Environmental diseases as an indicator of air pollution

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Abstract. The article is devoted to the calculation and spatial analysis of the impact levels on the anthropogenic environment as an indicator of atmospheric air pollution in Krasnoyarsk. The population lives in conditions of exceeding the standards of environmental pollution for 26 substances (from 516 maximum one-time MAC to 132 MAC daily average). The additive effect of chemicals creates a high level of risk in relation to the population in certain areas of the city. The established levels of aerogenic exposure cause about 80.9 thousand additional cases of diseases of the entire population per year (71.0 cases per 1000 people), which is 4.15% of the actual incidence rate. The priority diseases of the entire population associated with the quality of atmospheric air are diseases of the circulatory system (52.8%), the musculoskeletal system and connective tissue (18.6%), digestive system (14.1%), genitourinary system (7.7%), and the respiratory system (7.7%). The foreground factors determining the formation of the established level of complementary incidence rate associated with atmospheric air quality are 23 chemical substances. The obtained results (zones and factors) can be applied to assess the effectiveness and efficiency of implemented measures to improve the atmospheric air condition.

1. Introduction. Problem statement
An indispensable condition for the sustainable development of human society is to ensure the environment safety. Currently, “sustainable development” is the evolution of civilization, which occurs within the framework of permissible impacts on the biosphere [1, 2].

Numerous scientific studies show that human health is determined by the complex interaction of a number of factors: heredity, lifestyle and quality of life (socio-economic and psychological well-being, availability and quality of medical care, lifestyle and bad habits, etc.), as well as the environment habitat [3–10]. Consequently, environmental conditions being risk factors and an essential determinant of health significantly increase the probability of disease occurrence among the population. According to the WHO and the latest estimates of the environmental factors contribution to health status, from 13 to 20% of the burden of disease in Europe can be attributed to them [11, 12]. About 4% is the contribution of sanitation and hygiene to the burden of disease, measured in disability-adjusted life years (DALY) [13].

According to the analytical data of the State reports “On the condition of sanitary and epidemiological well-being of the population in the Russian Federation” [4], the priority sanitary and epidemiological factors of the environment that form medical and demographic losses are: chemical pollution of atmospheric air and drinking water, as well as physical factors of influence (noise, vibration, ultrasound, infrasound, etc.). According to domestic epidemiological studies, about 5.5-10
2 million additional cases of diseases were associated with the harmful effects of external factors caused by the environment abnormal quality over the past 10 years in the Russian Federation. To date, more than 60% of the population of the Russian Federation lives in conditions in which the facts of the environment unsatisfactory state are established by regulatory authorities.

If a person can, to a certain extent, regulate the impact of particular risk factors coming with drinking water and food (consumption of purified drinking water of a physiological composition, ecologically wholefood), then atmospheric air is not a controlled object of the habitat from the standpoint of an ordinary inhabitant.

A number of industries and vehicles cause the main pollution of the atmosphere. According to analytical data in State Reports, in 2019 in the Russian Federation, the share of samples exceeding MAC for atmospheric air was 0.59% for urban and 0.53% for rural settlements for maximum one-time concentrations, 0.36% for average daily concentrations. In 2019, the excess of hygienic standards for the pollutant content in the atmospheric air in the territories of urban settlements was more often recorded in places located on highways in the residential construction area (0.87% of samples). The share of samples surpassing hygienic standards was 0.46% in industrial zones. The priority substances that form excessive air pollution in both urban and rural areas of the Russian Federation are suspended solids, carbon oxide, nitrogen dioxide, sulfur dioxide, hydrocarbons and other compounds [14–17].

Nowadays, the federal project “Pure Air” of the national project “Ecology” is being implemented in the Russian Federation [18]. The primary objective of the project is to significantly improve the quality of atmospheric air in cities where the problems of air pollution and the associated risks and damage to the residents’ health are most acute. Systematic monitoring of changes in the quality of atmospheric air based on the outcomes of instrumental studies and computational modeling of the spatial dispersion of impurities, as well as their associated assessment is an urgent task. The population health risk formed by the established exposure levels in priority areas, as well as damage to health in the form of additional cases of diseases associated with atmospheric air quality can be the basis for assessing the effectiveness of measures taken to improve the state of atmospheric air.

The purpose of the study is a spatial assessment of the level of additional associated incidence rate of the population, formed by the quality of atmospheric air, using the example of Krasnoyarsk.

2. Materials and methods
The hypothesis is that emissions from stationary and mobile sources of atmospheric air pollution form the concentrations of pollutants and, subsequently, considering spatial and temporal characteristics, the population exposure levels and the levels of inhalation health risks. Taking into account the risk criteria, chemical substances (risk factors) can form supplementary health disorders (cases of additional incidence rate) of the population associated with the quality of atmospheric air, which are indicators of the realized prior health risk. The levels of incidence rate formed in particular zones and associated with the population density in the given zones, as well as the contribution of risk factors to the incidence rate are able to become an additional criterion for assessing the effectiveness and efficiency of the implemented protection measures for the environment.

The study was carried out on the example of a pilot territory - the city of Krasnoyarsk. The given city annually belongs to the list of priority most polluted industrial cities of the country and is included in the “Pure Air” federal project, which is currently being realized in the Russian Federation [18].

The following steps were sequentially carried out for the spatial assessment of the level of additional associated incidence rate of the population, formed by the quality of atmospheric air: spatial modeling of the chemicals spread in the atmospheric air with the data subsequent verification from instrumental studies; calculation of parameters of the generated inhalation risk to public health; georeferencing of cases of people seeking medical care to the address register of an electronic topographic base (map); a spatial model construction of the distribution of population incidence indicators; parametrization of the system of cause-and-effect relationships between the content of pollutants in the air and indicators of the population incidence rate; computation of indicators of population health disorders associated with exposure to air pollution (associated cases of diseases).
A hygienic assessment of the atmospheric air quality based on the outcomes of instrumental studies was carried out by the virtue of the data from systematic environmental and socio-hygienic monitoring of the atmospheric air quality at 35 observation posts for the period of 2014–2018.

The dispersion calculations were performed from more than 7.9 thousand stationary sources, autonomous heat supply sources and 320 sections of the road network on a regular grid with a step of 200x200 m for 268 substances using the UPAPE software module (Unified Program of Air Pollution Estimation) of “Ecologist-City” (ver. 4.50) with the “Average” calculation block. The obtained results were applied to a cartographic base containing electronic vector layers of city boundaries, buildings and constructions with an address register and sections of the road network.

The calculated data verification with the data of field studies was conducted in accordance with MR 2.1.6.0157-19 [19]. The assessment of the inhalation risk to public health was carried out by means of the verified data in accordance with R. 2.1.10.1920-04 “Guidelines for assessing the risk to public health when exposed to chemicals that pollute the environment” [20].

The procedure for georeferencing the cases of people seeking medical care to the address register of an electronic topographic map was performed according to the data provided by the Territorial Compulsory Medical Insurance Fund of the Krasnoyarsk Territory for 2016-2018 as given in heading codes of ICD-10.

The spatial model construction of the distribution of population incidence indicators was carried out by calculating the indicators of the population incidence rate at each point of the computational grid. Parametrization of the system of cause-and-effect relationships between the incidence rate indicators and air pollution indicators was implemented using methods of statistical modeling of dependencies (multiple regression analysis) pursuant to MR 5.1.0095-14 [21] with the Statistica 10 package. The biological credibility of the model matrix was estimated by means of the risk criteria given in R. 2.1.10.1920-04 [20].

The calculation of indicators of public health disorders associated with exposure to air pollution at each point of the computational grid of residential areas was conducted in conformity with MR 5.1.0095-14 [21]. Concentrations of chemicals at 0.1 $R_{fc}$ level, in the absence of $R_{fc}$ - 0.1 MAC d/a or 0.1 SRLI were used as critical inactive levels. Considering the result of the given stage, data sets were obtained in accordance with the relative and absolute incidence rate of the population associated with air pollution at each point of the regular computational grid for each age group of the population, which is differentiated by classes of diseases and separate nosological groups of diseases, as well as the contributions of each chemical.

3. Results and Discussion

3.1 Level assessment of formed inhalation exposure and the risk to public health

According to the data of instrumental monitoring of the atmospheric air quality in the study area for 2014–2018, the excess of hygienic standards established in the Russian Federation is recorded in relation to ammonia (up to 2.7 MAC mot), benzol (up to 5.20 MAC mot), suspended solids (up to 3.43 MAC d/a, up to 7.60 MAC mot), suspended particulate matters of RM10 (up to 6.47 MAC d/a, up to 3.04 MAC mot), suspended particulate matters of RM2.5 (up to 10.66 MAC d/a, up to 5.51 MAC mot), nitrogen dioxide (up to 2.85 MAC d/a, up to 2.33 MAC mot), sulfur dioxide (up to 1.18 MAC mot), xylene (up to 3.20 MAC mot), nitrogen oxide (up to 1.53 MAC mot), carbon oxide (up to 3.60 MAC mot), hydrogen sulfide (up to 1.63 MAC mot), toluene (up to 1.43 MAC mot), phenol (up to 2.30 MAC mot), formaldehyde (up to 47.20 MAC mot); hydrogen fluoride (up to 3.20 MAC mot), hydrogen chloride (up to 26.5 MAC mot), ethyl benzene (up to 5.00 MAC mot), and benzopyrene (up to 9.00 MAC d/a).

More than 190 thousand tons (over 260 compounds) of pollutants are annually emitted into the air in Krasnoyarsk. Hygiene standards excess in residential areas for 19 substances in the range from 1.06 MAC mot (ethyl benzene) to 88.7 MAC mot, (inorganic dust: 70-20% of silicon dioxide), and from 1.1 MAC d/a (fluoride gaseous compounds) up to 601.3 MAC d/a (nitrogen dioxide) were established.
owing to the outcomes of consolidated calculations of the spatial dispersion of air pollutants from stationary (over 6100 objects) and mobile (over 360,000 objects) sources.

Exceeding hygienic standards for 26 chemicals, including from 1.46 MAC mot (ethanethiol) to 516.5 MAC mot (ozone), and from 2.13 MAC d/a (fluoride gaseous compounds) to 132.8 MAC d/a (formaldehyde) were formed according to verified data from consolidated calculations of dispersion with data from field studies in residential construction areas.

The established levels of spatial exposure generated the increase in levels of inhalation risk, expressed by coefficients and hazard indices. Thus, excessive hazard factors are formed by 14 substances under acute exposure (from 1.39 HQac for nitrogen oxide to 98.69 HQac for suspended solids), and 21 chemical compounds under chronic exposure (from 1.28 HQcr for ammonia to 442.67 HQcr for formaldehyde). The excess of the individual carcinogenic risk (CR) was caused by ethylbenzene (up to $8.82 \times 10^{-3}$), formaldehyde (up to $7.63 \times 10^{-3}$), benzol (up to $1.93 \times 10^{-3}$), carbon (up to $1.14 \times 10^{-3}$), and chromium (CR up to $1.39 \times 10^{-4}$).

The additive effect of chemicals during chronic exposure in particular zones of residential buildings formed a high level of risk (more than 6.0 HI [19]), expressed by hazard indices for the respiratory system, circulatory system, central nervous system, liver, developmental processes, blood system, immune, reproductive, endocrine systems, kidneys, organs of vision, etc. A high level of risk, expressed by hazard indices, was formed during acute exposure to the respiratory system, developmental processes, the reproductive system, organs of vision, the immune system and systemic effects. The total carcinogenic risk in the residential construction area ranged from TCR $1.34 \times 10^{-5}$–$8.95 \times 10^{-3}$.

3.2 Spatial assessment of the level of additional associated incidence rate of the population formed by the atmospheric air quality

According to georeferencing the cases of people seeking medical care to the address register of an electronic topographic map and a spatial model construction of the distribution of population incidence indicators, the data set was obtained in each of 1637 grid points distributed by the incidence rates in 34 types of classes and nosological groups of diseases of five age groups (the entire population, children, adolescents, adults of working age, adults over working age).

Parametrization of cause-and-effect relationships between the content of 268 substances in the atmospheric air in 1637 calculated points of residential development of the city and indicators of the population incidence rate with a subsequent statistical expertise and examination of biological plausibility made it possible to obtain 131 multiple models of the relationship of health disorders from the levels of pollutant concentrations in the atmospheric air in the form of cases of additional associated incidence rate.

The outcomes of calculating indicators of population health disorders in the form of additional cases of diseases associated with atmospheric air quality showed that the established exposure levels (by verified data) caused about 80.9 thousand supplementary cases of diseases of the entire population a year (71.0 cases per 1000 people), which accounted for 4.15% of the total incidence rate of the population in the study area recorded by the Federal Compulsory Medical Insurance Fund data (Fig. 1).

Additional levels of the incidence rate associated with the atmospheric air quality are practically formed throughout the study area in residential construction zones (99.8% of the area).
The largest number of associated cases of diseases in absolute indicators is formed for people over working age - more than 51 thousand cases (in relative indicators - 206.6 cases per 1000 people). The level of additional associated incidence rate for the child population (0-14 years old) is generated at the level of 23.5 cases per 1000 children.

The priority diseases of the entire population associated with the atmospheric air quality are diseases of the circulatory system (52.8%), diseases of the musculoskeletal system and connective tissue (18.6%), digestive system (14.1%), genitourinary system (7.7%), and the diseases of respiratory organs (7.7%). Digestive system diseases (36.7%) occupy a leading position among the child population, followed by diseases of the respiratory system (30.9%) and circulatory system (18.8%). Foreground places in terms of the number of health disorders associated with the atmospheric air quality among adolescents are occupied by: respiratory diseases (49.9%), diseases of the digestive system (15.0%), and diseases of the circulatory system (10.5%).

The maximum levels of associated incidence rate are formed in the central areas of the city with an intensive transport structure, as well as in the zone of industrial enterprises, along highways, and in areas where autonomous heat supply sources are located.

Generally, 23 substances are the factors that determine the formation of a given number of associated cases of diseases, considering the criterion of a critical inactive level of health disorder development 0.1 from $R/fc$ ($MAC/SRLI$): diAluminum trioxide (equivalent to aluminum), chromium (hexavalent chromium, equivalent to chromium oxide (VI), cerium and its compounds, sulfur dioxide, dihydrosulfide, carbon oxide, gaseous fluorides, poorly soluble fluorides, chlorine, pentane, 1,3-butadiene, benzol, dimethylbenzene, ethyl benzene, benzopyrene, hydroxybenzene, prop-2-en-1-al, formaldehyde, prop-2-ene-1-nitrite, petrol (oil, low-sulfur, equivalent to carbon), suspended solids.

The formed levels of additional associated incidence rate of the population with the atmospheric air quality and their spatial distribution have a certain convergence with the spatial zones of the formed...
health risk, both in the list of generated responses and in the structure of contributions of chemical risk factors.

4. Conclusions
The established levels of spatial exposure indicate that the entire population of the studied area lives in conditions of abnormal quality of atmospheric air. Hygiene standards are exceeded for 26 chemicals, including from 1.46 MAC mot (ethanethiol) to 516.5 MAC mot (ozone), and from 2.13 MAC d/a (fluoride gaseous compounds) to 132.8 MAC d/a (formaldehyde).

The additive effect of chemicals in particular areas of the city forms a high level of risk (over 6.0\%\), expressed by hazard indices, in relation to the respiratory system, cardiovascular system, central nervous system, liver, developmental processes, blood system, the immune, reproductive, and endocrine systems, kidneys, organs of vision, etc.

The formed exposure levels cause about 80.9 thousand supplementary cases of diseases of the entire population a year (71.0 cases per 1000 people), which accounted for 4.15\% of the total incidence rate of the population in the study area recorded by the Federal Compulsory Medical Insurance Fund data.

The largest number of associated cases of diseases is formed for people over working age - 206.6 cases per 1000 people. The level of additional associated incidence rate for the child population (0-14 years old) is generated at the level of 23.5 cases per 1000 children.

The priority diseases of the entire population associated with the quality of atmospheric air are diseases of the circulatory system (52.8\%), the musculoskeletal system and connective tissue (18.6\%), diseases of the digestive system (14.1\%), genitourinary deseases (7.7\%), and the deseases of respiratory organs (7.7\%). Digestive system diseases (36.7\%) occupy a leading position among the child population, followed by diseases of the respiratory system (30.9\%) and circulatory system (18.8\%). The priority factors determining the formation of the established level of additional incidence rate associated with atmospheric air quality are 23 chemical substances, including diAluminum trioxide, chromium (VI), sulfur dioxide, formaldehyde, dihydrosulfide, etc.

The established zones with an increased level of formed additional associated incidence and the inhalation risk factors that determine it are the supplementary information resource for the development of adequate protection measures for the environment and assessment of the effectiveness and efficiency of the implemented measures to improve the atmospheric air condition.

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