COMPARATIVE PERFORMANCE OF GENERALIZED REGRESSION NEURAL NETWORK AND ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM MODELS FOR EVAPOTRANSPIRATION ESTIMATION IN DJELFA, ALGERIA

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Abstract. Evapotranspiration (ET) is a critical component of the hydrological cycle, representing the sum of evaporation from the soil and transpiration from plants. Accurate estimation of ET is essential for effective water resource management, particularly in arid regions where water scarcity is a significant concern. The models that estimate ET using readily available meteorological data and those based on FAO-56 method gained popularity. Among these models, the Generalized Regression Neural Network (GRNN) and the Adaptive Neuro-Fuzzy Inference System (ANFIS) are widely used due to their ability to handle complex, nonlinear relationships between inputs and outputs. In this study, we compare the performance of GRNN and ANFIS models for estimating ET in the arid region of Djelfa, Algeria. By evaluating these models, we aim to determine the most accurate and reliable method for ET estimation in this challenging environment. The ANFIS model demonstrated moderate accuracy with RMSE values of 0.737, 0.650, and 0.698, and MAE values of 0.483, 0.438, and 0.462 for training, validation, and testing, respectively. Its R^2 and NSE values consistently around 0.904 to 0.919 indicate a strong correlation and good predictive performance. However, the GRNN model significantly outperformed ANFIS, achieving much lower RMSE values of 0.270, 0.222, and 0.217, and MAE values of 0.192, 0.147, and 0.145 across the same phases. The GRNN's R^2 and NSE values were exceptionally high at 0.987 to 0.991, reflecting nearly perfect fit and predictive accuracy. Additionally, the GRNN's lower RSR values and higher Willmott's index further underscore its superior performance, making it a more precise and reliable tool for evapotranspiration estimation in the arid region of Djelfa, Algeria.

Keywords: Evapotranspiration (FAO-56)-Estimation-GRNN-ANFIS- Arid – Djelfa-Algeria.

1. Introduction

Evapotranspiration is a crucial parameter in many applications, from agricultural water management to hydrological modeling, as it represents the combined process of water evaporation from the soil and transpiration from plant surfaces. Accurately estimating evapotranspiration is particularly important in arid and semi-arid regions, where water resources are scarce and efficient irrigation is crucial. However, estimating evapotranspiration can be challenging, as it requires several meteorological variables that may not be readily available, especially in remote or under-instrumented areas. To address this challenge, researchers have explored various modeling approaches, including empirical and data-driven techniques. One such approach is the Generalized Regression Neural Network, which has shown promise in accurately estimating evapotranspiration. Another model, the Adaptive Neuro-Fuzzy Inference System, has also been used for evapotranspiration estimation, combining the strengths of neural networks and fuzzy logic. (Hadria et al., 2021) In this study, we aim to compare the performance of these two models in estimating evapotranspiration in the Djelfa region of Algeria, a -arid area 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.

1.1. Study area

The Djelfa region of Algeria, situated at latitude 34.6728 and longitude 3.263, is characterized by an arid climate (Figure 1). This arid environment poses significant challenges for the region's agricultural activities, which primarily focus on crop cultivation and livestock farming. These agricultural practices are heavily reliant on irrigation and efficient water management, as the region experiences a mean annual temperature of 17.85°C and an average annual precipitation of 286.51 mm. Q2, a bioclimatic index that indicates the relationship between temperature and precipitation, is 28.72 for the Djelfa region, reflecting its relatively dry climate (Belhadj et al., 2023). The agricultural sector in the Djelfa region, as in other arid and semi-arid regions of Algeria, faces various environmental and sustainability challenges. Intensive agricultural practices, including conventional tillage, excessive irrigation, and excessive fertilization, have been identified as the primary causes of soil degradation in similar semi-arid areas of Morocco (Bourhrami et al., 2022). These practices can lead to a decline in soil quality and fertility, ultimately impacting the long-term productivity and sustainability of the region's agricultural systems.

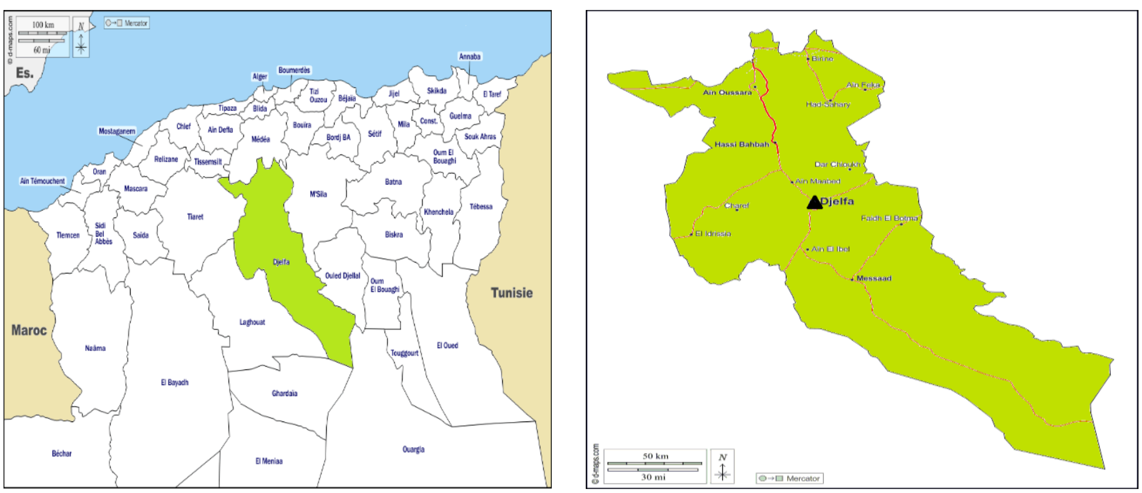

Fig. 1. Localization of studied region (Djelfa) -Algeria (D-Maps, 2024).

2. Methodology

The meteorological data used in this study were obtained from the Djelfa weather station, located within the study area. The data includes daily air temperature, relative humidity, dew point, precipitation, surface pressure, vapor pressure deficit, wind speed, soil temperature, soil moisture, sunshine duration, and terrestrial radiation from the year 2000 to 2022. The collected data are thoroughly examined and preprocessed to ensure its quality and suitability for the subsequent analyses. We divided the data to 3 sets which are 70 % training, 15 % Validation and 15% Test.

The Generalized Regression Neural Network is a type of neural network that can be used for function approximation and nonlinear regression. The GRNN model is composed of four layers: input layer, pattern layer, summation layer, and output layer. The input layer receives the meteorological variables, the pattern layer calculates the distance between the input and the training samples, the summation layer sums the weighted responses, and the output layer provides the evapotranspiration estimate. The GRNN proposed model is implemented from scratch in Python without relying on deep learning libraries. The architecture consists of an input layer, a nearest neighbor search to find similar training samples, and a weight calculation and prediction step that computes the output as a weighted average of the target values, with closer samples having a greater influence.

However, the Adaptive Neuro-Fuzzy Inference System is a hybrid model that combines the strengths of artificial neural networks and fuzzy logic. The ANFIS model consists of a network of interconnected nodes, where each node represents a fuzzy set or a fuzzy logic operation. The model is trained using a combination of back-propagation and least-squares estimation to optimize the parameters of the fuzzy membership functions and the fuzzy rules. To develop the ANFIS model, the same meteorological input variables used for the GRNN model were employed. The ANFIS model is implemented using a neural network approach in TensorFlow/Keras, with an architecture comprising an input layer, a fully connected layer with tanh activation to simulate fuzzy logic membership functions, and an output layer for regression. Both models are trained, validated and tested using the 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) tracked as a performance metrics.

3. Results and Discussion

The performance metrics for the Adaptive Neuro-Fuzzy Inference System and General Regression Neural Network models are presented in Table 1. These metrics include Root Mean Square Error, Mean Absolute Error, R-squared (R^2), Nash-Sutcliffe Efficiency, Root Sum Ratio, and the Willmott Index. Each metric is evaluated across three datasets: training, validation, and testing.

Table 1. Performance metrics of GRNN, and ANFIS models.

MODELS	METRIC	TRAINING	VALIDATION	TESTING
ANFIS	RMSE	0,737	0,650	0,698
	MAE	0,483	0,438	0,462
	R^2	0,904	0,919	0,909
	NASH	0,904	0,919	0,909
	RSR	0,310	0,285	0,301
	Willmott Index	0,812	0,820	0,813
GRNN	RMSE	0,270	0,222	0,217
	MAE	0,192	0,147	0,145
	R^2	0,987	0,991	0,991
	NSE	0,987	0,991	0,991
	RSR	0,114	0,097	0,094
	Willmott Index	0,916	0,931	0,933

The ANFIS model shows RMSE values of 0.737, 0.650, and 0.698 for the training, validation, and testing datasets, respectively, suggesting moderate accuracy. The MAE values follow a similar trend, with 0.483, 0.438, and 0.462 for the respective datasets, indicating that the ANFIS model has a reasonable level of accuracy. The R-squared values are quite high at 0.904, 0.919, and 0.909, respectively, suggesting that the model explains a significant portion of the variance in the data. The NSE values mirror the R-squared values, indicating strong predictive performance. The RSR values of 0.310, 0.285, and 0.301 suggest that the ANFIS model performs reasonably well. The Willmott Index values of 0.812, 0.820, and 0.813 indicate a good level of agreement between observed and predicted values. In contrast, the GRNN model demonstrates significantly lower RMSE values of 0.270, 0.222, and 0.217 for the training, validation, and testing datasets, respectively, indicating superior accuracy compared to the ANFIS model. The MAE values for GRNN are 0.192, 0.147, and 0.145, which are also lower than those of the ANFIS model, suggesting better performance. The R-squared values for GRNN are 0.965, 0.975, and 0.976, indicating that the model explains a very high proportion of the variance in the data. The NSE values for GRNN are 0.965, 0.975, and 0.976, mirroring the R-squared values and suggesting excellent predictive performance (Figure 2).

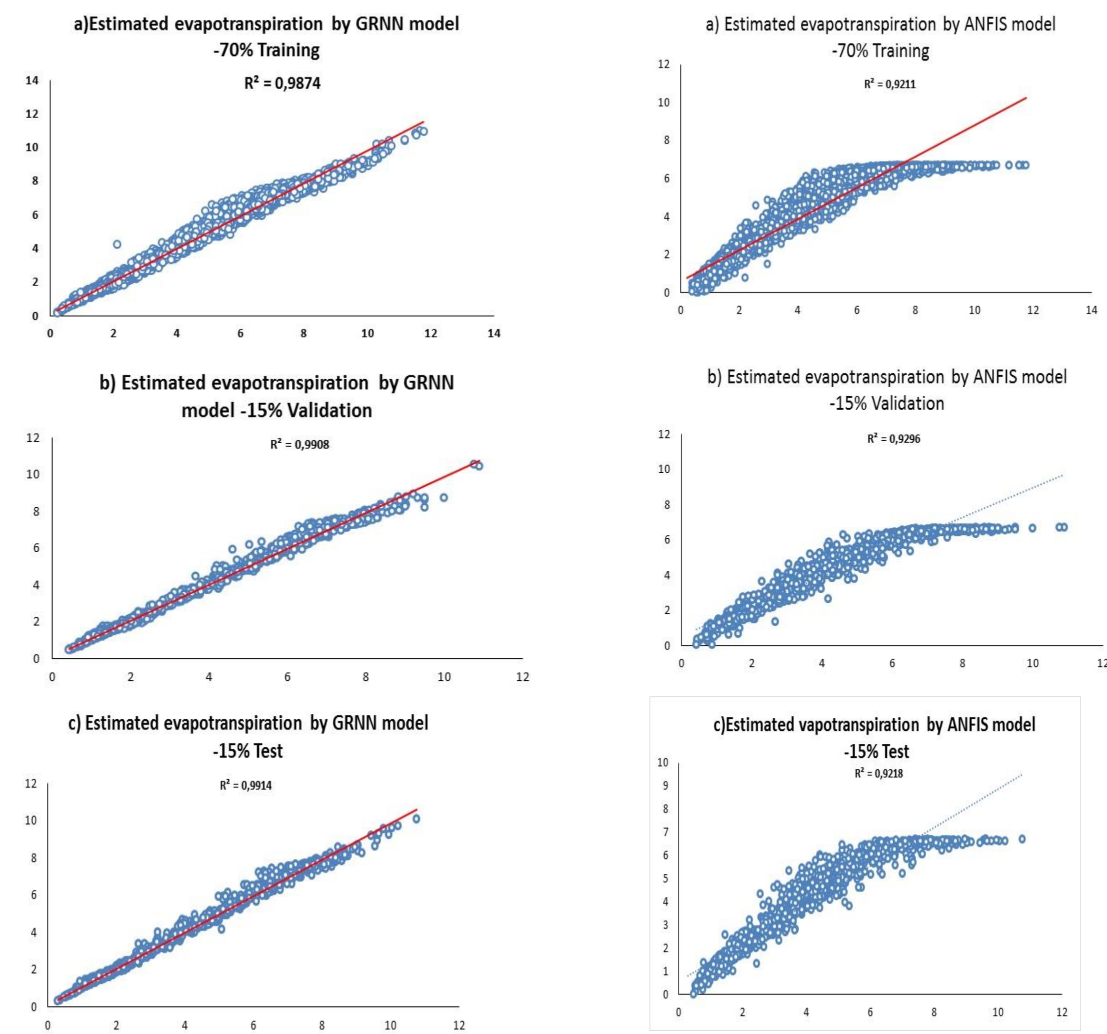

Fig. 2. Scatter plots of 70% training, 15%Validation, 15% Test for GRNN and TSFS models.

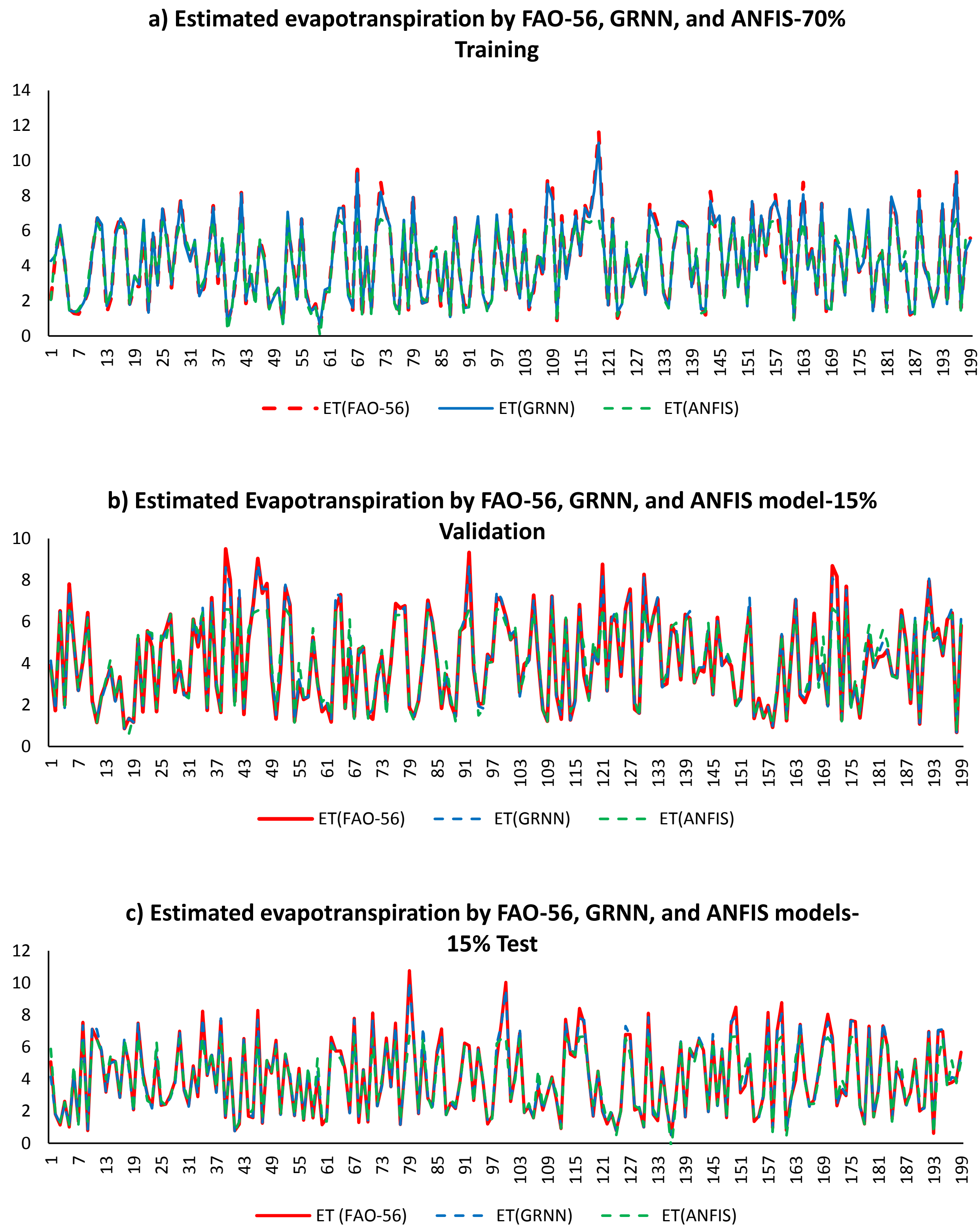

Fig. 3. Graphic representation of Estimated daily evapotranspiration (ET) in (mm) by FAO-56, GRNN, and ANFIS models.

The Figure 3 (a, b, c) shows clairly that in the three sets, training, validation and test, the estimated evapotranspiration by Fao-56 method and GRNN model are practically aligned. In contrast, the estimates from the ANFIS model show a noticeable divergence from these two methods.

4. Conclusion

Based on the findings of this study, it is concluded that the GRNN model be further explored and potentially employed in similar prediction, as it has demonstrated superior performance compared to the ANFIS model. Additionally, it is suggested that the ANFIS model could be further optimized and refined to enhance its predictive capabilities, potentially through the incorporation of additional input variables or the fine-tuning of its hyperparameters. Future research should also investigate the conditions under which the ANFIS and GRNN models may be more or less suitable, as well as explore the possibility of hybridizing these models to leverage the strengths of both approaches.

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