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Air pollution modelling with the aid of computational intelligence methods in Thessaloniki, Greece

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Abstract

Air pollution modelling is necessary for simulating the atmospheric environment system in terms of pollutants and meteorological conditions, taking into account the nonlinearities of the underlying phenomena. In the current paper, Artificial Neural Networks are used for modelling ozone, and for simulating its behaviour in relation to other atmospheric parameters of interest, for the city of Thessaloniki, Greece. This behaviour is also investigated with the aid of Principal Component Analysis (PCA). Results suggest the operational capabilities of such models, and the research potential in the application of computational intelligence methods for the environmental sector.

Keywords: Artificial Neural Networks; Principal component analysis; Air pollution modelling

1. Introduction

The urban atmosphere's quality is regulated by a number of EU directives against high air pollution concentration levels that aim to protect human health and to minimise environmental degradation. These directives define the pollutants to be addressed and the related criteria to be applied for assessing atmospheric quality, while in addition they specify the methods to be used for the assessment. One of these methods is air pollution modelling for the simulation of the atmospheric environment system, towards a twofold goal: increased domain knowledge and reliable forecasting. The latter is to be used for both strategic planning and environmental decision making (and thus has a long term nature), or for short term warning at a citizen and administration level. On this basis, computational methods that allow for domain modelling and quality of life parameter forecasting are becoming more and more important.

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Air pollution concentration levels are a combination of pollutant emissions, chemical and physical processes in the atmosphere, and earth surface properties and geometry. For the purposes of modelling and simulation, the urban atmosphere may be considered as a system that under varying meteorological conditions (i.e. "input"), will "respond" by producing different sets of output, i.e. concentration levels of the pollutants of interest [21]. Yet, one of the factors of complicity concerning the simulation of the urban atmospheric quality is related to the nonlinear behaviour of secondary pollutants, i.e. pollutants that are not directly emitted but are rather formed within the atmosphere as a result of chemical reactions. Such a substance is ozone (O_3), a typical photochemical pollutant created from the reaction of hydrocarbons and nitrogen oxides in the presence of sunlight that acts as a catalyst.

The need for modelling and forecasting of ozone concentrations has been raised due to the mandates of the EU environmental legislation like the air quality (AQ) framework directive (1996/62/EC) and the so called ozone directive (2002/3/EC). As a first step towards environmental knowledge modelling, it is of primary interest to identify the major parameters influencing ozone formation in the vicinity of human activities and everyday life. Principal component analysis (PCA) is a proper method for multidimensional data analysis and may support the investigation of "hidden" relationships between the pollutant examined and the factors that favour its formation. The outcomes of PCA analysis are also used as driving parameters for ozone modelling, with the aim to simulate its behaviour and thus produce reliable forecasts that may be used for operational air quality management. Such modelling requires methods that are capable of adapting to the requirements of the knowledge domain of interest, while learning from changes within the system modelled. Artificial Neural Networks (ANNs) are selected for this purpose.

ANNs are computational data structures that try to mimic the biological processes of the human brain and nervous system. ANN models have been widely used for modelling air pollutant concentrations with the aim to forecast them. Due to the fact that ANNs can capture nonlinear relationships, their performance is superior when compared to statistical methods such as multiple linear regression [2,6,10,12,29], while it is supported from the usage, in parallel, of PCA [26].

The aim of this paper is to examine the relation between ozone (O_3), nitrogen dioxide (NO_2) and meteorological variables for the purposes of domain knowledge investigation and modelling, and to develop on this basis ANN models that are capable of simulating the ozone formation phenomenon, and then evaluate their operational forecasting capabilities with the air of appropriate statistical indexes.

2. Area of interest and data used

Thessaloniki is the second largest city of Greece, where air emissions come mainly from traffic, while formation and transportation of pollutants is heavily influenced by the local meteorological and topographic characteristics. Focusing on traffic, it should be noted that recent studies in Thessaloniki have estimated that travel demand has climbed up almost 70% over the period 1988–1998. In addition, the improvement of fuel quality and the renewal of the vehicle fleet during the last decade contributed significantly to the decreasing trend of some primary air pollutants like CO (carbon monoxide), SO_2 (sulphur dioxide), and Pb (lead), but they did not similarly influence the trend of PM10 (suspended particulates), NO_2 (nitrogen dioxide) and O_3 (ozone) [16,17].

Data used in the present paper were obtained from the monitoring stations located in Kalamaria (urban station in the east side of the city), and Eleftherio-Kordelio (urban station in the west side of the city). The selection of the stations emphasized on locations that are not in the city centre, as the latter is mostly influenced by traffic, this resulting in ozone depletion. On the other hand, ozone is known to accumulate at the city edges, and then to travel with the aid of air movement over urban and rural areas alike.

The data set comprised of hourly observations for the time period of 2001–2003 for Eleftherio-Kordelio, and for the period of 2001–2004 for Kalamaria. The atmospheric parameters monitored included hourly values of ozone (O_3) and nitrogen dioxide (NO_2) concentrations, temperature, humidity, wind speed and wind direction. For the latter a transformation was applied for replacing the cyclic nature of the parameter with a linear one, as follows:

$$\sin \mathrm{WD} = \frac{\sin(2\pi(v - \min(v)))}{\max(v) - \min(v)}, \quad \cos \mathrm{WD} = \frac{\cos(2\pi(v - \min(v)))}{\max(v) - \min(v)}, \quad v \in [0, 360] \tag{1}$$