Study of PM10 and PM2.5 Emissions in Urban Conditions

Asen Asenov, Jonas Matijošius, Velizara Pencheva and Desislava Beleva

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Asen Asenov  
Department of Transport, University of Ruse,  
Ruse, Bulgaria  
asasenov@uni-ruse.bg

Jonas Matijosius  
Mechanical Science Institute, Vilnius Gediminas Technical University  
Vilnius, Lithuania  
jonas.matijosius@vlniustech.lt

Velizara Pencheva  
Department of Transport, University of Ruse,  
Ruse, Bulgaria  
vpenceva@uni-ruse.bg

Dessislava Beleva  
Directorate “Ecology and Green Urban Environment”, Ruse Municipality,  
Ruse, Bulgaria  
desi_beleva_80@abv.bg

Abstract — A study was made of the concentration of PM10 and PM2.5 emitted in a medium-sized city in Bulgaria. The relationship between PM10 and PM2.5 was established for the different seasons of the year. Data processing was done with the program product Origin. The analyzed data are presented with the average hourly emission values for a period of one year. The results show the trend of change based on the Pearson test. The applied methodology for evaluating the pollution based on the average hourly value of the emissions shows what the PM2.5 and PM10 pollution are in the city of Ruse. When considering pollution by the hourly average value, PM2.5 pollution shows much higher values than PM10.

Keywords — PM10, PM2.5, emissions assessment methodology, statistical analysis

I. INTRODUCTION

According to the World Health Organisation, PM10 and PM2.5, O3, NO3, SO2, measured in µg/m³, and CO, measured in mg/m³, have a serious impact on the health of people in cities. Substantial importance is given to PM10 and PM2.5, which are released by industry, vehicles, household heating, and dust that is on the ground and is carried in the air. The wind further intensifies the effect. Due to their small size, these particles easily penetrate human lungs, leading to the assumption that they cause serious diseases related to the cardiovascular and respiratory systems [1]. In connection with this, in 2021, it is proposed that the average annual values of PM10 not exceed 15 µg/m³, and the average day and night values be 45 µg/m³. For PM2.5, the annual average values should not exceed 5 µg/m³, and the day-night average should be 15 µg/m³.

Studies on the effects of PM10 and SO2 in China show that pregnant women and young children who are exposed to these emissions because they live in such areas have an increased risk of allergic rhinitis [2]. We have not yet investigated the influence of PM2.5 and recommend it as the next cause for analysis. Research from various countries has led the corresponding authors to propose various methods for measuring and forecasting urban air pollution. Using the PRISMA methodology, Macedonian researchers analyse and determine that there are suitable, accurate methods for different conditions that can be used by decision-makers to deal with pollution [3]. In their work, serious attention is paid to PM10 and PM2.5 pollution in the city of Skopje, which is exposed to the strong influence of these emissions during the winter period due to the use of wood and coal for heating, transportation by old cars, and industry. In order for the mentioned models to predict pollution with high accuracy, the authors note that measurement methods are also essential, which often lead to inaccurate predictions due to the use of low-accuracy sensors. In this regard, it is of interest to analyse the pollution with PM10 and PM2.5 in a medium-sized border town in Bulgaria, through which there is a transit flow of car traffic, a large part of the inhabitants are heated with wood and coal, they mainly use cars older than 15 years, and there are industrial zones on the outskirts.

II. DESCRIPTION OF THE PM10 AND PM2.5

When a systematic analysis was made of the problematic places in Algeria, it was determined that the main factors can be divided into the following groups, ordered by weight, according to Pareto analysis: operations, infrastructure, human factors, rolling stock, and environmental factors [4]. Environmental factors are associated with noise and air emissions, while other factors influence the creation of their quantity.

Globally, authors from 419 sources conducted studies on the causes of the measured concentrations of PM10 and PM2.5 [5]:

- 25% of urban PM10 is from traffic, 18% from industrial activities, 15% from domestic fuel burning, and 42% from other sources.
- 25% of urban PM 2.5 is from traffic, 15% from industrial activities, 20% from domestic fuel combustion, and 40% from other sources.

In this case, the main cause of pollution is human activity, aided by atmospheric conditions and especially wind. The concentration of PM10 and PM2.5 depends on two groups of emission sources. One is exhaust gases from car engines, and the other is unrelated to exhaust gases. In a study in Boston, USA, it was found that in the mass of PM10, 65.6% of the sources are not related to exhaust gases, with only road dust having a share of 29.6%. For PM2.5, the share of sources that are not related to exhaust gases is much smaller, at 29.1% of their mass, such as car tyre abrasion, which represents 12.3% [6]. This shows that the condition of the roads has a serious impact.

On the other hand, when considering solutions to reduce emissions from internal combustion engines in cars, the
authors most often do targeted research, where they consider the amounts of harmful gases CO and NO₃ and do not include PM10 and PM2.5, leaving them for further research [7]. Even when research has been done with the inclusion of fuels with biocomponents from animals and plants, analyses are made for the amounts of CO and CO₂ [8]. At the same time, emissions from car engines and other pollutants in the air can enter the passenger compartment of the vehicle. In order to avoid this unpleasant moment, in addition to using filters for air purification and ionization, it is proposed [9]. In this way, the harmful influence of PM1.0 and PM2.5 in the vehicle compartment is reduced. The actual amounts of PM10 and PM2.5 emissions released by cars were determined after tunnel tests [10]. The results showed that traffic and weather conditions strongly influence their concentration, with PM2.5 contributing 66% of the amount of PM10, and the two emissions are linked.

III. DESCRIPTION OF THE OF THE ASSESSMENT

METHODICS

To assess pollution, some authors use the air quality index (AQI) [11]. It is determined using the hourly AQI readings with the highest index of 6 pollutants: ground-level ozone (O₃), sulphur dioxide (SO₂), particulate matter (PM10 and PM2.5), carbon monoxide (CO), carbon dioxide (CO₂), and nitrogen dioxide (NO₂). However, research shows that this indicator is not widely used for assessment, but data for individual pollutants is used and predictions are made about their values. When estimating and forecasting the quantities of individual emissions, it is recommended to take into account the influence of meteorological factors (wind speed, wind direction, temperature, and humidity) in order to obtain a more accurate picture of the pollution [12]. Similar research was done over a period of 13 years on the hourly values of CO, NO₂, SO₂, nitrogen monoxide (NO), and ozone (O₃) in the Atika basin, Athens, Greece, and six meteorological factors. Air temperature (Air-Temp) was also taken into account, as were relative humidity (RH), atmospheric pressure (PR), solar radiation (SR), wind speed (WS), and wind direction (WD) [13]. As a result of the work, a model was proposed for more accurate prediction of the concentrations of each investigated pollutant. The studies of PM10 and PM2.5 emissions for the city of Lima in Peru show that the analysis of average hourly values makes it possible to estimate the exceedances of norms during the day [14]. It was established that the concentration of PM10 and PM2.5 is highest in the central city areas, and there is the highest population density. On this basis, it is proposed to take measures to reduce their concentration.

When analysing the data collected from the measuring stations, there is sometimes missing data for a certain time. To conduct a more comprehensive analysis, researchers have developed methodologies that enable the computation of missing data as well as their subsequent processing and analysis. For PM10, data from adjacent days was used, or if there were values for at least 25% of the measurement time for the day [15]. Results obtained in [16] estimate the daily average values of PM 2.5 at 50% of the daily concentration of PM10. There are also analogous relationships for NO₂ and PM10.

In order to most accurately study the emissions in a given area in terms of day and night, day of the week, and season, it is accepted that the measurements are made at the smallest possible intervals and that the data processing and analysis are done on an hourly basis [17]. There are suggestions for understanding the seasonal variation in a country's pollution.

The emissions that are analyzed are obtained based on the fuel used to operate the vehicle’s engine.

In the Republic of Bulgaria, the national legislation has adopted an assessment methodology in which the average daily values of PM10 must not exceed 50 µg/m³ 35 times a year, the average annual values of PM10 must not exceed 40 µg/m³, and the average annual values of PM2.5–20 µg/m³ [18]. The pollution rating scale is five points. For PM10, the grades are as follows: "good" 0–20; "acceptable" 20–40; "medium" 40–50; "bad" 50–100; "very bad" over 100. For PM2.5, the grades are as follows: "good" 0–10; "acceptable" 10–15; "medium" 15–25; "bad" 25–30; "very bad" over 30.

In the city of Ruse, under the integrated project "Bulgarian municipalities work together to improve the quality of atmospheric air," implemented with the support of the LIFE Programme of the European Union, two automatic stations have been installed that measure PM10 and PM2.5. "Rodina 2" station is located at "Sarnena Gora" street (36), which is part of a residential area with a school. „Druzhba 2“ station is located on a site near Bulgaria Blvd. № 96, which is a busy international transit corridor between Bulgaria and Romania, near a school [19].

The characteristic of the city of Ruse is that it is a border city located along the Danube River near the northeast of the city of Giurgiu, Romania. This also determines the location of the built bridge between the two cities in its northeastern part. This Danube bridge provides road and rail traffic between Bulgaria and Romania, with the traffic passing through the middle of the city. This conditionally divides it into two parts and, at the same time, unites the transport flows from the three main arteries: Silistra-Ruse, Ruse-Varna, and Ruse-Veliko Tarnovo/Sofia. The construction of industrial zones occurs to the east, northeast, and west of the residential districts (Fig. 1). This implies that, considering the annual wind rise, [20] the emissions released by industry, the city of Giurgiu, residential users, transit transport flows, and urban traffic for the majority of the year either pass through or remain in the residential areas of the city of Ruse.

![Map of the zones in the city of Ruse](image)

Fig. 1. Map of the zones in the city of Ruse

IV. EXPERIMENTAL RESEARCH

Data were collected on PM10 and PM2.5 emissions for one year, 01.01.2023–31.12.2023, from the two measuring stations and the corresponding values of temperature, humidity, wind direction, and strength. Part of the data is presented in TABLE I.
**Pollution analysis employs a variety of research methods, one of which is to ascertain the law of distribution and the strength of the relationship [21]. Usually in research, one of the tests is related to a test for linear dependence, which can be Pearson’s test [22]. This is done by determining the correlation coefficient** $r$

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}},$$  

(1)

where $x_i$ are the values of the $x$ variable;

$y_i$ – the values of the $y$ variable;

$\bar{x}$ is the sample mean $x$;

$\bar{y}$ – sample mean $y$.

The city of Ruse has five measuring stations, each located in a different part of the city. It is of interest to determine whether one station’s data can determine the trend of pollution in the city. It can determine this by simultaneously analysing data from all five stations. The locations of all stations were considered for the analysis. Two of the stations are mobile and change locations according to a prepared measurement programme and depending on whether there is a signal of pollution in any part of the city. Therefore, these stations will not be considered. The third station, "Vazrazhdane" is located near a park for people to walk and is close to the station "Rodina 2". Therefore, it will not be considered either. The two stations "Rodina 2" and "Druzhba 2" remain.

The software product ORIGIN processed the PM10 and PM2.5 data between the two stations in accordance with the methodology described in [22]. The results are presented in Fig. 2.

![Fig. 2. Comparison of PM10 and PM2.5 emissions between the two stations](image)

Table II confirm, through the Pearson correlation coefficient, the linear character.

**Comparison of PM10 emissions according to the four groups formed**

**Fig. 3. Comparison of PM10 emissions according to the four groups formed**
The research was done in periods in which the months are divided into the following 4 groups: group 1 (January, February, and March); group 2 (April, May, and June); group 3 (July, August, and September); and group 4 (October, November, and December). When presenting the data, the limit value is set with a red horizontal line. The change of data for PM10 is presented in Fig. 3.

The results show that in the months from October to March of 2023, there was an exceedance of the average day and night norms of PM10 in the average hourly data. In the other months, such values are not observed. This means that the main polluter is the domestic heating of citizens and companies that use wood and coal. The rest of the time, pollution comes mainly from transport, manufacturing plants, and street cleanliness. Regarding the linearity trend, Fig. 4 shows that it was absent during the entire considered period.

In Table III, the values show that the dispersion of the data in the first and last quarter periods is very large, at 82.9 µg/m³, from a minimum value of 7 µg/m³ to a maximum value of 89.9 µg/m³, while in the remaining period the difference is almost two times smaller.

TABLE III. RELATIONSHIP BETWEEN PM10 DATA

With PM 2.5, the situation is a little different (Fig. 5). In Fig. 5, the results show that the nature of PM2.5 change is similar to that of PM10, but exceedances of the average day-night norm are observed in all three-month periods, regardless of whether people use wood and coal for heating or not. In addition to transport and industry, dust particles on the streets and other parts of the city, carried by the wind and vehicle movement, may also contribute to this issue.

Regarding the trend of PM2.5 emissions (Fig. 6), it is similar to that of PM10. For a more detailed clarification of this issue, in-depth studies are needed, in which the conditions under which norm exceedances occur are reflected on a daily basis.

From the TABLE IV, it can be seen that in the months of June, July, and August, the excess of the norm is the least because the maximum value is 25 µg/m³, while in the period of January, February, and March, this value reaches 77 µg/m³, which is characteristic of PM10.

TABLE IV. RELATIONSHIP BETWEEN PM2.5 DATA
VI. CONCLUSION

The analysis of PM10 and PM2.5 data from the two measuring stations in "Rodina 2" and "Druzhba 2" shows that there is a linear relationship between the measured emissions, both for PM10 and PM2.5, which is confirmed by the coefficient of correlation because for the first and second stations, r = 0.89 for PM10 and r = 0.91 for PM2.5. Therefore, in research, analyses can be made based on the data from one station.

During the studied period, we found that the hourly average values of PM10 exceeded the average daily norm in two of the four three-month periods, including the months with low temperatures from October to March 2023. Citizens' use of wood and coal for heating, which contributes significantly to these emissions, is the primary cause of this excess.

With PM2.5, the situation is radically different. Regardless of the use of wood and coal for heating, we observe exceedances of the PM2.5 norm throughout the year, as evidenced by the average daily excesses of PM2.5 amounts compared to the average daily norm. It still needs to investigate other factors in detail to determine the cause in this case.

The results show that, regardless of the presence of traffic in the city during the considered period, it can be assumed that there is the same influence, which is added to the other sources of emissions and affects the average hourly exceedances of the norm for both types of emissions.

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REFERENCES

[13] Municipality of Ruse, "Report on project № BG16M1OP002-5.005 "Development/Update of municipal programs for atmospheric air quality" 2021", 2021, P.252 (In Bulgarian), https://life.obshtnaruse.bg/editors/files/D0%95%5D%BA%0D%BB%0D%BB%0D%BB%0D%BB%0D%BB%0D%99%0D%99%0D%9B%2D%9A%0D%90%0D%92%0D%98%0D%99%0D%9B%0D%92.pdf (accessed March 22, 2024)