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Web technologies for rapid assessment of pollution of the atmosphere of the industrial city

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Abstract. The functionality, architectural features, the user interface of the geoinformation web-system of environmental monitoring of Krasnoyarsk is discussed. This system is created in service-oriented architecture. Data collection from the automated stations to monitor the state of atmospheric air has been implemented. An original device to measure the level of contamination of the atmosphere by fine dust PM2.5 has developed. Assessment of the level of air pollution is based on the quality index AQI atmosphere.

1 Introduction

The quality of atmospheric air is the most important environmental factor determining the health of population and the state of ecosystems. Air monitoring systems have been created nowadays in almost all large population centers and industrial zones in Russia and other countries of the world; they control dozens of indicators and concentrations of various chemicals (pollutants) in the atmosphere.

Taking into account the multi-pollutant nature of the atmospheric air contamination and its dynamism and spatial heterogeneity, an important task is to characterize in a comparable and clear form the level of total (integral) air pollution averaged over different periods of time and the health risks of population of a certain territory [1–4].

This scientific work examines the experience of work related to monitoring of the atmospheric air pollution in Krasnoyarsk, an industrial city with population exceeding 1 million people. Krasnoyarsk is one of the most polluted regions in the country according to reports of Federal Service for Hydrometeorology and Environmental Monitoring of Russia. The city monitoring is carried out by a number of organizations at the federal and regional levels (the Federal State Budget Office "Central Siberian Department for Hydrometeorology and Environmental Monitoring", the Regional State Budget Office "Center for Implementation of Environmental Management and Environmental Protection of the Krasnoyarsk Territory", the Main Directorate of the Ministry of Emergency Situations of the Krasnoyarsk Territory, Siberian Federal University, research institutes of the Russian Academy of Sciences, etc.). Each of these organizations has its own methods, technologies, and systems for data collecting, storing, and processing. In addition, with appearance of the available instruments for assessing the air pollution, public environmental organizations and independent activists and bloggers have become involved in collecting information on pollution levels. The variety of the applied solutions, interdepartmental and organizational disconnection lead to the fact that a complex analysis and operative evaluation of the entire array of the recorded information is currently technically difficult and practically not carried out. Taking into account the expanding number of

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stationary posts that monitor the state of the natural environment in the coming years, planned by the authorized organizations, the situation will only worsen [5, 6].

Research and development for the atmospheric pollution monitoring carried out at the Institute of Computational Modeling of the Siberian Branch of the Russian Academy of Sciences (ICM SB RAS) are aimed at solving this problem. At first, a web-based geoinformation analytical system for monitoring the atmospheric pollution is being developed. Its distinctive feature is presentation of information about the level of atmospheric pollution in a simple visual form, based on the atmosphere quality index (AQI).

Secondly, it solves the problem of collecting information on the level of urban atmospheric pollution, this information comes from different sources into a centralized database. Within the framework of the organized information interaction with the authorized regional subordinate organizations, the information about the state of the atmosphere is collected in real time from the automated monitoring posts. A web-based interface has been developed for analytical processing and data presentation.

Third, based on the available components, a working prototype of a device for measuring the level of atmospheric pollution by the fine dust (particulate matter) has been developed, and its small-scale production is being prepared. The created device provides automatic transmission of contamination level data into the monitoring system database via the cellular network.

2 Air Quality Index

For this integrated assessment, in many countries around the world, complex indicators, i.e. various types of the air pollution index, have been developed and put into practice nowadays [7]. The main areas of application of such indexes are the integrated assessment of the level of the air pollution in the city as a whole or its areas, the comparison of the levels of the air pollution, identification of the long-term changes in the quality of the atmospheric air. These indexes are used as a tool for decision-making in environmental management [8–10].

In particular, the Canadian Meteorological Service uses the AQI air quality index, for which the scale of values varies from 0 to 100, for presentation of the air monitoring results. The higher the index value, the higher the risk to human health. The index is calculated for six key pollutants: SO_2, O_3, NO_2, the total content of the reduced sulfur compounds, CO and suspended particles (PM – particulate matter). Using the monitoring stations network data, the Ministry of the Environmental Protection determines the AQI for each territory on which monitoring stations are located. These information is communicated to the public and media on a daily basis in a timely manner. The AQI scale is as follows: 0–25 is a good quality (green color); 26-50 is moderate (yellow); 51–100 is poor (orange); and over 100 is very poor quality (red color).

In France, the ATMO index is used for integrated assessment of the atmospheric air pollution. It is regulated at the national level by a special Decree of the Ministry of Ecology and Environmental Protection. The ATMO is calculated by the contents of four pollutants: SO_2, NO_2, O_3, and particulate matter 10 microns and below (PM_{10}). For each pollutant, the primary index is calculated, and the daily atmospheric pollution index is calculated by summing the highest primary indexes.

The UK Meteorological Department publishes the air quality forecasts, where the level of the air pollution is described by index (from 1 to 10) and the corresponding pollution level (from 1 to 3 – low, from 4 to 6 – moderate, from 7 to 9 – high, 10 – very high). These levels are established on the basis of how each pollutant affects people's health. During the index calculation, the concentrations of SO_2, NO_2, O_3, and PM measured at the stations are taken into account.

In Hong Kong since 1995, the API Index is used to assess the air quality. Two API types are calculated: aggregate (General) and applicable for transport roads (Roadside). The Department of Environmental Protection evaluates hourly both types of the API indexes and builds the API forecast for the next day. At the same time, it is calculated on the basis of levels of six contaminants: SO_2, NO_2, suspended particles PM, CO, O_3, Pb, measured at the monitoring posts. At values of API up to

25, the level of atmospheric air pollution is considered low, 26–50 is medium, 51–100 is high, 100-500 is very high, and 201–500 is considered extremely high.

The Environmental Protection Agency (EPA) of the United States and its regional offices regularly calculate and publish the Air Quality Index (AQI). AQI is a tool for providing information about the air pollution to the wide public in a simple and visual form. The basic idea is that for each substance a scale of pollution levels is formed, consisting of several classes, depending on the degree of the impact on human health. AQI calculation is based on concentration indexes of several pollutants, i.e. suspended particles of less than 10 μm in diameter (PM_{10}) and less than 2.5 μm ($PM_{2.5}$), carbon dioxide CO, gas SO_2, NO_2, and ozone O_3. For each class of the pollution level scale, a color designation is also introduced (green / yellow / red / burgundy / black means the corresponding degree of the air pollution and health effects, ranging from a safe level to a natural disaster), followed by recommendations to the public.

The China Environmental Monitoring Center used a variety of integrated pollution assessment methods for a number of years, but currently presents data in the form of AQI in a way similar to the US EPA; the differences are mainly in the choice of the averaging period for the air pollution data.

It should also be mentioned, that in the US, China and other countries of the world, along with the AQI index, auxiliary indexes, such as InstantAQI, NowCast, NowCastChina, and others are used. The NowCast is a weighted average of hourly air monitoring data used by the United States Environmental Protection Agency for real-time reporting of the Air Quality Index (AQI) for PM (PM10 or PM2.5) or Ozone data. The PM NowCast is computed from the most recent 12 hours of PM monitoring data, but the NowCast weights the most recent hours of data more heavily than an ordinary 12-hour average when pollutant levels are changing. The PM NowCast is used in lieu of a 24-hour average PM concentration in the calculation of the AQI until an entire calendar day of hourly concentrations has been monitored [11,12].

3 The system of monitoring the data collection, presentation, and analysis

The source of the data about the level of the atmospheric pollution is the Regional Departmental Information and Analytical System on the State of the Environment of the Krasnoyarsk Territory (RIAS), which has been collected since 2009. The system operator is the Regional State Budgetary Institution "Center for Implementation of Environmental Management and Environmental Protection Measures in the Krasnoyarsk Territory". Observations on the quality of the atmospheric air are carried out at 8 automated observation posts, 6 of which are located in Krasnoyarsk. These posts are equipped to provide continuous automatic measurement of mass concentrations of oxide and nitrogen dioxide, sulfur dioxide, carbon monoxide, dust, formaldehyde in the ambient air, as well as collection, processing, storage, and transfer of the accumulated information to a remote server. Along with measurements of the atmospheric concentrations of pollutants, the meteorological parameters are measured in automatic mode at meteorological posts (wind direction and speed, temperature, humidity, atmospheric pressure). In addition, in some Krasnoyarsk areas monitoring of the air pollution, with application of the mobile laboratory on a sliding schedule, for detecting pollutants of ammonia, hydrogen sulfide, hydrochloride, hydrofluoride, benz(a)pyrene and suspended substances are daily conducted [13].

Implementation of the data collection system is based on the software tools of the ICM SB RAS geoportal. Access to observational data is carried out by means of standard geoportal tools, including viewing of the tabular data, exporting, viewing of the data on maps with possibility to select time intervals and access with application of generally accepted standards. A new resource type i.e. "observational data" was added to the geoportal resource catalog. When publishing this resource on the geoportal, the user is provided with a number of settings, including selection from the list of the available monitoring stations and sensors. Each observation post has a spatial reference and a certain set of sensors. In this case, different observation posts, not belonging to the same group, may have several common sensors [14, 15].

To view the observation data, the capabilities of the existing cartographic web interface of the geoportal have been extended. The key elements of the new interface include a background base map and observation data in the form of a semitransparent layer at the selected time point for the selected indicator. The user of the web application is provided with such control elements as the choice of one of the indicators and the time interval. With the help of the additional tools, the data with a certain time step in one direction can be viewed. To search the anomalies, the data output is provided in the form of an active graph of the maximum values with a rapid transition to the viewing data at a certain point in time.

To download the data to the geoportal, a software module with the appropriate "driver" for processing and transforming the input data is prepared; it provides the observational data periodic loading via the web service. The web service provides access to the data in json format and contains three sections of information: observation posts and their coordinates, a list of indicators (pollutants and meteodata), the value of indicators with reference to the time. To minimize the load on the remote server at loading of the archive of observations from 2009 to 2017, the text files in json format are generated. The data import directly from the database on a remote server to the geoportal server took several days. After the archive import, the data is loaded once per hour. The information from the mobile laboratories is downloaded every few days. When import problems arise from a remote web service, the developed software automatically finds the date of the last received data and forms a request for new data download. To minimize the load on the remote service, the data is loaded in portions at a certain time interval until the current data time is reached.

4 Instrument for measuring the air pollution level

Design and development of a device for recording the concentration of finely dispersed suspended particles up to 2.5 μm in size ($PM_{2.5}$) in the air was made on the basis of the available electronic components on the market. The system is based on the Arduino microcontroller, an electronic designer and a convenient platform for rapid device development, which is very popular all over the world owing to convenience and simplicity of the programming language, as well as open architecture and software code. The microcontroller is programmed with the use of the Wiring language (a simplified version of C ++) and the Arduino IDE development environment.

Arduino Nano 3.0 board was chosen from a number of different microcontroller modifications, based on sufficient memory, I/O ports, miniaturized size and convenience. The following components were also used: the GSM SIM800L cellular communication module for data transmission to the geoportal, the data modules via Ethernet and Wi-Fi, the OLED SSD1306 display for the current values, the AMS1117 linear regulator at 3.3 V, LogicLevelConverter, power supply.

The key element of the device is the PMS7003 module, a universal digital sensor, developed by the Plantower company for measuring the concentration of suspended air particles [16]. The basis of this sensor is measurement of the laser radiation scattering on suspended particles. Using the built-in microcontroller, based on the physical model of scattering of a spherical, homogeneous, isotropic, and non-magnetic particle in a nonabsorbing medium, the equivalent particle diameter and the number of particles with different diameters per unit volume are calculated. The sensor has a digital serial interface, using which the measured values of dust concentrations are fed to the Arduino microcontroller.

The developed device can function in 2 modes, passive and active. In the active mode, the sensor periodically outputs the measurement data. It is divided into two sub-modes: stable and fast. If the concentration of suspended particles is small, the sensor will operate in stable mode with a real update interval of 2.3 seconds. Otherwise, the sensor will operate in a fast mode with an update interval of 200-800 ms (the higher is the concentration – the shorter is the interval). In passive mode, the data is issued only after a preliminary request. The device requires an external power supply, connected via a standard micro-USB connector (Figure 1).

Figure 1. Prototype of the device for measuring the level of the atmospheric pollution by particulate matter.

5 Atmospheric pollution monitoring system

Design and development of the web GIS monitoring user interface was carried out on the basis of the application program interfaces (API) of the ICM SB RAS geoportal, a set of previously developed software tools. To design the web application's screen forms, a mechanism for generating dynamic content based on templates was used. Templates allow to change the order and the form of the attribute data output according to the objects in map layers, including different elements of style design, i.e. color, font parameters, etc. The developed monitoring system is currently in trial operation [17, 18].

To collect and process the data on the air pollution by suspended particles, the SensorCollector service of the ICM SB RAS geoportal is used. The service API is built based on the REST approach, and the requests are transmitted by HTTP methods GET / POST / DELETE with parameters. The transmission of the current values of the indicators is performed by the following query:

http://gis.krasn.ru/sc/api/1.0/projects/<project_id>/values/send?key=<key>&
site=<site_id>&<values>, where:

- key is the user's key to access the service;
- project_id is the project identifier within which the data are collected;
- site_id is the identifier of the site on which the sensor is located;
- values are values of indicators transmitted by separate parameters in the following form: <code> = <value> & ... <code> = <value>, where code is the indicator code in the system, and value is its numerical value.

6 Preliminary monitoring results

The developed software and hardware tools to support the archives of observations of the environment state in Krasnoyarsk provided the opportunity to conduct a spatio-temporal analysis of the ecological state of the city.

Krasnoyarsk is the most eastern Russian city with population exceeding million people. The climatic conditions are very unfavorable for dispersion of impurities. The city is located in the zone of high potential of atmospheric pollution (PAP). Frequent air stagnations lead to accumulation of impurities in the atmosphere and formation of high levels of the air pollution. Presence of the aluminum plant, three coal-fired power plants and a large number of vehicles contribute to the atmosphere pollution. In particular, in 2015 the total emissions amounted to 195 thousand tons, including 128.7 thousand tons from stationary sources [19].

The city residents call the visually visible aerosol pollution of the atmosphere residents as "black sky", although the correct name of this phenomenon is could. Monitoring of the PM_{10} concentration in the surface layer of the Krasnoyarsk atmosphere has been made since the end of 2012.

Services of the geoportal operational monitoring subsystem data provide tools for data analyzing and presenting. In particular, based on the available data, a preliminary conclusion can be made, that concentration of suspended particles (PM_{10}) in the surface layer of the atmosphere at 1.10–1.68

exceeds the average annual maximum permissible concentration (MAC). The analysis shows that in Krasnoyarsk there is clearly lack of the automated observation stations (AOS) that could provide a reliable estimate of the level of aerosol pollution of the atmospheric air in a metropolis. In those city areas where the AOSs are located, the PM_{10} concentration in most cases exceeds the average annual MAC. It can be interpreted as aerosol pollution in a certain region of Krasnoyarsk. In 2015–2016, the aerosol pollution was recorded at suburban AOS as well.

With calm and weak wind, the aerosol pollution is observed over the territory of almost entire city. At the same time, all AOSs record PM_{10} concentrations exceeding the maximum single permissible concentration. Similar situations are realized in the unfavorable meteorological conditions period, which in Krasnoyarsk reach 60 days per year.

Figure 2 shows the values of daily average and maximum single concentrations of suspended particles (PM_{10}) in 2016. Apparent is the excess over the maximum permissible concentrations; for PM_{10} they are as follows: maximum single = 0.3 mg/m^3, and daily average = 0.06 mg/m^3.

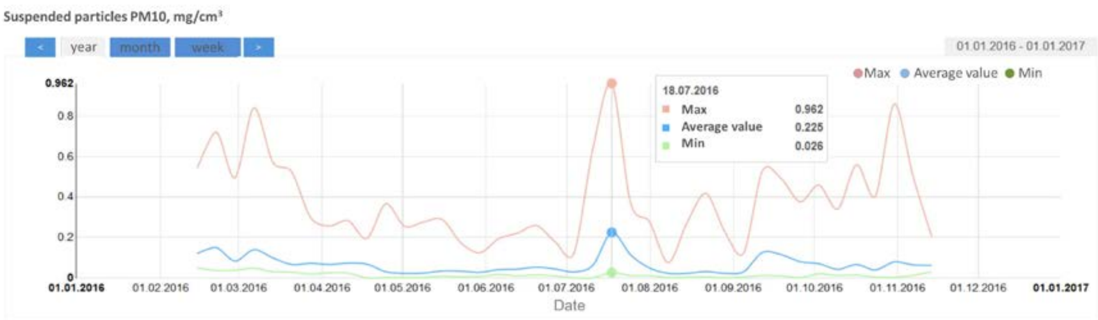

Figure 2. Dynamics of concentration of suspended particles of 10 μm (PM10) in 2016.

7 Conclusion

Work has been done on design and development of information and analytical software for monitoring and assessing the quality of the atmospheric air. The software components for calculating the AQI atmosphere quality index are developed; they are integrated into the subsystem of operational and scientific research monitoring over the state of pollution of the ICM SB RAS geoportal. Application web services have been created to automatically download the data from the edge system of observations of the state of the atmospheric pollution into the geoportal database. A web application has been developed to visualize this data.

A model of a device, based on Plantower PMS7003 sensor and Arduino Nano microcontroller, for measuring PM2.5 suspended particles concentration in the atmosphere, was created. The device logics and control modes are implemented with the help of firmware in the Wiring (Simplified C ++) language with application of a number of open source libraries. This device provides reflection of the current values of contamination levels on the OLED display and transfer of the recorded data to the geoportal through the cellular network. The geoportal implements a specialized web service for receiving the data and placing them into the operational monitoring database.

The studies are conducted, and results of the spatial distribution of the atmospheric pollution in Krasnoyarsk are obtained according to the official environmental reporting. As a result, a geospatial data base was formed, on the basis of which the integrated maps of emission sources for city pollutants were constructed, taking into account, among other things, the terrain inhomogeneity.

References

[1] Qilu Li, Kong Yang, Kechang Li, Xin Liu, Duohong Chen, Jun Li, Gan Zhang 2017 *Environmental Pollution* **224** 679–688

[2] Sharma M, Maheshwari M, Sengupta B, Shukla B P 2003 *Environmental Modelling and Software* **18** 405—411
[3] Brian R P, Daniel J, Mehaffey M, Jackson L E, Neale A 2015 *Ecosystem Services* **14** 45–55 doi: 10.1016/j.ecoser.2015.04.005
[4] Lanzafame R, Monforte P, Patanè G, Strano S 2015 *Energy Procedia* **82** 708–715
[5] Kadochnikov A A, Yakubailik O E 2015 *NSU Journal of Information Technologies* **1** 37
[6] Yakubailik O E, Popo V G 2009 *Computational Technologies* **6** 116–126
[7] McCarty J, Kaza N 2015 *Landscape and Urban Planning* **139** 168–179
[8] Gayathree Devi P K, Sujatha C H 2016 *Atmospheric Pollution Research* **7** 1053–1064
[9] Wu J, Cheng J, Zhang L, Chen M, Pan L, Chen X *Journal of Computational Information Systems* **10** 9839–9848
[10] Ayushi Vyas, Siby John 2016 *MATEC Web of Conferences* **57** 05002
[11] Rabee A M 2015 *Environmental Monitoring and Assessment* **187** 4203
[12] Ling Xue, Yeping Zhu, Yan Xue, 2013 *Mathematical and Computer Modelling* **58** 480
[13] Shaparev N, Yakubailik O 2016 MATEC Web of Conferences **79**, 01081
[14] Kadochnikov A A, Popov V G, Tokarev A A, Yakubailik O E 2008 *Journal of Siberian Federal University. Engineering & Technologies* **4**, pp. 377–386
[15] Yakubailik O, Kadochnikov A, Tokarev A 2015 *Scientific GeoConference SGEM* **1** 487
[16] Korose C P, Locke Ii R A, Blakley C S, Carman C H 2014 *Energy Procedia* **63** 3945–3955
[17] Mekhtiyev A *et al* 2016 METALURGIJA **55** 47–50
[18] Yakubailik O E 2010 *Vestnik of SibGAU* **1** 40–45
[19] Yakubailik O E, Gosteva A A, Erunova M G, Kadochnikov A A, Matveev A G, Pyataev A S, Tokarev A V 2012 *Vestnik of KemSU* **52** 136–142