

Non-cancer risk assessment of the atmospheric air pollution effect on the population health on the basis of evolutionary models

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Abstract

Aim and Scope: The aim of this study is to assess the non-carcinogenic risk and determine the accumulation of additional risks of health response for the cardiovascular and respiratory systems based on building the evolutionary models on chronic exposure to chemicals in the atmospheric air. **Materials and Methods:** The testing of the proposed methodological approaches was carried out by the example of a model scenario, according to the observation results based on systematic supervision within the social-hygienic monitoring. **Result and Discussion:** The results of calculation with the application of the evolutionary deterministic risk models in case of two scenarios (the background and the studied ones) allowed determining that the risk of respiratory diseases was formed earlier. It was established based on the indices of additional risk and presented risk index that the unacceptable (moderate) health risk was formed by the age of 27 years, and after the age of 40 years, it could be classified as high. **Conclusion:** We carried out the testing of the non-cancer risk assessment for the population health in the city of Kazan on exposure to chemicals coming with the atmospheric air (PM₁₀, CO, NO₂, and SO₂) on the basis of evolutionary model. The cardiovascular and respiratory systems were found to be the critical organs for exposure to mentioned major pollutants.

Key words: Forecasting, health risks, hygienic assessment, the evolution of risk

INTRODUCTION

Air pollution is one of the major health risk factors associated with the environment. More than 80% of residents living in city districts with a well-run system of the air quality control are exposed to air pollution, the level of which exceeds the limit values specified in the World Health Organization (WHO) air quality guidelines.^[1] The risk of stroke, heart diseases, lung cancer, and chronic and acute respiratory diseases including asthma increases in people with decrease of the air quality. Chemical substances can have immediate acute consequences, as well as chronic consequences often resulting from the long-term effect. Evidence for associations with long-term exposure to traffic pollutants, in contrast, is rather mixed.^[2-4] According to the WHO data, solids present in the atmospheric air have an adverse effect on the human health. The increase of PM₁₀ concentration per 0.01 mg/m³ causes the growth of total mortality by 1%,

mortality from cardiovascular diseases by 1.4%, and from respiratory diseases by 3.4%. The impact of only suspended particulate matters (PM) decreases the life expectancy on average by 1 year mainly due to the increasing risk of cardiovascular and respiratory diseases and also lung cancer.^[5] Hygienic standards on finely dispersed suspended PM sized <10 microns (PM₁₀) and <2.5 microns (PM_{2.5}) for the atmospheric air are valid in the RF since the year of 2010.^[6] The dose-effect and dose-response relationships in children under 14 years old due to differences from the older children

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and the adults in structural and functional characteristics are responsible for their high vulnerability on exposure to chemical substances.^[7] Conventionally, accepted comparison of the morbidity levels in the regions and cities with regional average indices, even if they are statistically significant, is not entirely correct. Such practices can bring to smoothing of territorial risk factors. The health risk assessment due to exposure to chemical substances according to average annual concentrations and their upper 95%-confidence limits determined from average daily concentrations in environmental compartments is considered to be an up-to-date and more accurate approach to assessment of pathological changes in the body.^[8] Due to this fact, we tried out the non-cancer risk assessment for the child population health from the release of chemicals contained in the atmospheric air of the city of Kazan on the basis of the evolutionary model.^[9]

MATERIALS AND METHODS

Annual state report materials “On sanitary- epidemiological situation in the Republic of Tatarstan” and data of the FSBI “Hydrometeorology and environmental monitoring administration of the Republic of Tatarstan” for the period from 2006 to 2014 were used as basic data on average annual concentrations of pollutants in the atmospheric air. Quantitative assessment of the non-carcinogenic risk on exposure to chemical substances based on building the evolutionary models was carried out in accordance with Methodological Recommendations MR 2.1.10.0062 – 12.^[8] The calculation of individual risks of health deterioration with different severity was carried out according to the system of recurrence equations.^[8,10,11]

The risk of health deterioration associated with chemical factors' effect (R_t) is calculated according to the following formula:

$$R_t = 1 - \prod_{i=1}^r (1 - R_t^i) \quad (1)$$

Where, R_t^i - risk of developing disorders in the i -critical system on exposure to chemical factors. The additional health risk associated with chemical factors (ΔR) is calculated according to the following formula:

$$\Delta R_t = R_t - R_t^0$$

Where

ΔR_t - additional health risk;

R_t - health risk on exposure to chemical factors;

R_t^0 - health risk without exposure to chemical factors (or in case the factor values are at reference levels).

Evolutionary equations are written in the form of recurrence proportions, which allow organizing an iterative calculation procedure in time steps. The system of recurrence equations

takes into account the risk accumulation of non-carcinogenic effects on critical organs/systems due to chemical substances.

The general form of recurrence relations is as follows:

$$R_{t+1}^i = R_t^i + (\alpha_i R_t^i + \sum_j \Delta R_t^{ij}) C$$

Where

R_{t+1}^i - risk of disorders of the i -body system at point in time $t+1$;

R_t^i - risk of disorders of the i -body system at point in time t ;

α_i - coefficient taking into account the risk evolution due to natural causes;

C - time empirical coefficient was taken as unity (1) (for average annual exposures).

The coefficients taking into account the risk evolution due to natural causes (α_i) are determined on the basis of the morbidity and mortality background indices for the disease classes reflecting functional disorders of the critical organs and systems (cardiovascular system - 0.05 and respiratory system - 0.0515). The health data, which are typical for the most favorable regions as far as environmental pollution, are chosen as the background levels.^[8] Formation of exposure factors scenarios for carrying out calculations on assessment of non-carcinogenic risks was based on the data of social-hygienic monitoring.

To solve the problem of assessing the level of non-carcinogenic health risk associated with the effect of chemical substances, the mentioned health risk index (\tilde{R}_t) is calculated as follows:

$$\tilde{R}_t = \frac{\Delta R_t}{1 - R_t^0} \quad (3)$$

The risk indicators are assessed according to the criteria: The value <0.05 is assessed as a negligible (acceptable) risk. The value of 0.05 corresponds to the upper boundary of the acceptable risk. The range of more than 0.05–0.35 is assessed as a moderate risk and that of more than 0.35–0.6 as a high risk. If the value is more than 0.6, it is assessed as a very high risk. The chronic effect of the chemicals (suspended PM_{10} , sulfur dioxide, carbonic oxide, and nitrogen dioxide) coming from the atmospheric air on the the cardiovascular and respiratory systems was assessed in accordance with the scenario.

RESULTS AND DISCUSSION

Kazan is a large industrial center of the Republic of Tatarstan, where more than a hundred of large, medium, and small industrial enterprises are located, and it is characterized by a high intensity of the traffic load. At present, the automobile

transport is one of the major sources of the city atmospheric air pollution. In recent years, the contribution of the automobile transport to the atmospheric pollution in Kazan remains high and makes from 69.4% to 77% of total gross emissions for the period under analysis. The majority of controlled substances in the atmospheric air of the city of Kazan (nitrogen dioxide, sulfur dioxide, carbon oxide, and suspended PM) are both on the list of priority substances contained in the atmospheric air in the cities of the RF international toxics release inventory of the Environmental Protection Agency. The analysis of the primary morbidity of the city child population showed that the first place in morbidity patterns (ICD-10) traditionally belonged to respiratory diseases (J00-J99), which made 56.4–62.7%. The dynamics of disease prevalence: J00-J99 covering a 10-year period in children (0–14 years old) varied from 27% to 50.1%. The level of disease prevalence in all J00-J99 in adult population varied from 15.7% to 17.7%, and all cardiovascular diseases (I00-I99) made from 18.8% to 21.7%.^[12]

In the case of urban background pollution, we used an annual mean of 0.04 mg/m³ (40 µg/m³) as the scenario reference point. As for PM₁₀, it is twice as high as the value recommended by the WHO.^[5] The acceptable values of exposure at the level of the reference concentrations of chemical substances in the atmospheric air were taken as exposure background conditions for the rest of substances [Table 1]. Actual levels of the exposure factors taken for calculating the non-carcinogenic risk are obtained on the basis of systematic observations within the social-hygienic monitoring for 9 years [Table 1].

The non-carcinogenic risk assessment was carried out on the basis of adapted recurrence equations in the form of a program module created in MS Excel in two versions. The statement on non-existence of active factors (in case of acceptable factor levels) was used as the first (basic) version. The second version implied modeling of the functional disorders risk accumulation according to the scenario chosen for the study [Figures 1 and 2].

The results show that the additional risk (ΔR) of the functional disorders accumulation under chosen scenario at the level of reference concentrations of chemical substances in the atmospheric air is formed earlier for the respiratory system than for the cardiovascular system, at the level of 0.6 by the

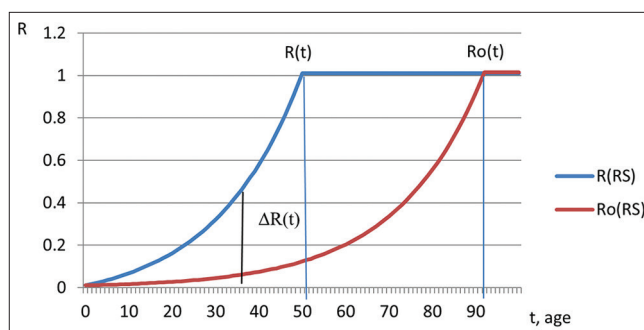


Figure 1: Evolution of risk and additional risk of harmful effects on the respiratory system (RS) on exposure to chemical substances in the atmospheric air

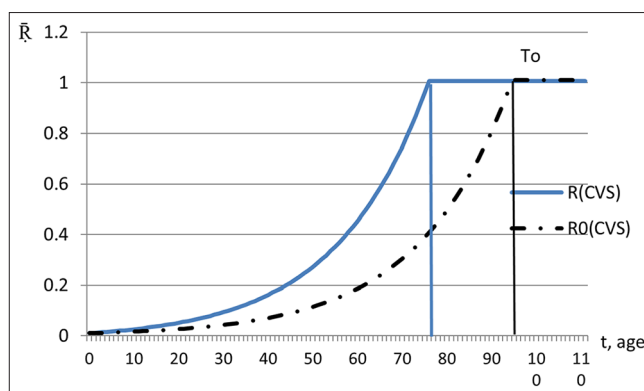


Figure 2: Evolutionary determined risk models under two scenarios for the cardiovascular system (calculation results), R (CVC), and Ro (CVC)

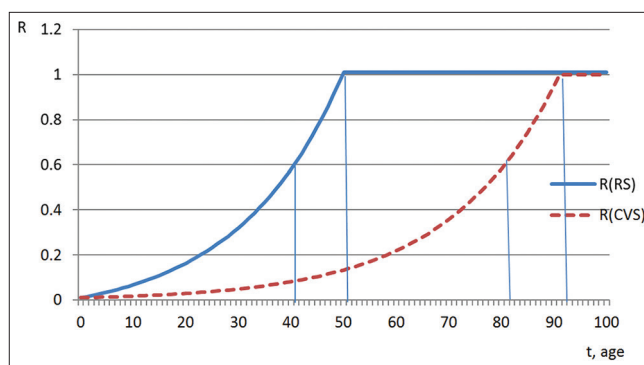


Figure 3: The model of functional disorders risk accumulation under the studied scenario

Table 1: Range of values of the habitat factors exposure level

Factor	Factor parameters	Acceptable (reference) level, mg/m ³ ^[6,13]	Recommendations of the WHO, µg·m ⁻³ ^[5,14]
Substances coming from the atmospheric air SD (min–max), mg/m ³			
Suspended PM ₁₀	0.113 (0.08–0.6)	0.04	20
Sulfur dioxide	0.0009 (0.001–0.003)	0.05	20 (for 24 h)
Carbonic oxide	1.31 (0.8–4.0)	3.0	7 mg/m ³ (for 24 h)
Nitrogen dioxide	0.073 (0.05–0.09)	0.04	40

age of 40 and 82 years, and at the level of 1.0 by the age of 51 and 93 years, respectively [Figure 3].

The assessment of additional risk for the population health associated with analyzed factors for two systems - the respiratory system and the cardiovascular system - was carried out on the basis of comparative analysis of the calculation results [Table 2 and Figure 4].

The assessment of the non-carcinogenic health risk level associated with the chemical substances' effect in the atmospheric air was carried out on the basis of calculation of the given health risk index (ΔR) separately for each of the system and integrally. The assessment of the additional health risk values was carried out with the use of special evaluation risk index.

Additional risk is formed primarily due to the effect of analyzed chemicals in the atmospheric air on the respiratory system. The risk structure, which is formed from the aggregate risks of certain systems, changes depending on the age and the factors' exposure duration [Figure 5].

Thus, the proportion of additional risk for the respiratory system of the aggregate risk value at the age of 10 years makes 87.2% and 22.2% at the age of 70 years, and for the cardiovascular system at the age of 10 years - 12.5% and 77.5% at the age of 70 years, respectively. The data obtained adequately reflect the current epidemiological and ecological situation in the city territory in recent years as discussed elsewhere.^[9]

The point in time (t), when the value of the non-carcinogenic effects risk takes the value equal to unity (one), is considered to be the predicted age at death or the predicted life expectancy [Figures 1 and 6].

Reduction of the life expectancy (ΔT) associated with harmful effect of the chemical factors for the respiratory system made 35 years and for the cardiovascular system made 19 years. The values of risk indices on exposure reflect mainly the long-term trend for the change of the population health indices in the city of Kazan, which is led, when all reference conditions in calculations are satisfied (for example, certain duration and intensity of exposure, constancy of exposure in time, and specific values of the exposure factors).

CONCLUSIONS

We consider that it is critical to move beyond the traditional assessment of the human health impact, which is geared mainly toward mortality. The approaches, which include potential effect of the atmospheric air pollution, should be also broadened on the basis of evolution of the non-carcinogenic health risk modeling. In spite of uncertainty and limitations, methodological approaches to risk assessment of the habitat factors exposure allow estimating its categories in accordance with the scale and modeling changes in the risk of functional disorders of the body organs and systems throughout life. It should be noted that there were uncertainties associated with non-existence of specific regional parameters for the

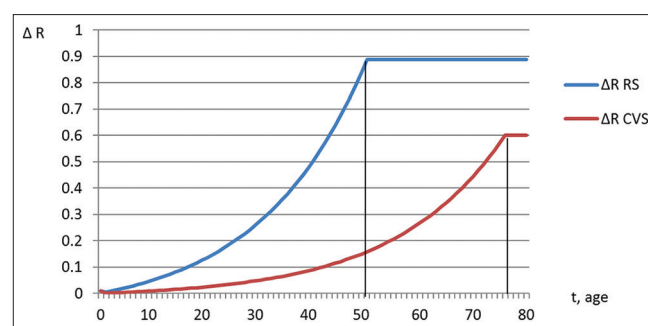


Figure 4: Additional health risks (ΔR) for cardiovascular and respiratory systems (ΔR CVS and ΔR RS.)

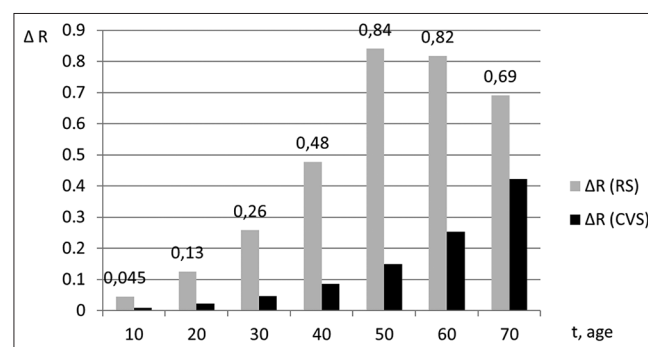


Figure 5: Additional risk of adverse effects for cardiovascular on the respiratory system on exposure to chemical substances in the atmospheric air

Table 2: Calculation results of additional health risks (ΔR) for cardiovascular (ΔR CVS) and respiratory systems (ΔR RS)

Age (years)	ΔR ($\Delta R_{RS} + \Delta R_{CVS}$)	Risk reduction index (\tilde{R})	Risk characterization
1-10	0.053	0.0278	Negligible (acceptable)
20	0.148	0.1068	Moderate
30	0.305	0.2373	Moderate
40	0.564	0.4524	High
50	0.990	0.8076	Very high
60	1.070	0.6835	Very high
70	1.113	0.477612	High

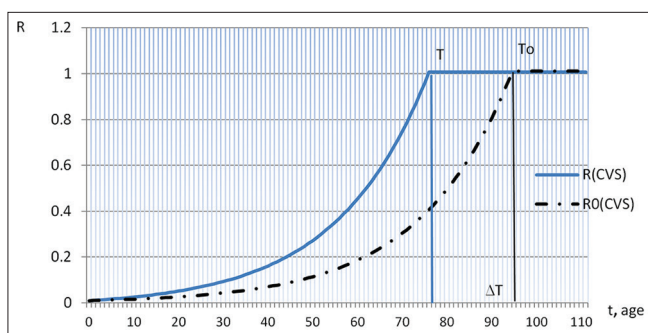


Figure 6: Evolution of risk of adverse effects on the cardiovascular system on exposure to chemical substances in the atmospheric air

exposure assessment in our calculations, such as incomplete data on concentration of pollutants in the atmospheric air and their territorial distribution and convention of the chosen exposure scenario not taking into account all specific aspects of seasonal and daily activities of the child and adults population for assessment of the inhalation intake of chemical substances with the atmospheric air. Our results indicate the possible growth of the respiratory diseases risk by the age of 10 years (\bar{R} - the range of more than 0.05–0.35) and that of the circulatory diseases by the age of 37 years. Thus, according to the data of epidemiological surveillance, a possible association between the chronic PM impact at an early age and the vulnerability to chronic obstructive pulmonary disease at a mature age was identified. The results of calculation with the application of the evolutionary deterministic risk models in case of two scenarios (the background and the studied ones) allowed determining that the risk of respiratory diseases was formed earlier. It was established based on the indices of additional risk and presented risk index that the unacceptable (moderate) health risk was formed by the age of 27 years, and after the age of 40 years, it could be classified as high.

The results of risk assessment are the most efficient tool for comparison of the chemical factors' harmful effect in different territories, in different periods of time, before and after carrying out of curative measures for determining their efficiency.

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