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Rainfall-Runoff Modeling Using Artificial Neural Networks and HEC- HMS (Case Study: Catchment of Gharasoo)

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Abstract:* One of the methods used in various scientific fields which can simulate the complex process of rainfall – runoff is the artificial neural network model. The present study aims to review the efficiency of artificial neural network in the simulation of the rainfall – runoff process and to compare the results obtained from this investigation with that of HEC-HMS model in Gharasoo catchment area located in Ardebil province. The research data is comprised of daily rainfall and daily and momentary discharge the aforementioned river over a 30-year statistical period. According to research results, each of the methods used in this study have a considerable ability to estimate the rainfall – runoff amount of Gharasoo catchment area. Thus, with a sufficient amount of confidence, it can be argued that these methods can be of use for estimating the rainfall – runoff amount and they can be considered as good and efficient methods in this field. Among the models above, by taking into account the evaluation models, the second model of neural network (today's rainfall and yesterday's runoff) has been selected as the best model with the highest determination coefficient (0.88) and lowest error in the verification stage. In addition, the results obtained from comparing the distribution graphs of the three model indicate that the second graph of neural network has more attractive features than the other two models.

Keywords: **Artificial neural network, HEC-HMS Model, Rainfall – Runoff, Gharesoo Catchment Area.**

I. Introduction

Given that the number of existing water resources and the access to these resources is now more limited than ever, the importance of water management and planning is becoming more and more apparent. Predicting runoff is an active and unavoidable topic of discussion and research in the field of surface water hydrology and it still is an evident issue because of the existing uncertainty in hydrologic and meteorological parameters. Moreover, planning for exploiting groundwater and surface water, organizing the river and giving warnings about flood calls for estimating river discharge and catchment runoff. The rainfall – runoff process in a catchment area is quite a nonlinear and complex phenomenon. Since the effective parameters and factors in rainfall – runoff process has temporal and spatial changes and is quite uncertain, it always leads to error in the predictions. Therefore, it is quite difficult to model them because of the complexity of this process [1].

Recently, researchers have sought to develop statistical and hydrological methods for predicting rainfall – runoff hydrographs. Statistical and hydrological methods are based on time series and the law of conservation of mass, respectively. These two are also based on the assumption that the rainfall – runoff phenomenon is approximately linear; whereas the relationship between rainfall and runoff is nonlinear and complex. Therefore, using these methods won't be quite efficient. Hydrological methods are based on continuity and momentum which can only be solved with numerical methods and by using quite complex techniques which requires a great deal of information on one hand and sufficient amount of time for long calculations on the other one. These restrictions are eliminated to a large extent by using artificial neural networks [2].

Using the neural networks method has become significantly important as a modern approach in meteorological and hydrological studies and it has better and more desirable results when it comes to predicting the value of atmospheric variables such as rainfall and temperature than other methods including time series analysis [3]. Significant features of artificial neural networks which have made them widely applicable in different sciences are their ability in leaning, expanding, parallel processing, resistance and distribution of information (processing information as texts) [4]. Accessibility of consistent information regarding rainfall and other climatic parameters which can be used for predicting the rate of current is a good beginning for simulating the rainfall – runoff phenomenon [5].

HMS model and software use a series of simple relations, catchment losses and single hydrograph for reconstructing floods using rainfall data. In this model, a relationship of surface runoff is considered which acts based on rain gauge of the incoming rain. Additional rainfall is calculated after deduction of penetration share and a series of hydrologic reductions based on certain functions such as curve number (CN) in the soil conservation service (SCS). The obtained additional rainfall leads to single hydrograph through which the hydrograph of the output runoff of each subarea is extracted. In this model, in order to calculate rainfall losses and direct runoff, there are different methods for calculating rate of loss and direct runoff [4]. Given the special agricultural potentials of Gharasoo catchment area and its importance in creating jobs and supplying the amount of water needed by the local people, as well as programs for optimal usage of water resources, flood control, soil conservation and restoration of vegetation, it is crucial to estimate the amount of runoff caused by rainfall in the aforementioned catchment area. On one hand, by taking into consideration the daily increasing application of neural networks and the fact that their efficiency in the complex rainfall – runoff process has been confirmed, this study aims to predict the rainfall – runoff relationship using artificial

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neural network and HEC-HMS method in Gharasoo catchment area located in Ardebil province.

II. Material and Methodology

1.1. Introducing the studied region

Gharasoo catchment has an area of 14161 square kilometres and it's located in the longitude of 20' 46̎ to 41' 48̎ and latitude of 47' 39º to 17' 37º north and comprises 21% of the area of Ardabil and Eastern Azerbaijan province and it is considered to be a part of Aras catchment area and Caspian Sea. Gharasoo River is the outcome of the link between numerous rivers and has a length of 285 kilometres and an average annual discharge of about 554 million cubic meters. That's why it is the longest and wateriest river in Ardabil province [6].

1.2. Artificial neural network2e

Artificial neural network is in fact a simplified model of human brain. This network is a mathematical structure which has the ability of showing desirable nonlinear processes and compounds regarding the relationship between inputs and outputs of any system. This network is educated during the learning process using the available data and is used for prediction in the future. The neural network is comprised of neural cells called neurons and communication units called axons. Neurons of artificial neural network are in fact the simplified forms of biological neurons. Artificial neural network is comprised of these neurons. Although they have a higher speed than biological neurons, but they are not as capable. Figure 1 shows a simple form of a neural network model. As it can be seen in figure 1, each artificial neural network has three layers that are: input layer, output layer and hidden layer.

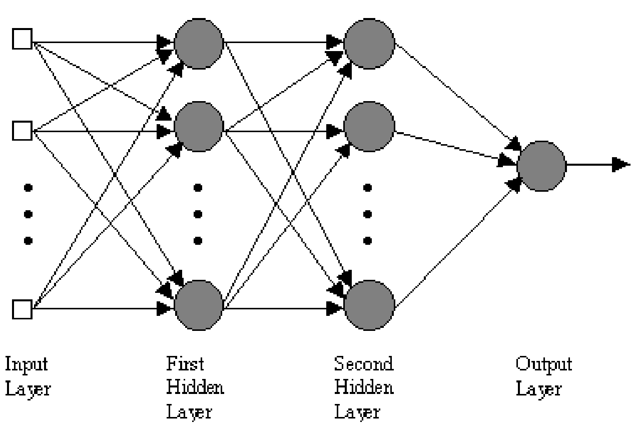

Figure 1 – simple scheme of neural network model

There are a number of neurons on each of these layers as processing units which are interconnected with weighted connections. These are operations that take place in each neuron: 1- neuron collects all the inputs that have reached the cell. 2- it deduces the threshold value of neuron. 3- it passes them through an activity function or driving function. 4- finally, the output of the neuron is obtained. Throughout some processes, the rate of error is minimized. In order to transfer the outputs of each layer to the next ones, the driving function is used. Sigmoid, linear and threshold functions are some of the driving functions. In general, artificial neural networks are divided into two groups which are: feedforward networks and feedback networks.

In the present study, the Levenberg-Marquardt (LM) algorithm has been used in order to identify the best method with the highest return for educating the network. This method is a changed version of newton classic algorithm which is used for finding a proper solution for problems that need minimization. This method considers an approximation for Hazen Matrix in changing weights just like Newton Method.

$$X_{k+1} = X_k - [J^T J + \mu]^1 J^T + e \quad (1)$$

In equation 1, x is the weight of neural networks and J is the Jacobins of the criterion matrix of the execution of the network which must be minimized, μ is the number that controls the education process and e is the residual error vector.

1.3. HEC-HMS software

This software is one of the HEC software which has been developed by the consulting engineers of America's Army. This software enables the user to simulate the rainfall – runoff process. The ability of analysing broad hydrological issues in a wide range of geographical levels with different topographies are the reasons why this software is used for modelling catchments and so on. This software is used for such things:

- Large river water supply studies
- Calculation of catchment runoffs
- Collection of surface waters in the cities
- Flood routing in rivers and reservoirs
- Designing the overflow of reservoirs
- Analysis of flood caused by breakage of the dam
- The effect of the process of urban planning in the hydrology of catchments
- Flood damages reduction studies

It has been attempted to make this software efficient for the user as well as ease of usage. Thus, graphic user interface (GUI) has been developed in association with this software.
Items such as the possibility of developing a report of the results of the analysis as graphs and tables, using a high range of hydrological relations, possibility of a connection between this software and GIS software, the possibility of calibrating parameters and optimizing the results are some of the considerable capabilities of the HEC-HMS software.

1.4. Research method

The method used in this research is a statistical and library method; in such a way that the data associated with daily rainfall of Doost Bigloo station is reviewed as input and daily and momentary discharge statistics of the same station are reviewed as the output in a 30-year statistical period. After collecting the information, data is extracted and developed that can be used for artificial neural networks and HEC-HMS model. At first, the rain gauge of multiple rainfall occurrences and runoff hydrographs was the basis of the work. Then, the artificial neural network with back propagation algorithm and sigmoid conversion function were used as the conversion function. In the present study, multilayer perceptron (MLP) network was used which is the

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most famous and well-known neural network in various scientific fields.

III. Results and Tables

1.5. Modeling with artificial neural network (ANN)

In the present study, for all models, the Levenberg-Marquardt (LM) algorithm and the FFBP method has been used and all of the results obtained from them have been presented in table 1. According to figure 2 and 3, the observed rainfall – runoff data and the data obtained from the second model of neural network is seen and the network is well-educated for modelling the rainfall – runoff phenomenon which is indicative of the high ability of neural network for patterning nonlinear phenomena using input and output data.

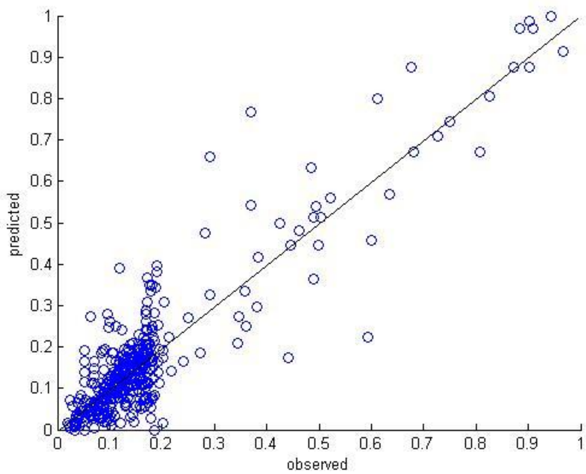

Figure 2 – scatter of the output plat of model 2 of artificial neural network and observed data – predicted data

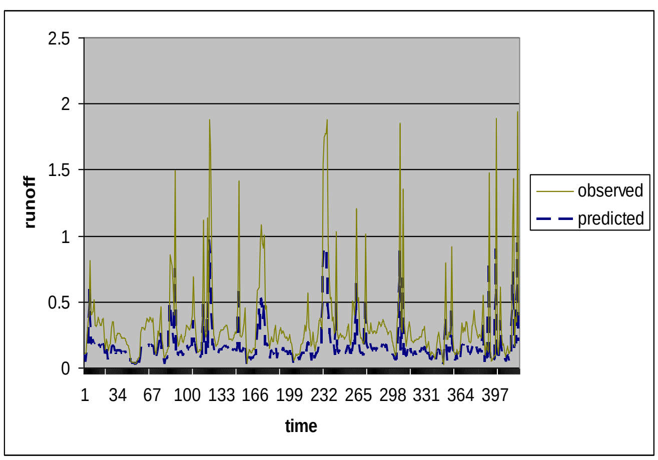

Figure 3 – output time series of artificial neural network and observed data – predicted data

According to figures 4 and 5, at the data verification stage, model number 2 is reviewed and the model functions well.

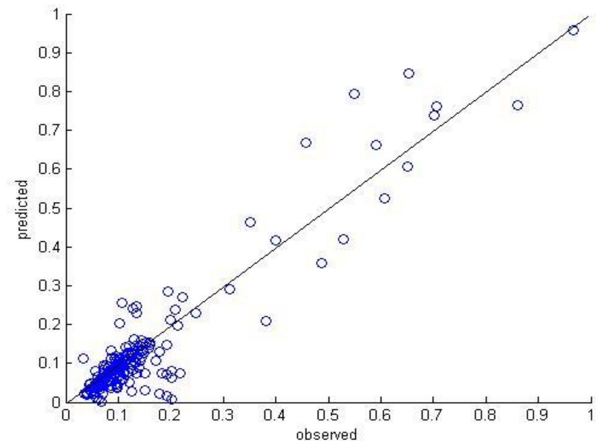

Figure 4 – scatter of the output plat of model 2 of artificial neural network and observed data –verification data

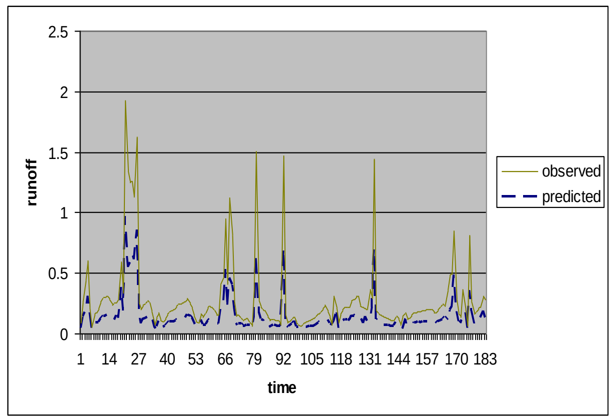

Figure 5 – output time series of artificial neural network and observed data – verification data

1.6. Simple regression

Simple regression is one of the common methods for estimating the rainfall – runoff of the studied stations. For this purpose, just like artificial networks, data has been divided into two groups of calibration and verification data. Calibration data has been used for the curve fitness and then the obtained regression relationship is applied to verification data and the verification correlation coefficient has been obtained and used for comparing the result of neural network. For this purpose, data has been divided into 4 parts. A curve is given to rainfall – runoff data of the fitness calibration stage so that a regression relationship would be obtained. Then, the rainfall data of the verification stage is placed in the obtained stage and in the following stage, the obtained result (calculated runoff) is compared with the runoff data of verification stage (observed runoff) so that the verification correlation coefficient would be obtained. Verification and calibration correlation coefficient of each mode can be seen in table 2. Curve graph and distribution graph of observed and calculated data have been presented in figures 6 and 7, respectively.

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Table 2 – result of regression

Model	Calibration correlation coefficient	Verification correlation coefficient
Regression	0.78	0.72

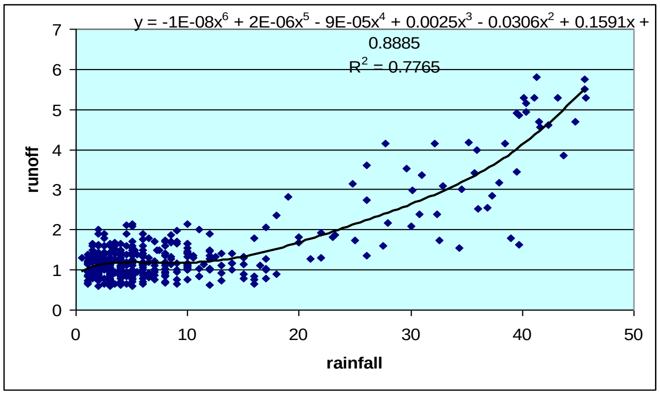

Figure 6 – simple regression – calibration stage

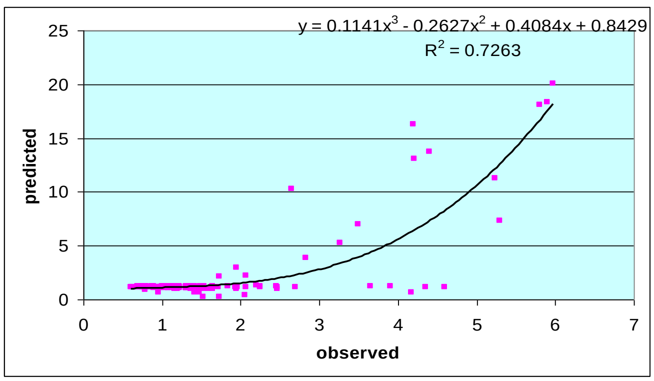

Figure 7 – distribution graph of observed and predicted data – verification stage

1.7. HEC-HMS software

In this software, the data of meteorological station of Meshkin Shahr was used as the input data and the data of Doost Bigloo station on Ghareou river was used as runoff. After completing model data and execution of the models, various data was created for various rainfalls. Then, the relationship between the obtained data and the observed data was evaluated.

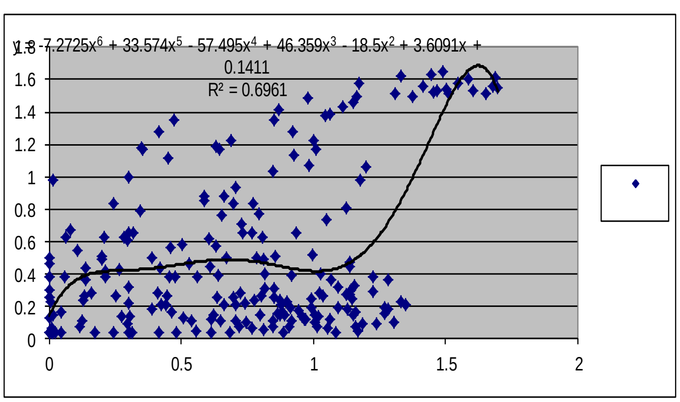

Figure (3-4): distribution software of HEC software data

Table 3 – comparing the results obtained from the three methods; artificial neural network, HEC and simple regression

Modelling	Model structure	Education determination coefficient	Verification determination coefficient
Neural network	Today's rainfall and yesterday's runoff	0.88	0.83
HEC			0.69
Simple regression	---	0.78	0.72

Given the calculations, each of the methods used in this research have a considerable ability to estimate the rainfall – runoff amount of Gharasoo catchment area. Thus, with a sufficient amount of confidence, it can be argued that these methods can be of use for estimating the rainfall – runoff amount and they can be considered as good and efficient methods in this field. Among the models above, by taking into account the evaluation models, the second model of neural network (today's rainfall and yesterday's runoff) has been selected as the best model with the highest determination coefficient (0.88) and lowest error in the verification stage. In addition, the results obtained from comparing the distribution graphs of the three model indicate that the second graph of neural network has more attractive features than the other two models.

IV. Conclusion

Neural network is more capable when it comes to estimating the amount of runoff and simulation of rainfall – runoff behavior than the other two methods used in this research (HEC and regression). The cause of such advantage can be the fact that neural network has been able to obtain a better response than the other methods by using numerical value of data through creating a nonlinear connection.

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