# Analysis of Atmospheric Pollutants in Bucharest in Correlation with Meteorological Parameters

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*In this paper we analyze the correlation between meteorological parameters (wind speed and direction, relative humidity, air temperature) and atmospheric pollutants in Bucharest during the cold period 26.02.2018-02.03.2018, which was based on the monitoring of the concentrations of nitrogen oxides, $NO_2$, $O_3$ and $SO_2$ sulfur dioxide within 24 h and the occurrence of exceedances above the prescribed limit. It was found based on the results obtained that the wind direction influences not only the concentrations of pollutants but also the correlation between the pollutants. Traffic pollutants were at the highest concentration when the wind speed was low. We have found that the highest average concentration for $NO_2$, $NO_x$, NO, $O_3$ occurred at 90% indicative humidity for vertical mixing of strong pollutants. Sulfur dioxide did not record exceeding over the limit standard in the analyzed period.*

*Keywords: urban environment, air pollution, $NO_x$, NO, $NO_2$, $SO_2$, $O_3$, air temperature, air humidity.*

Air quality is determined by air emissions from stationary and mobile sources as well as long-distance transport of pollutants [1].

Pollutants are transported to the air environment. The effects of pollution occur by changes of all the main meteorological elements, the decrease of the solar radiation and the increase of the temperature, the increase of the air humidity [2,3].

To date, 3000 atmospheric pollutants have been identified in their majority of organic. Sources of combustion, especially vehicles, emit about 500 compounds [9]. To understand the processes responsible for the spatial and temporal distribution of acid aerosols, a local analysis of wind direction, wind speed and atmospheric stability is required [10-12].

Atmospheric pollution has the greatest impact on the environment due to the quantity and diversity of pollutants, and due to the damage to geographical areas, atmospheric pollution is a global problem, the scale of which is the order of the years, emphasizing greenhouse effect and ozone depletion stratospheric [4]. Aspects on environmental pollution and soil depollution methods were studied in [25-33].

There is dependence between urban aerosols and weather conditions [12, 21]. This paper analyzes the relationship between meteorological parameters and atmospheric pollutants in Bucharest during the cold 26.02.2018-02.03.2018.

The wind direction influences the concentrations of pollutants and the correlation between the pollutants. Traffic pollutants are high when wind speed is low. At higher wind speeds, dust is entrained by the wind, thus contributing to the suspended particulate levels. The highest average concentration for $NO_2$, $NO_x$ and $O_3$ occurs at 90% humidity, indicating a strong vertical mixing of pollutants.

## Experimental part

*Materials and methods*

The NO, $NO_2$, $NO_x$, $O_3$, $SO_2$ pollutants were analyzed in correlation with the meteorological parameters: precipitation, temperature, humidity, direction and speed of wind, in the gloomy period 26.02.2018-02.03.2018 in Bucharest, with the AWS / EV weather station from Politehnica University of Bucharest, Faculty of Biotechnical Systems Engineering.

$NO_2$ pollutant is due to stationary mobile sources such as power plants, industrial enterprises, homes with their own heating sources.

Nitric acid formed by the reaction of $NO_2$ with $H_2O$ causes the formation of several types of corrosion, which affect the metallic structures, $H_2NO_3$ form nitrogen by reaction with various cations present in the atmosphere [13, 36]. The worst effect of $NO_2$ is the destruction of the ozone layer [1].

The oxidation reactions are:

$$N + O_2 \rightarrow NO + O \quad (1)$$

$$2NO + O_2 \rightarrow 2NO_2 \quad (2)$$

The main source of pollution of the atmosphere with sulfur oxides is the thermoelectric power plants which burning coal and fuel oil, and whose emissions may exceed 60% of the total sulfur oxide emissions in relation to $SO_2$. Emitted to atmosphere $SO_2$ reacts 1-2% with oxygen under the action of ultraviolet radiation, generating $SO_3$. This gas reacts with water vapor and forms sulfuric acid. When fog and high humidity is achieved a degree of transformation up to 15.7%. The impact on the environment is reflected by the amplification of the effects of chronic respiratory diseases [31-35]. In low concentrations it causes spasm and contraction of upper respiratory muscles in high concentrations, causes burning of respiratory and conjunctival mucous membranes, breathing disorders, choking [16-19].

The main pollutants resulting from the energy generation processes are $SO_2$, $NO_2$, which are the pollutants that form the basis of acid formation, which become factors of influence of the climate [6].

$SO_2$ can form aggressive chemical compounds in the free atmosphere. $SO_2$ enters photochemical or catalytic reactions with other pollutants in the atmosphere, forming sulfur trioxide ($SO_3$), sulfuric acid [6]. Sulfur oxidation reaction:

$$S + O_2 \rightarrow SO_2 \quad (3)$$

$$SO_2 + \frac{1}{2}O_2 \rightarrow SO_3 \quad (4)$$

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Under high humidity conditions, sulfuric acid forms:

$$SO_2 + H_2O \rightarrow H_2SO_4 \quad (5)$$

$$2SO_2 + 2H_2O + O_2 \rightarrow 2H_2SO_4 \quad (6)$$

The latter reaction is an oxidation reaction, which evolves rapidly in the presence of iron and magnesium sulphates and chlorides, which act as a catalyst for the reaction. Such reactions form the basis of the formation of acid rain.

The highest ozone concentration is found in the stratosphere (approximately 35 km high) and is about 10 ppm (parts per million).

Ozone acts as a protective layer for the Earth, protecting us from harmful UV rays.

The production and destruction of ozone in the atmosphere is described by Chapman's reactions:

Production:

$$\lambda < 240 \text{ nm}$$

$$O2 + h\nu = O \quad (7)$$

$$O + O_2 + M = O_3 + M \quad (8)$$

Destruction:

$$\lambda < 325 \text{ nm}$$

$$O3 + h\nu = O_2 + O \quad (9)$$

$$O + O3 = 2\,O_2 \quad (10)$$

where hv is the sun's UV radiation, M, it is an excited molecule.

When the M molecule returns to the fundamental state, energy is released in the form of heat. That is why the stratospheric temperature is higher than the troposphere, the conditions for heat and UV radiation required for ozone formation.

## Results and discussions

Bucharest is located in the S-SE part of Romania, having geographic coordinates between 25°49'50 "and 26° 27'15" east longitude and 44°44'30 "north latitude 44°14'05" consisting of two administrative-territorial units: Bucharest and Ilfov County, representing 0.76% of the total area of Romania. The Bucharest region is delimited by the counties of Prahova (N), Ialomita (E-NE), Calarasi (E-SE), Giurgiu (S-SV) and Dambovita.

The hourly concentrations of nitrogen dioxide, $SO_2$, $O_3$ were analyzed with the AWS / EV meteorological station at the Faculty of Biotechnical Systems Engineering at the Politehnica University of Bucharest. Concentrations of $NO_2$ in the air are assessed using the hourly limit value for human health protection (200µg / m$^3$) allowed to exceed 18 times per year and the annual limit value for human health protection (40µg / m$^3$) [13]. Regression analysis with the Medcalc program was performed and the NO, $NO_x$, $NO_2$, $SO_2$, $O_3$ concentrations were plotted against temperature, humidity, wind velocity during the analyzed period (26.02.-02.03.2018 in Bucharest) (figs. 3a -3h). The hourly concentrations of nitrogen dioxide in the air show an exceedance of the annual limit value for human health (40µg / m$^3$) during the period analyzed in Bucharest on 2 and 3 March 2018 in the 7-15 h interval when the wind speed was 0 m / s and the pollutants were at ground level, not being carried by the wind, the air temperature was low. The same exceedances of the annual limit values were recorded for $NO_x$, over the other days there were exceedances only for $O_3$.

The wind has an important role in transporting pollutants. It can intensify the action of pollution or the cleaning of the urban atmosphere. The wind contributes to spreading pollutants at greater or smaller distances from the source depending on its direction and speed, and in calm conditions the pollutants stay near the source. The importance of the wind environment for the quality of the environment is related to the location of the sources of air pollution to the populated centers. It is evident from the graphical representation of the wind direction (fig. 1) that the main wind directions are east (ES and ESE) and N (NE, NV). The average frequencies in the analyzed period for the east and west winds were 25.6 and 34.2%. The $NO_x$, NO and $O_3$ concentrations were highest when the transport of wind pollutants was from the East, from intensive traffic areas in industrial areas. The wind speed is also of particular importance in the pollutant diffusion process, the concentration of which is inversely proportional to the wind speed in the analyzed period, the concentration of the pollutants increased when the wind speed had values equal to 0 m / s (fig. 2). The air temperature was low, the relative humidity of the air was high [16].

Temperature variations influence the dispersion and transport of pollutants and on health. The temperature decreases with altitude, when a layer of cold air is absorbed under a layer of warm air, there is a thermal inversion, the pollutants accumulate at the surface of the earth. With this phenomenon, ozone layer destruction takes place to filter out the ultraviolet radiation [22]. When the ultraviolet radiation is not stopped, the greenhouse effect occurs, causing the average temperature of the planet to rise. The thermal inversion layer acts as a lid preventing the dispersion and transport of pollutants.

Air humidity has an important role in the climate-pollution relationship [14-16]. In the cold season of the year, when the air is over-saturated with vapors, humid smog may occur in the urban atmosphere Air humidity can be an aggravating factor in impurity because in periods of high humidity dispersion of impurities is hampered by weak air movements [25]. Relative moisture is recorded when the air temperature is low (in winter) and in 24 h during the morning. Solid impurities have the role of condensation nuclei for air vapor in the air, therefore high moisture prevents the dispersion of pollutants [14,15]. When moisture is high, chemical reactions occur in the chain when water vapor comes into contact with noxes, degrading the air quality.

Emissions from city-driven vehicles, industry, natural dispersion conditions are responsible for the high concentrations of pollutants observed in the large metropolitan area of Bucharest.

It can be seen that the air pollution level is high during this winter because the temperature is low due to the traffic density. The concentrations of $O_3$, $NO_x$ and $NO_2$ are high due to the high emissions of motor vehicles. There is a high level of pollutants, indicating that the problem of air pollution is in fact regional, not limited to the city's borders [23, 24]. Winds can carry moisture or aerosol particles from distant sources [25]. Correlation analysis indicates a significant negative correlation between total urban concentration and wind speed.

I realised regression analyzes using the medcalc program and we graphically plotted the dependence of the atmospheric pollutant concentrations on the meteorological parameters in the cold period 26.02.-02.03. 2018. It is noticed that atmospheric pollutants exceeded the standard value when the humidity had high values, the wind speed was low, the air temperature had low values (figs. 3a-3r).

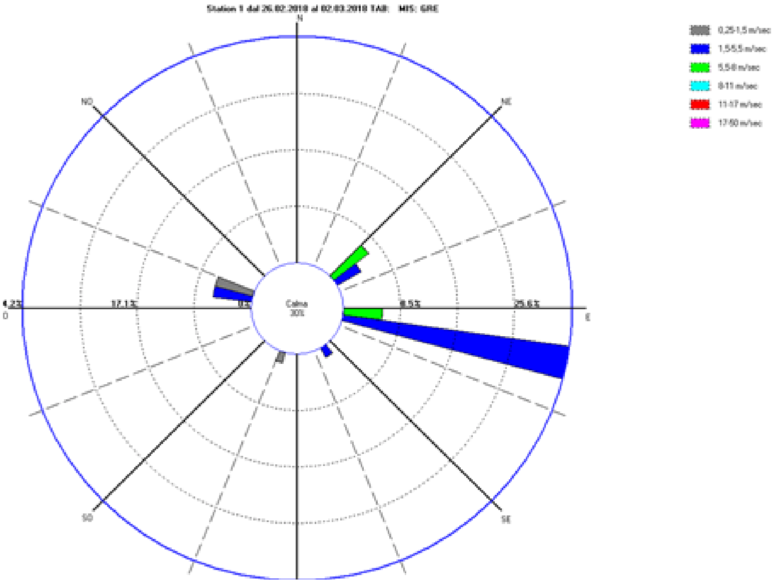

Fig. 1. Graphical representation of the wind direction

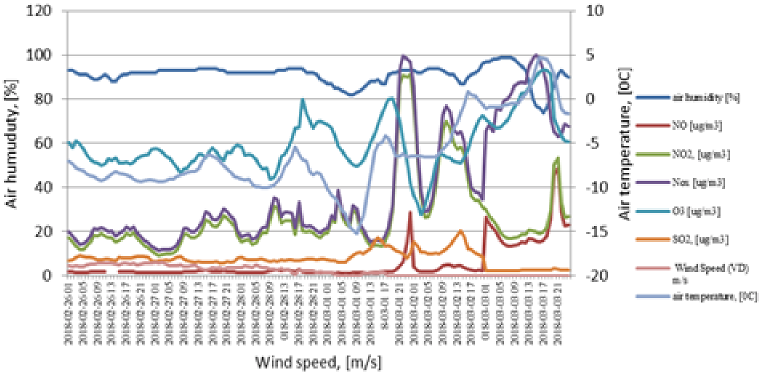


Fig.2. Graphical representation of concentrations of atmospheric pollutants in correlation with some meteorological parameters

I realised multiple regression using the medcalc program to verify the veracity of the correlation between the meteorological parameters and the pollutant concentrations analyzed during the gloomy period in Bucharest. The interpretation of the p values is done in most statistical tests as follows: $p < 0.05$, the statistical link is significant (95% confidence); $p < 0.01$, the statistical link is significant (99% confidence); $p < 0.001$, the statistical link is highly significant (99.9% confidence); $p > 0.05$, the statistical link is insignificant [20].

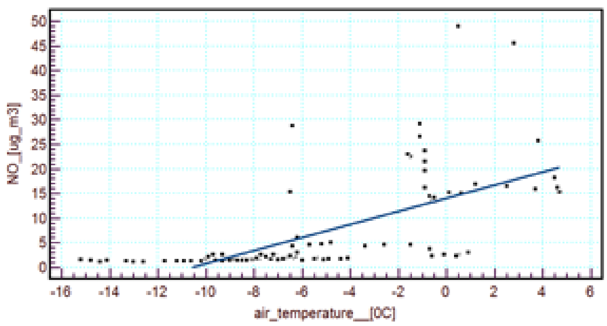


Figure 3 a

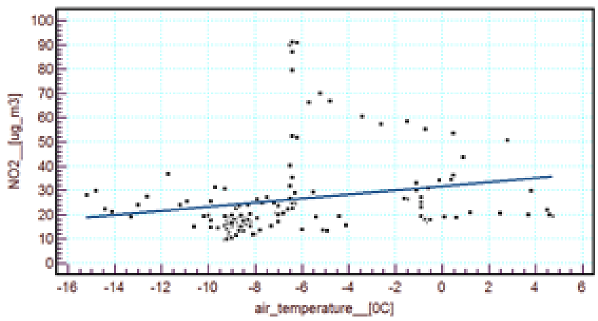


Figure 3 b

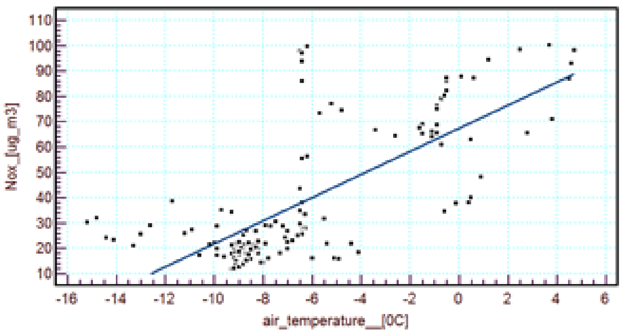


Figure 3 c

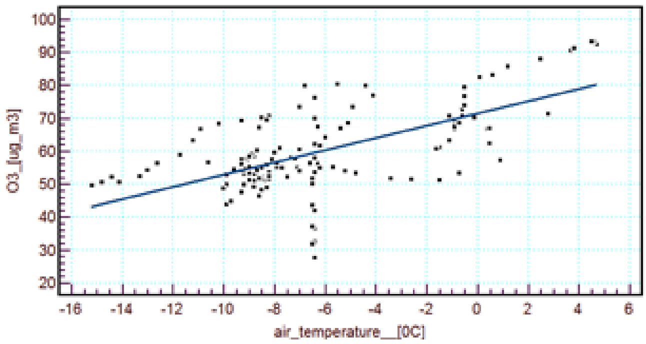


Figure 3 d

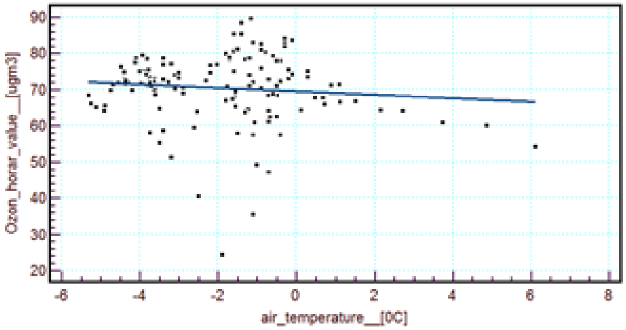


Figure 3 e

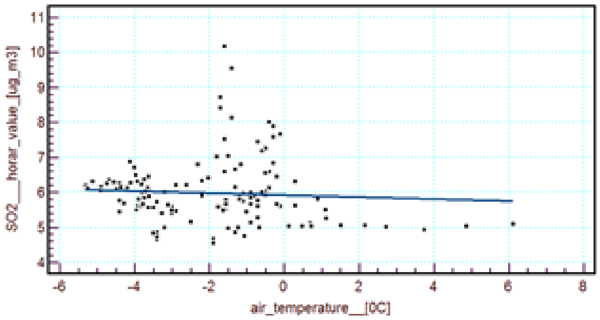


Figure 3 f

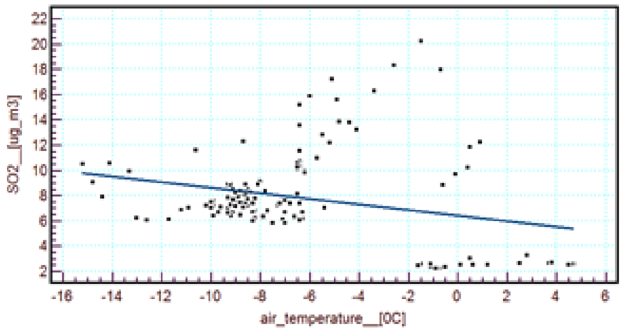


Fig. 3 g. Dependence of atmospheric pollutants (NO, $NO_x$, $NO_2$, $SO_2$, $O_3$) on air temperature

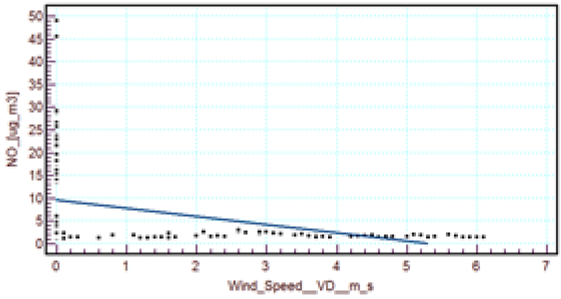


Figure 3 h

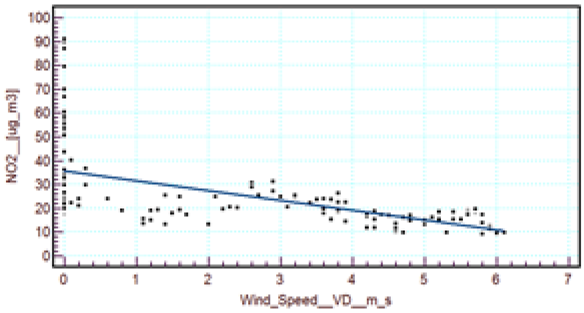


Figure 3 i

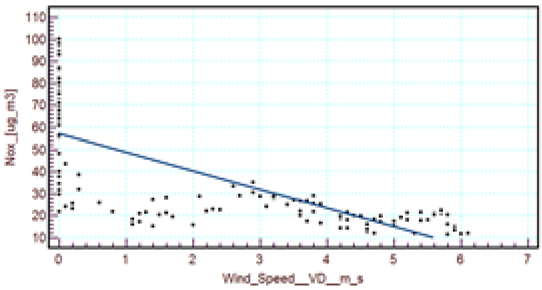


Figure 3 j

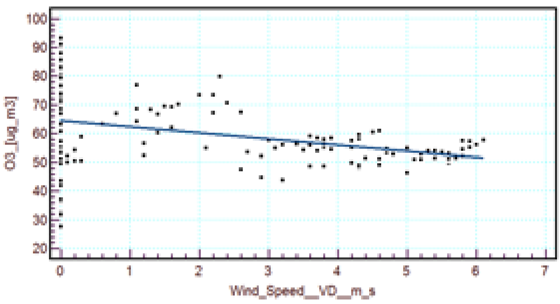


Figure 3 k

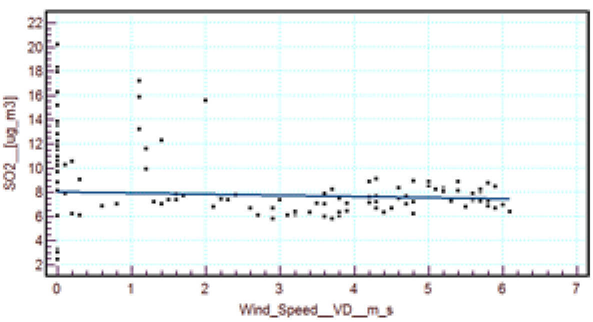


Fig. 3 l. Dependence of atmospheric pollutants (NO, $NO_x$, $NO_2$, $SO_2$, $O_3$) on wind speed

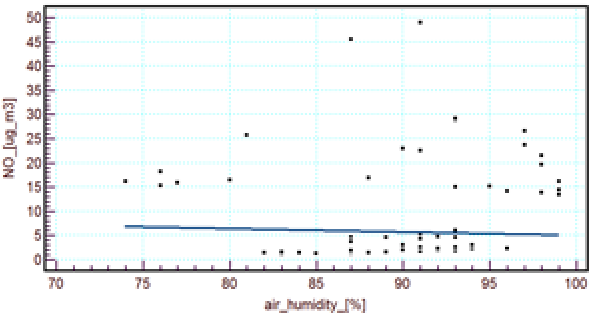


Figure 3 m

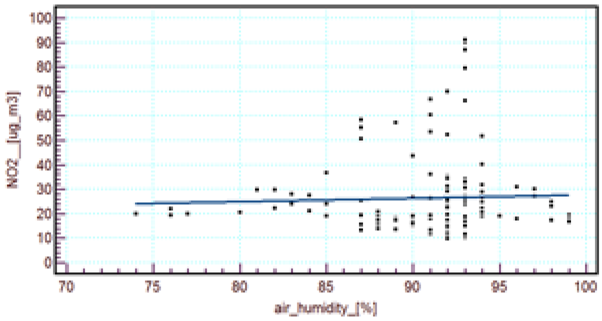


Figure 3 n

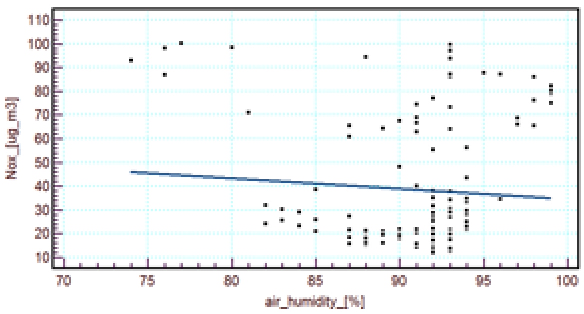


Figure 3 o

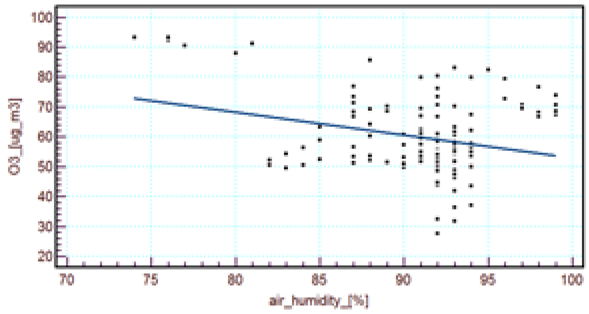


Figure 3 p

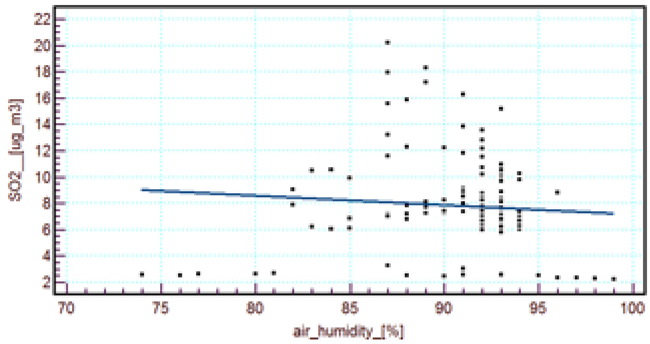


Fig. 3 r. Atmospheric pollutants (NO, $NO_x$, $NO_2$, $SO_2$, $O_3$) depend on the relative humidity of the air

I have verified by multiple regression analysis with medcalc program, pollutant dependence on relative humidity, air temperature, wind speed. From the multiple regression analysis of the correlation of atmospheric pollutant concentrations with relative air humidity, it is observed that there is a correlation, the statistical link is significant (P = 0.002, confidence 99%).

```
Dependent Y   : air_humidity_[%]

Sample size                      =        137
Coefficient of determination     =          0,1327
  R-adjusted = 0,0996
Multiple correlation coefficient =          0,3643
Residual standard deviation      =          4,1971

--- REGRESSION EQUATION --------------------------------------------
Independent variables      Coefficient     Std.Error      t        P
(Constant)                   100,54844
NO_[ug_m3]                    -0,02232       0,06675   -0,334   0,7386
NO2__[ug_m3]                   0,04054       0,03985    1,017   0,3109
Nox_[ug_m3]                   -0,01457       0,02774   -0,525   0,6003
O3_[ug_m3]                    -0,11538       0,03900   -2,959   0,0037
SO2__[ug_m3]                  -0,38461       0,15073   -2,552   0,0119

-- ANALYSIS OF VARIANCE --------------------------------------------
Source            DF        Sum of Squares         Mean Square
Regression         5             353,1546             70,6309
Residual         131            2307,6629             17,6157

F-Ratio = 4,0095       P = 0,002

-- ZERO ORDER CORRELATION COEFFICIENTS -----------------------------
-0,036  for  NO_[ug_m3]
 0,030  for  NO2__[ug_m3]
-0,082  for  Nox_[ug_m3]
-0,280  for  O3_[ug_m3]
-0,089  for  SO2__[ug_m3]
```

From the multiple regression analysis of the correlation of atmospheric pollutant concentrations to wind speed, it is observed that there is a correlation, the statistical link is highly significant (99.9% confidence, $P < 0.001$).

```
Dependent Y    : Wind_Speed__VD__m_s

Sample size                       =        137
Coefficient of determination      =          0,5866
  R-adjusted = 0,5709
Multiple correlation coefficient =          0,7659
Residual standard deviation       =          1,4211

--- REGRESSION EQUATION -------------------------------------------
Independent variables      Coefficient    Std.Error      t         P
(Constant)                      8,05154
NO_[ug_m3]                     -0,03299     0,02260   -1,460    0,1468
NO2__[ug_m3]                   -0,01220     0,01349   -0,905    0,3674
Nox_[ug_m3]                    -0,04418     0,00939   -4,705   <0,0001
O3_[ug_m3]                     -0,03811     0,01320   -2,886    0,0046
SO2__[ug_m3]                   -0,18004     0,05103   -3,528    0,0006

-- ANALYSIS OF VARIANCE --------------------------------------------
Source            DF         Sum of Squares          Mean Square
Regression         5              375,4438              75,0888
Residual         131              264,5521               2,0195

F-Ratio = 37,1822        P < 0,001

-- ZERO ORDER CORRELATION COEFFICIENTS -----------------------------
-0,459   for   NO_[ug_m3]
-0,527   for   NO2__[ug_m3]
-0,703   for   Nox_[ug_m3]
-0,369   for   O3_[ug_m3]
-0,051   for   SO2__[ug_m3]
```

From the multiple regression analysis of the correlation of the atmospheric air temperature concentrations, it is observed that there is a correlation, the statistical link is highly significant (confidence 99.9%, $P < 0.001$).

```
Dependent Y    : air_temperature__[OC]

Sample size                       =        137
Coefficient of determination      =          0,7463
  R-adjusted = 0,7366
Multiple correlation coefficient =          0,8639
Residual standard deviation       =          2,2006

--- REGRESSION EQUATION -------------------------------------------
Independent variables      Coefficient    Std.Error      t         P
(Constant)                    -17,57192
NO_[ug_m3]                      0,19344     0,03500    5,527   <0,0001
NO2__[ug_m3]                   -0,09254     0,02089   -4,429   <0,0001
Nox_[ug_m3]                     0,10733     0,01454    7,381   <0,0001
O3_[ug_m3]                      0,09086     0,02045    4,444   <0,0001
SO2__[ug_m3]                    0,39358     0,07903    4,980   <0,0001

-- ANALYSIS OF VARIANCE --------------------------------------------
Source            DF         Sum of Squares          Mean Square
Regression         5             1866,2727             373,2545
Residual         131              634,3895               4,8427

F-Ratio = 77,0762        P < 0,001

-- ZERO ORDER CORRELATION COEFFICIENTS -----------------------------
 0,674   for   NO_[ug_m3]
 0,204   for   NO2__[ug_m3]
 0,731   for   Nox_[ug_m3]
 0,634   for   O3_[ug_m3]
-0,263   for   SO2__[ug_m3]
```

We have found that, the highest average concentration for $O_3$, $NO_x$ and $NO_2$ was at humidity greater than or equal to 90%. This can be attributed mainly to the increased oxidation of the afternoon hydrocarbons, which support the production of ozone [13].

Concentrations of $NO_2$ are slightly higher at lower relative humidity because the $NO_2$ reaction with OH is low. For the other highest pollutants, the average concentrations occurred at a humidity of over 80%. An increase in humidity reflects an increase in air pollution [13].

The highest average concentration of surface ozone occurred at a humidity of over 90%. It is concluded that there is a correlation between atmospheric pollutants and relative humidity.

## Conclusions

The reason for the study was to determine how the meteorological parameters influence the concentrations of pollutants. Based on the present study, it can be concluded that the relative wind and humidity influence the behavior of atmospheric pollutants. Pollutants associated with traffic (eg $NO_x$, $NO_2$) had high concentrations when the wind speed was low. Based on relative humidity, we found that the highest average concentration for $NO_2$ and $NO_x$ occurred at humidity above 90%. This may be the main thing attributed to high oil oxidation in the afternoon, which sustain ozone production.

For the other components, the highest average concentrations occurred at a humidity of over 90%. An increase in humidity reflects an increase in air pollution. In the case of pollutants, $O_3$ surface ozone (93.26% at 4.7 ° C) and $NO_2$ show a temperature-increasing trend. Sulfur dioxide did not record over-the-limit in the analyzed periodof the study was to determine how the meteorological parameters influence the concentrations of pollutants. Based on the present study, it can be concluded that the relative wind and humidity influence the behavior of atmospheric pollutants. Pollutants associated with traffic (eg $NO_x$, $NO_2$) had high concentrations when the wind speed was low. Based on relative humidity, we found that the highest average concentration for $NO_2$ and $NO_x$ occurred at humidity above 90%. This may be the main thing attributed to high oil oxidation in the afternoon, which sustain ozone production.

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