

EVALUATION OF TAKAGI-SUGENO FUZZY INFERENCE FOR ESTIMATING EVAPOTRANSPIRATION IN MILA-ALGERIA'S SUB-HUMID CLIMATE

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Abstract. Effective water resource management is crucial for sustaining agricultural productivity, particularly in regions prone to water scarcity. The FAO-56 method, developed by the Food and Agriculture Organization, has become a cornerstone for accurately estimating reference evapotranspiration (ET_0), a key component in understanding water requirements for crops. The FAO-56 method integrates key meteorological data—temperature, humidity, wind speed, solar radiation, and other climatic parameters to provide accurate and consistent ET estimates, which are crucial for effective water resource management in agriculture. To enhance ET estimation in the sub-humid region of Mila, Algeria, a Takagi-Sugeno (TS) fuzzy inference system model was developed. The TSFS model demonstrated strong performance with low RMSE (0.417-0.434), high R^2 (0.945-0.950), and a high Willmott index (0.827-0.831), indicating reliable and accurate ET predictions for the Mila region. These results suggest that the Takagi-Sugeno fuzzy inference system is a viable alternative to traditional methods, offering robust ET estimates tailored to the specific climatic conditions of Mila, Algeria.

Key-words: Evapotranspiration, FAO-56, Takagi-Sugeno Fuzzy System, Model, Sub-humid, Mila, Algeria

1. Introduction

The effective stewardship of water resources is crucial for sustaining agricultural productivity, particularly in regions prone to scarcity (. The FAO-56 method, developed by the Food and Agriculture Organization, has become a cornerstone for accurately estimating reference evapotranspiration (ET_0), a key component in understanding water requirements for crops. The effective stewardship of water resources is crucial for sustaining agricultural productivity, particularly in regions prone to scarcity

(Khoshravesht et al., 2017) (Djaman et al., 2016) (Hadria et al., 2021) (Adnan et al., 2020). The FAO-56 method, developed by the Food and Agriculture Organization, has become a cornerstone for accurately estimating reference evapotranspiration (ET_0), a key component in understanding water requirements for crops (Djaman et al., 2016) (Hadria et al., 2021), integrates key meteorological data as temperature, humidity, wind speed, solar radiation, and other climatic parameters to provide accurate and consistent estimates of evapotranspiration, which are essential for water management and agriculture.

Previous studies have explored various methods for estimating reference evapotranspiration, with the FAO-56 method being widely regarded as the standard method. For instance, studies have shown that regression-based models, such as multivariate fractional polynomial, robust regression, and Bayesian regression, can provide close agreement with the calculated values for FAO-56 Penman-Monteith at a monthly scale (Khoshravesht et al., 2017). However, these models often require a large amount of data and multiple input variables. Additionally, studies have highlighted the significance of solar radiation and air temperature in estimating evapotranspiration, particularly in arid and semi-arid regions. (Hadria et al., 2021).

2. Methodology

In this study, a Takagi-Sugeno fuzzy inference system model is developed to estimate daily reference evapotranspiration in the sub-humid region of Mila, Algeria. The Takagi-Sugeno model is a type of fuzzy inference system that combines the strength of fuzzy logic and regression-based techniques to provide robust and accurate predictions (Adnan et al., 2020). The model is trained, validated, and tested using key meteorological data, such as air temperature, relative humidity, dew point, precipitation, surface pressure, vapor pressure deficit, wind speed, soil temperature, soil moisture, sunshine duration, and terrestrial radiation, as input variables from the year 2000 to 2022.

We mention that the proposed model is applied in three phases: 70% training, 15% validation, and 15% testing. To evaluate the performance of the Takagi-Sugeno model, the following statistical metrics is calculated: coefficient of determination (R^2), root mean square error (RMSE), mean absolute error (MAE), Nash-Sutcliffe (NSE), root sum ratio (RSR), and Willmott index (WI).

2.1. Study area

Located in the northeastern corner of Algeria (Fig. 1), the Mila region boasts a geographic situation that has a profound influence on its climatic features. The region lies at an altitude of 36.4503°N and a longitude of 6.2644°E , placing it within the sub-humid climate zone. The climatic characteristics of the Mila region are defined by a mean annual temperature of 18.76°C , with a mean minimum temperature of 2.50°C and a mean maximum temperature of 35.01°C . The region experiences a significant amount of precipitation, with an average annual rainfall of 734.61 mm, and a Q2 value (an indicator of aridity) of 77.46, classifying the region as sub-humid.

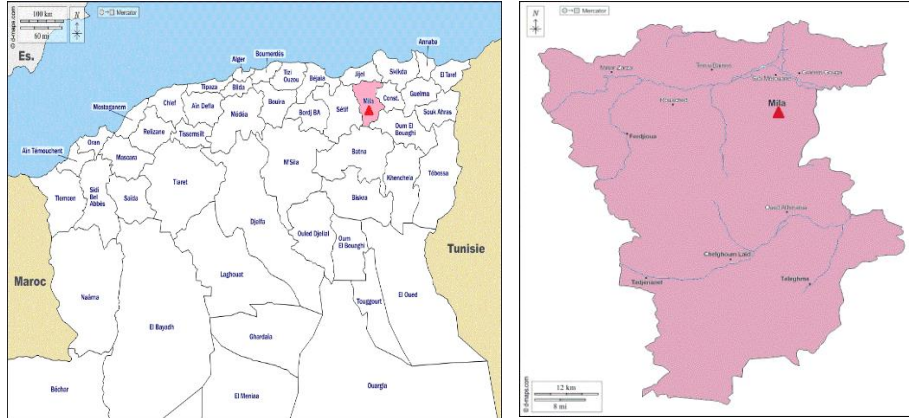


Fig. 1. Localization of studied region (Mila) -Algeria (D-Maps, 2024).

2.2. Method

Takagi-Sugeno fuzzy inference system has emerged as a powerful tool for modeling complex nonlinear systems, including the estimation of evapotranspiration. The architecture of the proposed model comprises a combination of fuzzy logic and neural network approaches, allowing it to capture the intricate relationships between various climatic variables such as: air temperature ($^{\circ}\text{C}$), relative humidity (%), dew point ($^{\circ}\text{C}$), precipitation (mm), surface pressure(hPa), vapor pressure deficit (kPa), wind speed (km/h), soil temperature ($^{\circ}\text{C}$), soil moisture (m^3/m^3), sunshine duration (s), and terrestrial radiation (W/m^2), and ET(FAO-56) , as input variables.

The proposed Takagi-Sugeno fuzzy inference system architecture involves five key stages:

Firstly, the data loading and preprocessing stage involves loading the relevant data from an Excel file, selecting the appropriate sheet, performing feature selection, data normalization, and splitting the data into training and validation sets. Secondly, the model definition and compilation stage define the input layer, lambda layer, and two dense layers, followed by compiling the model. Thirdly, the model training stage trains the model on the training data and validates it on the validation set. Fourthly, the predictions and evaluation stage generate predictions, saves them to an Excel file, and computes relevant evaluation metrics. Finally, the results output stage creates a results data frame and prints the key findings.

3. Results and discussion

The results indicate that the Takagi-Sugeno model exhibited strong predictive capabilities, with root mean square error values of 0.352, 0.342, and 0.348 for the

training, validation, and test sets, respectively. Additionally, the model achieved high values for R^2 (0.965, 0.966, 0.964) (Figure 2) and Nash-Sutcliffe efficiency, which ranged from 0.964 to 0.966 (Table 1), further demonstrating its robust and accurate performance. The results of this study suggest that the Takagi-Sugeno fuzzy inference system is a viable alternative to traditional evapotranspiration estimation methods, such as the FAO-56 Penman-Monteith method. The model's ability to accurately estimate evapotranspiration in the sub-humid region of Mila, Algeria, can be attributed to its ability to handle non-linear relationships between the input variables and the target variable. Furthermore, the Takagi-Sugeno model's flexibility in incorporating various meteorological parameters allows it to be tailored to the specific climatic conditions of the region, enhancing its performance and applicability.

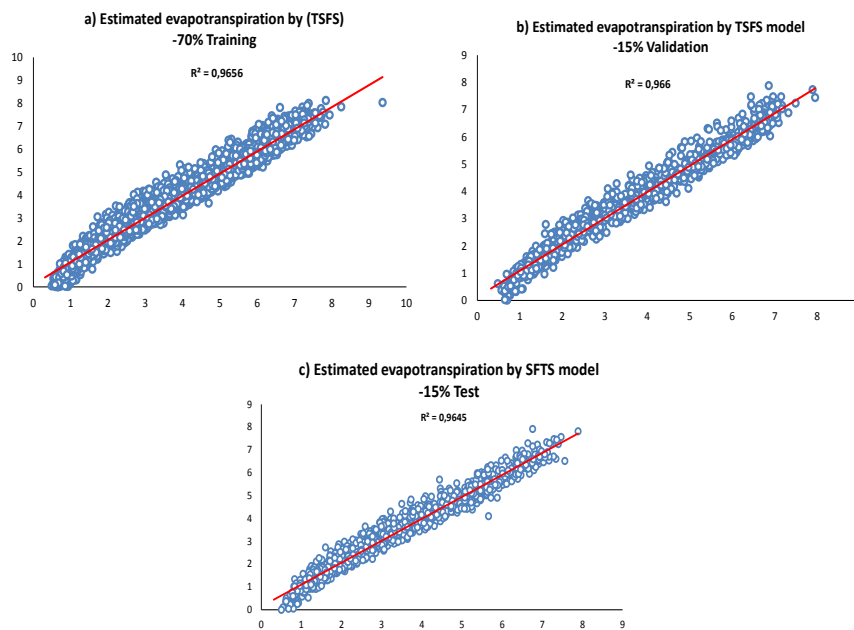


Fig 2. Scatter plots of 70% training, 15% Validation, 15% Test for TSFS model.

Table 1. Performance metrics of TSFS model

MODEL	METRICS	TRAINING	VALIDATION	TEST
TAKAGI-SUGENO FUZZY SYSTEM	RMSE	0,434	0,417	0,434
	MAE	0,337	0,329	0,335
	R^2	0,948	0,950	0,945
	NSE	0,948	0,950	0,945
	RSR	0,229	0,224	0,235
	Willmott Index	0,831	0,830	0,827

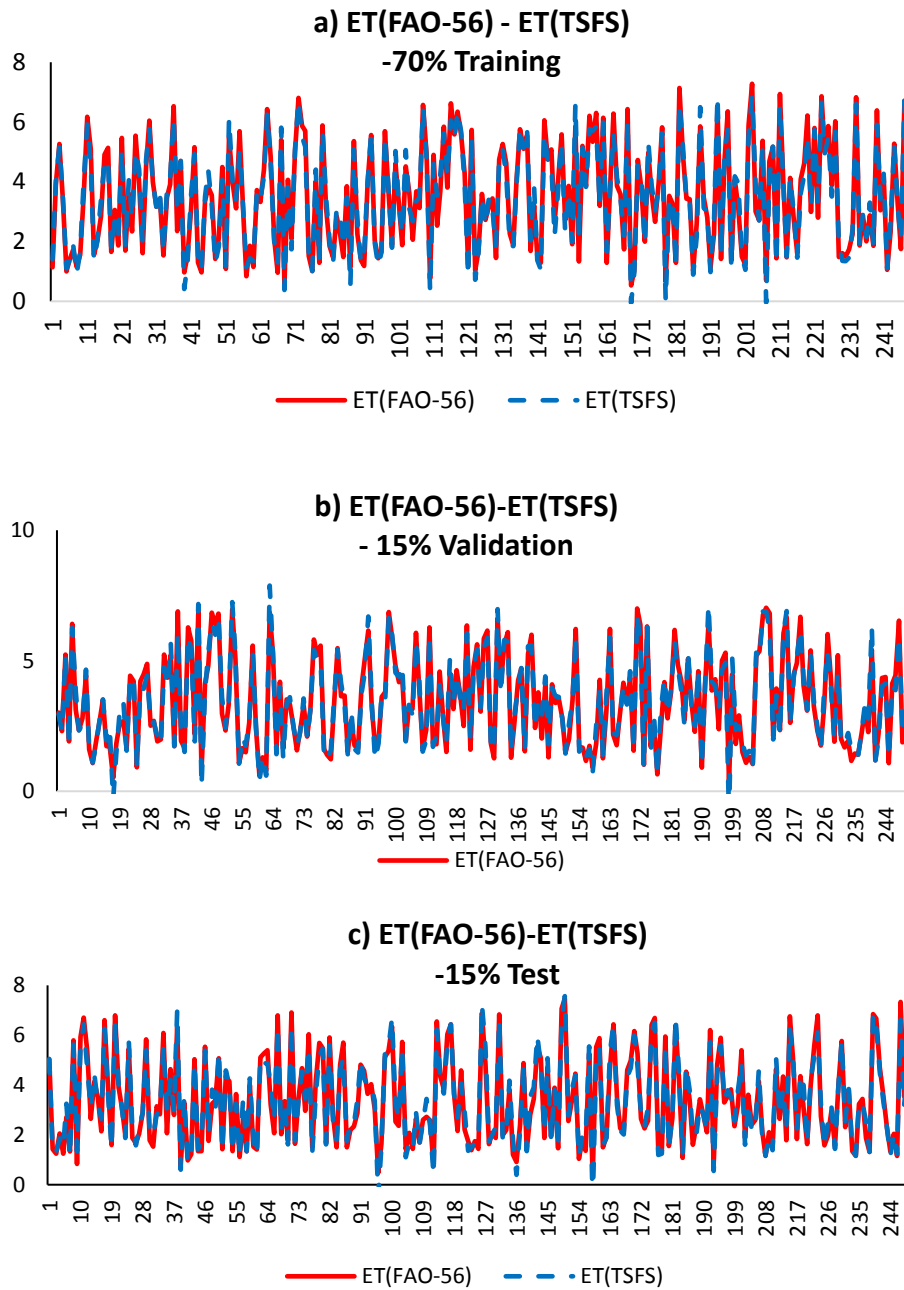


Fig. 3. Graphic representation of Estimated daily evapotranspiration (ET) in (mm) by FAO-56 method and TSFS model.

Figure 3 shows that the estimated evapotranspiration by Takagi-Sugeno Fuzzy inference System is practically identical across the three sets.

4. Conclusion

Effective water resource management is crucial for sustaining agricultural productivity, particularly in regions prone to water scarcity. The FAO-56 method, developed by the Food and Agriculture Organization, has become a cornerstone for accurately estimating reference evapotranspiration (ET_0), a key component in understanding water requirements for crops. To enhance ET estimation in the sub-humid region of Mila, Algeria, a Takagi-Sugeno fuzzy inference system model was developed. The TSFS model demonstrated strong performance with low RMSE, high R^2 , and a high Willmott index, indicating reliable and accurate ET predictions for the Mila region. These findings suggest that the Takagi-Sugeno fuzzy inference system may offer a robust alternative for estimating evapotranspiration, providing tailored and precise ET forecasts that account for the sub-humid climatic conditions in Algeria.

Building upon the promising results of this study, the authors recommend further exploring the potential of the Takagi-Sugeno fuzzy inference system for estimating evapotranspiration in the Mila region by incorporating additional relevant meteorological variables and expanding the geographic scope to other sub-humid areas in Algeria.

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