

Air quality analysis for a metropolitan area in Romania during the first half of 2021

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Abstract. This paper aims to interpret and to use within a statistical analysis the concentration profiles of the main air pollutants – i.e., nitrogen oxides (NO_x), sulfur dioxide (SO₂), carbon monoxide (CO) and suspended particulate matter (PM₁₀) – results recorded during the first half of 2021 by two air quality monitoring stations in Craiova, which is an important metropolitan area in Southern Romania. Another goal of the paper is finding the best numerical diffusion model to fit the recorded values for PM₁₀, as this pollutant seems to be the major problem, because its daily average is often higher than the European Union threshold, meaning that imperative measures have to be taken for reducing particulate matter concentration in Craiova (like in other major Romanian metropolitan areas), in order for Romania to get the exoneration regarding air pollution from the European Union and, of course, for its citizens to improve the quality of their lives.

1 Introduction

A large number of epidemiological studies conducted around the world lead to associations between air pollutants and excesses in daily mortality and morbidity [1-4].

As air pollution represents such a stringent problem of the modern society, the current work consists in gathering and mathematically modeling a series of results which were obtained in Craiova, during the first half of 2021, picturing the evolution of atmospheric pollutants' concentration (the most representative air pollutants were produced within the urban agglomeration of Craiova by linear or point pollution sources – mainly city transports and coal-fired power plants, respectively).

To achieve an increasing air quality in the urban agglomeration of Craiova (which is obviously a fundamental aspect in increasing life quality), several measures have to be taken for reducing the concentration of particles found in suspension in the atmosphere and also the concentrations of the gaseous pollutants that are present in the inspired air.

The main air pollutants that shall be investigate within this paper are: nitrogen oxides (NO_x), sulfur dioxide (SO₂), carbon monoxide (CO) and suspended particulate matter (PM₁₀).

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Air quality has been proven to affect our health, as living in a polluted environment signifies a worse quality of life. Air pollution causes more than six million deaths a year worldwide. Among others, growth of the urban population, in addition to the way in which the energy in urban areas is consumed, result in the emission of large quantities of gases and particles that are harmful to human health [5]. Urban populations are more exposed to the air pollution (especially the children and the elderly) and, particularly, people who are already ill are particularly vulnerable.

It is known that physical and mental wellbeing is differently disturbed by the air pollution that we are exposed to [6]. There are many consequences, as different physical functions might be harmed. The most usual organs and systems that are in risk to be damaged are: the respiratory and cardiovascular system; the eyes; nose and throat; reproductive organs; the liver; the spleen; the blood and, of course, the nervous system.

2 Preliminaries

Values recorded for the four major atmospheric pollutants previously mentioned at two modern automatic air quality monitoring stations shall be presented in this paper, in order to compare them with their limit-values.

2.1 Limit-values for the main pollutants

According to the Law 104 /June 15th, 2011 [5], the hourly limit-value for NO₂ is 200 µg/m³, in order to preserve health protection.

Similarly, the same law states that 350 µg/m³ is the hourly limit-value for SO₂ and that 10 mg/m³ is the daily limit-value of the eight hours averages for CO, whereas the daily average value of PM₁₀ concentration should not exceed 50 µg/m³.

2.2 Automatic air quality monitoring stations

The two selected stations are representative for Craiova urban agglomeration: RO0078A (DJ1), situated on the main street (Calea Bucureşti) and RO0079A (DJ2), which is located near City Hall; data points were plotted in four charts – one for each major air pollutant previously mentioned; these charts will be shown in what follows (there are obviously too many data to be given as a table).

3 Values recorded for the main pollutants

The concentrations of the air pollutants are influenced by the air pollutants' levels, meteorological conditions and topography.

3.1 Values recorded for nitrogen oxides

The nitrogen oxides are generally denoted as NO_x. The first chart represents the hourly values recorded for NO₂ (the main part of NO_x) at both stations, during the first half of 2021.

With a single exception, the graph shows no alarming temporal variability of NO₂ (and therefore for NO_x).

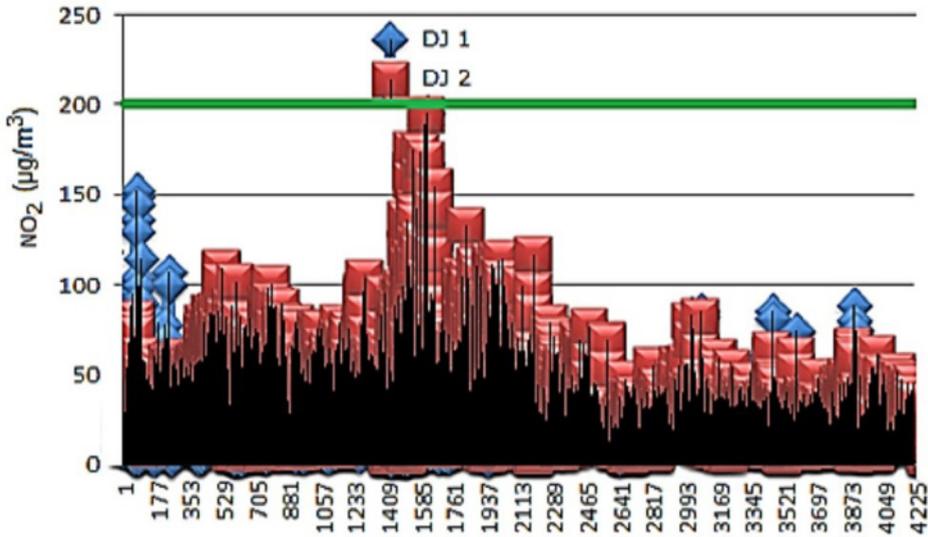


Fig. 1. Temporal variability of NO₂ (main part of NO_x) concentration values, recorded at both DJ 1 and DJ 2 stations.

3.2 Values recorded for sulfur dioxide

The second chart represents the hourly values recorded for sulfur dioxide, SO₂, at both DJ 1 and DJ 2 stations, during the above mentioned period.

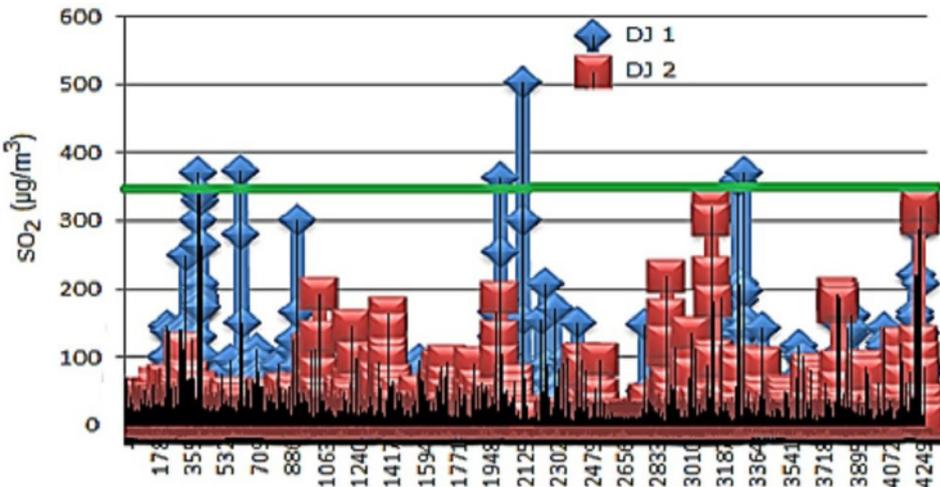


Fig. 2. Temporal variability of SO₂ concentration values, recorded at both DJ 1 and DJ 2 stations.

Once again, the graph shows no really worrying temporal variability, although the imposed limit of 350 µg/m³ was sometimes exceeded.

3.3 Values recorded for carbon monoxide

The third chart represents the eight-hour average values recorded for carbon monoxide, CO, at both DJ 1 and DJ 2.

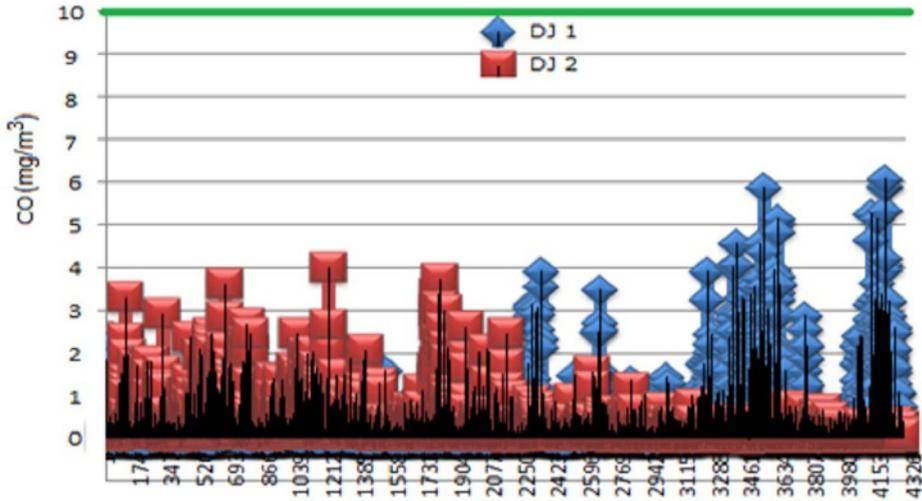


Fig. 3. Temporal variability of CO concentration values, recorded at both DJ 1 and DJ 2 stations.

The graph shows no upsetting temporal variability of CO, the values being far away from the eight-hour limit.

3.4 Values recorded for suspended particulate matter

The fourth chart represents the daily values recorded for PM_{10} at DJ 1 only, during the investigation periods (this one being closer to the meteorological station which recorded the wind speed).

Indeed, these data were then correlated to the wind speed, showing that, as it was expected, a low value for the wind velocity usually leads to high values of the particulate matter in the atmosphere (according to Fick's law).

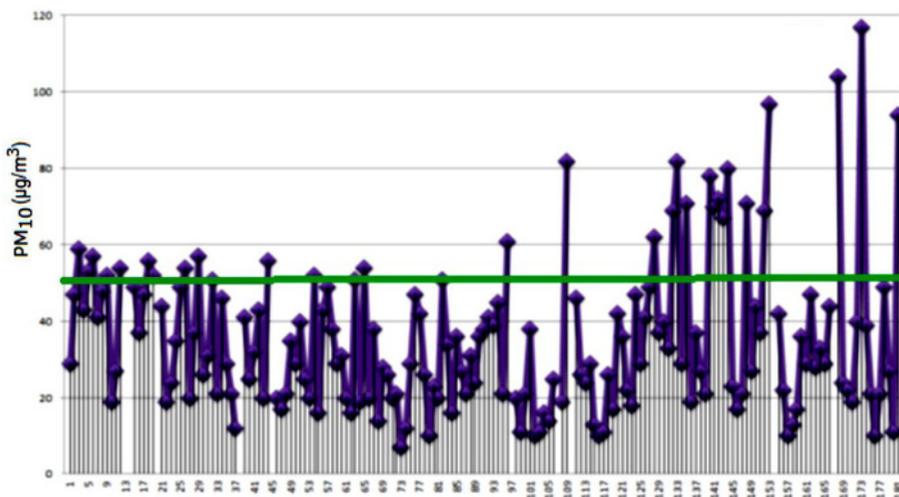


Fig. 4. Temporal variability of PM_{10} concentration values, recorded at DJ 1 station only

Most of the time, no disquieting values were recorded, but the number of times when the limit value of $50 \mu\text{g}/\text{m}^3$ was exceeded requires more concern about the human health. The correlation between the PM_{10} concentration and the wind velocity were also plotted into a chart.

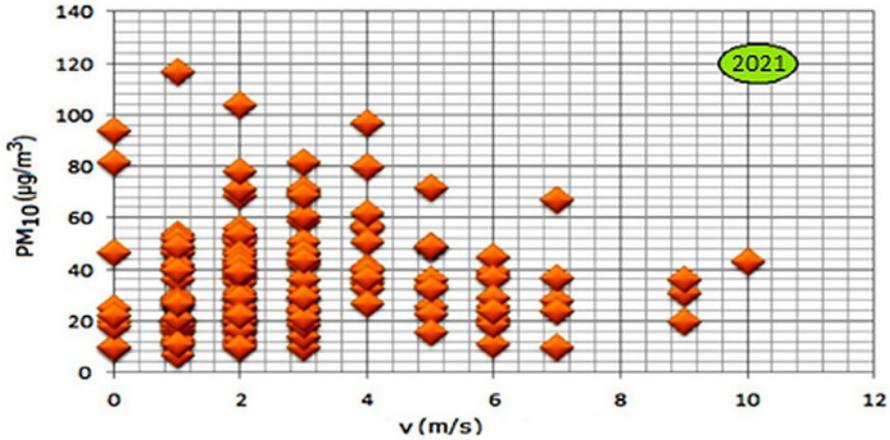


Fig. 5. Correlation between the PM_{10} concentration values and the wind speed

4 Statistical analysis

Statistical analysis and modeling has important benefits, such as: application of appropriate statistical analysis techniques; development of appropriate conclusions and key learning from the data; ensuring results address experimental objectives; maximizing information gained from the data; maximizing chances of the interpretation being successful.

4.1 Log-normal distribution

In the probability theory, a log-normal distribution is a probability distribution of a random variable whose logarithm is normally distributed. Parameters of the log-normal distribution, namely the geometric mean μ_g and the standard geometric deviation, σ_g , are defined by (1) and (2), respectively.

4.2 Probability density function

The probability density function of the log-normal distribution, the cumulative distribution function, which is defined as the probability of the variable x to be smaller than a critical value x_0 and the complementary distribution function, which is defined as the probability of the variable x exceeding the critical value x_0 , are given by (3), (4) and (5), respectively.

The variable m that is involved in (4) is calculated by (6). In (1)-(6), variable x represents the concentration of a pollutant.

$$\mu_g = (x_1 \cdot x_2 \cdot \dots \cdot x_N)^{\frac{1}{N}} \quad (1)$$

$$\sigma_g = \exp \left\{ \frac{1}{N} \left[\sum_{i=1}^N (\ln x_i - \ln \mu_g)^2 \right] \right\}^{\frac{1}{2}} \quad (2)$$

$$p(x_i) = \frac{1}{\sqrt{2\pi} \times x_i \times \ln \sigma_g} \exp \left[-\frac{(\ln x_i - \ln \mu_g)^2}{2 \times \ln^2 \sigma_g} \right] \quad (3)$$

$$F(x) = \Pr[x_i < x_0] = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^m e^{-\frac{t^2}{2}} dt \quad (4)$$

$$F'(x) = \Pr[x_i > x_0] = 1 - F(x) \quad (5)$$

$$m = \frac{(\ln x_0 - \ln \mu_g)}{\ln \sigma_g} \quad (6)$$

4.3 Statistical indexes

The suitability of a distribution can be examined via statistical indexes, to perform the computational analysis. The mean bias error (MBE), the mean absolute error (MAE), the root mean square error (RMSE), its systematic (RMSE_s) and unsystematic (RMSE_u) components and the index of agreement (d) are those that will be calculated within this study.

A drawback of RMSE is that few large errors in the sum may produce a significant increase in its value, whereas a drawback of MBE means that an overestimation in one observation may be canceled by an underestimation in the other (P and O represent the predicted and the observed values respectively, whereas the overbar indicates mean values).

$$MBE = \bar{P} - \bar{O} \quad (7)$$

$$MAE = \frac{1}{N} \sum_{i=1}^N |P_i - O_i| \quad (8)$$

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^N (P_i - O_i)^2 \right]^{\frac{1}{2}} \quad (9)$$

$$RMSE_s = \left[\frac{1}{N} \sum_{i=1}^N (P_i^* - O_i)^2 \right]^{\frac{1}{2}} \quad (10)$$

$$RMSE_u = \left[\frac{1}{N} \sum_{i=1}^N (P_i^* - P_i)^2 \right]^{\frac{1}{2}} \quad (11)$$

$$d = 1 - \frac{\sum_{i=1}^N (P_i - O_i)^2}{\sum_{i=1}^N (|P_i - \bar{O}| + |O_i - \bar{O}|)^2} \quad (12)$$

$$t = \left[\frac{(N-1)MBE^2}{RMSE^2 - MBE^2} \right]^{\frac{1}{2}} \quad (13)$$

In (10) and (11), P_i^* is calculated as $a + b \cdot O_i$, where a and b are the intercept and the slope of the least squares line between the predicted and the observed values, whereas N is the number of concentration classes in which the data are divided. The reduction R in current emissions to meet air quality standards is often calculated by “the rollback equation” (14), where $E\{C\}$ is the current annual mean value of the pollutant’s concentration, $E\{C\}_s$ is the annual mean value corresponding to air quality standards and C_b is the background concentration.

$$R = \frac{E\{C\} - E\{C\}_s}{E\{C\} - C_b} \quad (14)$$

The mean concentration for log-normal distribution can be therefore calculated.

$$\ln E\{C\} = \ln \mu_g + \frac{1}{2} \ln^2 \sigma_g \quad (15)$$

When the parent probability distribution of air pollutants is properly chosen, this specific distribution can be used to estimate the mean concentration, the number of times when the air quality standards is exceeded and the emission sources reduction, to meet the air quality standards.

Fig. 6 shows that the log-normal distribution fits very well to the real distribution of the PM₁₀ concentration values.

4.4 Verifying goodness-of-fit

The goodness-of-fit is verified by calculating the statistical indicators previously presented.

The mean of the observed values is identical to the mean of predicted values ($O = P$).

Verifying goodness-of-fit shows that the log-normal distribution is capable to simulate the experimental data the most accurately.

There is a good accordance between parent and observed distribution.

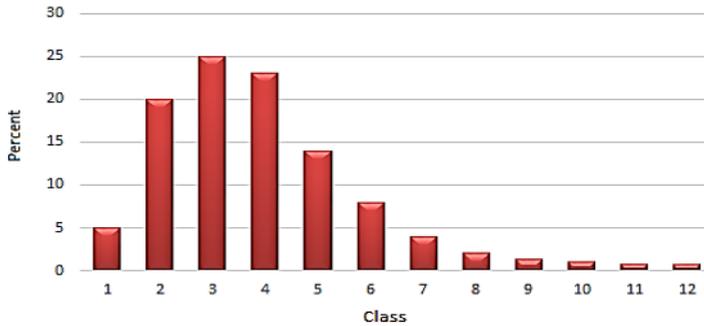


Fig. 6. Log-normal distribution of the real data

Conclusion

In this study, the log-normal distribution is applied in order to describe the observed distribution of PM_{10} levels in Craiova city – capital of Dolj County (south-western Romania).

The first conclusion is that the PM_{10} levels (slightly higher compared to the air quality standards imposed by the European Union) are very good fitted by a log-normal distribution, which also is valuable as a prediction.

By comparing the data with the ones obtained through other similar studies recently performed in India or Spain [1-4], one can see that air quality in Craiova does not constitute a reason for concern, although the main air pollutants' levels are not the best possible.

Taking into account the results of this study, the following measures are recommended: closing the historical center for road traffic and revitalizing it, which would be advantageous in both short and long term; developing green areas; implementing an efficient traffic routing and traffic lights system in order to provide functional links between the central roads and the other roads; implementing roundabouts in order to eliminate increasing concentrations of air pollutants and reducing road congestion by default; improving public transport, using biofuels in the bus fleet; using electric vehicles, thus eliminating the generation of additional emissions; carrying out desulphurization installations by the local energy complex; wetting the ash and slag deposits in the dry season, in order to eliminate flying ash involvement.

It is estimated that, by implementing these measures, air pollution would decrease by 5% by closing the road and revitalizing its historical center, also with 2% by developing and introducing roundabouts and proper traffic lights routing system, with another 4% after completing the subway passage and putting it into use and other 4% by using electric vehicles and alternative fuels.

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