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Research Article

Comparative analysis of ANFIS models in Prediction of Streamflow: the case of Seyhan Basin

Furkan Ozkan [a,*], ***Bulent Haznedar*** [b]

[a]*Hasan Kalyoncu University, Faculty of Engineering, 27010 Gaziantep, Turkey*
[b]*Gaziantep University, Faculty of Engineering, 27010 Gaziantep, Turkey*

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ABSTRACT

In order to sustain human life without problems, a rational planning is required for the conservation and use of existing water resources. The potential of future water sources should be determined as the first step in such planning. Therefore, river flow forecasting is necessary to provide basic information about a variety of problems related to the operation of river systems. In this study, the long-term daily flow values of the Zamantı River-Değirmenocağı, Zamantı River-Ergenuşağı, and Eğlence River-Eğribük stations in the Seyhan Basin in Turkey were examined. In order to predict the forward flow rate from past flow measurement values, the Adaptative Neuro-Fuzzy Inference System (ANFIS) model was trained using Backpropagation (BP), Hybrid Learning (HB), and Simulated Annealing (SA) algorithms, and the results were compared. The performance of ANFIS models created with different input parameters using Grid Partitioning (GP) and Fuzzy C-Means Clustering (FCM) methods was also examined. The evaluation criteria used for comparison were Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), Determination Coefficient (R^2), and Mean Absolute Percentage Error (MAPE). The best results for R^2 values of 0.6854, 0.9242, and 0.9373 were obtained for FMSs using the BP model. As a result of the analysis, it was concluded that the BP algorithm could be used more successfully and effectively than other algorithms for training ANFIS parameters in nonlinear problems.

1. Introduction

Thanks to its current potential, water is a natural resource that meets the energy needs of humanity [1]. Therefore, river flow estimation is necessary to provide basic information on a wide variety of problems related to the functioning of river systems and for rational planning for the conservation and use of existing water resources [2]. At the beginning of the plans to be made, the potential created by the water source to be used and the potential to be made in the future should be determined. The availability of extended flow records and other climate data that can be used to derive streamflow data has prompted the application of runoff forecasting modelling [3]. In recent years, estimation of river flow in hydrological processes has become very important in order to facilitate the sustainable use and effective planning and management of water resources [4]. Behaviour detection is possible with the observation values of existing measuring stations. The estimation of river flow is a critical task in water resources management, as it helps in the planning and management of various water-related activities such as irrigation, hydropower generation, and water supply [5]. Accurate estimation of river flow is essential for effective water management, especially in regions where water resources are limited, and water scarcity is a significant concern. The Seyhan Basin in Turkey is one such region where water resources are limited, and there is a high demand for water due to agricultural activities and urbanization [6]. The Seyhan River is the primary source of water in the basin, and the accurate estimation of its flow is crucial for effective water management.

Traditional methods usually give good results in solving small-sized problems. Conceptual or physically based models are important in understanding hydrological

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* Corresponding author. E-mail address: *furkan.ozkan@hku.edu.tr*
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processes [7]. In fact, the statistical properties of time series data often violate the assumptions of traditional methods. Therefore, the analysis of time series data requires a unique set of tools and methods known as time series analysis [8]. With this sense, artificial Intelligence techniques have gained momentum in the last two decades, particularly for modelling and assessing the disruption of water distribution networks [9]. Artificial intelligence techniques are frequently and successfully used in the estimation of flow values [10]. The forecast results provide appropriate planning for both the producer and the user for the production of water resources for living things, irrigation, hydroelectric power generation and transferring water to future generations [11].

The aim of this study is to investigate the applicability of artificial intelligence techniques such as ANFIS (Adaptive Neuro-Fuzzy Inference System) and develop an accurate and reliable model in the estimation of flow rate in the river system. The model can be used by water managers and policymakers to make informed decisions on water allocation and management. In the study, it is planned to measure the success in river flow rate problems by using the HB, BP and SA algorithms, which are the optimization algorithms of ANFIS. Performance analysis of ANFIS structures in nonlinear problems is done by comparing traditional derivative-based BP and HB algorithms with the heuristic optimization technique SA algorithm. Applications have been made on estimating the future flow value using past stream flows and estimating the measurement at the unmeasurable flow observation station. Model performance comparisons have been made comprehensive with GP and FCM clustering methods. In addition, performance analysis with R^2, MAE, MAPE and RMSE evaluation criteria was performed for BP, HB and SA models.

This paper is organized as follows: Section 2 presents relevant studies in the literature on the problem of river flow rate are mentioned and information about classical approaches is given. In section 3 detailed information is given about the data set and stations used. Information on how the algorithms used are trained and the parameter optimization results of the created models are examined. in Section 4. The interpretations of the models were made according to the performance evaluation criteria. In the conclusion section, the studies are summarized and information is given about the advantages and disadvantages of the models obtained as a result of the study. Ideas about future work in this area have been put forward.

2. Related Work

The use of Artificial Intelligence Methods in hydrology has recently been conducted with artificial intelligence techniques such as Fuzzy Logic, ANN and ANFIS [12]. When these studies are examined, both the convenience they provide in modeling and the compatible results obtained show that these methods can be applied. When modeling with these methods, only the current flow data is used without the need for the physical characteristics of the basin or the region. In addition, these methods are advantageous in solving nonlinear problems in terms of approach.

[13] developed ANFIS and Linear Multiple Regression (MLR) methods for flow estimation in rivers in this study. They observed that ANN models and Fuzzy Logic models are applicable for flow prediction in rivers. [14] used fuzzy logic modeling techniques for seasonal flow forecasting and water supply at Lodge Creek and Middle Creek airports in Canada. The reservoir control system for Yuvacık dam is modeled using the Fuzzy Logic System method with four input parameters: losses, precipitation, inlet and outlet flow, and lake water level as the outlet parameter [15]. The results of the study showed that the fuzzy theory is more flexible and reliable than other systems in reservoir control because it also handles different hydrological uncertainties and the relationship between inputs and outputs can be interpreted in the rules. The feasibility of water resource estimation was investigated using fuzzy logic modeling techniques [16]. Findings from fuzzy expert systems were found to be far superior to regression models in water resource estimation. In [17] hydrological modeling of the Seethawaka River Basin was performed with Artificial Neural Networks that simulate the flow and compare the flow with data-driven techniques. Training algorithms such as Levenberg-Marquardt (LM), Bayesian regularization (BR) and scaled conjugate gradient (SCG) were used in the training process of the developed ANNs. ANN was used at Aghbalou station in a basin in a semi-arid climate in Morocco [18]. In this study, a multilayer perceptron (MLP) neural network was preferred to model the precipitation flow relationship. Based on the results, it clearly shows that the neural network method can develop better than the classical regression model in such arid regions where precipitation and runoff are very irregular.

It is aimed to apply a new hybrid model named ANFIS-PSO for monthly flow prediction in the Barak River basin near India. A hybrid model combining particle swarm optimization (PSO) algorithm and ANFIS has been developed [19]. It has been observed that the ANFIS-PSO model has the best performance compared to the independent ANFIS and ANN models. In another study [20] using log flow and precipitation data, artificial neural network, adaptive neural-based fuzzy inference system, extreme learning machine (ELM), Gaussian process regression (GPR) and support vector machine (SVM), Artificial intelligence methods were used to examine the log Streaming potential. In the study, Hongjiadu reservoir and Xinfengjiang reservoir in China were analyzed as two different areas. All artificial intelligence techniques used performed well in daily flow problems and when the models were compared, SVM, GPR and ELM techniques found the best results when evaluated in the given criteria.

3. Materials and Method

3.1. Adaptive Neuro-Fuzzy Inference System (ANFIS)

ANFIS consists of the representation of the Sugeno type fuzzy system as a network structure with neural learning capability [21]. Both artificial neural networks and fuzzy logic are used in its structure [22]. The main purpose of ANFIS is to optimize the parameters of the equivalent fuzzy logic system by means of a learning algorithm using input-output datasets. Parameter optimization is done in such a way that the error value between the actual output and the target output is minimum [23]. Based on the two fuzzy rules given below, the possible ANFIS architecture for the first order fuzzy Sugeno model is given in Figure 1.

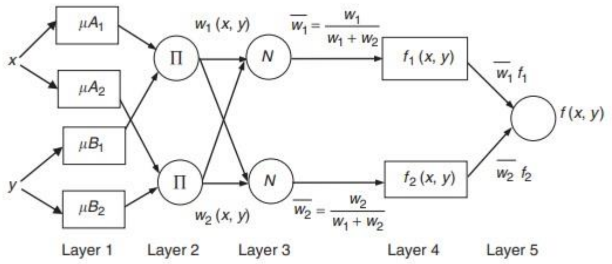

Figure 1. The Scheme of the Adaptive Neural–fuzzy Inference System

Briefly, the fuzzification is done by applying membership functions to the input data in the first layer. In the second layer, rules are created according to the fuzzy logic inference system. In the 3rd layer, a weighted average and normalization process is applied to each node coming from the rule layer. In the 4th layer, the fuzzy results are converted to numerical values, and finally, in the 5th layer, the output values of all nodes are collected to produce the single output value of the system [24].

3.2. Assessment Methods

The most important step in any machine learning model is to evaluate the accuracy of the related models to describe how well the model is performing in its predictions. MAE, RMSE, R^2 and MAPE evaluation criteria are used to evaluate the performance of the model in statistical analysis. Among these performance measures, R^2 is the accuracy rate decision coefficient of the model. A high value of this coefficient indicates a good estimation relationship [25]. Since MSE, RMSE and MAE are error measures, low results are measures that show high performance inversely proportional to performance [26]. These parameters are defined as:

$$\text{MAE} = \frac{1}{n}\sum_{t=1}^{n}|X_i - Y_i| \quad (1)$$

$$\text{MAPE} = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{X_i - Y_i}{X_i}\right| \times 100 \quad (2)$$

$$\text{RMSE} = \sqrt[2]{\frac{1}{n}\sum_{t=1}^{n}(X_i - Y_i)^2} \quad (3)$$

$$R^2 = 1 - \frac{RSS}{TSS} \quad (4)$$

Where X_i is the sum of the actual data, Y_i is the sum of the predicted data, n is the total number of data points and RSS is the residuals sum of squares, TSS is total sum of squares. The aim is to minimise MAE, MAPE and RMSE given in Equation 1,2 and 3. On the contrary, it is to maximize the value of R^2 given in Equation 4.

3.3. Study Area

In this study, the daily flow values of Zamanti River-Degirmenocagi (1827), Zamanti River- Ergenusagi (1826) and Eglence Stream-Egribuk (1825) stations in the Seyhan Basin in Turkey were investigated to analyze the applicability and capacity of ANFIS and ANN methods for daily river flow estimation. The data used was provided by the DSI (Hydraulic State Works). The upper part of the Seyhan Basin is located in Central Anatolia, the middle and lower part in the Mediterranean Region, in the north of Adana province, between 36º 30' and 39° 15' north latitudes and 34º 45' and 37º 00' east longitudes. It has a length of 560 km and a surface area of 22.035 km² [27].

All values in the dataset include daily river flow values. To control the prediction potential of the compared models, 3 flow measurement stations (FMS) carrying various hydrological conditions of the Seyhan basin were used. The locations of the relevant stations in the Seyhan basin on the map of Turkey are given in Figure 2. In addition, daily long-term, 24-year stream flow data are obtained from all stations. In the training phase of the models, 7143 daily flow data, which is 80 percent of the data set, and 1785 daily flow data, which is the remaining 20 percent, were used in the testing phase. Table 1 shows the coordinates of all stations and the time range of the data used.

Table 1. FMSs Located in the Seyhan Basin

FMS	Coordinates East (° ' ")	Coordinates North (° ' ")	Elevation (m)	Observation (Year)
Egribuk	35 11 35	37 21 50	222	1988-2011
Ergenusagi	35 34 47	37 39 55	360	1988-2011
Degirmenocagi	35 29 10	37 51 18	740	1988-2011

As shown in Figure 3, the daily flow potentials of all three stations were examined during the flow analysis of the river and the lowest and highest flows of the stations were given in m^3/s. When the three stations are examined together and the stream flow is controlled, the lowest stream flow was observed at Egribuk station in August 2008 with 0.95 m^3/s. The highest flow rate was observed at Ergenusagi station in December 2002 with 434 m^3/s.

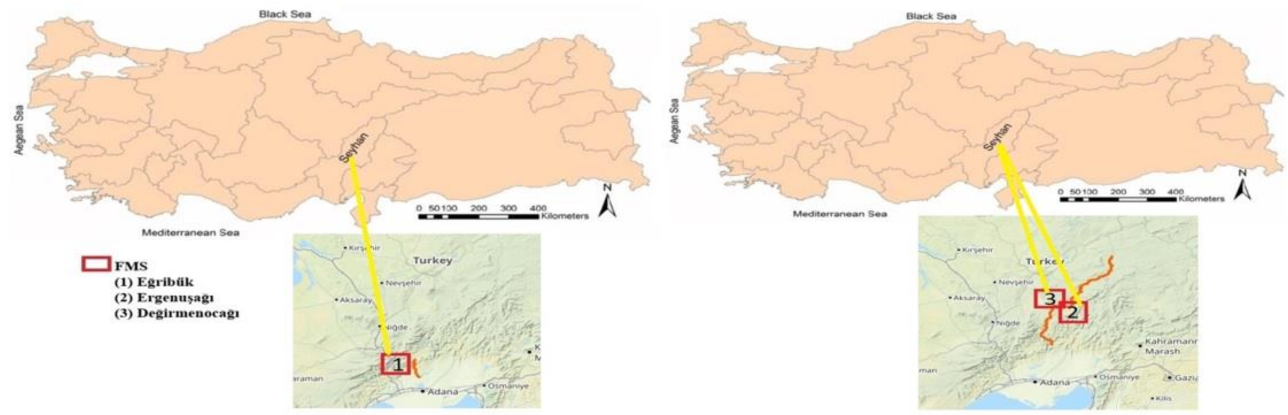

Figure 2. Study sites in the Seyhan river basin

4. Experiments

One of the main problems to be solved is the creation and configuration of the ANFIS model in the application phase for problem solving [28]. All these processes, such as selecting input variables, partitioning the input space, choosing the type and number of membership functions for the inputs, determining the number of rules by creating a rule layer, determining the initial values of the membership functions parameters, include the creation of the ANFIS model [29]. In this study, the performances of ANFIS models created using GP and FCM methods in river flow estimation were compared. In addition, BP, HB and SA algorithms were used to train the ANFIS parameters. Numerous attempts were made to determine the best ANFIS model. As a consequence of the attempts, the membership functions (MF) type and count of the ANFIS model created using GP, and output functions were selected as gaussmf, 2, linear respectively. Also, the MFs type and the number of clusters were determined as gaussmf and 10, respectively in the ANFIS model created using FCM. While estimating the current flow value Q(t), 3 models were established. In the first model, Q(t) is estimated based on the current value Q(t–3) of the previous three days. In the second model, Q(t) is estimated based on the flow value Q(t–4) 4 days ago and the flow value Q(t–5) 5 days ago. It is set up similarly in other models. ANFIS model of all algorithms to predict river flow was constructed from 3 input variables (lag-3, lag-4 and lag-5). Based on the previous steps, we can conclude that Q(t–3) as lag-3, Q(t–4) as lag-4, and Q(t–5) as lag-5 are considered ANFIS inputs. According to the 5-time delay scenario, daily flow values starting from 5 days before and up to one day before are used as input in the 6th Day forecast. For the data set of the 4 time-shifted scenarios, the daily flow values starting from 4 days before and up to the day before are used as input in the 5th Day forecast. In the data set of the 3 shift scenarios, the 4th day flow values were estimated by using the flow values from 3 days before to 1 day ago. These lag values are given as input values to the 4 membership functions in GP clustering. Consequently, all performance measurements obtained for each FMS are presented in Table 2.

Table 2. Performance Measures for Q(t-5) (All values in m^3/s)

FMS	ANFIS Models	RMSE	MAPE	MAE	R^2
1825	FCM-BP	5.0968	17.143	1.397	0.6662
	GP-BP	**4.9082**	13.056	**1.290**	**0.6854**
	FCM-HB	4.9861	**12.022**	1.294	0.6782
	GP-HB	5.3614	12.663	1.352	0.6351
	FCM-SA	6.2486	19.4916	1.4607	0.5982
	GP-SA	5.0981	39.0915	1.8213	0.6630
1826	FCM-BP	6.9416	5.3772	3.236	0.9219
	GP-BP	**6.8502**	**5.1395**	**3.155**	**0.9242**
	FCM-HB	7.0432	5.5184	3.325	0.9202
	GP-HB	7.1958	6.1119	3.521	0.9162
	FCM-SA	8.8353	5.5786	3.3322	0.8736
	GP-SA	7.7590	7.5758	4.1743	0.9001
1827	FCM-BP	3.5235	16.574	1.856	0.9327
	GP-BP	**3.3904**	16.577	1.807	**0.9373**

FCM-HB	3.5118	**15.083**	1.795	0.9329
GP-HB	3.5451	15.251	**1.783**	0.9320
FCM-SA	4.5008	18.6014	2.7641	0.8172
GP-SA	3.8089	19.1908	2.1158	0.9209

Table 2 illustrates the statistical measure of the model results. The comparison estimations of these three models for Egribuk, Ergenusagi and Degirmenocagi FMS, respectively are presented in Table 1. While the estimated MAE values of the benchmark BP and HB was 1.2900, 3.1554, 1.8074 and 1.2944, 3.3251, 1.7828, respectively. Concerning RMSE, the BP model is detected to be 4.9082, 6.8502, and 3.3904 while benchmark HB is 4.9861, 7.0432, and 3.5118. The best MAPE values are discovered as 12.0222, 5.1395, and 15.0825 for the models. Ultimately, according to the R^2, the BP model is found to be 0.6854, 0.9242, and 0.9373 while benchmark HB is 0.6782, 0.9202, 0.9329 respectively. Thus, BP carries a high estimation success with its statistical measures. The HB model also obtained close results according to the measurement values. Considering all the RMSE, MAE, MAPE and R^2 statistics, the BP model will be chosen as a preference to the HB model.

5. Conclusions

In this study, the daily flow rate values of Zamanti River-Degirmenocagi, Zamanti River-Ergenusagi and Eglence River-Egribuk stations in the Seyhan Basin in Turkey have been investigated. In our modelling approaches, the models were being trained such that 80% of the data was used in the training part and 20% in the test part. The aim of this study is to compare the river flow estimation of 3 FMS with ANFIS approaches. Taking long-term daily river flow data as input to the ANFIS model, the model was trained using BP, HB and SA algorithms.

When the results were examined, low estimation errors measured the usability of ANFIS methods in river flow problems. The training process was tested in all models with different input parameters and existing membership functions, and the evaluation method values were recorded each time. As seen in the results tables of three stations, it was concluded that traditional derivative-based that BP algorithm can be used more successfully and effectively than other algorithms in training ANFIS parameters in nonlinear problems.

Factors such as data quality and quantity, input variable selection, model complexity, model validation have influenced the accuracy of the ANFIS model used in this study for river flow estimation in the Seyhan Basin in Turkey. Inaccurate or incomplete data can negatively affect the model's performance, and future research can focus on improving data quality by collecting data from additional monitoring stations, using advanced data processing techniques, and incorporating remote sensing data. Likewise, input variable selection is also crucial for identifying the most relevant model using feature selection techniques. The complexity of the ANFIS model can influence its accuracy, and future research can optimize the model's architecture and parameters to achieve a balance between accuracy and simplicity. Adequate model validation procedures are also crucial to ensure the model's accuracy and reliability. Finally, external factors such as climate change, land-use changes, and infrastructure development can also influence the accuracy of the model, and future research can incorporate these factors into the model and use scenario analysis to assess their potential impact on river flow estimation.

It is very difficult to accurately determine all the parameters of the flow in rivers and to make parametric modelling. Prospective river flow estimates were created by reducing this complexity to facilitate interpretation and comparison of models by taking only one input. Algorithms such as SA are iterative-based and usually try to find a global optimum by improving a randomly selected candidate solution. This kind of algorithm can generally obtain the optimal solution in a shorter time interval than population-based algorithms. For this reason, the performance of the SA algorithm, which we applied within the scope of the thesis, fell behind the BP and HB algorithms. ANFIS will be used frequently in the future as an improved method for researchers working in the field of Hydrology. Also, studies will be conducted to train ANFIS with metaheuristic artificial intelligence algorithms and apply the same model to different problems.

In conclusion, the ANFIS model has significant potential for use in river flow estimation and water resources management in the Seyhan Basin and other regions with similar characteristics. The ANFIS model can be used to improve the accuracy and reliability of river flow estimation, which is crucial for effective water resources management. Furthermore, the ANFIS model has potential applications in predicting future river flow under different climate change scenarios and developing water resources management strategies that can ensure sustainable use of water resources. Other potential applications of the ANFIS model in river flow estimation include the development of real-time water management systems and the integration of the model with optimization techniques to develop efficient water allocation strategies. With the continued development and application of the ANFIS model, decision-makers can make more informed decisions regarding water resources management, leading to more efficient and sustainable water use in the Seyhan Basin and beyond.

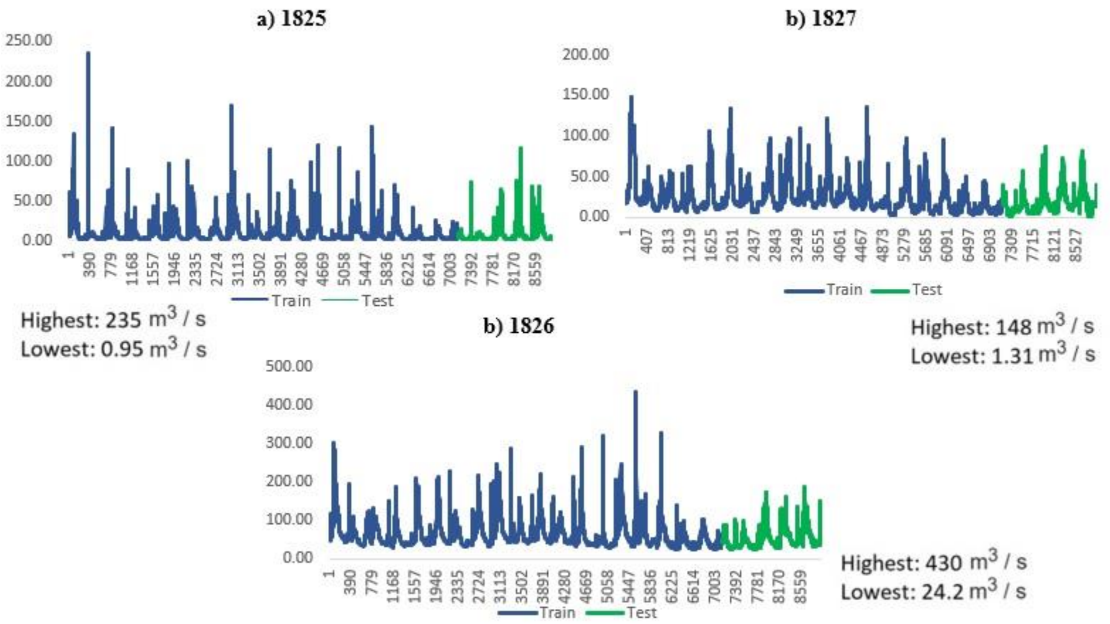

Figure 3. Daily streamflow for a) Egribuk (1825) and b) Ergenusagi (1826) c) Degirmenocagi (1827) stations

Author's Note

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References

[1] Gleick, Peter H. "Basic water requirements for human activities: meeting basic needs." Water international 21.2 (1996): 83-92.

[2] Storck, Pascal, et al. "Application of a GIS‐based distributed hydrology model for prediction of forest harvest effects on peak stream flow in the Pacific Northwest." Hydrological Processes 12.6 (1998): 889-904.

[3] Dibike, Y. B., and Solomatine D. P. (2001). River flow forecasting using artificial neural networks. Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere 26.1 1-7.

[4] Firat, M., and Turan M. E. (2010). Monthly river flow forecasting by an adaptive neuro-fuzzy inference system. Water and environment journal 24.2 116-125.

[5] Liu, Yuqiong, et al. (2008). Linking science with environmental decision making: Experiences from an integrated modeling approach to supporting sustainable water resources management. Environmental Modelling & Software 23.7: 846-858.

[6] Tezcan, Levent, et al. (2007). Assessment of climate change impacts on water resources of Seyhan River Basin. The final report of impact of the climate changes on the agricultural production system in the arid areas, Turkey.

[7] Behzad, M., et al. (2009). Generalization performance of support vector machines and neural networks in runoff modelling. Expert Systems with applications 36.4 7624-7629.

[8] ALTUNKAYNAK, A., and BASAKIN, E. A. (2018). River flow estimation using time series and comparison with different methods. Journal of Erzincan University Institute of Science and Technology 11.1 92-101.

[9] Dawood, Thikra, et al. "Artificial intelligence for the modeling of water pipes deterioration mechanisms." Automation in

[10] Firat, M. A. H. M. U. T. "Comparison of artificial intelligence techniques for river flow forecasting." Hydrology and Earth System Sciences 12.1 (2008): 123-139.

[11] Agarwal, Anil, et al. Integrated water resources management. Stockholm: Global water partnership, 2000.

[12] Sarma, A. K., et al., eds. (2016). Urban hydrology, watershed management and socio-economic aspects. Basel, Switzerland: Springer International Publishing.

[13] Bisht, D. CS. and Ashok J. (2011). Discharge modelling using adaptive neuro-fuzzy inference system. International Journal of Advanced Science and Technology 31.1 99-114.

[14] Mahabir, C., F. E. Hicks, and A. Robinson Fayek. (2003). Application of fuzzy logic to forecast seasonal runoff. Hydrological processes 17.18 3749-3762.

[15] Bizimana, H., Demir F., and Sonmez O. (2016). Modeling of Yuvacık Dam Water Level Changes with Fuzzy Logic. 4th International Symposium on Innovative Technologies in Engineering and Science (ISITES2016) 3-5 Nov 2016 Alanya/Antalya-Turkey.

[16] Altunkaynak, Abdusselam, Mehmet Ozger, and Mehmet Cakmakci. "Water consumption prediction of Istanbul city by using fuzzy logic approach." Water Resources Management 19.5 (2005): 641-654.

[17] Gunathilake, M. B., et al. (2021). Hydrological models and Artificial Neural Networks (ANNs) to simulate streamflow in a tropical catchment of Sri Lanka. Applied Computational Intelligence and Soft Computing 2021

[18] Riad, S., et al. (2004). Rainfall-runoff model using an artificial neural network approach." Mathematical and Computer Modelling 40.7-8 839-846.

[19] Samanataray, S., and A.Sahoo. (2021). A Comparative Study on Prediction of Monthly Streamflow Using Hybrid ANFIS-PSO Approaches. KSCE Journal of Civil Engineering 25.10 4032-4043.

[20] Niu, W., and Feng, Z. (2021). Evaluating the performances of several artificial intelligence methods in forecasting daily streamflow time series for sustainable water resources management. Sustainable Cities and Society 64 102562.

[21] Ozcalık, H., Uygur, A., (2003). Effective modeling of dynamic systems based on coherent neural-fuzzy network structure. KSU Journal of Science and Engineering, 6 (1): 36-46.

[22] Avcı, E., Akpolat, Z. H. (2002). Speed control of DC motors with an adaptive network-based fuzzy inference system. ELECO’2002 Electrical-Electronics-Computer Engineering Symposium, Bursa. 193-196.

[23] Guney, K., Sarıkaya, N., (2008). Calculation of patch radius of circular microstrip antennas with adaptive networks based on fuzzy logic system optimized by various algorithms. ELECO'2008 Electrical-Electronics-Computer Engineering

Symposium and Fair, Bursa.
[24] Cihan, P., Ozel, H., and Ozcan H. K. (2021). Modelling of atmospheric particulate matters via artificial intelligence methods. Environmental Monitoring and Assessment 193.5 1-15.
[25] Atik, I. (2022). A New CNN-Based Method for Short-Term Forecasting of Electrical Energy Consumption in the Covid-19 Period: The Case of Turkey. IEEE Access 10 22586-22598.
[26] Wang, Weijie, and Yanmin Lu. "Analysis of the mean absolute error (MAE) and the root mean square error (RMSE) in assessing rounding model." IOP conference series: materials science and engineering. Vol. 324. No. 1. IOP Publishing, 2018.
[27] Fujihara, Yoichi, et al. "Assessing the impacts of climate change on the water resources of the Seyhan River Basin in Turkey: Use of dynamically downscaled data for hydrologic simulations." Journal of Hydrology 353.1-2 (2008): 33-48.
[28] Tulun, S., et al. (2021). Adaptive neuro-fuzzy interference system modelling for chlorpyrifos removal with walnut shell biochar. Arabian Journal of Chemistry 14.12 103443.
[29] Olatunji, O. M., et al. (2022). Application of hybrid ANFIS-based non-linear regression modelling to predict the% oil yield from grape peels: Effect of process parameters and FIS generation techniques. Cleaner Engineering and Technology 6 100371.