METHODOLOGICAL APPROACHES TO RISK ASSESSMENT OF MIXED ENVIRONMENTAL FACTORS ON PUBLIC HEALTH BASED ON EVOLUTIONARY MODELS[1]

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Abstract. The article focuses on methodological approaches to the assessment of public health risks associated with exposure to environmental and lifestyle factors. Practical approval of the methodological approaches showed that they can be used to calculate the indicators of the individual and population risks and life expectancy; the risk level was ranged according to the proposed scale. It was determined that exposure to mixed chemical factors of air pollution, road traffic noise, and negative living habits contributed to the development of an unacceptable (moderate) health risk level by the age of 47, and of a high health risk level – by the age of 58. Unhealthy behaviors such excessive alcohol consumption, smoking, and poor motion activity result in highest levels of risk factors and reduce life expectancy by an average of 12.3 years.
Kew words: health risk assessment, risk evolution, integral risk, life expectancy, environmental factors.

Current sanitation and epidemiological situation is characterized by a combined impact of mixed environmental factors on public health. They include biological, chemical, social, and environmental factors that have or can have an effect on human beings and (or) health of the future generations, [1]. Under the circumstance, existing approaches to the assessment of public health risks associated with certain factors and groups of factors can be used to achieve sanitary and epidemiological goals only at the local level. For this reason, assessment of risks associated with simultaneous exposure to mixed environmental and lifestyle factors is of current interest. This justifies the use of methodological approaches that, on the one hand, rely on available data on cause-and-effect relations between the public health indicators and exposure to certain factors [2-4], and, on the other hand, involve current scientific approaches to data processing.

Risk modeling is one of the approaches based on coordinated application of statistical and analytical models that are considered to be among the most appropriate methods for the prediction and assessment of environmental and human habitat impact on public health.

Negative transformations modeling of human body functions takes into account the effects associated with mixed negative exposure including age-related factors. Evolutionary models help (under given exposure scenarios throughout a whole life) assess the risk of organ and system dysfunction, and analyze the contribution of certain factors and/or their combinations to health risk development [5, 6]. Such analytical approaches aimed at the development of health risk assessment methodology help conduct numerical (virtual) experiments that are difficult to simulate in real-world environment, and assess the risk of negative effects under given exposure scenarios that combine the conditions of residential area, industrial environment, nutrition, lifestyle, etc.

According to the conceptual terms of health risk modeling, a human body is an open system that is constantly interacting with the environment and consists of a surfeit of absolutely interdependent target organs [7]. Negative exposure to mixed environmental and lifestyle factors

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may cause organ and system dysfunctions. They may include both function recovery processes under zero negative exposure as well as accumulation of functional disorders. Since mixed environmental and lifestyle factors can impact the same body functions, health risk modeling is the most appropriate risk assessment method [8].

Evolution of the negative effect risks can be described by a differential equation system that reflects the accumulation of the functional disorders related to the adverse impact of environmental and lifestyle factors based on the natural processes proceeding in a body.

$$\frac{dR^i}{dt} = \alpha_i R^i - \beta_i (1 - R^i)^n + \sum_k \gamma_{ki} f_{ki}(F_k), \quad i = \overline{1, r} \qquad (1)$$

where

R^i – risk of i-system dysfunction;

αi – coefficient that takes into account natural risk evolution;

βi – coefficient that takes into account self-recovery of body organs and systems;

$\gamma_{ki} f_{ki}(F_k)$ – summand that reflects the accumulation intensity of i-system dysfunction risks associated with k-factor exposure.

The most appropriate method to solve this combined equation is finite difference approximation. Presentation of an evolutionary model (1) as a recurrent relation allows for the use of an iterative process with time intervals:

$$R^i_{t+1} = R^i_t + (\alpha_i R^i_t + \sum_k \Delta R^{ik}_t) C \qquad (2)$$

where

R^i_{t+1} – risk of i-system dysfunction at a point of time t+1;

R^i_t – risk of i-system dysfunction at a point of time t;

αi– coefficient that takes into account natural risk evolution;

ΔR^{ik}_t – risk gain of i-system dysfunction due to k-factor exposure at a point of time t;

C – empirical conversion factor for various averaging times (for annual average exposures C=1, monthly average C=0.083, daily average C=0.0027).

Application of risk evolution modeling methods allows for the integral risk assessment. Integral health risk is a risk of the development of adverse effects of varying severity caused by simultaneous exposure to various factors. Integral health risk assessment should be viewed as part of integrated risk assessment without risk assessment for the ecosystems. According to the international health risk assessment methodology, integral risk assessment involves the following step-by-step procedure: hazard identification, selection of the «exposure – effect» relation, exposure assessment, and risk specification.

Hazard identification includes identification of environmental and lifestyle factors that may impact human health, possible effects of such factors, mechanisms of the negative impact on human health, and risk groups. At this stage it is necessary to make a decision regarding the need for an integral risk procedure for each individual case.

Exposure assessment includes determination of the quantitative parameters of the intensity and duration of negative environmental exposure, development of detailed scenarios of environmental exposure including the type of assessed exposure (one-time, chronic, intermittent, etc.)

Selection of the «exposure – effect» relation includes the analysis of available parameters in the form of mathematical representations and epidemiologic indicators that describe the relationship between the exposure to individual risk factors and associated health effects. Based on these parameters, it is possible to develop defining relations that are necessary for the integral risk calculation. Development of the methodology at the point of the «exposure – effect» relation selection involves risk modeling in accordance with the selected scenarios (simulation modeling).

Risk specification includes the calculation of additional integral health risk values related to the combined impact of the studied factors, adjusted health risk index, and shortened predicted life expectancy due to mixed negative exposure; it also includes the prediction of public health risk factors in the form of expected disease incidence and death rate within the population.

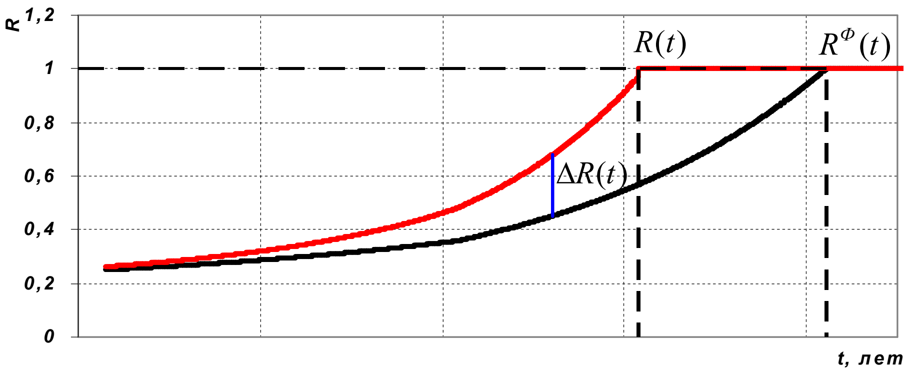
Additional risks of various health disorders associated with adverse effects of environmental factors can be calculated based on the formula below:

$$\Delta R_t = R_t - R_t^{\phi}, \quad (3)$$

Where

$\Delta R_t^{A/j}$ – Additional risk of various health disorders at a point of time t.

The plot of health disorder risk as a function of exposure duration and conditions with zero exposure and under exposure to environmental and lifestyle factors as well as the value of additional risk is shown in Figure 1.



Years

Figure 1: Evolution of risk and additional risk under exposure to the lifestyle and environmental factors

The adjusted health risk index related to the impact of adverse factors is calculated to assess the risk level:

$$\widetilde{R}_t = \frac{\Delta R_t}{1 - R_t^{\phi}} \quad (4)$$

The adjusted index shows the probability of health disorders under exposure to the lifestyle and environmental factors with the account of the increase in total health risk under longer exposure.

Assessment of the integral health risk values is based on the scale in Table 1.

Table 1: Integral risk assessment scale

Risk Rating Index	Risk Specification
0-0.1	Negligible risk
0.1-0.35	Moderate risk
0.35-0.6	High risk
0.6-1	Very high risk

Reduction in life expectancy related to environmental exposure is calculated based on the formula below:

$$\Delta T = T_0 - T_1, \quad (18)$$

where ΔT – reduction in the predicted life expectancy, years; T_0 – predicted life expectancy without environmental exposure obtained based on a step-by-step calculation without due regard to environmental exposure; T_1 – predicted life expectancy under adverse environmental exposure on a step-by-step calculation, years.

The proposed methodical approaches were tested on a model scenario developed on the basis of the results of an environmental quality monitoring within a social and hygienic monitoring project combined with the results of the sociological surveys of the influence of environmental and lifestyle factors in a large industrial urban area in the Russian Federation. Under the scenario, the integral effect of the chemical (carbon oxide, nitrogen dioxide, suspended matters PM2.5, suspended matters PM10, lead, cadmium, incoming from atmospheric air) and physical risk factors (road traffic noise), as well as the lifestyle factors, i.e. smoking, alcohol consumption, physical activity was assessed (Table 2).

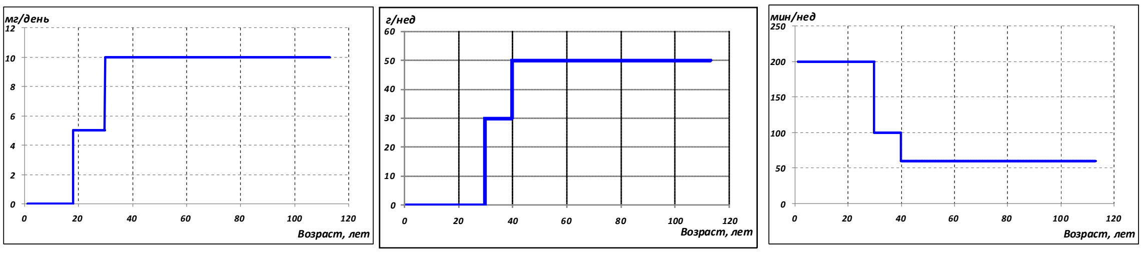
The assessment of time distribution of the road traffic noise based on the results of the analysis of chronology and duration of noise events in the studied area showed that this value can be described as stable and can considered as constant actual load matching the equivalent noise level of 55,72 dBA.

Table 2: Range of exposures to environmental and lifestyle factors

Factor	Unit	Factor Parameters	Permissible (reference) level
Substances coming from atmosphere air:			
– nitrogen dioxide	mg/m^3	0.022-0.127	0.04
– carbon oxide	mg/m^3	3.5-5.33	3.0
– suspended particulate matters $PM_{2.5}$	mg/m^3	0.034-0.043	0.025
– suspended particulate matters	mg/m^3	0.052-0.075	0.04

PM_{10}			
– lead	mg/m^3	0.000874-0.000929	0.0005
– cadmium	mg/m^3	0.00038-0.00041	0.00002
Physical exposure factors			
– noise	dBA	55.72	50
Social factors and lifestyle factors			
– smoking	mg nicotine/day	0-10	0.1
– alcohol consumption	g/week	0-50	30
– physical activity	min/week	200-60	min 200

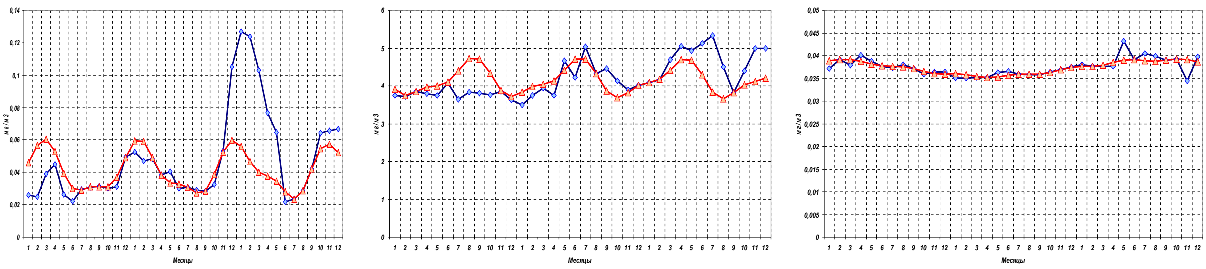
Levels conforming to the age ranges were determined for the lifestyle factors. Life-long distribution of lifestyle factors is shown in Figure 2.



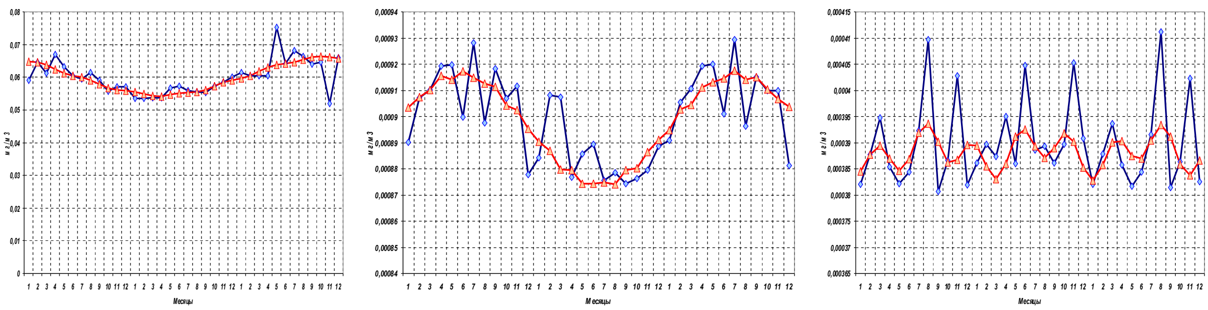
a) nicotine abuse b) excessive alcohol consumption c) activity

Figure 2: Time distribution of the lifestyle factors.

To obtain data estimates on the bases of a three-year air quality monitoring in the conditions of life-long exposure, we determined dynamic regularities of monthly average concentration, identified harmonic models, and calculated predictive estimates (Figure 3).



a) NO_2 b) CO_2 в) $PM_{2.5}$ c) $PM_{2.5}$



d) PM_{10} e) Pb f) Cd

Figure 3: Approximation of chemical substances concentrations in the air.

Background exposure conditions included permissible values of exposure at the reference concentrations level of chemical substances in the air, maximum permissible noise level, and recommended non-hazardous behaviors.

Integral risk was calculated on the basis of recurrence equation system in the form of a MS Excel program module. As a result, developmental deterministic risk models were obtained under two scenarios (background and test) (Figure 4)

Calculations based on the obtained additional risk models and adjusted risk index determined that under the exposure scenario in question impermissible (moderate) health risk is formed by the age of 47, and by the age of 58 this risk can be classified as high (Table 3).

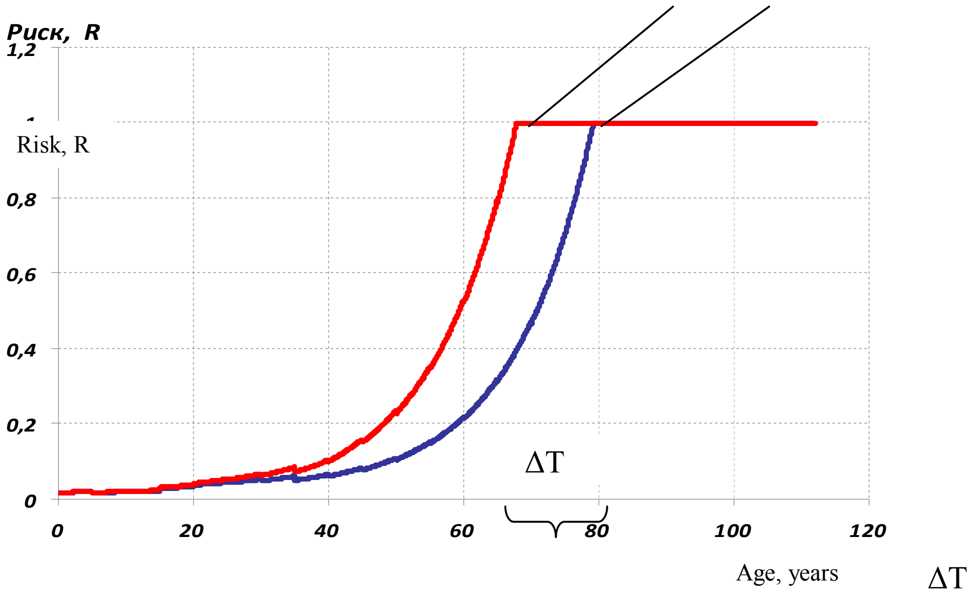


Figure 4: Developmental deterministic risk models under two scenarios (calculation data).

Table 3: Integral health risk calculation data

Age	Integral risk	Adjusted Risk Index	Risk Specification
10 years old	0.0206	0.0010	Negligible
20 years old	0.0377	0.0044	Negligible
40 years old	0.1005	0.0418	Negligible
50 years old	0.2228	0.1383	Moderate
60 years old	0.5227	0.3924	High

Analysis of the integral risk structure for the given exposure scenario showed that the most significant risk factors included excessive alcohol consumption and noise pollution as they generated the highest additional integral health risk by the age of 60. Smoking, low physical activity, and air pollutants like nitrogen dioxides and cadmium were classified as less hazardous risk factors.

Additional integral risk is generally determined by the impact of the studied factors on the cardiovascular system as well as, to a lesser degree, on the respiratory, endocrine, and digestive systems.

Lifestyle factors such as excessive alcohol consumption, smoking, and low physical activity contributed to risk generation to the maximal extent (Figure 5)

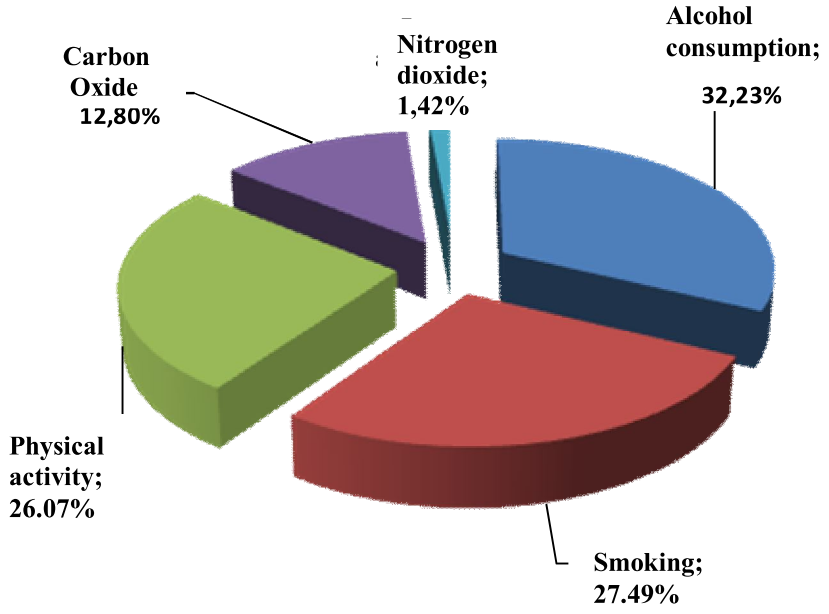


Figure 5: Contribution of various environmental and lifestyle factors to health risk generation under the studied exposure scenario.

The values of integral public health risk calculated on the basis of the developed methodological approaches [9] indicated a possible increase in disease incidence by the age of 60, including diseases of the circulatory system (up to 577‰), digestive system (up to 234‰), and respiratory system (up to 73‰). Additional death rate caused by the above diseases may total 6‰, 1‰, and 0.3‰ respectively. The value of predicted reduction in life expectancy associated with an integral adverse impact of environmental and lifestyle factors was used as an additional integral health risk parameter. Under the given scenario, this value for the studied population will constitute 12.3 years on average.

Conclusions:

1. Risk evolution modeling is an appropriate method for the assessment of health risks associated with mixed environmental and lifestyle factors; it helps obtain quantitative estimates of the individual and population risks including reduced life expectancy.

2. Methodical approaches to the assessment of risks associated with mixed environmental and lifestyle factors help assess their categories based on the use of a proposed scale and develop a model of organ and system risk dysfunction dynamic during the whole life

3. Testing of the proposed methods with the use of a model exposure scenario showed that the combined impact of mixed environmental and lifestyle factors (air pollution, road traffic noise, excessive alcohol consumption, smoking, low physical activity) can generate impermissible health risk by the age of 47, and by the age of 58 the risk can be classified as high.

4. Specification of the integral health risk under the studied scenario shows a possible increase in the level of disease incidence by the age of 60 including diseases of the circulatory, digestive, and respiratory systems. Additional death caused by the above diseases can total 6‰, 1‰, and 0.3‰ respectively; this results in reduced life expectancy by 12.3 years on average.

References

1. O sanitarno-epidemiologicheskom blagopoluchii naseleniya: Federal'nyy zakon ot 30 marta 1999 g. [On Health and Epidemiological Well-Being of the Population: the federal law as of March 30, 1999. № 52-FZ]. Available at: http: //files.stroyinf.ru/Data1/6/6000/.

2. Zaytseva N.V., Shur P.Z., May I.V., Kir'yanov D.A. Metodicheskie podkhody k otsenke integral'nogo riska zdorov'yu naseleniya na osnove evolyutsionnykh matematicheskikh modeley [Methodological approaches to integral health risk assessment based on mathematical evolutionary models]. Zdorov'e naseleniya i sreda obitaniya, 2011, no. 10. pp. 6–9.

3. Zaytseva N.V., Trusov P.V., Kir'yanov D.A. Kontseptual'naya matematicheskaya model' nakopleniya narusheniy funktsiy organizma, assotsiirovannykh s faktorami sredy obitaniya [A conceptual mathematical model of the accumulation of disorders in the body functions associated with environmental factors]. Meditsina truda i promyshlennaya ekologiya, 2012, no. 12, pp. 40–45.

4. Trusov P.V., Zaytseva N.V., Kir'yanov D.A., Kamaltdinov M.R., Tsinker M.Yu., Chigvintsev V.M., Lanin D.V. Matematicheskaya model' evolyutsii funktsional'nykh narusheniy v organizme cheloveka s uchetom vneshnesredovykh faktorov [A mathematical model of the evolution of functional disorders in the human body, taking into account environmental factors]. Matematicheskoe modelirovanie i bioinformatika, 2012, no. 2, pp. 589–610.

5. Kir'yanov D.A., Sukhareva T.N. Metod postroeniya integral'nogo indeksa funktsional'nogo sostoyaniya mochevydelitel'noy sistemy [A method for constructing the integral index of the functional condition of the urinary system]. Gigienicheskie i mediko-profilakticheskie tekhnologii upravleniya riskami zdorov'yu naseleniya v promyshlenno razvitykh regionakh: materialy nauchno-prakticheskoy konferentsii s mezhdunarodnym uchastiem. Ed. G.G. Onishchenko, N.V. Zaytseva. Perm: Knizhnyy format, 2010. 638 p.

6. Zaytseva N.V., Shur P.Z., Kir'yanov D.A., Kamaltdinov M.R., Tsinker M.Yu. Metodicheskie podkhody k otsenke populyatsionnogo riska zdorov'yu na osnove evolyutsionnykh modeley [Methodological approaches to population health risk assessment based on evolutionary models]. Zdorov'e naseleniya i sreda obitaniya, 2013, no. 1, pp. 4–6.

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