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Short-run prediction of suspended particles' pollution; a neural network application: Case study: Ahvaz city, Iran

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Abstract

In order to take proper policies for pollution alleviation, it is necessary to forecast the trend of air pollution. Based on reports of World Health Organization, Ahvaz, a city located in south of Iran, is the most polluted city in the world. In this study, we employ daily time series data of maximum suspended PM10, a 10-micron suspended particle causing intensive air pollution, in order to predict pollution volume of PM10 in the air of Ahvaz city. For which, we used LMS learning algorithm to design a lag network by which concentration of PM10 is predicted for October of 2011. The results indicate that the average amount of the pollutant in this month is 482 microgram per square meter, and the maximum and minimum concentrations are respectively 722 and 319 microgram per square meter which are many times more than the maximum amount, 20 microgram per square meter, which is recognized by WHO. To control this phenomenon undoubtedly demands attention and cooperation of neighboring countries.

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Introduction

Because of its important effect on the equilibrium of bio elements, environment plays a vital role in human life and development. Nowadays, environment is endangered due to misappropriate exploitation of natural resources. As one of the most important environmental problems, air pollution is known as a serious permanent threat for society health. Air pollution is the introduction of chemicals, particulate matter, or biological materials that cause harm or discomfort to humans or other living organisms, or cause damage to the natural environment or built environment, into the atmosphere (WHO, 2005). Potential effects of air pollution on human health include increase of mortality rate, increase in hospital and increase of changes in body physiologic function, specially respiratory and cardiovascular function. Major sources of air pollution include natural and artificial sources. However, in another major classification, regarding the form of substance, air pollutants are categorized as: Particles: it includes liquid and solid particles like dust, smoke, volatile ash, spray, etc. Gases: sulfur oxides, azot oxides, hydrocarbons, and oxidants (Harrison, 1998). Nitrogen oxides, especially NO_2, sulphur oxides, especially SO_2, hydrocarbons, CO, CO_2 and suspended particles are the most common air pollutants, among which suspended particles is the most harmful pollutant in the world, based on Environment Plan of UN (WHO, 1992). Suspended particles are one of the six most hazardous pollutants which hurt human health intensively. They could spread as suspended particles (liquid or solid) in the phase of gas. One of the most important particles which cause extreme pollution is PM_{10} that refers to the particles with a diameter of 10 micron or less which are formed in the atmosphere when nitrogen oxide and sulfur dioxide are combined (Lippmann, 1998) Considering the highly destructive effects of suspended pollutants, biological measures could be taken to prevent and control dust storms. One of such approaches is growing plants in desert areas. Another is setting biological barriers such as woods to prevent the spread of the desert (United Nation Environment Program, 2005). Due to destructive damages of air pollution, forecasting the amount of pollutants is nowadays of interest of researchers in order to suggest accurate information policy makers for their decision making. Some of studies related to prediction of air pollution are as follows: Taking advantage of neural system, Ibarra-Berastegi, *et al* (2008) developed software, called BISTAPOF (Bilbao Short-Term Air Pollution Forecast) for prediction of air pollution in Bilbao. They used three networks; namely, MLP, RBF, and GRNN to make predictions. Brunelli *et al* (2007) employed neural network technique to predict the maximum daily pollution concentration of SO_2, NO_2, O_2, PM_{10} and CO in urban areas in Italy. Perez and Reyes (2006) developed an integrated artificial neural network model to forecast the maxima of 24 h average of PM_{10} concentrations 1 day in advance and applied it to the case of five monitoring stations in the city of Santiago, Chile. Gardner and Dorling (1998) have described the usefulness of a multilayer neural network (a nonlinear model) for applications in atmospheric sciences. Bodagpour and Charkhestani (1999) employed artificial neural network to predict concentration of air pollutants in Tehran. The results revealed that the prediction of neural network was more precise than of the linear regression. In their study, Aliyari *et al.* (2008) predicted air pollution data by using Multi Layer Percepteron, Time Delay Line, Gamma and ANFIS by gradient free learning methods. Their analysis is carried out in two stages: Predictability analysis using Lyapanov, Exponent, Correlation Dimension and Rescaled Range Analysis (R/S), Prediction using Multi layer Perceptron, Time delay line, Gamma and ANFIS. Then, a comparative study is performed using the different methods employed and prediction results are provided to show the effectiveness of the predictions.

In Iran, the volume of such air pollutants exceeds the danger level in many cities of Iran such as Tehran, Ahvaz, Sanadaj, Mashhad and Isfahan. Increasing each 10 µg of suspended particles causes 1-3% increase in mortality rate (WHO, 2005).In order to manage suspended particles pollution and take proper policies for pollution alleviation, it is necessary to study characteristics of pollutants; the way they spread forecast and their origins and forecast the trend of air pollution. To this end, after reviewing studied researches working on air pollution, we investigate the sources of air pollution and suspended particles in Ahvaz City; then, a neural network is designed in order to predict PM10 pollution; lastly, air pollution originated from 10-micron suspended particles in Ahvaz is predicted for October 2011.

Nowadays, it is imperative to study suspended particles, the sources and the ways they spread, and also to predict the process of the pollution caused by these particles. This could help manage this phenomenon and, make policies for controlling and reducing pollution which is a priority in cities. Hence, this study, firstly, tried to find out the sources of air pollution and suspended pollutants in Ahvaz. Then, a neural network was designed to predict the pollution caused by the spread of PM10. Finally, the pollution caused by ten-micron suspended particles in the city was predicted for one month.

Statistical analysis

World Health Organization in 2011 published a report based on the data announced by countries in the last recent years about particles smaller that ten micrometer. In this report WHO seriously demands the reduction of air pollution which causes the early death of 1034 million people annually. The amount of these particles must not exceed 20 microgram per square meter in a year. According to this report, the annual pollution in Ahvaz is 372 microgram per square meter which means Ahvaz stands first in 1100 cities in the world. Also, figure (1) demonstrates the monthly average concentration of PM10 in autumn of 2010 and winter, spring and summer of 2011, according to the statistics by the environment organization of Iran. According to this figure, the biggest amount of 10-micron suspended particle during the time of the study was spread in October 2010 which was 1298 microgram per square meter.

Figure 2 compares the maximum concentration of suspended particles in different days of different seasons. As the figure shows, spring and its first month are reported to suffer the maximum concentration of 10-micron suspended particles. Considering the fact that Ahvaz is suffering extremely high levels of pollution, this research tries to study and predict the pollution of this city caused by 10-micron suspended particles regarding the present condition of the city.

Materials and methods

Time series prediction

Sequence a set of observations in a period of time is called Time Series which can be stated by digits or vectors (Chatfield, 1989). The analysis of time series deals with data that are not independent and successively affect on each other. This analysis is exploited for phenomena which lack applicable input, and only the output of the system could be observed and analyzed. Generally, a time series has characteristics such as non-linear, chaotic, unstable, and periodic like seasonal. It could also be noisy (ibid).

Time series predictions play a significant role in a lot of scientific and engineering fields. In general, using the input-output (black box), such systems could be analyzed and predicted where the input of model is present and past variables of system, and the output is the future of time series (Nelles,2001).

In time series, the fact that the data of each series are interdependent is so important that has received a lot of attention and analysis in applied statistics. Modeling such data which are closely interdependent is used in different fields ranging from economical processes to air pollution. Generally, frequent items of time series depend on their preceding items.

Neural networks

Time series of air pollution is nonlinear dynamic; so, employing nonlinear models could improve the predictions. One of the best models which have proven to be valuable in pattern detecting modeling is smart systems which include neural networks (Comrie, 1997).The general structure of artificial neural networks is inspired by human neural networks. Research on neural networks has accompanied the study and analysis of learning in human brain. Artificial neural networks are systems which are able to execute operations like natural neural networks. In other words, they could copy the functions of human brain. When there is precise knowledge and explanation of a problem, using the acquired rules and relations to solve a problem will help solve the problem, and will be the best way to solve it. Artificial neural networks, processing the experimental data, transfer the knowledge and latent rules which lie beyond the data to the model. That is why they are called smart systems as they learn the general rules by processing the numbers or examples (Vemuri, 1994).

In neural networks, the input moves progressively and is multiplied by the weights from the first layer to the last, and finally forms the output of the network. The fact that these networks can learn creates different methods and decisions to teach such networks. Such a network is instructed with a set of data at the input and then by moving progressively, it produces the best and closest option to the real output with the least error done (Sivanandam, *et al.*, 2006). Neural networks are used in time series predictions particularly when we lack certain conditions such as stationary or other conditions which are necessary in application of classic techniques as well as when the time series suffers high dynamic (Dorffner,1996).

In the studies working on the prediction of air pollution, most of methodologies have been based on MLP (Multi Layer Percepteron). MLP networks are usually applied in short-run predictions.

Linear networks

Linear networks are completely similar to Percepteron networks except that they could produce any number as well as 0 and 1 since they use a linear function instead of a hardlim one. In such networks, the difference between the output and the target is considered as error (Gilat, 2005). Following the way neural networks are instructed, we look for weights and biases which result in the least Mean Square Error or lower than a certain level. To do so, we could instruct such networks to reach the least amount of error with the algorithm of Least Mean Squared.A linear network with the input R is shown in figure (3):

This network includes a layer with S neurons and the matrix of their weights is W. This network is completely similar to a Percepteron except that it uses a hardlim function instead of a purelin transfer function (Yegnanarayana, 2010).

Linear networks have a decision border which is the result of wp+b=0. The decision border in these networks is shown in the figure (4).

In the hachured part, the output is bigger than zero, and in the non-hachured part, the output is smaller than zero. Therefore, the data are divided into two groups (Natick, 2005).

Tapped Delay Line Networks (TDL)

To make a delay in the network, a new part is needed called TDL which is shown in figure (5).

TDL has an input which has gone through a set of N-1 delays. As a result, there is an N-member vector with a time dimension as the output. This vector includes the present input as well as the input from the previous stages. Now, TDL can combine a linear network and make a linear filter which is shown in figure (6).

The output of this network will be as formula (1):

$$a(k) = purelin(wp + b) = \sum_{i=1}^{R} w_{1,i}\, a(k - i + 1) + b \qquad (1)$$

Considering the characteristics of this kind of neural network, this study tries to predict the amount of suspended particles in Ahvaz by using a linear network with a time delay which can be instructed by LMS algorithm.

Results

To predict the amount of suspended pollutants in Ahvaz, the study takes advantage of a delay neural network (TDL) with three layers. There is a hidden layer and an output layer. The delay is in the output layer. This network contains 20 and 1 neurons respectively in the hidden and output layer. To calculate the number of the neurons in the hidden layer of the network, different networks with different hidden neurons are designed and instructed. Following MSE criterion, an optimal network was selected from those networks. The input layer has one neuron due to the fact that the input data are a one-year (365 days) time series. From the different algorithms used for the instruction of the neural networks, LMS algorithm was selected. Finally, the neural network with the daily data of the maximum amount of PM10 (microgram per square meter) in 24 hours was designed and estimated by using MATLAB software. To test the network, the maximum concentration of PM10 in 24 hours for spring and autumn of 2011 was predicted, and the monthly average of the predicted concentration, which is shown in figure (7), was compared to the real concentration as shown in figure (8).

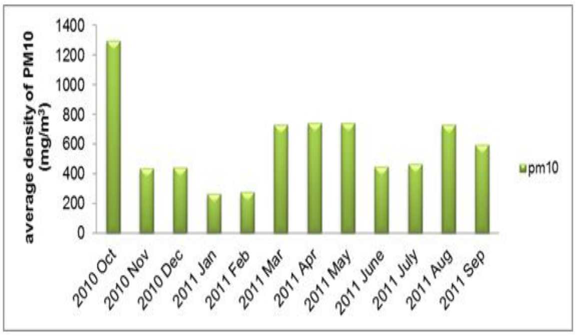

Fig. 1. The monthly average concentration of PM10 in autumn of 2010 and winter, spring and summer of 2011.

Finally, as during the study period the highest concentration of PM10 was reported to be in October, the amount of this pollutant in October of 2011 is predicted as figure (9) shows.

According to the predictions by the designed neural network, the highest and the lowest amount of concentration in October were respectively 722 and 319 microgram per square meter.

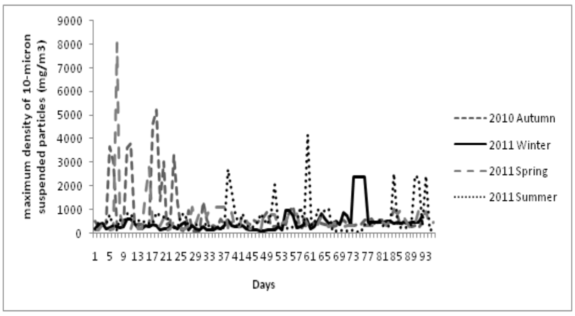

Fig. 2. The maximum concentration of suspended particles in different seasons.

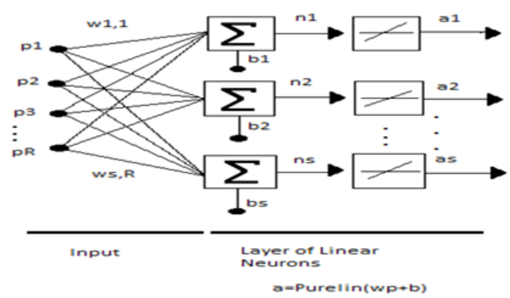

Fig. 3. Linear neural network.

Discussion

Studies carried out by researchers demonstrate that dust storms start when the speed of wind reach over 8 meters per second in deserts. This depends on soil humidity, the size of the granules, plant life, and soil tissue, cohesiveness of the soil particles, and the slopes and the hills. The major sources of dust storms in Iran are the deserts in Iraq, Syria, and the North desert in the peninsula of Saudi Arabia. Dust has harmful effects on the environment and human health. Suspended particles in atmosphere could prevent sunshine and this could result 30 to 35 percent reduction in agricultural production. Also, dust storms could increase lung problems and the death toll. Particles as big as 10 micron and smaller could increase the probability of lung death in children younger than one year old. Biological measures are the key solution to overcome dust storms. In Iran, oil mulch is used to control dust storms from deserts.

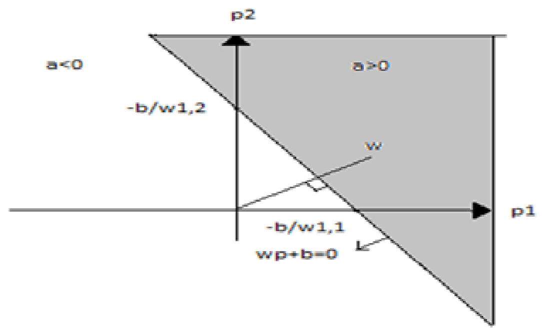

Fig. 4. Decision border in linear networks.

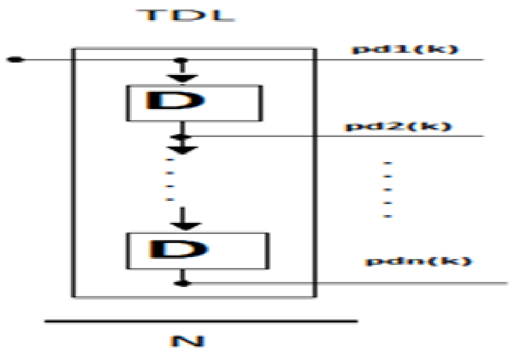

Fig. 5. Tapped Delay Line Networks.

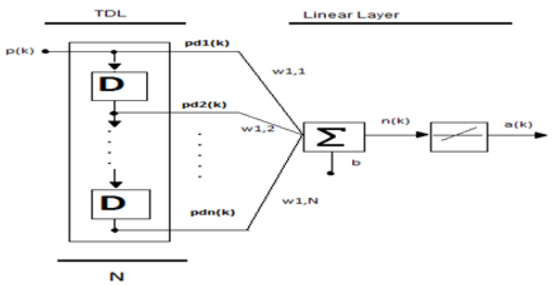

Fig. 6. Linear delay network.

As the World Health Organization reported that Ahvaz was the most polluted city with 10 micron suspended particles, and October of 2010 was reported to have the highest amount of PM10 in this city, this study considering the daily data of PM10 in a year, and designing a delay neural network with three layers and 20 neurons in the hidden layer, and LMS algorithm, tried to predict the amount of the spread of 10 micron suspended particles in the October month in 2011. The results of the network revealed that the average amount of the pollutant in this month is 482 microgram per square meter, and the maximum and minimum concentration are respectively 722 and 319 microgram per square meter. These amounts are too big in comparison with the maximum amount recognized by WHO which is 20 microgram per square meter. To control this phenomenon undoubtedly demands attention and cooperation of neighboring countries. As this problem harms the health of residents of west and southwest of Iran, particularly Ahvaz, authorities are expected to make appropriate policies and take immediate measures to control pollution in these areas.

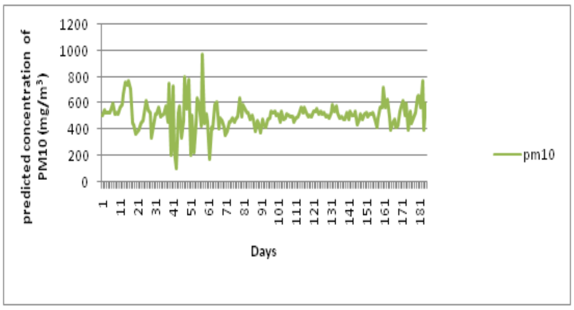

Fig. 7. The maximum concentration of PM10 in 24 hours for spring and summer of 2011.

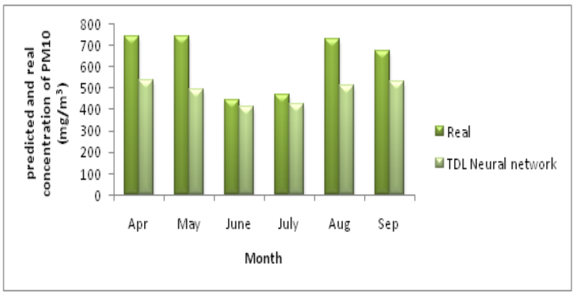

Fig. 8. The predicted concentration of PM10 compared to the real concentration.

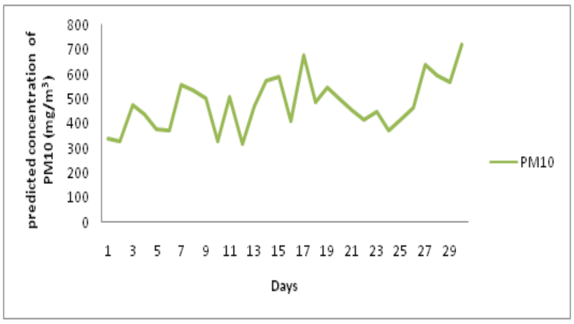

Fig. 9. Predicted concentration of PM10 for days of October 2011.

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