IOP Conference Series: Materials Science and Engineering

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To cite this article: A Tokarev and N Shaparev 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **516** 012045

IOP Conf. Series: Materials Science and Engineering **516** (2019) 012045 doi:10.1088/1757-899X/516/1/012045

Using the Monitoring Network and Geoportal Technologies to Analyze the State of the Atmosphere in Krasnoyarsk (Russia)

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Abstract. This study examines the state of the atmosphere in Krasnoyarsk in terms of sustainable development, based on the analysis of data presented in state reports on the state of the environment from 2007 to 2017, and data obtained from automated observation posts located on the city territory.

1. Introduction

Being a natural mixture of surface layer gases, the atmospheric air is an essential component of the environment. During the active industrial activity, large quantities of pollutants are emitted into the atmosphere, worsening the quality of atmospheric air both near the source of pollution, causing the local environmental problems, and influencing the environmental processes. According to WHO, about 7 million people worldwide died of the air pollution in 2012 [1]. This result is about 2 times higher than the previous showed estimates [2]; it confirms that the air pollution is currently the world's largest environmental health risk.

This study examines the state of the atmosphere in Krasnoyarsk in terms of sustainable development, based on the analysis of data presented in State Reports "On State and Protection of the Environment in the Krasnoyarsk Territory" for the period from 2007 to 2017, and data obtained from automated observation posts, located in Krasnoyarsk.

2. Object of Study

Krasnoyarsk was founded by the Russian Cossacks in 1628. To protect them from winds, they chose a place in the valley of the Yenisei River, partly framed by mountain ranges. Subsequently, the Moscow state route passed through Krasnoyarsk, connecting the central part of Russia with its Far Eastern regions. In 1832, Krasnoyarsk became the administrative center of the Yenisei Province. The favorable geographical location and presence of rich natural resources predetermined (since 1934) the intensive development of chemical, metallurgical, pulp and paper, machine-building, fuel and energy industries in the city, which eventually led to a large amount of atmospheric emissions. The situation worsened in the 1990s for the reason of sharp increase in the number of imported used cars. The security of the city from the winds additionally worsened the ecological situation and led to occasional appearance of the city smog. Currently, the city is located on both sides of the Yenisei extending for 25 km along the river, its size in the transverse direction is about 10 km. According to the Krasnoyarskstat for 2018, the city's population is about 1 million.

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3. Methods and Tools of Research

3.1. Indicators of Sustainable Development for the Atmosphere
There are several systems of indicators of sustainable development in the world practice, among them one of the most comprehensive in terms of coverage is the UN system of indicators of sustainable development (132 indicators) [3].

The indicators of sustainable development to protect the atmospheric air (recommendations of the UN Commission) are determined by the following indicators [3]:

- *Input impact*:
  - Emissions of gases causing the greenhouse effect (CO_2, CH_4, N_2O); measured in gigagrams (Gg).
  - Emission of sulfur oxides (SOx); measured in tons / year per person, GDP, DE
  - Emissions of nitrogen oxides (NOx); measured in tons / year per person, GDP
  - Consumption of ozone depleting substances; measured in tons / year
- *States*:
  - Concentration of pollutants in the city's atmosphere (ozone, carbon monoxide, suspended solids, sulfur dioxide, nitrogen dioxide, nitrogen oxide); measured in mg / m^3
- *Management*:
  - Expenses on the air pollution abatement; USD

The use of sustainable development indicators to analyze the water use in Krasnoyarsk was shown in [4, 5].

3.2. Air Quality Index (AQI)
For an integrated assessment of the degree of the air pollution in many countries, standardized indicators are used, i.e. atmosphere quality indexes. Among them, the most widespread is the air quality index AQI, developed by the US Environmental Protection Agency [6]. This is 1st of all because it is informative and the easiest to understand, it can provide information on the atmospheric air pollution to the general public in a simple and clear way. AQI can take values from 0 to 500, the higher its value, the higher is the level of the air pollution and the greater is the health hazard. The scale of values is divided into a number of categories (Table 1): Good, Moderate, Unhealthy for Sensitive Groups, Unhealthy, Very Unhealthy, Hazardous. Each category has a visual color designation.

AQI is calculated based on concentrations of several pollutants: suspended particles with a diameter of less than 10 microns (PM_{10}) and less than 2.5 microns ($PM_{2.5}$), carbon dioxide CO, sulfur dioxide SO_2, nitrogen dioxide NO_2 and ozone O_3. Calculation of this index is carried out sequentially for each substance according to the formula of piecewise linear interpolation [6]:

$$AQI = \frac{I_{high} - I_{low}}{C_{high} - C_{low}}(C - C_{low}) + I_{low} \qquad AQI^* = \max[AQI_k] \tag{1}$$

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

Table 1. Conversion Factors for Individual Pollutants.

O_3 (ppb)		$PM_{2.5}$ (μg/m^3)	PM_{10} (μg/m^3)	CO (ppm)	SO_2 (ppb)		NO_2 (ppb)	AQI	
8 hr	1 hr	24 hr	24 hr	8 hr	1 hr	24 hr	1 hr		
$C_{low} – C_{high}$ *(avg)*								$I_{low} – I_{high}$	Category
0 – 54	–	0.0 – 12.0	0 – 54	0.0 – 4.4	0 – 35	–	0 – 53	**0 – 50**	Good
55 – 70	–	12.1 – 35.4	55 – 154	4.5 – 9.4	36 – 75	–	54 – 100	**51 – 100**	Moderate
71 – 85	125 – 164	35.5 – 55.4	155 – 254	9.5 – 12.4	76 – 185	–	101 – 360	**101 – 150**	Unhealthy for Sensitive Groups
86 – 105	165 – 204	55.5 – 150.4	255 – 354	12.5 – 15.4	186 – 304	–	361 – 649	**151 – 200**	Unhealthy
106 – 200	205 – 404	150.5 – 250.4	355 – 424	15.5 – 30.4	–	305 – 604	650 – 1249	**201 – 300**	Very Unhealthy
–	405 – 504	250.5 – 350.4	425 – 504	30.5 – 40.4	–	605 – 804	1250 – 1649	**301 – 400**	Hazardous
–	505 – 604	350.5 – 500.4	505 – 604	40.5 – 50.4	–	805 – 1004	1650 – 2049	**401 – 500**	

3.3. Air Quality Monitoring Network in Krasnoyarsk

According to the data of 2017 [7], Krasnoyarsk is included into the priority list of 20 large Russian cities with the highest level of air pollution.

Now there are 7 automated observation posts (AOP) in Krasnoyarsk and its suburbs, i.e. 1-Cheryomushki, 2-Severny, 3-Solnechny, 4-Berezovka, 5-Kubekovo, 6-Vetluzhanka, 7-Pokrovka. The posts make automatic measurement of mass concentrations of contaminants in the atmospheric air, meteorological parameters (wind direction and speed, temperature, humidity, atmospheric pressure), as well as collection, processing and transmission of the accumulated data to a remote server. The set of measurable indicators differs in different AOPs, but most of them transmit data on such pollutants as nitric oxide, nitrogen dioxide, sulfur dioxide, carbon monoxide, suspended particles $PM_{2.5}$. The collected data comes into the regional departmental information and analytical system on the state of the environment of the Krasnoyarsk Territory (RDIAS) [8].

The Institute of Computational Modeling (ICM SB RAS) also conducts research and development of software and hardware to control the level of the air pollution. Based on the geoportal software and technological platform [9] a scientific and research monitoring block was created [10, 11]. The system provides data collection from external sources, data storage and aggregation, automatic calculation of derived indicators, data upload and presentation via the web interface. Data sources can be either individual sensors, or external databases, or information systems through additional adapters. An API is also supported for integration with external 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. Apart from that, a software module is developed aimed at regularly download of the data from observation posts from the KVIAS system through a specialized web service. This facilitates processing and analysis of data owing to the geoportal functions and software tools.

4. Results

4.1. Analysis of Pollutant Emissions According to UN Indicators

The initial data on the total emissions of pollutants into the atmospheric air of Krasnoyarsk from stationary and mobile sources were obtained on the basis of public information provided by the Territorial body of the Federal State Statistics Service for the Krasnoyarsk Territory and the Federal Service for Supervision of Natural Resources [7].

Industrial Krasnoyarsk enterprises, with the highest emissions of pollutants into the atmosphere [7] for 2017 are JSC RUSAL Krasnoyarsk – 56.8 thousand tons, Krasnoyarsk CHP-1 – 17.0 thousand tons, Krasnoyarsk CHP-2 – 14.0 thousand tons, Krasnoyarsk CHP-3 – 9.6 thousand tons.

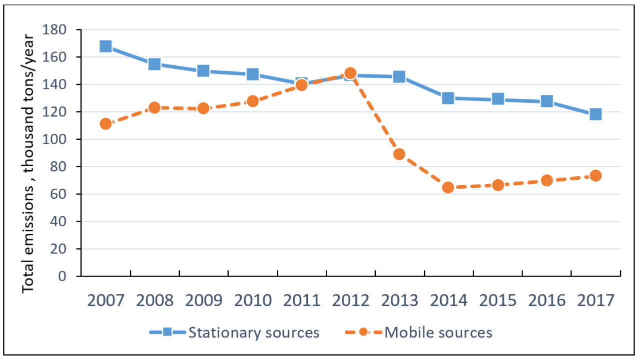

Figure 1. Gross Emissions of Pollutants into the Krasnoyarsk Atmosphere.

The gross volume of pollutants is a total characteristic of the amount of pollution entering the city's atmosphere. Figure 1 shows change in gross emissions from stationary and mobile sources to the air in Krasnoyarsk for 2007–2017. In 2017, the contribution from the mobile sources to the total emissions was about 38%.

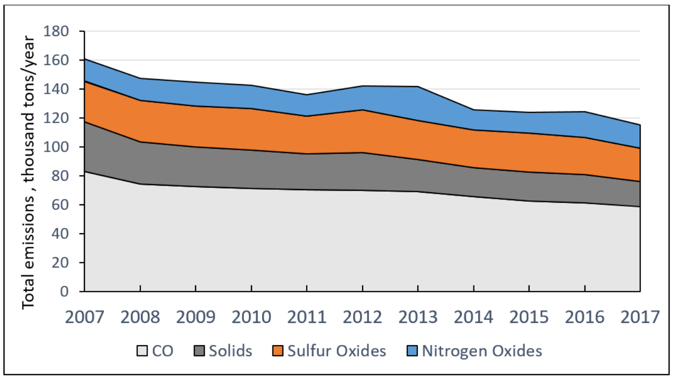

Figure 2. The Structure of Emissions of Pollutants From Stationary Sources Into the Krasnoyarsk Atmosphere.

Since 2013, changes have been added to the methodology for estimating the air emissions from the road transport [12]. In connection with the use of the new methodology, emissions from road transport are obtained almost 1.5 times lower than according to the previously used method.

Figure 2 shows the structure of emissions of various pollutants into the Krasnoyarsk atmosphere for 2007 – 2017. Figure 3 shows the gross emissions of various pollutants per person.

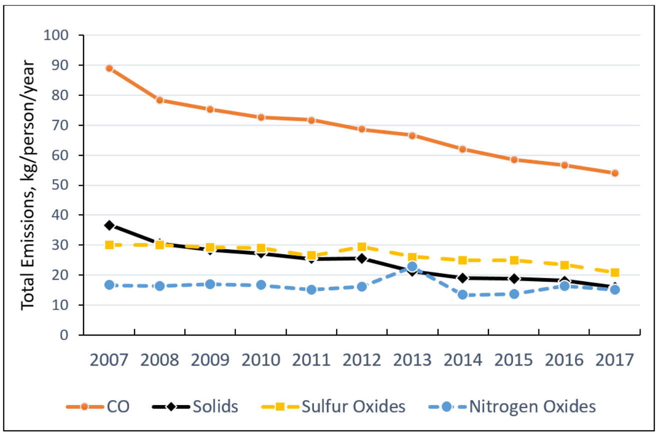

Figure 3. Dynamics of Emissions of Solids, Sulfur Oxides, and Nitrogen into the Krasnoyarsk Atmosphere per Person.

4.2. Air Quality Index Analysis

For AQI calculation, the data on the level of the air pollution from 7 automated observation posts of the KVIAS system were used. With regard to the AQI calculation, the source data set has several disadvantages:

- ozone and dust PM_{10} data are not available;
- measurements on $PM_{2.5}$ appeared only from the end of 2017;
- gaps in the data.

The full year 2018 was selected for analysis. The method of the AQI calculation uses the hourly data, so the source data coming every 20 minutes was transformed into per hour statistics data. Since the influence of individual components in the integral index was estimated, only hours containing data on most of the available substances were selected, i.e. $PM_{2.5}$, NO_2, CO, SO_2. The lack of data on suspended particles PM_{10} was compensated by data on $PM_{2.5}$, since they correlate and effects of the latter on health are more significant [13]. To assess the city's atmosphere state as a whole, the values were averaged at all observation posts.

The processing results are presented in Table 2, with Figures given per individual months and on average for 2018, where:

- *AQI** are average values for 2018.
- *Components* are average AQI values for each pollutant.
- *Influence* is the percentage of time when the corresponding pollutant was decisive for calculating the total air quality index (the sum for all components may exceed 100%, if there were moments in time when different substances had the same effect on the result).
- *Number of hours* is the number of hours for which there is data available on all pollutants.

Table 2. The Average AQI Values and the Effect of Individual Components for the Year 2018, by Months.

Month	AQI*	Components				Influence, %				Number of hours
		$PM_{2.5}$	NO_2	CO	SO_2	$PM_{2.5}$	NO_2	CO	SO_2	
January	94.6	94.5	20.0	5.4	8.4	99.5	0.4	0	0.1	2280
February	118.1	117.8	31.0	7.3	9.0	99.2	0	0	0.8	2381
March	80.7	78.2	29.6	4.2	7.7	91.0	8.8	0.1	0.4	2619
April	50.9	49.5	18.6	2.4	6.3	92.8	7.2	0	0.3	2722
May	38.8	37.8	11.8	2.3	8.6	94.2	2.8	0	3.4	2855
June	66.1	66.0	14.1	2.9	8.4	99.2	0.8	0	0	2443
July	84.5	84.2	13.9	3.7	2.9	98.7	1.4	0	0	2286
August	54.4	53.0	16.0	3.4	5.1	93.3	6.9	0	0.1	3405
September	53.7	50.5	23.3	4.4	4.0	85.5	14.8	0	0.3	2286
October	61.3	56.4	29.3	5.9	6.5	81.7	18.8	0	0.2	2534
November	57.9	53.9	23.3	6.0	7.8	76.3	20.7	0	4.0	3071
December	85.9	79.4	36.8	7.8	9.3	80.8	19.5	0	0.1	2131
2018 year	**68.9**	**66.8**	**21.9**	**4.5**	**7.0**	**90.9**	**8.6**	**0**	**0.9**	**31013**

The obtained data show that the main influence on the air quality index is caused by pollution by suspended particles – 91%. A small contribution comes from nitrogen dioxide pollution — about 8.6% and sulfur dioxide — less than 1% respectively.

4.3. Analysis of Correlation between Adverse Weather Conditions and AQI

Adverse meteorological conditions (AMC) are a short-term special combination of meteorological factors contributing to accumulation of pollutants in the surface layer of the atmospheric air. In accordance with Article 19 of the Federal Law “On Protection of the Atmospheric Air” No. 96-FZ, legal entities having sources of pollutant emissions into the atmospheric air, must take measures to reduce the emissions of pollutants into the atmosphere when receive AMC forecasts.

Depending on the expected level of atmospheric pollution, the FSBI Central Siberian DSMS, based on long-term observations of weather conditions and the level of atmospheric pollution using a specially developed forecasting scheme, provides warnings about the AMC periods.

Table 3 shows the list of announced periods with the AMC regime in the city of Krasnoyarsk for 2018, according to the data of the Federal State Budgetary Institution “Central Siberian DSMS”.

Table 3. Announced AMC Regimes for 2018.

№	Begin	End	Duration, hours
1	03.01.2018 19:00	05.01.2018 19:00	48
2	20.01.2018 19:00	27.01.2018 15:00	164
3	02.02.2018 19:00	06.02.2018 19:00	96
4	12.02.2018 19:00	16.02.2018 19:00	96
5	28.02.2018 19:00	02.03.2018 19:00	48
6	06.04.2018 19:00	07.04.2018 16:00	21
7	26.06.2018 19:00	28.06.2018 19:00	48
8	19.10.2018 19:00	22.10.2018 7:00	60
9	06.12.2018 19:00	07.12.2018 19:00	24
10	25.12.2018 19:00	28.12.2018 19:00	72
11	28.12.2018 19:00	31.12.2018 19:00	72

Figure 4 shows the dynamics of changes in the average value of AQI and the periods of AMS in January – February 2018. Bold lines at the top of the graph indicate the AMS periods.

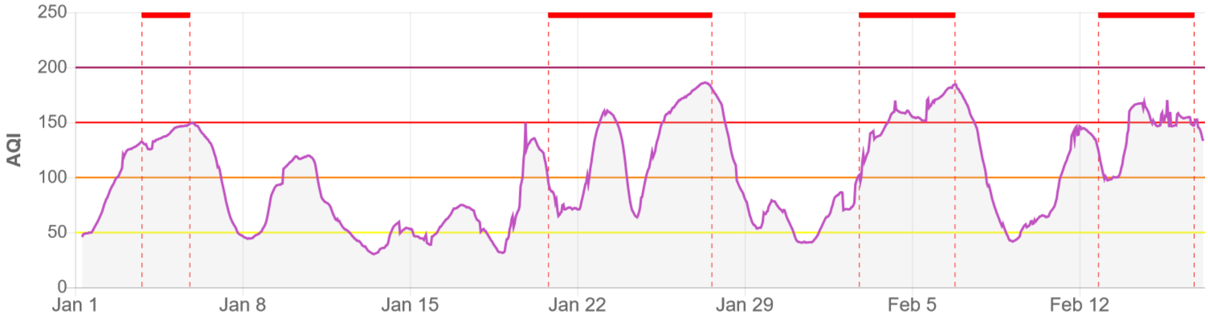

Figure 4. Comparison of Average AQI and AMS Modes in January – February, 2018.

5. Conclusion

The analysis of the state of the atmosphere in Krasnoyarsk in indicators of sustainable development was carried out on the basis of the data obtained from the State Reports "On State and Environmental Protection in the Krasnoyarsk Territory" for 2007 – 2017. The results showed that gross emissions in 2017 from stationary sources amounted to 62%, and from mobile sources – to 38% respectively. The structure of emissions of various substances in 2017 from stationary sources is as follows: carbon monoxide – 50%, sulfur dioxide – 19.3%, solids – 14.7%, nitrogen oxides – 14%. It should be noted that specific emissions per person for all pollutants decreased during 2007 – 2017.

During 2018, the value of the AQI air quality index was determined online, based on the data received from the KVIAS system and our calculations. The data on individual posts and on average in the city showed that the determining component of the AQI value is the concentration of suspended particles $PM_{2.5}$. In normal periods, the AQI was not exceeding 100 (good / average level on the scale), while during AMC it was about 150 (an unfavorable level on the scale).

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