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Rain intensity forecast using Artificial Neural Networks in Athens, Greece

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ABSTRACT

The forecast of extreme weather events become imperative due to the emerging climate change and possible adverse effects in humans. The objective of this study is to construct predictive models in order to forecast rain intensity (mm/day) in Athens, Greece, using Artificial Neural Networks (ANN) models. The ANNs outcomes concern the projected mean, maximum and minimum monthly rain intensity for the next four consecutive months in Athens. The meteorological data used to estimate the rain intensity, were the monthly rain totals (mm) and the respective rain days, which were acquired from the National Observatory of Athens, for a 111-year period (1899–2009). The results of the developed and applied ANN models showed a fairly reliable forecast of the rain intensity for the next four months. For the evaluation of the results and the ability of the developed prognostic models, appropriate statistical indices were taken into consideration. In general, the predicted rain intensity compared with the corresponding observed one seemed to be in a very good agreement at a statistical significance level of $p<0.01$.

1. Introduction

The enhancement of the greenhouse effect, caused by continuous increasing anthropogenic emissions of greenhouse gases into the atmosphere, is expected to induce severity of damaging climate change. Solomon et al. (2009) showed that climate change, which takes place due to increases in carbon dioxide concentration, is largely irreversible for 1000 years after emissions stop. The extreme events are likely to be more often in the future (IPCC, 2007). During the last decades, there was a lot of discussion concerning the impacts of climate change in extreme events, such as heavy rain, resulting in significant flooding in urban environments, or in combination with tornado outbreak causing damage in properties (Mateo et al., 2009; Nastos and Matsangouras, 2010). Besides, recent studies have concluded that, heavy storms of convective nature in the developed mega-cities could be attributed to the urban heat island (UHI) (Paliatsos et al., 2005; Nastos and Zerefos, 2007; 2008; Philandras et al., 2010a). On the other hand, water scarcity and decreasing run off appear as adverse consequences of climatic change in vulnerable regions such as the Mediterranean region (IPCC, 2007). Nastos and Zerefos (2009) concluded that the temporal variability of consecutive wet days shows statistically significant (confidence level of 95%) negative trends, mainly in the western region of Greece, characterized by large orographic precipitation amounts (Metaxas et al., 1999). Insignificant positive trends for consecutive dry days appear almost all over the country with emphasis in the southeastern region.

Rainfall is one of the most complex and difficult elements of the hydrology cycle to understand and to model due to the complexity of the atmospheric processes that generate rainfall and the tremendous range of variation over a wide range of scales both in space and time (French et al., 1992). Sokol and Bližňák (2009) analyzed data in cases of short duration

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heavy rainfall during the summer at the Czech Republic. They found that there was a relatively high incidence of such cases in southern and central Czech Republic, during the years 2002–2007. Federico et al. (2009) in their work announced the first exploratory analysis and results for the precipitation in the peninsula of Calabria in southern Italy, for the period 1978–2007. It was found that although the annual rainfall is greater on the west side of the peninsula, more intense precipitation is affecting mainly the east side, which is exposed to strong positive and strong storms. Thus, accurate rainfall forecasting is one of the greatest challenges in operational hydrology, despite many advances in weather forecasting in recent decades (Gwangseob and Ana, 2001).

For these reasons, any attempt to predict such extreme precipitation events is very important in order to protect population, infrastructure and prevent disasters due to flooding with major economic impacts. Several studies on the prediction of rainfall have been carried out during the last years. So far, long-term climate prediction using numerical models demonstrate not a useful performance (Zwiers and Von Storch, 2004). During the last decade, ANN models have been applied to rainfall forecasting (Bodri and Cermak, 2000; Luck et al., 2000; Silverman and Dracup, 2000; Sakellariou and Kambezidis, 2004; Cigizoglou and Alp, 2004). More specifically, Sahai et al. (2000) used ANN models in order to forecast total precipitation during the summer monsoon period across India. As input data, they used rainfall recorded from 306 stations throughout India during the months of June-July-August and September for the time period 1871–1994. The prediction was based on the knowledge of the total rainfall amount for four consecutive months (June-September) of the previous four years. The results showed good forecast estimates of rainfall with Root Mean Square Error (RMSE) equal to 54.2 mm. The quite satisfactory results are primarily due to the frequency of occurrence of heavy rainfall during the summer monsoon in India as well as the large number of data used for ANN models training, which makes them able to obtain a fairly good knowledge-experience of the phenomenon. Freiwan and Cigizoglu (2005) developed a number of different multilayer perceptron ANN models that were trained with the method of back-propagation algorithm in order to predict rainfall for the next month. As input data, they used the rainfall of the previous two months and a periodic component for each month. The rainfall prediction concerned the airport area in Amman, Jordan, during the period 1924–2000. The predictions for the next month, showed a satisfactory reliability: for instance, the coefficient of determination (R^2) between true and predicted rainfall amounts was about 0.112 and 0.466, while the RMSE was between 25.8 and 33.6 mm, depending on the used ANN model type. Iseri et al. (2005) created different types of predictive models, including ANN models, in order to predict the rainfall in the Fukuoka-Japan. Prediction was based on data recorded during the time period 1901–1997. Their prediction concerned the monthly amount of rainfall in August. As input data for ANN models training, they used the change of the sea surface temperature and three different climate indices regarding the previous three to twelve months before the predicted month. Between all the models, ANN models showed the best forecasting ability with R^2 values between 0.147 and 0.366. Mar and Naing (2008) used ANN models for monthly rainfall amount prediction in Yangon (Myanmar-South East Asia), taking as input data monthly values of rainfall for the period 1970–2006. The applied ANNs resulted in RMSE between 9.9 and 22.9 mm, depending on the used ANN model type.

Therefore, there are many relevant studies on the prediction of precipitation so far, but these are not enough for long-term prognosis i.e. for four consecutive months and especially for rain intensity. In the present study, the efficiency of applying ANN models in forecasting long term rain intensity in the greater Athens area (GAA) is demonstrated and analysed.

2. Data and methodology

2.1. Artificial Neural Networks

The ANN models are inspired by the structure and function of the human brain. Neurons are a key component of the brain. They are essentially nerve cells that create a dense network between them. Typical ANN models use very simplified models of neurons, which only very rough characteristics of human neurons may maintain (Hecht-Nielsen, 1989).

The first ANN models occurred during the decades of 1940 and 1950 with the basic artificial neuron model of McCulloch and Pitts (1943) and the first ANN training algorithm of Rosenblatt (1958). In the following decades there was a decline in the use of the ANNs because of high computing power required for their use, which was not readily available from the computers of that era. The recession was followed by regeneration of ANNs with the introduction of the ANN models of Hopfield (1982, 1987). These are known as Multi-Layer Perceptron (MLP) ANN models, which along with the training algorithm of back-propagation, proposed by Werbos (1974), caused the interest of the scientific community again. This interest coupled with the rapid growth of parallel computing capabilities.

The structure of a feed forward MLP artificial neural network can be represented as in Fig. 1. The first layer is the input layer with one or more neurons, depending on the number of necessary input data for the proper training of an ANN model. One or more hidden layers follow with a number of artificial neurons that are necessary for the processing of the input signals. Each neuron of the hidden layer communicates with all the neurons of the next hidden layer, if any, having in each connection a typical weight factor (Fig. 1). Finally, the signal reaches the output layer, where the output value from the ANN is compared with the target value and error is estimated. Thus, the values of weight factors are appropriately amended and the training cycle is repeated until the error is acceptable, depending on the application.

In general, ANN model applications can be applied in a lot of different disciplines, such as air pollution, urban bioclimatology, water quality, rainfall prediction, classification of rainfall prediction, climate analysis etc. (Zwick and Canarelli, 1996; Melas et al., 2000; Michaelides et al., 2001; Papanastasiou et al., 2007; Sengorur et al., 2006; Diamantopoulou et al., 2007; Moustris et al., 2009, 2010).