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Journal of Civil Engineering and Environmental Sciences

ISSN: 2455-488X DOI CC By

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Dates: Received: 01 December, 2016; **Accepted:** 29 December, 2016; **Published:** 30 December, 2016

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Keywords: Meteorological conditions; Orthogonal array; PM10 pollution; Prediction; Taguchi

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Research Article

Impacts of Meteorological Factors on Particulate Pollution: Design of Optimization Procedure

Abstract

In this study, Taguchi L_8 orthogonal array design was applied to determine the most polluted meteorological conditions in Kocaeli. Meteorological factors were decided as temperature, relative humidity and rainfall in two different levels. Larger is better function was applied for calculation of signal-to-noise ratios. The impact ratios of meteorological factors were also determined by using Taguchi model. PM_{10} concentrations were predicted by the model. Results of the model showed that predicted and obtained concentrations were closer to each other. These calculations and results show the success of Taguchi model in this study.

Introduction

Particulate matter (PM) is one of the major air pollutants in urbanization region [1]. Effects of PM pollution on human and environmental systems have been discussed by many of scientists. Particulates with aerodynamic diameters <10µm (PM_{10}) and <2.5µm ($PM_{2.5}$) causes lung cancer, asthma, morbidity and mortality [2,3]. So, air pollution control and monitoring are very important for saving ecological system.

Relationship between aerosol concentration and meteorological variables should be investigated for better control and monitoring applications. Aerosol concentrations are controlled by atmospheric mixing, chemical transformation, emission etc. [4]. Although this presence of concentration-meteorology system is real, the understanding of the connection between meteorological factors (relative humidity, temperature, wind, rainfall etc.) with particulate matter is not clear [5]. Because in lots of countries, researchers have limited number of studies about different aerosol fractions for a long time to characterization of relationship between meteorological factors and air pollution [4-6].

In last decades, some statistical and optimization tools such as multiple linear regression analyses [7], artificial neural networks [7,8], Box-Behnken designs [9], Taguchi orthogonal arrays [10-12] etc. are used for investigation of pollution in different environments. Taguchi bases on statistical design systems and successfully applied in lots of scientific disciplines. Compared to other statistical methods, Taguchi model is simple, effective and innovator for investigation of environmental risks [13,14]. Harmful effects of multiple factors on environment can be investigated by this model. On the other hand, the influence of individual factors is more important for success of this model [10].

In line with the above information, statistical and optimization model studies that can explain the connection between pollutant concentration and meteorological factors should be increased. Taguchi generally require less data and researchers can make successful comments with orthogonal array designs. So, this method will find a place in the field of the effects of meteorological factors on distribution of air pollutants (especially particulate matter). In this study, the impacts of three different meteorological factors (temperature, relative humidity, rainfall) on the average concentration of particulate matter (PM_{10}) will be examined by Taguchi's L_8 orthogonal arrays. Air pollution levels of PM_{10} were also predicted by using the model. For this study, air monitoring data (average pollutant levels and meteorological factors) obtained from Ministry of Environment and Urban Planning in industrial areas of Kocaeli.

Materials and Methods

Study area

Kocaeli is one of the important and crowded cities in Turkey. Lots of heavy industrial plants have been located here. On the other hand, it has quite an intense traffic network. So, air pollution is the major environmental problem in this city.

Citation: Özdemir U (2016) Impacts of Meteorological Factors on Particulate Pollution: Design of Optimization Procedure. J Civil Eng Environ Sci 2(1): 030-033. DOI: http://doi.org/10.17352/2455-488X.000011

In this study, PM_{10} and meteorological data sets obtained from the station of Ministry of Environment and Urban Planning. The study area is located between latitude of 40° 46' North and 29° 31' East (Figure 1).

Taguchi procedure

Selection of the control factors is the most important step in Taguchi applications. Temperature, relative humidity and rainfall with two levels were selected as control factors in this model study (Table 1).

In Taguchi model studies, the variability of factors expressed by signal-to-noise ratios (S/N). One of the S/N functions must be chosen as "smaller is better", "nominal is better" and "larger is better" [15]. Larger is better characteristics was chosen for this work. Because this study was designed to investigate the meteorological factors which cause maximum PM_{10} concentration in Kocaeli. The S/N ratio for the larger is better function was calculated as:

$$S/N = -10\log\left(\frac{1}{n}\sum\frac{1}{y_i^2}\right) \qquad (1)$$

where y_i is the observed PM_{10} concentrations and n is the number of repetitions.

L_8 orthogonal array was chosen for this study. Table 2 shows L_8 orthogonal array of meteorological factors onto PM_{10}.

All calculations and applications of this study were hosted in Minitab 16 software package and Microsoft Excel 2007.

Results and Discussions

In this study, the general goal was to determine the impacts of some meteorological factors such as temperature, relative humidity and rainfall onto PM_{10} pollution in an industrial area of Kocaeli. Taguchi method was designed as L_8 orthogonal array for this work.

In Taguchi applications, calculating of S/N ratios are the most important stage for evaluate the meteorological and PM_{10} data sets clearly. S/N ratios show the consistency between control factors (temperature, relative humidity and rainfall) and response data (PM_{10}). Larger is better type of S/N ratios were calculated according to Eq. (1) and the results were given in Table 3.

As seen from Table 3, obtained data sets providing the highest signal-to-noise ratio are as 1-2-2. This code (1-2-2) indicates that PM_{10} concentration became higher in winter seasons conditions (temperature <15 °C, relative humidity > %65 and rainfall > 55 mm). PM_{10} concentrations in winter are higher in Kocaeli because of warming-induced. This shows models better reality capacities of Taguchi models. Minitab graph of S/N were also given in Figure 2.

Taguchi model shows that temperature is the most important meteorological factors on PM_{10} pollution in Kocaeli. The impact ratio of temperature was calculated as 69.40%. Whereas impacts of temperature were higher, relative humidity was the less effective factor in this model study. Impact ratios of the meteorological factors were presented in Table 4.

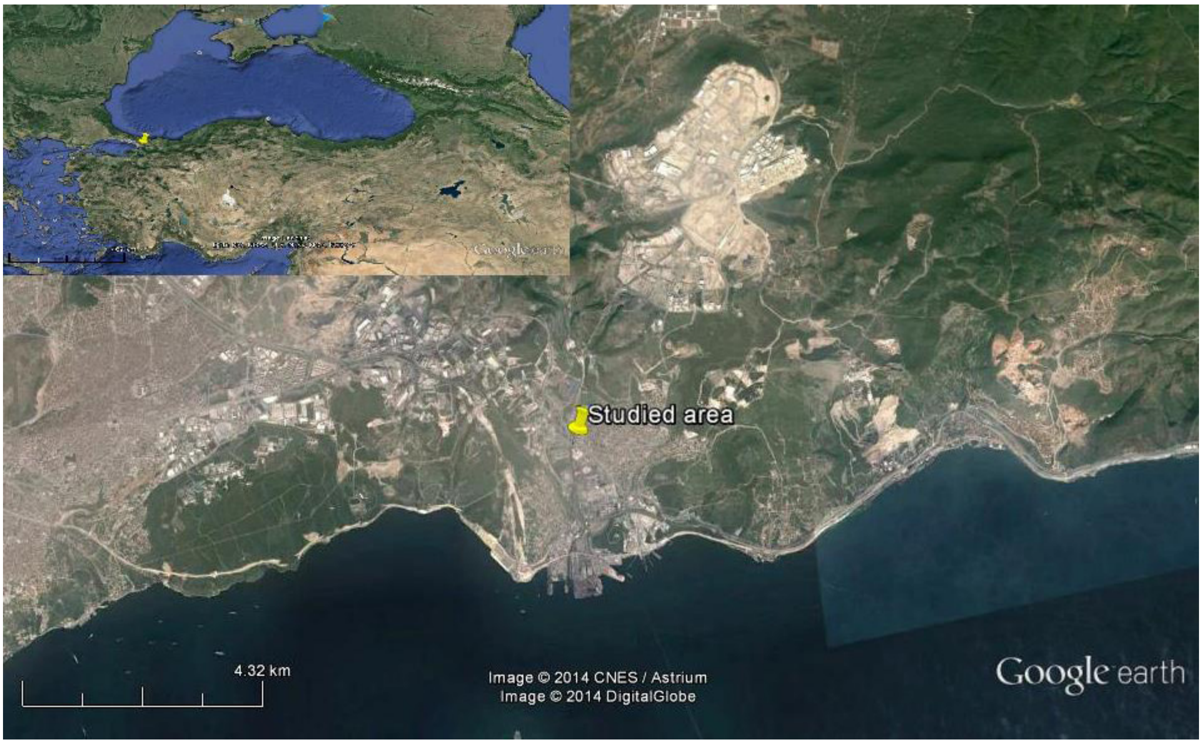

Figure 1: Map of the study area.

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Taguchi statistical optimization model has also a prediction capacity. PM_{10} concentrations in Kocaeli were also predicted by this model. Predicted pollutant concentrations versus obtained concentrations are given in Figure 3.

Figure 3 shows that higher correlation was obtained between predicted and real PM_{10} concentrations (R^2= 0.95). So, Taguchi model was successful in prediction of pollutant concentration of Kocaeli.

Conclusion

Taguchi's L_8 orthogonal array design was applied in this study for determine the meteorological conditions which have the most intense PM_{10} concentrations in Kocaeli. Signal-to-noise ratios showed that temperature was the most important factor in particulate pollution for this study. It has 69.40% impact ratio on PM_{10} concentration. This study demonstrates the seasons of area are very remarkable in particulate concentration. Because Taguchi data indicates that PM_{10} concentration became higher in winter seasons conditions (temperature <15 ºC, relative humidity > %65 and rainfall > 55 mm). On the other hand, higher correlation (R^2=0.95) was determined the strong relationship between predicted and actual PM_{10} concentrations.

Table 1: Control factors and their levels

Factors	Level 1	Level 2
Temperature (^0C)	< 15	15-25
Relative Humidity (%)	50-65	> 65
Rainfall (mm)	< 55	> 55

Table 2: Taguchi L_8 design for this study

Data No.	Temperature	Relative Humidity	Rainfall
1	1	1	1
2	1	1	2
3	1	2	1
4	1	2	2
5	2	1	1
6	2	1	2
7	2	2	1
8	2	2	2

Table 3: Calculated S/N ratios for all control factors and response data.

Coded Data			S/N
1	1	1	33.90
1	1	2	36.41
1	2	1	34.22
1	**2**	**2**	**37.75**
2	1	1	32.88
2	1	2	32.25v
2	2	1	31.62
2	2	2	32.01

Table 4: Impact ratios of the meteorological factors.

Factors	Impact Ratios (%)
Temperature (^0C)	69.40
Relative Humidity (%)	0.83
v	29.77

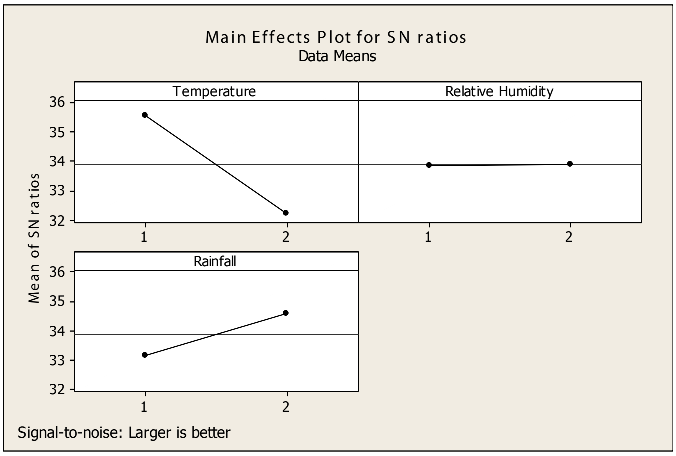

Figure 2: Main effects of ratios in this study.

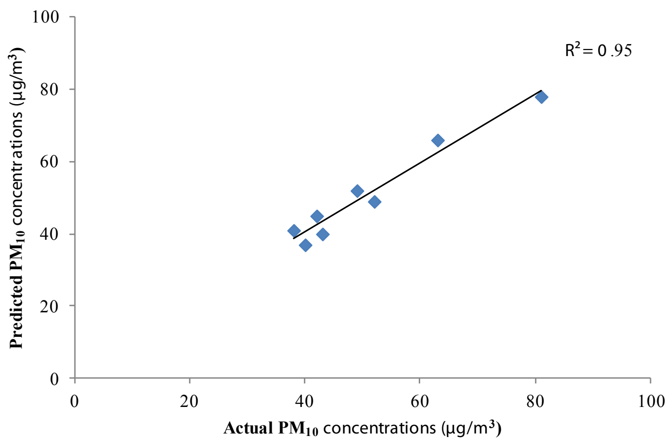

Figure 3: Predicted PM10 concentrations versus obtained PM10 concentrations.

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