PREVENTIVE HEALTHCARE: TOPICAL ISSUES OF HEALTH RISK ANALYSIS

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Research article

SCIENTIFIC SUBSTANTIATION OF PRIORITY CHEMICALS, OBJECTS FOR SETTING QUOTAS AND TRENDS IN MITIGATING AIRBORNE PUBLIC HEALTH RISKS WITHIN ACTIVITIES PERFORMED BY THE SANITARY SERVICE OF THE RUSSIAN FEDERATION

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The study was conducted due to the necessity to streamline management of ambient air quality in large industrial cities in the country. The relevant tasks were set within the 'Clean Air' Federal project and the system for setting emission quotas.

The aim was to develop scientific-methodical approaches that would support Rospotrebnadzor in performing its functions and duties as regards management of ambient air quality, including those accomplished within the 'Clean Air' Federal project.

We took into account that initial data for the whole system for setting emission quotas were represented by aggregated calculation of pollutant dispersion. The study relied on input and output data provided by the 'Ekolog-Gorod" software package for calculating ambient air pollution. This software employs methods for calculating emission diffusion in ambient air that are applied as standards in Russia. Calculations were accomplished at points located within residential areas in the analyzed cities and covered not less than 20 major contributions made by emission sources to levels of each chemical at each calculation point. Airborne health risks were assessed in accordance with the valid methodical documents. We applied the following criteria for permissible (acceptable) risks: carcinogenic ones should not exceed $1.0{\cdot}10^{-4}$; non-carcinogenic chronic and / or acute risks should be at a level of a hazard index for chemicals with the same effects equal to 3.0. The brunch and bound method of linear programming was applied to substantiate optimal regulatory impacts aimed at minimizing health risks by reducing emissions into ambient air.

We developed a fundamental algorithm for identifying a list of priority pollutants and a list of objects for setting emission quotas, as well as for substantiating optimal regulatory impacts to mitigate airborne public health risks. We suggest ranking chemicals as priority pollutants in case their registered levels are higher than the established hygienic standards and they in total account for not less 95 % of contributions to unacceptable health risks for critical organs and systems at least at one calculation point. Priority objects are those that are responsible for not less than 95 % of unacceptable health risks and violations of the established hygienic standards. The study describes a developed and tested instrument for selecting optimal regulatory impacts as per relevant hygienic indicators, including levels of public health risks.

The suggested approaches support the Sanitary Service in its effort to provide proper quality of ambient air. They make it possible to identify priority chemicals and objects for setting emission quotas on the unified methodical basis for any city on the country, including those listed within the 'Clear Air' Federal project as priority ones. They also allow estimating whether environmental protection activities are relevant to the essence and levels of public health risks.

Keywords*: health risk, emissions into ambient air, regulation, 'Clear Air' Federal project, priority substances, priority objects for setting emission quotas, airborne risks, Linear programming.*

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The major strategic task in the country development is to provide such quality of ambient air that means absence of any unacceptable public health risks, cases of health harm or any other violations of sanitary-epidemiological welfare of the population. Finding solution to this task requires wide interactions between authorities at all levels of public administration.

The 'Clean Air' Federal project aims to achieve a fundamental decrease in ambient air pollution in large industrial centers (when the project started, 12 cities were included into it[1]; in 2022, 29 cities were added to the list[2])

To achieve the target decrease in ambient air pollution, an experiment on setting emission quotas has been accomplished since January 01, 2021 in accordance with the Federal Law issued on July 26, 2019 No. 195-FZ[3]. This experiment is to be completed by December 31, 2026, considering the alterations made by the Federal Law issued on March 26, 2022 No. 71-FZ[4]. Therefore, the 'Clean Air' project and the experiment on setting emission quotas are closely connected [1, 2].

Quotas are viewed as a specific procedure for regulating emissions considering their targeted decrease; within this procedure, quotas are to be set for participating enterprises to regulate their emissions as per priority ambient air pollutants based on aggregated calculations[5].

Introducing such a concept as 'priority pollutants' into the regulatory base is an extremely important step in developing the whole system for regulation of emissions. It is primarily due to the fact that industrial enterprises, motor transport (and railways in some cities as well) and autonomous heat sources jointly emit dozens or even hundreds of chemicals into ambient air in cities. Thus, for example, more than 130 chemicals are emitted annually by 211 industrial enterprises into ambient air in Chita [3]; in Nizhnii Tagil, approximately 166 chemicals [4]; in Norilsk, 107 varied chemicals are emitted [5] etc. Given that, an important research and methodical task has always been to substantiate the most effective actions aimed at reducing pollution levels.

Variable approaches have been suggested and applied to rank emissions and identify priority ones on a territory within public administration. In some cases, regardless of actual emission masses, chemicals were considered priority ones if they were included into various international or Russian regulatory, reference

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[1] Federal'nyi proekt «Chistyi vozdukh» ['Clean Air' Federal project]. *The Ministry of Natural Resources and Environment of the Russian Federation*. Available at: https://www.mnr.gov.ru/activity/clean-air/ (September 15, 2022) (in Russian).

[2] O rasprostranenii eksperimenta po kvotirovaniyu vybrosov zagryaznyayushchikh veshchestv na gorodskie poseleniya i gorodskie okruga s vysokim i ochen' vysokim zagryazneniem atmosfernogo vozdukha: Protokol soveshchaniya u Zamestitelya Predsedatelya Pravitel'stva RF V.V. Abramchenko ot 18 noyabrya 2021 g. № VA-P11-77pr [On including urban settlements and districts with high and extremely high levels of ambient air pollution into the experiment on setting emission quotas: The proceedings of the meeting headed by V.V. Abramchenko, the Deputy to the RF Government Chairman, dated November 18, 2021 No. VA-P11-77pr] (in Russian).

[3] O provedenii eksperimenta po kvotirovaniyu vybrosov zagryaznyayushchikh veshchestv i vnesenii izmenenii v otdel'nye zakonodatel'nye akty Rossiiskoi Federatsii v chasti snizheniya zagryazneniya atmosfernogo vozdukha: Federal'nyi zakon ot 26.07.2019 № 195-FZ [On performing an experiment on quoting emissions of pollutants and making alterations into some legislative acts existing in the Russian Federation as regards reduction in ambient air pollution: the Federal Law issued on July 26, 2019 No. 195-FZ]. *The official Internet portal for legal information*. Available at: http://publication.pravo.gov.ru/Document/View/0001201907260064 (September 15, 2022) (in Russian).

[4] O vnesenii izmenenii v otdel'nye zakonodatel'nye akty Rossiiskoi Federatsii: Federal'nyi zakon ot 26.03.2022 № 71-FZ [On making alterations into certain legal acts of the Russian Federation: The Federal Law issued on March 26, 2022 No. 71-FZ]. *The official Internet portal for legal information*. Available at: http://publication.pravo.gov.ru/Document/View/0001202203260008 (September 15, 2022) (in Russian).

[5] Ob utverzhdenii pravil kvotirovaniya vybrosov zagryaznyayushchikh veshchestv (za isklyucheniem radioaktivnykh veshchestv) v atmosfernyi vozdukh: Prikaz Minprirody Rossii ot 29.11.2019 № 814 [On Approval of the rules for setting quotas of pollutant emissions (radioactive substances excluded) in ambient air: The Order by the RF Ministry of Natural Resources and Environment dated November 29, 2019 No. 814]. *The official Internet portal for legal information*. Available at: http://publication.pravo.gov.ru/Document/View/0001201912260045 (September 15, 2022) (in Russian).

or instructive documents. These documents are represented, for example, by lists of priority substances issued by the Agency for Toxic Substances[6], The Order by the RF Ministry of Natural Resources and the Environment 'On the Procedure for identifying emission sources of harmful substances (pollutants) into ambient air that are subject to the state regulation and standardization, and on the List of harmful substances (pollutants) subject to the state regulation and standardization'[7], The Letter of the RF Public Healthcare Ministry about the list of priority chemicals that can occur in the environment and their influence on public health[8], the Guide on control over ambient air pollution RD 52.04.186-89[9] and others.

Applied approaches included selecting priority substances as per their contributions to the total gross mass of emissions; as per a rank of a numeric value calculated for ratios between masses of emissions and maximum permissible concentrations or complex indexes of ambient air pollution [6, 7]; as per substances being able to produce mutagenic, carcinogenic or teratogenic effects [8]. Since the Guide entitled 'Human Health Risk Assessment from Environmental Chemicals' was published in Russia[10], it has become quite a common practice to identify priority chemicals as per a hazard index value. This value is determined considering reference levels of a given substance and preset weight factors to estimate carcinogenic and / or non-carcinogenic effects [9, 10].

The Federal Law 195-FZ '*On performing an experiment …*' has a clear definition that *'priority pollutants are those emissions of which facilitate violation of the hygienic standards for ambient air quality and create risks for human health on the territories included into the experiment'*. Therefore, it is necessary to develop a strict procedure for identifying priority substances as per health risk indicators.

Since reduction in emissions of priority substances should take place at specific objects, another important task is to identify priority emission sources of these substances and their contributions to ambient air pollution.

Finding solutions to both tasks, identifying priority chemicals and participating in substantiating lists of priority objects, is enlisted in the Clause 4 of the Federal Law dated July 26, 2019 No. 195-FZ among responsibilities borne by a federal executive

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[6] Support Document to the 2022 Substance Priority List (Candidates for Toxicological Profiles). *Agency for Toxic Substances and Disease Registry Division of Toxicology and Human Health Sciences*. Atlanta, USA, 2022, 12 p. Available at: https://www.atsdr.cdc.gov/spl/resources/ATSDR-2022-SPL-Support-Document-508.pdf (October 02, 2022).

[7] O Poryadke ustanovleniya istochnikov vybrosov vrednykh (zagryaznyayushchikh) veshchestv v atmosfernyi vozdukh, podlezhashchikh gosudarstvennomu uchetu i normirovaniyu, i o Perechne vrednykh (zagryaznyayushchikh) veshchestv, podlezhashchikh gosudarstvennomu uchetu i normirovaniyu: Prikaz Minprirody RF ot 31.12.2010 № 579 (zaregistrirovano v Minyuste RF 09.02.2011 № 19753) [On the Procedure for identifying emission sources of harmful substances (pollutants) into ambient air that are subject to the state regulation and standardization, and on the List of harmful substances (pollutants) subject to the state regulation and standardization: the Order by the RF Ministry of Natural Resources and Environment dated December 31, 2010 No. 579 (registered by RF Ministry of Justice on February 09, 2011 No. 19753)]. *KonturNormativ*. Available at: https://normativ.kontur.ru/document?moduleId=1&documentId=229990 (August 18, 2022) (in Russian).

[8] O spiske prioritetnykh veshchestv, soderzhashchikhsya v okruzhayushchei srede, i ikh vliyanii na zdorov'e naseleniya: Pis'mo Departamenta Gossanepidnadzora Minzdrava RF ot 07.08.1997 № 11/109-111 [On the list of priority substances in the environment and their influence on public health: The Letter by the Department of the State Sanitary and Epidemiological Surveillance of the RF Public Healthcare Ministry dated August 07, 1997 No. 11/109-111]. *The library for regulatory documentation*. Available at: https://files.stroyinf.ru/Data2/1/4293737/4293737491.htm (September 03, 2022) (in Russian).

[9] RD 52.04.186-89. Rukovodstvo po kontrolyu zagryazneniya atmosfery [Guide RD 52.04.186-89. The Guide on control over ambient air pollution]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200036406 (September 03, 2022) (in Russian).

[10] The Guide R 2.1.10.1920-04. Human Health Risk Assessment from Environmental Chemicals (approved and introduced by G.G. Onishchenko, the First Deputy to the RF Public Healthcare Minister and RF Chief Sanitary Inspector on March 5, 2004). *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200037399 (November 22, 2022) (in Russian).

authority conducting the federal state sanitary-epidemiological surveillance[11].

Still, it is noteworthy that the Federal Law 'On sanitary-epidemiological welfare of the population'[12] gives chief state sanitary inspectors and their deputies the power to introduce suggestions on implementation of activities aimed at improving a sanitary-epidemiological situation and on public health protection to executive authorities at any level in public administration. It is advisable and important to use this power, including activities conducted within the 'Clean Air' Federal project. The latter is also associated with the fact that regulatory and methodical documents on the system for setting quotas do not envisage assessment of residual health risks or estimation whether any implemented activity has been effective as per health risk indicators. Absence of such estimation can result in insufficient or excessive expenses borne by economic entities and wasted on activities that hardly yield any results and / or lower social and medical-demographic significance of decisions made by authorities [11, 12]. At the same time, it seems advisable not only to estimate effectiveness of activities that have already been implemented but also to perform predictive analysis of action plans and programs in order to identify whether they are relevant to the structure, levels and spatial distribution of public health risks on a given territory.

Development of theoretical grounds for solutions to optimization tasks within emission standardization has been described in literature and their practical implementation has been addressed in research works issued by the Voeikov Main Geophysical Observatory [13, 14].

The aim of this study was to develop scientific-methodical approaches that would support Rospotrebnadzor in performing its functions and duties as regards management of ambient air quality, including those accomplished within the 'Clean Air' Federal project.

Materials and methods. Methodical approaches were developed considering that the whole system for decision making to regulate emissions through such an instrument as quotas was based on initial data represented by aggregated calculations of emission dispersion.

In this study, we relied on the structure of input and output data applied in the 'Ekolog-Gorod' unified software package for calculating ambient air pollution, version 4.60.1, with the embedded module for calculating 'Mean values'. The software employs methods for modeling emission diffusion in ambient air that are applied as standards in Russia. When considering contributions made by specific sources to pollution, we considered not less than 20 priority contributions to concentrations of each substance at each calculation point.

The developed approaches involved binding all the sources of calculation points to vector maps of territories and mandatory calculations of contributions to ground concentrations at each point made by economic entity, motor transport (at specific sections of traffic networks) and other pollution sources.

Risk assessment was performed in accordance with the valid methodical documents approved by Rospotrebnadzor as per conventional procedures[13]. We applied the following criteria for permissible (acceptable) risks: carcinogenic ones should not exceed $1.0 \cdot 10^{-4}$; non-carcinogenic chronic and / or acute risks

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[11] O provedenii eksperimenta po kvotirovaniyu vybrosov zagryaznyayushchikh veshchestv i vnesenii izmenenii v otdel'nye zakonodatel'nye akty Rossiiskoi Federatsii v chasti snizheniya zagryazneniya atmosfernogo vozdukha: Federal'nyi zakon ot 26.07.2019 № 195-FZ [On performing an experiment on quoting emissions of pollutants and making alterations into some legislative acts existing in the Russian Federation as regards reduction in ambient air pollution: the Federal Law issued on July 26, 2019 No. 195-FZ]. *The official Internet portal for legal information*. Available at: http://publication.pravo.gov.ru/Document/View/0001201907260064 (September 15, 2022) (in Russian).

[12] O sanitarno-epidemiologicheskom blagopoluchii naseleniya: Federal'nyi zakon ot 30.03.1999 № 52-FZ [On sanitary-epidemiological welfare of the population: the Federal Law issued on March 30, 1999 No. 52-FZ]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/901729631 (September 15, 2022) (in Russian).

[13] The Guide R 2.1.10.1920-04. Human Health Risk Assessment from Environmental Chemicals (approved and introduced by G.G. Onishchenko, the First Deputy to the RF Public Healthcare Minister and RF Chief Sanitary Inspector on March 5, 2004). *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200037399 (November 22, 2022) (in Russian).

should be at a level of a hazard index (HI) for chemicals with the same effects equal to 3.0; hazard quotient (HQ) was set at 1.0 for certain chemicals[14].

The algorithm included a procedure for estimating and verifying calculated data by using field observations obtained at the posts of environmental and / or social-hygienic monitoring with the following corrections of the aggregated database on emission sources.

Identifying which direction the study had to go involved establishing specific economic entities; in case their emissions of priority chemicals were reduced, health risks would drop to their acceptable levels in a whole city. Within this study, minimal sufficient reduction in masses of emissions on a given territory was taken as an optimization indicator. The procedure was developed relying on a baseline solution to an optimization task which was to determine such a change in masses of pollutant emissions by objects chosen for setting quotas that would ensure conformity with targeted risk levels at selected reference points. The brunch and bound method of linear programming in the R-studio environment (the state registration No. for PC is 2022669645) was applied to find a solution to the task within the suggested mathematical setting.

Basic results. We developed a fundamental algorithm for identifying a list of priority pollutants and a list of objects for setting emission quotas, as well as for substantiating optimal regulatory impacts to mitigate airborne public health risks. It is given in Figure 1. The algorithm assumes aggregated calculations to be accomplished for short-term ambient air pollution (a 20-minute period, the worst possible diffusion conditions are acute population exposure) and for average annual ambient air pollution (chronic exposure).

When selecting priority chemicals, the most optimal way is to identify ground concentrations at calculation points that correspond to geometric centers of all the residential buildings and territories used by people for recreational or health-improving purposes.

Calculation points are given preference over a regular mesh considering several important aspects:

– residential areas are often not uninterrupted rows of buildings; some spots with residential buildings might be located at a significant distance from each other and are quite small zones; it is hardly correct to consider them using a mesh with its step being more than 200 × 200 m;

– we eliminate a possibility that some calculation points would be located on industrial sites adjacent to residential areas or on motorways, etc.; this allows archiving more correct health risk assessment;

– when calculation points are located directly in residential areas, it fully corresponds to goals of health risk assessment.

In future, the same calculation points are applied to select optimal trends in actions aimed at mitigating health risks.

A ground concentration of each chemical is described with several parameters:

- shares of maximum single MPC;
- shares of average annual MPC (or average daily MPC[15]);
- a level of lifetime carcinogenic risk;
- a level of detected acute health risk, shares of ARfC;
- a level of detected chronic health risk, shares of RfC.

[14] MR 2.1.10.01156-19. Otsenka kachestva atmosfernogo vozdukha i analiz riska zdorov'yu naseleniya v tselyakh prinyatiya obosnovannykh upravlencheskikh reshenii v sfere obespecheniya kachestva atmosfernogo vozdukha i sanitarno-epidemiologicheskogo blagopoluchiya naseleniya (utv. rukovoditelem Federal'noi sluzhby po nadzoru v sfere zashchity prav potrebitelei i blagopoluchiya cheloveka, Glavnym gosudarstvennym sanitarnym vrachom RF A.Yu. Popovoi 02.12.2019) [The Methodical Guidelines MR 2.1.10.01156-19. Assessment of ambient air quality and public health risk analysis in order to provide well-grounded decision making as regards providing ambient air quality and sanitary-epidemiological welfare of the population (approved by A.Yu. Popova, the Head of the Federal Service for Surveillance over Consumer Rights Protection and Human Wellbeing and the RF Chief Sanitary Inspector on December 02, 2019)]. *YuIS Legalakt: laws, codes and regulatory documents of the Russian Federation*. Available at: https://legalacts.ru/doc/mr-21100156-19-2110-gigiena-kommunalnaja-gigiena-sostojanie-zdorovja-naselenija/ (November 22, 2022) (in Russian).

[15] In case an average annual MPC for a given substance has not been identified.

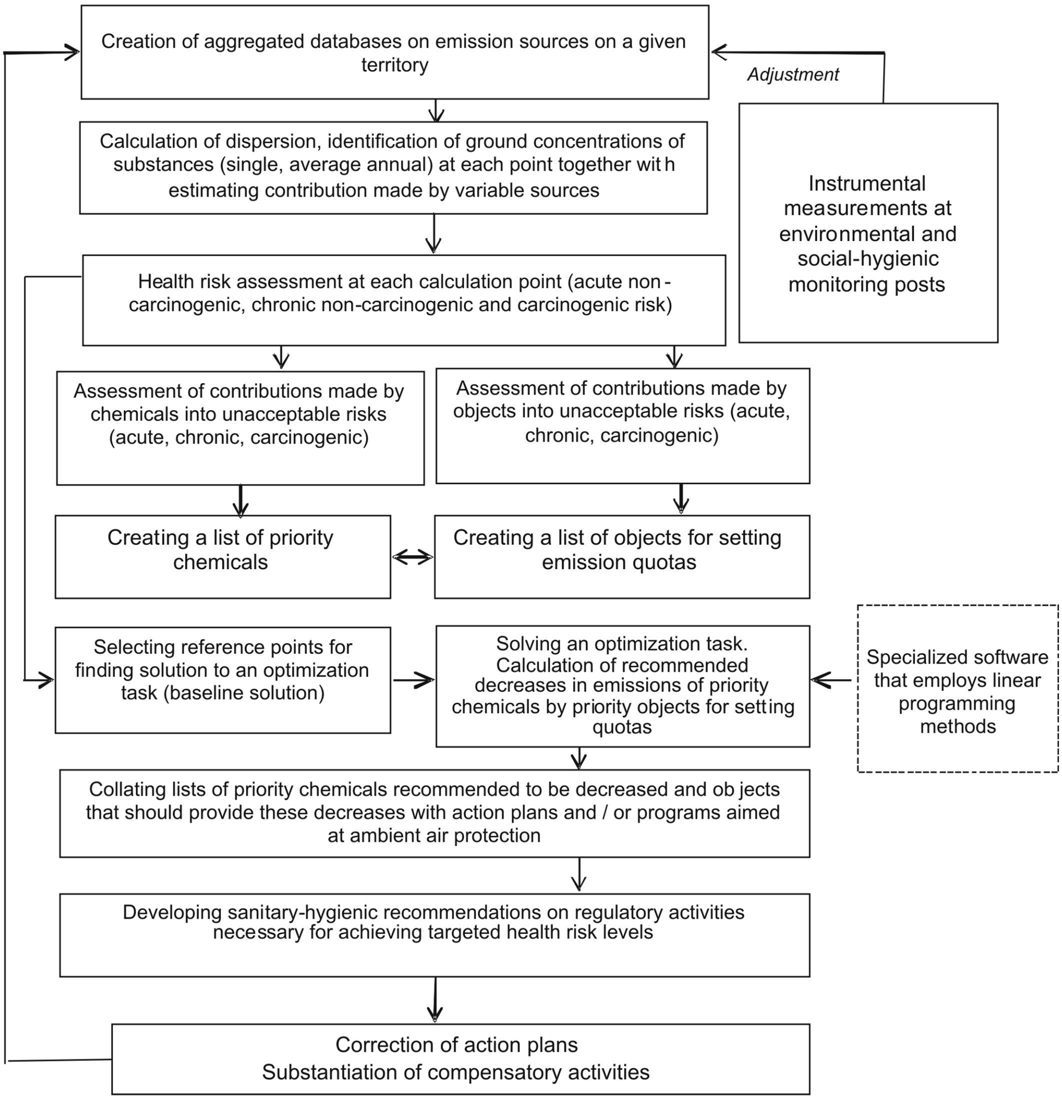

Figure 1. The fundamental algorithm for identifying a list of priority pollutants and a list of objects for setting emission quotas, as well as for substantiating optimal regulatory impacts to mitigate airborne public health risks

In case impermissible (unacceptable) health risks are detected, contributions made by specific chemicals to each health risk (carcinogenic, acute non-carcinogenic and chronic non-carcinogenic) are estimated at each point where impermissible (unacceptable) health risks have been detected. Chemicals are ranked as per their contributions to the total health risk at each calculation point where impermissible (unacceptable) health risks have been detected.

Priority substances include:

– chemicals identified in levels higher than maximum single MPC and / or average annual MPC as per results of dispersion calculation;

– chemicals with individual hazard indexes (HQ) > 1.0 or a carcinogenic risk being $1 \cdot 10^{-6}$ or higher;

– chemicals that are responsible (considering all the contributions in a descending order) for not less than 95 % of unacceptable health risks for critical organs and systems at least at one calculation point (HI > 3.0; a carcinogenic risk > $1 \cdot 10^{-4}$).

Table 1 provides an example of selecting priority chemicals at calculation points for one type of risk.

A final list of priority chemicals for a city as a whole is created based on all the aggregated data. Table 2 provides an example.

Table 1

An example how priority chemicals are identified as per such an indicator as 'Contribution to unacceptable chronic risks of respiratory diseases'

Code*	Calculation point	1	2	3	4	5	6	7	8
	Hazard index (HI) at a given point	**3.33**	**4.32**	**4.49**	**5.34**	**5.51**	**5.97**	**9.53**	**12.10**
	Total dusts, including	**69.19**	**76.33**	**69.27**	**60.63**	**71.12**	**72.96**	**77.51**	**68.95**
2908	Non-organic dust: 70–20 % SiO2	60.44	75.27	55.39	46.31	70.09	44.55	22.75	34.00
2909	Non-organic dust: up to 20 % SiO2	1.02	0.22	0.37	0.56	0.16	0.39	0.30	0.31
2902	Particulate matter	4.13	0.64	10.12	9.10	0.65	22.32	46.02	29.36
2930	Abrasive dust	0.21	0.02	0.36	0.30	0.02	0.58	1.27	0.67
2936	Wood dust	2.21	0.12	1.87	3.86	0.13	4.73	6.87	4.29
2937	Grain dust	1.15	0.05	1.14	0.47	0.06	0.35	0.19	0.27
3749	Charcoal dust	0.013	0.001	0.008	0.012	0.001	0.012	0.007	0.01
330	Sulfur dioxide (sulfuric anhydride)	14.04	17.57	12.96	10.57	16.10	10.28	5.37	7.98
301	Nitrogen dioxide (Nitrogen (IV) oxide)	10.83	5.17	13.69	18.89	11.18	11.22	7.06	16.44
150	Sodium hydroxide	0.82	0.21	1.59	3.45	0.16	3.34	3.42	1.27
304	Nitrogen (II) oxide (Nitrogen oxide)	4.47	0.55	1.45	2.54	1.19	1.19	0.75	0.75
322	Sulfuric acid (as per H2SO4 molecule)	0.08	0.04	0.08	0.06	0.03	0.12	0.09	0.23
1325	Formaldehyde	0.24	0.06	0.23	0.47	0.13	0.21	0.12	0.30
1301	Prop-2-en-1-al (Acrolein)	0.09	0.01	0.21	0.16	0.01	0.39	2.39	1.83
	The sum of contributions made by priority chemicals	98.53	99.07	95.92	96.08	98.4	97.8	95.75	96.47

N o t e : * means a code assigned to a chemical in the aggregated calculation system; ** means that coloring highlights substances with their ranked contribution to unacceptable health risks being more than 95 %.

Table 2

Priority substances – components in emissions from industrial facilities and motor transport

No.	Code	Chemical	Criterion for inclusion*						
			1	2	3	4	5	6	7
1	143	Manganese and its compounds (recalculated as per manganese (IV) oxide)							+
2	150	Sodium hydroxide						+	+
3	164	Nickel oxide (recalculated as per Ni)						+	+
4	301	Nitrogen dioxide	+	+			+	+	+
5	304	Nitrogen oxide							+
6	328	Carbon (Soot)							+
7	330	Sulfur dioxide						+	+
8	337	Carbon oxide	+						
9	342	Gaseous fluorides						+	+
10	602	Benzene			+	+		+	+
11	703	Benz/a/pyrene (3,4-benzpyrene)			+				
12	1301	Prop-2-el-1-al (Acrolein)						+	+
13	1325	Formaldehyde			+	+			
14	2902	Dusts (total) with priority				+	+	+	+
15	2907	*Non-organic dust > 70 % SiO2*	+			+	+	+	+
16	2909	*Non-organic dust: up to 20 % SiO2*				+	+	+	+

N o t e : *criteria for inclusion:
1 – levels higher than single maximum MPC are detected as per dispersion calculation;
2 – levels higher than average annual MPC are detected as per dispersion calculation;
3 – acute HQ > 1;
4 – chronic HQ > 1;
5 – a chemical is among substances responsible for 95 % of unacceptable carcinogenic risks;
6 – a chemical is among substances responsible for 95 % of unacceptable acute non-carcinogenic risks;
7 – a chemical is among substances responsible for 95 % of unacceptable chronic non-carcinogenic risks.

A priority list of chemicals for which quotas should be set seems to be dynamic and should be changed when new emission sources appear or old ones are relocated. So, an aggregated database on all the emission sources in a given city ought to be dynamic.

Results obtained by calculating contributions made by specific sources to ground concentrations of priority pollutants and unacceptable risks are applied to identify priority objects for setting emission quotas[16].

Calculation should cover all the sources that account for not less than 95 % of unacceptable health risks and the total violations of the established hygienic standards.

A contribution made to risk levels (hazards indexes) by a specific object (an industrial facility, a section in a traffic network with emissions from motor transport, or an autonomous heat source) is identified at each point as a weighted average of contributions as per the following formulas:

– for chronic risks:

$$\delta(HI_{Rfc\,j})_n^k = \frac{\sum\limits_{i \in I_j^{Rfc}} HQ_{Rfc\,i}{}^k \cdot \delta aa_{in}^k}{\sum\limits_{i \in I_j^{Rfc}} HQ_{Rfc\,i}{}^k}, \qquad (1)$$

where $\delta(HI_{Rfc\,j})_n^k$ is a contribution made by the n-th object to a hazard index for the j-th organ or system at the k-th point under chronic exposure;

I_j^{Rfc} is a multitude of pollutants that create a chronic health risk as per the j-th organ or system;

$HQ_{Rfc\,i}{}^k$ is a hazard quotient under chronic exposure to the i-th pollutant at the k-th point;

δaa_{in}^k is a contribution made by the n-th facility to average annual concentrations at the k-th point as per the i-th pollutants;

– for acute risks:

$$\delta(HI_{ARfc\,j})_n^k = \frac{\sum\limits_{i \in I_j^{ARfc}} HQ_{ARfc\,i}{}^k \cdot \delta sm_{in}^k}{\sum\limits_{i \in I_j^{ARfc}} HQ_{ARfc\,i}{}^k}, \qquad (2)$$

where $\delta(HI_{ARfc\,j})_n^k$ is a contribution made by the n-th object into a hazard index for the j-th organ or system at the k-th point under acute exposure;

I_j^{ARfc} is a multiplicity of pollutants creating a health risk under acute exposure as per the j-th organ or system;

$HQ_{ARfc\,i}{}^k$ is a hazard quotient under acute exposure to the i-th pollutant at the k-th point;

δsm_{in}^k is a contribution made by the n-th facility into single maximum concentrations at the k-th point as per the i-th substance;

– for carcinogenic risks:

$$\delta(CR)_n^k = \frac{\sum\limits_i SF_i \; Caa_i^k \cdot \delta aa_{in}^k}{\sum\limits_i SF_i \; Cad_i^k}, \qquad (3)$$

where $\delta(CR)_n^k$ is a contribution made by the n-th object into a carcinogenic risk at the k-th point under acute exposure;

Caa_i^k is an average annual concentration of the i-th pollutant calculated at the k-th point;

δaa_{in}^k is a contribution made by the n-th facility into average annual concentrations at the k-th point for the i-th pollutant;

SF_i is a slope factor for the i-th pollutant.

Contributions are calculated at each point concerning all critical organs and systems under chronic and acute exposure.

An integral estimation of contributions made by specific objects into health risk levels involves using weighted averaging as per all the points:

[16] In case there is no technical feasibility to calculate contributions made by sources at each point when calculating ground concentrations in accordance with the item 4.2, contributions made by enterprises, infrastructure objects or other sources are calculated at reference points.

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– for chronic exposure:

$$\delta(HI_{Rfc\,j})_n = \frac{\sum_k HI_{Rfc\,j}^{\;k} \cdot \delta(HI_{Rfc\,j})_n^k}{\sum_k HI_{Rfc\,j}^{\;k}}, \qquad (4)$$

where $\delta(HI_{Rfc\,j})_n$ is an average weighted contribution made by the *n*-th object into a hazard index for the *j*-th organ or system under chronic exposure as per the total points;

$HI_{Rfc\,j}^{\;k}$ is a hazard index for the *j*-th organ or system under chronic exposure at the *k*-th points.

Similar to (4), an integral estimation is performed to calculate a contribution made by a specific object into levels of an acute and / or carcinogenic risk.

All the objects with their contributions accounting for 95 % of unacceptable (carcinogenic, acute and / or chronic) risks are included into a list of objects for which it is advisable to set emission quotas if we want to reduce health risks down to their safe levels. Factors (chemicals) emissions of which are subject to immediate reduction should be identified for each object. Table 3 provides an example how to substantiate a list of priority objects.

Table 3

Substantiating a list of priority objects as sources of impermissible health risks on a given territory (a fragment)

	A contribution made by a specific object to a certain impermissible health risk, %						Chemicals making contributions to an impermissible health risk
	Chronic, respiratory diseases	Chronic, impacts on development	Chronic, diseases of the nervous systems	Chronic, diseases of blood	Acute, respiratory diseases	Acute, diseases of the immune system	
Facility 1	38.51		56.71	57.90	2.1	67.0	Nickel oxide, manganese and its compounds, benzene
Motor transport	21.57			27.87	1.92		Nitrogen dioxide, nitrogen oxide
Facility 2	17.26	96.35	8.11		13.10		Gaseous fluorides, non-organic fluorides, sulfur dioxide, non-organic dusts, nitrogen dioxide, benz(a)pyrene, benzene
Autonomous heat sources	8.19				5.50		Sulfur dioxide, non-organic dusts, nitrogen dioxide, particulate matter
Facility 3	3.62		11.56	4.33	37.2		Nitrogen dioxide, nitrogen (II) oxide non-organic dusts, manganese and its compounds, carbon (soot), sulfur dioxide
Facility 4	3.08				20.4		Nitrogen dioxide, sulfur dioxide, non-organic dusts, nitrogen (II) oxide
Facility 5	1.92						Non-organic dusts, sodium hydroxide, copper oxide
Facility 6	1.29			5.20	8.70		Prop-2-en-1-al (acrolein), sulfur dioxide, nitrogen dioxide, sodium hydroxide, nickel oxide
Facility 7			7.68				Manganese and its compounds
Facility 8			6.30				Manganese and its compounds
Facility 9						12.3	Manganese, benzene
Facility 10						8.20	Benzene
Facility 11						5.60	Benzene
… others (9 facilities overall)			4.90		8.10	2.30	Sulfur dioxide, non-organic dusts, nitrogen dioxide, benzene, particulate matter
Total	95.44	96.35	95.23	95.30	96.62	95.4	

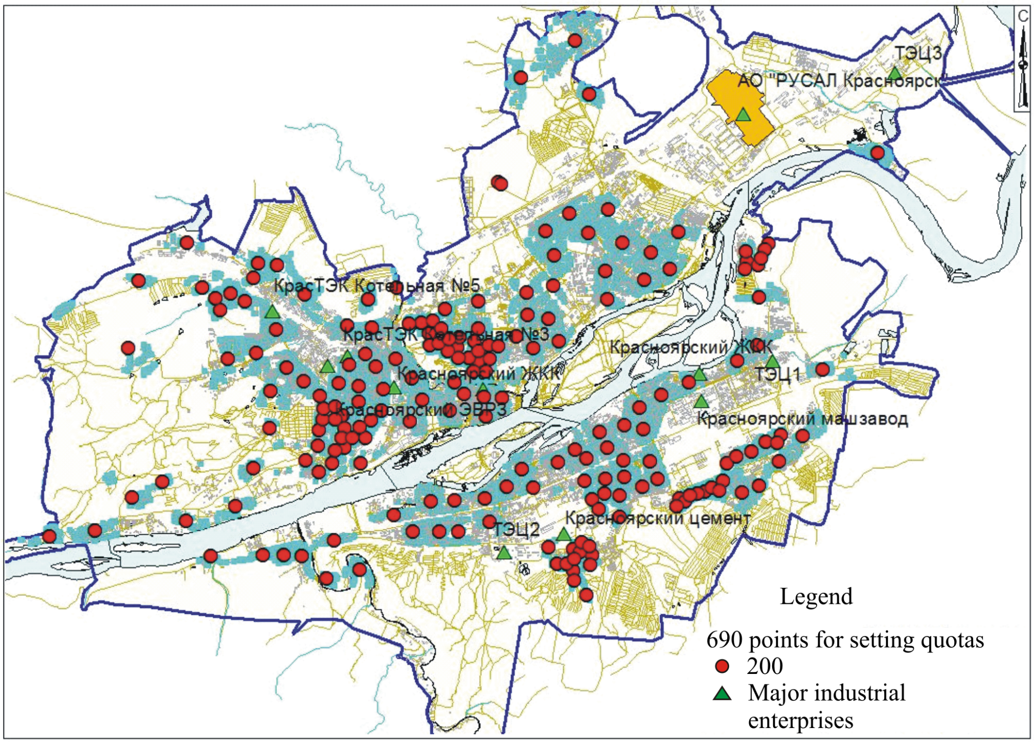

Figure 2. The electronic map of Krasnoyarsk with marked local maximum points applied as reference ones when solving the task of setting quotas

This example illustrates that 20 industrial facilities, motor transport and autonomous heat sources are to be enlisted as priority ones on the examined territory. Contributions made by these sources and lists of priority chemicals emissions of which should be reduced are different and specific for each object. Therefore, it is hardly advisable to reduce an emission from each object by a certain share since this obviously does not guarantee ultimate mitigation of health risks down to their acceptable (permissible) levels.

The Sanitary Service needs reliable tools that do not replace the order and methodology for setting emission quotas but make it possible to estimate whether any accomplished activities on environmental protection are relevant to the existing risk levels. To do that, we suggest this method for selecting optimal trends in regulatory impacts as per hygienic indicators.

A system of reference points is applied to reduce time required for calculations and volumes of output information necessary to solve the task. These points are those where local maximums are established in compact residential areas as per indicators describing conformity to hygienic standards (average annual and single maximum MPC), hazard quotients for acute and chronic exposure, hazard indexes for acute and chronic exposure and its effects on critical organs and systems, and carcinogenic risks.

Use of local maximums as reference points for setting quotas makes it possible to reduce dimensionality of the task by several orders without any substantial losses in precision of obtained estimates thereby reducing needs in computational resources.

The suggested method was tested in Krasnoyarsk; the testing gave an opportunity to identify 35 compact residential areas with local maximum points as per all the safety indicators (Figure 2).

A minimal total change in masses of pollutant emissions as per all the objects for setting quotas can be applied as a target function (an optimization criterion) (5):

$$\sum_{n=1}^{N}\sum_{i=1}^{I}(1-q_{in})M_{in} \to \min, \qquad (5)$$

where q_{in} is a share by which a mass annual emission of the i-th pollutant from the n-th object is reduced;

M_{in} is a mass emission of the i-th pollutant from the n-th object per a unit of time, tons/year.

The task is to reduce mass emissions that influence average annual concentrations of pollutants and levels of chronic (carcinogenic and non-carcinogenic) health risks.

The solution assumes that the following conditions should be met at each calculation point:

– a tolerance range for reduction in mass emissions of pollutants at objects for setting quotas varies between 0 to 1.0[17] (control parameters) (6):

$$0 \le q_{in} \le 1, i = \overline{1...I}, n = \overline{1...N} \tag{6}$$

– a hazard quotient (HQ) for chemicals creating a non-carcinogenic risk should not exceed 1.0 (7):

$$HQ_{Rfci}^{\ k} = \frac{\sum_{n=1}^{N} q_{in} Caa_{in}^{k}}{Rfc_i} \le R_{HQ}, \tag{7}$$
$$i = \overline{1...I}, k = \overline{1...K},$$

where Rfc_i is a reference concentrations of the i-th pollutant under chronic (average annual) exposure, mg/m^3; all the other denominations are the same as in the previously described equations;

– a hazard index (HI) for affected organs and systems should not exceed 3.0 if we aim to achieve ‘acceptable risk’ level (8):

$$HI_{Rfc\,j}^{\ k} = \sum_{i \in I_j^{Rfc}} \frac{\sum_{n=1}^{N} q_{in} Caa_i^k}{Rfc_i} \le R_{HI}, \tag{8}$$
$$j = \overline{1...J}, k = \overline{1...K}$$

– a carcinogenic risk CR^k should not exceed 10^{-4} (9):

$$CR^k = \sum_{i=1}^{I} SF_i \, q_{in} Caa_i^k \le R_{cr}, k = \overline{1...K}. \tag{9}$$

The results yielded by solving the task should be considered a tool to estimate advisability and sufficiency of plans with their aim to reduce emissions of a certain chemical by a certain object. The estimation should focus on whether there was a resulting reduction in public health risks and be useful for developing recommendations on making corrections into actions plans of both economic entities and local authorities.

Table 4 provides an example of solving the task on substantiating regulatory actions aimed at minimizing health risks associated with manganese levels in ambient air in a given city.

Manganese emissions are declared by approximately 240 objects in the analyzed city. The total emissions are equal to 1.7563 tons/year. An unacceptable chronic non-carcinogenic risk of nervous diseases is established at 32 calculation points within residential areas. It varies between 3.1 to 6.15 HI.

Contributions to 95 % of this unacceptable risk are made by 14 economic entities. The targeted reduction is down to 3.0 HI at all the points where this unacceptable risk level has been detected.

The solution to the task indicates that it is advisable to develop activities aimed at reducing manganese emissions at the enterprises No. 1, 5 and 6 and to introduce control over their implementation. Major attention should be paid to activities performed at the enterprise No. 1. Any reduction in emissions from other objects might not guarantee that acceptable health risk levels are achieved.

Other optimization criteria can be used as well; it depends on targets and available initial data.

Thus, for example, economic indicators can be used as a target function (optimization criteria) apart from the total mass of emissions; they can be, for example, minimal financial expenses on environmental protection. Functional that reflects regularities in growing total expenses on activities aimed at reducing emissions (tons/year) can be applied as an optimization criterion based on an assumption

[17] There are certain limitations here such as exclusion of permissible reduction in emissions down to 0; limitations of reduction below a certain level at specific object etc. can be introduced into the task additionally.

Table 4

Substantiating regulatory actions aimed at reducing risks of the nervous diseases down to their acceptable levels under exposure to manganese and its compounds emitted into ambient air

Economic entity	Total emissions, tons/year	A contribution to total emissions, shares	A contribution to a chronic health risk (impacts on the nervous system)	Recommended targeted emissions, tons/year, that provide achieving acceptable risks	Recommended reduction, a share of the initial emission volumes
Facility 1	0.640	0.364	0.567	**0.353**	**0.551**
Facility 2	0.152	0.086	0.019	0.152	0.000
Facility 3	0.140	0.080	0.015	0.140	0.000
Facility 4	0.117	0.067	0.077	0.117	0.000
Facility 5	0.104	0.059	0.116	**0.010**	**0.096**
Facility 6	0.058	0.033	0.063	**0.003**	**0.052**
Facility 7	0.049	0.028	0.012	0.049	0.000
Facility 8	0.045	0.026	0.004	0.045	0.000
Facility 9	0.041	0.023	< 0.01	0.041	0.000
Facility 10	0.037	0.021	0.015	0.037	0.000
Facility 11	0.037	0.019	< 0.01	0.037	0.000
Facility 12	0.029	0.016	< 0.01	0.029	0.000
Facility 13	0.027	0.015	0.019	0.027	0.000
Facility 14	0.026	0.015	< 0.01	0.026	0.000

that the latter are inversely proportionate to a relative change in their mass flow (10).

$$\sum_{n=1}^{N}\sum_{i=1}^{I}\frac{M_{in}}{q_{in}} \to \min \qquad (10)$$

Inclusion of cost-related parameters into the optimization task can yield a bit different results when it comes down to selecting relevant activities aimed at reducing emissions. At the same time, decision-makers get access to new information that enables them to make necessary corrections into action plans and programs.

It is noteworthy that these instruments are universal. Other health risk indicators can be applied as safety criteria when the optimization task is solved; for example, if our task is to achieve minimal targeted carcinogenic risk levels, this indicator can be a risk level equal to $1\cdot10^{-6}$; if our target is reduction in non-carcinogenic risks, the target indicator is HI = 1.0).

Discussion. Activities performed by Rospotrebnadzor within its authorities, including those outlined by the 'Clean Air' Federal project, are aimed at making environmental protection be largely guided by public health indicators. This approach, while not being limited to reducing emissions made by specific economic entities, seems to be able to provide solutions to the whole set of strategic tasks set within the National projects such as creating a comfortable living environment, providing public health protection and an increase in life expectancy at birth in Russia [11, 12].

Use of health risks and health harm as indicators for managing ambient air quality fully corresponds to the recommendations issued by the World Health Organization [15–17] and to the best world practices [18]. Moreover, such approaches give much more social significance to implemented actions and make population much more satisfied with activities performed by authorities and businesses [19, 20].

At the same time, implementation of these approaches requires the following:

– systemic interdepartmental interaction at the stage when action plans and / or programs aimed at ambient air protection are being analyzed on a given territory;

– making businesses more socially responsible since achieving permissible (acceptable) risk levels may require more profound and effective measures aimed at reducing emissions than achieving maximum permissible concentrations of certain chemicals or established summation groups. This concerns even chemicals with their long-term (average annual) MPC established considering health risk indicators.

– constant monitoring of actual ambient air quality. The latter is due to the fact that calculated data are far from always being highly convergent with data obtained by field measurements [21, 22]. In some cases, calculated values can be higher than actual measured ones. This leads to excessive expenses on ambient air protection, which hardly brings any economic benefits. In cases, when calculated ground concentrations are lower than measured ones, quotas and reductions in emissions may fail to provide safe levels both as per MPC and permissible health risks.

– predictive analysis of plans and / or programs of environmental protection activities by Rospotrebnadzor experts in order to develop recommendations on their improvement taking into account public health risks and health harm.

Conclusions. We have suggested the fundamental algorithm for identifying a list of priority pollutants and a list of objects for setting emission quotas, as well as for substantiating optimal regulatory impacts to mitigate airborne public health risks. Its major stages involve health risk assessment relying on data of aggregated dispersion calculations; identifying contributions made by chemicals and objects and emission sources to impermissible health risks; calculating recommended values of reductions in emissions of priority pollutants by priority objects.

We suggest ranking chemicals as priority pollutants in case their registered levels are higher than average annual or single maximum MPC according to the results of dispersion calculations and they in total account for not less 95 % of contributions to unacceptable health risks for critical organs and systems at least at one calculation point on a given territory.

Priority objects are those that are responsible for not less than 95 % of unacceptable health risks and violations of the established hygienic standards.

The Sanitary Service should be provided with tools that do not replace the order and methodology for setting emission quotas but make it possible to estimate whether environmental protection activities are relevant to the existing health risks. To do that, we have suggested the described method for selecting optimal regulatory impacts as per relevant hygienic indicators, including levels of public health risks.

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