Air quality index in Krasnoyarsk (Russia) for 2018–2019

A V Tokarev¹, N Ya Shaparev² and O E Yakubailik³
¹ Senior researcher, Institute of Computational Modeling SB RAS, Krasnoyarsk, Russia
² Chief researcher, Institute of Computational Modeling SB RAS, Krasnoyarsk, Russia
³ Leading researcher, Institute of Computational Modeling SB RAS, Krasnoyarsk, Russia
E-mail: tav@icm.krasn.ru

Abstract. In the work, we calculated the air quality index (AQI) in the city of Krasnoyarsk for 2018 and 2019. The initial data were obtained from automatic observation posts of the regional environmental monitoring system. The effect of individual components (pollutants) on the index value is analyzed. The dependence of the index values on seasonal and weather conditions is studied.

1. Introduction
The problem of urban air pollution is widely known in the world. According to the World Health Organization (WHO), about 7 million people died from air pollution worldwide in 2012 [1]. This result is about twice as high as the previous estimates [2] and confirms that air pollution nowadays is the world's largest environmental health risk. The most appropriate and economically feasible policy measures to reduce particulate matter and ozone are explored in Israel [3]; in China effective measures to combat air pollution are developed [4, 5] and the impact of urban air pollution on urban ecosystems is investigated [6]; concentrations of the major air pollutants in London and Moscow are compared [7].

The first occurrence of smog was recorded over London in December 1952, which resulted from the burning of coal. In today's situation, smog occurs in many cities around the world.

This paper analyses the state of the atmosphere in Krasnoyarsk based on the atmosphere quality index and meteorological conditions, using data collected from the automated observation posts.

2. Object of Study
The Krasnoyarsk city is located on both sides of the Yenisei river extending for 25 km along the river, its size in the transverse direction is about 10 km. The city’s population is about 1 million. The peculiarities of relief of the Krasnoyarsk territory, the influence of the Krasnoyarsk Hydroelectric Power Station, and the local climatic conditions lead to occurrence of unfavorable meteorological conditions (UMC). In this situation, an increase in concentration of substances emitted by stationary industrial enterprises and mobile sources (vehicles) arises in the city atmosphere. The accumulation of suspended substances in the atmosphere leads to the emergence of smog over the city and degradation of the living conditions of the population.

According to the 2018 data [8], Krasnoyarsk has been included in the priority list of 20 Russian cities with the highest level of air pollution. The amount of pollutants per year emitted by stationary sources of pollution in Krasnoyarsk is 629 thousand tonnes, 81.3% of which is captured, and 42.2% of them are utilized.
3. Methods and Tools of Research

3.1 Air Quality Index (AQI)

Air Quality Index (AQI) is a clear indicator for representing daily air quality. It informs the public about how clean or unhealthy the surrounding air is and what health effects a person may have. One of the most common indices is the Air Quality Index, developed by the US Environmental Protection Agency (EPA) [9]. The AQI calculation takes into account 6 pollutants: suspended particles with a diameter of less than 10 microns (PM$_{10}$) and less than 2.5 microns (PM$_{2.5}$), carbon oxide CO, sulfur dioxide SO$_2$, nitrogen dioxide NO$_2$ and ozone O$_3$. AQI can take values from 0 to 500. The higher the index value, the higher the level of air pollution and the greater the health hazard the air poses. For clarity, the scale is divided into categories (Table 1): Good, Moderate, Unhealthy for Sensitive Groups, Unhealthy, Very Unhealthy, Hazardous. Each category has a visual color designation.

Calculation of AQI [9] is carried out sequentially for each substance according to the formula of piecewise linear interpolation:

$$AQI = \frac{C_{\text{high}} - C_{\text{low}}}{I_{\text{high}} - I_{\text{low}}} (C - C_{\text{low}}) + I_{\text{low}}$$

$$AQI^* = \max[AQI_k]$$

In equation (1), C is the average concentration of the pollutant, $[C_{\text{low}}, C_{\text{high}}]$ are the limits of the concentration interval, in which C falls, $[I_{\text{low}}, I_{\text{high}}]$ is corresponding AQI value interval from Table 1. The integral index AQI* is calculated as the maximum value for all pollutants AQIk, where k is the type of substance.

| Pollutant | 8 hr C$_{\text{low}}$ – C$_{\text{high}}$ (avg) | 1 hr C$_{\text{low}}$ – C$_{\text{high}}$ | 24 hr | 24 hr | 8 hr | 1 hr | 24 hr | 1 hr | I$_{\text{low}}$ – I$_{\text{high}}$ | Category |
|-----------|---------------------------------------------|-----------------|-------|------|-----|-----|------|-----|-------------------|----------|
| O$_3$ (ppb) | 0 – 54 – | 0.0 – 12.0 | 0 – 54 | 0 – 35 | – | 0 – 53 | 0 – 50 | Good |
| PM$_{2.5}$ (µg/m$^3$) | 55 – 154 | 4.5 – 9.4 | 36 – 75 | – | 54 – 100 | 51 – 100 | Moderate |
| PM$_{10}$ (µg/m$^3$) | 155 – 254 | 9.5 – 12.4 | 76 – 185 | – | 101 – 360 | 101 – 150 | Unhealthy for Sensitive Groups |
| CO (ppm) | 255 – 354 | 12.5 – 15.4 | 186 – 304 | – | 361 – 649 | 151 – 200 | Unhealthy |
| SO$_2$ (ppb) | 355 – 424 | 15.5 – 30.4 | – | 305 – 604 | 650 – 1249 | 201 – 300 | Very Unhealthy |
| NO$_2$ (ppb) | 425 – 504 | 30.5 – 40.4 | – | 605 – 804 | 1250 – 1649 | 301 – 400 | Hazardous |

3.2. Air Quality Monitoring Network in Krasnoyarsk

In the Krasnoyarsk Region, atmospheric air quality is monitored at stationary observation posts. In automatic mode, data is transmitted to the Regional departmental information and analytical system on the state of the environment of the Krasnoyarsk Territory (RDIAS) [10]. The system operator is the Regional State Budgetary Institution ‘Center for the Implementation of Measures on Nature Management and Environmental Protection of the Krasnoyarsk Territory’.

There are 9 automated observation posts (AOP) in Krasnoyarsk and its suburbs, i.e. 1-Vetluzhanka, 2-Pokrovka, 3-Severniy, 4-Solnechniy, 5-Kubekovo, 6-Berezovka, 7-Cheryomushki, 8-Kirovskiy, 9-Sverdlovskiy. The posts perform automatic measurement of meteorological parameters and the concentration of pollution in the air with a period of 20 minutes. Such pollutants as nitric oxide, nitrogen dioxide, sulfur dioxide, carbon monoxide, etc. are determined. At the end of 2017, the equipment of the posts was modernized and PM$_{2.5}$ suspended particulate measurement was added. For this purpose, BAM-1020 model dust analyzers (Met One Instruments Inc., USA) are used.
Figure 1 shows a map with the boundaries of the city, contours of heights and points of placement of posts on the territory of the city.

![Figure 1. The boundaries of Krasnoyarsk and locations of the observation posts](image)

It is impossible to solve the problems of information support of observations of the state of the natural environment without the use of modern measuring and communication tools, new computer technologies. The Institute of Computer Modeling (ICM SB RAS) is conducting research in the field of air pollution monitoring. Based on the Geoportal software and technological platform [11], a scientific and research monitoring module was created [12, 13]. The system has a modular architecture and supports data collection from external sources, data storage and aggregation, automatic calculation of derived indicators, presentation and export data via a web interface. Various types of data sources are supported: individual sensors, external databases, external information systems through additional adapters. An application programming interface (API) was developed for interaction with third-party information systems.

Currently, several data streams are connected, such as open sources of climate data, autonomous meteorological stations, and systems to control the state of the environment. The connection of the RDIAS system as a data source was also performed. A software module has been developed for the regular transfer of data from observation posts through a specialized web service. This facilitates the processing and analysis of monitoring data owing to the functions and software tools of the Geoportal.

4. Results

4.1. Assessment of Influence of AQI Components

For AQI calculation, the data on the level of the air pollution from 9 automated observation posts of the RDIAS system were used. The years 2018–2019 was chosen for the analysis. The AQI calculation method uses hourly data, so the raw data coming in with a period of 20 minutes were averaged for each hour. Since we estimate the influence of individual components in the integrated index, only those hours were selected that had data available for the most substances – PM$_{2.5}$, NO$_2$, CO, SO$_2$. The lack of data on PM$_{10}$ is compensated by the data on PM$_{2.5}$, as they correlate and the impact of the latter on human health is more significant [14].
The results are presented in Table 2, where: AQI* are year average values from all AOPs; Components are average AQI values for each pollutant; Influence is the percentage of hours when the corresponding pollutant was decisive for calculating the total air quality index.

| Year | AQI* | Components | Influence, % |
|------|------|------------|--------------|
|      |      | PM<sub>2.5</sub> | NO<sub>2</sub> | CO | SO<sub>2</sub> | PM<sub>2.5</sub> | NO<sub>2</sub> | CO | SO<sub>2</sub> |
| 2018 | 68.9 | 66.8       | 21.9        | 4.5 | 7.0       | 90.9     | 8.6 | 0    | 0.9 |
| 2019 | 61.1 | 60         | 19.9        | 3   | 7.7       | 93.3     | 5.6 | 0    | 1.5 |

The obtained data show that the main influence on the air quality index is caused by pollution by suspended particles – 93%. A small contribution comes from nitrogen dioxide pollution – about 5.6% and sulfur dioxide – 1.5% respectively.

4.2. AQI Spatial Distributions
Annual averages of AQI values for individual observation posts are presented in Table 3. The average Air Quality Index values were 68.9 in 2018 and 61.1 in 2019 (Moderate level).

| Post              | AQI 2018 | AQI 2019 |
|-------------------|----------|----------|
| Vetluzhanka       | 59.1     | 62.7     |
| Pokrovka          | 80.5     | 60.1     |
| Severny           | 69       | 64.3     |
| Solnechny         | 58.9     | 48.5     |
| Kubekovo          | 95       | 81.7     |
| Berezovka         | 75.7     | 69.1     |
| Cheryomushki      | 65.9     | 57.2     |
| Kirovskiy         | -        | 66       |
| Sverdlovskiy      | -        | 51.6     |
4.3. Assessment of Distribution of AQI Values

The AQI index scale is divided into 6 intervals depending on the health hazard degree. We estimate the relative time the index stays in each interval. Table 4 shows the averaged data for individual observation posts and the city as a whole for 2018-2019. Most time, the level of contamination remains in relatively favorable intervals Good (36.5%) and Moderate (46.8%).

| Post          | Good (0 – 50) | Moderate (51 – 100) | Unhealthy for Sensitive Groups (101 – 150) | Unhealthy (151 – 200) | Very Unhealthy (201 – 300) | Hazardous (301+) |
|---------------|---------------|---------------------|---------------------------------------------|-----------------------|----------------------------|-----------------|
| Vetluzhanka   | 45.4          | 41.1                | 8                                           | 5.2                   | 0.3                        | 0               |
| Pokrovka      | 42.1          | 37.8                | 8.9                                         | 8.7                   | 2.5                        | 0               |
| Severn        | 36.6          | 44.2                | 9.9                                         | 9.1                   | 0.2                        | 0               |
| Solnechny     | 54.9          | 35.7                | 5.6                                         | 3.7                   | 0.1                        | 0               |
| Kubekovo      | 7.9           | 60                  | 15.4                                        | 15.1                  | 0.5                        | 1.1             |
| Berezovka     | 22.2          | 57.3                | 8.1                                         | 12.1                  | 0.3                        | 0               |
| Cheryomuski   | 36.4          | 49.3                | 8.3                                         | 6.1                   | 0                          | 0               |
| Kirovskiy     | 44.8          | 48.4                | 6.4                                         | 0.4                   | 0                          | 0               |
| Sverdlovskiy  | 54            | 44.2                | 1.8                                         | 0                     | 0                          | 0               |
| City          | 36.5          | 46.8                | 8.4                                         | 7.8                   | 0.4                        | 0.1             |

We should also note, that with AQI> 100, the adverse conditions occur for sensitive people, and with AQI> 150 – for the whole population. Therefore, in future, we will consider the value AQI> 100 as critical.

4.4. Dependence of AQI on Season and Weather Conditions

Figure 2 shows that the AQI critical values mostly fall on the winter period. A statistical analysis of dependence of the AQI values on the wind speed and direction, air pressure, relative humidity, and temperature was carried out. For example, Figure 3 present data for 2018 reflecting statistical dependence between AQI (ordinate axis) and the wind speed (abscissa axis). Each point shows an average value of the indicators for a single hour in the year.
Analysis of the statistical data shows that the critical values of AQI set in under the following circumstances:

- wind speeds of less than 1 m/s;
- north-East, East and South-East wind directions;
- air temperatures from -10°C to -35°C and 10°C to 30°C;
- atmospheric pressure from 750 to 770 mm Hg;
- relative air humidity in the range of 70–80%.

Figure 4. AQI values and weather data averaged over all observation posts (January 2018)

In late June, due to the east wind the value of AQI began to increase, but change of the wind direction to the south-west brought it back down. In mid-July, AQI reached its critical value. This was caused by the south-east wind, which did not allow the suspended particles to leave the basin. Later on the wind changed its direction to the south-west and the value of AQI decreased.

In winter (Figure 4), the critical AQI values are caused by an increase in pressure up to 770 mm Hg, temperature decrease down to -30°C and the presence of the south-east wind.

5. Conclusion

For the period 2018–2019 the Air Quality Index in the city of Krasnoyarsk was calculated and analyzed. We used data from an observation posts of the RDIAS system. The data on average in the city showed that the determining component of the AQI value is the concentration of suspended particles PM2.5.

In the city of Krasnoyarsk most of the time the level of pollution remains in relatively favorable intervals: Good (36.5%) and Moderate (46.8%) on the AQI scale. We have been able to relate the critical AQI values to certain adverse weather conditions, including the absence of wind or its blowing in the north-east or south-east direction, the formation of an anticyclone in winter and a temperature inversion layer in the atmosphere in summer.

References

[1] 2014 Burden of disease from the joint effects of Household and Ambient Air Pollution for 2012. (WHO: Geneva)
[2] 2009 Global Health Risks: mortality and burden of disease attributable to selected major risks (WHO: Geneva)
[3] Lavee D 2018 Int J Sustain Dev World Ecol. 25 683–695 doi: 10.1080/13504509.2018.1466210
[4] Hu Jin-Li 2006 Int J Sustain Dev World Ecol. 13 327–340 doi: 10.1080/13504500609469684
[5] Bell J N B et al 2011 Int J Sustain Dev World Ecol. 18 226–235 doi: 10.1080/13504509.2011.570803
[6] Longyu Shi et al 2018 Int J Sustain Dev World Ecol. 25 420–430 doi: 10.1080/13504509.2017.1419390
[7] Zvyagintsev A M et al 2014 Atmos Ocean Opt. 27 417–427
[8] State report 2018 ‘On the state and protection of the environment of the Russian Federation in 2017’ Available at: http://mpr.krkstate.ru/dat/File/3/doklad%202017..pdf
[9] US EPA 2018 Technical Assistance Document for the Reporting of Daily Air Quality – the Air Quality Index (AQI) EPA 454/B-18-007 (Sep 2018)
[10] Subsystem for monitoring air pollution. Available at: http://krasecology.ru/Air
[11] Shaparev N, Yakubailik O 2016 MATEC Web Conf. 79 01081 doi: 10.1051/matecconf/20167901081
[12] Shaparev N et al 2018 IOP Conference Series: Materials Science and Engineering 363 012034 doi: 10.1088/1757-899X/363/1/012034
[13] Yakubailik O E et al 2018 Optoelectronics, Instrumentation and Data Processing 54 243–249
[14] 2006 WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005: summary of risk assessment. Geneva: World Health Organization.