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REVIEW

Artificial Neural Networks (ANNs) for flood forecasting at Dongola Station in the River Nile, Sudan

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Abstract Heavy seasonal rains cause the River Nile in Sudan to overflow and flood the surroundings areas. The floods destroy houses, crops, roads, and basic infrastructure, resulting in the displacement of people. This study aimed to forecast the River Nile flow at Dongola Station in Sudan using an Artificial Neural Network (ANN) as a modeling tool and validated the accuracy of the model against actual flow. The ANN model was formulated to simulate flows at a certain location in the river reach, based on flow at upstream locations. Different procedures were applied to predict flooding by the ANN. Readings from stations along the Blue Nile, White Nile, Main Nile, and River Atbara between 1965 and 2003 were used to predict the likelihood of flooding at Dongola Station. The analysis indicated that the ANN provides a reliable means of detecting the flood hazard in the River Nile.

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1. Introduction

Flooding leads to numerous hazards, with consequences including risk to human life, disturbance of transport and communication networks, damage to buildings and infrastructure, and the loss of agricultural crops. Therefore, prevention and protection policies are required that aim to reduce the vulnerability of people and public and private property. Many solutions for flood mitigation and prevention have been suggested however, a vast amount of data and knowledge are required about the causes and influencing factors of floods and their resulting damage.

Flood forecasting and prediction capabilities evolved slowly during the 1970s and 1980s. However, recent technological advances have had a major impact on forecasting methodologies. For instance, hydrological models use physical detection systems to forecast flood conditions based on predicted and/or measured parameters [9]. River flow models are used as components in actual flood forecasting schemes, where forecasts are required to issue warnings and to permit the evacuation of populations threatened by rising water levels. The basis of such forecasts is invariably observation and/or predictions of rainfall in the upper catchment area and/or river flows at upstream points along main rivers or tributaries. Forecasts about the discharge are obtained in real-time, by using the model to transform the input functions into a corresponding discharge function time.

At present, two main approaches are employed in hydrological forecasting. The first approach is based on mathematical modeling. It models the physical dynamics between the principal interacting components of the hydrological system. In general, a rainfall-runoff model is used to transform the point values of rainfall, evaporation, and flow data into hydrograph predictions by considering the spatial variation in storage capacity. A hydraulic channel flow routing model is then used to calculate flow. An example of this type of deterministic modeling is River Flow Forecasting (RFFS), which is a large-scale operational system currently employed by the Outer River Catchment [8]. The second approach is based on modeling the statistical relationship between the hydrologic input and output, without explicitly considering the relationships that exist among the involved physical processes. Examples of stochastic models used in hydrology are autoregressive moving average models (ARMA) [2] and the Markov method [13].

Models that provide a physically sound description about the hydrological processes that occur in a basin are expected to have significant advantages over purely empirical models. The main advantages of these models are their accuracy and the potential for performing comprehensive sensitivity analyses. The parameters of these models have direct physical interpretation, and their values might be established through field or laboratory investigations [9].

Stream flow modeling is a key tool in water resources management, early warning for flood hazards, and related impacts. Many advanced types of models exist, but they have been developed for a diverse range of climatic regions. Hence, these models must be adapted to the local situation of the Nile Basin prior to application. The ability to simulate river flow quickly and accurately is of crucial importance in flood forecasting operations. Hydrodynamic models provide a sound physical basis for this purpose, and have the capability of simulating a wide range of flow situations. However, these models require accurate river geometric data, which may not be available at many locations. It is also not possible to integrate observed data directly at desired locations to improve model results [9].

Thus, the Artificial Neural Network (ANN) provides a quick and flexible approach for data integration and model development. Therefore, this research used ANN models to forecast flooding along the River Nile. It is anticipated that this work will provide baseline information toward the establishment of a flood warning system for certain sections of the River Nile.

2. Study area

Sudan has been subjected to a number of major floods along the Nile and its tributaries, as well as along seasonally flowing riverbeds (termed wadis). Examples of major floods occurred in 1946, 1988, 1994, 1996, 1998, 1999, 2000, 2001, 2006, and 2007. Such floods normally cause the loss of life and massive scale damage to the agricultural sector and properties in the vicinity of the rivers.

The study area was located in Dongola town (Fig. 1). This area is located down-stream of the junction of the main tributaries to the Nile; including the White Nile, Blue Nile, and River Atbara. This region has suffered a severe flood in 1998.

3. Artificial neural networks

An alternative approach to flow forecasting has been developed in the recent years, which is based on the ANN [3]. Recent studies have reported that ANN may offer a promising alternative for the hydrological forecasting of stream flow [7]. The ANN is a computer program that is designed to model the human brain and its ability to learn tasks [4]. An ANN differs to other forms of computer intelligence in that it is not rule-based, as in an expert system. An ANN is trained to recognize and generalize the relationship between a set of inputs and outputs.

Early artificial neural networks were inspired by perceptions of how the human brain operates. In the recent years, ANN technological developments have made it more of an applied mathematical technique with some similarities to the human brain. ANNs retain two characteristics of the brain as primary features: the ability to (1) 'learn' and (2) generalize from limited information [5].

Both biological and artificial neural networks employ massive, interconnected simple processing elements, or neurons. The knowledge stored as the strength of the interconnecting