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Analysis of the state of the air environment in Krasnoyarsk based on atmospheric pollution indexes

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Abstract. This study examines the state of the atmosphere in Krasnoyarsk in terms of sustainable development, and based on atmospheric pollution indexes API-5, AQI. The data presented in state reports on the state of the environment from 2007 to 2017, as well as monitoring data obtained from automated observation posts located in the city territory were used.

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, the transfer and transformation of which depend on meteorological conditions, atmospheric circulation, prevailing winds, terrain aeration, etc.

According to WHO, about 7 million people worldwide died of the air pollution in 2012 [1], which is about 2 times higher than the previous showed estimates [2] and 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 in 1628 in the valley of the Yenisei River, partly framed by mountain ranges. The favorable geographical location and presence of rich natural resources predetermined (since 1934) the intensive development of industries in the city, which eventually led to a large amount of atmospheric emissions. The city’s security 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.

3. Methods and Tools of Research

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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.
  - Emissions of nitrogen oxides (NOx); measured in tons / year per person.
  - 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.

3.2. Indexes Used to Study the Air Pollution in Russia

In practice, two atmospheric pollution indexes are used: API for each substance and integrated API-5, which examines the air pollution by five prior for the city substances [4]. Indexes characterize the level of the air pollution during the year.

The API calculation is based on the assumption that at values on the level of the maximum permissible concentrations (MPC), all harmful substances are characterized by the same effect on humans, and with further increase in concentration, their degree of harmfulness increases at different rates, depending on the substance hazard class. The API value for a single substance Ii and a complex API indicator for m substances I (m) are calculated by formulas (1).

$$I_i = \left(\frac{q_i}{MPC_i}\right) K_i \quad , \qquad I(m) = \sum_{i=1}^{m} \left(\frac{q_i}{MPC_i}\right) K_i \tag{1}$$

where q_i is the average annual concentration of the i-th pollutant; MPC_i is its daily average maximum allowable concentration; K_i is a dimensionless coefficient showing the degree of danger of the i-th substance in comparison with sulfur dioxide. K_i values are 0.85; 1.0; 1.3; 1.5 for 4-, 3-, 2- and 1-st hazard classes of substances, respectively.

The API $I_i < 5$ corresponds to a low level of pollution, $5 \leq I_i < 8$ – to an elevated level, from $8 \leq I_i < 15$ to a high level. Index $I_i \geq 15$ characterizes a very high level of the air pollution.

3.3. 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 [5]. It provides information on the atmospheric air pollution in a simple and visual form. AQI scale of values from 0 to 500 is divided into a number of categories: Good, Moderate, Unhealthy for Sensitive Groups, Unhealthy, Very Unhealthy, Hazardous.

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 [5]:

$$AQI = \frac{I_{high} - I_{low}}{C_{high} - C_{low}}(C - C_{low}) + I_{low} \quad , \qquad AQI^* = \max_k [AQI_k] \tag{2}$$

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where C is the average concentration of the pollutant, [C_{low}, C_{high}] are the limits of the concentration interval, in which C falls, [I_{low}, I_{high}] is corresponding AQI value interval. The table with intervals is given in [5]. The integral index AQI* is calculated as the maximum value for all pollutants AQIk, where k is the type of substance.

3.4. Air Quality Monitoring Network in Krasnoyarsk

Now there are 7 automated observation posts (AOP) in Krasnoyarsk and its suburbs, which make automatic measurement of mass concentrations of contaminants in the atmospheric air and meteorological parameters. The collected data comes into the regional departmental information and analytical system on the state of the environment of the Krasnoyarsk Territory (RDIAS) [6].

The Institute of Computational Modeling (ICM SB RAS) conducts research and development of software and hardware to control the level of the air pollution. Based on the geoportal software and technological platform [7] a scientific and research monitoring block was created [8, 9]. 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.

4. Results

4.1. Analysis of Pollutant Emissions According to UN Indicators

The initial data on the emissions of pollutants into the atmospheric air of Krasnoyarsk were obtained on the basis of public information presented in state reports on the state of the environment [10].

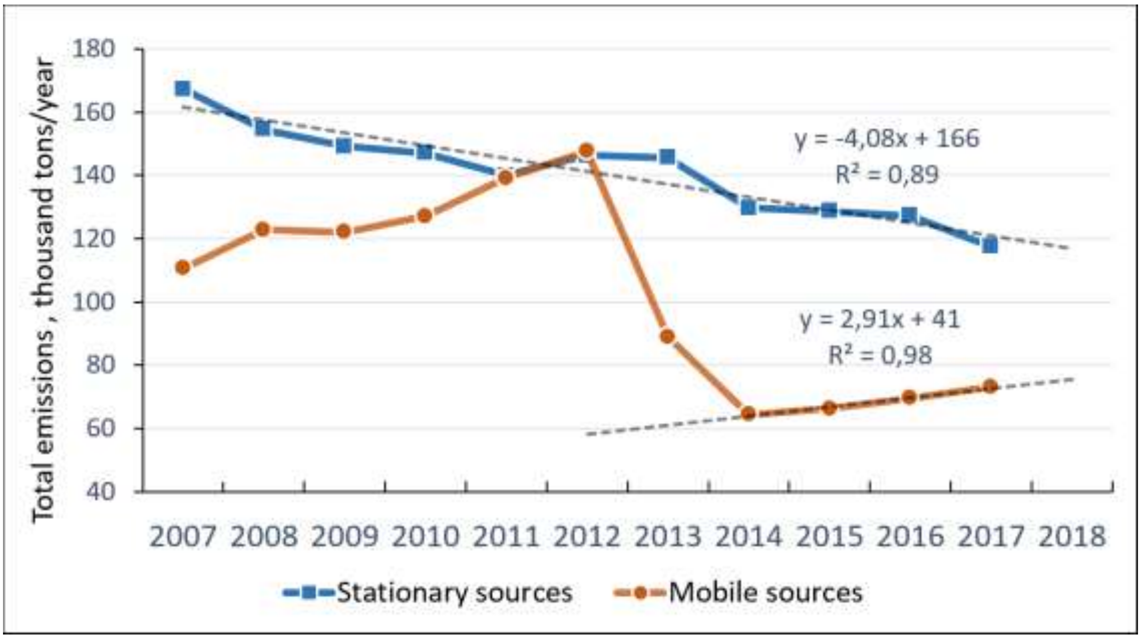

Figure 1. Gross Emissions of Pollutants into the Krasnoyarsk Atmosphere.

The gross volume of pollutants is a total characteristic of the amount of pollution entering the city's atmosphere for the year. Figure 1 shows change in gross emissions from stationary and mobile sources to the air in Krasnoyarsk for 2007–2017. Dashed lines indicate the corresponding trend lines and forecast for 2018. Since 2013, changes have been added to the methodology for estimating the air emissions from the road transport which led to a decrease in estimates by almost 50% [11].

From 2007 to 2017, gross emissions from stationary sources almost continuously decrease by about 4 tons per year. Emissions from road transport increase by about 3 tons per year. In 2017, the contribution from mobile sources to the total emissions was about 38%.

Table 1 demonstrates the structure of emissions of various pollutants into the Krasnoyarsk atmosphere from stationary sources for 2007-2017. The figures show both a gross value of emissions, and the value per person. Approximately 50% of emissions come from carbon monoxide. Gross emissions of nitrogen oxides remain approximately the same for the period under review.

Table 1. Dynamics and Structure of Emissions of Various Pollutants.

Year	Population (*10^3)	Total Emission (tons/year)	Emission (tons/year)				Total Emission (kg/person/year)	Emission (kg/person/year)			
			Solids	SOx	CO	NOx		Solids	SOx	CO	NOx
2007	932.5	163.9	34.3	28.0	83.0	15.5	175.8	36.8	30.0	89.0	16.6
2008	948.5	150.4	29.0	28.5	74.4	15.6	158.6	30.5	30.1	78.4	16.4
2009	963.2	149.3	27.4	28.2	72.5	16.4	155.0	28.4	29.2	75.3	17.0
2010	979.6	147.1	26.7	28.4	71.1	16.2	150.1	27.2	29.0	72.6	16.6
2011	979.6	140.1	24.9	25.9	70.3	14.8	143.0	25.4	26.4	71.7	15.1
2012	1017.2	146.3	26.0	29.9	69.8	16.4	143.8	25.6	29.4	68.6	16.1
2013	1036.6	145.6	22.1	27.1	69.1	23.6	140.5	21.3	26.1	66.7	22.7
2014	1053.2	129.8	20.0	26.3	65.4	14.1	123.3	19.0	25.0	62.1	13.4
2015	1066.9	128.7	20.1	26.7	62.5	14.6	120.6	18.8	25.0	58.6	13.7
2016	1082.9	127.3	19.6	25.4	61.3	17.8	117.6	18.1	23.5	56.6	16.4
2017	1090.8	117.6	17.3	22.7	58.8	16.5	107.8	15.9	20.8	53.9	15.1

4.2. Analysis of the Air Pollution Index

Table 2 shows the dynamics of changes of the annual atmospheric quality indexes in Krasnoyarsk:

- *API-5* is a complex index of the air pollution according to five pollutants prior for the city;
- *Substances* are priority pollutants (F – formaldehyde, BaP – benzo[a]pyrene, SS – suspended solids, NO_2 – nitrogen dioxide, NH_3 – ammonia, Eb – ethylbenzene);
- *SI* (standard index) is the highest impurity concentration divided by MPC maximum one-time, from the measurement data for all impurities in the city during the year;
- *NP* is the highest MPC excess repeatability according to the measurement data at all observation posts for all detected substances.

Table 2. Dynamics of the Annual Atmospheric Quality Indexes.

Year	API-5	Substances	SI	NP (%)	Pollution level
2007	14.66	BaP, F, SS, NO_2	12.8	27.7	very high
2008	15.31	BaP, F, SS, NO_2, NO	18.0	23.3	very high
2009	18.56	BaP, F, SS	10.4	15.2	very high
2010	21.86	BaP, F, SS, NO_2	20.4	23.2	very high
2011	23.75	BaP, F, SS, NO_2, NH_3	20.0	27.7	very high
2012	22.93	F, BaP, SS, NO_2	17.0	29.0	very high
2013	17.05	F, BaP, SS, NO_2	17.1	22.9	very high
2014	17.48	F, BaP, Eb	30.2	8.1	very high
2015	>7	F, BaP, SS, NO_2, NO	18.5	18.0	high
2016	>14	BaP, F, NH_3, NO_2, SS	40.6	21.9	very high
2017	>14	BaP, F, NH_3, NO_2, SS	20.1	23.1	very high

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During the reviewed period, the level of pollution remains consistently very high. The main impurities affecting the complex pollution index values are benzo[a]pyrene and formaldehyde.

4.3. Air Quality Index Analysis
For AQI calculation, the data on the level of the air pollution from 7 automated observation posts of the RDIAS system were used. With regard to the AQI calculation, the source data set has several features:

- 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 [12]. 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 3, 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 3. The Average AQI Values and the Effect of Individual Components for the Year 2018.

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.

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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%. From 2007 to 2017, gross emissions from stationary sources almost continuously decrease by about 4 tons per year. Emissions from road transport increase by about 3 tons per year. 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 RDIAS 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 $PM_{2.5}$.

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* (World Health Organization: Geneva)
[3] 1996 *Indicators of Sustainable Development Framework and Methodologies* (United Nations: New York)
[4] 1991 *Atmospheric Pollution Control Manual RD 52.04.186–89* (L.: Gidrometeoizdat)
[5] 2016 *Technical Assistance Document for the Reporting of Daily Air Quality – the Air Quality Index (AQI)*. U.S. Environmental Protection Agency (USA)
[6] *Subsystem for monitoring air pollution* Avalable from: http://krasecology.ru/Air
[7] Shaparev N and Yakubailik O 2016 *MATEC Web Conf.* **79** 01081
[8] Shaparev N, Tokarev A, Yakubailik O and Soldatov A 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **363** 012034
[9] Yakubailik O E, Kadochnikov A A and Tokarev A V 2018 *Optoelectronics, Instrumentation and Data Processing* **54(3)** 243–9
[10] 2008 – 2018 *State reports On the state and protection of the environment in the Krasnoyarsk Territory for 2007–2017* (Krasnoyarsk)
[11] 2013 Order of the Federal Service for the Supervision of Natural Resources of November 1, 2013 No 6-p *On approval of the procedure for organizing work on the assessment of emissions from certain types of mobile sources*
[12] 2006 *WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005: summary of risk assessment* (WHO: Geneva)