates of daily ETo and hourly ETo (EToD - EToH). The red line represents the fitted linear model.



Source: Author

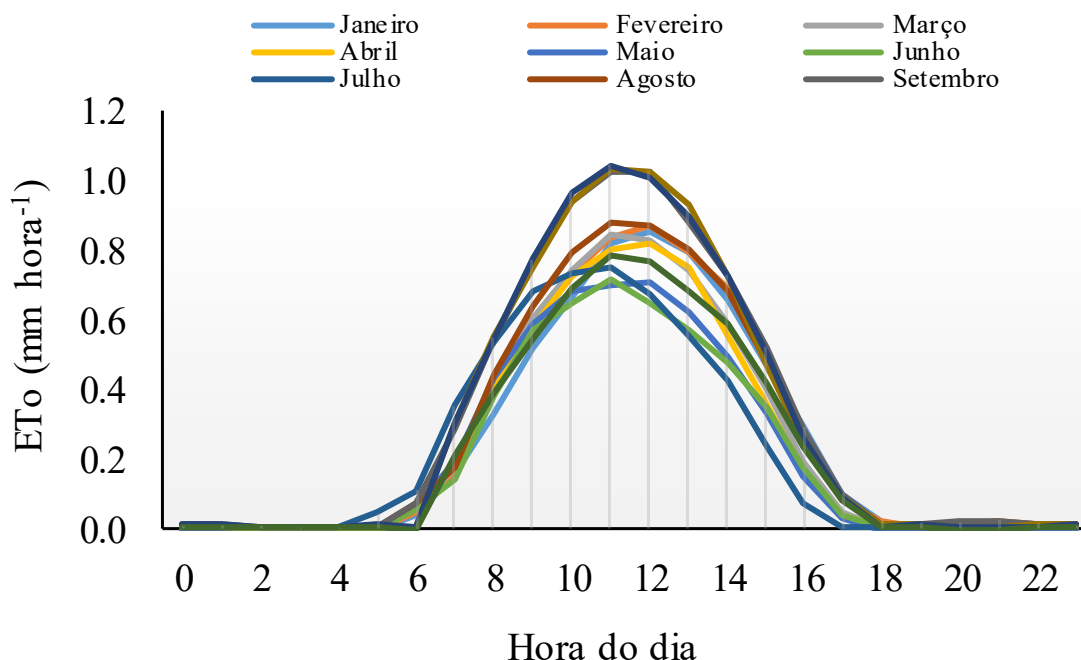
This more detailed analysis by season would allow for a better understanding of the mechanisms governing evaporation under different environmental conditions and, thus, improve ETo estimation models, increasing their sensitivity to seasonal variability. Furthermore, these data could guide more effective water management strategies, adjusting evaporative demand estimates according to climate change throughout the year and contributing to more sustainable water resource management in the studied region (Yetbarek; Vashishth; Ojha 2024).

The typical pattern of daily variation in the analyzed variable is shown in Figure 3, highlighting recurring behaviors throughout a 24-hour cycle. The lowest values occur during the night, generally in the hours after sunset until the early morning, reflecting the absence of solar radiation and, consequently, the reduction in energy available for processes such as evapotranspiration or air heating. This decrease in nighttime values is related to the

decrease in air temperature and lower incident radiation, which are factors that limit the rate of evaporation and other processes sensitive to solar energy.

On the other hand, the highest peaks appear during the central hours of the day, approximately between 10 am and 2 pm, when solar radiation reaches its maximum point because it is the most direct angle of incidence of the sun. During this period, there is a significant increase in available energy, increasing the air temperature and stimulating evaporation, which reaches its maximum values. Furthermore, the combination of intense solar radiation and high temperatures favors an increase in the evapotranspiration rate, reflected in the peaks observed in the curve.

ETo values during peak hours, exceeding 1.0 mm h^{-1} , indicating a higher evaporative demand during this period. This is possibly associated with lower levels of relative air humidity and higher solar incidence, which are common during the dry season.

Figure 3. Average hourly reference evapotranspiration (ET_o) for each month.

Source: Author

ET_o values throughout the day, with peaks close to 0.8 mm h⁻¹, reflecting a lower evaporative demand. These results are possibly due to higher humidity or reduced solar radiation from cloud cover during this period, which also coincides with the rainy months in this region.

4 CONCLUSIONS

The results of this study revealed that the estimate of reference evapotranspiration (ET_o) performed at hourly intervals presents higher values than those obtained through daily estimates do, especially in the dry months of August to December, a period in which environmental conditions present greater variability. This difference occurs because the hourly ET_o is more sensitive to fluctuations in meteorological variables throughout the day and more accurately captures the peaks of solar radiation, temperature, and wind that directly influence the evapotranspiration process.

Analysis of the meteorological variables revealed that wind speed was the main factor responsible for the differences observed between the two methods, since stronger winds increase water loss through evaporation, and their variations throughout the day are not well

represented by daily averages. Therefore, hourly estimation is more suitable for regions with high climatic variability, such as the Cariri region of Ceará, providing a more accurate assessment of water demand.

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