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Urban air pollution, climate and its impact on asthma morbidity

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ABSTRACT

Objective: To study the mechanism of formation of air quality and to determine the impact of the studied factors on asthma morbidity in Vladivostok.

Methods: The evaluation of air pollution in Vladivostok was done using long-term (2008–2012) monitoring data (temperature, humidity, atmospheric pressure, wind speed, *etc*.). The levels of suspended particulate matter, nitrogen and sulfur dioxide, carbon monoxide, ammonia, formaldehyde (mg/m^3) in six stationary observation posts were assessed. We studied the aerosol suspensions of solid particles, which were collected during snowfall from precipitation (snow) and air in 14 districts with different levels of anthropogenic impact. Melted snow was analyzed on laser granulometry. The impact of air pollution on the distribution of asthma morbidity was evaluated in various age groups by data of federal statistical observation obtained from 8 adults and 7 children municipal clinics in Vladivostok (2008–2012).

Results: The content of suspended particulate components of pollution remained more stable, due to the features of atmospheric circulation, rugged terrain and residential development. The nano- and micro-sized particles (0–50 μm), which can absorb highly toxic metals, prevail in dust aerosols. These respirable fractions of particles, even in small doses, can contribute to the increase in asthma morbidity in the city.

Conclusions: We determined that asthma morbidity depends from general air pollution (in the range of 18.3%). It was detected that the highest age-specific dependence is associated with the content of particulate matter, carbon monoxide and nitrogen dioxide in air.

1. Introduction

All of the environmental processes are the functional elements of the integrated systems (climate, topography, biota, *etc.*) and their interactions form the state of the air. Currently, the studies of air pollution have reached a new level due to the possibility of detecting new classes of toxicants: nano- and micro-sized particles. The microparticles have a higher toxicity and possess the ability to penetrate cell membranes, to circulate and accumulate in organs and tissues. They cause severe pathomorphological changes in the respiratory system, and their removal from body is very complicated [1,2]. Weather largely determines the conditions of accumulation and dispersion of pollutants in the air, significantly affecting the formation of air quality.

The polluted air of large cities is one of the causes of asthma morbidity. Air pollutants affect health differently, depending on age and individual features of response to the environment impact [3,4]. Therefore, the study of system “key” structures and positions responsible for the qualitative state of the city air will identify the contribution of individual pollutants in asthma morbidity in Vladivostok.

The aim of our work was to study the mechanism of formation of air quality and to determine the impact of the studied factors on asthma morbidity in Vladivostok.

2. Materials and methods

Vladivostok, large industrial city located in Primorsky region, Russia, was taken as an object of investigation. The

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industrial enterprises and intensive road traffic on low-quality roads significantly contribute to air pollution in Vladivostok. The rugged terrain of the city causes the unevenness of aerodynamic characteristics and high levels of air pollution, but the climatic features support air self-purification.

2.1. The evaluation of air pollution and climatic conditions in Vladivostok

The evaluation of air pollution in Vladivostok was done using long-term monitoring data on air quality (2008–2012) by Primorsky Department of Hydrometeorology and Environmental Monitoring and Center of Hygiene and Epidemiology of Primorsky Krai. The levels of suspended particulate matter, nitrogen and sulfur dioxide, carbon monoxide, ammonia, formaldehyde (mg/m^3) in six stationary observation posts were assessed [5].

We studied the aerosol suspensions of solid particles, which were collected from precipitation (snow) and air. Snow was collected during snowfall in 14 districts with different levels of anthropogenic impact. Melted snow was analyzed on laser particle sizer Analysette 22 NanoTec (Germany) to determine the size distribution and shape of the particles [6]. The laser granulometry method was used for the determination of the size of suspended particulate matter (PM), originated from the surface layer of the atmosphere, with preliminary aspiration of given air volume into liquid medium [7]. Suspended particles with various sizes were evaluated not only by size range, but also by the adsorption of toxic heavy metals [6].

We used monitoring data from Federal Service for Hydrometeorology and Environmental Monitoring (Primorsky Department of Hydrometeorology and Environmental Monitoring) to study the climatic conditions of the city. The actual parameters of temperature (T1), humidity (φ1), atmospheric pressure (P1), wind speed (V1), *etc*. were assessed. The previous (1–2 days) climatic data (T2, φ2, P2, V2, *etc*.) were also used for the characterization of the stability of the atmosphere, determining prolonged response from human respiratory system.

2.2. The assessment of asthma morbidity in Vladivostok

The impact of air pollution on the distribution of asthma morbidity was evaluated in various age groups by data of federal statistical observation (form No. 12) obtained from 8 adults and 7 children municipal clinics in Vladivostok (2008–2012). All the cases of acute illnesses and the first visit in year on the exacerbation of chronic disease (per 100 000 people) were included into the study. During the years 2008–2012, the large-scale construction of roads and bridges took place in the city, causing heavy air pollution by suspended components.

2.3. Statistical analysis

Statistica 10.0 (Statsoft) software was used for the mathematical and statistical methods of data processing (canonical analysis, multiple and rank correlation) and the probabilistic information-entropy analysis. Canonical analysis was used to determine systemic interconnections (R) between the groups of climatic parameters and anthropogenic pollutants. Multiple correlation was used to evaluate the correlation (r). Spearman rank correlation was used to identify air pollutants having the most impact on asthma morbidity in the city. Information-entropy analysis was used to determine the total quantitative contribution (%) of air pollutants in morbidity in conditions of informational uncertainty and randomness. The unconditional and conditional entropy were used as an analytical tool. The unconditional entropy indicated the level of informational uncertainty in variational series in morbidity. The conditional entropy allocated informational uncertainty from the perspective of air pollution impact (as a cause), arranging the entropy in the systemic relations “morbidity-air environment” [8,9]. Comparison of unconditional and conditional entropy allows to identify “useful information”, according to assessing the level of environmental dependence of morbidity. Since the data were of different dimensions and the number of components, the unit of account was taken as the rate of the relative entropy-the coefficient of redundancy (R%). The increase in the coefficient of redundancy indicated the decrease in entropy [9].

3. Results

Canonical analysis showed the intersystem relationships between the groups of climatic parameters and atmospheric pollutants ($R = 0.57$, $P = 0.0042$), which suggested a significant contribution of climatic conditions to the formation of air quality in the city. Pair correlations (r) between meteorological parameters and anthropogenic pollutants were calculated to select the climatic factors having the most impact on the level of air pollution (Table 1).

Table 1

The correlation (r) of climatic factors and indicators of anthropogenic air pollution in Vladivostok.

Climatic factors	Indicators of anthropogenic air pollution (mg/m^3)			
	Nitric oxide	Nitrogen dioxide	Particulate matter	Formaldehyde
Season (winter, spring, summer, autumn)		0.25^b	0.20^a	0.21^b
Actual atmospheric effects		0.27^b		
Actual humidity, φ1 (%)		0.25^b	0.17^a	0.16^a
Actual temperature, T1 (°C)			0.23^b	0.24^b
Previous temperature, T2 (°C)				0.24^b
Actual dew point, t_p1 (°C)			0.23^b	0.23^b
Change in atmospheric pressure, (P2−P1) (mm Hg)	0.26^b	0.28^b		
Previous wind speed, V2 (m/s)				0.21^b
Change in wind speed, (V2−V1) (m/s)	0.20^b	0.25^b		0.31^b
Wind direction, wd1 (compass points)			0.18^a	0.24^b

Statistically significant differences between groups: ^{a} for $P \le 0.05$, ^{b} for $P \le 0.01$.

The statistically significant correlations (r, $P < 0.01$ and $P < 0.05$) were detected for 11 climatic parameters and 4 indicators of pollution from 29 climatic parameters and 7 indicators of anthropogenic pollution.

All selected climatic parameters in one way or another are involved in the natural process of self-purification of the atmosphere. The correlation between air pollution and season is due to the influence of the monsoon features of atmospheric circulation including specific wind patterns with different intensities, which supports air purification throughout the year. Such factors as high humidity, temperature characteristics, dew point (the temperature at which the water evaporation stops and condensation begins) prevent the self-purification of atmosphere, especially from gas components. The “atmospheric effects” (rain, snow, drizzle, storms) purify city air most effectively. Table 1 shows that climatic factors have the greatest impact on gas components of air pollution (formaldehyde, carbon dioxide and nitrogen oxide). The content of suspended matter in the air is more stable, which is caused by the rugged terrain and residential development in the city, and increase risk of respiratory morbidity.

The impact of suspended matter on respiratory system depends on the size of the particles and toxic components included in their structure [1,2]. The fine particles with diameter of 0–1 (PM_1) and 1–10 (PM_{10}) μm are the most pathogenetic, so we carried out a detailed study of the formation of fractional composition of particulate matter in the city air.

Aerosol suspensions of particulate matter (particulate matter in the atmosphere), collected from precipitation (snow), and air samples were analyzed by particle size, shape and sorption of toxic heavy metals and compared with one another (multiple correlation) (Table 2).

Table 2

The correlation (r, $P < 0.001$) of size fractions of suspended particulate matter and content of particulate matter and toxic metals in the atmosphere of Vladivostok.

Size fractions of suspended particulate matter (μm)	0–1 (PM_1)	1–10 (PM_{10})	10–50	50–100	400–700	>700
Content of particulate matter (mg/m^3)	0.54		0.48		0.30	0.39
Content of toxic metals (μg/L)						
Cr	0.88		0.79			
Co	0.86		0.86			
Cu	0.77		0.67			
Zn			0.74			0.86
Pb						0.65
Mn						0.65

Table 2 shows that suspended particulate matter in the city air is distributed by size fractions-PM_1 (r = 0.54) and 10–50 μm (r = 0.48), which indicates a high risk of respiratory diseases. The fraction of fine particles (PM_1) is dangerous to health also because of sorbed toxic metals (Cr, Co, Cu) (r = 0.77–0.88). The fractions with diameter of 10–50 μm have a strong correlation (r = 0.67–0.86) with toxic metals with first (Zn) and second (Cr, Co, Cu) hazard classes (Table 2). Large size fractions with diameter of > 400 μm are also presented in the atmosphere of Vladivostok (r = 0.3; 0.39). They adsorb metals with first (Zn, Pb) and third (Mn) hazard classes (Table 2).

The impact of air pollution on asthma morbidity in Vladivostok was studied from two points of view: (a) the total (cumulative) impact of air pollution; (b) the contribution of each pollutant (nitrogen oxide and dioxide, formaldehyde, particulate matter, hydrogen sulfide, ammonia and carbon monoxide) on the age distribution of morbidity.

The total pathogenetic contribution of air pollution in asthma morbidity was estimated as “useful information” (R%), corresponded with the development of environmentally induced disease. The results showed that children asthma morbidity was the most related with pollution (R = 18.3%), while the asthma morbidities for adolescents and adults were a little lower (17.7% and 13.8%, respectively).

According to the literature, the impact of the environment on health in Russia ranged from 16% to 54%, depending on regional environmental features [4]. The value of the total impact of air pollution on asthma morbidity in Vladivostok indicated the presence of many unaccounted causes in the development of disease. However, the connection with air pollution indicated the problem of public health preservation and the prevention of risks in the city.

The determination of the individual contribution of each air pollutant in asthma morbidity was selected as the second area of study. We used rank correlation between asthma age incidence and air pollution to identify the statistically significant ($P < 0.05$) top priority factors. As a result, it was found that asthma in children and adolescents was largely determined by the presence of particulate matter in air (Table 3).

Table 3

The correlation (r, $P < 0.05$) of asthma morbidity and air pollutants in Vladivostok.

Patients	NO	NO_2	CH_2O	PM	H_2S	NH_3	CO
Children				0.69			0.63
Adolescents				0.75			
Adults		0.78					

NO: Nitric oxide; NO_2: Nitrogen dioxide; CH_2O: Formaldehyde; H_2S: Hydrogen sulfide; NH_3: Ammonia; CO: Carbon monoxide.

The predominance of microsized particulate matter with hazard toxic metals, which are the most pathogenetic to human respiratory system (Table 2), in the Vladivostok air probably explains the high risk of asthma morbidity in the city. In addition to suspended particles, carbon monoxide also affects the respiratory system of children in the city, causing acute asthma (Table 3). The main source of anthropogenic carbon monoxide is currently presented by the exhaust gases of internal combustion engines in automobiles. Due to results, the respiratory system of adults is more sensitive to high content of nitrogen dioxide, a potential respiratory irritant resulting from the combustion of transport fuels.

4. Discussion

According to statistics, the number of cars per capita in Vladivostok ranks first in Russia-more than 600 automobiles per 1 000 inhabitants [10]. The rugged terrain of the city, lack of multi-storey car parks, traffic instability exacerbate air pollution by products of incomplete fuel combustion. In addition to road transport, heating plants and a large number of different boiler houses with equipment exploited for a long time (> 25 years) actively pollute city air. Energy facilities use mainly brown and black coal, fuel oil, diesel fuel, and only a few-gas [11,12].

Human respiratory system is particularly sensitive to the impact of car emissions, causing pathological changes in bronchopulmonary system and promoting the increase in general morbidity. A number of exhaust gas components including solid nano- and microparticles of carbon, carbon monoxide, sulfur oxides, formaldehyde, heavy metals, and, as it has recently been shown, carbon nanomaterials with adsorbed toxic components have the most harmful effect [1,2]. Metal particles are the toxic components of exhaust gases, as well as fractions of atmosphere particulate matter. The most significant source of metals (Fe, Pb, Zn, Mn, Ni, Cr, Cu, Sn) is mechanical and chemical wear of the internal combustion engine (high and low-carbon steel, cast iron), tire and braking system runout [1].

Vladivostok is located in the southern extremity of Muravyov-Amursky Peninsula. The type of climate in Vladivostok is monsoon climate with seasonal circulation of the atmosphere. The main features of climate are the predominance of south wind from the sea in the summer and north wind from continent in the winter. The summer is characterized by an abundance of precipitation (rain, drizzle, fog), while in winter there is relatively little precipitation. Sea impact causes a high number of days with increased and high air humidity (in summer up to 100%) and moderate temperature difference throughout year. Sea also affects the seasonal increase in wind speed and humidity, and air temperature mitigation. The complex elevated terrain of the city creates a local areas with calm wind and air "tubes" with strong wind. Aforementioned climatic features largely determine the level of air self-purification and, as a result, a qualitative condition of city air.

The levels of air pollution in Vladivostok are affected by the features of the monsoon climate. The climatic factors have the highest influence on gas components of air pollution (formaldehyde, carbon dioxide, and nitrogen oxide), especially the actual and the previous atmospheric effects, humidity, air temperature, wind speed. The content of suspended particulate matter in the air is less tended to be affected by climatic factors, due to the rugged terrain and residential building, which contributes to relatively tense situation with the dust pollution in the city.

The study of size distribution in aerosol suspensions of solid particles showed the presence of fine particles (PM_1, PM_{10-50}) in the Vladivostok air, adsorbing toxic metals of 1 and 2 hazard classes (Zn, Cr, Co, Cu), which have the most negative impact on the respiratory system. The assessment of the total impact of air pollution on asthma morbidity in Vladivostok has shown a relatively high dependence of morbidity from air pollution (up to 18.3%), with possible latent unaccounted causes. The predominance of microsized particulate matter with hazard toxic metals in the Vladivostok air manifest itself in the top priority impact of it on asthma morbidity in children and adolescents in Vladivostok. In addition to the suspended particles, carbon monoxide and nitrogen dioxide, the products of exhaust gases of internal combustion engines in automobiles, also have a high impact on the respiratory system in city population.

Conflict of interest statement

We declare that we have no conflict of interest.

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