



USING ARTIFICIAL NEURAL NETWORK TO ESTIMATE REFERENCE EVAPOTRANSPIRATION

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ABSTRACT: Irrigation, when rationally used, can contribute to the efficient performance of the agribusiness. Planning irrigation, monitoring the soil moisture, the rainfall and the reference evapotranspiration (ET_0) is necessary for a rational water management. The FAO Penman-Monteith (FAO PM) method is the standard method for estimating ET_0 , but in some cases, the use of this method is restricted due to missing some climatic variables. For this reason, methods with a lower number of meteorological variables, as temperature values, are quite often used. This study aims to propose an artificial neural network (ANN) to estimate the ET_0 as a function of maximum and minimum air temperatures for the city of Salinas, Minas Gerais State, Brazil. After training, validation and comparison with the Hargreaves methodology, it was observed the existence of a good correlation between the values estimated by the standard method and those estimated by ANN, with the performance index classified as optimal, better than the Hargreaves methodology one. The use of ANN proved to be an excellent alternative for ET_0 estimation, reducing the costs of acquiring climatic data.

Keywords: Hargreaves, FAO Penman-Monteith, Salinas

USO DE REDE NEURAL ARTIFICIAL PARA A ESTIMATIVA DA EVAPOTRANSPIRAÇÃO DE REFERÊNCIA

RESUMO: A irrigação, sempre que utilizada de forma racional, contribui de forma importante para o desempenho do agronegócio nacional. Para um manejo racional da água de irrigação é preciso um bom planejamento das irrigações, de monitoramento da umidade do solo, das precipitações e da evapotranspiração de referência (ET_0). O método Penman-Monteith FAO é o método padrão para a estimativa da evapotranspiração de referência, porém, em alguns casos, o uso do método é restrito pela ausência de algumas variáveis climáticas. Por essa razão, muitas vezes há necessidade de se calcular a ET_0 empregando-se métodos que utilizem somente valores de temperatura. O objetivo deste trabalho foi propor uma rede neural artificial (RNA) para estimar a evapotranspiração de referência em função das temperaturas máxima e mínima do ar para a cidade de Salinas-MG. Após o treinamento, validação e comparação com a metodologia de Hargreaves, pode-se observar a existência de boa correlação entre os valores estimados pelo método padrão e pela RNA, além do índice de desempenho classificado como ótimo, superando a metodologia de Hargreaves. O uso da RNA mostrou-se uma excelente alternativa para a determinação da ET_0 , proporcionando a diminuição dos custos de aquisição de dados climáticos.

Palavras-Chave: Hargreaves, FAO Penman-Monteith, Salinas

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INTRODUCTION

The majority of farmers do not use any irrigation management technique, applying water based on their daily experience with irrigated crops (Testezlaf et al., 2017).

The irrigation scheduling, the soil moisture monitoring, the precipitation, and the reference evapotranspiration (ET_0) are required for a rational water management in agriculture (Pires et al., 2008).

The reference evapotranspiration is a term that expresses the simultaneous occurrence of the soil water evaporation and the crop transpiration processes on a vegetated surface (Pereira, 1997). In this way, it is possible to estimate the water consumption by the plants and calculate the replacement through irrigation.

There are several methods for estimating ET_0 . The FAO Penman-Monteith method is considered, internationally, the most appropriate for the estimation of reference evapotranspiration and uses values of air temperature, solar radiation, wind speed and relative air humidity (Allen, 1998).

In some cases, the use of the FAO Penman-Monteith method is restricted by the lack of some input variables, since part of the Brazilian meteorological services only provides data on rainfall and air temperature (Conceição & Mandelli, 2005). For this reason, it is often necessary to calculate ET_0

using methods that use only temperature values.

The search for solutions to obtain evapotranspiration by the FAO Penman-Monteith method in the absence of complete datasets (solar radiation, air temperature, humidity and wind speed) has led to the development of a variety of approaches, including the use of artificial neural networks (ANN), fuzzy and neuro-fuzzy systems, genetic algorithms and multiple regression analysis (Pereira et al., 2015).

In this context, Hargreaves methodology and intelligent systems, such as artificial neural networks, in the estimation of ET_0 has shown to be a reliable method, as shown in Sobrinho et al. (2011); Landeras et al. (2008); Zanetti et al. (2008) and Khoob (2008).

An artificial neural network (ANN) is a system designed to model the way the brain performs a particular task, usually implemented using electronic components or simulated by propagation on a digital computer. To achieve good performance, neural networks employ a massive interconnection of simple computational cells, called 'neurons' or processing units (Haykin, 2001). These neurons make up a distributed parallel system, arranged in one or more interconnected layers (Braga et al., 2012).

Considering the importance of Meteorology, located at latitude 16.15 ° South, Longitude 42.28 ° West and altitude of 471.32 m (INMET, 2016). this work aimed to propose an ANN to estimate ET_0 as a function of maximum and minimum air temperatures for the city of Salinas, in Minas Gerais State, Brazil.

MATERIAL AND METHODS

For the development of this work we used climatic data available in the Meteorological Database for Teaching and Research (BDMEP) of the conventional meteorological station of Salinas - MG (N ° 83441), of the National Institute of

South, Longitude 42.28 ° West and altitude of 471.32 m (INMET, 2016).

The variables used in the study were: maximum and minimum air temperatures, relative air humidity, wind speed and the sunshine from January 1980 to December 2015. It should be emphasized that the days that did not have values for at least one of the variables were excluded.

From the meteorological data, the reference evapotranspiration (ET_0) was determined by the FAO Penman-Monteith method (Equation 1), using electronic spreadsheets from the MS Excel software.

$$ET_0 = \frac{0,408\Delta (R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0,34 u_2)} \quad (1)$$

where:

ET_0 = reference evapotranspiration, mm d⁻¹;

R_n = net radiation at the crop surface, MJ m⁻² d⁻¹;

G = soil heat flux density, MJ m⁻² d⁻¹;

T = air temperature at 2 m height, °C;

u_2 = wind speed at 2 m height, ms⁻¹;

e_s = saturation vapour pressure, kPa;

e_a = actual vapour pressure, kPa;

Δ = slope vapour pressure curve, kPa °C⁻¹;

γ = psychrometric constant, kPa °C⁻¹;

With the ET_0 data calculated by FAO Penman-Monteith method, the data were divided into two sets, one for training (7,560 daily values between January 1980 and

November 2005) and one for ANN validation (3,595 daily values between February 2006 and December 2015).

The implementation of ANN was done in Matlab software. ANN input variables were the maximum air temperature, the minimum air temperature and the day of the year, represented by numbers from 1 to 366, normalized between -1 and 1. As the output variable, it was used the ET_0 value calculated by the FAO Penman-Monteith method.

Aiming to train the network with all the data to generate more reliable results, cross-validation was used with the division of the

data set for training in 10 subgroups. We tested some neural networks with different intermediate layer numbers and different numbers of neurons for these layers.

In order to evaluate the performance of the ANNs, it was calculated the mean square error (MSE) of the 10 iterations using Equation 2, with the ANN being chosen with a lower number of intermediate layers, a smaller number of neurons and a lower MSE.

$$MSE = \frac{\sum_{i=1}^n (Y_p - Y_{RNA})^2}{n} \quad (2)$$

where:

MSE = mean square error, mm d^{-1} ;

Y_{ANN} = ET_0 estimated by the standard method, mm d^{-1} ;

Y_p = ET_0 estimated by the ANN, mm d^{-1} ;

N = number of samples.

The ANN chosen was a Feedforward Multilayer Perceptron type, consisting of 3 neurons in the input layer, 10 neurons in the intermediate layer and 1 in the output layer,

as shown in Figure 1. The sigmoid hyperbolic tangent function was defined for activation of the intermediate layer and the linear function for output layer activation.

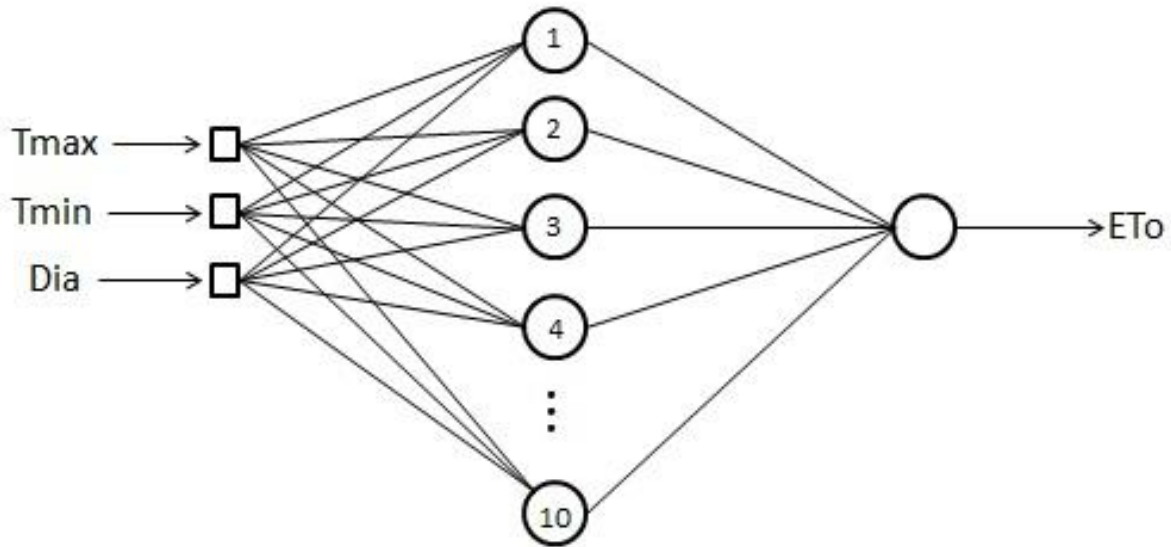


Figure 1. The ANN model used for reference evapotranspiration (ET_0) estimation.

The ANN was trained with the Levenberg-Marquardt algorithm. The criteria used to finish the training was the maximum number of 100 epochs or mean square error of less than 0.0000001.

To validate the ANN, daily mean climate data from February 2006 to

December 2015 were used. In order to aid in the evaluations, the ET_0 was also estimated by the Hargreaves method (Hargreaves and Allen, 2003), since the method only needs temperature and extraterrestrial solar radiation data (Equation 3).

$$ET_0 = 0,0023 Ra(T_{m\acute{a}x} - T_{m\acute{i}n})^{0,5} (T + 17,8) \quad (3)$$

where:

Ra = extraterrestrial radiation, in mm d^{-1} ;

Tmax = maximum temperature in $^{\circ}\text{C}$;

Tmin = minimum temperature, in $^{\circ}\text{C}$;

The values estimated by ANN and Hargreaves method were compared using the square root of mean square error (RMSE), the standard error of estimate (SEE), the Pearson correlation coefficient (r), the agreement index (d) and the performance index (c) in

relation to the FAO Penman-Monteith standard method.

The square root of the mean square error (RMSE) was calculated with the following equation:

$$RMSE = \left[\frac{\sum_{i=1}^n (Yp_i - Ym_i)^2}{n} \right]^{0,5} \tag{4}$$

where:

RMSE = square root of mean square error, mm d⁻¹;

Yp_i = ET₀ estimated by the standard method (PM), mm d⁻¹;

Ym_i = ET₀ estimated by the neural network and Hargreaves, mm d⁻¹;

n = number of samples.

The standard error of estimate (SEE) was determined through Equation 5.

$$SEE = \left[\frac{\sum_{i=1}^n (Yp_i - YRNA_i)^2}{n - 1} \right]^{0,5} \tag{5}$$

The Pearson correlation coefficient (r) was determined by the Equation 6.

$$r = \frac{\sum_{i=1}^n Yp_i YRNA_i - \frac{\left(\sum_{i=1}^n Yp_i\right)\left(\sum_{i=1}^n YRNA_i\right)}{n}}{\sqrt{\left[\sum_{i=1}^n Yp_i^2 - \frac{\left(\sum_{i=1}^n Yp_i\right)^2}{n} \right] \left[\sum_{i=1}^n YRNA_i^2 - \frac{\left(\sum_{i=1}^n YRNA_i\right)^2}{n} \right]}} \tag{6}$$

According to Willmott (1982), the agreement index (d) was obtained as follows.

$$d = 1 - \frac{\sum_{i=1}^n (YRNA_i - Yp_i)^2}{\sum_{i=1}^n \left(|YRNA_i - \bar{Yp}| + |Yp_i - \bar{Yp}| \right)^2} \tag{7}$$

The performance index (c), presented by Camargo & Sentelhas (1997), evaluates the performance of the different ET₀ estimation methods. This index gathers the precision indexes, given by the Pearson correlation coefficient (r) which indicates the degree of dispersion of the data obtained in relation to the mean, that is, the random error and the agreement index (d). The performance index is calculated by

multiplying the r and the d and the Table 1 defines its interpretation criteria.

Table 1. The Performance Index classification of the estimation models, proposed by Camargo & Sentelhas (1997).

Performance index (c)	Classification
> 0.85	Excellent
0.76 a 0.85	Very good
0.66 a 0.75	Good
0.61 a 0.65	Reasonable
0.51 a 0.60	Bad
0.41 a 0.50	Very bad
≤ 0.40	Unacceptable

RESULTS AND DISCUSSION

The values of maximum, average and minimum air temperature for the period

studied are shown in Figure 2. The mean temperature was 24.4 ° C and the mean maximum and minimum temperatures were 30.6 and 18.1 ° C, respectively.

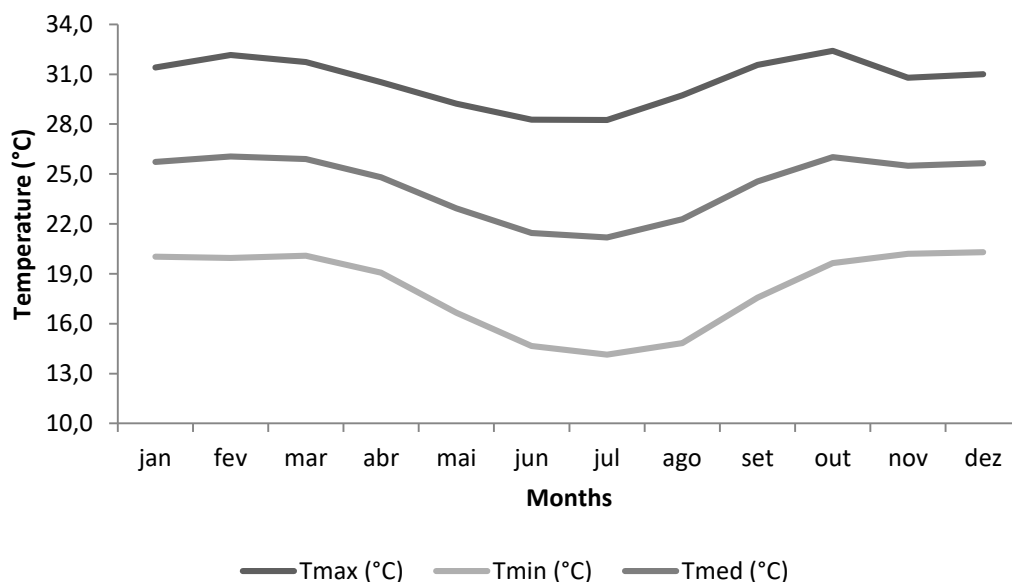


Figure 2. Maximum, minimum and mean air temperature of Salinas, Minas Gerais State, Brazil, from 1980 to 2015.

The daily mean values of the reference FAO Penman-Monteith, ANN and evapotranspiration (ET_0) estimated by the Hargreaves methods for the study period

were 4.77, 4.78 and 4.86 mm d⁻¹, respectively. Estimated evapotranspiration by ANN overestimated by only 0.2% as determined by the standard method, as estimated by the Hargreaves method overestimated by 1.8%.

Table 2 shows the statistical indicators of the adjustment between the ET₀ values calculated by the FAO Penman-Monteith method and those estimated by the ANN and Hargreaves.

Table 2. Pearson correlation coefficient (r); agreement index (d); performance index (c), the standard error of estimate (SEE) and square root of the mean square error (RMSE).

Method	r	d	c	SEE (mm d ⁻¹)	RMSE (mm d ⁻¹)
ANN	0,97	0,98	0,95	0,24	0,24
Hargreaves	0,90	0,95	0,85	0,41	0,40

The results in Table 2 shown that ANN obtained better values for the c-index (c = 0.95) than Hargreaves (c = 0.85), presenting "good" and "very good" criteria according to with the interpretation criterion proposed by Camargo & Sentelhas (1997).

ANN also had a smaller standard error of estimate (SEE) of 0.24 mm d⁻¹ than Hargreaves, with 0.41 mm d⁻¹. It also obtained lower value of RMSE. It is observed that the result obtained by ANN was closer to the method by the FAO Penman-Monteith method, corroborating with those presented

by Sobrinho et al. (2011) and Landeras et al. (2008). The ANN correlation coefficient (0.97) was similar to those found by Rodríguez et al. (2012).

It can be observed in Figure 3 that the maximum and the minimum ET₀ daily values estimated by the ANN were observed in October and June, respectively, coinciding with periods of higher and lower average monthly temperatures, as shown in Figure 2. The values estimated by the ANN follow the trend of the data estimated by the FAO Penman-Monteith method.

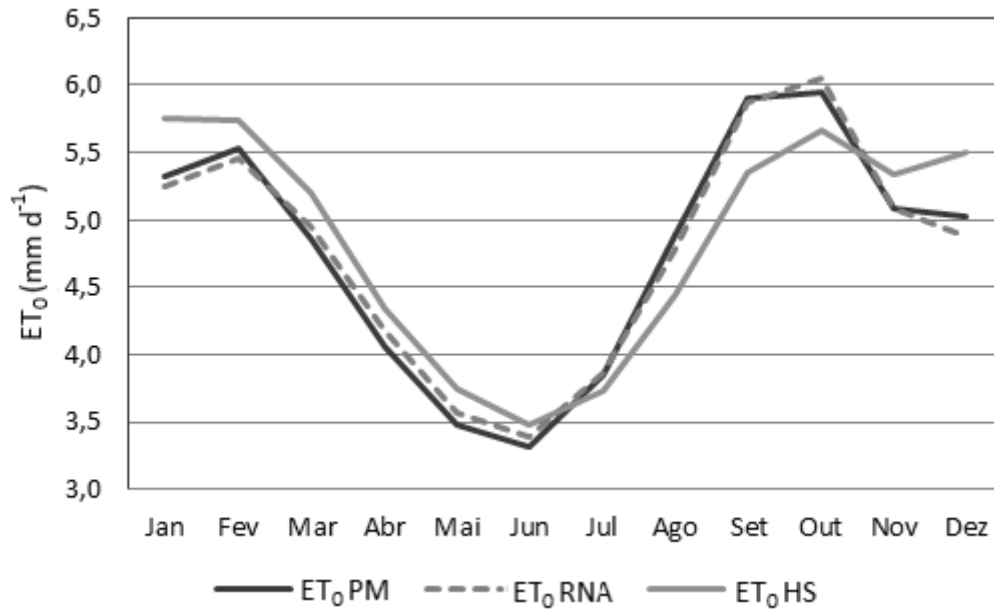


Figure 3. ET_0 estimation by ANN (ET_0 ANN), Hargreaves (ET_0 HS) and FAO Penman-Monteith (ET_0 PM) for daily mean values, from 2006 to 2015.

Analyzing the results of Tables 2 and Figure 3, it is observed that the model based on ANN was more efficient in the estimation of evapotranspiration than the Hargreaves method. Similar results were found by Zanetti et al. (2008), in 17 cities in the state of Rio de Janeiro, and by Cervantes (2013). Traore et al. (2010) also observed that the estimation of ET_0 by ANN based only on temperature is superior to the estimation using Hargreaves.

Figures 4 and 5 show the regression analysis of the ET_0 estimation by ANN Hargreaves in relation to the values estimated

by the standard method. The coefficient of determination (R^2) of the regression analysis with ANN ($R^2 = 0.9317$) presented a better correlation with the FAO Penman-Monteith method than Hargreaves ($R^2 = 0.8145$).

The Hargreaves equation provided greater dispersion (R^2) when compared to ANN. similar results were found by Rodriguez et al. (2012) and Traore et al. (2010). There was an improvement of 11.7% of the R^2 value when ANN was used to estimate ET_0 .

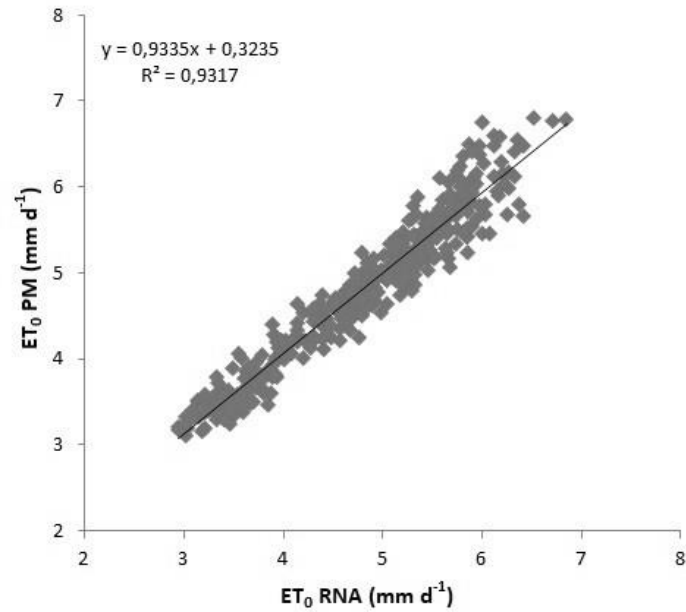


Figure 4. Regression analysis of the reference evapotranspiration (ET₀) estimated by the artificial neural network (ANN) in relation to the values of the FAO Penman-Monteith method.

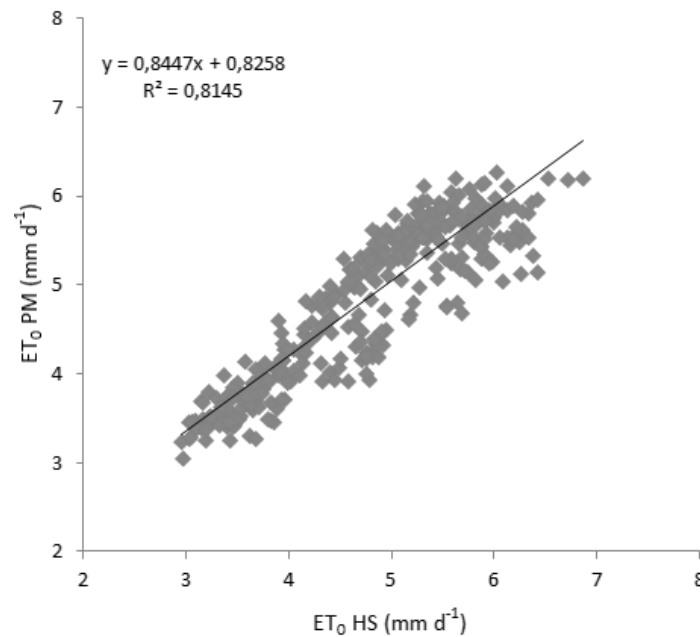


Figure 5. Regression analysis of the reference evapotranspiration (ET₀) estimated by the Hargreaves in relation to the values of the FAO Penman-Monteith method.

The ET₀ estimation by ANN allows a obtaining values closer to the standard better precision than the Hargreaves method, method. It also allows the reduction of costs

of automated irrigation systems, as there is a need for only temperature sensors, in addition to precipitation. The ET_0 estimation by ANN can provide improvements in the water and energy use efficiency to the irrigated agriculture.

It should be noted that the estimation of reference evapotranspiration by ANN requires knowledge in the application and use of the software Matlab, which is a very useful tool for estimating ET_0 .

CONCLUSIONS

According to the results, it was concluded that the artificial neural network proved to be a reliable alternative to estimate ET_0 from maximum and minimum air temperatures for Salinas, presenting better performance index, standard error of estimate and correlation than Hargreaves in relation to the FAO Penman-Monteith methods.

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