Study of PM10 and PM2.5 Emissions in Urban Conditions

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***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, O_3, NO_2, SO_2, measured in μg/m^3, 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/m^3, and the average day and night values be 45 μg/m^3. For PM2.5, the annual average values should not exceed 5 μg/m^3, and the day-night average should be 15 μg/m^3.

Studies on the effects of PM10 and SO_2 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 NO_x 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 CO_2 [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 (O_3), sulphur dioxide (SO_2), particulate matter (PM10 and PM2.5), carbon monoxide (CO), carbon dioxide (CO_2), and nitrogen dioxide (NO_2). 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, NO_2, SO_2, nitrogen monoxide (NO), and ozone (O_3) 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 NO_x 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/m^3 35 times a year, the average annual values of PM10 must not exceed 40 μg/m^3, and the average annual values of PM2.5–20 μg/m^3 [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.

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.

TABLE I. PM10 AND PM2.5 DATA

Day	Hour	Rodina 2							
		HR	PM10	PM2.5	Press	RADST	Temp	WD	WS
		Hourly average	Hourly average	Hourly average	Hourly average	Hourly average	Hourly average	Predominantly hourly direction	Hourly average
		[%]	[µg/m³]	[µg/m³]	[mbar]	[W/m2]	[°C]	[°N]	[m/s]
2023/01/01	08:00	69,55191	40,29854	32,398952	1023,7078	0,9902615	8,520985	228	0,7222635
2023/01/01	09:00	70,53625	40,29854	32,398952	1024,3228	17,331034	8,2057495	224	0,46252757
2023/01/01	10:00	63,01818	40,29854	32,398952	1024,4772	133,62225	10,475144	220	0,62711877
2023/01/01	11:00	56,40145	40,29854	32,398952	1024,7137	235,86249	12,654446	219	0,8579653
2023/01/01	12:00	54,917297	40,29854	32,398952	1024,5127	292,12128	13,412985	193	1,4424088
2023/01/01	13:00	53,2812	40,29854	32,398952	1024,1755	291,08365	14,538651	193	1,7174175
2023/01/01	14:00	48,784912	40,29854	32,398952	1023,7418	255,26608	15,877746	194	1,1926986
2023/01/01	15:00	47,584763	40,29854	32,398952	1023,34406	178,79501	16,363153	191	1,3536532
Day	Hour	Druzhba 2							
		HR	PM10	PM2.5	Press	RADST	Temp	WD	WS
		Hourly average	Hourly average	Hourly average	Hourly average	Hourly average	Hourly average	Predominantly hourly direction	Hourly average
		[%]	[µg/m³]	[µg/m³]	[mbar]	[W/m2]	[°C]	[°N]	[m/s]
2023/01/01	08:00	75,88683	24	20,30017	1020,96826	0,58495414	6,8153787	227	2,6398456
2023/01/01	09:00	75,00134	24	20,30017	1021,49835	12,31457	7,0923977	240	1,763721
2023/01/01	10:00	69,63931	24	20,30017	1021,7193	32,920425	8,933593	235	1,4392154
2023/01/01	11:00	63,129513	24	20,30017	1021,95825	40,051983	11,027913	235	1,6091576
2023/01/01	12:00	58,102882	24	20,30017	1021,79535	45,539894	12,557068	232	2,4103253
2023/01/01	13:00	56,85356	24	20,30017	1021,4682	35,162003	13,548653	231	2,4025307
2023/01/01	14:00	51,528282	24	20,30017	1021,01556	228,90431	14,950706	235	2,1470513
2023/01/01	15:00	50,080544	24	20,30017	1020,6413	109,106346	15,600949	233	2,4237876

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

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{(x_i - \bar{x})^2 (y_i - \bar{y})^2}}, \quad (1)$$

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.

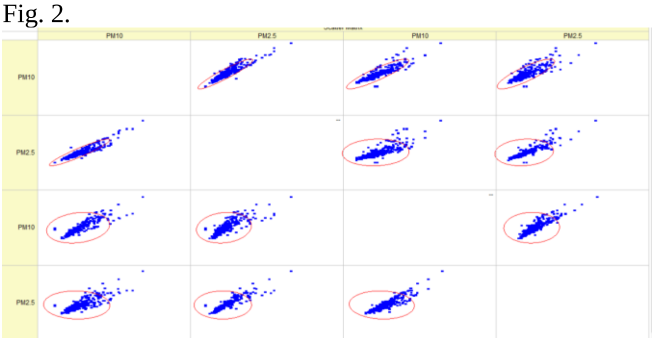

Fig. 2. Comparison of PM10 and PM2.5 emissions between the two stations

Fig. 2 shows that between the two stations, the trend of both types of emissions is almost the same. The results of TABLE II confirm, through the Pearson correlation coefficient, the linear character.

TABLE II. RELATIONSHIP BETWEEN PM10 AND PM2.5 DATA

Descriptive Statistics

	N	Mean	SD	Sum	Min	Max
PM10	8311	25,52431	12,65551	212132,5812	0	89,90327
PM2.5	8311	18,10717	10,07371	150488,72928	0	77
PM10	8311	24,27693	10,42729	201765,60094	6,80017	75,59729
PM2.5	8311	17,43108	8,65983	144869,71124	4,5	68,59765

Pearson Correlations

		PM10	PM2.5	PM10	PM2.5
PM10	Pearson Corr.	1	0,93476	0,89972	0,8454
	Sig.	--	0	0	0
PM2.5	Pearson Corr.	0,93476	1	0,83507	0,90857
	Sig.	0	--	0	0
PM10	Pearson Corr.	0,89972	0,83507	1	0,91049
	Sig.	0	0	--	0
PM2.5	Pearson Corr.	0,8454	0,90857	0,91049	1
	Sig.	0	0	0	--

2-tailed test of significance is used

TABLE II proves three statements. The first is that between PM10 and PM2.5 at both stations, there is a strong linear trend, because for the first and second stations, r = 0.89 for PM10 and r = 0.91 for PM2.5.

The second statement is that in each station there is a relationship between PM10 and PM2.5 because, for the first station, r = 0.935 and for the second, r = 0.91.

The third statement that can be seen from the data is that there is a relationship between PM10 from the first station and PM2.5 from the second station because r = 0.845, and vice versa, the situation is analogous because r = 0.835 between PM10 from the second station and PM2.5 from the first station. In this situation, an analysis of PM10 and PM2.5 pollution for the city can be made using the data from one station. In this case, the data from the “Rodina 2” station was considered, Fig.3.

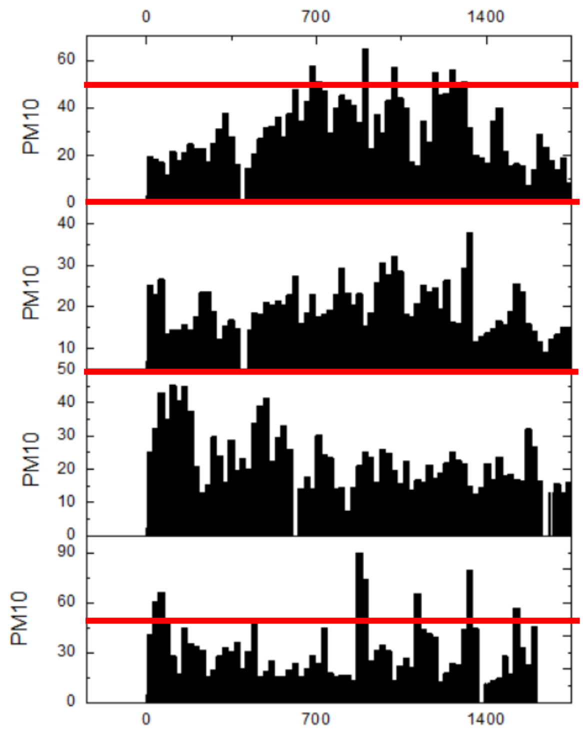

Fig. 3. Comparison of PM10 emissions according to the four groups formed

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.

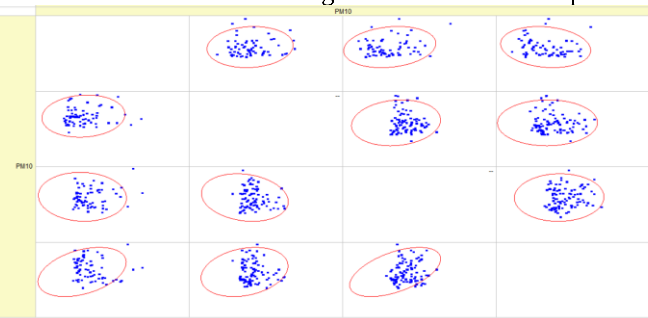

Fig. 4. Comparison of PM10 emissions by quarter

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/m^3, from a minimum value of 7 μg/m^3 to a maximum value of 89.9 μg/m^3, while in the remaining period the difference is almost two times smaller.

TABLE III. RELATIONSHIP BETWEEN PM10 DATA

Descriptive Statistics

	N	Mean	SD	Sum	Min	Max
PM10	1575	31,14937	17,17041	49060,2603	11,19959	89,90327
	2117	22,31008	7,79217	47230,43441	7,30021	45,20164
	2173	20,94415	5,9411	45511,63011	9,09972	37,79865
	2153	28,08795	13,37646	60473,36358	7	64,7021

Pearson Correlations

		PM10			
PM10	Pearson Corr.	1	0,0875	0,17992	-0,15985
	Sig.	--	5,72365E-4	1,13443E-12	2,67524E-10
	Pearson Corr.	0,0875	1	-0,16429	-0,10383
	Sig.	5,72365E-4	--	4,59632E-14	2,30135E-6
	Pearson Corr.	0,17992	-0,16429	1	0,12224
	Sig.	1,13443E-12	4,59632E-14	--	1,34037E-8
	Pearson Corr.	-0,15985	-0,10383	0,12224	1
	Sig.	2,67524E-10	2,30135E-6	1,34037E-8	--

2-tailed test of significance is used

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.

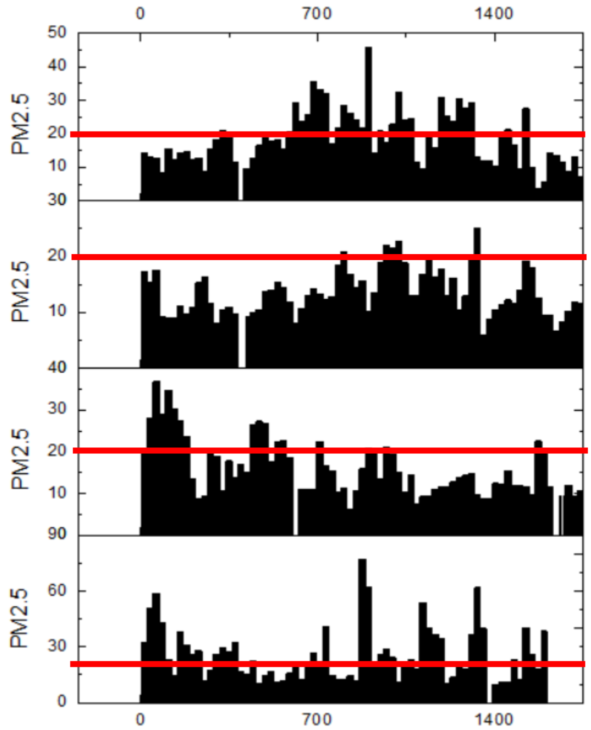

Fig. 5. Comparison of PM2.5 emissions according to the four groups formed

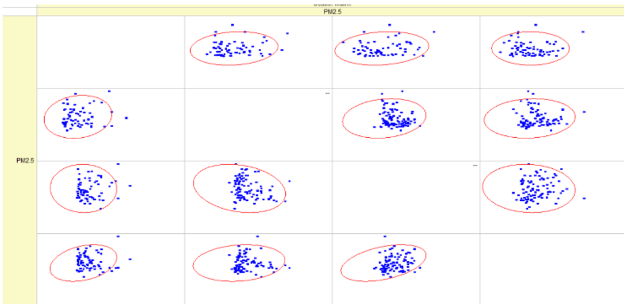

Fig. 6. Comparison of PM2.5 emissions by quarter

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

Descriptive Statistics

	N	Mean	SD	Sum	Min	Max
PM2.5	1575	25,86868	14,54687	40743,16875	9,90013	77
	2117	15,39085	6,26824	32582,42956	6,19989	36,79872
	2173	14,38055	4,23802	31248,92797	5,80006	25
	2153	17,6669	7,76296	38036,83189	3,79987	45,79834

Pearson Correlations

		PM2.5			
PM2.5	Pearson Corr.	1	0,12836	0,1493	-0,00674
	Sig.	--	4,10706E-7	3,92354E-9	0,79123
	Pearson Corr.	0,12836	1	-0,23544	-0,04534
	Sig.	4,10706E-7	--	0	0,03954
	Pearson Corr.	0,1493	-0,23544	1	0,09744
	Sig.	3,92354E-9	0	--	6,12912E-6
	Pearson Corr.	-0,00674	-0,04534	0,09744	1
	Sig.	0,79123	0,03954	6,12912E-6	--

2-tailed test of significance is used

V. 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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