Statistical Assessment and Model for a River Flow under Variable Conditions

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Abstract Many articles emphasize the impact of dam reservoirs on the environment and river discharge. This aspect is mainly studied using the Indicators Hydrologic Alteration (IHA). Even if IHA is a comprehensive set of indicators, for documented decisions on the management of water resources (including the forecasting), knowledge on the statistical characteristics (as distribution, trend existence, stationarity etc.) are necessary. Therefore, in this article we focus on the study of statistical characteristics of the series of annual liquid flow of Buzău River (Romania), before and after building Siriu Dam. Mathematical models for the river discharge are built using Artificial Neural Networks.

Keywords: statistical analysis, modeling, GRNN

1. Introduction

The rivers' flow is marked by temporal oscillations, determined mainly by the precipitation regime, anthropogenic activities, the land use policy and the controlled storage or discharge of large volumes of water into/from the lakes. The frequency and volume of leakage extreme phases, especially floods, induces stress to the human communities.

Poff *et al*. (2010) explained the necessity of development of management standards for river at regional and global scales.

Heidari (2009) presents different alternatives for flood mitigation for two river floodplain areas, in Iran, Van Stokkom *et al*. (2005) took into account the climate change, for the study of different scenario of flood mitigation in Netherlands.

The meeting of Water Directors of the European Union, Norway, Switzerland and Candidate Countries held at Copenhagen, in November 2002, took an initiative on flood prediction, prevention and mitigation (EU2002), taking into account the effects of floods on the human life.

Since adaption to the flood risk is an important concern for the human life and activities, the scientists that proposed different models in relationship with the climate change (Wilby, 2012).

Among the structural measures adopted, dams have major impacts in streamflow regime, through changes in the duration, magnitude, frequency and rate of change of hydrologic events (Magilligan and Nislow, 2005), fluid flow regime and of channel beds, changes of water temperature, nutrient regimes, sediment transport biodiversity (Sakaris, 2013).

In this context, we study the statistical characteristics of the daily discharge of Buzau River (Romania), measured at Nehoiu hydrological station, before and after building Siriu Dam.

We also model the data series using Artificial Neural Networks.

2. Study area and data

The study area is a part of Buzău River's catchment (5264 km^2), situated in Romania, in the Curvature Carpathians, in a temperate - continental climate region. From the lack of space we shall not present details about this catchment. The reader can refer for this information to (Chendes, 2011; Minea and Barbulescu, 2014).

Our study series is formed using the daily mean flow data, collected at Nehoiu hydrometric station, situated on Buzău River, at the latitude of 45°25'29" and the longitude of 26°18'27, and it covers the period 01.01.1955 – 31.12.2010.

On 1st of Jan 1984 Siriu Dam has been put in operation, on Buzau River, on the upper part of Bizau chatchment. Therefore, changes in its flow regime have been registered, as proved by IHA analysis provided in (Minea and Barbulescu, 2014). Therefore, here we shall provide models for the two periods – before and after 1984.

In the extended article we shall also analyze the distribution of the flow series, in different seasons, before and after the same date, that will explain the influence of the season on the river flow.

3. Methodology

Firstly, the statistical characteristics of the series are analyzed. The mean, standard deviation, coefficient of variation have been computed for the entire series and the series before and after putting in function of Siriu Dam. The existence of an increasing/decreasing trend had been also assessed.

Modeling the daily discharge of Buzau River has been performed using GRNN, taking into account the high variability of the study series. The same method was successfully used in the studies of intermittent river flow by Cigizoglu (2005), for evapotranspiration modeling, by Kisi (2006) and pollutants' dissipation by Bărbulescu and Barbeş (2013, 2016).

The General Regression Neural Network (GRNN) is an artificial neural network architecture used for solving approximation problems. The network learn the data and the learnt knowledge is used to predict the future values. In mathematical terms, the learning process means finding a surface in a multidimensional space that provides a best fit to the training data.

The second step is using the found surface for the test data interpolation.

The structure of a GRNN is presented in Figure 2. It consists of:

- The input layer,
- The hidden layer, where the input data are transformed by applying a nonlinear transformation, φ,
- The output layer.

The series has been divided in a ratio of 90:10 for training and prediction.

For a deep insight on Generalized Neural Network design and functioning, the reader can refer to (Sprecht, 1991).

The model's quality has been estimated using the mean absolute prediction error (MAPE), defined in equation (1) and the normalized mean squared error (NMSE), defined in equation (2).

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{A_i - F_i}{A_i}\right|, \qquad (1)$$

$$NMSE = \frac{1}{n}\sum_{i=1}^{n}\frac{(A_i - F_i)^2}{\overline{A}\,\overline{F}}, \qquad (2)$$

where:

A_i is the i - th actual value of the studied series,

F_i - the i - th predicted value;

$\overline{A}$ - the mean value of the actual ones,

$\overline{F}$ - the mean value of the predicted ones,

n - the series length.

4. Results

Table 1 contains the values of the basic statistics (mean, standard deviation, coefficient of variation) for the entire series (S) and its sub-series before (S_1) and after (S_2) 1st of Jan 1984, when the Siriu dam has been put into operation.

Table 1. Values of basic statistics for the study series

series	mean	std.dev	coef.var
S	22.062	27.795	1.730
S1	20.800	24.441	1.730
S2	23.236	30.543	1.750

The highest average and standard deviation correspond to the series S2, but the variation coefficients are almost equal for all the series.

All the series are right skewed, the highest skewness being computed for S1 (7.14). The distribution are leptokurtic for all the series, the highest values of the kurtosis (128.85) being attached to S1.

The hypothesis that the series present monotonic trends has been rejected. The existence of a linear trend has been rejected as well. Since high maximum values has been registered without a periodicity, modeling the evolution of the flow using the GRNN appear to be a good idea.

The network has been trained on 90% of the data, using a Gaussian kernel. The remaining data have been used for validation. Figure 2 presents the

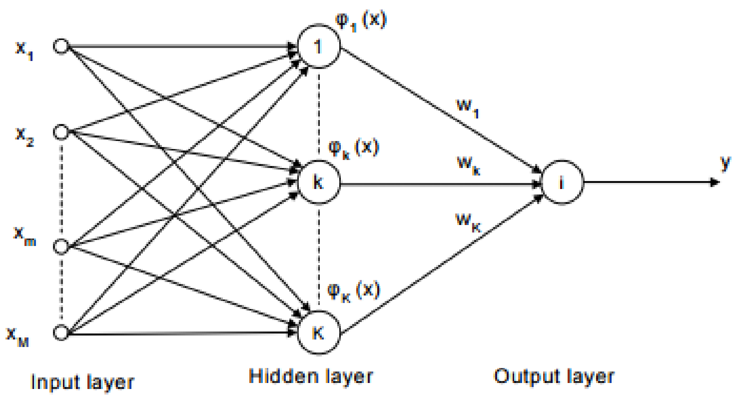

Figure 1. General Regression Neural Network

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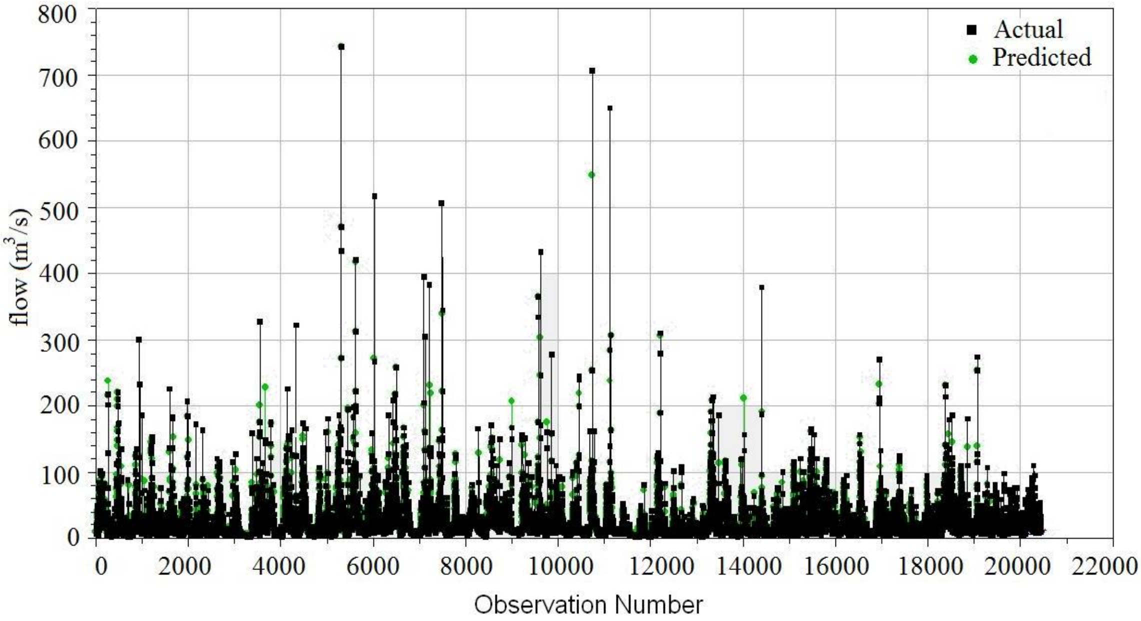

Figure 2. GRNN model for the series S

performances of the GRNN model on for the entire series.

The following values of the goodness of fit indicators have been obtained: NMSE= 0.256 and MAPE = 32.86 and the correlation between actual and predicted values = 0.821, proving a good fitting of the data series.

Similar performances are registered after performing the modeling for S1 and S2

Conclusion

The model for the entire series, with S_1 as training set and S_2 as validation doesn't perform very well, because of the change in the flow regime, after puting in exploitation of Siriu Dam. So, the the model couldn't capture well the change of the law that governs the process.

The models performed very well for S1 and S2, even if the series are very long, proveing that the choice of GRNN as a modeling tool is appropriate. From the luck of space we can't provide the details here, so they will be extensively presented in the extended article.

Comparing this result with those sased on the statistical analysis performed using IHA software (Minea and Barbulescu, 2014), we consider that the hydrologic alterations of daily mean discharge Buzău River, registered at Nehoiu hidrologucal was moderate in the period 1984 – 2010, after the inauguration of Siriu Dam.

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