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Evapotranspiration Prediction Using Adaptive Neuro-Fuzzy Inference System and Penman FAO 56 Equation for St. Johns, FL, USA

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Abstract. Evapotranspiration (ET) estimation is a primary problem for irrigation engineers and hydraulic designers because it is an important part of hydrologic cycle. Even it is non-negligible in hydraulic design calculations, it is not clear enough to estimate or calculate ET. There are some meteorological parameters which effect ET directly or indirectly such as Relative Humidity (RH), Solar Radiation (SR), Air Temperature (AT) and Wind Speed (U). In this study authors used Adaptive Neuro-Fuzzy Inference System (ANFIS) for prediction of ET and results are compared with Penman FAO 56 empirical formula. 1158 daily AT, SR, RH and U values are used to train ANFIS model and 385 daily values are used to test it. ANFIS model determination coefficient with daily observed ET values found as 0.909. Also test set values are used to calculate Penman FAO 56 formula and the determination coefficient of Penman FAO 56 with daily observed ET values found as 0.857. For the comparison of the ANFIS model and Penman FAO 56 formula results Mean Square Error (MSE) and Mean Absolute Error (MAE) are computed. According to the comparison it is understood that ANFIS model has better performance than Penman FAO 56 empirical formula for the prediction of daily ET.

Keywords: evapotranspiration, penman FAO 56, artificial intelligent, forecasting, hydrologic modelling.

Conference Topic: Water engineering.

Introduction

Evaporation and transpiration are interdependent and it is not easy to make a complete distinction between them in any research about it. Evapotranspiration (ET) is defined as the combination of evaporation and transpiration in a specific area. When the crop is small in an area evaporation is the main factor of ET, but when the crop is well developed main factor of ET is being transpiration (FAO n. d.). Prominence of evaporation and transpiration in hydrologic cycle is given by Figure 1.

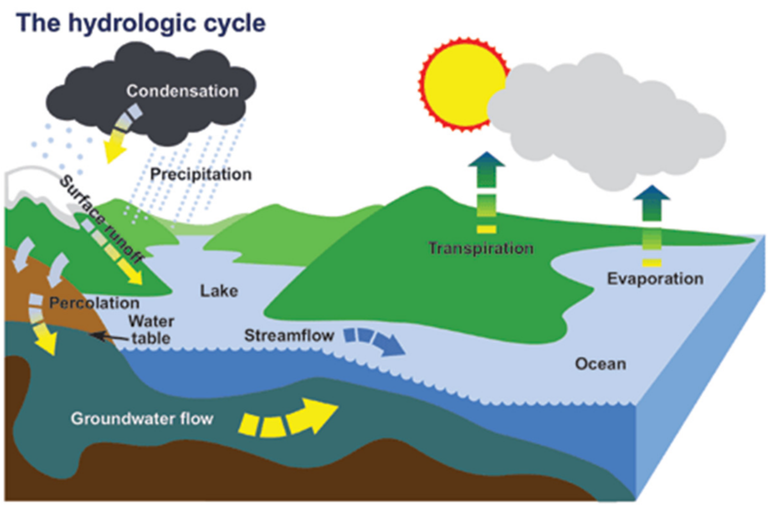

Fig. 1. Hydrologic cycle (Government of Canada n. d.)

ET estimation is a primary problem for irrigation engineers and hydraulic designers. Estimation ET accurately is important for determining crop water need. Scarce water resources make ET loss more imperative for planning and management of irrigation (Kisi 2007).

Brutsaert (1982) suggested various methods about the calculation of evapotranspiration. Generally aerodynamic calculations and rational relationships give more accurate results (Jensen *et al.* 1990). In the past decades some artificial intelligence methods are used to estimate ET, evaporation and pan evaporation more accurately such as Kim *et al.* (2015), Kumar *et al.* (2011), Pal and Deswal (2009).

In this study authors focused on estimate daily ET using adaptive neuro-fuzzy inference system. Data set is downloaded from USGS website (USGS.gov | Science for a changing world n.d.). 1158 daily SR, AT, U and RH parameters are used for training ANFIS model and 385 daily parameters are used to test it. Model results are compared with Penman FAO 56 empirical formula results.

Methodology

Adaptive neuro-fuzzy inference system

Adaptive neuro-fuzzy inference system (ANFIS) is a hybrid artificial intelligence method which uses the learning ability and parallel calculation of neural networks and benefits of fuzzy logic together. ANFIS model is built up by Jang (1993) and this model uses Sugeno&Kank type (Takagi, Sugeno 1985) fuzzification system and hybrid learning algorithm. Adaptive networks occur from directly connected nodes and each node represents a transaction unit.

Figure 2 shows a structure of ANFIS which is created using two input and one output. The meaning of each layer is given as below:

1. Layer 1: Fuzzification of input values;
2. Layer 2: Rules obtained fuzzy logic system;
3. Layer 3: Normalization of parameters;
4. Layer 4: Defuzzification of results;
5. Layer 5: Sum of results.

For further information about ANFIS readers are referred to (Jang 1993).

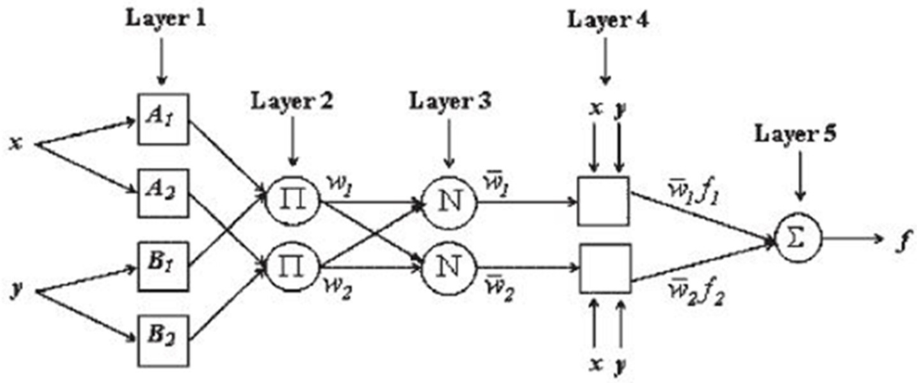

Fig. 2. An ANFIS model structure with two inputs and one output

Penman FAO 56 Equation

SR, AT, RH, U daily meteorological parameters are needed to calculate daily ET using Penman FAO 56 equation. Equation is given as below (Jensen *et al.* 1990),

$$ET = \left(\frac{\Delta}{\Delta+\gamma}\right)R_n + \frac{\gamma}{\Delta+\gamma}\left[15.36\left(1+0.0062u_2\right)\left(e_w - e_a\right)\right]\frac{1}{\lambda} \quad (1)$$

where: γ is the psychometric constant, Δ is the slope of the vapour pressure curve, R_n is the net radiation, u_2 is the wind speed at 2 m height, e_w is the saturation vapour pressure, e_a is the actual vapour pressure and λ is the latent heat of vaporization in equation (1).

Results

Ability of ANFIS model for the estimation of daily ET is the main target of this study. Model is created using daily SR, AT, U, RH meteorological values. Parameters are recorded in St. Johns station FL, USA. Data set is separated as training set and test set. Test set correlation coefficient of ANFIS with observed daily ET is obtained as 0.953 and correlation coefficient for Penman FAO 56 empirical equation is calculated as 0.926.

ANFIS daily distribution graph and scatter chart are given by Fig. 3 and Fig. 4.

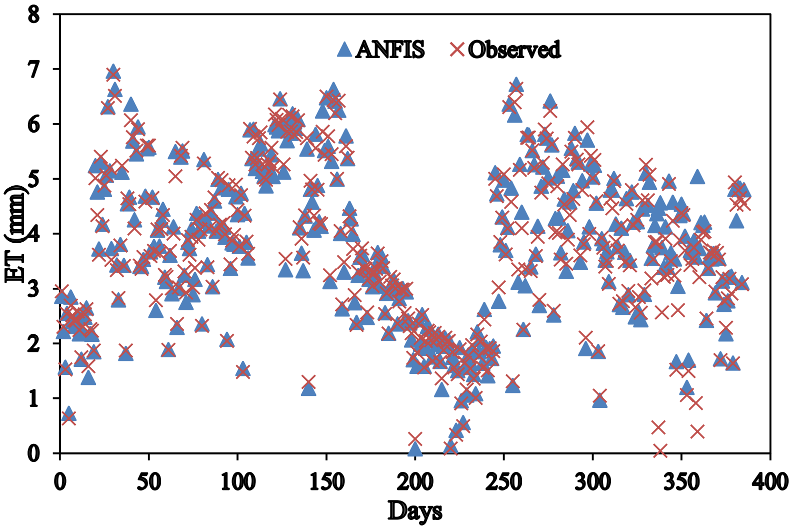

Fig. 3. Distribution graph of daily ANFIS results

Examining daily distribution graph shows that there is high correlation between ANFIS results and observed values.

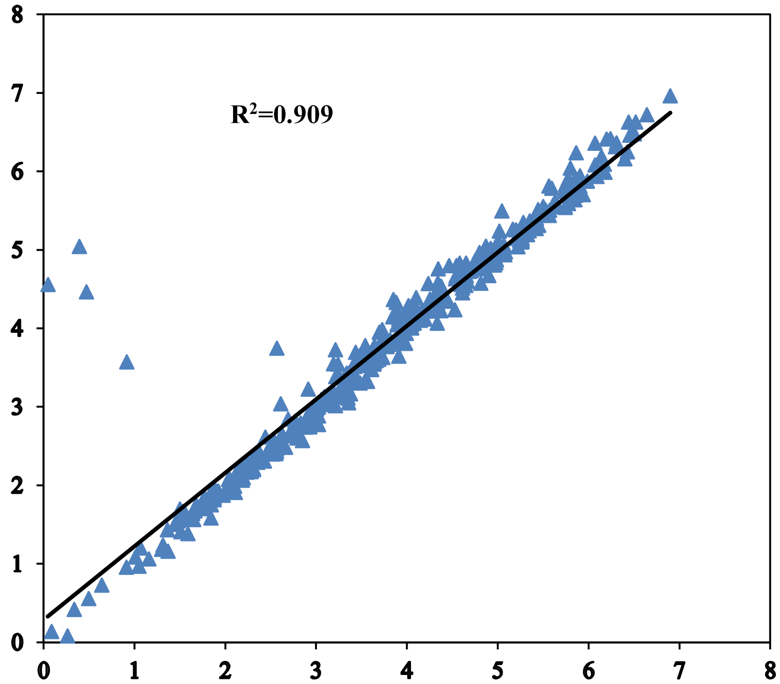

Fig. 4. Scatter chart of ANFIS and observed values

Fig. 4 shows the scatter chart of ANFIS and observed values for test set results. Determination coefficient is calculated as 0.909.

Same graph and chart are also given for Penman FAO 56 empirical formula by Fig. 5 and Fig. 6.

It is possible to see that there is a meaningful correlation between the distribution of daily Penman FAO 56 empirical formula and observed daily values of ET for test set in Fig. 5.

Determination coefficient for Penman FAO 56 empirical equation is calculated as 0.857. Test set comparison statistics are given by Table 1.

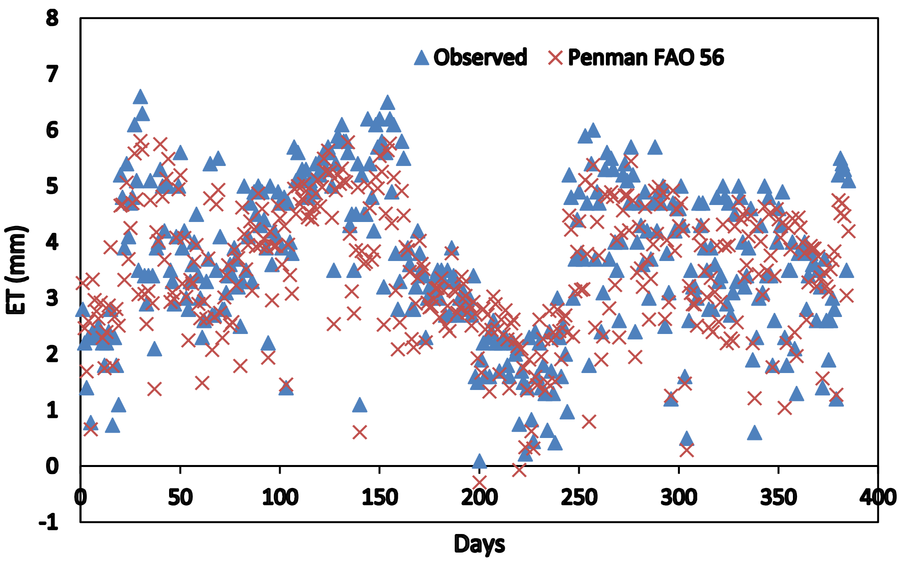

Fig. 5. Distribution graph of daily Penman FAO 56 results

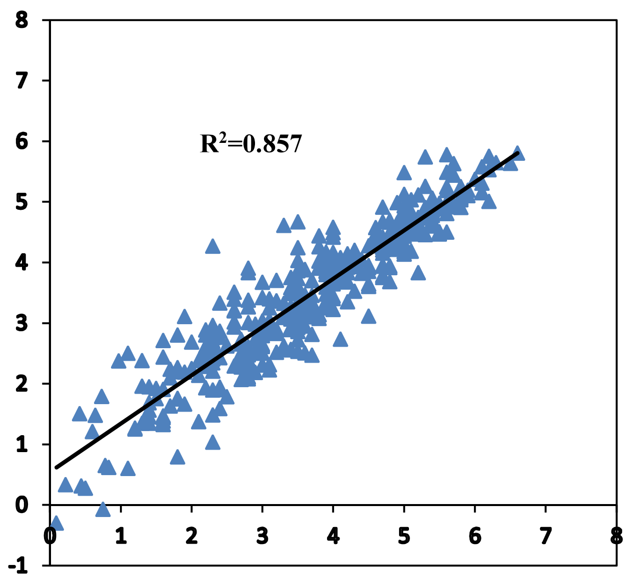

Fig. 6. Scatter chart of Penman FAO 56 and observed values

Table 1. Comparison statistics of test set

Method	Parameters Used	Determination Coefficient	MSE	MAE
ANFIS	SR, U, RH, AT	0.909	0.192	0.149
Penman FAO 56	SR, U, RH, AT	0.857	0.312	0.463

Evaluation Criteria

ANFIS and empirical formula results are evaluated using determination coefficient MSE and MAE statistics.

$$MSE = \frac{1}{N}\sum_{i=1}^{n}\left(fi - yi\right)^2; \qquad (2)$$

$$MAE = \frac{1}{N}\sum_{i=1}^{n}\left| fi - yi \right|; \tag{3}$$

$$R = \frac{\sum_{i=1}^{n}(x_i -).(y_i -)}{\sqrt{\sum_{i=1}^{n}(x_i -)^2} \cdot \sqrt{\sum_{i=1}^{n}(y_i -)^2}}, \tag{4}$$

where: f_i represents predicted values and y_i represents daily observed values for equation (2&3), x_i shows *i*th actual value, y_i shows *i*th predicted value, $\bar{x}$ represents x_{mean} and $\bar{y}$ represents y_{mean} at equation (4).

Conclusion

In this study daily ET is estimated using an ANFIS model and empirical equation. Determination coefficient, Mean Square Error (MSE) and Mean Absolute Error (MAE) statistics are calculated as it is shown in Table 1. According to the statistical results it is understood that ANFIS model is more effective than Penman FAO 56 empirical equation for estimation daily ET in St. Johns FL, USA region. Also it is seen that used empirical formula for this study gives quite close results to observed daily ET values which means this empirical formula is also can be used effectively for daily ET prediction. Authors proposed that ANFIS model should be applied to different regions which have different climatic conditions to verify ANFIS model ability for prediction daily ET.

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