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ESTIMATION OF WINTER SEASON SULPHUR DIOXIDE CONCENTRATIONS WITH AN ARTIFICIAL NEURAL NETWORK MODEL

Mehmet Aktan
Necmettin Erbakan University

Ahmet Reha Botsali
Necmettin Erbakan University

Abstract: An understanding of pollution sources and emissions, and their interactions with terrain and the atmosphere is the most important step in developing appropriate air pollution management plans and action strategies. In this study, relationship between sulphur dioxide (SO_2) concentration and meteorological parameters such as wind direction, wind speed, temperature, air pressure, precipitation, sunshine amount, sunshine duration, and relative humidity is modeled by using winter season data. Since the relation between SO_2 concentrations and many meteorological parameters is complex, an artificial neural network (ANN) model is developed to predict the SO_2 levels. Wind direction is modeled as the combination of two variables, which enables to appropriately define the wind direction. The ANN model exhibited an R–squared value of 0.85

Keywords: Air pollution, artificial neural network, estimation

Introduction

Emissions resulting from domestic heating may become important sources of pollution in cities with cold winter seasons. Air quality in cities is correlated with a combination of various meteorological factors. Sulphur dioxide (SO_2) is an important air pollutant that has been closely associated with urban air quality problems during winters in Erzurum, like many cities in Turkey. Given a set of air monitoring observations, discovering the relationship among variables is possible by using techniques such as neural networks and regression models. Such models have low development costs and resource requirements (Szepesi, 1989; Aktan, 2008).

There are numerous studies in literature for statistically determining the effects of meteorological parameters on SO_2 concentration. SO_2 concentrations were related with meteorological factors and some policies were proposed for Shangai by Chao (1990). Tirabassi et al. (1991) found that there is a close relationship between wind speed and SO_2 and particle concentrations in the coastal city of Ravenna. Cuhadaroglu and Demirci (1997) used multiple linear regression analysis to assess the relation of pollutant concentrations with several meteorological factors in Trabzon city. In the study presented by Bridgman et al. (2002), relationship of SO_2 concentrations obtained from six major meteorological parameters was investigated. Yildirim and Bayramoglu (2006) proposed an adaptive neuro-fuzzy logic method to estimate the impact of meteorological factors on SO_2 (Aktan, 2008).

This study models SO_2 concentration in Erzurum city for winter seasons using ten meteorological parameters (wind speed, wind direction, temperature, pressure, precipitation, relative humidity, sunshine duration, and sunshine amount, and SO2 concentrations of previous two days) by developing an artificial neural network. Wind direction is modeled as a combination of two variables. Contribution of SO_2 concentrations in the previous two days to the current SO_2 concentration is introduced to the model with an autoregressive structure using data between years 1996 and 2006 (Aktan, 2008).

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*Corresponding author: Gulsah Karaca- E-mail: maktan@konya.edu.tr

Methods

Erzurum city, which is located in the eastern part of Turkey, is situated on a plateau surrounded by high mountains to the east, north and south. Height of this plateau is nearly 1900 meters above the sea level. Population is around 400,000 and it has land area of 52.80 km^2. With an annual average temperature of 6 ºC, Erzurum is one of the coldest cities in Turkey. While the average wind speed is above 3 m/s during summer season, it is 2.5 m/s in winter season, and dominant wind direction is WSW-ENE (Aktan, 2008).

Measurement of SO_2 and its evaluation

Sulphur dioxide (SO_2) measurements were taken by Environmental Pollution Research Center at six different stations that are located considering the topography of the city. Daily meteorological data were provided by Meteorology Department of Erzurum (Aktan, 2008).

Artificial Neural Network Model

An artificial neural network (ANN) makes possible to define the relation (linear or nonlinear) among a number of variables without knowledge of their cause-effect mechanisms. They can act as universal approximations of nonlinear functions (Hornik et al., 1989) and consequently, can be used in assessing the dynamics of complex non-linear systems. In this study, an artificial neural network model is developed for predicting the SO_2 concentration in Erzurum for winter seasons using 1033 records. Alyuda Neurointelligence software was used to develop and train the ANN model (Aktan, 2008).

In this study, a linear transfer function was used in input neurons and the log-sigmoid function in the neurons located in hidden and output layers. The error function was sum of squares. Networks were trained using Levenberg-Marquardt algorithm. Variables east (*e*) and north (*n*) were defined in order to include wind direction factor in the ANN model. Variable *e* changes from −1 to 1 as the wind direction changes from west to east. Variable *n* changes from −1 to 1 as the wind direction changes from south to north. Fig. 1 lists the wind directions and corresponding *e* and *n* values in the ANN model. Values in the parenthesis show the *e* and *n* values, respectively. Previous studies model wind direction as nominal values or in degrees, and such models cannot appropriately differentiate wind directions that are close to each other such as 0 and 338 degrees, or apart from each other such as 0 and 180 degrees on a 360 degrees scale. By using these two variables (*e* and *n*), all wind directions can logically be differentiated by the ANN model (Aktan, 2008).

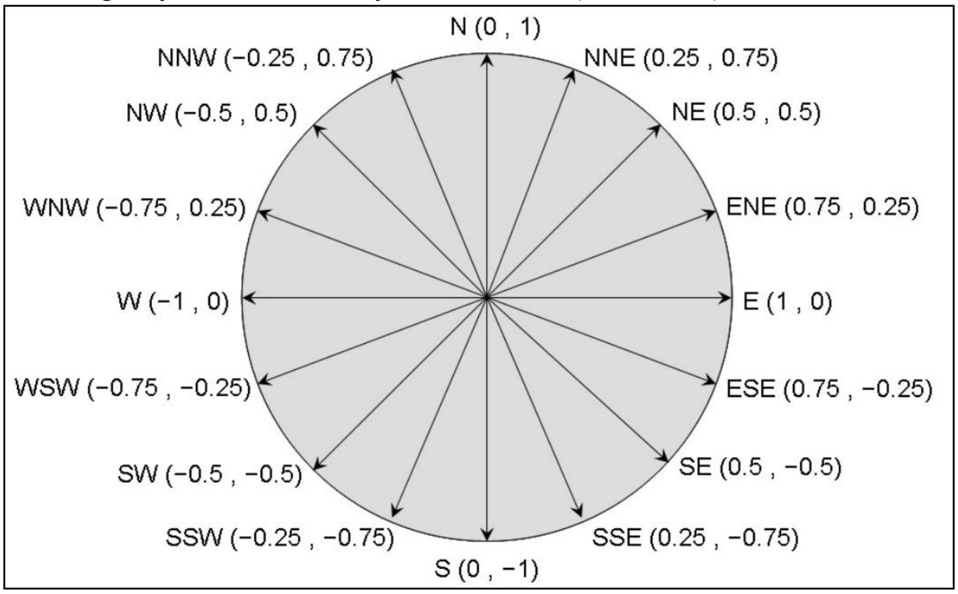

Figure 1. Wind directions and corresponding (*e*, *n*) values

Input data were randomly partitioned into training (68.1% of the records), validation (15.95% of the records) and test (15.95% of the records) sets that contained 703, 165, and 165 records, respectively. Training set is used for neural network training, i.e., for adjustment of network weights. Validation set is used to tune network topology or network parameters other than weights. Test set is used to test how well the neural network will perform on new data (Aktan, 2008).

Results and Findings

One and two hidden layer network architectures up to 15 neurons in the hidden layers were investigated, and the network with minimum mean absolute error on the test set was selected. Minimum mean absolute network error on the test set was obtained with the (2-5) architecture, which has two neurons in the first hidden layer, and five neurons in the second hidden layer (Aktan, 2008).

Fig. 2 shows the selected network architecture which has eleven neurons in the input layer, two neurons in the first hidden layer, five neurons in the second hidden layer, and one neuron in the output layer. Statistical analysis of the data shows that correlation of SO_2 levels for one day difference (between $SO_{2,t}$ and $SO_{2,t-1}$) is 0.82, and two-day difference (between $SO_{2,t}$ and $SO_{2,t-2}$) is 0.60. These correlation coefficients indicate that a SO_2 reading is strongly related with SO_2 levels in the past two days (Aktan, 2008). Therefore, SO_2 is defined with a mixed autoregressive model as a function of eleven variables as in Eq. (1):

$$SO_{2,t} = f\,(SO_{2,t-1}, SO_{2,t-2}, temp, w, e, n, p, h, pr, sa, sd) \qquad (1)$$

Variables in the model are temperature (*temp*), wind speed (*w*), east (*e*), north (*n*), air pressure (*p*), humidity (*h*), precipitation (*pr*), sunshine amount (*sa*), sunshine duration (*sd*), SO_2 concentration of the previous day ($SO_{2,t-1}$), and SO_2 concentration two days ago ($SO_{2,t-2}$) (Aktan, 2008).

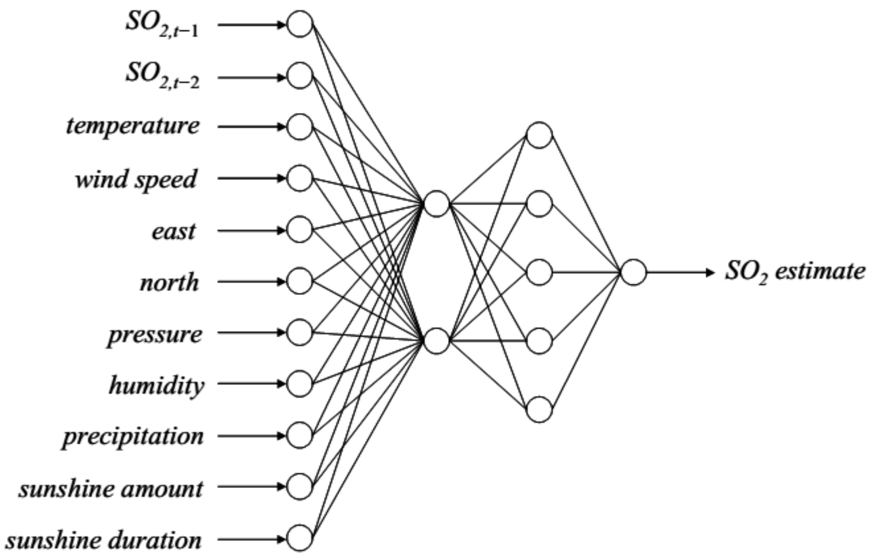

Figure 2. Selected artificial neural network architecture

ANN model presents a correlation coefficient of 0.92 between the actual and the predicted SO_2 concentrations. *R*-squared value of the ANN model is 0.85. The *R*-squared value is the proportion of the total variability in the dependent variable (SO_2) that is accounted for by the model (Aktan, 2008).

Conclusion

Apparent air pollution has been a problem in Erzurum during winter seasons. High SO_2 concentrations are mainly due to low temperature and low wind speeds during winter seasons. An understanding of pollution sources and emissions, and their interactions with terrain and the atmosphere is the most important step in developing appropriate air pollution management plans and action strategies. Without this type of knowledge, incorrect decision making related to air pollution management is possible, creating wasted resources and undesirable results (Bridgman et al., 2002).

Neural networks can be used in assessing the dynamics of complex non-linear systems. Since the relation between SO2 concentrations and meteorological parameters is complex, an artificial neural network model was developed to predict the SO_2 levels. Wind direction was modeled as the combination of two variables, which enables to appropriately define the wind direction. The model exhibited a large *R*-squared value of 0.85, which means that the model has a good fit and prediction performance. Furthermore, correlation of SO_2 levels for one day difference (between $SO_{2,t}$ and $SO_{2,t-1}$) is 0.82, and two-day difference (between $SO_{2,t}$ and $SO_{2,t-2}$) is 0.60. This relation was introduced to the model by using an autoregressive structure in the ANN.

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