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Design of Experiments Applied in Particulate Material of Urban Areas of High Vehicular Traffic

[1]Luz Vargas, [1]Waldyr Fong, [2]Irlena Ahumada, [2]Jorge Posada, [2]Ivan Orjuela, [2]Jose Palacio, [3]Carlos Vidal and [2]Carlos Severiche
[1]Universidad de Cartagena, Cartagena de Indias, Bolivar, Colombia
[2]Corporacion Universitaria Minuto de Dios-UNIMINUTO, Barranquilla, Atlantico, Colombia
[3]Universidad de Santander-UDES, Valledupar, Cesar, Colombia
jorge.posada@uniminuto.edu

Abstract: An experimental design was carried out to determine the effect of sampling point, day, temperature and wind speed in the presence of particulate material in main roads of the city of Cartagena de Indias (Colombia). Initially, descriptive statistics were obtained for the variables with respect to the day and the sampling point, later, the assumptions of the model for the data are tested and finally an analysis of covariance is made, using as main factors the location and the working day and as covariates to the temperature and the wind speed. The data indicate that in general there is a high dispersion of the contents of particles in the different days and sampling points, it is also found that the assumptions of the model are verified correctly in addition at the Ronda Real sampling point and the rainy day, there is a greater presence of the particles and as the size of the particles increases, a lesser effect of the factors is observed. The wind speed negatively influences the presence of MP0.3 and MP5 particles; in the same way as the size of the particles increases, less effect of the variables considered is observed.

Key words: Air pollutants, particulate material, design of experiments, descriptive statistics, Ronda Real, assumptions

INTRODUCTION

The dynamics of population growth that cities face represent a serious threat to the environment as well as to the health and quality of life of its inhabitants (Severiche-Sierra *et al*., 2017). This growth generates new economic processes and is generally, accompanied by an increase in industrial activities, higher motorization rates, higher fuel consumption and therefore, the generation of greater emissions of air pollutants (Severiche-Sierra *et al*., 2017). Pollution can be defined as any undesirable modification of the environment, caused by the introduction of physical, chemical or biological agents in quantities greater than natural that is harmful to human health, damages natural resources or alters the ecological balance (Wei *et al*., 2013). However, there are few studies that evaluate the levels of the main pollutants in Latin American countries (Liu *et al*., 2014).

Although, the industrial development of a territory can induce a strong socio-economic reactivation and improvements in the quality of life of the population, it is also capable of causing important changes in the environment and various forms of air, water and soil pollution, depletion of natural resources and their degradation (Prasannavenkatesh *et al*., 2015). All this will negatively influence, directly or indirectly, the welfare, the quality of life and the health of the population. A rigorous scientific analysis must be carried out aimed at identifying and weighing the magnitude and severity of the possible environmental and health impacts; derived from a development project and consequently, the adoption of the pertinent prevention and control measures, so, the negative effects will be minimized as long as the positive ones are maximized, proceeding called "environmental impact assessment (Olumayede and Ediagbonya, 2018).

Air pollution is a problem faced by many cities around the world. It is characterized as the conglomeration of different substances present in the atmosphere emitted to a greater extent by industries and automotive vehicles (Banerjee and Christian, 2018). Concerns about the effects that air pollution has on health is not a new issue, on the contrary, it has been debated for several decades. In the second half of the 20th century, several studies found that high levels of air

Corresponding Author: Jorge Posada, Corporacion Universitaria Minuto de Dios-UNIMINUTO, Barranquilla, Atlantico, Colombia, jorge.posada@uniminuto.edu

pollution as a result of large emissions of gases related to the consumption of fossil fuels, cause public health problems associated with respiratory diseases (Schneider *et al*., 2015).

The particulate material is one of the most studied atmospheric pollutants at present, this is defined as the set of solid and/or liquid particles (with the exception of pure water) present in suspension in the atmosphere that originate from a great variety from natural or anthropogenic sources and possess a wide range of morphological, physical, chemical and thermodynamic properties (Karagulian *et al*., 2015). According to Speak *et al*. (2012), he adverse effects on health due to atmospheric particulate pollution have been the subject of a growing number of studies in recent years. Urban residents are at particular risk from certain anthropogenic sources such as traffic and they are increasingly exposed to urban particulate pollution. Particles smaller than 10 μm in diameter (PM10) can penetrate deep into the pulmonary passages where any transition metals such as iron and copper can release free radicals in lung fluid and cause cellular inflammation.

There are several types of experimental fixed-effect designs; choosing one of them depends on the availability of resources such as time. One of the advantages of these studies is that they do not require many sample units (better known as experimental units) or replicas, since, the source of variability is controlled because the same conditions are guaranteed in each run or run of the experiment, since, the assignment of the experimental units to the treatments is random, balancing the biases in each treatment. In this sense according to Salazar and Baena in total an experiment will yield observations where is the number of treatments and the number of replicas. The statistical tools used to analyze the data resulting from an experiment are widely known and many of them are based on the analysis of variance and the multiple regression or general linear model but also and more broadly in the generalized linear models; if necessary, it is possible to use equivalent non-parametric methods.

Currently, the district of Cartagena de Indias is considered one of the main cities of the country and one of the most promising tourist destinations in Latin America, the city has had an evident industrial growth but this growth brings environmental problems. Some researchers have carried out pollution measurement studies in Colombia and Cartagena but these studies are descriptive, therefore, it is pertinent to carry out experimental studies to establish the physical and environmental factors that influence the presence of particulate material. In the present study an analysis of covariance is performed to identify the effect of temperature, wind speed, location and day (rainy or sunny) on the presence of particulate material MP0.3, MP5 and MP10 as well as the conditions of these variables that increase the risk of the presence of particles in the busiest roads in the city.

MATERIALS AND METHODS

Location: The study was conducted in the city of Cartagena is located in the Colombian Caribbean (10° 23 ‘59 ‘North, 75° 30’ 52 “ West) and has about 1.2 million inhabitants. The sampling points for Bomba del Amparo, Cuatro Vientos traffic light and Ronda Real were considered for the study as illustrated in the map (Fig. 1).

Collection of information: In each of the sampling points considered, variables PM0.3, PM5, PM10 temperature and wind speed were measured in rainy and dry days, during, for 2 days for each day. The measurement of the particulate material was made using the methodology worked by Matson *et al.* (2004) using a CEM brand particle counter, reference DT-9881 and to measure the wind speed and temperature the established by Martin *et al*. for this the equipment used was a CEM Brand Thermo-Anemometer, reference DT-8894.

Statistical analysis: Table 1 summarizes the variables to be analyzed as well as their nature. According to the measurements collected, the following statistical analyzes are carried out similar to those carried out by Ghasemian *et al*. (2012).

Fig. 1: Location of sampling points

Table 1: Classification of the variables

Controllable variables	Non-controllable variables
Day (rainy and dry)	Wind speed (m/sec)
Location (Cuatro Vientos, Bomba del Amparo and Ronda Real)	Temperature (°C)
	No. of particles (ppm)

Descriptive statistics: The maximum, minimum, average, standard deviation and coefficient of variation are calculated for the different non-controllable variables in terms of the controllable variables.

Proof of the assumptions: The streak test, Shapiro-wilks and Levene tests are carried out to verify, respectively, the assumptions of independence, normality and homogeneity of variance of the data.

Experimental design: A 2×3×2 factorial experiment is carried out under a covariance analysis where the variables to be controlled are particulate material of 0.3, 5 and 10 ppm; the controllable factors correspond to the day and the sampling point and the covariates are wind speed and temperature (Dunea *et al*., 2016; Zhou *et al*., 2014). The analysis of the results was done through the statistical program R 3.3.5.

RESULTS AND DISCUSSION

Descriptive statistics: Table 2 shows the descriptive statistics for the different non-controllable variables with respect to the sampling point. It is observed that the highest values of particulate material and temperature are found in the Ronda Real point while in this the lower values of wind speed are presented. The values for the Coefficient of Variation (CV) show that the variables with the highest dispersion are MP0.3 and MP5 (coefficients of variation >40%) while the temperature is the one with the lowest dispersions having coefficients of variation below 5%. With regard to the sampling points, it is observed that the greatest variations for the different variables are presented in the Bomba del Amparo.

In Table 3, according to the results obtained for the variables with respect to the working day, the greatest variations are observed in particulate material 5 (MP5) while temperature presents variations below 4%. With respect to the day in rainy day the highest contents of the different particles are shown as well as the highest variations.

Table 2: Descriptive Statistics by sampling point

Sampling point/variable	Minimum	Maximum	Average	CV(%)
Bomba del Amparo				
MP0.3	26618	62976	44631.75	46.48
MP5	38	148	69.00	76.48
MP10	18	35	25.50	29.78
Temperature	30	34	31.80	4.04
Wind speed	2	3	2.43	18.72
Ronda Real				
MP0.3	30614	83126	61604.25	38.71
MP5	83	258	174	48.93
MP10	39	58	48.75	20.81
Temperature	31	35	32.88	4.84
Wind speed	1.00	1.50	1.19	18.81
Cuatro Vientos				
MP0.3	25605	61698	42557.5	40.91
MP5	40	161	86.25	60.40
MP10	22	40	31.75	23.34
Temperature	30.60	33.30	32.18	3.56
Wind speed	1.58	2.86	2.04	27.81

Proof of the assumptions: Table 4 shows the p-values of the tests of independence, normality and homogeneity of variances for each of the dimensions of the particles. The results show that the null hypothesis of the different tests are not rejected at a level of significance of 10% (p-value >0.1), therefore, the assumptions of the model are fully met and it is valid to perform the analysis of variance. Next, the analysis of covariance is performed to explain the behavior of the presence of particulate material.

Experimental design: Analysis of covariance is performed for the variables PM 0.3, PM 5 and PM 10, depending on the working day and the sampling point; using as covariates at wind speed and temperature. Table 5 shows the analysis of covariance for PM0.3.

It is observed that the day and the sampling point have a highly significant effect on the presence of PM 0.3

Table 3: Descriptive Statistics by day

Working day/variable	Minimum	Maximum	Average	CV(%)
Rain				
MP0.3	52712	83126	66661	16.91
MP5	40	258	147.67	62.02
MP10	21	58	40.50	35.98
Temperature	30.4	33.4	31.65	3.73
Wind speed	1.06	3.02	2.09	38.92
Sunny				
MP0.3	25605	55432	32534	35.05
MP5	38	121	71.83	41.37
MP10	18	41	30.17	30.48
Temperature	31.50	34.80	32.92	3.61
Wind speed	1.00	2.22	1.68	28.54

Table 4: p-values for the design assumptions

Particles	Streak test	Test of Shapiro-Wilks	Test of Levene	
PM0.3	0.1300	0.1220	Working day	0.73850
			Sampling point	0.66450
PM5	0.7520	0.1822	Working day	0.10510
			Sampling point	0.38420
PM10	0.3639	0.7620	Working day	0.14720
			Sampling point	0.36390

Table 5: Covariance analysis for PM0.3

Source	Sum of squares	Gl	Square medium	p-values
Covariables				
Temperature	1.72E+08	1	1.72E+08	0.0795*
Wind speed	1.56E+08	1	1.56E+08	0.0902*
Main effects				
A: Time	7.53E+08	1	7.53E+08	0.0081**
B: Point	7.63E+08	2	3.82E+08	0.0201**
Interactions				
AB	5.09E+07	2	2.54E+07	0.5072
Waste	1.26E+08	4	3.15E+07	
Total	4.78E+09	11		

*: $p<0.1$; **: $p<0.05$

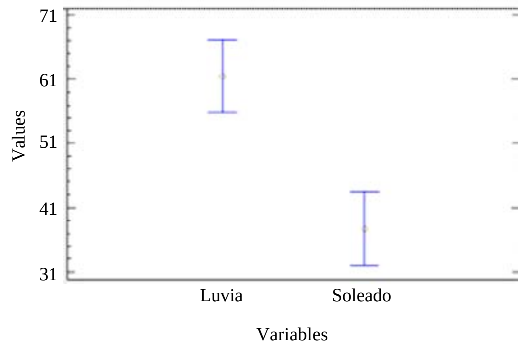

Fig. 2: Mean comparison chart for MP0.3 according to the day

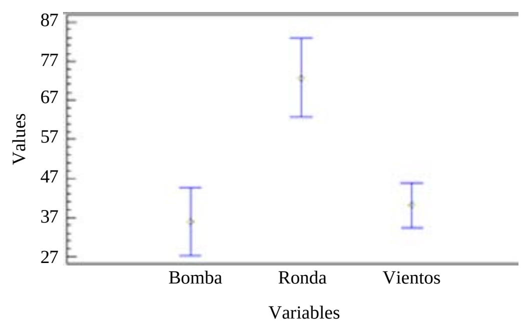

Fig. 3: Average comparison chart for MP0.3 according to the sampling point

(p<0.05) while the wind speed and temperature show a significant effect (p-value<0.10). With respect to the interaction, it is observed that there is no significant effect (p-value = 0.5071). Below, the comparison graphs of means by day and by sampling point are shown to observe the behavior of PM 0.3 in relation to these (Fig. 2).

The graph of means for MP0.3 with respect to the day shows that in the rainy season there is statistically an average higher than the sunny day. While for the sampling points, it is observed that for the Ronda Real point, Fig. 3, it is the one with the highest average particle content.

With respect to the analysis of covariance for PM5, Table 6 and 7, there is a significant difference between the sampling points and the effect of wind speed is also observed (p-values of 0.0638 and 0.0817, respectively). It is observed that unlike that obtained for MP0.3, there is no effect of temperature and wind speed. The graph of means shows the behavior of these differences is detailed in Fig. 4.

It is observed that as with PM0.3, the Ronda Real sampling point is the one with the highest PM5 content.

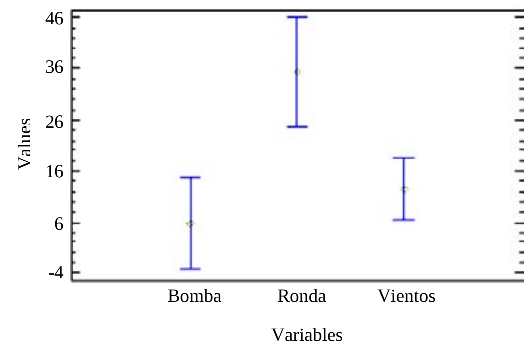

Fig. 4: Mean comparison chart for MP5 according to the sampling point

Table 6: Analysis of covariance for PM5

Sources	Sum of squares	Gl	Square medium	p-values
Covariables				
Temperature	3.77E+06	1	3.77E+06	0.7558
Wind speed	1.82E+08	1	1.82E+08	0.0817*
Main effects				
A: Time	4.53E+07	1	4.53E+07	0.3126
B: Point	4.03E+08	2	2.01E+08	0.0638*
Interactions				
AB	1.43E+08	2	7.13E+07	0.2384
Waste	1.36E+08	4	3.40E+07	
Total	1.21E+09	11		

*: p-value<0.1

Table 7: Analysis of covariance for PM10

Sources	Sum of squares	Gl	Square medium	p-value
Covariables				
Temperature	6.64079	1	6.64079	0.7002
Wind speed	41.0139	1	41.0139	0.3619
Main effects				
A: Time	116.117	1	116.117	0.1586
B: Point	386.938	2	193.469	0.0819*
Interactions				
AB	106.974	2	53.4869	0.3503
Waste	155.102	4	38.7754	
Total	1792.67	11		

*: p-value<0.1

For MP10 it is observed that only the sampling point influences the presence of 10 micron particulate material (p = 0.0819). The graph of means, Fig. 5 shows that the Ronda Real sampling point is the one with the highest particle content.

It is generally, observed that the presence of particulate material depends on the working day and the sampling point considered; in addition as the particle size increases, less effects of the different variables and covariates are observed. The foregoing indicates that it is more difficult to detect changes in large particles while the small ones are more sensitive to these changes but they can only be detected with the help of special devices.

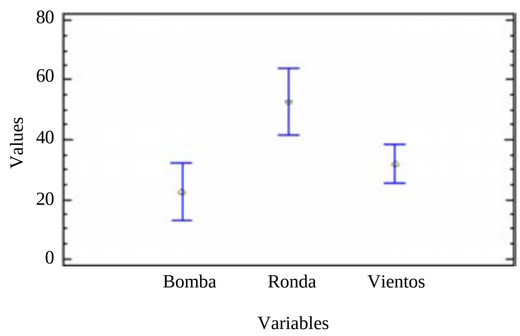

Fig. 5: Average comparison chart for MP10 according to the sampling point

CONCLUSION

According to the review of the bibliography, the results and their discussion can be concluded that: the main variations of the contents of 0.3, 5 and PM10 are found at the Ronda Real sampling point and the rainy day, then, the assumptions of the model were perfectly fulfilled in each of the particle sizes considered also for each of the particle sizes, it was observed that the sampling point has an important effect being Real Ronda the point with the highest average presence of the different particles; likewise there was a significant difference between the days with respect to MP0.3 being the rainy day the one that presents greater values as for wind speed negatively influences the presence of particles 0.3 and MP5, finally, as the size of the particles increases, less effect of the variables considered is observed.

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