Available online at www.sciencedirect.com
ScienceDirect
Mathematics and Computers in Simulation 75 (2007) 87–96
MATHEMATICS AND COMPUTERS IN SIMULATION
www.elsevier.com/locate/matcom

River flow estimation using adaptive neuro fuzzy inference system

Mahmut Firat *, Mahmud Güngör

Civil Engineering Department, Faculty of Engineering, Pamukkale University, 20017 Denizli, Turkey

Received 28 March 2006; received in revised form 20 September 2006; accepted 20 September 2006
Available online 24 October 2006

Abstract

Accurate estimation of River flow changes is a quite important problem for a wise and sustainable use. Such a problem is crucial to the works and decisions related to the water resources and management. In this study, an adaptive network-based fuzzy inference system (ANFIS) approach was used to construct a River flow forecasting system. In particular, the applicability of ANFIS as an estimation model for River flow was investigated. To illustrate the applicability and capability of the ANFIS, the River Great Menderes, located the west of Turkey and the most important water resource of Great Menderes Catchment's, was chosen as a case study area. The advantage of this method is that it uses the input–output data sets. Totally 5844 daily data sets collected in 1985–2000 years were used to estimate the River flow. The models having various input structures were constructed and the best structure was investigated. In addition four various training/testing data sets were constructed by cross validation methods and the best data set was investigated. The performance of the ANFIS models in training and testing sets were compared with the observations and also evaluated. The results indicated that the ANFIS can be applied successfully and provide high accuracy and reliability for River flow estimation.

Keywords: River flow estimation; Great Menderes River; ANN; Fuzzy logic; ANFIS

1. Introduction

The modeling techniques used in hydrological processes are quite important to provide the accurate and sustainable use of the water resources. In modeling of the hydrological processes, the measurement of natural phenomena is firstly necessary. In order to estimate the hydrological processes such as precipitation, runoff and change of water level by using existing methods, some parameters such as the physical properties of the watershed region and observed detail data are necessary. In the literature, there have been many approaches generally used to forecast River flow. Recently, artificial neural networks (ANN) have been accepted as an efficient alternative tool for modeling of complex hydrologic systems and widely used for prediction. Some specific applications of ANN to hydrology include modeling rainfall-runoff process [18], rainfall forecasting [1], River flow forecasting [6,9], sediment transport prediction [8], sediment concentration estimation [15], and reservoir operation [10]. Moreover, The ASCE Task Committee Reports (2000) did a comprehensive review of the applications of ANN in the hydrological forecasting context. Fuzzy logic method was first

* Corresponding author. Tel.: +90 258 213 4030; fax: +90 258 212 5548.
E-mail addresses: mfirat@pamukkale.edu.tr (M. Firat), mgungor@pamukkale.edu.tr (M. Güngör).

0378-4754/$32.00 © 2006 IMACS. Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.matcom.2006.09.003

Nomenclature

(a_i, b_i, c_i)	the nonlinear input parameters
A_i, B_i	the linguistic labels
c_{vx}	variation coefficient
c_{sx}	skewness coefficient
O_i^n	the node output
(p_i, q_i, r_i)	the antecedent parameter
Q_t	represents the River flow at time
$Q(t-n)$	the River flow at times $(t-n)$
s_x	standard deviation
$\bar{w}_i$	the ith node's output from the previous layer
x, y	the crisp inputs to the node i
$\bar{x}$	mean value of data set
x_{min}	minimum value of data set
x_{max}	maximum value of data set
z	the output to the node i

Greek letters

μ_{A_i}, μ_{B_i}	the membership functions

developed to explain the human thinking and decision system by Zadeh (1965). Several studies have been carried out using fuzzy logic in hydrology and water resources planning [4,7,12–14,16]. Recently, Adaptive neuro fuzzy inference system (ANFIS), which consists of the ANN and fuzzy logic methods, have been used for many application such as, database management, system design and planning/forecasting of the water resources [2,3,5].

The main purpose of this study is to present a novel neuro fuzzy approach, namely adaptive network-based fuzzy inference system (ANFIS) to estimate the River flow. To verify the application of this approach, the Great Menderes River catchment's location in the western part of Turkey was chosen as the case study area. Great Menderes Catchment's, located the west of Turkey, is one of the most important water resources in Turkey. In this region Great Menderes River has a quite significant effect on drinking water, irrigation, hydroelectric energy and recreation. Great Menderes River flow changes depend on various impacts such as climatic and hydro-meteorological variables of the basin, anthropogenic effects of human activities and water usage for agricultural and hydroelectric energy. In the face of these impacts, forecasts of future River flow can be of help in making efficient operating decisions of water demand, for a wise and sustainable use of the River. Great Menderes River was chosen simply because the variability of Great Menderes River flow cannot be solely determined by meteorological effects. Human knowledge and its operating decisions could significantly change the conditions of water resource within a short period in yearly basis. Therefore, a timely and/or reasonable prediction model should give information on climatologic chances and human decisions for all uses of this fresh water source. To exemplify this applicability and to demonstrate that the adaptive network fuzzy inference system has the ability to deal with human activities, we developed Seven ANFIS models for River flow forecasting with having various input structures. In the following, firstly, the main network structure of the ANFIS model and the parameters estimating algorithms are given. Then, a description of the study area, available data and the model construction are described. Lastly, the results of all ANFIS models are discussed.

2. Adaptive neural fuzzy inference system (ANFIS)

The fuzzy logic approach is based on the linguistic uncertain expression rather than numerical uncertainty. It is an artificial intelligence technique that has been used currently in hydrological processes. Since Zadeh (1965) proposed the fuzzy logic approach to describe complicated systems, it has become popular and been successfully used in various engineering problems, especially on control processes [2,3,12,13,16,17,19,20]. Nonetheless, the main problem with this approach is that there is no systematic procedure for a design of fuzzy controller. However, a neural network