Road Transport and Air Pollution in an Urban Congestion

Florinela Ardelean[1]

[1] Technical University of Civil Engineering Bucharest, Faculty of Engineering Installations
Bd. Pache Protopopescu, no.66, Bucharest, Romania
E-mail: florinela.ardelean@gmail.com

Abstract. *Depreciation of outdoor air quality in an urban centre is a certainty and is due mainly to road traffic.The objective of this work is to evaluate the influence of emissions from road transport over ambient recorded in an urban area with high density of population. For this, the level of pollution of the lower troposphere from Bucharest was monitored with the help of a network of eight points of measurement. The analyzed pollutants were ozone(O_3), nitrous oxides (NO_x/NO_2) and other chemical species involved in photochemical smog. Among other things, resulted in the fact that concentrations of ozone and nitrogen oxides are inversely correlated.*

Key words: road transport, air quality, photochemical smog, correlation coefficient

1. Introduction

The pollution of the atmosphere is a very complex phenomenon, taking into account the diversity of susceptible pollutants to be present simultaneously in the troposphere air. Concerning this, a special research direction was represented by measuring and predicting of outside pollution levels, in urban congestions. Taking into account the fact that road transport represents the most important element of exterior air quality depreciation in an area like this, the realization of a study was mandatory, study that would emphasize the pollutant contribution of the automobile looking at the general chemical pollution of lower atmosphere based on direct indicative measurements.

The article contains a description of the monitoring network for air quality existent on Bucharest's territory, as well as a revealing of the results as a visualization of concentrations variations of pollutants: carbon monoxide (CO), nitrous oxides (NO_x/NO_2) and ozone (O_3). These chemical species were chosen because of their elevated levels of toxicity and the fact that they are precursors or follow photochemical smog and acid rains.
Similar studies were performed for other urban areas, like: Milan [1], Lisbon [2], Izmir [3], New Delhi [4], Kosovo [5], Paris, Helsinki and Cambridge.

The high pollution potential of this source is due to pollutant emissions which take place close to the ground, at road height, even in the area where pedestrians walk, on the sidewalk, as well as the large surface that is covered by pollutants (due to the source's mobility).

From the complex processes that take place in the engine, the process of fuel ignition has a special importance, because of it's perfection depend, in a high measure, the economical and power indexes, durability of the internal combustion engine, and last, but not least, the quantity of pollutants that are being emitted into the atmosphere. From a complete burn of the fuels, the following substances are ensued: water vapors (13%), carbon dioxide (13%) and nitrogen (74%) [6]. In reality, based on the quality of the air/fuel mix (the dosage coefficient), CO is also formed, hydrocarbons and others.

The evaluation of the negative impact of traffic on exterior air quality is achieved through monitoring the next categories of pollutants: inorganic gases (nitrous oxides, sulfur dioxide, carbon oxide, ozone), powders, powder components (elementary carbon, aromatic multi cycle hydrocarbons, lead) and volatile organic compounds (benzene).

2. Experimental study

The city of Bucharest falls in the category of great urban congestions (0.8% of Romania's surface), characterized through a greatly human modified environment. The density of the population, in this metropolis, in 2008, was of 8168 inhabitants/square km. The main sources of pollution are traffic (responsible for about 70% of atmospheric pollution), electro-thermal power plants, very diversified industry, construction works and residential heating. In the precedent years, these kind of studies have been performed for Bucharest as well [7] and [8].

The used database in this study is the result of measuring processes in real time ran between 2004 and 2009, with measuring stations that form the monitoring network for air quality, located in Bucharest's territory. The network is formed out of 8 fixed monitoring stations for the quality of air, placed in the urban area (6), as well as in the city limits (2). Every station is equipped with:

- analyzers for real time measuring of the next categories pollutant concentrations: SO_2, $NO/NO_2/NO_x$, CO, O_3, benzene, suspension particles;
- meteorological sensors for the identification of: wind speed and direction, temperature, relative humidity (all except the station on Mihai Bravu).

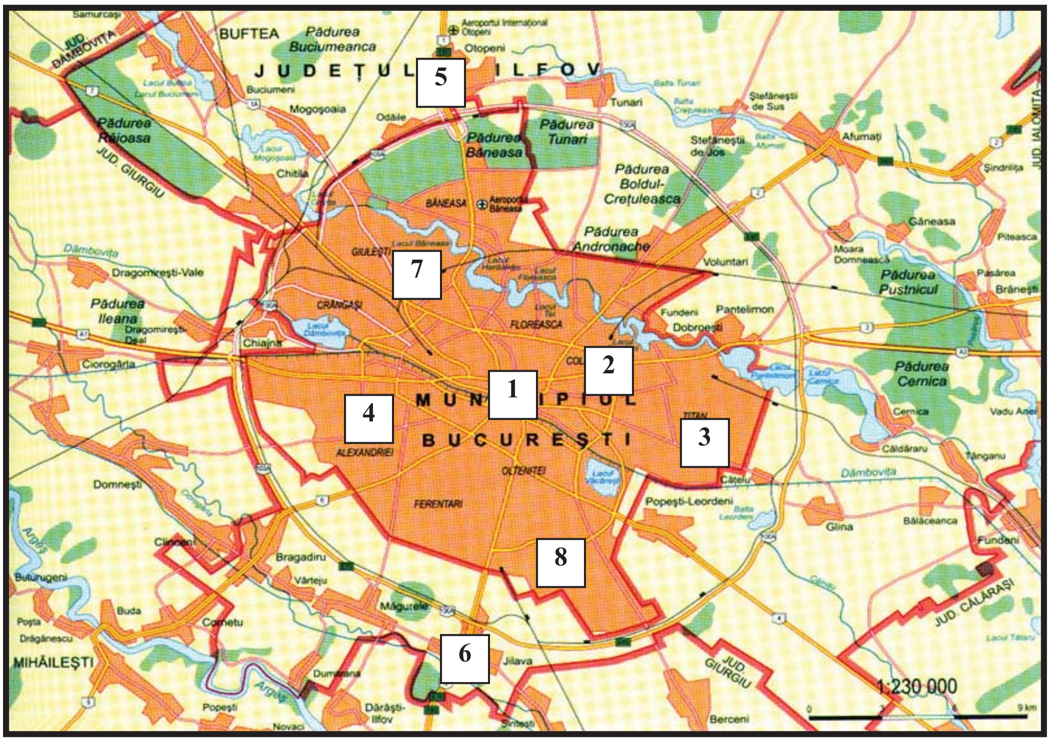
Details regarding the category and the placement of the measuring stations are found in table 1.

Table 1

The categorization and placement of measuring stations.

Station no./Area	**Station category** **Placement details**
1 – Cercul Militar	- Traffic - Placed right in the centre of the city, in Bucharest's most polluted city, where the contribution of traffic is the most important
2 – Mihai Bravu	- Traffic - Placed in the centre of the city
3 – Titan	- Industrial - Placed in the city, in an area quite far from the centre
4 – Drumul Taberei	- Industrial - Placed in the city, in an area quite far from the centre
5 – Baloteşti	- Peripheral (in the forest), at 35km North of Bucharest - Placed in a rural area
6 – Măgurele	- Peripheral, South of Bucharest, right after the city's „belt" - Placed in a rural area, near the city
7 – Lacul Morii	- Peripheral - Placed in city, in an area very far from the centre
8 – Berceni	- Industrial - Placed in city, in an area quite far from the centre

The map below (picture 1) is relevant to the geographical position of these locations and their closeness to the central area of the city.



Picture 1. Geographical placement of measuring stations

In table 2 the evolution of ambient air pollution evolution is presented, based on annual average hourly concentrations for NO_2 (µg/m^3) and O_3 (µg/m^3).

Table 2

Annual average concentration evolution for NO_2 and O_3

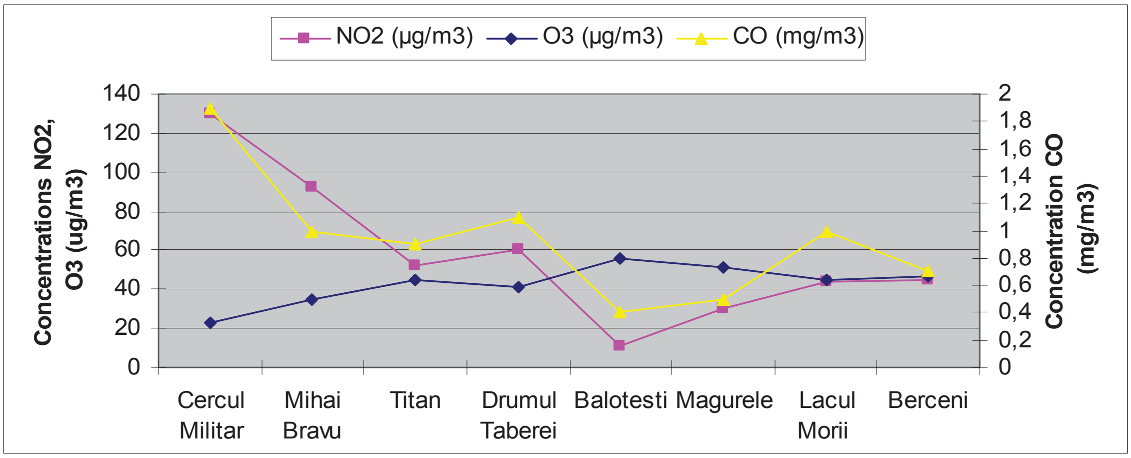
Station / pol. conc.	2004		2005		2006		2007		2008		2009	
	NO_2	O_3	NO_2	O_3	NO_2	O_3	NO_2	O_3	NO_2	O_3	NO_2	O_3
Cercul Militar	88	28	130	23	126	13,2	111	16,2	78	12,6	62	31,4
Mihai Bravu	81	36	92	35	90	24,8	62	22,2	68	18	67	34,2
Titan	44	52	52	45	54	32,7	46	43	33	37,8	20	36,1
Drumul Taberei	52	38	60	41	53	35,8	59	31,1	49	26,8	39	39,6
Baloteşti	10	60	11	56	12	52,4	13	58,1	12	51,4	11	53,8
Măgurele	23	52	30	51	30	24	26	27,6	26	31	27	36,9
Lacul Morii	40	50	44	45	31	45,9	43	47,4	33	44,8	36	40,9
Berceni	33	52	45	47	35	42,8	41	39,9	38	34,7	24	35,1

In this way, the following aspects can be emphasized:

- Annual average values for NO_2 have increased in 2005, have decreased in 2006 and 2007, and in 2008 and 2009 a significant decrease has been registered. Annual averages exceed the limit value at stations characterized by intense traffic: Cercul Militar, Mihai Bravu and Drumul Taberei. According to the current legislation [9], the maximum admitted value for annual concentration is *40 µg/m^3*.
- The maximum values for hour concentration of NO_2 have been recorded in the evening, at stations located in the central area of the capital, following the oxidation of NO, effect of traffic. Some examples can be given: *545 µg/m^3* – Mihai Bravu (10/22/2005 – midnight), *605 µg/m^3* – Mihai Bravu (10/04/2006 – midnight), *489 µg/m^3* – Cercul Militar (10/18/2007 – 8 PM).
- You can notice frequent overtaking [9] of NO_2 hour concentration – *200 µg/m^3*, of the inferior evaluation threshold – *100 µg/m^3*, as well as the superior evaluation threshold – *140 µg/m^3*.
- The smallest values for the maximum NO_2 hour concentration have been recorded at the station outside of Bucharest – Balotesti (*173 µg/m^3* – 11/23/2007, 4 PM and *71 µg/m^3* – 12/09/2008, 3PM). At this station frequent 0 values have been recorded, rare exceeding the lower evaluation threshold, and very rarely exceeding the superior evaluation threshold, the values for the hour or annual concentrations [9] never been achieved in the monitoring interval 2004 – 2009.
- Values exceeding the target value for ozone (maximum daily concentration of averages/8 hours) – *120 µg/m^3* have been recorded especially in the warm period of the year (fact that helped the development of photochemical reactions), but the thresholds of informing – *180µg/m^3* and of alert – *240 µg/m^3* have not been passed [9].

- The highest values of hour O_3 concentrations have been recorded at Balotesti station: *137,5 μg/m*^{3} – 08/18/2006, 7 PM, *157,7 μg/m*^{3} – 07/22/2007, 8 PM and *168 μg/m*^{3} – 09/05/2008, 9 PM.

In the second picture, for year 2005 (the year in which the highest level of pollution has been recorded), the annual average variations of hour concentrations for pollutants presented above will be visualized, to which the annual average at 8 hours for pollutant CO (mg/m^3) is added – representative for the partial combustion, most of the time incomplete from the engines.



Picture 2. Annual pollution levels – 2005

Following the curve similar to the graphics that represent annual average values, recorded at all stations that form the monitoring network for air quality, we can have the conclusion that CO and NO_2 imissions are strongly related to the emissions from the same pollution source – traffic. The variation tendency, from one station to another, of the secondary O_3 pollutant annual average is opposite to the first two.

3. Correlation Studies

The simultaneity of linear variations of the analyzed two parameters is emphasized by the statistic parameter called "co_varianta" [10]. The normalization and adymensionalization of this statistic parameter is realized by dividing it to the multiplication result of the standard deviation of every parameter. A correlation coefficient is obtained that varies between [-1, 1]. The negative values symbolizes that an increase of one parameter is followed by the decrease of the second one, the positive values indicate a variation in the same sense of the parameters, and a value close to zero emphasizes the fact that the two parameters are not correlated [11,12].

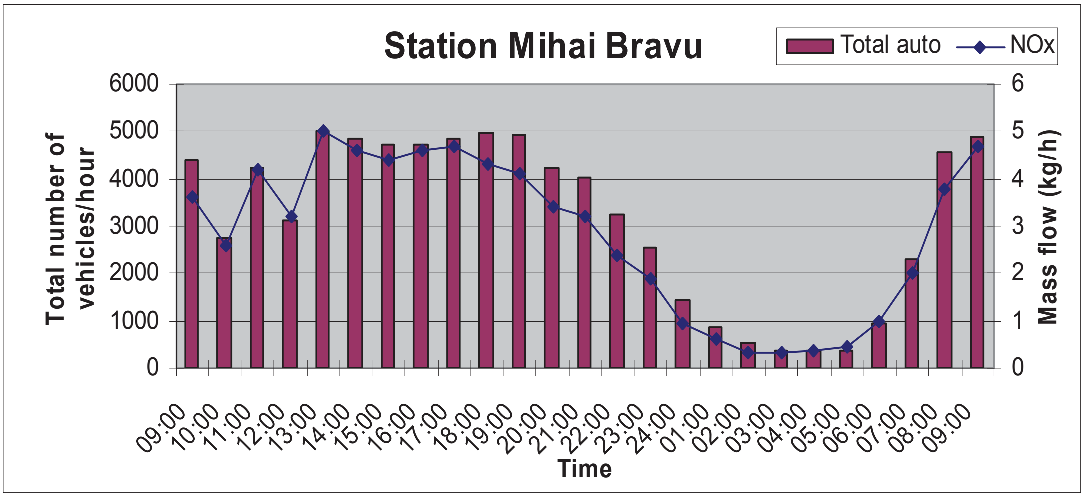
It will continue to track the achievement of two types of analyses:

- Study of troposphere response reaction at increasing man-made pressure exerted by transport activities with auto vehicles through correlation of the imissions measurements results with simultaneous monitoring of traffic.
- Identifying type of correlation between NO_2 and O_3 imission day values, recorded in a hot day, in downtown as well as outside Bucharest.

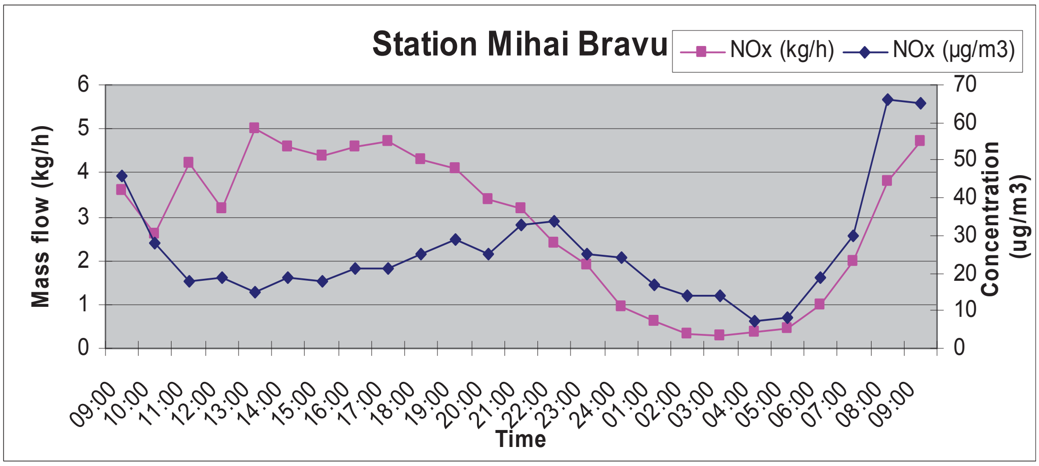
3.1. Evaluating the contribution of traffic at the pollution of Bucharest with nitrous oxides and carbon monoxide.

For the making of this study, an area characterized through intense traffic has been chosen – Mihai Bravu street, and the data used are the estimated daytime emissions to be generated by auto vehicle flow (with the help of a special software called IMPACT), over which imissions overlapped, resulted from measurements done in the same time interval, with equipment in the monitoring station's endowment, located in Mihai Bravu street, no. 62. IMPACT-ADEME 2000 software allows the quantification of consumed fuel quantity and main pollutants emitted by an auto vehicle flow, of which distribution is known in the conditions of a known infrastructure.

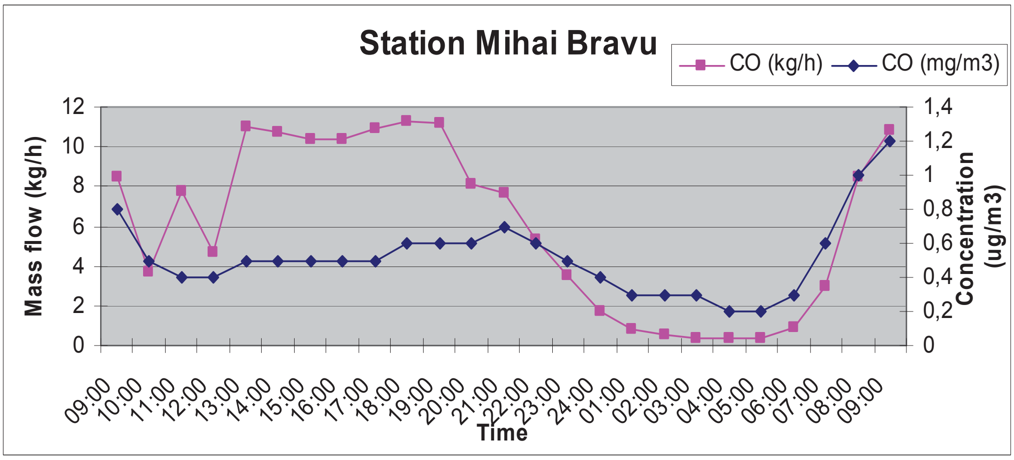
In pictures 3, 4 and 5 the results of this study are presented, study performed for the time interval 05/06-07/2007.



Picture 3. Traffic values and the nitrous oxides (NO_x) quantity, estimated to come from traffic, 05/06-07/2007



Picture 4. Emission / Imission NO_x



Picture 5. Emission / Imission CO

To follow the relation between the *emissions* that were forecasted to result from traffic and *imissions* measured in the analyzed area, the correlation coefficient between the two parameters (x and y) is calculated, using relation (1):

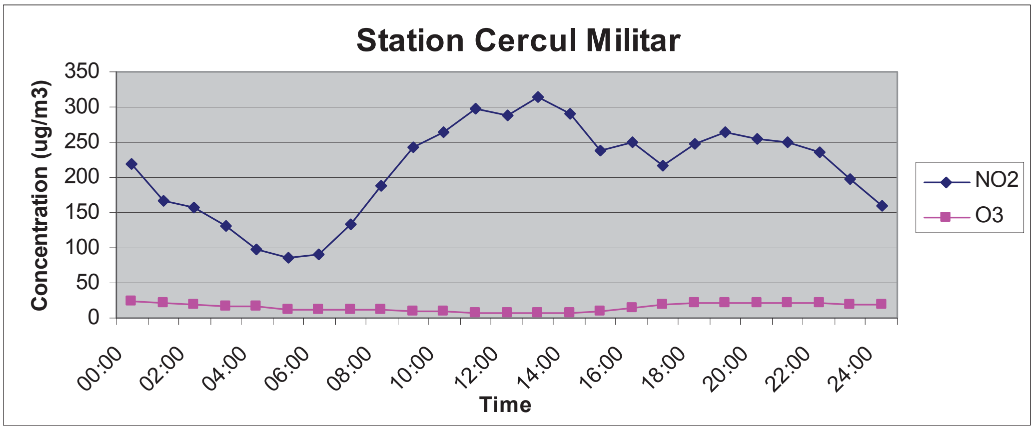
$$\rho = \frac{\sigma_{x,y}}{\sigma_x * \sigma_y} = \frac{\sigma_{x,y}}{\sqrt{\sigma_{x,x}} * \sqrt{\sigma_{y,y}}} = \frac{\frac{1}{n}\sum_i (x_i - x_{med})(y_i - y_{med})}{\sqrt{\frac{1}{n}\sum_i (x_i - x_{med})^2} * \sqrt{\frac{1}{n}\sum_i (y_i - y_{med})^2}} \quad (1)$$

The correlation coefficient between *NO_x emissions* that were forecasted to result from traffic and *NO_x imissions* is ***0.395***, which means that *the two analyzed parameters are directly correlated.*

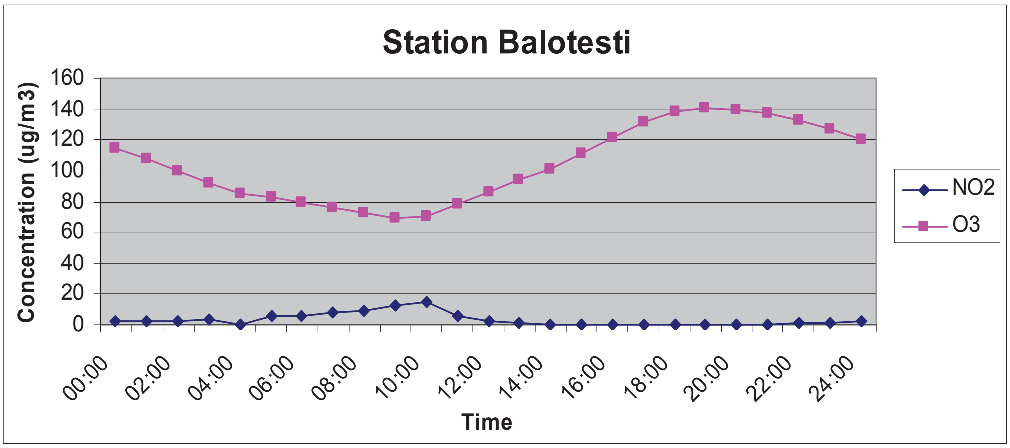
The correlation coefficient between *CO emissions* that were evaluated to result from traffic and the *CO imissions* is ***0.621***, which means that *the two analyzed parameters are direct strong correlated.*

3.2. Traffic and photochemical smog

This type of pollution appears especially above great urban congestions, and from the conditions that provide the production of *photochemical smog*, we can emphasize: introduction into the atmosphere of a high quantity of HC hydrocarbons and nitrous oxides NO_x (generally emanated from traffic), as well as the existence of certain time frames characterized through elevated temperatures and intensities of global solar radiation, generated by photochemical reactions [13]. Necessary data for this study is represented by hour averages of pollutants NO_2 and O_3 concentrations, measured in a summer day (07/20/2007), downtown as well as outside Bucharest. Daily variations of NO_2 and O_3 imissions are presented in pictures 6 and 7.



Picture 6. NO_2/O_3 imissions–urban



Picture 7. NO_2/O_3 imissions –rural

The correlation coefficient between *NO_2* and *O_3 day imissions*, at Cercul Militar station, based in downtown Bucharest, where traffic is very intense, is of **-0.19136**, which means that *the two analyzed parameters are reverse correlated*.

The correlation coefficient between *NO_2* and *O_3 day imissions*, at Balotesti station, based outside Bucharest, is of **-0,76089**, which means that *the two analyzed parameters are strongly reversed correlated*.

Therefore, the variation profiles of ozone and nitrous dioxide are "opposite".

Intense traffic recorded downtown (generator of a supplementary quantity of NO) and the special topography of the built perimeter (which strongly influences the dispersion and synergy of pollutants), lead to the obtaining of a reverse correlation between these two pollutants, but of a smaller value.

4. Conclusions

Urban pollution has, as a main component, traffic, that is in a continuous ascension.

Imission measurements that represent atmospheric air concentrations of the following pollutants: NO_x, CO (the most representative for traffic), have demonstrated the existence of a direct conditioning link regard if traffic hour flow. A *direct correlation* between forecasted *emissions* that result from traffic and *imissions* measured in the same area.

The highest values for nitrous oxides and carbon monoxide were registered in the central area (area well known for its intense traffic) and have decreased towards the periphery.

Spatial and temporal distributions of ozone differs from the pollutants mentioned above. The highest levels of O_3 concentrations have been recorded at the periphery and outside of Bucharest. A *reversed correlation* between ozone and nitrous dioxide concentrations has been noticed.

References

[1] *E. Angelino, R. Degani, M. Gnagnetti*, Traffic induced air pollution in Milan city: a modelling study – Urban transport V: urban transport and the environment for the 21st century, pp. 41-50, 2000

[2] *C. Borrego, O. Tchepel, N. Barros*, Impact of road traffic emissions on air quality of the Lisbon region, Atmospheric Environment, vol. 34, pp. 4683-4690, 2000.

[3] *T. Elbir*, Comparison of model predictions with the data of an urban air quality monitoring network in Izmir, Turkey, Atmospheric Environment, vol. 37, pp. 2149-2157, 2003.

[4] *P. Chandra Mouli, M. Praveen Kumar*, Monitoring of air pollution in indian metropolitan cities: modeling and quality indexing, International Journal of Environnement, vol. 21, pag. 365-382, 2003.

[5] *F. Shala, R. Hajdari, L. Latifi, H. Demolli, S. Shala,* Impact of transport on air quality in Gjilan town of Kosovo-particulate matters, 14th International Multidisciplinary Scientific Geoconferences, Bulgaria, pp.407-414, 2014

[6] Bucharest Regional Agency for Protecting the Environment, Annual reports

[7] *F. Ardelean*, Atmosphere pollution in the urban area, Doctoral thesis, Technical University of Civil Engineering Bucharest, 2005.

[8] *F. Ardelean, V. Iordache*, Study relating the pollution level in Bucharest, U.T.C.B. Scientific Bulletin, no. 1, pag. 41-50, 2009.
[9] *** The law on air quality surrounding no. 104/2011
[10] *T. Wonnacott, R. Wonnacott*, Statistique – Economie – Gestion – Sciences – Médecine, Éditions Economica, 1991.
[11] *C. Gavrila, C.P. Lungu, I. Gruia*, A Numerical Simulation of the Phenomena in Be Plasma, Proc. of SPIE Vol. 8001, pp.80013D1 - 80013D7, ISSN: 0277-786X, 2011
[12] *C. Gavrila I. Gruia, C. Lungu*, Determining the radial distribution of the emission coefficient from a plasma source – OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 3, No. 8, August 2009, p. 835 – 838, ISSN 1842-6573.
[13] *C. Gavrila, F. Ardelean, A. Coman, E. Burchiu*, Statistical Analysis for Prognosis of a Photochemical Smog Episode, Mathematical Modelling in Civil Engineering nr 2, ISSN 2066-6926, pp. 25-29, 2013