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An evaluation of artificial neural network technique for the determination of infiltration model parameters

Ashu Jain *, Amit Kumar

Department of Civil Engineering, Indian Institute of Technology, Kanpur 208016, India

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Abstract

Infiltration is a key component in the rainfall runoff models employed for runoff prediction. Conventionally, the hydrologists have relied on classical optimization techniques for obtaining the parameters of various infiltration equations. Recently, artificial neural networks (ANNs) have been proposed as efficient tools for modelling and forecasting. This paper proposes the use of ANNs for calibrating infiltration equations. The ANN consists of rainfall and runoff as the inputs and the infiltration parameters as the outputs. Classical optimization techniques were also employed to determine flow hydrographs for comparison purposes. The performances of both the approaches were evaluated using a variety of standard statistical measures in terms of their ability to predict runoff. The results obtained in this study indicate that the ANN technique can be successfully employed for the purpose of calibration of infiltration equations. The regenerated and predicted storms indicate that the ANN models performed better than the classical techniques. It has been found that the ANNs are capable of performing very well in situations of limited data availability since the differences in the performances of the ANNs trained on partial information and the ANNs trained on the complete information was only marginal and the ANN trained on partial information consisted of a more compact architecture. A wide variety of standard statistical performance evaluation measures are needed to properly evaluate the performances of various ANN models rather than relying on a few global error statistics (such as RMSE and correlation coefficient) normally employed.

Keywords: Artificial neural networks; Model calibration; Optimization; Infiltration; Horton's infiltration model; Green-Ampt infiltration model

1. Introduction

When the rain water falls on the surface of the earth, some of it gets intercepted on the obstructions such as buildings, vegetation, etc., some of it gets trapped in the depressions on the surface of the earth, some of it evaporates back into the atmosphere, some of it seeps into the soil, and the remaining portion runs off towards oceans via streams and rivers in the form of what is known as runoff. The runoff in a river is measured and represented graphically by a curve showing volumetric runoff discharge (m^3/s) passing

* Corresponding author. Tel.: +91 512 2597411; fax: +91 512 2597395.
E-mail address: ashujain@iitk.ac.in (A. Jain).

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through a cross section in a river as a function of time. This type of graph between direct runoff in a river as a function of time is called a direct runoff hydrograph (DRH). The downward seepage of water through the soil surface is known as 'infiltration'. The infiltrated water percolates deep and joins what is called the groundwater. The groundwater can move horizontally for long distances over long periods of time to appear on the earth in the rivers in the form of base flow. The water can evaporate from the vegetation, soil moisture, and the surface of the earth in the form of evapotranspiration. This whole cycle of movement of water from the atmosphere to the oceans via different parts of the earth is called the rainfall-runoff process. The rainfall-runoff process is an extremely complex, non-linear, dynamic, and fragmented process that is affected by many physical factors. The involvement of many often-interrelated physiographic and climatic factors makes the rainfall-runoff process not only very complex to understand but also extremely difficult to model [1]. Researchers have devoted considerable attention in developing the mathematical models of the complex rainfall-runoff process using either deterministic/conceptual techniques or the systems theoretic techniques. The mathematical models of the rainfall-runoff process attempt to capture the characteristics of the underlying physical processes through the use of equations of mass, momentum, and energy in case of the deterministic models and their simplified forms in case of the conceptual models. The systems theoretic models do not consider the underlying physics of the rainfall-runoff process.

The mathematical models of the rainfall-runoff process are essential components in the planning, design, and operation of many water resources projects. For example, in order to plan for the distribution and allocation of the available water resources for different uses (such as drinking, irrigation, industrial, hydro-power, etc.) in a region, accurate estimates of the runoff forecasts in the area are needed. The design of major hydraulic structures such as dams, bridges etc. requires the knowledge of the rainfall-runoff process under extreme conditions. Runoff forecasts are also needed for the routine operation and management of various municipal water supply systems, and for the floods and drought management, etc. Many mathematical rainfall-runoff models of varying degree of sophistication and complexity have been proposed by various researchers and hydrologists in the past.

A key component of any mathematical model of the complex rainfall-runoff process is modelling of the infiltration process. Many models of the infiltration process are available such as Overton's model, Green-Ampt model, Horton's model, Holtan's model, and Kostikov method, etc. [2]. The Horton's and Green-Ampt's infiltration equations are the most commonly used methods, which provide estimates of the infiltration capacities as a function of time. The Horton's infiltration equation is a simplified version of the Richard's equation under simplified assumptions. The Richard's equation is the basic governing differential equation for the movement of water through unsaturated soil under unsteady conditions that is based on the laws of conservation of mass and momentum [3]. While the Horton's equation is developed from approximate solution of the Richard's equation, the Green-Ampt equation is based on a more approximate physical theory that has an exact analytical solution. Regardless of the choice for the infiltration model to be adopted in a rainfall-runoff model, the first step in its use is the determination of the parameters of the infiltration model. The infiltration parameters are normally determined through model calibration or field measurements. In using model calibration, classical non-linear optimization techniques can be adopted to determine the optimal set of infiltration parameters using known rainfall and runoff data. The performance of the rainfall-runoff models using infiltration parameters determined using classical optimization techniques are only reasonable. Recently, the soft computing techniques have become very popular especially in the last couple of decades. Artificial neural networks (ANNs) have been used as efficient tools of modelling and forecasting in all disciplines. The ANNs are inspired by the workings of a human brain, and have the capability to generalize from facts or the information presented to them. The ANNs have been used in a wide variety of areas including modelling of the complex rainfall-runoff process [4–12] but the efforts of using the ANNs for model calibration have been limited. It may be possible to improve the performance of the rainfall-runoff models by the use