Spatial Analysis of Air Pollution in Krasnoyarsk

Oleg E. Yakubailik[1,2,3], Valery V. Zavoruev[2,3], Maxim I. Malimonov[1], Alexander A. Pushkarev[1]

[1] Federal Research Center Krasnoyarsk Science Center of the SB RAS, Krasnoyarsk, Russia
[2] Institute of Computational Modelling SB RAS, Krasnoyarsk, Russia
[3] Siberian Federal University, Krasnoyarsk, Russia
oleg@icm.krasn.ru

Abstract. The pollution of Krasnoyarsk by particulate matter PM2.5 according to scientific and research environmental monitoring network of the FRC KSC SB RAS is considered. The quality of data measured by CityAir monitoring stations is analyzed and compared with the data of certified devices. Special attention is paid to the period of adverse weather conditions in the first half of February 2019. The dynamics of the spread of pollution in the city, as well as its subsequent purification are analyzed. It is shown that a significant role is played by the terrain. The conclusion is made about significant influence of furnace heating on air pollution of Krasnoyarsk.

Keywords: air pollution, PM2.5, Krasnoyarsk, web mapping, GIS, environment, spatial data, ecological monitoring, furnace heating, CityAir.

1 Introduction

The tasks of operational monitoring and assessment of air pollution in areas with high population density, and especially in large urban agglomerations, are currently the subject of numerous scientific and applied research in many countries. A wide range of problems is considered, including the construction of mathematical and information models of various types [1-3], pollution assessment [4,5], creation and operation of monitoring networks [6-8], computational modeling of processes in the atmosphere [9]. Considerable attention is paid to these problems by government agencies and relevant departmental organizations, which are engaged in the organization and conduct of relevant activities on this issue. Independent public environmental organizations are also actively involved in these studies. Thanks to modern information technology, social networking on the web more meaningful role in the discussion of problems of environmental monitoring play a proactive citizen, such as bloggers, leading popular online diaries on LiveJournal, Instagram, Vkontakte, Facebook, and so on. [10].

Legal and regulatory support of the tasks is based on the environmental legislation of the Russian Federation. The most important laws are: Federal Law of 10.01.2002 N 7-FZ (ed. of 27.12.2018) "On environmental protection", Federal Law of 04.05.1999 N 96-FZ (ed. of 29.07.2018) "On the protection of atmospheric air". Legal and regulatory support is also being developed at the regional and local authority levels.

Monitoring of air pollution in Krasnoyarsk, Russia, conducted by several organizations of the Federal and regional level. The main organizations that carry out monitoring are The Federal State Budgetary Institution "Central Siberian Department for Hydrometeorology and Environmental Monitoring" (Central Siberian DHEM), The Territorial State Institution "Center of Implementation of Nature Management and Environment Protection of Krasnoyarsk Territory" (TSI CINMEP), EMERCOM in the Krasnoyarsk Territory (Regional Division), Siberian Federal University (SFU), Federal Research Center "Krasnoyarsk Science Center of the Siberian Branch, Russian Academy of Sciences" (FRC KSC SB RAS), and others. Each of these organizations has its own methods, technologies and systems of data collection, storage and processing.

The variety of solutions used, interdepartmental and organizational disunity lead to the fact that a comprehensive analysis and rapid assessment of the entire array of recorded information on air pollution is currently technically difficult and practically not carried out. Taking into account the planned expansion of the number of automatic stationary environmental observation posts by a number of authorized organizations in the coming years, the situation will only get worse [11].

Research and development for monitoring atmospheric pollution, performed in the FRC KSC SB RAS, aimed at solving this problem. Created software and technology provides reception and integration of information coming from different data sources. The formed database is provided with tools of operational aggregation and visualization of data, their analytical processing [10, 11].

The results presented below are devoted to the assessment of the dynamics of pollution of Krasnoyarsk by particulate matter according to scientific and research environmental monitoring network of the FRC KSC SB RAS, which is built using various monitoring devices, including CityAir monitoring stations. Calibration of the used sensors was performed with the help of TSI CINMEP devices.

2 Object of research

The subject of the study in this paper was the dynamics of air pollution of Krasnoyarsk by particulate matter (PM). Particulate matter, also known as PM2.5 and PM10, are a complex mixture of extremely fine suspended particles. Their composition is diverse: acids (for example, nitrates and sulfates), emissions of industries, organic chemicals, metals and soil particles, dust, soot exhaust gases, asphalt particles and worn tires, etc. Sources of suspended particles are cars and roads, power plants and production, sandstorms, smoke from fires. Particulate matter also appear because of evaporation of water and combustion of any fuel, for example because of furnace heating in the private sector of Krasnoyarsk in the winter. Natural sources of particulate matter are plants. It is because of its size that they cause health problems, because particles get through the throat and nose get into the lungs. After inhalation, these particles affect the cardiovascular and pulmonary systems and can cause serious health effects. Some particles, such as dust, dirt, soot, smoke are large enough and if there are many of such particles, they can be seen with the naked eye. Other particles are so small that they can only be detected by an electron microscope. Particulate matter are usually divided into several categories according to their size: with a diameter less than 10 μm (PM10) and particles with a diameter of 2.5 micrometers and less (PM2.5).

In this paper, we considered the period from December 2018 to May 2019, for which the available data on the level of concentrations of PM2.5 particulate matter in the atmosphere of Krasnoyarsk obtained by research environmental monitoring network of the FRC KSC SB RAS were analyzed. Special attention was paid to the first half of February, as during this period Central Siberian DHEM was declared the regime of adverse weather conditions. This time is particularly interesting for the reason that adverse weather conditions for the entire 2019 year were observed only once, during exactly this period.

The regime of adverse weather conditions (AWS) is a short-term special combination of meteorological factors contributing to the accumulation of harmful (polluting) substances in the surface layer of atmospheric air. In accordance with article 19 of the Federal Law "On air protection" № 96-FZ legal entities with sources of emissions of harmful (polluting) substances into the air, when declaring the AWS regime are required to take measures to reduce emissions of harmful (polluting) substances into the air. Depending on the expected level of air pollution, warnings of three degrees are drawn up, which correspond to the three modes of operation of enterprises during AWS periods.

The environmental monitoring network of the FRC KSC SB RAS is based on the CityAir air monitoring stations created by the group of companies from the Novosibirsk (CityAir, UniScan, TION) [12]; currently, 20 of these stations have been installed in Krasnoyarsk, mainly on the left bank of the Yenisei river. These CityAir monitoring stations are designed to collect data on the state of the ambient air (mass concentration of aerosol particles, temperature, humidity and atmospheric pressure) and transmit them to the server via a wireless communication channel. The practice of operation of monitoring stations has confirmed their ability to use, performance at low temperatures up to -40°C [13]. All information from the stations is first transferred to the cloud data storage of the developer company and then, through web services, enters the database of operational monitoring of the geoportal of the Institute of Computational Modeling SB RAS. Original software based on geoportal web services is used for data visualization and analysis.

3 Analysis of the quality of the measured data

One of the first tasks was to compare the data on PM2.5 particulate matter obtained by CityAir monitoring stations with the results of measurements of the same concentrations at the TSI CINMEP automated monitoring stations (AMS) equipped with certified dust meters. In this paper, we used information from the AMS in Pokrovka district (AMS "Pokrovka-Krasnoyarsk"), where, in agreement with TSI CINMEP, CityAir monitoring device was installed. Within six months, the stations located in one place worked in parallel, simultaneously measuring the concentration of particles. An example of the results of these measurements during one week (during the Universiade 2019 in Krasnoyarsk) is shown in Fig. 1.

Maximum permissible concentration levels of pollutants are established as state standards. In particular, the Resolution of the Chief State Sanitary Doctor of the Russian Federation of December 22, 2017 № 165 approved "Maximum permissible concentrations (MPC) of pollutants in the air of urban and rural settlements". For particulate matter, this document indicates the following levels: maximum one-time MPC = 0.16 mg/m^3, average daily MPC = 0.035 mg/m^3, average annual concentration = 0.025 mg/m^3. Figure 1 also shows the levels of the maximum one-time MPC and average daily MPC.

Comparative analysis of the presented measurement data shows that different devices record relatively similar qualitative changes in the particle concentration but at the same time, there are significant quantitative differences. The reasons for these serious differences apparently associated with the CityAir devices. Further research is needed on the accuracy of these devices.

It should be additionally noted that direct comparison of the obtained data is difficult, because in the devices under consideration different physical principles of measurement are used. In devices installed on the TSI CINMEP automated monitoring stations concentration of particulate matter is measured (radioisotope principle of operation based on the attenuation of β-radiation by the dust particles deposited on the filter tape) and the station CityAir measures the concentration of aerosols (CityAir device has optical sensor. The air passing through this optical sensor is continuously illuminated by a laser, which allows the highly sensitive photocell to recognize the particulate matter amount contained in the air).

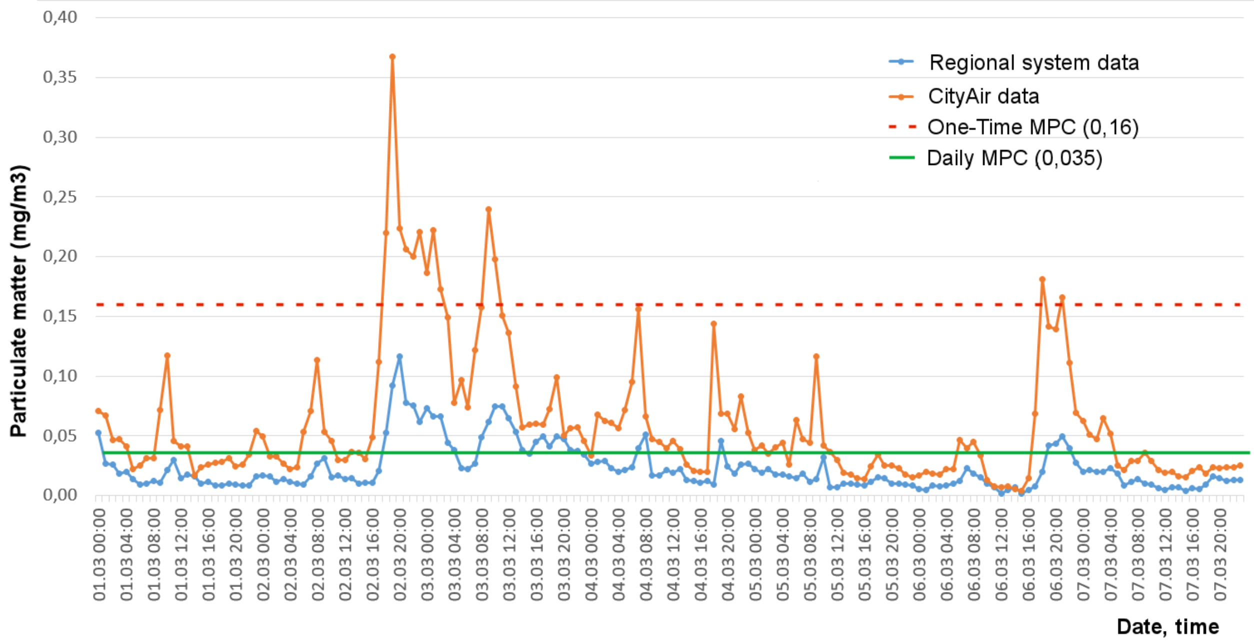

Figure 1. Comparison of PM2.5 concentration data of CityAir and official certified regional system measurements for the first week of March 2019 at the AMS "Pokrovka-Krasnoyarsk".

One of the issues considered was related to the analysis of the observed differences in the value of concentrations measured by different instruments. As a first approximation in the solution of this problem is possible to consider the introduction of step-down "calibration factor" that you need to multiply the concentrations of CityAir, to obtain values comparable to those acquired by TSI CINMEP certified devices. Calculations on the available data on the AMS "Pokrovka-Krasnoyarsk" for six months showed that the average value of this coefficient is the value of

$$k = 0.46$$

Attempts to find any dependence of this coefficient on weather conditions (temperature, humidity, dew point, etc.) or any other parameters at this stage did not lead to success (Fig. 2).

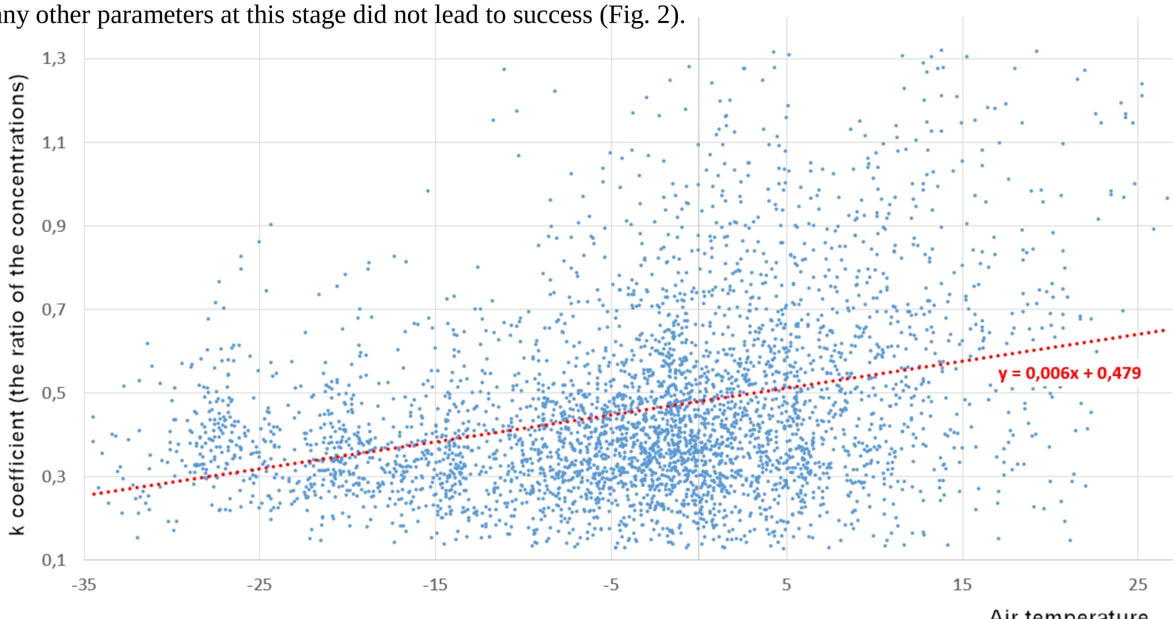

Figure 2. The dependence of the calibration factor *k* from the air temperature.

The AWS regime was declared in the city of Krasnoyarsk in the period from 7 PM on February 8 to 7 PM on February 13. As it turned out, during this period, TSI CINMEP devices at AMS "Pokrovka-Krasnoyarsk" did not measure the concentration of PM2.5 particulate matter, because they were sent to the scheduled certification check (Fig. 3). However, CityAir monitoring stations were operating at that time, which allowed analyzing the dynamics of the spread of pollution over the city and its subsequent cleaning.

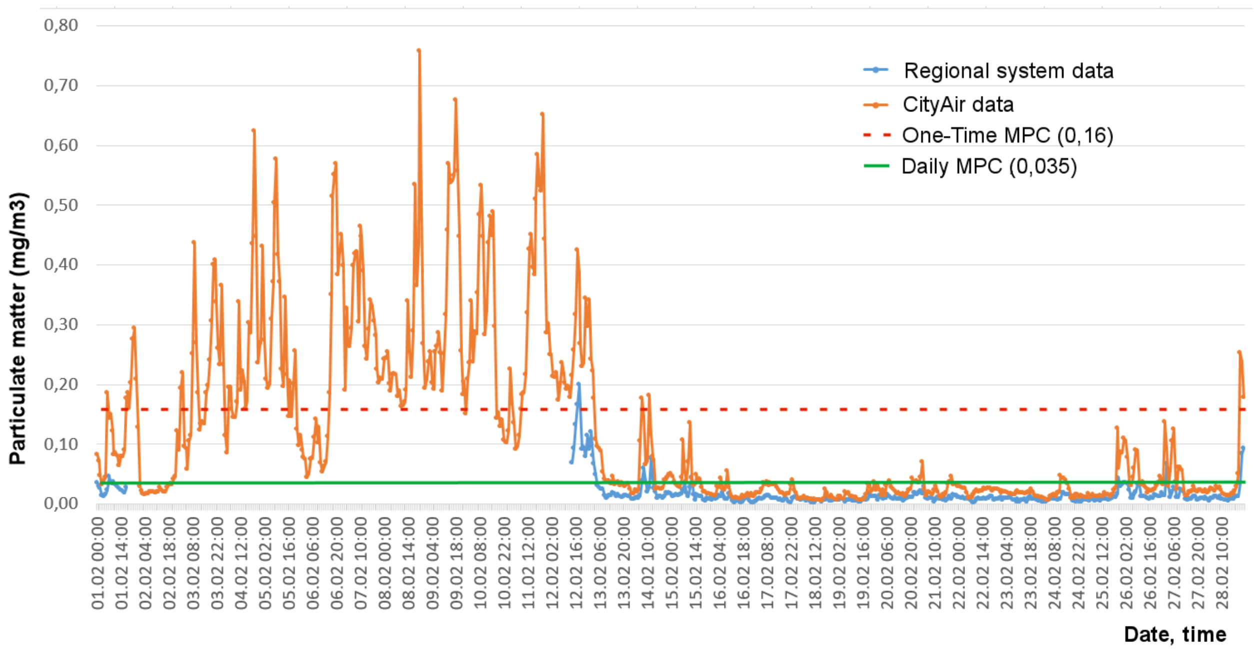

Figure 3. Results of PM2.5 measurements in February 2019 at the AMS “Pokrovka-Krasnoyarsk”.

4 Dynamics of pollution of Krasnoyarsk by particulate matter

The study of the distribution of particulate matter on the territory of Krasnoyarsk depending on time was based on data collected by CityAir monitoring stations. Although there are doubts about the accuracy of the measured values of absolute values of concentrations, the main trends in the recorded parameters at the qualitative level can be considered acceptable.

Analysis of the data showed that the pollution of the city began on the night from February 2 to February 3. Even in the evening of February 2, the prevailing wind direction was South-West, at a speed of 2-3 m/s, and at this time point, the city was absolutely clean. Approximately at midnight, its direction changed to the South-East, at a speed of about 1 m/s. Already at 2 AM (Fig. 4) half of the city was relatively dirty. The spatial distribution of pollution at this time shows the maximum concentrations of PM2.5 in the private sector of the city (Nikolaevka, Pokrovka) and in the villages located in the immediate vicinity of the city (Solontsy, Drokino, Minino), mainly from the North. All of these areas can be described as low-rise buildings with a large number of stove heating, which is highly likely the main reason for the high concentrations of PM2.5, given that the air temperature at this point was about -30°C and all residents actively heated (mainly using brown coal) their homes at this time.

The dynamics of the spread of pollution over time shows that smog from these areas of the private sector smoothly covers a significant part of the city, in accordance with the wind, which balances between the South-Eastern and Southern directions, partially observed calm conditions. Pollution, respectively, extends from North to South. Uneven terrain leads to heterogeneity of the spread of pollution. In particular, at the first stage, the Western part of the city (Akademgorodok district) located on the hills, which is higher than the city center by more than 100 meters, remains clean. We can say that the wave of pollution "hits the wall" and therefore stops.

By the late evening of February 4, the city is almost completely dirty, with high concentrations of PM2.5. Irregular multidirectional fluctuations in wind speed with a predominance of the South-Eastern direction lead to the fact that the pollution extends to the highest parts of the city. During the next few days, there were no significant changes in the wind regime.

The reverse process ("cleaning the city") begins at midnight from 12 to 13 February. The wind changes its direction to the South-West, at a speed of 1-4 m/s. By noon on February 13, the city becomes absolutely clean. Attention is drawn to the uneven cleaning of the city, apparently associated with the terrain – in the lowlands, including in the Central part of the city, the pollution is delayed longer.

Details of spatial distribution of pollution and dynamics of its change studied in this work are available in two videos on air pollution and purification in the city [14, 15].

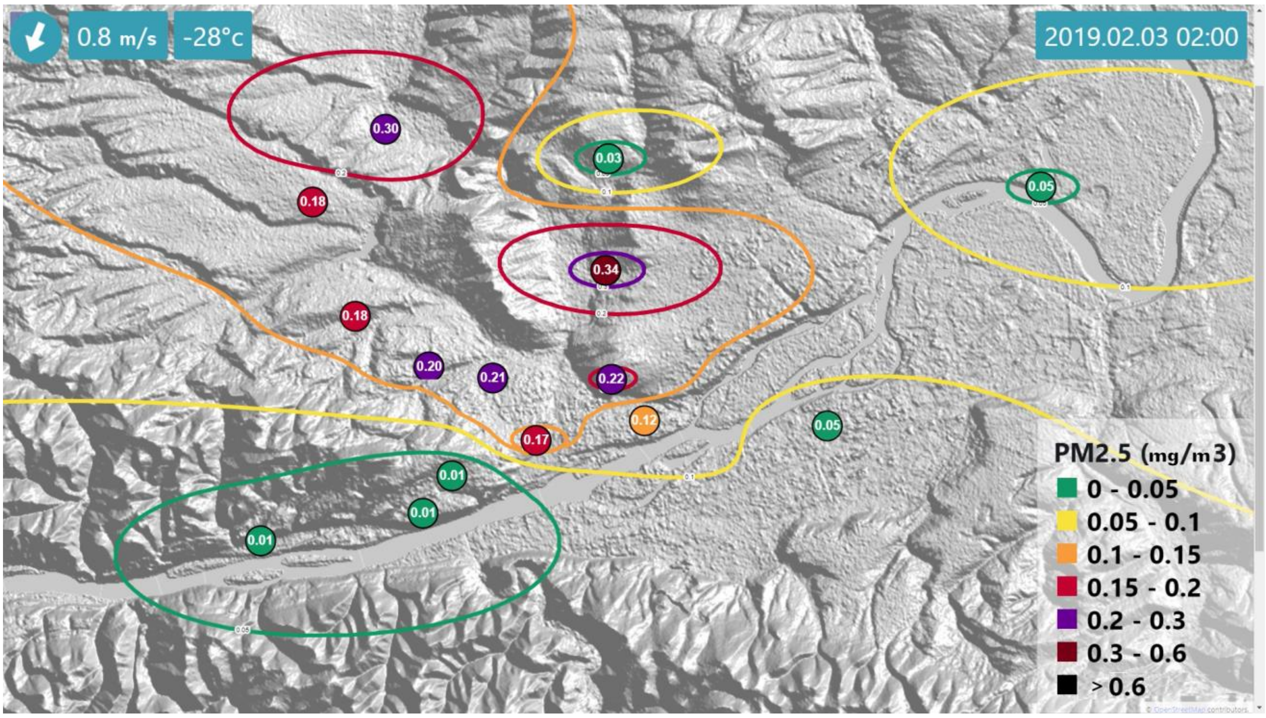

Figure 4. The distribution of concentrations of particulate matter in the pollution of Krasnoyarsk.

5 Conclusions

The network of scientific and research monitoring of atmospheric pollution, based on a large number of space-distributed stations in the city provides an opportunity for a detailed spatial and temporal analysis of data. It is possible to determine the centers of the initial appearance of pollutants, to trace the dynamics of the spread of pollution on the territory at the level of individual neighborhoods of the city. Such data can help to identify the sources of pollution, to identify characteristic trends of its spread.

Preliminary results of processing of the received information show significant influence of furnace heating on pollution of Krasnoyarsk. Further research in this area is needed to obtain valid results.

References

[1] Sunil Gulia, S.M. Shiva Nagendra, Mukesh Khare, Isha Khanna. Urban air quality management – a review // Atmospheric Pollution Research. 2015. V. 6, Is. 3. pp. 286-304.

[2] Xuezhen Qiu et al. Development of an integrated policy making tool for assessing air quality and human health benefits of air pollution control // Frontiers of Environmental Science & Engineering. 2015. V.9, Is. 6. pp. 1056-1065.

[3] Stefan Wiemann, Johannes Brauner, Pierre Karrasch, Daniel Henzen, Lars Bernard. Design and prototype of an interoperable online air quality information system // Environmental Modelling & Software. 2016. V. 79. pp. 354-66.

[4] Mehran Ghodousi, Farideh Atabi, Jafar Nouri, Alireza Gharagozlou. Air quality management in Tehran using a multi-dimensional decision support system // Polish Journal of Environmental Studies. 2017. V. 26, Is. 2. pp. 593-603.

[5] Hua Wang et al. Design and demonstration of a next-generation air quality attainment assessment system for PM2.5 and O3 // Journal of Environmental Sciences. 2015. V. 29. pp. 178-188.

[6] Ashitko A.G., Man'shina I. V. System of monitoring of atmospheric air quality in the city of Kaluga // Herald of the Kaluga state University. 2014. Vol. 22, No. 1. P. 5-9. (in Russian)

[7] Tom Savu, Bogdan Alexandru Jugravu, Daniel Dunea. On the development of a PM2.5 monitoring network for real-time measurements in urban environments // REVISTA DE CHIMIE. 2017. V. 68, № 4. pp. 796-801.

[8] Lei Hu, Peng Yue, Mingda Zhang, Jianya Gong, Liangcun Jiang, Xining Zhang. Task-oriented sensor web data processing for environmental monitoring // Earth Science Informatics. 2015. V. 8, Is. 3. pp. 511-525.

[9] Hrebtov M, Hanjalic K. Numerical Study of Winter Diurnal Convection Over the City of Krasnoyarsk: Effects of Non-freezing River, Undulating Fog and Steam Devils // Boundary Layer Meteorology. 2017. V. 163, Is. 3. pp. 469-495.

[10] Kadochnikov A.A., Tokarev A.V., Zavoruev V.V., Yakubailik O.E. Prototype of city environmental monitoring system based on geoportal technologies // IOP Conference Series: Materials Science and Engineering, 2019, V. 537, 062052.

[11] Yakubailik O.E., Kadochnikov A.A., Tokarev A.V. Development of computational technologies and software for assessment of air pollution in Krasnoyarsk // IOP Conference Series: Earth and Environmental Science, 2018, V. 211, 012080.

[12] City quality monitoring system CityAir. Available at: http://cityair.io/.

[13] Zavoruev V.V., Zavorueva E.N., Kadochnikov A.A., Tokarev A.V., Yakubailik O.E. Assessment of the possibility of using CityAir air monitoring station in environmental engineering // IOP Conference Series: Materials Science and Engineering, 2019, V. 537, 062053.

[14] Dynamics of pollution of Krasnoyarsk by particulate matter in early February 2019
Available at: http://doi.org/10.6084/m9.figshare.8343944.v1

[15] Dynamics of cleaning of Krasnoyarsk after particulate matter pollution in mid-February 2019
Available at: http://doi.org/10.6084/m9.figshare.8343962.v1