JEE Journal of Ecological Engineering
Volume 20, Issue 4, April 2019, pages 150–156
https://doi.org/10.12911/22998993/102808

Received: 2018.10.30
Revised: 2018.12.01
Accepted: 2019.02.16
Available online: 2019.02.27

Assessment of the Aerotechnogenic Situation in the City of St. Petersburg Based on Instrumental Measurements of air Dustiness and Computer Modeling of its Distribution

Igor S. Ilyashenko[1], Stanislav V. Kovshov[1*], Edita A. Navitskaite[1]

[1] Department of Industrial Safety, Saint Petersburg Mining University Saint Petersburg, Russia
* Corresponding author's e-mail: stanisl.kovsh@gmail.com

ABSTRACT
The aim of this study was to analyze the dust load in St. Petersburg based on the measurements of dust levels in different areas of the city using a CEM DT-9880 portable dust particle counter. A uniform one-character bottom up zoning was performed to determine the parameters, and the dependencies of dust distribution on various factors were identified using the "Ecolog" software package. The zoning was based on more than 2.5 thousand measurements of dust levels. An effective and rational solution to the problem of increased aerotechnogenic load in different areas of the city through the use of modern technologies of hydro-dedusting of city roads with a dust-binding solution based on surfactants was proposed for increasing the adhesion ability of the solution to the standard roadbed.

Keywords: dust; air dustiness; dust distribution; dust control; injector; surfactant.

INTRODUCTION

The ecology analysis of any modern residential area, as well as statistical data on the population morbidity, reflect the increasing level of impact of dust on the people's health [Kim et al., 2015; Patra et al., 2016; Dubey et al., 2018; Kim et al., 2018]. Human life and activities cause increased aerotechnogenic load typical of almost all cities [Davydova, & Znamenskaya, 2016; Baltrėnaitė et al., 2018; Shevchenko et al., 2018].

Many dust sources in the city, such as construction sites, open soil areas without vegetation, industrial facilities associated with the dust factor, and many others, determine the extent of dusting in the locality. The largest contribution to the fine-sized dust may be brought by traffic and then by road dust [Manoli et al., 2002]. The mass flows of dust-air mixture from numerous sources spread over long distances, largely affecting the ecological situation of the city, causing the development of various diseases and pathologies among the population.

Due to the significant impact of dust on the condition of residential areas and human health, continuous monitoring and control of the dust content in the air, as well as detailed quantitative and qualitative analyses are necessary to ensure protection from the harmful factors. Environmental scientists have been working to study and solve the problem of excessive dustiness since the 1930s. Some Russian scientists connected with dust control and ecology [Barkan et al., 2015; Gorshkov & Nasimi, 2016; Azarov et al., 2016; Volkodaeva & Kiselev, 2017; Pashkevich & Petrova, 2017; Korshunov & Romanchenko, 2016], and noticeable foreign scientists as well [O'Shaughnessy et al., 2012; Heitbrink et al., 1990].

The main goal of the research conducted by the authors was to obtain the information on the environmental situation of the city of St. Petersburg with relation to the dust level, determine the most important factors affecting the distribution of dust particles in the city, as well as search for the possible ways and technologies to reduce the increased aerotechnogenic load.

METHODOLOGY

The study of the problem of dust in St. Petersburg consisted of 4 stages:

Instrumental assessment of the dust level

Instrumental assessment of the dust level was based on the measurements obtained using instruments for determining the level of dust in the air.

The measurements were conducted using a DT-9880 dust particle counter (Shenzhen Everbest Machinery Industry Co., Ltd, China) and a PKA-1 (LLC Kuzbass Regional Mining Center for Labor Protection, Kemerovo, Russia) air dust control device.

The DT-9880 dust particle counter is designed to determine the dispersed composition of dust and provides fast and accurate readings of the content of dust particles in the air at the measurement site, measures the air temperature and relative humidity. The device is an environmental mini-laboratory that performs the entire set of measurements, thereby enabling to identify the dust level and take effective measures to protect the environment.

The device for air dust control PKA-1 is designed to measure the mass concentration of dust. It can be used for measuring the dust concentrations of any origin. It is a small-sized high-speed instrument for the operational control of air dust content with a wide range of measurements, which allows to obtain instant and accurate data on the concentration of dust in the air.

In order to assess the environmental situation in the city of St. Petersburg, more than 5,000 measurements of the fractional composition and dust concentration in the city were made: 3 spots were selected in each of the 18 districts of the city – specific areas with potential sources of the most intensive dust formation with 50 measurements made in each spot. The experiment was carried out twice: in winter, when de-icing substances and mixtures are used intensively, and in spring – when the snow melts and these mixtures become suspended in the air due to wind and traffic. Moreover, the data on air temperature, relative humidity and air velocity were taken into account as the factors affecting the physical and chemical properties of dust and its distribution. This approach allows to obtain as accurate and as close to the actual result of a quantitative assessment of aerotechnogenic load as possible. The relative dispersion of measurement spots enables to carry out a comprehensive estimation of the degree of the dust factor influence over a large area of a metropolis.

Computer simulation of dust distribution

The computer simulation of dust distribution was based on the "Ecolog" software (Integral Company, St. Petersburg, Russia).

The "Ecolog" software implements the methods for calculating the dispersion of hazardous pollutants in the air. This system allows processing statistical information and carrying out a summary calculation of the content of hazardous substances in the atmosphere of the city currently and in the future. The "Ecolog-gorod" software package enables to calculate the maximum one-time concentrations of pollutants in the surface layer of the atmosphere from stationary spots and multiple sources of emissions, and it also displays the results of calculating the dispersion of hazardous substances on an electronic map.

Zoning of the territory

Zoning of the territory of St. Petersburg was made in terms of dust levels.

As a result of the research, a zoned map of the city was compiled by the dust factor, reflecting the actual distribution of dust in the city. The city of St. Petersburg was divided into 18 administrative districts, with 3 spots selected in each district with the highest concentration of sources of intense dusting. The city districts and areas of measurements with the largest number of sources of dusting are reflected on the electronic map. Moreover, the correlation of statistical coefficients and indicators was calculated, allowing to draw conditional boundaries of the dust distribution of a certain dispersed composition. It also reflects the dependencies of dust dispersion, taking into account the factors causing dusting and dispersion of dust streams.

The analysis of existing technologies

The analysis of existing technologies for dust reduction and selection of recommendations for specific conditions were made.

On the basis of the additional research conducted on the dust suppression technologies used in St. Petersburg, an analysis pertaining to the effectiveness of the measures used to reduce the aerotechnogenic load on the city's air was conducted. The authors propose a solution to the problem of insufficient efficiency of dust suppression by changing the existing technologies.

RESULTS AND DISCUSSION

A quantitative assessment of the dust load in St. Petersburg reflects a partial excess in the winter period and a strong excess of the normalized dust parameters in the spring period. The fractional composition of dust (Table 1) shows that the dust particles up to 2.5 microns, which are most harmful to human health, are more common within the city, they do not linger in the airways and sink deep into the lungs, affecting tissues, mucous membranes and skin. This is in agreement with previous studies, which showed a high presence in city air the smallest dust particles [Shi et al., 2003; Chan & Yao, 2008; Gupta et al., 2006]. The table also shows the physical parameters of the air, with western winds predominant for both periods.

It should be noted that the dust level depends on the road coating: porous quartzite concrete pavement retains dust better than dense granite asphalt concrete [Amato et al., 2011]. The areas of St. Petersburg in question have no significant sources of highly fibrogenic dust formation. Therefore, the measurements, regulation and computer simulation were carried out using nuisance dust with a silica content of less than 20% in the mass of dust.

The values of dust concentration in the atmospheric surface layer, obtained during measurements, show the excess of the maximum permissible concentration (MPC) on the dust factor compared to the normal levels (Table 2).

The zoned map of St. Petersburg, compiled on the basis of the data obtained as a result of the experiment, is shown in Figure 1. The map reflects the actual distribution of dust flows, as well as a simplified view of the uniform one-feature zoning of the dust concentration in the city.

On the basis of the data received, a map of inorganic dust dispersion (Figure 2) from a stationary source was constructed; the dependencies were obtained of dust concentration around the source on the distance to the emission source, wind speed and direction (\Figure 3).

The data analysis showed that at the speed of the western wind of 1–4 m/s, the locations of maximum workplace and urban area dustiness lie to the west of the dust sources and at a considerable distance from them. The excess concentration of dust in these areas equals 3–5 MPC standards (for workplaces, 1 MPC standard for inorganic dust containing SiO_2 < 20% is 4 mg/m^3).

The main amount of dust forms in the spring, and the greatest damage is caused when the dust cloud spreads beyond 300 m of the sanitary protection zone. While performing calculations, the climatic conditions corresponding to the winter and spring periods were considered, and the western wind direction was chosen as the most hazardous, coinciding with the prevailing wind direction during the period under study. At the actual value of 17.7 g/s of the intensity of dust emission from a source and road surface, a scatter map of inorganic dust was constructed based of the "Ecolog 3.0" software package (Figure 3).

Table 1. Example of dust analysis

No.	Measurement site	Season	Particle size	Number of particles	Air humidity	Air temperature	Air speed
			μm		*%*	*°C*	*m/sec*
1	Vasileostrovsiy district, The Kalinin plant, construction site	Winter, February, 2018	0.3	103747	41.0	-3.3	1.5
			0.5	34072			
			1.0	4265			
			2.5	357			
			5.0	102			
			10.0	15			
2	Nevskiy District, The Obukhovsiy plant	Spring, May, 2018	0.3	113698	67.4	+28.4	4.0
			0.5	39764			
			1.0	6851			
			2.5	655			
			5.0	376			
			10.0	166			

Table 2. Dust concentration in the city air

No.	Measurement site	Dust concentration
		mg / m³
1	Kronshtadtskiy district, Kronshtadt confectionery producing plant	15.1
2	Vasileostrovsiy district, Kalinin plant, construction site	16.3
3	Nevskiy District, Obukhovskiy plant	18.2
4	Krasnoselskiy district, “Argument” concrete plant	21.4

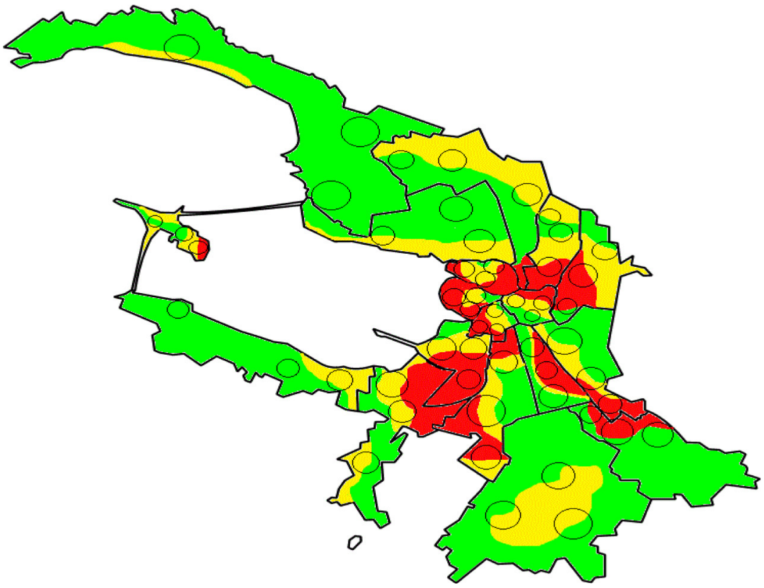

Fig. 1. The actual dust distribution in the districts of St. Petersburg

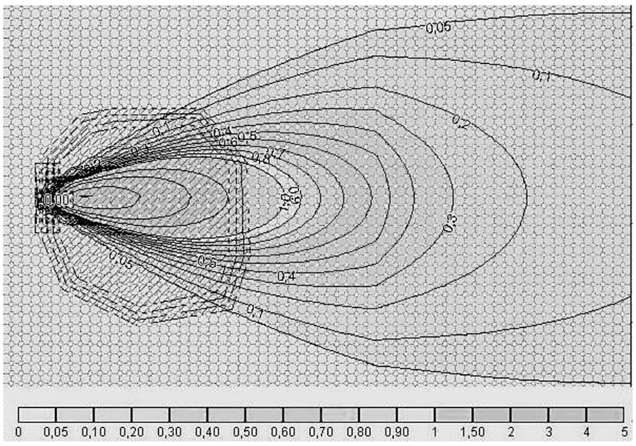

Fig. 2. Inorganic dust dispersion map (Kronshtadt confectionery producing plant)

Dust suppressing systems and technologies

As a result of the analysis of the dust suppression technologies used in St. Petersburg, it was found that the most frequently used watering machines in the city are KO-713 derived from MAZ-4380P2 and KO-806 derived from KAMAZ-43253, as well as “vacuum cleaners” KO-326 – vacuum equipment with sweeper brushes and suction shafts (Figure 4).

The analysis was carried out for the spring period, since the use of the equipment in the winter period is impossible.

Technical data show that “vacuum cleaners” are the most efficient cleaning equipment, but at the moment, the fleet of vacuum trucks used by utility services is too small for effective reduction of dust generation.

Watering machines are used most frequently because of the relative simplicity and low cost of

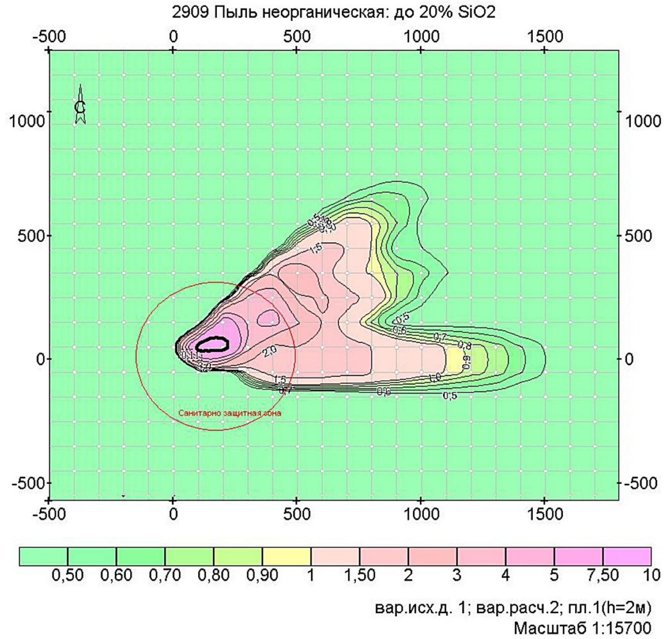

Fig. 3. Inorganic dust dispersion map ("Granit-Neva" concrete plant)

their maintenance. This technique allows washing the road from large accumulations of salt-sand mixture and other dusty substances as well as sprinkling the roads with water or surface-active substances (SAS) for dust suppression. The width of irrigation and sprinkling can be up to 8 meters, depending on the vehicle used. Moreover, the nozzles are located at different angles: for irrigation – by 15–20° up, to the side – no more than 10°; for washing – 10–12° down and to the right – for flushing dusty material into road trays.

Since the use of the current dust suppression methods in the city are not effective and the level of dustiness exceeds the specified parameters, the authors propose to increase the temperature of the water used for irrigation of the city's roads and construction sites, which will increase the efficiency of dust suppression several times. A large amount of energy is expended on heating the water, so it will be efficient and economical to use the solar energy: if the water tanks are painted black, they will absorb much more solar energy and will heat up more.

Moreover, reducing the size of spray nozzles may allow water to be sprayed more effectively, capturing larger areas of irrigation and adsorbing dust particles of the most common fine dispersion. The nozzles should be reduced to such a size that will prevent their clogging and will not require any pretreatment of water.

A more widespread use of environmentally friendly, but effective surfactants can be rational: today they mostly use ordinary water, which quickly evaporates at high temperatures and strong winds, and the effectiveness of dust suppression decreases sharply. Surfactants, however, will allow binding the dust particles for a significantly longer time due to the relative

a) KO-713	b) KO-806	c) KO-326

Fig. 4. Combined machines KO-713 (a), KO-806 (b) and vacuum sweeping-and-cleaning machine KO-326 (c) (OJSC Kommash, Mzensk, Russia)

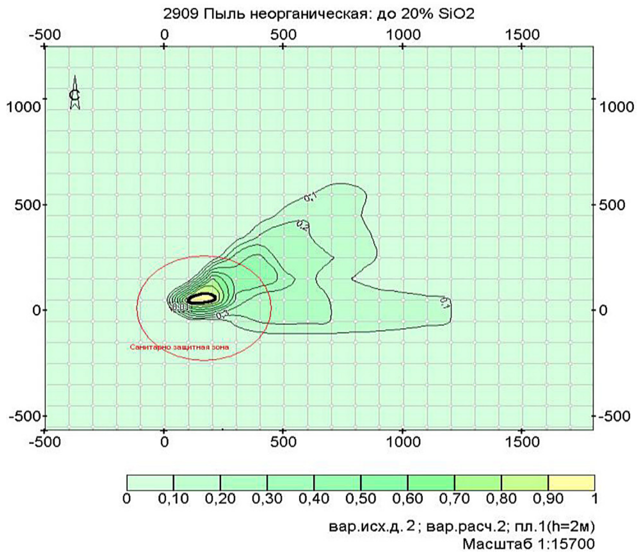

Fig. 5. Inorganic dust dispersion map after the use of proposed solutions – model (“Granit-Neva” concrete plant)

resistance to evaporation in comparison with water [Kovshov, 2013; Kovshov et al., 2015; Kovshov & Kovshov, 2015].

The analysis of the proposed solutions enables to predict the potential decrease in the dust level due to the application of the above-mentioned methods using the “Ekolog-gorod” software package (Figure 5).

CONCLUSIONS

The study of the air environment in St. Petersburg, reflecting a set of quantitative parameters of dust and features of its distribution, shows the excessive dust level in some areas of St. Petersburg, associated with the source and intensity of dusting, as well as climatic parameters: air velocity and direction, relative humidity and temperature. The features of the occurrence and distribution of dust flows are primarily associated with the presence of a source of intense dusting; climatic parameters are also important, since they can affect both the characteristics of dust particles (for example, dispersion) and the characteristics of the dust spreading along the city limits (for example, the distance from the source).

High values of dust concentration in the air of the city indicate ineffectiveness of the measures used to combat dust and, consequently, the need to introduce additional measures to reduce the aerotechnogenic load or improve the methods used for dust suppression.

REFERENCES

1. Amato, F., Pandolfi, M., Moreno, T., Furger, M., Pey, J., Alastuey, A., ... & Querol, X. 2011. Sources and variability of inhalable road dust particles in three European cities. Atmospheric Environment, 45(37), 6777–6787.
2. Azarov, V., Barikaeva, N., & Solovyeva, T. 2016. Monitoring of Fine Particulate Air Pollution as a Factor in Urban Planning Decisions. Procedia Engineering, 150, 2001–2007.
3. Baltrėnaitė, E., Lietuvninkas, A., & Baltrėnas, P. 2018. Biogeochemical and engineered barriers for preventing spread of contaminants. Environmental Science and Pollution Research, 25(6), 5254–5268.
4. Barkan, M., Kovshov, S., & Orlov, F. 2015. On the problem of spraying water and dust suppression solutions. Problem of modern science and education, 11 (41), 100–103.
5. Chan, C.K., & Yao, X. 2008. Air pollution in mega cities in China. Atmospheric Environment, 42(1), 1–42.
6. Davydova, N. D., & Znamenskaya, T. I. 2016. The geological problems of Siberia associated with the development of nonferrous metallurgy. Geography and Natural Resources, 37(4), 313–318.
7. Dubey, B., Pal, A.K., & Singh, G. 2018. Airborne particulate matter: source scenario and their impact on human health and environment. In: Climate Change and Environmental Concerns: Breakthroughs in Research and Practice, IGI Global, 447–468.
8. Gorshkov, E., & Nasimi, M. 2016. Investigation of urban air pollution with fine dust of natural origin. Engineering Journal of Don, No. 4.

9. Gupta, P., Christopher, S.A., Wang, J., Gehrig, R., Lee, Y.C., & Kumar, N. 2006. Satellite remote sensing of particulate matter and air quality assessment over global cities. Atmospheric Environment, 40(30), 5880–5892.
10. Heitbrink, W.A., Todd, W.F., Cooper, T.C., & O'Brien, D.M. 1990. The Application of Dustiness Tests to the Prediction of Worker Dust Exposure. American Industrial Hygiene Association Journal, 51, 217–223.
11. Kim, K.H., Kabir, E., & Jahan, S. A. 2018. Airborne bioaerosols and their impact on human health. Journal of Environmental Sciences, 67, 23–35.
12. Kim, K.H., Kabir, E., & Kabir, S. 2015. A review on the human health impact of airborne particulate matter. Environment International, 74, 136–143.
13. Korshunov, G., & Romanchenko, S. 2016. Development of innovative technologies of dust removal in treatment and tunneling faces. Journal of Mining Institute, 218, 339–344.
14. Kovshov, S. 2013. Biological ground recultivation and increase of soil fertility. Int. J. of Ecology and Development, 25(2), 105–113.
15. Kovshov, S., Erzin, A., & Kovshov, V. 2015. Bonding dust with environmentally safe compositions on open dust-forming surfaces in coal producing enterprises. Int. J. of Ecology and Development, 30(1), 11–23.
16. Kovshov, S., & Kovshov, V. 2015. Chemical technology of dust suppression on open-pit mines. Int. J. of Ecology and Development, 30(3), 55–67.
17. Manoli, E., Voutsa, D., & Samara, C. 2002. Chemical characterization and source identification/apportionment of fine and coarse air particles in Thessaloniki, Greece. Atmospheric Environment, 36(6), 949–961.
18. O'Shaughnessy, P.T., Kang, M., & Ellickson, D. 2012. A Novel Device for Measuring Respirable Dustiness Using Low Mass Powder Samples. J. Occup. Environ. Hyg., 9(3), 129–139.
19. Pashkevich, M., & Petrova, T. 2017. Assessment of area air pollution in the metropolis using geographic information systems. Journal of Mining Institute, 228, 738–742.
20. Patra, A.K., Gautam, S., & Kumar, P. 2016. Emissions and human health impact of particulate matter from surface mining operation–A review. Environmental Technology & Innovation, 5, 233–249.
21. Shevchenko, V.P. et al. 2018. Dispersed Sedimentary Matter of the Atmosphere. In: The Handbook of Environmental Chemistry. Springer, Berlin, Heidelberg, pp. 38.
22. Shi, Z., Shao, L., Jones, T.P., Whittaker, A.G., Lu, S., Berube, K.A., ... & Richards, R.J. 2003. Characterization of airborne individual particles collected in an urban area, a satellite city and a clean air area in Beijing, 2001. Atmospheric environment, 37(29), 4097–4108.
23. Volkodaeva, M., & Kiselev, A. 2017. About development of system of environmental monitoring of atmospheric air quality. Journal of Mining Institute, 227, 589–596.