Inhomogeneous pollution by particulate matter of the atmospheric surface layer of the Oktyabrsky district of the city of Krasnoyarsk in 2019

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Abstract. Using the air monitoring system of the Krasnoyarsk Scientific Center of the SB RAS, the nature of the atmospheric surface layer pollution by particulate matter (PM\textsubscript{2.5}) in the Oktyabrsky district of the millionth industrial city was studied. The average annual and seasonal concentrations of PM\textsubscript{2.5} were determined in the area where six air monitoring stations are located. Statistical analysis showed that the distribution of PM\textsubscript{2.5} in the air is uneven in the Oktyabrsky district of Krasnoyarsk. In the summer air pollution was caused by the smoke of large-scale forest fires in the northeastern regions of Siberia.

1. Introduction

In Russia monitoring of air pollution is carried out by the Ministry of Natural Resources and Ecology at the state level. The regular monitoring network in 2015 consisted of 612 stationary atmospheric pollution observation posts (POP) (https://files.stroyinf.ru/Data2/0/4294799/4294799878.pdf).

In the city of Krasnoyarsk there are eight POP. They are distributed across seven administrative districts: one POP is in six regions and two POP are in the Leninsky district. Assessment of the level of atmospheric pollution in the city of Krasnoyarsk is carried out according to the results of the analysis of average annual concentrations, measured at all POP. The list of pollutants determined in the air is presented on the website http://meteo.krasnoyarsk.ru. There are no particulate matter (PM) in this list.

The modernization of the POP began in 2020. In particular, EDM 180 dust analyzers are installed at the posts, which are used to measure the concentration of PM\textsubscript{2.5} and PM\textsubscript{10} in air [1-4].

For a correct assessment of the level of pollution, it is necessary to know the laws of the spatial distribution of particulate matter in the atmosphere of Krasnoyarsk. Moreover, based on the features of the POP placement scheme in the city of Krasnoyarsk, it is necessary to study the nature of the distribution of particulate matter in the atmosphere of administrative regions.

The regularities of the distribution of PM concentration on the scale of the administrative regions of the city can be determined using the air monitoring system of the Krasnoyarsk Scientific Center of the SB RAS (http://air.krasn.ru). This network includes 22 complexes of special equipment and software designed to collect and analyze objective data on the state of atmospheric air in the city of Krasnoyarsk. Five such complexes (observation posts) are located in the Oktyabrsky district.
The aim of the work was to assess the levels of pollution of the surface layer of the atmosphere by particulate matter of PM$_{2.5}$ in five different microdistricts located on the territory of the Oktyabrsy district.

2. Location of observation points, equipment and research methods
Observations were carried out during 2019 in five microdistricts of the Oktyabrsy district (Akademgorodok, Vetluzhanka, Ovinniy, Televisyon, Udachny) and in the microdistrict of Nikolaevka, which is adjacent to the border of the Oktyabrsy district. The coordinates of the location of observation posts are presented in table 1.

| Microdistrict | Coordinates | Height above sea level, m | Distance from the left bank of the Yenisei River, km |
|---------------|-------------|---------------------------|-----------------------------------------------|
| 1 Akademgorodok | 55.98657°N 92.76222°E | 255 | 0.47 |
| 2 Ovinniy | 56.04457°N 92.72616°E | 216 | 7.31 |
| 3 Televisyon | 56.02594°N 92.79871°E | 186 | 3.80 |
| 4 Udachny | 55.97847°N 92.67719°E | 156 | 0.55 |
| 5 Vetluzhanka | 56.02930°N 92.76537°E | 204 | 4.82 |
| 6 Nikolaevka | 56.00772°N 92.82126°E | 177 | 1.35 |

CityAir certified air monitoring stations (AMS), developed by a group of companies from the Novosibirsk Technopark and the Skolkovo Innovation Center are used as the basic equipment of the air monitoring system of the Krasnoyarsk Scientific Center of the SB RAS.

AMS CityAir UNSL.421451.1000-01 is designed to collect data on the state of surrounding air (mass concentration of aerosol particles, temperature, humidity and atmospheric pressure) and transmit them to the server via a wireless communication channel.

The methodology and results of verification of data from CityAir air monitoring stations are presented in [5].

As criteria for assessing the level of atmospheric pollution by particulate matter PM$_{2.5}$, we used the values of maximum permissible concentrations of maximum one-time (MPC$_{\text{ot}}$ = 160 $\mu$g/m$^3$), daily average (MPC$_{\text{da}}$ = 35 $\mu$g/m$^3$) and annual average (MPC$_{\text{aa}}$ = 25 $\mu$g/m$^3$). These criteria are officially established by the legislation of Russia.

3. Results and discussion
The lowest average annual concentrations of PM$_{2.5}$ in the surface layer of the atmosphere were observed in the microdistricts of Akademgorodok and Udachny on the territory of the Oktyabrsy District in 2019 (table 2). The average annual values were 10.1 $\mu$g/m$^3$ and 10.4 $\mu$g/m$^3$, respectively. The maximum concentration of PM$_{2.5}$ reached 180.2 $\mu$g/m$^3$ and 163.8 $\mu$g/m$^3$ in the microdistricts of Akademgorodok and Udachny respectively. The level of air pollution relative to MPC$_{\text{aa}}$ was exceeded in the districts of Ovinniy and Televisyonny. The maximum concentration of PM$_{2.5}$ for the entire Oktyabrsy district was recorded in the atmosphere of the Vetluzhanka microdistrict, which amounted to 396.9 $\mu$g/m$^3$ (table 2).

It is known that the concentration of pollutants in the atmosphere of the city of Krasnoyarsk reaches its highest values in winter [6]. An assessment of air pollution levels by particulate matter in different seasons of the calendar year was carried out for the Oktyabrsy district for this reason. The results are presented in tables 3-6. The criterion for the level of pollution was the MPC$_{\text{da}}$ value.
Table 2. Average annual and maximum concentrations of PM$_{2.5}$ in the atmosphere of various microdistricts in 2019.

| №  | Microdistrict   | Concentration of PM$_{2.5}$, $\mu$g/m$^3$ | Average annual | Maximum |
|----|----------------|------------------------------------------|----------------|---------|
| 1  | Akademgorodok  | 10.1±0.2                                 | 180.2          |         |
| 2  | Ovinny         | 26.6±0.5                                 | 313.4          |         |
| 3  | Televizornyy   | 26.9±0.5                                 | 340.2          |         |
| 4  | Udachnyy       | 10.4±0.2                                 | 163.8          |         |
| 5  | Vetluzhanka    | 22.4±0.5                                 | 396.9          |         |
| 6  | Nikolayevka    | 29.7±1.0                                 | 406.1          |         |

Table 3. Average and maximum concentrations of PM$_{2.5}$ in the atmosphere of various microdistricts in the winter of 2019.

| №  | Microdistrict   | Concentration of PM$_{2.5}$, $\mu$g/m$^3$ | Average | Maximum |
|----|----------------|------------------------------------------|---------|---------|
| 1  | Akademgorodok  | 13.7±0.2                                 | 161.8   |         |
| 2  | Ovinny         | 46.7±2.5                                 | 313.4   |         |
| 3  | Televizornyy   | 54.2±3.3                                 | 340.2   |         |
| 4  | Udachnyy       | 13.7±0.8                                 | 156.7   |         |
| 5  | Vetluzhanka    | 57.4±4.2                                 | 396.9   |         |
| 6  | Nikolayevka    | 63.2±3.3                                 | 406.1   |         |

Table 4. Average and maximum concentrations of PM$_{2.5}$ in the atmosphere of various microdistricts in spring 2019.

| №  | Microdistrict   | Concentration of PM$_{2.5}$, $\mu$g/m$^3$ | Average | Maximum |
|----|----------------|------------------------------------------|---------|---------|
| 1  | Akademgorodok  | 5.7±0.2                                  | 67.0    |         |
| 2  | Ovinny         | 15.9±0.9                                 | 157.6   |         |
| 3  | Televizornyy   | 19.2±0.9                                 | 165.9   |         |
| 4  | Udachnyy       | 6.8±0.3                                  | 82.6    |         |
| 5  | Vetluzhanka    | 14.9±0.9                                 | 144.8   |         |
| 6  | Nikolayevka    | 17.5±0.8                                 | 154.0   |         |

Table 5. Average and maximum concentrations of PM$_{2.5}$ in the atmosphere of various microdistricts in the summer of 2019.

| №  | Microdistrict   | Concentration of PM$_{2.5}$, $\mu$g/m$^3$ | Average | Maximum |
|----|----------------|------------------------------------------|---------|---------|
| 1  | Akademgorodok  | 15.5±0.2                                 | 180.2   |         |
| 2  | Ovinny         | 18.9±1.1                                 | 174.7   |         |
| 3  | Televizornyy   | 18.4±0.9                                 | 153.8   |         |
| 4  | Udachnyy       | 15.2±0.9                                 | 163.8   |         |
| 5  | Vetluzhanka    | 17.7±1.0                                 | 175.5   |         |
| 6  | Nikolayevka    | 18.3±1.0                                 | 176.9   |         |

Analysis of tables 3-6 shows that, air pollution was observed in all seasons of the year in the districts of Ovinniy and Televizion. The excess of MPCda for PM$_{2.5}$ in the air was not observed only in the autumn period in the Vetluzhanka microdistrict. Air pollution was recorded only in the summer in the microdistricts of Akademgorodok and Udachny. It is characteristic that in the summer period pollution was observed by particulate matter in all microdistricts (table 5). This was due to the long-term preservation of the center of the high-altitude cyclone over the eastern regions of the Irkutsk Region and
the north of the Krasnoyarsk territory, as well as the displacement of smoke plumes from fires in the southern and south-western directions. Smoke from forest fires spreading from the north-eastern regions of Siberia in July-August 2019 was often involved and transported in the south-west direction. The result of such movements of the air masses was smoke in the city of Krasnoyarsk, which was repeatedly recorded from outer space during July-August 2019 (figure 1).

Table 6. Average and maximum concentrations of PM$_{2.5}$ in the atmosphere of various microdistricts in autumn 2019.

| №  | Microdistrict | Concentration of PM$_{2.5}$, µg/m$^3$ |
|----|---------------|--------------------------------------|
|    |               | Average    | Maximum    |
| 1  | Akademgorodok | 5.4±0.2    | 170.2      |
| 2  | Ovinnyy      | 9.5±0.7    | 165.7      |
| 3  | Televizornyy | 21.2±2.0   | 193.7      |
| 4  | Udachnyy     | 19.4±1.6   | 219.2      |
| 5  | Vetluzhanka  | 9.5±0.7    | 165.7      |
| 6  | Nikolayevka  | 19.2±1.4   | 257.6      |

Figure 1 clearly demonstrates that smoke from large-scale forest fires (northeast of Siberia) is transported in the south-west direction, “covers” Krasnoyarsk and moves towards Kazakhstan. It is noteworthy that in the summer period, the maximum concentration range of PM$_{2.5}$ was small - 366.2 ÷ 429.1 µg/m$^3$ in five microdistricts (table 5), compared with a spread of these indicators in winter - 373.2 ÷ 944.9 µg/m$^3$ (table 3).

Forest fires in Siberia in 2019 are the record for the area of fire in the last few years. According to Greenpeace, fires in Siberia reached record levels by August 5, 2019 in the entire history of observation since 2001 in terms of burning area (4 million ha), area of burned forests (more than 13 million ha) (https://www.znak.com/2019-08-05/greenpeace_plochad_lesnyh_pozharov_v_sibiri_prevysila_4_mln_gektarov). This fact allows us to consider that the level of air pollution in the summer
period of 2019 is not characteristic of the air environment of the city of Krasnoyarsk and, in particular, the Oktyabrsky district.

Processing of data series of PM$_{2.5}$ concentrations was performed using correlation analysis to clarify the characteristics of atmospheric pollution in the Oktyabrsky district. The calculated correlation coefficients are presented in table 7.

**Table 7. Correlation coefficients.**

|       | Akad $^a$ | Ovin $^a$ | Telev $^a$ | Udach $^a$ | Vetl $^a$ | Nikol $^a$ |
|-------|-----------|-----------|------------|------------|-----------|------------|
| Akad $^a$ | 1         |           |            |            |           |            |
| Ovin $^a$  | 0.54      | 1         |            |            |           |            |
| Telev $^a$ | 0.56      | 0.89      | 1          |            |           |            |
| Udach $^a$ | 0.89      | 0.51      | 0.51       | 1          |           |            |
| Vetl $^a$  | 0.54      | 0.91      | 0.94       | 0.53       | 1         |            |
| Nikol $^a$ | 0.51      | 0.85      | 0.86       | 0.49       | 0.89      | 1          |

$^a$ Akademgorodok - Akad, Ovinny - Ovin, Televizornyy - Telev, Udachnyy - Udach, Vetluzhanka - Vetl, Nikolaevka – Nikol

The values of the correlation coefficients lie in two ranges of 0.49-0.56 and 0.85-0.94. This indicates a different nature of atmospheric pollution in the microdistricts of the Oktyabrsky district.

It follows from the analysis of table 7 that microdistricts can be combined into two groups. One first group consists of the microdistricts of Akademgorodok and Udachny, the second group includes the microdistricts of Ovinny, Vetluzhanka, TV, Nikolaevka (figure 2).

![Figure 2. Grouping of observation posts, terrain and wind rose in the Oktyabrsky district. The names of the posts are given in table 1.](image-url)

Microdistricts of the first group are located near the left bank of the Yenisei River. Observation posts are located in Akademgorodok and Udachny at a distance of 0.47 km and 0.55 km from the river edge.
respectively. Akademgorodok microdistrict is located 100 m higher than the Udachny microdistrict (table 1). The residential districts of Vetluzhanka, Ovinniy, Television, Nikolaevka are located lower than Akademgorodok, but higher than the Udachny microdistrict (table 1). These four microdistricts are removed from the river Yenisei at 1.35 - 7.3 km. The Nikolaev hill about 500 m high is between the two groups of microdistricts (figure 2).

Western and south-western winds dominate in Krasnoyarsk according to the data for 2008-2018 (https://lakka-sails.ru). Probably, the Nikolaev hill contributes to the fact that the prevailing winds decrease over the territory of the second group of microdistricts. There is an increase in the concentration of PM$_{2.5}$ due to the low wind speed. The effect of wind on the concentration of particulate matter is shown in [7-10].

The low concentration in the first group of microdistricts may be due to both the influx of clean air with prevailing winds and the influence of the ice-free Yenisei River [11].

In addition, factor analysis shows a significant difference between the posts of the first and second groups.

Thus, the spatial pollution of the atmosphere in the Oktyabrsky district is uneven. Therefore, it is necessary to create additional POP for the correct state monitoring of the concentration of PM$_{2.5}$ in this area.

The problem of the lack of monitoring posts for air pollution has been reported in a number of works [12-14].

4. Conclusion
Thus, using the air monitoring system of the Krasnoyarsk scientific center SB RAS (http://air.krasn.ru) a investigation of the spatial and temporal distribution of the concentration of PM$_{2.5}$ in the surface layer of the atmosphere of the Oktyabrsky district was conducted. The features of this distribution are established. First, the lowest average annual concentration of PM$_{2.5}$ in microdistricts located near the non-freezing Yenisei river. Secondly, there is statistically significant uneven air pollution in the Oktyabrsky district. Third, the level of atmospheric pollution is significantly affected by smoke from forest fires in 2019.

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