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Research article

PARAMETERIZATION OF RELATIONSHIPS BETWEEN RISK FACTORS AND PUBLIC HEALTH UNDER CHRONIC EXPOSURE TO COMPLEX AMBIENT AIR POLLUTION

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The relevance of the present study follows from the necessity to establish parameterized cause-effect relationships that describe additional disease cases among population caused by chronic exposure to chemical factors.

In this study, our aim was to explore relationships within the 'environment – public health' system to quantify and predict chronic risks under exposure to chemicals in ambient air.

To achieve this, we collected statistical data on some municipalities located in the Russian Federation with different structures and levels of chemical pollution in ambient air. Data on population incidence and ambient air quality were coordinated at places where calculation points were located; these points were centers of residential buildings and their coordinates were applied in the study. Mathematical modeling of the relationships was conducted by using multiple linear regressions. Pollution indicators (chemical concentrations in ambient air) that met the requirements of biological plausibility and statistical significance of pair correlations were selected as independent variables. The obtained regression models contain 190 factors for 36 chemicals occurring in emission into ambient air from stationary and mobile sources, which allow calculating the frequency of additional disease cases for 29 diseases. The established factors make it possible to perform operative estimations of a number of diseases associated with ambient air quality at a place of residence relying on medical aid applications.

The resulting relationships can be used to predict chronic health risks. Establishing criteria for ranking chemical health risks in zones influenced by hazardous chemical objects can become a next step in development of the suggested approaches.

Keywords: *chronic risk, ambient air pollution, chemicals, mathematical modeling, multiple regression, health risk assessment, incidence, additional cases.*

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At the present stage in the society development, the health risk assessment methodology is in great demand at any level of public administration in Russia. When any activities are being planned, health risk assessment gives grounds for identifying the most effective measures aimed at mitigating threats and hazards. When action plans are being implemented, it gives an opportunity to estimate effectiveness of implemented activities. When it comes down to control and surveillance, health risk assessment makes it possible to identify priorities for concentrating the efforts by relevant authorities on objects that create the highest risks for public health [1, 2].

The necessity to perform health risk assessment is fixed by the RF President Order dated March 11, 2019 No. 97 "On Essentials of the state policy in the Russian Federation on providing chemical and biological safety for the period up to 2025 and beyond". This Order is the fundamental ground for the public administration in the sphere of the RF national security [3, 4]. The tasks set by the 'Clean Air' Federal project of the 'Ecology' National project highlight the importance of assessing health risks caused by exposure to chemicals in ambient air. This project (2019–2024) is aimed at improving the environmental situation and reducing pollutant emissions into ambient air.

Development of the health risk assessment methodology poses some challenges; tackling them involves using advanced scientific and methodical approaches that combine some allied sciences such as medicine, physiology, biology, biomechanics, and mathematics. Use of mathematical modeling is a most promising approach for predicting and estimating contributions made by variable factors into health impairment as well as for establishing cause-effect relations.

At present, the most popular methodical approaches within chemical risk assessment include calculation of hazard indexes and hazard quotients (HI and HQ) of chemicals under various administration ways and classification of risk levels. This approach is easy to implement and relevant data for calculations are also easy to obtain. This makes the method the most available for conducing express-estimations of pollution levels in environmental objects and selecting priority risk factors. The approach is widely used in assessing adverse effects produced by ambient air pollution on health of people in settlements [5, 6]; in assessing health risks created by exposure to pollutants for different population groups [7–9]; in estimating and mitigating influence exerted by an enterprise on environmental objects [10]; in conducting monitoring studies with their focus on pollution in ambient air, water, soils, etc. [11–13]; in urban development and organization of environmental protection; as well as in estimating effectiveness of activities aimed at providing sanitary-epidemiological wellbeing of the population. The method adequacy for health risk assessment is confirmed by its wide prevalence both in Russian and foreign studies [14, 15].

At the same time, our review of available research articles established that calculations and analysis of hazard quotients and indexes did not give an opportunity to quantify such probable negative outcomes for population as additional disease cases [16, 17]. This results in much more narrow range of solvable tasks related to providing chemical and biological safety, public health management and protection, substantiating rehabilitation activities, planning necessary volumes of medical aid rendered to population, predicting expected demographic and economic losses etc.

The methodology for calculating hazard quotients and indexes within risk assessment can be enhanced analytically by introducing certain algorithms. They are based on models describing relationships between environmental factors and negative health outcomes and allow calculating additional likelihood of health disorders associated with exposures to various factors. It is noteworthy, that most published studies with their focus on creating similar relationships address specific cases of effects produced by exposure to a limited number of factors on certain health disorders under specific socioeconomic, weather and climatic and other conditions [18–20].

The methodology for risk evolution modeling involves coordinated use of statistical and analytical models and can be considered one of the most relevant methods for predicting and estimating probable effects produced by environmental factors on public health. This makes it possible to consider effects caused by exposure to heterogeneous factors more comprehensively, including situations when age-related changes should be taken into account. Evolution models give an opportunity to estimate risks that functional disorders would occur in specific organs and systems under present exposure scenarios during the whole lifetime and to analyze contributions made by specific factors and / or their combinations into health risks [21].

By now, multiple studies have established a relation between ambient air pollution and growing incidence of respiratory diseases, diseases of the digestive organs, circulatory system, nervous system, etc., for various population groups, the most sensitive included [22–25]. If we generalize the available materials, we can spot out several limitations of formalized relationships described in research articles. Research results are not repeatable, highly localized and generalized rather poorly for possible use to solve variable tasks. Also, practically all the relationships or their quantitative parameters have not been fixed in regulatory or methodical documents on health risk assessment. Most relationships or their models require further investigations to be applied correctly in risk assessment; a significant share of such relationships were obtained in 1980ties and are not relevant for the current technical and technological development, social sphere, pollution levels in environmental objects, and development of public institutions as regards environmental control and environmental quality and public health management.

In this study, our aim was to examine relationships within the 'environment – public health' system to quantify and predict chronic risks under exposure to chemicals in ambient air.

Materials and methods. The study relied on systemic and statistical analysis. Mathematical models to describe relationships were built by using multiple linear regressions.

We made several basic hypotheses when planning the present study:

– influence exerted by chemical pollution in environmental objects on public health is determined only by levels of the analyzed factors (chemical concentrations or their doses) and combined exposure to any other influencing factors is neglected;

– the additivity property is applied under combined exposure to several chemical factors and their influence on one specific health indicator and any effects able to reinforce or weaken influences exerted by specific chemicals under occurrence of other chemicals are neglected.

To solve the task, we collected statistical data on several large municipalities located in the Russian Federation. Chemical pollution in environmental objects was different in them as per its stricture and levels of chemicals. This condition allowed necessary differentiation in sampling data as regards lists of chemicals and pollution levels for correct statistical modeling.

The modeling procedure involved collecting, preparing and analyzing data on six municipalities over the three-year period from 2019 to 2021 (Perm, Krasnoyarsk, Norilsk, Bratsk, Chita and Shelekhov). We collected the following data on the listed municipalities:

a) data on chemical concentrations in ambient air obtained at the posts belonging to the Centers for Hydrometeorology and Environmental Monitoring (Rosgidromet);

b) data on chemical concentrations in ambient air obtained at the social and hygienic monitoring posts (Rospotrebnadzor);

c) data on pollutant emissions from stationary and mobile sources taken from the aggregated data collections on maximum permissible emissions (Rosprirodnadzor);

d) data on medical aid applications taken from the registers of paid disease cases (regional offices of the Fund for Obligatory Medical Insurance);

e) data on points where residential areas were located within the analyzed municipalities with location 'binding'.

All the data were taken from official sources, coordinated and combined into electronic tables to make them eligible for further relationship modeling procedures.

Data on population incidence and ambient air quality were coordinated at places where calculation points were located; these points were centers of residential buildings and their coordinates were applied in the study. To coordinate and prepare data on ambient air quality, the following operations were accomplished:

– data taken from the location register of electronic maps were actualized and coordinates of the centers of polygons in the 'Buildings and Constructions' layer were identified;

– dispersion of chemicals emitted by stationary and mobile sources was calculated at the selected calculation points that were centers of residential buildings;

– results obtained by calculating dispersion were verified as per data of laboratory control performed at control points;

– verified data for all the analyzed territories were coordinated.

Dispersion of chemicals was calculated according to the methodology MRR 2017 with the 'Ekolog-Gorod' unified program for calculating ambient air pollution, version 4.60.1.

The results obtained by calculating chemical dispersion were verified in accordance with the methodical guidelines MR 2.1.6.0157-19 'Creation of the programs for surveillance over ambient air quality and quantification of population exposure within social-hygienic monitoring', approved by the Head of the Federal Service for Surveillance over Consumer Rights Protection and Human Wellbeing, the RF Chief Sanitary Inspector on December 02, 2019. According to the aforementioned procedure, the results obtained by calculating ground levels of chemicals at the calculation points on each territory (the points were located within residential areas) were verified by data obtained by field observations at the posts for monitoring of ambient air quality (they were corrected by approximating conformity factors of calculated and field data at the monitoring points). A major condition here was that both calculated and field data were available for a given territory.

When verifying calculated data obtained on various territories, we had to analyze several possible situations regarding specific chemicals:

a) in case there were no field data on some chemicals on all the analyzed territories, they were completely excluded from the modeling;

b) in case there were no calculated data for some chemicals, but their levels were measured by laboratory control at the control points, we approximated their levels in residential areas by applying the backward distance method;

c) in case some chemicals were not measured with laboratory tests but there were calculated data regarding their dispersion, verification was accomplished with using an averaged conformity factor at the control points on other territories.

Coordination of the verified chemical concentrations for all the territories involved creating a joint electronic table. It contained data on levels of all the selected chemicals with binding to territory identifiers and residential areas. As a result, 48 chemicals were selected for constructing relationships. We should note that cause-effect relations can be detected and later applied only at the stage when a model is determined; therefore, it is important to analyze distribution of ambient air pollution indicators. Table 1 provides basic data on distribution of chemical levels on the analyzed territories. These parameters were applied for relationship modeling.

Data on population incidence with binding to the calculation points on the analyzed territories were prepared by using depersonified information on the number of insured people and their medical aid applications. This information was provided by regional offices of the Fund for Obligatory Medical Insurance.

Table 1

Distribution of chemical levels applied in mathematical modeling

Chemical	Concentration, mg/m^3				
	Minimum	25th percentile	Median	75th percentile	Maximum
Nitrogen (II) oxide (Nitrogen oxide)	0	0.009	0.013	0.019	0.167
Nitrogen dioxide (Nitrogen (IV) oxide)	0	0.015	0.024	0.033	0.238
Ammonia	0	0.010	0.016	0.021	1.413
Benz(a)pyrene	0	0	0.109	0.400	5.759
Benzene	7.86E-06	9.06E-04	2.09E-03	0.005	1.636
Particulate matter	0.005	0.055	0.079	0.125	1.767
Particulate matter PM_{10}	0	0	0	0.040	0.267
Particulate matter $PM_{2.5}$	0	0	0	0.018	0.251
Hydroxybenzene (Phenol)	9.87E-06	5.11E-04	9.80E-04	1.72E-03	1.101
Hydrogen chloride	0	3.88E-03	0.011	0.025	0.515
Dialuminum trioxide (recalculated as per aluminum)	0	8.88E-05	1.24E-04	1.95E-04	0.02
Dihydrosulfide (Hydrogen sulphide)	5.5E-05	3.47E-04	5.86E-04	1.73E-03	0.38
Dimethyl benzene (Xylene)	0	1.09E-03	3.86E-03	0.010	0.645
Cadmium oxide (recalculated as per cadmium)	0	0	0.01	0.01	0.01
Cobalt oxide (recalculated as per cobalt)	0	0	0	0	1.59E-04
Manganese and its compounds (recalculated as per manganese (IV) oxide)	2E-06	5.33E-05	0.013	0.033	0.224
Copper (II) oxide (recalculated as per copper)	2.3E-06	4.39E-05	0.012	0.059	9.213
Methylbenzene (Toluene)	3.3E-05	1.10E-03	3.56E-03	9.67E-03	0.243
Methyl mercaptan	0	1.66E-08	7.73E-07	1.94E-06	8.32E-04
Nickel oxide (recalculated as per nickel)	2.25E-06	4.04E-05	1.95E-03	0.018	0.255
Ozone	0	0	0	1.08E-03	0.149
Prop-2-enenitrile	0	3.26E-05	5.14E-05	1.02E-03	0.073
Lead and its non-organic compounds (recalculated as per lead)	5.18E-08	7.70E-06	3.87E-03	0.012	0.17
Sulfur dioxide (Sulfuric anhydride)	2.29E-04	8.90E-04	1.56E-03	0.008	0.696
Sulfuric acid	0	0	0	3.06E-04	0.161
Tetrachloroethylene	0	0	0	6.56E-03	0.46
Trichloroethylene	0	0	0	0.025	46.665
Carbon (Soot)	1.63E-03	0.829	1.205	2.207	34.059
Carbon oxide	0.053	0.422	0.548	0.998	15.520
Formaldehyde	0	3.00E-03	6.91E-03	0.01167	0.104
Poorly soluble non-organic fluorides	0	0	0	3.17E-03	0.04
Gaseous fluoride compounds (recalculated as per fluorine)	3.54E-06	1.27E-03	1.92E-03	3.94E-03	0.043
Chlorobenzene	0	0	0	1.00E-04	4.00E-04
Chromium (hexavalent chromium) (recalculated as per chromium (VI) oxide)	4.48E-07	1.11E-05	4.34E-03	0.021	0.097
Zinc	0	2.05E-03	0.09	0.16433	0.322
Ethylbenzene	0	1.00E-03	2.12E-03	5.65E-03	31.436

The obtained data were 'bound' to location registers of electronic maps of the analyzed territories and differentiated as per age groups (children aged 0–17 years, people of working age, elderly people beyond working age) and classes and groups of diseases as well as specific diseases.

A preliminary biomedical examination made it possible to create a list of 43 priority diseases and their groups; they were considered probable health outcomes as a response to negative effects produced by chemical pollutants in ambient air. It also gave an opportunity to fill the 'factor – response' expert matrix with relevant data. The examination was performed by 11 experts specializing in hygiene and epidemiology as well as Candidates and Doctors of Medical and Biological Sciences with work records in the sphere being longer than 15 years. The examination was conducted in three stages. The first stage involved creating a list of diseases and their groups; it was done by experts resorting to their available experience during a group meeting. At the second stage, each expert filled in the 'factor – response' matrix independently relying on analysis of relevant Russian and foreign literature sources. The score '1' was put in case there was a potential relationship between a chemical pollutant in ambient air and a disease; otherwise, the score '0' was put. The third stage was a group discussion when all the individual expert scores were discussed and the ultimate matrix was filled (by the majority of votes). It is noteworthy that any expert could change his or her opinion during the final voting if persuaded to do so by other experts' arguments or literature sources provided by them.

Two coordinated data arrays were created by preparing all the relevant data for construction of relationships:

1) verified average annual levels of chemicals at the calculation points on the analyzed territories;

2) relative frequency of people's applications for medical aid in residential areas (the calculation points) for three age groups as per selected diseases.

Relationship modeling to quantify chronic health risks was based on all the collected and prepared data and involved accomplishing the following tasks:

– to construct a matrix of possible (probable) relationships between chemical factors and incidence rates (the biological plausibility matrix) according to expert scores and known pathogenetic regularities;

– to create and analyze correlations between chemical factors and health disorders, to identify statistically authentic correlations;

– to formalize and parameterize relationships relying on multiple linear regression analysis.

The correlation analysis relied on calculating Pearson's correlation coefficients and testing statistical hypotheses to identify authenticity of differences with Student's t-test. Modeling was conducted separately for each dependent variable (incidence as per a group of diseases or a specific disease). Pollution indicators (levels of chemicals in ambient air) were taken as independent variables in case they were biologically plausible and met the requirements as per statistical authenticity of pair correlations.

The modeling process itself involved examining models that described cause-effect relations by using multiple linear regression analysis as per the following formula (1):

$$z = a_0 + \sum_i a_i x_i \,, \qquad (1)$$

where z is relative frequency of a disease, cases/100,000;

x_i is a level of exposure to the i-th chemical factor;

a_0, a_i are model parameters.

A step-by-step procedure was developed to build multiple regression models. It entailed exclusion of summands with negative regression coefficients from the complete model for each dependent variable (obtained with multiplicity of selected independent variables). These summands were excluded due to nonconformity with the accepted hypotheses. The applied algorithm made it possible to obtain models with only positive coefficients included in them; this means that these models consider only negative effects produced on health by chemical pollutants in ambient air.

We created a script in the *R-studio* environment to automate the procedure for constructing relationship models since it involved an inspection with using statistical and biological indicators and multiple regression analysis is iterative in its essence.

Results and discussion. In this study, we analyzed approximately 6.3 thousand pair relationships between frequency of medical aid applications by different age groups (children, people of working age, elderly people beyond working age) and levels of chemical in ambient air on the analyzed territories. Based on them, we built 56 multiple regression models that were statistically authentic and biologically plausible. Since standard and measured levels of various chemicals in ambient air can differ considerably (by several orders of magnitude), the model coefficients also have values that differ significantly. Therefore, Table 2 provides parameters of the obtained multiple regression models a_i for each age group that are adjusted as per a unit of the reference concentration (RFC, mg/m^3) for chronic inhalation exposure[10]

The regression models obtained by modeling the relationships within the 'environment (levels of chemical in ambient air) – health (incidence)' system contain 190 coefficients for 36 chemicals occurring in emissions into ambient air from stationary and mobile sources. These coefficients make it possible to calculate frequency of additional cases for 29 various diseases. Coefficients presented in the tables have certain dimensionality that corresponds to relative frequency of additional medical aid applications during one year (cases per 100,000 people) per a change in levels of chemicals in ambient air by one unit of the reference concentration (RFC, mg/m^3) for chronic exposure. When using the obtained formal relationships and model coefficients for health risk assessment and analysis, we should bear in mind several limitations and uncertainties arising in the process. Basic limitations of using the modeling results are as follows: the obtained models have a limited range of definition and exposure parameters for some chemicals in ambient air and health outcomes in population have not been estimated statistically.

When factor values go beyond the model range of definition, we should remember that the process linearity might be disrupted towards its intensification. In this case, when the obtained coefficients are used, calculations of the corresponding risks may yield understated results. The aforementioned facts do not eliminate the possibility to extrapolate the obtained relationships beyond the range of definition (towards its increase); still, when interpreting the results of risk calculations, one should treat them as the lower estimation limit.

There are several uncertainties that should be considered when developing the risk assessment methodology. They include the following:

– the constructed models are liner in their essence;

– errors are accumulated when calculations are performed beyond the model range of definition;

– the territories have not been covered in full when preparing data for the modeling;

– different programs for laboratory control of ambient air quality are used on the analyzed territories.

Despite the considerable number of uncertainties and limitations that occurred during the modeling process, the obtained coefficients give an opportunity to perform operative estimations of a number of diseases associated with ambient air quality in residential areas relying on medical aid applications. The obtained relationships can also be used to predict chronic health risks by substituting relevant predicted levels of exposure to factors into the formula (1). The formal relationships described in this work give grounds for developing and implementing methods for chronic health risk assessment.

[1] 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 the RF Chief Sanitary Inspector on March 5, 2004). *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200037399 (October 17, 2022) (in Russian).

Table 2

Parameters of the models describing 'environment (levels of chemical in ambient air) – health (incidence)' relationships, cases per 100,000 people per a unit of the reference concentration (RFC, mg/m^3)

Group of diseases (ICD-10 codes)	Chemical	Children	Working age	Beyond working age
Disorders of conjunctiva (H10, H11)	Trichloroethylene	0.46	1.14	
	Formaldehyde	159.79	73.93	37.70
Certain disorders involving the immune mechanism (D80, D81, D82, D83, D84, D86, D89)	Zinc	2.87	0.44	0.47
Arthrosis (M15–M19)	Fluorides*		2978.39	1288.28
Deforming dorsopathies (M40–M43)	Fluorides *		6242.21	4679.50
Other dorsopathies (M50–M54)	Fluorides *		2589.20	4162.21
	Gaseous fluorides*			1376.33
Diseases of myoneural junction and muscle (G70–G73)	Manganese and its compounds*		0.06	
Demyelinating diseases of the central nervous system (G35–G37)	Hydroxybenzene (Phenol)		51.83	
	Manganese and its compounds*		0.04	0.12
	Methylbenzene (Toluene)		117.33	1235.86
	Lead and its compounds*		2.13	1.31
	Tetrachloroethylene		71.97	
Other degenerative diseases of the nervous system (G30–G32)	Benzene			2.70
	Hydroxybenzene (Phenol)			2.29
	Dimethyl benzene (Xylene)			13.12
	Tetrachloroethylene			4.96
	Trichloroethylene			0.07
Other disorders of the nervous system (G90–G99)	Manganese and its compounds*	2.46		1.49
	Tetrachloroethylene	885.92		
Polyneuropathies and other disorders of the peripheral nervous system (G60–G64)	Manganese and its compounds*	0.06		
Cerebral palsy and other paralytic syndromes (G80–G83)	Tetrachloroethylene	527.71		
Episodic and paroxysmal disorders (G40–G47)	Tetrachloroethylene	648.11	372.81	
Other diseases of upper respiratory tract (J30, J31, J32, J34, J35, J37)	Nitrogen (II) oxide		793.42	709.29
	Nitrogen dioxide	1667.65	692.41	281.97
	Particulate matter	25.09	7.29	
	Particulate matter $PM_{2.5}$			2.10
	Hydroxybenzene (Phenol)	1514.42	404.60	
	Dihydrosulfide	13.97		
	Dimethyl benzene (Xylene)	457.03		
	Manganese and its compounds*		0.55	
	Methyl mercaptan	6809.72		
	Nickel oxide *		0.14	
	Ozone	6363.46	1295.37	406.06
	Carbon (Soot)	1.83	4.52	7.82
	Fluorides *	462.31	809.60	964.30
Acute upper respiratory infections (J00, J01, J02, J03, J04, J05)	Nitrogen (II) oxide		1015.42	1426.06
	Nitrogen dioxide	4446.44	110.04	
	Particulate matter	5036.79	307.21	329.62
	Particulate matter $PM_{2.5}$	1511.14		
	Hydroxybenzene (Phenol)	9252.80	1083.52	47.07

End of the table 2

Group of diseases (ICD-10 codes)	Chemical	Children	Working age	Beyond working age
	Hydrochloride		142.53	722.86
	Cadmium oxide*		2.65	
	Cobalt oxide *		781.06	936.20
	Methylbenzene (Toluene)		3320.82	
	Ozone			1957.86
	Prop-2-enenitrile	2355.55		
	Sulfur dioxide	17510.12		72.92
	Carbon (Soot)	296.52	9.23	5.82
	Formaldehyde	1770.93		
	Fluorides *			305.56
	Zinc		1.99	
Pneumonia, organism unspecified (J18)	Nitrogen (II) oxide	1260.76		
	Particulate matter		3.86	3.87
	Particulate matter PM_{10}		93.85	120.92
	Particulate matter $PM_{2.5}$		110.87	71.41
	Hydroxybenzene (Phenol)	240.28		
	Hydrochloride	22.73		27.20
	Cobalt oxide *		812.75	612.30
	Copper (II) oxide *		0.02	0.01
	Nickel oxide *	0.40		0.14
	Prop-2-enenitrile	98.62	30.82	38.74
	Sulfur dioxide			29.44
	Formaldehyde			13.37
	Gaseous fluorides *		344.32	384.01
	Zinc	1.25		
Chronic lower respiratory diseases (J40, J41, J42, J44.1, J44.8, J44.9, J45, J46)	Nitrogen (II) oxide	703.75		
	Nitrogen dioxide	12.93		
	Ammonia	127.48		
	Particulate matter	128.09		
	Hydroxybenzene (Phenol)	188.99	2248.89	
	Hydrochloride	51.03		
	Dialuminum trioxide *	73.34		
	Dimethyl benzene (Xylene)	201.68		
	Methylbenzene (Toluene)	991.40		
	Nickel oxide *		0.21	
	Sulfuric acid	16.86		
	Formaldehyde	87.20		
	Fluorides *	168.23		
	Chromium *		1.05	
	Zinc		12.41	
Glomerular diseases (N00–N08)	Hydroxybenzene (Phenol)		155.81	
	Cadmium oxide *	0.30	0.21	
	Trichloroethylene		0.25	
	Ethylbenzene		45.90	
Other disorders of kidney and ureter (N25, N28)	Dimethyl benzene (Xylene)			2.17
	Cadmium oxide *	0.01		
	Chlorobenzene	339.13		234.45
	Ethylbenzene	7.72		
Renal failure (N17, N18, N19)	Hydroxybenzene (Phenol)	0.50	10.17	
	Dimethyl benzene (Xylene)		8.68	
	Trichloroethylene	0.00		

End of the table 2

Group of diseases (ICD-10 codes)	Chemical	Children	Working age	Beyond working age
Renal tubulo-interstitial diseases (N10, N11, N12, N13, N14, N15)	Hydroxybenzene (Phenol)	143.68		
	Dimethyl benzene (Xylene)	158.03		
	Cadmium oxide *	0.47		
	Lead and its compounds*	1.37		
	Chlorobenzene		9043.25	
	Ethylbenzene		8.10	
Congenital malformations, deformations and chromosomal abnormalities	Benz(a)pyrene	0.004		
	Lead and its compounds*	69.38		
	Trichloroethylene	9.52		
Hypertensive diseases (I10, I11, I12, I13)	Particulate matter PM_{10}		5150.12	60.71
	Particulate matter $PM_{2.5}$		868.02	88.42
	Hydroxybenzene (Phenol)		5437.70	104.95
	Carbon oxide		4531.99	863.09
Other forms of heart disease (I30.0, I30.8, I30.9,I31, I33, I34, I35, I36, I37, I38, I40.1, I40.8, I40.9, I42, I45, I49, I50)	Hydroxybenzene (Phenol)			0.02
	Carbon oxide			2.07
Other and unspecified disorders of the circulatory system (I95.0, I95.8, I95.9, I99)	Benzene			0.18
	Particulate matter PM_{10}	14.41		0.21
	Particulate matter $PM_{2.5}$	5.08		0.04
	Carbon oxide	1.97		
Ischaemic heart diseases (I20, I21, I22, I24.0, I24.8, I24.9, I25)	Benzene			43.61
	Particulate matter $PM_{2.5}$			40.24
	Hydroxybenzene (Phenol)			30.00
	Carbon oxide			443.08
Aplastic and other anaemias (D60–D64)	Nitrogen dioxide	37.97		
	Nickel oxide *		0.05	
	Lead and its compounds*	0.07	0.46	
	Zinc	0.75		
Other diseases of blood and blood-forming organs (D70, D71, D72.1, D72.8, D72.9, D74.8, D74.9, D75.8, D75.9)	Nitrogen (II) oxide		45.78	0.26
	Nitrogen dioxide			43.39
	Benzene		0.22	
	Nickel oxide *	0.02		
	Lead and its compounds*	0.70		
	Carbon oxide		73.25	60.61
	Chlorobenzene	7486.82	3279.83	
Purpura and other haemorrhagic conditions (D69.0; D69.1, D69.2, D69.4, D69.6, D69.8, D69.9)	Lead and its compounds*	1.33		
Endocrine, nutritional and metabolic disorders	Cadmium oxide *		9.36	
	Lead and its compounds*	11.45	20.63	
	Trichloroethylene	6.46		

N o t e : *some chemicals were given shortened denominations in the table; the full ones are: Poorly soluble non-organic fluorides, Gaseous fluoride compounds (recalculated as per fluorine), Manganese and its compounds (recalculated as per manganese (IV) oxide), Lead and its non-organic compounds (recalculated as per lead), Cadmium oxide (recalculated as per cadmium), Cobalt oxide (recalculated as per cobalt), Copper (II) oxide (recalculated as per copper), Nickel oxide (recalculated as per nickel), Dialuminum trioxide (recalculated as per aluminum), Chromium (hexavalent chromium) (recalculated as per chromium (VI) oxide).

Conclusion. The present study has enhanced our knowledge on quantitative characteristics of influence exerted by chemical pollution in ambient air on public health. It has also given a certain insight into how they can be applied in future when assessing and predicting health risks without abandoning the existing methods that are being actively used at present. To obtain the maximum objective models of the relationships, we collected relevant data on ambient air quality in residential areas on several territories in our country. These territories differ considerably both in their geography and frequency of detected diseases. The required relationships have been modeled based on the collected and systematized data; as a result, we build 56 multiple regression models for chronic exposure.

The table with model coefficients for the obtained relationships is the major result of this study. These coefficients describe how intensively health disorders develop under exposure to chemical pollution in ambient air; they have been obtained within the hypothesis that influence on the model ranges of definition is linear. It is noteworthy that it seems hardly possible to consider all the uncertainties within the present study; still, this can become possible in future. The results of this study can provide a basis for further research with its focus on modeling cause-effect relations between ambient air pollution and public health. This research may rely on more complicated and enhanced system of initial data as well as on more complicated and enhanced relationship models. Establishing criteria for ranking chemical health risks in zones influenced by hazardous chemical objects can become a next step in development of the suggested approaches.

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References

1. Zaytseva N.V., Popova A.Yu., May I.V., Shur P.Z. Methods and technologies of health risk analysis in the system of state management under assurance of the sanitation and epidemiological welfare of population. *Gigiena i sanitariya*, 2015, vol. 94, no. 2, pp. 93–98 (in Russian).

2. Gurvich V.B., Kuzmin S.V., Dikonskaya O.V., Gileva M.A., Boyarsky A.P. Methodical approaches, experience and perspectives of the implementation of the risk model of surveillance activities in the sphere of the assurance of sanitary and epidemiological welfare of population, population's health risk management and the consumer rights protection. *Gigiena i sanitariya*, 2015, vol. 94, no. 2, pp. 104–108 (in Russian).

3. Zaytseva N.V., Popova A.Yu., Onishchenko G.N., May I.V. Current problems of regulatory and scientific-medical support for the assurance of the sanitary and epidemiological welfare of population in the Russian Federation as the strategic government task. *Gigiena i sanitariya*, 2016, vol. 95, no. 1, pp. 5–9. DOI: 10.18821/0016-9900-2016-95-1-5-9 (in Russian).

4. Onishhenko G.G., Kozovenko M.N. Ensuring the chemical and biological safety of the Russian Federation for the period up to 2025 and beyond COVID-19. *Infektsionnye bolezni: novosti, mneniya, obuchenie*, 2020, vol. 9, no. 3 (34), pp. 10–15. DOI: 10.33029/2305-3496-2020-9-3-10-15 (in Russian).

5. Anan'ev V.Yu., Zhigaev D.S., Kislitsyna L.V., Kiku P.F. Otsenka vliyaniya atmosfernogo vozdukha na zdorov'e naseleniya Vladivostoka i ee osobennosti [Assessment of the impact of ambient air on the health of the population of Vladivostok and its features]. *Zdorov'e. Meditsinskaya ekologiya. Nauka*, 2012, vol. 49–50, no. 3–4, pp. 79–82 (in Russian).

6. Berezhnaya E.V. Assessment of risk to human health in Voronezh exposure to chemical pollutants in the air. *Modelirovanie, optimizatsiya i informatsionnye tekhnologii*, 2013, vol. 1, no. 1, pp. 2 (in Russian).

7. Masnavieva L.B., Efimova N.V., Kudaeva I.V. Individual risks to adolescent health, caused by contaminating the air, and their relationship with the levels of specific autoantibodies. *Gigiena i sanitariya*, 2016, vol. 95, no. 8, pp. 738–742. DOI: 10.18821/0016-9900-2016-95-8-738-742 (in Russian).

8. Sheveleva T.E. Assessment and minimization of non-carcinogenic risk for health workers of rubber goods on chemicals exposure polluting of working spaces. *Vestnik novykh meditsinskikh tekhnologii (Elektronnyi zhurnal)*, 2016, no. 4, pp. 241–247. DOI: 10.12737/22054 (in Russian).

9. Grigoriev Yu.I., Lyapina N.V. The impact of air quality on the health of the child population. *Vestnik novykh meditsinskikh tekhnologii*, 2012, vol. 19, no. 4, pp. 112–113 (in Russian).

10. Krupskaya L.T., Rastanina N.K. Otsenka riska dlya zdorov'ya naseleniya, svyazannogo s zagryazneniem atmosfernogo vozdukha v raione khvostokhranilishcha TsOF Solnechnogo GOKa [Assessment of the population health risk associated with ambient air pollution in the area of the COF Solnechnii GOK tailing damn]. *Gornyi informatsionno-analiticheskii byulleten'*, 2007, no. S15, pp. 318–323 (in Russian).

11. Konshina L.G., Lezhnin V.L. Assessment of the quality of drinking water in the industrial city and risk for public health. *Gigiena i sanitariya*, 2014, vol. 93, no. 3, pp. 5–10 (in Russian).

12. Kiku P.F., Kislitsyna L.V., Bogdanova V.D., Sabirova K.M. Hygienic evaluation of the quality of drinking water and risks for the health of the population of the Primorye territory. *Gigiena i sanitariya*, 2019, vol. 98, no. 1, pp. 94–101. DOI: 10.18821/0016-9900-2019-98-1-94-101 (in Russian).

13. Tsareva S.A., Krasnova V.P., Gryaznova M.V. Role of estimation of exposure of chemical contaminants polluting foodstuffs in environmental safety research. *Ekologiya cheloveka*, 2013, no. 6, pp. 26–32 (in Russian).

14. Bhandari G., Zomer P., Atreya K., Mol H.G.J., Yang X., Geissen V. Pesticide residues in Nepalese vegetables and potential health risks. *Environ. Res.*, 2019, vol. 172, pp. 511–521. DOI: 10.1016/j.envres.2019.03.002

15. De Lima N.V., Granja Arakaki D., de Padua Melo E.S., Machate D.J., do Nascimento V.A. Assessment of Trace Elements Supply in Canned Tuna Fish Commercialized for Human Consumption in Brazil. *Int. J. Environ. Res. Public Health*, 2021, vol. 18, no. 22, pp. 12002. DOI: 10.3390/ijerph182212002

16. Kukkoev S.P., Nikishina T.F., Nikolaevich P.N. The effect of air pollution in the city of Krasnodar on health. *ZniSO*, 2017, vol. 292, no. 7, pp. 22–25 (in Russian).

17. Golikov R.A., Kislitsyna V.V., Surzhikov D.V., Oleshchenko A.M., Mukasheva M.A. Assessment of the impact of air pollution by heat power plant emissions on the health of the population of Novokuznetsk. *Meditsina truda i promyshlennaya ekologiya*, 2019, vol. 59, no. 6, pp. 348–352. DOI: 10.31089/1026-9428-2019-59-6-348-352 (in Russian).

18. Plotnikova I.A., Kovtun O.P., Anokhina L.A. Clinical and hematologic abnormalities in children health, caused by exposure to lead. *Meditsina truda i promyshlennaya ekologiya*, 2010, no. 2, pp. 29–35 (in Russian).

19. Kopytenkova O.I., Levanchuk A.V., Tursunov Z.Sh. Assessment of health damage due to exposure to mineral wool fine dusts. *Kazanskii meditsinskii zhurnal*, 2014, vol. 95, no. 4, pp. 570–574 (in Russian).

20. Petrov S.B. Ekologo-gigienicheskaya otsenka zabolevaemosti naseleniya raiona razmeshcheniya medeplavil'nogo proizvodstva [Ecological and hygienic assessment of the morbidity of the population of the area where the copper smelting production is located]. *Vyatskii meditsinskii vestnik*, 2006, no. 3–4, pp. 56–60 (in Russian).

21. Zaitseva N.V., Trusov P.V., Shur P.Z., Kiryanov D.A., Chigvintsev V.M., Tsinker M.Yu. Methodical approaches to health risk assessment of heterogeneous environmental factors based on evolutionary models. *Health Risk Analysis*, 2013, no. 1, pp. 15–23. DOI: 10.21668/health.risk/2013.1.02.eng

22. Kiku P.F., Veremchuk L.V., Tatarkina N.D. Structural model of habitat factors influence on the prevalence of respiratory diseases in Primorsky krai. *Byulleten' fiziologii i patologii dykhaniya*, 2012, no. 43, pp. 107–111 (in Russian).

23. Gorbanev S.A., Sarkisyan F.S., Devyatkina A.A., Redchenko A.V., Radilov A.S., Kombarova M.Y. Ecological and hygienic analysis of the impact of pollutant chemicals of industrial enterprises in Tikhvin on health. *Profilakticheskaya i klinicheskaya meditsina*, 2012, vol. 43, no. 2, pp. 68–71 (in Russian).

24. Sazonova O.V., Isakova O.N., Sukhacheva I.F., Komarova M.V. Habitat and incidence of respiratory organs diseases in the Samara population. *Gigiena i sanitariya*, 2014, vol. 93, no. 4, pp. 33–36 (in Russian).

25. Golikov R.A., Surzhikov D.V., Kislitsyna V.V., Shtaiger V.A. Influence of environmental pollution to the health of the population (review of literature). *Nauchnoe obozrenie. Meditsinskie nauki*, 2017, no. 5, pp. 20–31 (in Russian).

Kiryanov D.A., Kamaltdinov M.R., Tsinker M.Yu., Babina S.V., Kleyn S.V., Andrishunas A.M. Parameterization of relationships between risk factors and public health under chronic exposure to complex ambient air pollution. Health Risk Analysis, 2022, no. 4, pp. 33–44. DOI: 10.21668/health.risk/2022.4.03.eng

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