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CALCULATION OF SUPPLEMENTARY MORBIDITY AND MORTALITY THROUGH EVOLUTIONARY MODELING OF PUBLIC HEALTH RISK

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Abstract. The algorithm of population quantitative estimates for additional morbidity and mortality, corresponding to the risk of disorders of the relevant functions of organs and systems of the human body, has been developed based on an evolutionary model. At each stage of the algorithm the necessary data sources, methods of treatment and intermediate results are described in detail, the method takes into account the peculiarities of age distribution of health indicators using Severity Index. Testing of the method is performed on the example of the complex influence of diverse environmental factors on several critical organs and systems. The calculation results show that the additional risk of morbidity and mortality due to diseases of almost all classes and systems increases with age, taking the invalid values in the above working age. In addition, the structure of the additional risks demonstrates overbalance of conditions associated with disorders of blood circulatory system. The results of risk assessment according to the proposed algorithms can serve as a basis for additional studies of environmental factors impacting on health, organization of health prevention and control and monitoring events.
Key words: assessment of additional morbidity and mortality, evolutional modeling, risk of disorder of functions of organs and systems.

Introduction of public risk assessment guidelines based on evolution-based modelling [8] into the work of Rospotrebnadzor agencies and organizations made it possible to improve the risk assessment methodology and increase the range of objectives. The newly developed methods result from the adaptation of the fundamental human organs and systems disorder accumulation under exposure to environmental factors to the use in practice [4]. The main advantage of evolution-based models for risk assessment is the possibility to estimate the accumulation of negative effects risk in the form of human organs and systems disorders associated with environmental exposure. This method is generally aimed at the assessment of individual risk and, secondly, at making calculations for the population at large though the latter is more on demand for the purposes of health risk management. A series of publications devoted to the use of evolution-based models for risk assessment describe the approaches to calculating the incidence of diseases and death cases related to environmental exposure [3, 6–7]. Along with this, the materials that they contain do not have clear algorithms to describe the data sources and data processing methods to assess the risk for the population. For this reason, it is important to develop an algorithm for the quantitative assessments of additional morbidity and death rates

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corresponding to the risks of human organs and systems disorders calculated using evolution-based models.

Evolution-based models use the term 'risk' in its international meaning to indicate the combination of a risk level and its probability [1]. These models give an option to conduct dynamic assessments of the risk of functional disorders related to prolonged environmental exposure [3, 5].

[At that, risk was presented as a non-dimensional quantity in the range [0; 1]. On the one hand, the risk value that equals 0 (R = 0) corresponds with the absence of functional disorders in a human body and, consequently, absence of the cases of diseases and deaths. On the other hand, approximation of the risk value to one (R –> 1) corresponds with the increase in the frequency of heavy diseases and deaths.

Evolution-based models adjusted for various risk calculations in the form of recurrent ratios are shown in the formula (1):

$$R_{t+1}^{i} = R_{t}^{i} + (\alpha_i R_{t}^{i} + \sum_{j} \Delta R_{t}^{ij})C \qquad (1)$$

where R_{t+1}^{i} – risk of disorder in the i body system at the moment of time t + 1; R_{t}^{i} – risk of disorder in the I body system at the moment of time t; αi – coefficient that takes into account the evolution of risk due to natural factors; C – temporary empirical coefficient depending on the average time.

We used the value of additional risk determined by environmental factors and calculated as the difference of risks under exposure and zero exposure at any specific time – as a value that describes the contribution of factors in the evolution of risk:

$$\Delta R_{t}^{i} = R_{t}^{i} - R_{t}^{i/\delta}, \qquad (2)$$

where t – age group with a 5-year interval; ΔR_{t}^{i} – additional risk of disorder in the i organ systems at the age t; R_{t}^{i} – risk of disorder of the i organ system under environmental exposure at the age $R_{t}^{i/\delta}$ – risk of disorder of the i organ system under zero environmental exposure at the age t.

Assessment of individual risk is carried out using the scale as shown in [5]. The scale allows the risk by category from permissible to very high. However it is important to conduct the population assessment not only by risk category but also by number of additional cases of health disorders differentiated by severity (in the form of diseases and deaths) at any specific time.

A general algorithm for the quantitative assessment of additional cases of diseases and deaths associated with the dysfunction risk is based on the analysis of the age distribution of health indicators and includes subsequent execution of several stages (Figure 1).

Stage 1. Calculation of the risk of organ and system dysfunction with (no) account for environmental and lifestyle factors (R_t^i, $R_t^{i/\hat{0}}$).

Stage 2. Assessment of the average population disease severity indicator gi in relation to organs and systems dysfunction. Assessment of the severity of diseases is based on the comparison of expert assessments and data provided by the local Compulsory Medical Insurance Foundation.

Stage 3. Calculating the average population organ and system dysfunction risk ($\overline{R}_t^i$) based on the data on the morbidity and death rates with the account for the disease severity.

Stage 4. Building a system of reduced disease and death indicators $\tilde{z}_t^{ij}$ and $\tilde{s}_t^{ij}$ corresponding with the evolution curve of health risk accumulation under zero environmental exposure.

Stage 5. Building a system of the estimated disease and death indicators z_t^{ij} and s_t^{ij} corresponding with the evolution curve of health risk accumulation under environmental and lifestyle factors.

Stage 6. Calculation of the additional cases of diseases and deaths (Δz_t^{ij}) and (Δs_t^{ij}) related to the risk of dysfunction accumulation.

Population risk assessments are conducted with the use of the disease severity indicator that allows the comparison of various nosological forms and acts as a weight coefficient under the addition of the frequency of diseases and deaths [9]. The disease severity indicator is normalized from 0 to 1; given that, minor illnesses are described by the value of severity coefficient that is close to 0, and serious diseases – close to 1. The average population disease severity indicator is calculated based on the morbidity data and expert assessments of the severity of the most common (representative) diseases. For example, severity of URTI is assessed as 0.1; non-infectious gastroenteritis and colitis – as 0.35; cardiac angina – 0.70; malignant growth in the brain – 0.95. It should be noted that the group of experts included 10 practicing general physicians with at least 5 years of professional experience. Such requirements to the experts are determined by the need for an objective assessment of the severity of representative diseases.

Stage 1. Calculation of the risk of organ and system dysfunction with (no) account for environmental and lifestyle factors $(R_t^i, R_t^{i/\phi})$	**Used data:** Exposure of factors	Results: Risk distribution by age $(R_t^i, R_t^{i/\phi}, \Delta R_t^i)$
Stage 2. Assessment of the average population disease severity indicator g_i in relation to organs and systems dysfunction.	**Used data:** Morbidity Register of the Compulsory Medical Insurance Foundation Expert assessments of the severity	Results: Assessment of the disease severity for all the nosological forms gi
Stage 3. Calculation of the average population organ and system dysfunction risk $(\bar{R}_t^i)$	**Used data:** - Disease registry of the Federal (TFCMI) - Death rate (form №C51) - Population (table 2PH) - Disease severity gi	Results: Age distribution of the general $(\bar{R}_t^i)$ population risk
Stage 4. Building of the system of reduced disease and death indicators $\tilde{z}_t^{ij}$ and $\tilde{s}_t^{ij}$	**Used data:** - Age distribution of risk $(\bar{R}_t^i, R_t^{i/\phi})$ indicators - Disease registry of the Federal (TFCMI) - Death rate (form №C51)	Results: Age distribution of the indicators $\tilde{z}_t^{ij}$, $\tilde{s}_t^{ij}$
Stage 5. Building of the system of estimated disease and death indicators $\tilde{z}_t^{ij}$ and $\tilde{s}_t^{ij}$	**Used data:** - Age distribution of the average population risk with the account for (zero) environmental $(R_t^i, R_t^{i/\phi})$; exposure - Age distribution of $\tilde{z}_t^{ij}$, $\tilde{s}_t^{ij}$ indicators	Results: Age distribution of the indicators $\tilde{z}_t^{ij}$, $\tilde{s}_t^{ij}$
Stage 6. Calculation of the additional cases of diseases (Δz_t^{ij}) .. and deaths (Δs_t^{ij})	**Used data:** Age distribution of reduced and calculated disease and death $\tilde{z}_t^{ij}$, z_t^{ij} indicators and $\tilde{s}_t^{ij}, s_t^{ij}$	Results: Age distribution of the indicators Δz_t^{ij}, Δs_t^{ij}

Figure 1. A general algorithm for the quantitative assessment of additional cases of diseases and deaths associated with the dysfunction risk

Determination of the severity of the rest of the diseases is based on comparison with the representative disease by the duration of treatment. By so doing, the function of recalculating should meet the following requirements:

– severity of a disease is characterized by the duration of treatment;

– absence of disease corresponds with the absence of severity;

– severity of a disease is always less than one.

Taking into account the above requirements for the calculation of disease severity values, use the following ratios for the disease subclass:

$$g_i = 1 - e^{T_i \frac{\ln(1-g_M)}{T_M}}, \qquad (3)$$

where gM и TM – value of the severity and average duration of a representative disease; gi and Ti – calculated value of severity and average duration of i disease.

With the help of severity coefficient based on the disease and death rates distribution by age, we determine a reduced system of population health indicators which includes an age distribution of population disease and death rate indicators that correspond with the background evolution health risk curve.

At the same time, for each age group, we determine an indicator that corresponds with the average population organ and system dysfunction, using the following ratio:

$$\overline{R}_t^i = \frac{\sum_j \overline{z}_t^{ij} g^j + \overline{s}_t^i}{1000}, \qquad (4)$$

where t – age group with a 5-year interval; $\overline{R}_t^i$ – indicator that corresponds with the average population health disorder risk in the i system or organ at the age t; $\overline{z}_t^{ij}$ – average population morbidity for the j disease and i system or organ at the age t (cases per 1000); $\overline{s}_t^i$ – average population death rate from the disorders of the i system or organ at the age t (cases per 1000); g^j – severity coefficient.

Based on the ration between the indicators corresponding with the average population dysfunction risk, the calculated health risk under exposure to the factors under study and the background evolution health risk curve, we calculated the reduction coefficients:

$$k_t^i = \frac{R_t^{i/\delta}}{\overline{R}_t^i}, \quad l_t^i = \frac{R_t^i}{R_t^{i/\delta}}. \qquad (5)$$

The reduced and calculated system of the population morbidity and death rate indicators is determined based on the following ratio:

$$\begin{aligned} \tilde{z}_t^{ij} &= \overline{z}_t^{ij} \cdot k_t^i \quad z_t^{ij} = \tilde{z}_t^{ij} l_t^i, \\ \tilde{s}_t^{ij} &= \overline{s}_t^{ij} \cdot k_t^i \quad s_t^{ij} = \tilde{s}_t^{ij} l_t^i, \end{aligned} \qquad (6)$$

where $\tilde{z}_t^{ij}$, z_t^{ij} – reduced and calculated morbidity for the j disease of the i system at the age t; $\tilde{s}_t^{ij}$, s_t^{ij} – reduced and calculated morbidity for the j disease of the i system at the age t.

Additional morbidity and death rate are calculated as the difference between the calculated and reduced values:

$$\begin{aligned} \Delta z_t^{ij} &= z_t^{ij} - \tilde{z}_t^{ij} \\ \Delta s_t^{ij} &= s_t^{ij} - \tilde{s}_t^{ij}, \end{aligned} \qquad (7)$$

where Δz_t^{ij} – additional rate of j disease concerning i system at the age t; Δs_t^{ij} – additional death rate from j disease concerning i system at the age t.

We tested new methods to calculate additional cases of diseases and deaths corresponding with the risk of dysfunction based on the results of evolution-based modelling of the health risk under environmental exposure determined by the level of exposure presented in Table 1.

The example describes combined exposure to heterogeneous factors of several critical organs and systems. Such situations are typical of the urban areas located in close proximity to industrial enterprises and characterized by various social issues.

The results of the risk assessment conducted with the use of evolution-based modelling are presented in Table 2.

Additional risk becomes impermissible in the age groups of 45+. Here, the main disorders concern the cardiovascular system. Impermissible risk of disorders of other systems begins to develop after the age of 60.

The obtained values of additional dysfunction risk are in line with the additional cases of diseases and deaths as shown in Tables 3 and 4.

The tables contain the values of the calculated morbidity and death rate that correspond with the additional dysfunction risks. Since the circulatory system as affected most of all, the composition of additional morbidity and death rate shows excess of conditions associated with cardiovascular disorders. The dynamic patter of the values of additional morbidity and death rate associated with the dysfunction risks is shown in Figure 2.

Table 1

The range of exposure values determined by environmental factors

Factor	Factor parameters	Permissible level
Nitrogen oxide in the atmospheric air, mg/m^3	0,022–0,127	0,04
Carbonic oxide in the atmospheric air , mg/m^3	3,5–5,33	3,0
Cadmium in drinking water, mg/dm^3	0,00038–0,00041	0,00002
Noise, dBA	55,72	50
Smoking, mg of nicotine/day	0–10	0,1
Alcohol consumption, g/week	0–50	30
Physical activity, min/week	200–60	Не менее 200

Table 2

Additional dysfunction risk associated with environmental exposure

Age, years old	Urinary system diseases	Central nervous system diseases	Respiratory diseases	Digestive tract diseases	Circulatory system diseases	Ear and mastoid bone diseases	Endocrine system diseases
from 20 to 24	0,001	0,003	0,001	0,001	0,004	0,004	0,002
from 25 to 29	0,001	0,003	0,002	0,002	0,008	0,004	0,003
from 30 to 34	0,002	0,006	0,004	0,003	0,012	0,006	0,005
from 35 to 39	0,003	0,009	0,007	0,006	0,022	0,007	0,008
from 40 to 44	0,008	0,015	0,01	0,013	0,042	0,009	0,016
from 45 to 49	0,015	0,026	0,014	0,026	0,077	0,011	0,028
from 50 to 54	0,021	0,037	0,017	0,041	0,131	0,012	0,045
from 55 to 59	0,029	0,049	0,022	0,057	0,213	0,015	0,068
from 60 to 64	0,036	0,061	0,027	0,074	0,338	0,018	0,096
from 65 to 69	0,043	0,074	0,033	0,093	0,527	0,021	0,136
from 70 to 74	0,051	0,087	0,04	0,114	0,478	0,024	0,189
75 and older	0,059	0,102	0,047	0,137	0,209	0,028	0,26

Table 3

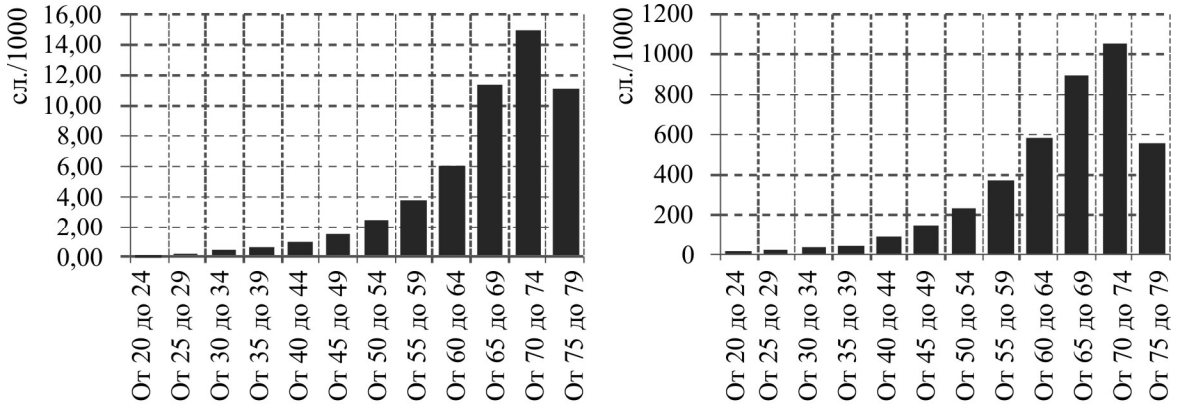
Additional morbidity by classes related to the main organs and systems (number of cases per 1000 population)

Age, years old	Urinary system diseases	Central nervous system diseases	Respiratory diseases	Digestive tract diseases	Circulatory system diseases	Ear and mastoid bone diseases	Endocrine system diseases
from 20 to 24	1,100	5,439	8,130	5,814	7,868	14,919	6,720
from 25 to 29	2,393	8,686	16,718	12,803	13,474	18,872	11,302
from 30 to 34	4,451	13,012	28,395	22,821	23,290	23,600	19,622
from 35 to 39	7,410	19,292	42,817	35,387	40,017	28,993	32,214
from 40 to 44	16,294	33,837	53,431	83,637	74,395	32,918	60,165
from 45 to 49	31,504	56,094	63,399	159,187	136,497	36,872	107,370
from 50 to 54	47,113	80,762	73,005	233,773	229,765	41,816	168,711
from 55 to 59	62,712	109,388	78,743	308,362	366,589	46,605	248,464
from 60 to 64	78,063	135,221	87,266	393,629	576,665	55,014	353,359
from 65 to 69	91,873	157,646	100,359	493,202	886,424	59,313	495,415
from 70 to 74	107,419	181,616	115,645	594,794	1052,728	65,513	684,385
75 and older	124,309	224,206	135,220	648,903	549,218	63,479	932,231

Table 4

Additional deaths by cause corresponding with the main organs and systems (number of cases per 1000 population)

Age, years old	Urinary system diseases	Central nervous system diseases	Respiratory diseases	Digestive tract diseases	Circulatory system diseases	Ear and mastoid bone diseases	Endocrine system diseases
from 20 to 24	0,000	0,000	0,001	0,001	0,029	0,000	0,002
from 25 to 29	0,001	0,000	0,013	0,006	0,151	0,000	0,000
from 30 to 34	0,002	0,000	0,032	0,019	0,386	0,000	0,007
from 35 to 39	0,007	0,000	0,042	0,039	0,613	0,005	0,014
from 40 to 44	0,025	0,000	0,078	0,124	0,944	0,000	0,006
from 45 to 49	0,033	0,000	0,142	0,238	1,547	0,000	0,034
from 50 to 54	0,069	0,000	0,141	0,490	2,404	0,000	0,036
from 55 to 59	0,104	0,000	0,211	0,786	3,737	0,004	0,060
from 60 to 64	0,207	0,000	0,271	1,080	6,073	0,000	0,131
from 65 to 69	0,198	0,000	0,406	1,392	11,282	0,000	0,184
from 70 to 74	0,276	0,000	0,556	1,758	15,000	0,000	0,388
75 and older	0,405	0,000	0,827	2,945	11,079	0,000	0,640



а *б*

Figure 2. Age distribution of population death risks associated with the circulatory system diseases (а) and circulatory system diseases (б) under exposure to environmental and lifestyle factors

The figure above shows that the age distribution of quantitative risk indicators corresponds with the main consistent patterns of age-related health disorders. The calculations showed that additional morbidity risk and deaths from diseases of various organs and systems increase with age. At an older age, additional morbidity and deaths are higher as compared to the respective indicators at a working age.

Conclusions. Consequently, the offered algorithm of the quantitative assessment of population health risks gives an opportunity to add data on the estimated additional disease and death cases related to environmental exposure to the assessment of individual risk using evolution-based models. Furthermore, the obtained results may serve as a basis for advanced

studies of the effects of environmental factors on public health as well as the development of medical and preventative programs. Introduction of this approach into the activities of the Federal Service on Surveillance for Consumer Rights Protection and Human Well-Being may help obtain evidence on the effects of pollution sources on public health, mainly, for the purposes of preventative and supervisory programs.

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