Concentration of particulate matter in the surface layer of the atmosphere of the village of Drokino (Krasnoyarsk territory)

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Abstract. Measurement of temperature, pressure and concentration of particulate matter (PM$_{2.5}$) in the surface layer of the atmosphere of the village of Drokino was performed using the CityAir air monitoring station. Air pollution occurs due to the burning of brown coal in the stoves of rural houses in winter. Air pollution is caused by smoke from forest fires in the summer of 2019. The average annual concentration of PM$_{2.5}$ in 2019 was 31 μg/m$^3$ and exceeded the hygiene standard by 1.24 times. It was shown that the concentration of PM$_{2.5}$ increases with increasing atmospheric pressure and lowering air temperature. It was established that the PM$_{2.5}$ concentration exceeds 3.00-4.49 times the hygiene standard established for the atmosphere of populated areas during periods of anticyclone.

1. Introduction

Almost half of the population lives in rural areas in India and China. They use biomass and coal for heating homes and cooking, [1, 2]. This fuel is burned in simple stoves. Air pollution occurs as a result [3]. A lot of research has been devoted to investigating the regularity of air pollution in rural settlements [4-8]. The results of some works are presented in "Indoor Air Pollution Database for China" in Human Exposure Assessment Series, Office of Global Environmental Health, World Health Organization, Geneva: Geenet, 1995 (https://apps.who.int/iris/handle/10665/59423).

As of January 1, 2020, 644,028 people lived in rural areas of the Krasnoyarsk territory (22.5% of the total population) (https://krasstat.gks.ru/folder/76355). Brown coal is used to produce thermal energy in almost all households located in the central and southern parts of the region. Large-scale use of brown coal due to its low price. This coal is mined by open-pit on the territory of the Kansk-Achinsk coal basin. Coal burning is the main source of air pollution in rural areas [9, 10].

In rural settlements, there is no regular state monitoring of the atmosphere. Assessment of air pollution is carried out according to the results of laboratory tests of samples, which are relatively rarely taken in rural areas. So, in 2018 the laboratory center of the FBHI “Center for Hygiene and Epidemiology in the Krasnoyarsk Territory” in the territories of rural settlements selected and analyzed 855 samples (4.1%) of atmospheric air, and in urban settlements - 19796 samples (95.9%) . It should be noted that benz(a)pyrene was not sampled. As a result of the analysis, it was found that the proportion of air samples that do not meet hygienic standards in urban settlements of the Krasnoyarsk Territory in 2018 was 1.7%, in the city of Krasnoyarsk - 1.3%, in rural settlements - 1.3%
(http://24.rospotrebnadzor.ru). It should be noted that the sampling did not measure the concentration of particulate matter.

At the level of the subject of the Russian Federation (Krasnoyarsk Territory), atmospheric monitoring is carried out only in two villages (Kubekovo and Beryozovka). The village of Kubekovo is located at a distance of 2 km from the north-eastern border of the city of Krasnoyarsk. The territory of the village of Berezovka is adjacent to the eastern border of the city of Krasnoyarsk. In 2018-2019, the average annual concentration of PM\(_{2.5}\) particulate matter in the atmosphere of these villages was 21.4-25.8 \(\mu g/m^3\) (http://krasecology.ru).

The concentration of particulate matter in the atmosphere can be determined in many rural settlements using certified air monitoring stations. The practical possibility of using CityAir stations in Siberia was shown in [11]. Such a station has been operating uninterruptedly in the village of Drokino since November 2018. There is an extensive database of measurement results (http://air.krasn.ru).

The purpose of this work was to analyze the level and patterns of air pollution in the village of Drokino in the period from 11/01/18 to 04/01/20.

2. The location of the village
The village of Drokino is located at a distance of 1.5 km from the north-western border of the city of Krasnoyarsk.

In the village of Drokino there are 494 houses with stove heating. More than 90% of these residential buildings are heated with brown coal. There are no industrial enterprises in the village that carry out emissions of particulate matter.

3. Methods and equipment
The concentration of PM\(_{2.5}\), atmospheric pressure and temperature were measured using the CityAir air monitoring station (https://cityair.io/equipment-ru). An optical sensor for measuring PM\(_{2.5}\) concentration installed in the housing of the CityAir air monitoring station was calibrated against the data of the e-BAM dust analyzer (Met One Instruments, Inc.) [11].

The sensors of the station "CityAir provide:
- measurement of the concentration of PM2.5, PM10 in the range from 0 to 1.6 mg/m3; permissible relative error - no more than ±20 %;
- measurement of ambient air temperature in the range from -40 to +50 °C; permissible absolute error - no more than ±1 °C;
- measurement of atmospheric pressure in the range from 600 to 850 mm Hg; permissible absolute error - no more than ±1 mm Hg.

As criteria for assessing the level of air pollution by PM\(_{2.5}\) particulate matter, the maximum permissible concentrations of average daily (MPC\(_{\text{cad}}\) = 35 \(\mu g/m^3\)) and average annual (MPC\(_{\text{aa}}\) = 25 \(\mu g/m^3\)) were used. These criteria are officially established by Russian law.

4. Results and discussion
The concentration of PM\(_{2.5}\) was measured at intervals of 20 minutes. 36630 measurements were taken out of 37224 potentially possible for the period from 11/01/18 to 04/01/20. Thus, the stability of the CityAir air monitoring station was 98.4 % over 17 months. It should be noted that this time interval includes two winter periods, with the onset of which the air temperature dropped to minus 41 °C. Therefore, convincing confirmation was obtained of the long-term operability of the CityAir station in the winter conditions of Siberia.

An estimate of the level of air pollution during each calendar month is presented in table 1. The hourly average concentrations of PM\(_{2.5}\) were used for the calculation. In winter periods (December, January and February), the average monthly concentration of PM\(_{2.5}\) was 1.31-2.24 times higher than the MPC\(_{\text{cad}}\). Exceeding MPC\(_{\text{cad}}\) was observed in November 2019. The average annual concentration of PM\(_{2.5}\) in 2019 (31 \(\mu g/m^3\)) was 1.24 times higher than MPC\(_{\text{aa}}\).
The average monthly air temperatures in 2019 are shown in figure 1. It can be seen that negative values were observed in January, February, November and December. Air pollution by particulate matter was recorded in these months (table 1). They were formed as a result of burning brown coal in domestic stoves.

**Table 1.** Monthly average concentrations of PM$_{2.5}$, $\mu$g/m$^3$ (C) in the atmosphere of the village of Drokino and the number of hourly average measurements (N).

|       | 2018          | 2019          | 2020          |
|-------|---------------|---------------|---------------|
|       | C             | N             | C             | N             | C             | N             |
| January | 73.6±5.4     | 744           | 45.8±4.1     | 744           |
| February | 78.5±5.4     | 672           | 59.9±3.7     | 696           |
| March   | 26.0±2.1      | 744           | 14.9±1.6     | 744           |
| April   | 20.7±1.8      | 720           |               |               |
| May     | 14.2±1.2      | 742           |               |               |
| June    | 9.0±1.0       | 720           |               |               |
| July    | 28.8±2.1      | 744           |               |               |
| August  | 13.4±0.9      | 744           |               |               |
| September | 11.3±1.0    | 720           |               |               |
| October | 15.6±1.5      | 743           |               |               |
| November | 30.7±2.8     | 720           | 35.2±4.5     | 540           |
| December | 88.5±5.9     | 729           | 50.0±4.0     | 744           |
| Year    | 31.0±1.0      | 8577          |               |               |

The amount of coal burned increases with decreasing outdoor temperature in order to maintain a comfortable temperature in a residential building. This is clearly confirmed by the dependencies shown in figure 2. We used the following approach to obtain these dependencies. Two rows of values were constructed - in one row the PM$_{2.5}$ concentration for 20 minutes of measurement, and in the other row - the air temperature at the time of measurement. The resulting pairs were ranked by temperature. Then the pairs were grouped into blocks that had an interval of five degrees. For example, from -40.00 to -35.01; from -35.00 to -30.01 and so on. For each temperature block, the average concentration of PM$_{2.5}$ and the confidence interval at $P = 0.95$ were determined.

![Figure 1](image_url)  
**Figure 1.** Dynamics of the average monthly temperature in the village of Drokino in 2019.

The trend lines for the periods 01.11.18-01.04.19 and 01.11.19-01.04.20, presented in figure 2, are described by linear equations, respectively:

\[
y = -3.3275x + 22.824, \quad R^2 = 0.9225, 
\]  
(1)
\[ y = -3.2302x + 18.668, \quad R^2 = 0.9492, \] (2),

where: \( y \) - the concentration of PM\(_{2.5} \), \( \mu g/m^3 \); \( x \) - temperature, \( ^\circ C \).

From equations (1) and (2) it follows that cooling by 1 \( ^\circ C \) in the winter period causes an increase in atmospheric pollution in the village of Drokino by 3.230 - 3.327 \( \mu g/m^3 \).

**Figure 2.** Dependence of concentration on air temperature for the periods 01.11.18-01.04.19 (black solid trend line) and 01.11.19-01.04.20 (black dashed trend line).

The investigation of the dependence of the concentration of PM\(_{2.5} \) on atmospheric pressure showed that a linear relationship is observed only in the range of 742.5-767.5 mm Hg (figure 3). The level of air pollution increases with increasing pressure. Trend lines for the periods 01.11.18-01.04.19 and 01.11.19-01.04.20, presented in figure 3, are described by linear equations, respectively:

\[ y = 6.6229x - 4937, \quad R^2 = 0.9455, \] (3); \[ y = 3.1416x - 2335, \quad R^2 = 0.9868, \] (4),

where: \( y \) - the concentration of PM\(_{2.5} \), \( \mu g/m^3 \); \( x \) - atmospheric pressure, mm Hg.

**Figure 3.** The dependence of the concentration of PM\(_{2.5} \) on atmospheric pressure for the periods 01.11.18-01.04.19 (black solid trend line) and 01.11.19-01.04.20 (black dashed trend line).
The tangent of the tilt angle of equations (3) and (4) differs by more than 2 times. This indicates that the increase in pressure by 1 mm Hg in winter in different years, causes a different increase in atmospheric pollution in the village of Drokino.

High pressure is observed with anticyclones (AC). From the analysis of weather maps that are posted on the site http://meteo.krasnoyarsk.ru it follows that in the winter, ACs are formed over the territory of the city of Krasnoyarsk and its suburbs. A sensor installed at the CityAir air monitoring station detected a pressure in excess of 750 mm Hg at the AC. Pressure above 750 mm Hg was observed in the period 01.11.18-01.04.19 in the village of Drokino: from 15 hours on December 2, 2018 to 4 hours on December 10, 2018 (AC 1); from 21 hours on December 23, 2018 to 1 hour on January 7, 2019 (AC 2); from 6 p.m. February 1, 2019 to 10 a.m. February 14, 2019 (AC 3).

During periods when pressure was recorded above 750 mm Hg, the regime of unfavorable meteorological conditions (UMC) was announced three times in the city of Krasnoyarsk. The start and end time of the UMC period was determined by Federal State Budgetary Institution «Central-Siberian Administration for Hydrometeorology and Environmental Monitoring»

The duration of the UMC periods was from one day to six days: from 19 hours on December 6, 2018 to 19 hours on December 7, 2018 (UMC 1); from 7 p.m. December 25, 2018 to 7 p.m. December 31, 2018 (UMC 2); from 19 hours on February 8, 2019 to 19 hours on February 13, 2019 (UMC 3).

The dynamics of the concentration of PM$_{2.5}$ and atmospheric pressure in the surface layer of the atmosphere of the village of Drokino is shown in figure 4.

![Figure 4](image.png)

**Figure 4.** Dynamics of PM$_{2.5}$ and atmospheric pressure in the area of CityAir air monitoring station in the village of Drokino. Straight horizontal lines show periods of adverse weather conditions and anticyclones.

Average concentrations of PM$_{2.5}$, including during periods of influence of anticyclones, are presented in tables 2. During periods of action of anticyclones, the concentration of PM$_{2.5}$ increases, which exceeds the MPCad by 3.00-4.49 times. From November 1, 2018 to April 1, 2019, the average concentration of PM$_{2.5}$ in the atmosphere of villages exceeded the average daily MPCad by 1.69 times. Excluding periods of AC influence, the excess of the hygienic standard was 1.08 times (table 2). Thus, ACs contribute to the formation of high PM$_{2.5}$ concentrations in the atmosphere of the village of Drokino.
During periods of UMC the concentration of PM$_{2.5}$ increases, which exceeds the MPCad t by 4.56-5.01 times. The excess of the hygiene standard was 1.41 times excluding the periods of UMC (table 3).

As mentioned earlier, UMC regimes were announced for the city of Krasnoyarsk. For the village of Drokino there is no regulation on the declaration of UMC. Therefore, we can only talk about the possible influence of UMC, which developed in the city of Krasnoyarsk, on the formation of high PM$_{2.5}$ concentrations in the atmosphere of the village of Drokino.

**Table 2.** Average concentration of PM$_{2.5}$, µg/m$^3$ for the period 01.11.18-01.04.19 ($C_{ac}$), during the period of anticyclone action (AC 1, AC 2, AC 3), in the period 01.11.18-01.04.19 for excluding AC periods (without AC).

| $C_{ac}$ | AC 1   | AC 2   | AC 3   | Without AC |
|----------|--------|--------|--------|------------|
| 59.1±2.2 | 105.0±9.7 | 157.1±8.3 | 122.9±7.5 | 37.7±1.8   |

**Table 3.** The average concentration of PM$_{2.5}$, µg/m$^3$ for the period 01.11.18-01.04.19 ($C_{ac}$), during the period of UMC (UMC 1, UMC 2, UMC 3), during the period 01.11.18-01.04.19 for excluding periods of UMC (without UMC).

| $C_{ac}$ | UMC 1   | UMC 2   | UMC 3   | Without UMC |
|----------|---------|---------|---------|-------------|
| 59.1±2.2 | 159.7±30.3 | 175.2±9.6 | 171.7±11.2 | 49.2±2.0    |

In summer, the highest concentrations of PM$_{2.5}$ were observed in July 2020 (table 1). The dynamics of air pollution in the village of Drokino for three summer months is shown in figure 5. It can be seen that in July and August there were periods when air pollution was observed for a day or more. At the same time forests burned on a huge area in the north-east of Siberia ([https://fires.ru](https://fires.ru)). Smoke from these fires spread over thousands of kilometers. The air environment of a huge number of settlements in Russia was polluted ([https://worldview.earthdata.nasa.gov](https://worldview.earthdata.nasa.gov)).

The atmospheric pollution of the village of Drokino was established on the basis of satellite images showing the aerosol index ([https://worldview.earthdata.nasa.gov](https://worldview.earthdata.nasa.gov)), PM$_{2.5}$ concentrations above MPC, and the pollution period is not less than ten hours.

**Figure 5.** Dynamics of PM$_{2.5}$ in the area of CityAir air monitoring station in the village of Drokino. The dashed line denotes the MPCad value, solid horizontal lines indicate periods of atmospheric smoke pollution from forest fires.
The smoke of forest fires entered the atmosphere of the village of Drokino at least four times (figure 5). The level of air pollution during smoke is presented in table 4.

### Table 4. Periods of atmospheric pollution of the village of Drokino by smoke from forest fires and the average concentration of PM$_{2.5}$, μg/m$^3$ during these periods.

| №  | The duration of the smoke | The beginning of the smoke | The end of the smoke | $C_{ac}$ |
|----|---------------------------|----------------------------|----------------------|---------|
| 1  | 35                        | 13.07.19 09:00             | 14.07.19 19:00       | 74,9 ± 7,4 |
| 2  | 21                        | 15.07.19 15:00             | 16.07.19 11:00       | 105,7 ± 15,4 |
| 3  | 192                       | 20.07.19 00:00             | 27.07.19 23:00       | 58,2 ± 2,6 |
| 4  | 33                        | 17.08.19 01:00             | 18.08.19 09:00       | 51,6 ± 4,0 |

During periods of smoke, the PM$_{2.5}$ concentration increased, which exceeded the MPC$_{ad}$ by 1.47-3.02 times (table 4).

### 5. Conclusion

The CityAir certified air monitoring station has been operating for 17 months in the village of Drokino. Climate conditions in Siberia do not affect the operation of the station. The stability of its work was 98.4%. Due to this fact, we can recommend the use of CityAir stations in rural localities for air monitoring.

The need for atmospheric monitoring in rural settlements is confirmed by the results of this work. The following conclusions are made.

1. The level of air pollution in the village of Drokino does not comply with hygiene standards. The average annual concentration of PM$_{2.5}$ in 2019 was 31 μg/m$^3$. This value is 1.24 times higher than the MPC$_{ad}$.

2. In the winter periods (December, January and February), the average monthly concentration of PM$_{2.5}$ is more than the MPC$_{ad}$ by 1.31-2.24 times. Sources of air pollution by particulate matter are households.

3. The atmosphere of the village was polluted by the smoke of forest fires in July and August 2019.

Monitoring of the air environment of rural settlements will make it possible to objectively determine the level of air pollution, and based on this, to assess the risk to the health of rural residents.

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