International Interdisciplinary Congress on Renewable Energies, Industrial Maintenance, Mechatronics and Informatics
Booklets

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# Title: Reference evapotranspiration prediction using neural network method

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**Editorial label ECORFAN:** 607-8695
**BCIERMMI Control Number:** 2021-01
**BCIERMMI Classification (2021):** 271021-0001

**Pages:** 12
**RNA:** 03-2010-032610115700-14

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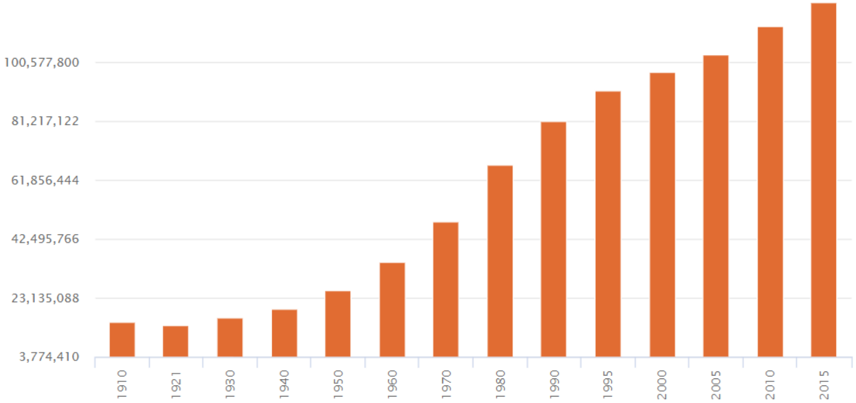
# Introduction

Agriculture is a sector with great importance in our country, however at present there are three problems that are strongly linked to each other, First the excessive growth of the population, according to census conducted by INEGI there is an estimated population for the current year of 127 billion inhabitants only in Mexico, the second as it is due to greater demand in the production of food of agricultural origin, of basic basket such as (white corn, tomato, rice, beans) due to that increase in population and third climate change; according to statistical data worldwide there is a trend in the rise of temperatures around the world and a decrease in the amount of annual precipitation, as a consequence, there has been a decrease in water resources in figure 1 se shows a graph the use of water by sector, in it can be seen that in the agricultural sector the use of this resource exceeds 70%, 4.72% is used to generate electricity, 4.86% is used for industry and 14.38% is used for public supply, the scarcity of water worldwide makes it necessary to develop alternatives to make water use more efficient and implement irrigation systems that regulate its consumption.



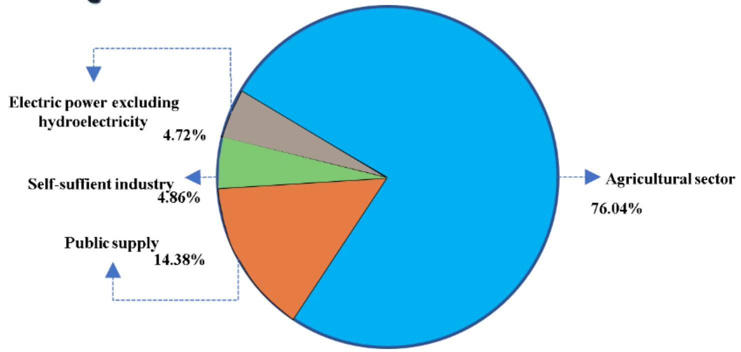




**Figure 1.** Consumption by sector. Source *(CONAGUA 2. , 2020)*

# Methodology

## Hargreaves method

The Hargreaves method is an empirical method considered in many studies because it is a method applicable to various geographical areas. This method is largely used for its great accuracy in daily irrigation plans.

## Empirical equation

$$ETo = 0{,}0023 \cdot R_s(T_m + 17{,}8) \cdot (T_{máx} - T_{mín})$$

Where:

$ET_o$ = reference evapotranspiration, expressed in mm/day.

$R_s$ = extraterrestrial solar radiation, expressed in mm/day. (Allen,1998)

$T_{med}$ = average daily temperature, understood as the average of the maximum temperature and the minimum temperature of the period, expressed in °C.

$T_{max}$ = maximum daily temperature, expressed in °C.

$T_{min}$ = minimum daily temperature, expressed in °C. (FAO, 1977)

# Methodology

**1. Data collection**

**2. Standardization and adequacy of data**

**3. Neural network architecture design**

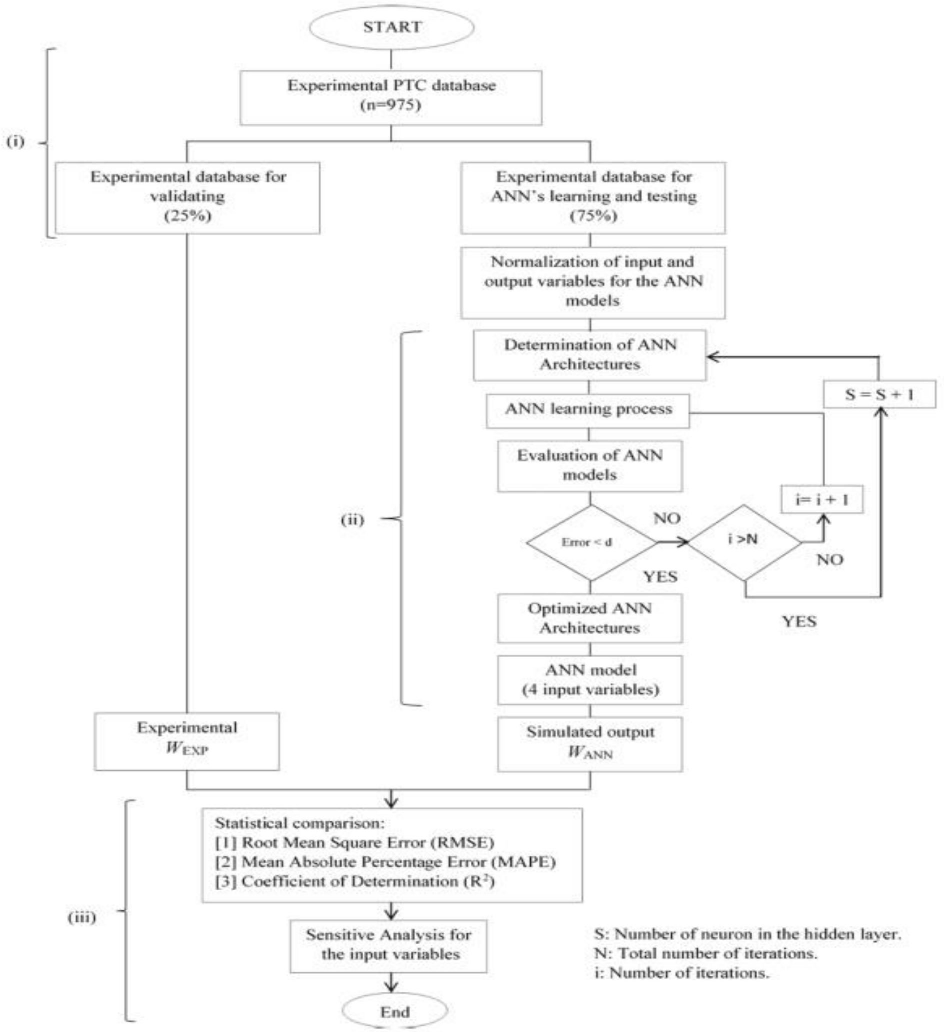
**4. Neural network training**

**5. Analysis of the RESULTS**

**Get equation function of the neural network model**

# Artificial Neural Networks

Artificial neural networks are a model inspired by the functioning of the human brain.
It is formed by a set of nodes known as artificial neurons that are connected and transmit signals to each other. These signals are transmitted from the input layer, the hidden layer, to generate an output.



# Artificial Neural Networks

The input variables of the network are the season of the year (spring, summer, autumn, winter), the date of measurement, the maximum temperature, the minimum temperature, average temperature and the incident solar radiation and the experimental response is evapotranspiration, the characteristics of the variables are found in table 1.

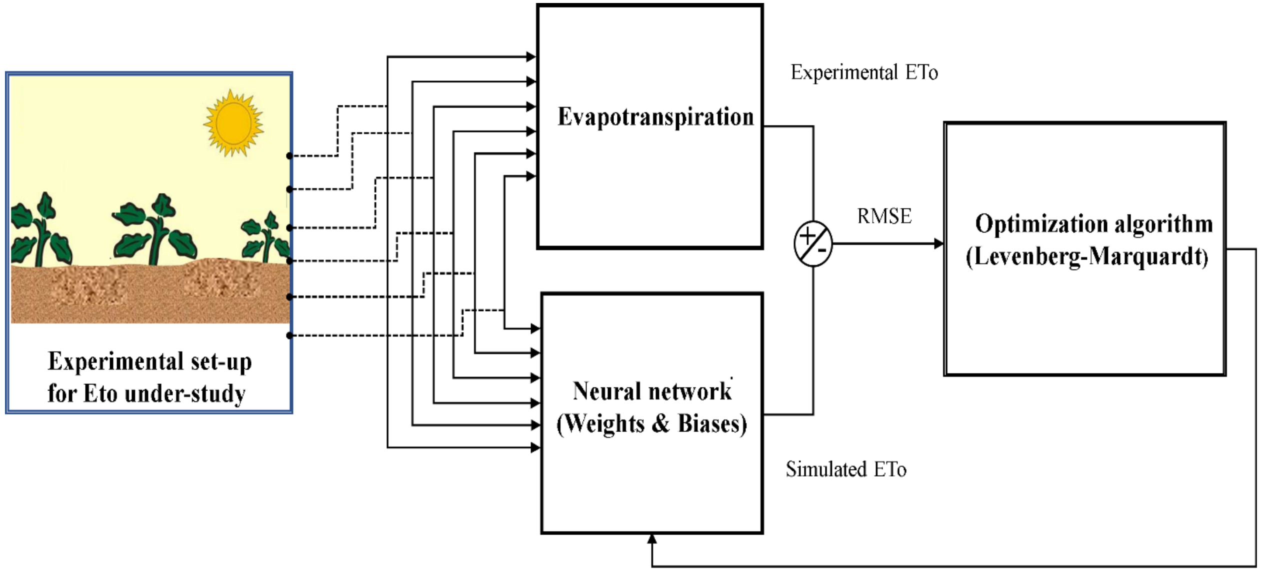



**Figure 2** Neural network architecture recurrent to ETo values.

| Variable input | Variable range |
|---|---|
| Season | 0.1-0.4 |
| Date | no rank |
| $T_{max}$ | 28-35 |
| $T_{min}$ | 24-27 |
| $T_{prom}$ | 24-35 |
| $R_s$ | 10.9-16 |
| $ET_o$ | 0-200 |

**Table 1** Input variables for the neural network Source *(Own source)*

# Artificial Neural Networks Method

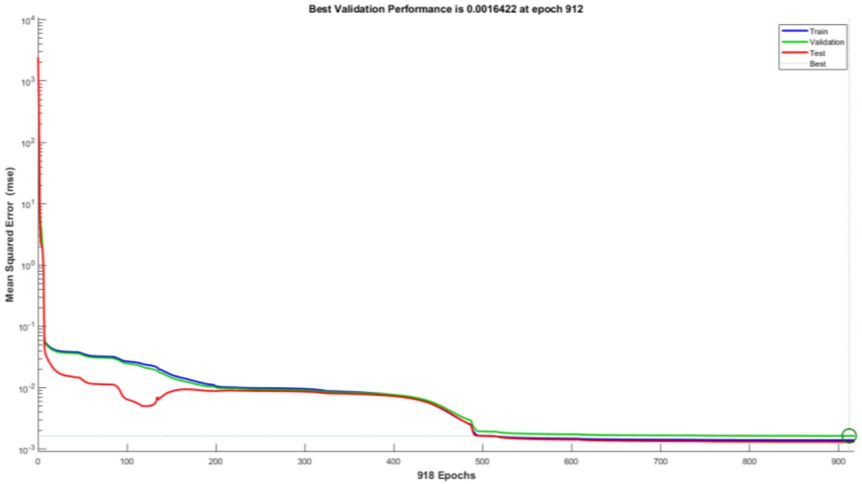
10 neural network training algorithms were compared to know which algorithm had better performance.

Tests performed determine that the Levenberg-Marquatd algorithm is the best for making predictions of baseline evapotranspiration

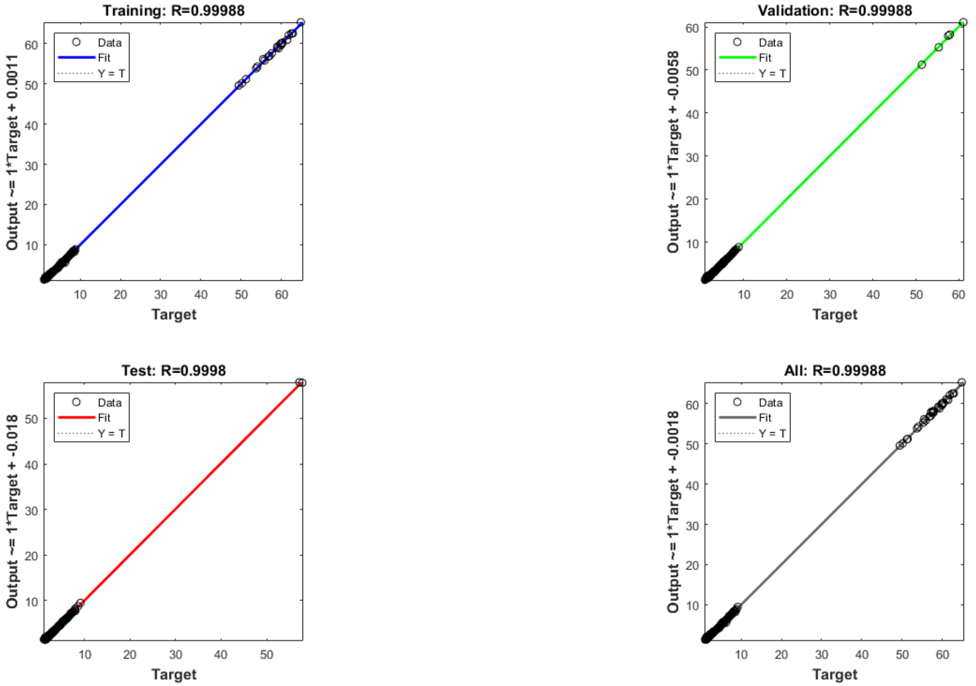
| FORWARD-BACKPROPAGATION ALGORITHM | FUNCTION | RMSE | EPOCH | CORRELATION COEFFICIENT | BEST LINEAR EQUATION | CPU TIME |
|---|---|---|---|---|---|---|
| LEVENBERG–MARQUARDT BACKPROPAGATION | TRAINLM | 0.00215 | 1000 | 0.9999 | Y= 0.999T+0.0077 | 104 |
| BATCH GRADIENT DESCENT | TRAINGD | 0.01657 | 2000 | 0.9888 | Y=0.986T+0.927 | 135 |
| BATCH GRADIENT DESCENT WITH MOMENTUM | TRAINGDM | 0.01982 | 2000 | 0.987 | Y= 0.988T+0.837 | 175 |
| POLAK–RIBIERE CONJUGATE GRADIENT BACKPROPAGATION | TRAINCGP | 0.03267 | 2000 | 0.979 | Y= 0.957T+2.53 | 227 |
| SCALED CONJUGATE GRADIENT BACKPROPAGATION | TRAINSCG | 0.44944 | 2000 | 0.974 | Y= 1.020T+0.783 | 295 |
| BFGS QUASI-NEWTON BACKPROPAGATION | TRAINBFG | 0.48621 | 2000 | 0.971 | Y= 0.982T+1.23 | 383 |
| POWELL–BEALE CONJUGATE GRADIENT BACKPROPAGATION | TRAINCGB | 0.50821 | 2000 | 0.965 | Y= 0.960T+2.03 | 497 |
| ONE STEP SECANT BACKPROPAGATION | TRAINOSS | 0.02754 | 2000 | 0.872 | Y= 0.617T+45.3 | 646 |
| FLETCHER–REEVES CONJUGATE GRADIENT BACKPROPAGATION | TRAINCGF | 0.01757 | 2000 | 0.782 | Y= 0.425T+34.8 | 839 |
| VARIABLE LEARNING RATE BACKPROPAGATION | TRAINGDX | 0.020397 | 2000 | 0.718 | Y= 0.386T+38 | 1090 |

**Table 1.** Comparison of 10 backpropagation algorithms with 3 neurons algorithms for neurons in hidden layer. Source (El Hamzaoui, y otros, 2011)

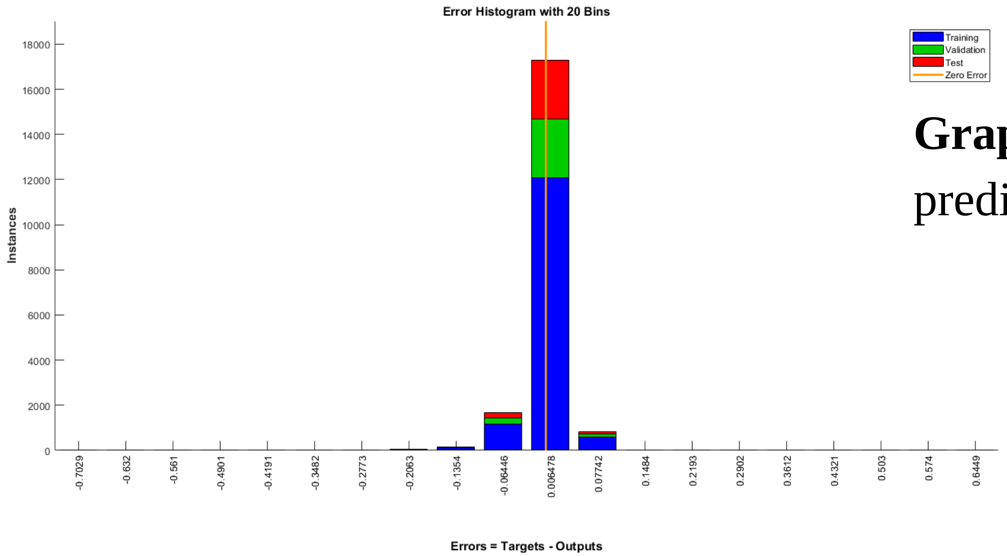
# Results




**Graph 1. Performance analysis of LM-ANN in terms of validation efficiency.**




**Graph 3.** Performance of LM-ANN in the prediction of evapotranspiration using dependent.




**Graph 2. Performance analysis of LM-ANN in terms of error histogram.**

# Results

$$ET_O = \sum_{s=1}^{S}\left[W_{o(1,s)}\left(\frac{2}{1+exp\left(-2\left(\sum_{k=1}^{K}\left(W_{i_{(s,k)}}In_{(k)}\right)+b1_{(s)}\right)\right)}-1\right)\right]+b2_{(l)} \qquad (13)$$

$$ET_o = 2\left[\frac{w_{o(1,1)}}{1+e^{x_1}}+\frac{w_{o(1,2)}}{1+e^{e^{x_2}}}+\frac{w_{o(1,3)}}{1+e^{x_3}}+\frac{w_{o(1,4)}}{1+e^{x_4}}+\frac{w_{o(1,5)}}{1+e^{x_5}}+\frac{w_{o(1,6)}}{1+e^{x_6}}\right]-\left(w_{o(1,1)}+w_{o(1,2)}+w_{o(1,3)}\right)+b2_{(l)} \qquad (14)$$

Where:

$$x_1 = -2(w_{i(1,1)}v_1 + w_{i(1,1)}v_2 + w_{i(1,1)}v_3 + w_{i(1,1)}v_4 +$$

**Weights and bias of neural network model. Source (Ownsource**

| $W_i(s,k)$ | | | | | |
|---|---|---|---|---|---|
| **0.008725251989250882439 5 (1,1)** | - 0.0010689693911364740297 (1,2) | 0.50786218884516198813 (1,3) | -0.34034455094710758249(1,4) | 0.074224938476511195806 (1,5) | 0.42287743562763169258(1,6) |
| **0.008122339574864136449 4 (2,1)** | - 0.0011517597181407821134 (2,2) | 0.38457704989763064063 (2,3) | -0.54397024146799344428 (2,4) | 0.33513113636399294304 (2,5) | -0.44825995399759621662 (2,6) |
| **0.000216581016270365783 91 (3,1)** | - 4.9382447682567528 17e-06 (3,2) | - 0.42556293532778288746 (3,2) | -.37401103609823516116 (3,2) | 0.71793543628936073997 (3,2) | 0.25896726816461623777 (3,6) |
| **Wo** | | | b1 | b2 | |
| **-2.017154500(1,1)** | -2.64094400(1,2) | - 1.802718000(1,3) | 1.4512509324867599592 (1,1) | 0.87266337252631542842 | |
| | | | 0.83307840581738845653 (1,2) | | |
| | | | -0.17241637336249560075 (1,3) | | |

**Table 2.** Weights and bias of neural network model.

# Annexes

| Date | Season | Tmax | Tmin | Tmed | Rs | ETor |
|---|---|---|---|---|---|---|
| 9832 | 0.3 | 28 | 22 | 25 | 0.02507 | 2.63 |
| 9833 | 0.3 | 28.2 | 21.5 | 24.85 | 0.02507 | 2.77 |
| 9834 | 0.3 | 26.5 | 21.5 | 24 | 0.02507 | 2.34 |
| 9835 | 0.3 | 26.1 | 20.4 | 23.25 | 0.02507 | 2.46 |
| 9836 | 0.3 | 26.2 | 21.9 | 24.05 | 0.02507 | 2.17 |
| 9837 | 0.3 | 28.3 | 21.4 | 24.85 | 0.02507 | 2.81 |
| 9838 | 0.3 | 26 | 22.4 | 24.2 | 0.02507 | 2.00 |

***Table* 1**. Data sample with input variables for training, validation of Red Neuronal. Source: *(CONAGUA S , 2020)*

https://smn.conagua.gob.mx/es/observando-el-tiempo/estaciones-meteorologicas-automaticas-ema-s

# Conclusions

This work presents a strategy that considers the modeling of evapotranspiration and estimates the operating conditions during the process of plant transpiration and soil evaporation by means of artificial neural networks. The results obtained were satisfactory since the neural algorithm adequately models the evapotranspiration behavior. Likewise, it has been observed that the Levenberg Marquardt method makes the network parameters converge faster to their weights and bias values. Therefore, this tool is powerful and flexible, since it allows evaluating what would happen in the system if one or the other alternative were taken, without affecting the real system.

Possible future work, perform a simulator implemented in MATLAB using inverse neural networks to validate the predictions by the algorithm, make a comparison between real data and those predicted by the algorithm, it is considered to make a physical prototype to be applied to an irrigation system and check the effectiveness of the algorithm proposed in this research work.

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