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Research article

# ASSESSMENT OF POTENTIAL HAZARDS POSED BY INFLUENCE OF RISK-INDUCING ENVIRONMENTAL FACTORS AND FACTORS RELATED TO THE EDUCATIONAL PROCESS ON SOMATIC HEALTH OF SCHOOLCHILDREN IN DIFFERENT SCHOOLS

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*Contemporary school should create favorable conditions for schoolchildren. The aim of the study was to comparatively analyze risk factors related to the educational process in different schools and to develop a new approach to objective assessment of combined exposure to environmental factors and factors related to the educational process and its influence on schoolchildren's health.*

*The study focused on the following research objects: 1) five different secondary schools, the test ones providing profound educational programs and the reference ones being ordinary secondary schools with the same or lower levels of pollution in environmental objects; 2) quality of components in the school environment (organization of the educational process, quality of meals provided by school, quality of ambient air on a school territory and inside a school, quality of drinking water, socioeconomic conditions); 3) health of 756 schoolchildren. The study was conducted by using sanitary-epidemiological, sanitary-hygienic and sociological methods; clinical and laboratory examinations; chemical analytical tests. Fuzzy logic was applied to estimate combined influence exerted by factors related to the educational process and environmental factors.*

*We established several determinants of negative effects produced by the educational process on schoolchildren's health. They included elevated intensity and monotony of educational and intellectual loads, shorter breaks between classes and recovery index deficiency. Diet-related factors included excess consumption of fats and carbohydrates, overall caloric contents being too high, protein and micronutrient deficiency. Chemical factors were elevated levels of metals, aromatic hydrocarbons, aldehydes, and chlorinated organic compounds in biological media. Risk-inducing factors of schoolchildren, regardless of a school and age, include organization of the educational process (Ipj = 0.45–0.58) and school meals (Ipj = 0.41–0.54); the group potential hazard index for these factors reached its peak values in primary school (Ipj = 0.49–0.58 and Ipj = 0.46–0.54). The maximum value of the integral potential hazard index ($I_{pdk}$ = 0.41–0.46) caused by combined exposure to factors related to the educational process and environmental factors, regardless of a school type, was detected in senior schoolchildren in school with profound studies of natural sciences ($I_{pdk}$ = 0.41); the minimum value was detected in a military school ($I_{pdk}$ = 0.33).*

***Keywords:*** *schoolchildren, health risk factors, educational process, diet, environment, fuzzy sets.*

Children's health protection is one of the key trends in the state social policy and sanitary-epidemiological wellbeing of the RF population is a way to provide it [1]. The years 2018–2027 have been declared the Childhood Decade by the RF President Order No. 240 issued on May 29, 2017. The priority activities that are to be performed during this period include providing a comfortable and safe educational environment for the rising generation. School should create favorable conditions for schoolchildren to study there and combine both educational activities and those beyond the educational process relying on health-protecting teaching technologies [2, 3]. The contemporary educational process covers not only issues concerning how education activities are organized at school but also tasks related to providing



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schoolchildren with a safe in-school environment and adequate meals. It should include teaching them useful skills as regards how to correctly organize their activities beyond school and how to pursue a healthy lifestyle [4]. The reforms of the contemporary secondary education involve, among other things, creating specialized schools (gymnasiums, schools with advanced studies of various subjects, military schools etc.). These specialized schools have the right to develop a wide range of their own educational programs and apply variable teaching technologies [5, 6]. However, these newly developed teaching technologies do not often undergo any sanitary-hygienic examination to establish their safety for schoolchildren's health whereas data obtained by multiple studies reveal unfavorable trends in basic health indicators of children when they are examined in dynamics over school years [7, 8]. Educational loads are growing and the educational process itself is being intensified and involving wider use of IT; given that, educational programs can only be mastered by significant exertion of schoolchildren's functional capabilities [9, 10].

At present, many studies focus on examining influence exerted by chemical pollutants in ambient air, air inside school buildings and drinking water on schoolchildren's health [5]. Air inside schools and on near-school territories is often polluted with formaldehyde, phenol, styrene and ethylbenzene in concentrations being higher than hygienic standards; drinking water is often polluted with chlorinated organic compounds in unsafe concentrations. All this leads to these chemicals occurring in children's biological media in concentrations being higher than permissible ones with subsequent adverse general somatic effects and those affecting specific organs or systems [11, 12].

Nutrition is a most significant factor influencing health of a growing body [13]. Diseases that result from improper nutrition can become apparent not only in childhood but also at later stages in ontogenesis [14]. Children's unhealthy diets are of growing concern not only in the RF but also abroad since they result in alimentary-dependent diseases and elevated risks of cardiovascular and other systemic diseases at an older age [15]. Children spend a significant amount of their time at school; despite that, we can't fail to consider a substantial role that belongs to socioeconomic factors in children's family homes as well as their activities beyond school. Some studies have established that half of schoolchildren have physical activity below levels recommended by the WHO whereas the rapidly developing information-interactive space involves more and more of them in becoming its active users [16].

Over the last decade, many studies have concentrated on examining effects produced by various factors related to the educational process on biological constants of development and schoolchildren's somatic health. However, issues related to combined exposure to such factors have not been given enough attention [16, 17]. Targeted management of health risks for schoolchildren associated with the educational process requires developing a new approach to objective assessment of combined exposure to intra-school factors and those beyond it. Such an approach makes it possible to identify priority risk factors and differentiate relevant sanitary-hygienic and medical-preventive activities.

**In this study, our aim was** to analyze priority risk factors associated with the educational process in different schools and to develop a new approach to objective assessment of combined exposure to environmental factors and factors related to the educational process and its influence on schoolchildren's health.

**Materials and methods.** Our research objects included the following:

– five different types of secondary schools; the test schools implemented educational programs with advanced studies of some subjects: type I school provided more profound studies of natural sciences; type II school focused on general development (more profound studies of humanitarian sciences); type III school had an additional educational program focusing on sports and physical training (more profound military training). The reference schools were ordinary secondary ones with the same (type IV school) and lower (type V school) levels of pollution in environmental objects;

– quality of components in the school environment (organization of the educational process, quality of meals provided at school, quality of ambient air on a school territory and inside a school, quality of drinking water, socioeconomic conditions)

– health of 756 schoolchildren.

The study design involved using sanitary-epidemiological, sanitary-hygienic and sociological procedures; performing clinical-laboratory tests and chemical analytical tests; using risk assessment, probabilistic analysis and fuzzy sets.

Organization of the educational process in primary, middle and senior school was estimated by comparatively analyzing them. The analysis aimed to identify their conformity with the requirements stipulated by the Sanitary Rules and Standards SanPiN 2.4.3648-20[1] and SanPiN 1.2.3685-21[2]. Intensity of the educational process was examined in accordance with the Federal Recommendations FR ROSHUMZ-16-2015[3].

Hygienic assessment of ambient air quality on near-school territories, air inside school premises and drinking water from centralized water supply systems was conducted by using field observation results. Outdoor and indoor air samples were taken according to the State Standards GOST 17.2.3.01 and GOST R ISO 16017-1. Air quality was estimated as per contents of phenol, benzene, toluene, ethylbenzene, manganese, lead, nickel, and chromium. Phenol was identified in ambient air by using spectrophotometry; formaldehyde, high performance liquid chromatography (HPLC); metals, mass spectrometry; aromatic hydrocarbons (benzene, toluene and ethylbenzene), gas chromatography; all identifications were performed as per conventional procedures[4]. Drinking water was analyzed to identify chloroform, tetrachloromethane, and 1,2-dichloroethane by using gas chromatography according to the State Standard GOST 31951-2012; formaldehyde, by using HPLC according to the State Standard GOST 55227-2012; metals, by using mass spectrometry with inductively coupled plasma. Water samples were taken from a source of centralized water supply (tap). We calculated simple mean concentrations of controlled chemicals in water. Quality of indoor and outdoor air as well as water quality was estimated by comparing single and average daily concentrations of the analyzed chemicals with the existing hygienic standards (single maximum MPC, average daily MPC, RfC, MPC) as well as with the same indicators on reference territories. Chemical analysis of phenol, formaldehyde, aromatic hydrocarbons, chloroform, manganese, nickel, chromium, and lead in blood was performed as per conventional

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[1] SanPiN 2.4.3648-20. Sanitarno-epidemiologicheskie trebovaniya k organizatsiyam vospitaniya i obucheniya, otdykha i ozdorovleniya detei i molodezhi (utv. postanovleniem Glavnogo gosudarstvennogo sanitarnogo vracha Rossiiskoi Federatsii ot 28.09.2020 № 28) [Sanitary Rules SP 2.4.3648-20. Sanitary-epidemiological requirements to organizing education, leisure and health improvement of children and youth (approved by the Order of the RF Chief Sanitary Inspector dated September 28, 2020 No. 28)]. Moscow, The Federal Service for Surveillance over Consumer Rights Protection and Human Wellbeing, 54 p. (in Russian).

[2] SanPiN 1.2.3685-21. Gigienicheskie normativy i trebovaniya k obespecheniyu bezopasnosti i (ili) bezvrednosti dlya cheloveka faktorov sredy obitaniya [Sanitary Rules and Standards SanPiN 1.2.3685-21. Hygienic standards and requirements to providing safety and (or) harmlessness of environmental factors for people]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/573500115 (October 19, 2022) (in Russian).

[3] Gigienicheskaya otsenka napryazhennosti uchebnoi deyatel'nosti obuchayushchikhsya: federal'nye rekomendatsii po okazaniyu meditsinskoi pomoshchi obuchayushchimsya [Hygienic assessment of the intensity of educational activities by students: federal recommendations on providing medical care for schoolchildren]. Moscow, 2015, 18 p. (in Russian).

[4] RD 52.04.186-89. Rukovodstvo po kontrolyu zagryazneniya atmosfery [RD 52.04.186-89. Guide on control over ambient air pollution]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200036406 (October 19, 2022) (in Russian); MUK 4.1.1045-01. VEZhKh opredelenie formal'degida i predel'nykh al'degidov ($C_2$–$C_{10}$) v vozdukhe [MUK 4.1.1045-01. Control procedures. Chemical factors. HPLC applied to determine formaldehyde and saturated aldehydess ($C_2$–$C_{10}$) in ambient air]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200029341 (October 19, 2022) (in Russian); MUK 4.1.3481-17. Izmerenie massovykh kontsentratsii khimicheskikh elementov v atmosfernom vozdukhe metodom mass-spektrometrii s induktivno svyazannoi plazmoi [MUK 4.1.3481-17. Measuring mass concentrations of chemicals in ambient air by mass spectrometry with inductively coupled plasma]. *The library for regulatory documentation*. Available at: https://files.stroyinf.ru/Index2/1/4293735/4293735234.htm (October 19, 2022) (in Russian); MUK 4.1.3167-14. Gazokhromatograficheskoe opredelenie geksana, geptana, benzola, toluola, etilbenzola, m-, o-, p-ksilolov, izopropilbenzola, n-propilbenzola, stirola, a-metilstirola, benzal'degida v atmosfernom vozdukhe, vozdukhe ispytatel'noi kamery i zamknutykh pomeshchenii [MUK 4.1.3167-14. Gas chromatography identification of hexane, heptane, benzene, toluene, ethylbenzene, м-, o-, p-xylene, isopropyl benzene, n-propyl benzene, styrene, a-methyl styrene, benzaldehyde in ambient air, air inside test chamber and closed premises]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200119249 (October 19, 2022) (in Russian).

procedures[5]. Reference regional background levels as well as levels identified in the reference groups were used as criteria for estimating chemical pollution in biological media.

Meals provided at school were comparatively estimated by analyzing daily menus and identifying the chemical structure and energy values of these meals; ratios between basic nutrients were estimated to determine their conformity with the requirements stipulated in the SanPiN 2.3/2.4.3590-20[6]. We analyzed daily meals to comparatively estimate whether an average daily food set corresponded to the established standards. An average weight of a helping and actual food consumption were identified by individual weighing that took place during four weekdays, 10 weight measurements taken each time [18]. We calculated nutrient and energy value of meals taken for breakfast and lunch (and additionally for a mid-afternoon snack in the type III school). Data on daily consumption of basic foods were obtained by questioning; they made it possible to calculate individual contents of macro- and micronutrients in a daily diet. All these calculations relied on data taken from the reference book on the chemical structure of foods in Russia[7].

Socioeconomic risk factors and factors related to lifestyle were analyzed relying on data of a social survey accomplished by handing out questionnaires to be filled in by participants. The questionnaire included five sets of questions to describe parents' education, family incomes, living conditions, schoolchildren's spare time, intensity of learning activities beyond school, and physical activity (65 questions overall). The results were estimated as per an integral indicator with its score varying between 1 and 3 (the higher the score, the better qualitative indicators).

Clinical and functional examination of children was performed as per conventional procedures and included anthropometric measurements (SD score was used as a reference value); bioimpedance analysis (BIA) to estimate BMI (kg/m$^2$), fat mass (FM, %), phase angle (PA, grades), bone and muscle mass (BMM, kg), body cell mass (BCM, kg) and fat-free mass (FFM, kg); electroencephalography (EEG); psychological testing (RT-test to assess a reaction time, motor function velocity, and attention level; STROOP-test to estimate cognitive functions; CORSI-test to estimate visual-spatial short-term working memory; and Luscher test to estimate psychological stress level); heart rate variability examination; analysis of children's outpatient medical records (the medical Form No. 112/u). Children's health

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[5] MUK 4.1.2108-06. Opredelenie massovoi kontsentratsii fenola v biosredakh (krov') gazokhromatograficheskim metodom [MUK 4.1.2108-06. Determination of mass concentration of phenol in biological media (blood) with gas chromatography]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200065240 (October 21, 2022) (in Russian); MUK 4.1.2111-06. Izmerenie massovoi kontsentratsii formal'degida, atsetal'degida, propionovogo al'degida, maslyanogo al'degida i atsetona v probakh krovi metodom vysokoeffektivnoi zhidkostnoi khromatografii [MUK 4.1.2111-06. Determination of mass concentration of formaldehyde, acetaldehyde, propionic aldehyde, fatty aldehyde and acetone in blood samples by high performance liquid chromatography]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200065243 (October 21, 2022) (in Russian); MUK 4.1.765-99. Gazokhromatograficheskii metod kolichestvennogo opredeleniya aromaticheskikh (benzol, toluol, etilbenzol, o-, m-, p-ksilol) uglevodorodov v biosredakh (krov') [MUK 4.1.765-99. Gas chromatography applied to quantify aromatic (benzene, toluene, ethylbenzene, o-, m-, p-xylene) hydrocarbons in biological media (blood)]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200039012 (October 21, 2022) (in Russian); MUK 4.1.2115-06. Opredelenie massovoi kontsentratsii khloroforma, 1,2-dikhloretana, tetrakhlormetana v biosredakh (krov') metodom gazokhromatograficheskogo analiza ravnovesnogo para [MUK 4.1.2115-06. Determination of mass concentration of chloroform, 1,2-dichloroethane, tetrachloromethane in biological media (blood) by gas chromatography analysis of equilibrium vapor]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200065247 (October 21, 2022) (in Russian); MUK 4.1.3230-14. Izmerenie massovykh kontsentratsii khimicheskikh elementov v biosredakh (krov', mocha) metodom mass-spektrometrii s induktivno svyazannoi plazmoi [MUK 4.1.3230-14. Determination of chemical mass concentrations in biological media (blood, urine) with mass spectrometry with inductively coupled plasma]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/495856222 (October 21, 2022) (in Russian); MUK 4.1.3161-14. Izmerenie massovykh kontsentratsii svintsa, kadmiya, mysh'yaka v krovi metodom mass-spektrometrii s induktivno svyazannoi plazmoi [MUK 4.1.3161-14. Determination of mass concentrations of lead, cadmium and arsenic in blood with mass spectrometry with inductively coupled plasma]. *The library for regulatory documents*. Available at: https://files.stroyinf.ru/Index2/1/4293766/4293766470.htm (October 21, 2022) (in Russian).

[6] SanPiN 2.3/2.4.3590-20. Sanitarno-epidemiologicheskie trebovaniya k organizatsii obshchestvennogo pitaniya naseleniya [Sanitary Rules and Standards 2.3/2.4.3590-20. Sanitary-epidemiological requirements to organizing catering provided for population]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/566276706 (October 19, 2022) (in Russian).

[7] Khimicheskii sostav rossiiskikh pishchevykh produktov: spravochnik [Chemical structure of foods in Russia: the reference book]. In: Professor I.M. Skurikhin and RAMS Academician, Professor V.A. Tutelyan eds. Moscow, DeLi print, 2002, 236 p. (in Russian).

was assessed by analyzing the results of clinical examinations performed by a pediatrician, allergologist, neurologist, gastroenterologist, ENT doctor, ophthalmologists, an expert in exercise therapy and a cardiologist[8]. Results of the laboratory tests were examined as per protocols of general clinical, biochemical, immunologic and immune-enzyme analysis[9].

The obtained data were analyzed with Statistica 6.0 software package and embedded statistical functions in Microsoft Excel 2010. The study results were mathematically treated with parametric statistic methods with preliminary assessment of their conformity with the normal distribution. Student's t-test and Fisher's test were applied to estimate authenticity of differences. The social survey results were statistically analyzed by calculating and comparing simple means, identifying frequency and structural properties. Authenticity of differences between social indicators was estimated by using Kruskal – Wallis and Mann – Whitney criteria considering children's age and a school they attended. We estimated influence exerted by the educational process, meals at school, chemical pollutants and socioeconomic factors on anthropometric indicators, children's somatic and mental health by using one-factor logistic regression modeling of 'dose – likelihood of response (effect)' relationships. The model significance was estimated as per Fisher's test ($F$) with giving a constant value ($b_0$), regression coefficient ($b_1$), and Nagelkerke determination coefficient ($R^2$). Any differences were considered statistically significant at $p \leq 0.05$. Overall, the logistic regression model was formulated as follows:

$$p = \frac{1}{1 + e^{-(b_0 + b_1 x)}}, \qquad (1)$$

where $p$ is a probability that a response will deviate from the standard; x is exposure level; $b_0$, $b_1$ are parameters of the mathematical model.

Combined effects produced by organization of the educational process, meals at school and anthropogenic contaminants were estimated by a method based on fuzzy logic (fuzzy sets). Each factor was estimated with integral values to identify whether it belonged to a set of a scaled indicator. To estimate influence exerted by each of three indicator groups on schoolchildren's health, we used a scale with score values between 0 and 1. It graded a potential hazard index considering weight contributions by specific indicators ($I_{pdi}$) and a whole group of indicators ($I_{pdj}$) to an ultimate result. Weight contributions made by meals at school, educational process and chemical environmental factors to severity of potential impairments of schoolchildren's biological status were taken as equal to 0.4; 0.5; 0.1, and primary, middle and senior school were taken as equal to 0.3; 0.2; 0.5 accordingly. The potential hazard index ($I_{pd}$) was considered as a basic quantitative value of contributions made by specific indicators. This value was used to estimate an integral index ($I_{pdk}$) and was calculated as a sum of products obtained by multiplying potential hazard indexes of each indicator group ($I_{pdj}$) and their weight contributions to severity of potential impairments of schoolchildren's biological status ($V_g$). When calculating a membership degree for a potential hazard index to identify whether it belonged to a certain set of the scale, the fuzzy set method implied the sets had fuzzy boundaries (± 20 % fuzzy). As a result, values within the neighboring sets of the scale could intersect. Each range of indicator values was a trapezoid fuzzy number with the membership function showing whether it belonged or did not belong to a certain set of the scale. The method was implemented by using the membership function $\mu(x)$ to a trapezoid fuzzy number, which was given by four numbers ($a_1$, $a_2$, $a_3$, $a_4$) as the basic instrument. In its general view, the membership function for an indicator $x$ to a specific trapezoid number was given with the following formula:

$$\mu(x) = \begin{cases} 0, & \text{if } x < a_1, \\ \dfrac{x - a_1}{a_2 - a_1}, & \text{if } a_1 \leq x < a_2, \\ 1, & \text{if } a_2 \leq x \leq a_3, \\ \dfrac{x - a_4}{a_3 - a_4}, & \text{if } a_3 < x \leq a_4, \\ 0, & \text{if } x > a_4. \end{cases} \qquad (2)$$

[8] All the examinations were performed by medical experts of the Federal Scientific Center for Medical and Preventive Health Risk Management Technologies.

[9] All the examinations were performed by experts from the Departments for clinical, cytogenetic and immune biological diagnostic methods of the Federal Scientific Center for Medical and Preventive Health Risk Management Technologies.

The value $\mu(x)$ reflected that a set of an indicator value belonged to a set of a scale showing potential hazard index values.

When estimating a potential hazard index for chemical factors, we identified a negative health outcome for each indicator in accordance with the Guide R 2.1.10.1920-04 and Methodical Guidelines 2.1.10.3014-12 as well as other relevant research data. A negative health outcome (a group of diseases in accordance with the ICD-10 from A00 to R99) was given a rank $l$ considering its severity ranked within a range between 0 and 1. We determined a weight (frequency) of each group of diseases ranked as per its severity in the total negative health outcome ($W_l$) as per Fishburne's Rule:

$$W_l = \frac{2(K-l+1)}{(K+1)K}, \quad (3)$$

where $W_l$ is a weight of a ranked group of diseases in the total negative health outcome; $K$ is the total number of groups of diseases identified in the total negative health outcome; $l$ is a rank of a negative health outcome (a group of diseases) as per its severity.

The calculated weight of each group of diseases ($W_l$) was applied to a weight of each indicator in this group participating in the total negative health outcome ($G_i$). To estimate the potential hazard index as per meals provided at school and factors related to the educational process, we established a weight of each indicator ($G_i$) as per the following formula:

$$G_i = \frac{1}{m}, \quad (4)$$

where $m$ is the number of all the analyzed indicators in the group.

$$w_j = \sum\nolimits_i G_i \cdot \mu_{ji}, j = 1,2,3,4,5, \quad (5)$$

where $w_j$ is a share of indicators belonging to a specific potential hazard index (or to the $k$-th scaled set of the potential hazard index and its rank) of the total number of indicators in the group;

$G_i$ is a weight of each indicator contributing to the total negative health outcome;

$\mu_{ji}$ is the membership function for each indicator showing its belonging to the $j$-the scaled set of the potential hazard index and its rank.

We calculated an index for each group of indicators ($I_{pdj}$) allowing for their share contributions to all kinds of negative health outcomes as per the following formula:

$$I_{pdj} = \sum_{j=1}^{5} \overline{I_j} \cdot w_j, \quad (6)$$

where $I_{pdj}$ is a value of an index for each indicator group allowing for their share contributions to all kinds of negative health outcomes;

$\overline{I_j}$ is the middle of each set on the scale with values of the potential hazard index determined by impacts exerted by each group of indicators;

$w_j$ is a share of indicators belonging to a specific potential hazard index (or to the $k$-th scaled set of the potential hazard index and its rank) of the total number of indicators in a group.

The integral potential hazard index ($I_{pdk}$) as per all the indicator groups was calculated as per the following formula:

$$I_{pdk} = \frac{1}{\overline{V_g}} \sum_{p=1}^{5} I_{pdj} \cdot V_g, \quad (7)$$

where $I_{pdj}$ is a value of an index for each indicator group allowing for their share contributions to all kinds of negative health outcomes;

$V_g$ is a weight contribution made by a group of indicators to the integral potential hazard index;

$\overline{V_g}$ is an average weight contribution made by all groups into the integral index.

The indexes were estimated separately for primary, middle and senior school; as per each factor and a group of factors; for each separate school. The obtained values allowed assigning a rank to each school as per potential hazards posed by its environment for schoolchildren's health.

**Results and discussion.** We analyzed how the educational process was organized in all the examined schools. The analysis revealed that the Sanitary Rules and Norms SanPiNH 2.4.3648-20[10]

[10] SanPiN 2.4.3648-20. Sanitarno-epidemiologicheskie trebovaniya k organizatsiyam vospitaniya i obucheniya, otdykha i ozdorovleniya detei i molodezhi (utv. postanovleniem Glavnogo gosudarstvennogo sanitarnogo vracha Rossiiskoi Federatsii ot 28.09.2020 № 28) [Sanitary Rules SP 2.4.3648-20. Sanitary-epidemiological requirements to organizing education, leisure and health improvement of children and youth (approved by the Order of the RF Chief Sanitary Inspector dated September 28, 2020 No. 28)]. Moscow, The Federal Service for Surveillance over Consumer Rights Protection and Human Wellbeing, 54 p. (in Russian).

were violated in all of them. However, the educational process in the schools with advanced studies of some subjects involved by 1.4 times more intensive educational loads and irrational use of electronic teaching aids as opposed to the ordinary secondary schools. The educational process itself was by 1.4–1.9 times more intensive in such schools.

Our assessment of outdoor and indoor air quality established that toluene and ethylbenzene occurred in air in all the analyzed schools; in addition, we identified elevated (against average daily MPC equal to 0.01 mg/m$^3$) phenol and formaldehyde levels. They were by 1.6–1.7 times higher than average daily MPC in ambient air (0.0162 ± 0.0022–0.0168 ± 0.0034 mg/m$^3$) and by 1.2-2.0 times higher in air inside school premises (0.0124 ± 0.0025–0.02136 ± 0.0044 mg/m$^3$), $p < 0.001$.

Quality of drinking water was established to deviate from the requirements stipulated in the SanPiN СанПиН 1.2.3685-21[11] in both groups of the analyzed schools (test and reference ones). Chloroform (0.138 ± 0.01 mg/m$^3$ and 0.186 ± 0.007 mg/m$^3$) and formaldehyde (0.123 ± 0.004 mg/m$^3$ and 0.094 ± 0.002 mg/m$^3$) levels in drinking water were higher than MPC (0.06 and 0.05 mg/m$^3$ accordingly) ($p < 0.001$). The chloroform level (0.138 ± 0.01 mg/m$^3$) was by 1.4 times lower and formaldehyde (0.123 ± 0.004 mg/m$^3$) and manganese (0.0093 ± 0.0015 mg/m$^3$) levels were by 1.3 and 28.2 times higher accordingly in the test schools against the same indicators in the reference ones (0.186 ± 0.007 mg/m$^3$; 0.094 ± 0.002 mg/m$^3$; 0.0033 ± 0.0004 mg/m$^3$ accordingly, $p < 0.001$).

We examined chemical contents in children's biological media and established elevated levels of certain chemicals that were higher than the regional background ones in all the analyzed schools. Thus, phenol levels were by 1.5–5.0 times higher (0.0100 ± 0.0036 µg/ml) and formaldehyde levels were by 2.2–16.8 times higher (0.0050 ± 0.0014 µg/ml) in primary, middle and senior school (0.0150 ± 0.0050–0.0502 ± 0.0073 µg/ml and 0.0110 ± 0.0007–0.0840 ± 0.0310 µg/ml accordingly; $p < 0.001$). Benzene and toluene were identified in biological media of children in the type I school; chromium contents were by 1.4–1.8 times higher than their reference values (0.0027 ± 0.00199 µg/ml) in biological media of children from the type II school: 0.0037 ± 0.0005–0.0049 ± 0.0010 µg/ml ($p < 0.001$), and we also identified benzene, toluene and chloroform in them; chromium levels were by 1.9–2.7 times higher than the reference ones in biological media of children in the type III school: 0.0052 ± 0.0005–0.0072 ± 0.0008 µg/ml ($p < 0.001$) and we also identified benzene, toluene and chloroform in them; benzene and ethylbenzene were identified in biological media of children in the type IV school; benzene, toluene and chloroform, the type V school.

Comparative hygienic assessment of meals provided at the analyzed schools revealed that the standard macronutrients ratios (1:1:4) were violated in menus in all of them. Meals provided at the type IV school were the closest to the recommended standards (1 : 1.1 : 3.8); meals provided at the type I school had total nutrient deficiency (0.8 : 0.7 : 2.6); the type II (1.6 : 1.6 : 5.0), III[12] (1.4 : 1.5 : 4.3) and V (1.4 : 1.3 : 4.8) schools had nutrients in excessive quantities. The lowest micronutrient deficiency was established in the type I school (calcium, vitamin A); the highest micronutrient deficiency was identified in the type III school ($B_1$, $B_2$, C, A, iron, calcium, magnesium, and phosphor). It is noteworthy that calcium deficiency was identified in meals provided at all the analyzed schools.

We established that, given the maximum contribution made to a daily diet by home meals (76.0–92.2 %), schoolchildren attending most of the analyzed schools consumed some products in excessive quantities (sausages, by 1.7–2.0 times higher than recommended; macaroni, by 1.4–1.5 times; confectionary, by 7.8–8.0 times) whereas others were consumed in insufficient ones (vegetables, fruits, fish and cereals were consumed in quantities by 1.6–3.8 times lower than recommended). Three meals provided at the type

[11] SanPiN 1.2.3685-21. Gigienicheskie normativy i trebovaniya k obespecheniyu bezopasnosti i (ili) bezvrednosti dlya cheloveka faktorov sredy obitaniya [Sanitary Rules and Standards SanPiN 1.2.3685-21. Hygienic standards and requirements to providing safety and (or) harmlessness of environmental factors for people]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/573500115 (October 19, 2022) (in Russian).

[12] Diets provided at the type III school were compared in accordance with the requirements fixed for military schools.

III school were the closest to the recommended daily diet for schoolchildren.

Our study of socioeconomic factors and children's lifestyles revealed that family incomes were substantially higher in families of children who attended innovative schools and their parents had higher education more frequently than parents of children who attended ordinary secondary schools. Schoolchildren in innovative schools tended to spend by 3.5 times more time on additional educational activities and sports.

Comparative assessment of schoolchildren's physical development established that schoolchildren who attended the type I school tended to develop harmoniously in primary and middle school and this harmonious development was by 1.8–2.4 times more frequent among them than in the reference schools. Still, a risk of disharmonious development grew in senior school and was by 4.0 times higher than in an ordinary school. Schoolchildren in the type II school typically had height, weight, and hand dynamometry corresponding to age-specific norms; still, a relative risk of excessive height was by more than 6.0 times higher for them than in the reference schools by the end of school studies. Schoolchildren attending the type II school tended to have average weight, a well-developed chest and there was a trend established for them that the chest excursion would grow by 1.6 times by senior school; a risk of overweight was by 3.0 times higher for school leavers of the type II school than in the reference schools. Senior schoolchildren in the analyzed ordinary secondary schools tended to have average height; however, each third adolescent in these schools had overweight ($p = 0.02$).

Our assessment of the nutritive status established that a number of children with BMI and FM being by 1.4–1.8 times higher than the standard grew by 2.0–2.3 times in senior school in the analyzed ordinary secondary schools. Simultaneously, low BMM and BCM were identified in 14.0–27.6 % and 25.6–31.0 % of the senior schoolchildren in these schools accordingly whereas there were only isolated cases of them in primary and middle schools. The schoolchildren in the type I school typically had by 2.5 times lower BMI and FM in senior school together with growing PA, BCM and BMM, which were by 1.3–2.6 times higher than in primary and middle school. The schoolchildren in the type II school tended to be physically active during the whole educational period; the fact is confirmed by higher BMM which is by 1.6–2.3 times more frequent in this school and a number of children with proper BMM being by 3.2 times higher in senior school. BIA results in the type III school revealed better physical form and activity than in the analyzed ordinary schools evidenced by BCM, BMM and PA being by 1.2–1.8 times higher in the schoolchildren who attended it.

Having analyzed EEG results, we established that frequency of impaired cerebral rhythms went down with age in all the analyzed schools. In the ordinary secondary schools (types IV and V), dysfunctions were identified in 10.0 % and 7.6 % of the senior schoolchildren accordingly whereas we detected a discontinuous trend in the type I and II schools: bioelectrical cerebral activity stabilized in most middle schoolchildren (86.4–100.0 %) and then destabilization was identified in 23.8–26.0 % of the senior schoolchildren. A relative risk that a number of children with deviations from the physiological standards would grow in senior school was by 3.8 times higher in the type I school than in the reference ones. In the type III school, a share of schoolchildren with their EEG indicators corresponding and not corresponding to the age-specific standard equaled 50.0 %. By senior school, a delay in cortical rhythm development was identified only in 13.3 % of the schoolchildren in the type II school; however, a relative risk that dysfunctional bioelectrical cerebral activity would persist was by 1.8 times higher for the schoolchildren in the type II school than in the reference ones.

Psychological tests identified by 1.2–2.9 times lower stress and anxiety levels and higher cognitive flexibility in the schoolchildren from the type I, II, and III school than in their counterparts from the ordinary schools (types IV and V). We compared test results obtained at the beginning and end of a school year and revealed a decrease in children's effectiveness in all the analyzed schools. This difference in test results was more typical for the schoolchildren in the type I and III schools (by 2.8 times). The schoolchildren who attended schools with advanced studies of some subjects had by 1.2–2.9 times more stable working memory but also higher stress, anxiety, fatigue and excessive excitation by senior school. A relative risk that a number of children with some mental stress would grow by senior school was by 12.0 times higher in the type I school and by more than 4.0 times higher in the type II school than in the reference ones.

We estimated functional state of children's autonomic nervous system and identified that the eutonic type of the initial vegetative tone (IVT) prevailed in the schoolchildren in all the analyzed schools in primary, middle, and senior school. In the type I school, a number of children with the eutonic IVT went down by 1.6 times (from 67.6 to 41.7 %); a relative risk that a number of children with the vagotonic IVT would grow in senior school was by 2.0 times higher than in the reference schools. A share of children with sympathicotonic vegetative reactivity (VR) remained stable in primary, middle and senior school in the reference schools and the type III school whereas it tended to decline by 1.3–1.8 times with age in the type I and II schools. The schoolchildren who attended the analyzed schools with profound studies of some subjects tended to have asympathicotonic VR by 4.0 times more frequently in senior school than in primary and middle school (from 0.0–5,9 % to 15.4–23.8 % cases).

Our analysis of incidence established that eye diseases occurred by 3.1–5.2 times more frequently in senior school in all the analyzed schools (the incidence grew from 7.7–18.2 % to 23.5–71.6 %); this was the most typical for the type I school (71.6 %) and the least typical for the type III school (23.0 %). Incidence of nervous diseases tended to grow by 1.7 times among the schoolchildren in the type I school (from 54.2 % to 89.5 %). Incidence of endocrine diseases was established to grow in all the other schools (from 35.4–77.1 % to 45.1–89.5 %). Somatic incidence of most groups of diseases tended to be by 1.2–3.1 times higher among the schoolchildren in the ordinary secondary schools.

We analyzed how the schoolchildren were distributed as per the health groups. The analysis revealed that the number of schoolchildren in the 1$^{st}$ and 2$^{nd}$ health group was by 1.2–1.8 times lower and the number of schoolchildren in the 3$^{rd}$ health group was by 1.8–2.5 times higher in primary and secondary school in the test schools than in the reference ones. In middle school, a relative risk that a number of schoolchildren in the 3$^{rd}$ health group would grow was by more than 3.0 times higher in the analyzed schools with advanced studies of some subjects than in the reference schools; in senior school, the same indicator was by 1.9 times higher in them.

We estimated regularities of developing negative health outcomes relying on the results obtained by laboratory tests. It revealed that a situation when factors related to the educational process did not conform to the standards, chemical contents in ambient air, air inside school premises, drinking water and biological media were higher than maximum permissible and background regional / reference levels, macro- and micronutrients balance and caloric contents of school meals did not conform fully to the age-specific standards, and social factors did not satisfy schoolchildren's physiological needs properly resulted in developing imbalance of the neuroendocrine and neuro-vegetative regulation ($R^2$ = 0.26–0.31), impaired oxidative-antioxidant processes ($R^2$ = 0.10–0.22), imbalance of basic metabolism types ($R^2$ = 0.13–0.89) and developing secondary transitory immune deficiency against background sensitization ($R^2$ = 0.10–0.68). Imbalance of the neuroendocrine and neurovegetative regulation in the children from the test group was evidenced with by 1.4 times lower serotonin and hydrocortisone levels, by 1.2 times lower free T4, by 1.7 times lower acetylcholine and by 2.0 times higher TSH. Impaired oxidative-antioxidant homeostasis was confirmed by 1.9 times more frequent lower AOA in the test group than in the reference one, by 2.9 times higher MDA levels and by 4.4 times higher Δ-ALA. Basic metabolic disorders became apparent through bilirubinemia, hyperglycemia and less active bone remodeling; they were by 1.3–1.6 times more frequent in the test group. Secondary immune suppression was evidenced with by 1.2–1.4 times higher sensitization indicators together with by 1.2–1.6 items lower levels of leukocytes, monocytes, CD19, IL-4 and phagocytic activity.

Our assessment of impacts exerted by the set of the analyzed factors on schoolchildren's body composition revealed that elevated phenol and chromium levels decreased a possibility that BCM would reach its physiological norm whereas iron, vitamin C and $B_1$ consumed with food in age-specific standard quantities increased it. BMM was more likely to reach its physiological standard in case calcium, magnesium, phosphor and proteins were consumed with food in balanced quantities; this likelihood went down due to elevated nickel and formaldehyde levels in blood. BCM and BMM were less likely to develop properly in case educational loads grew. FFM development was authentically affected in primary school by monotonous and intensive educational loads; in secondary school, by shorter breaks between classes and reduced recovery indexes as well as elevated chromium and formaldehyde levels in blood. In senior school, FFM development was affected considerably by magnesium and protein deficiency in school meals. Basic metabolic indicators were largely impaired by elevated educational loads, shorter breaks and reduced recovery index as well as growing chromium and formaldehyde levels in blood. Lower educational loads and reduced intellectual components in them as well as shorter breaks made FM accumulation and BMI growth more probable whereas elevated chromium levels in blood made these indicators decline. In primary school, elevated benzene levels in children's blood made excessive FM accumulation more likely. Adequate consumption of proteins, fats and carbohydrates became especially vital in middle and senior school. Elevated nickel and lead levels in blood reduced growth indicators in primary school, whereas likelihood that height would conform to its physiological standard grew in middle and senior school provided that meals corresponded to the recommended standards as per calcium, phosphor, iron and vitamins $B_1$, $B_2$, and C contents.

Next, we estimated effects produced by the set of the analyzed factors on incidence among the examined schoolchildren. The estimation revealed that cardiovascular diseases developed mostly due to influence exerted by such factors as elevated benzene, nickel and lead levels in blood, growing educational loads and recovery index deficiency, as well as shorter breaks. Diseases of the nervous system were more likely to occur due to excessive caloric contents in school meals; magnesium and vitamin $B_1$ deficiency; growing monotony of learning, daily educational and emotional loads; elevated lead, formaldehyde and phenol levels in blood. Chloroform in blood as well as levels of nickel, formaldehyde, chromium, lead and phenol in it being higher than maximum permissible ones made diseases of the genitourinary, digestive and respiratory systems more probable. Diseases of the digestive system might be induced by monotonous learning; growing daily educational loads and greater deficiency of recovery index; shorter breaks; magnesium, protein and vitamin C deficiency; excessive fat consumption. Respiratory diseases were more likely to develop due to monotony and intensity of learning, growing number of classes a day, as well as toluene in biological media. Prevalence of diseases of the eye grew due to elevated formaldehyde levels in blood, vitamins A and C deficiency in school meals as well as due to growing emotional and intellectual loads and more classes a day than recommended by the hygienic standards. Diseases of skin and subcutaneous tissue were induced by chromium and nickel levels in blood being higher than reference ones as well as growing monotony and intensity of learning and daily educational loads. We established a relationship between diseases of the musculoskeletal system and excessive caloric contents of school meals, excessive quantities of carbohydrates in them, vitamin C deficiency, a growing number of classes a day, increasing intensity of learning and its intellectual component as well as lead and manganese contents in blood. Diseases of the endocrine systems developed due to excessive quantities of carbohydrates, protein and vitamin C and $B_1$ deficiency in school meals as well as due to shorter breaks.

The next estimation focused on influence exerted by the set of the analyzed factors on the results obtained by psychological testing. It established that greater educational loads, longer classes, growing monotony of learning, increasing intellectual and emotional loads impaired visual-spatial short-term working memory; at the same time, a lower index of recovery deficiency and longer breaks improved it. Cognitive processes became less effective due to longer classes, shorter breaks, growing intellectual and daily educational loads. Our assessment of effects produced by anthropogenic contaminants revealed lower cognitive functions among schoolchildren of all ages in case they had elevated manganese, lead, nickel, phenol and chloroform levels in blood. Spatial-visual short-term working memory was established to be impaired by elevated nickel level in primary school; phenol and chloroform, in middle school; and manganese and nickel, in senior school. Elevated magnesium, nickel, lead, and phenol levels as well as chloroform contamination lead to more probable increase in reaction time in schoolchildren of all ages. Estimated effects produced by meals on the results of psychological testing included lower flexibility of cognitive processes due to protein, calcium, iron and vitamin C and $B_1$ deficiency and excessive carbohydrates and total caloric contents. Visual-spatial short-term working memory was impaired by calcium, vitamin C, A, and $B_2$ and protein deficiency and excessive fat consumption. Reaction time in psychological testing was authentically prolonged by calcium, iron, magnesium, vitamin C and protein deficiency and excessive carbohydrate contents. We established a relationship between impaired cognitive functions and growing intensity of learning in primary, middle and secondary school whereas an increase in physical activity made cognitive processes more flexible. Effectiveness of working memory directly depended on socioeconomic conditions in a family; however, a contribution made by this factor did not exceed 6.0–10.0 % in primary, middle and senior school.

Therefore, we identified several basic determinants of negative effects produced by the educational process on schoolchildren's development, somatic and mental health. They included growing intensity and monotony of learning; increased intellectual loads; shorter breaks and recovery deficiency index; as for meals provided at school, these factors were excessive fat and carbohydrate contents, excessive caloric contents. protein and micronutrient deficiency; chemical factors included elevated manganese, lead, chromium, nickel, phenol and formaldehyde levels in blood as well as occurrence of aromatic hydrocarbons in biological media.

The fuzzy logic was applied to identify values and a structure of a potential hazard index and to rank it; this index fully describes effects produced by exposure to factors related to the educational process and environmental factors on schoolchildren's morphofucntional state, their somatic and mental health. For the type I school the potential hazard index associated with improper school meals equaled $I_{pdj} = 0.065$ in primary school; $I_{pdj} = 0.033–0.082$ in middle and senior school; its overall value for all age groups equaled $I_{pdj} = 0.180$ (hazard was low, negligible). The potential hazard index due to improper organization of the educational equaled $I_{pdj} = 0.087$ in primary school, $I_{pdj} = 0.052$ in middle school and $I_{pdj} = 0.123$; the overall value for all age groups was $I_{pdj} = 0.262$ (low hazard). The potential hazard index associated with anthropogenic contaminants equaled $I_{pdj} = 0.005–0.003$ in primary and middle school but there was an ascending trend in it in senior school up to $I_{pdj} = 0.008$; the overall value for all age groups was $I_{pdj} = 0.016$ (negligible hazard) (Table).

The integral potential hazard index associated with multi-component influence exerted by school meals, the educational process and anthropogenic contaminants equaled $I_{pdk} = 0.39$ (average-low) in primary and middle school and $I_{pdk} = 0.46$ (average) in senior school. In the type I school, the integral potential hazard index was by 2.6–3.1 times higher than its safe level ($I_{pd} < 0.15$) for all age groups and grew by 1.2 times from primary to senior school. The overall integral potential hazard index for impaired biological status equaled $I_{pdk} = 0.47$ (average) for the schoolchildren of all ages who attended the type I school. This value was by 3.0 times higher than the upper limit of its safe level (Figure).

In the type II school, the potential hazard index associated with improper meals equaled $I_{pdj} = 0.052$ in primary school, $I_{pdj} = 0.033$ in middle school and $I_{pdj} = 0.082$ in senior school; its total value for all age groups reached $I_{pdj} = 0.166$ (negligible or low hazard). The potential hazard index associated with the factors of the educational process equaled $I_{pdj} = 0.074$ in primary school, $I_{pd} = 0.045$ in middle school and $I_{pd} = 0.123$ in senior school; its total value for all age groups was $I_{pdj} = 0.242$ (negligible or low hazard). The potential hazard index associated with anthropogenic contaminants equaled $I_{pdj} = 0.005$ in primary school, $I_{pdj} = 0.003$ in middle school and $I_{pdj} = 0.008$ in senior school; its total value for all age groups was $I_{pdj} = 0.016$ (negligible hazard). The integral potential hazard index for impaired schoolchildren's biological status under exposure to all the analyzed factors equaled $I_{pdk} = 0.34$ in primary school, $I_{pdk} = 0.32$ in middle school (low hazard); its value grew by 1.2–1.32 times in senior school and reached $I_{pdk} = 0.42$ (average-low hazard). The integral potential hazard index for all schoolchildren who attended the type II school equaled

The potential hazard indexes for schoolchildren's impaired biological status in different schools

| Risk factors | Type I school | | | Type II school | | | Type III school | | | Type IV school | | | Type V school | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Primary (I), middle (II) or senior (III) school | | | | | | | | | | | | | | |
| School meals | I | II | III | I | II | III | I | II | III | I | II | III | I | II | III |
| Proteins, g | 0.06 | 0.05 | 0 | 0 | 0 | 0 | 0.04 | 0.03 | 0.05 | 0 | 0.04 | 0 | 0 | 0.03 | 0 |
| Fats, g | 0 | 0.04 | 0.07 | 0.07 | 0.07 | 0.07 | 0.03 | 0.03 | 0.04 | 0.1 | 0.03 | 0.07 | 0.10 | 0.05 | 0,07 |
| Carbohydrates, g | 0 | 0.04 | 0.06 | 0.05 | 0.06 | 0.06 | 0.04 | 0.04 | 0.05 | 0.1 | 0.04 | 0.06 | 0.10 | 0.05 | 0,06 |
| Caloric contents, kcal | 0 | 0.04 | 0.05 | 0.07 | 0.05 | 0.04 | 0.04 | 0.03 | 0.04 | 0.1 | 0.04 | 0.05 | 0.10 | 0 | 0,05 |
| $B_1$, mg | 0.07 | 0.04 | 0.05 | 0.05 | 0.06 | 0.05 | 0.05 | 0.05 | 0.05 | 0 | 0.03 | 0.05 | 0 | 0.05 | 0,05 |
| $B_2$, mg | 0.06 | 0.03 | 0.05 | 0.07 | 0.06 | 0.06 | 0.04 | 0.03 | 0.05 | 0 | 0.05 | 0.05 | 0 | 0.05 | 0,05 |
| C, mg | 0.06 | 0.04 | 0 | 0 | 0 | 0 | 0.06 | 0.05 | 0.06 | 0.09 | 0.04 | 0 | 0.09 | 0.05 | 0 |
| A, mg | 0.08 | 0.05 | 0 | 0.06 | 0 | 0 | 0.05 | 0.05 | 0.05 | 0 | 0.07 | 0 | 0 | 0.03 | 0 |
| Ca, mg | 0.06 | 0.07 | 0.08 | 0 | 0.08 | 0.08 | 0.05 | 0.05 | 0.05 | 0 | 0.06 | 0.08 | 0 | 0.03 | 0,08 |
| P, mg | 0.06 | 0.03 | 0.05 | 0.07 | 0.05 | 0.05 | 0 | 0 | 0 | 0.08 | 0.06 | 0.05 | 0.08 | 0.05 | 0,05 |
| Mg, mg | 0.06 | 0 | 0 | 0 | 0 | 0 | 0.04 | 0.03 | 0.05 | 0 | 0.04 | 0 | 0 | 0.04 | 0 |
| Fe, mg | 0.05 | 0 | 0 | 0 | 0 | 0 | 0.05 | 0.04 | 0.03 | 0 | 0.04 | 0 | 0 | 0 | 0 |
| Total ($I_{pd}$) | 0.54 | 0.42 | 0.41 | 0.43 | 0.41 | 0.41 | 0.46 | 0.42 | 0.49 | 0.46 | 0.53 | 0.41 | 0.46 | 0.43 | 0,41 |
| $I_{pdj}$ per age groups | 0.065 | 0.033 | 0.082 | 0.052 | 0.033 | 0.082 | 0.054 | 0.033 | 0.098 | 0.055 | 0.042 | 0.082 | 0.055 | 0.034 | 0,082 |
| $I_{pdj}$ for a school as a whole | 0.180 | | | 0.166 | | | 0.185 | | | 0.180 | | | 0.171 | | |
| Educational process | | | | | | | | | | | | | | | |
| A break between classes and additional studies | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.13 | 0.09 | 0.14 | 0.17 | 0.17 | 0.14 | 0.14 | 0.15 |
| The longest break | 0.08 | 0.08 | 0.08 | 0.07 | 0.07 | 0.07 | 0.08 | 0 | 0 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.07 |
| Breaks between classes | 0.1 | 0.1 | 0.1 | 0.07 | 0.07 | 0.07 | 0.08 | 0 | 0 | 0.1 | 0 | 0 | 0.1 | 0.1 | 0.07 |
| A number of students in a class, $m^2$ | 0.08 | 0.08 | 0.08 | 0.06 | 0.06 | 0.06 | 0.06 | 0.1 | 0.1 | 0.06 | 0.08 | 0.08 | 0.06 | 0.06 | 0.06 |
| Weekly educational loads | 0.08 | 0.06 | 0.07 | 0.08 | 0.06 | 0.07 | 0.06 | 0.08 | 0.08 | 0.07 | 0.09 | 0.08 | 0.07 | 0.07 | 0.06 |
| Daily educational loads, classes | 0.08 | 0.05 | 0.07 | 0.08 | 0.05 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.07 | 0.07 |
| Total ($I_{pd}$) | 0.58 | 0.52 | 0.55 | 0.49 | 0.45 | 0.49 | 0.50 | 0.38 | 0.34 | 0.53 | 0.49 | 0.48 | 0.53 | 0.51 | 0.47 |
| $I_{pdj}$ per age groups | 0.087 | 0.052 | 0.123 | 0.074 | 0.045 | 0.123 | 0.068 | 0.038 | 0.085 | 0.080 | 0.049 | 0.120 | 0.080 | 0.051 | 0.012 |
| $I_{pdj}$ for a school as a whole | 0.262 | | | 0.242 | | | 0.191 | | | 0.249 | | | 0.142 | | |
| Anthropogenic contaminants | | | | | | | | | | | | | | | |
| Phenol, $mg/dm^3$ | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.01 |
| Toluene, $mg/dm^3$ | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Benzene, $mg/dm^3$ | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Formaldehyde, $mg/dm^3$ | 0.01 | 0.01 | 0.02 | 0.03 | 0.02 | 0.02 | 0.00 | 0.00 | 0.00 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.02 |
| Manganese, $mg/dm^3$ | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| Chromium, $mg/dm^3$ | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| Nickel, $mg/dm^3$ | 0 | 0.03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Chloroform, $mg/dm^3$ | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 |
| 1,2-dichloroethane, $mg/dm^3$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ethylbenzene | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 |
| Carbon tetrachloride, $mg/dm^3$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lead, $mg/dm^3$ | 0.03 | 0.02 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| Total ($I_{pd}$) | 0.15 | 0.15 | 0.16 | 0.17 | 0.16 | 0.16 | 0.15 | 0.15 | 0.15 | 0.16 | 0.16 | 0.16 | 0.15 | 0.15 | 0.16 |
| $I_{pdj}$ as per age group | 0.005 | 0.003 | 0.008 | 0.005 | 0.003 | 0.008 | 0.004 | 0.003 | 0.007 | 0.005 | 0.003 | 0.008 | 0.005 | 0.003 | 0.008 |
| $I_{pdj}$ for a school as a whole | 0.016 | | | 0.016 | | | 0.014 | | | 0.016 | | | 0.016 | | |
| The integral $I_{pdk}$ as per age group | 0.39 | 0.39 | 0.46 | 0.34 | 0.32 | 0.42 | 0.34 | 0.30 | 0.32 | 0.36 | 0.37 | 0.42 | 0.35 | 0.37 | 0.41 |
| Total as per age group, % | 100.0 | 4.60<br>95.30 | 100.0 | 16.53<br>83.47 | 42.89<br>57.11 | 23.85<br>76.15 | 2.36<br>97.64 | 87.1<br>21.9 | 67.43<br>32.57 | 100.0 | 100.0 | 29.49<br>70.51 | 100.0 | 6.58<br>93.42 | 36.17<br>63.83 |
| The integral ($I_{pdk}$) for a school as a whole | 0.472 | | | 0.425 | | | 0.400 | | | 0.444 | | | 0.435 | | |
| Total as per school, % | 100.0 | | | 25.46<br>74.54 | | | 50.05<br>49.95 | | | 5.63<br>94.37 | | | 15.2<br>84.8 | | |

Note:

- blue – negligible hazard
- green – low hazard
- yellow – average hazard
- orange – high hazard
- red – extremely high hazard

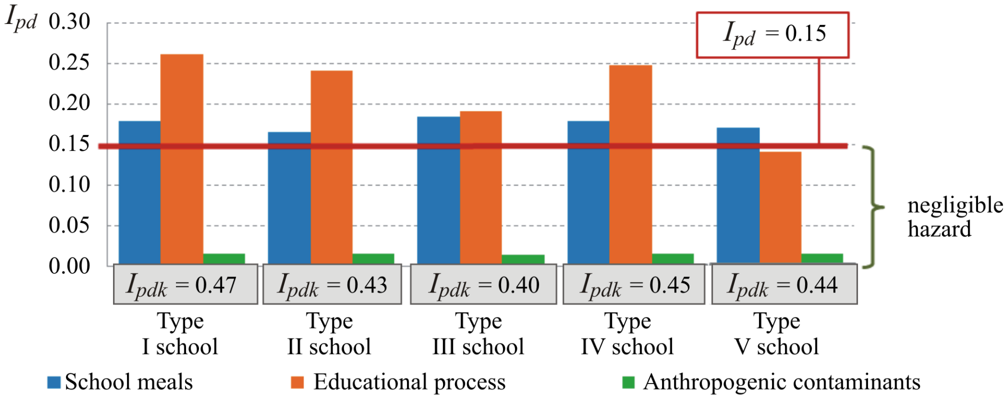


Figure. Profiles of potential hazard indexes for impaired schoolchildren's biological status under combined exposure to the set of the analyzed environmental factors ad factors related to the educational process

$I_{pdk}$ = 0.43 (average-low hazard) and this value was by 2.9 times higher than its permissible level. In the type III school, the potential hazard index associated with improper school meals equaled $I_{pdj}$ = 0.054 in primary school, $I_{pd}$ = 0.033 in middle school and $I_{pd}$ = 0.098 in senior school. Its total value for all age groups reached $I_{pdj}$ = 0.185 (negligible – low hazard). Improper organization of the educational processes created the potential hazard index being equal to $I_{pdj}$ = 0.068 in primary school, $I_{pdj}$ = 0.038 in middle school and $I_{pdj}$ = 0.085 in senior school; its total value for all age groups equaled $I_{pdj}$ = 0.191 (negligible – low hazard). The potential hazard index associated with anthropogenic contaminants equaled $I_{pdj}$ = 0.004 in primary school, $I_{pdj}$ = 0.003 in middle school and $I_{pdj}$ = 0.007 in senior school; its total value for all age groups equaled $I_{pdj}$ = 0.014 (negligible hazard). The integral potential hazard index for impaired schoolchildren's biological status under exposure to all the analyzed factors equaled $I_{pdk}$ = 0.34 in primary school; $I_{pdk}$ = 0.30 in middle school and $I_{pdk}$ = 0.32 in senior school (low hazard). The integral potential hazard index for all schoolchildren who attended the type III school equaled $I_{pdk}$ = 0.40 (average-low hazard) and this value was by 2.7 times higher than its permissible level ($I_{pd}$ < 0.15). In the type IV school, the potential hazard index associated with improper school meals equaled $I_{pdj}$ = 0.055 in primary school, $I_{pd}$ = 0.042 in middle school and $I_{pdj}$ = 0.082 in senior school; its total value for all age groups reached $I_{pdj}$ = 0.180 (negligible – low hazard). The potential hazard index associated with improper organization of the educational process equaled $I_{pdj}$ = 0.080 in primary school, $I_{pdj}$ = 0.049 in middle school and $I_{pdj}$ = 0.120 in senior school; its total value for all age groups equaled $I_{pdj}$ = 0.249 (negligible – low hazard). The potential hazard index associated with anthropogenic contaminants equaled $I_{pdj}$ = 0.005 in primary school, $I_{pdj}$ = 0.003 in middle school and $I_{pdj}$ = 0.008 in senior school; its total value for all age groups reached $I_{pdj}$ = 0.016 (negligible hazard). The integral potential hazard index for impaired schoolchildren's biological status under exposure to all the analyzed environmental factors and factors related to the educational processes actors equaled $I_{pdk}$ = 0.36 and $I_{pdk}$ = 0.37 in primary and middle school accordingly and $I_{pdk}$ = 0.42 in senior school (average-low hazard) and therefore was unacceptable ($I_{pdk}$ > 0.15) for all age groups growing by 1.2 times from primary to senior school. The integral potential hazard index for all schoolchildren who attended the type IV school equaled $I_{pdk}$ = 0.45 (average hazard) and this value was by 3.0 times higher than its permissible level. In the type V school, the potential hazard index associated with improper school meals equaled $I_{pdj}$ = 0.055 in primary school, $I_{pdj}$ = 0.034 in middle school and $I_{pdj}$ = 0.082 in senior school; its total value for all age groups reached $I_{pdj}$ = 0.171 (negligible – low hazard). The potential hazard index associated with improper organization of the educational process equaled $I_{pdj}$ = 0.080 in primary school, $I_{pdj}$ = 0.051 in middle school and $I_{pdj}$ = 0.012 in senior school; its total value for all age groups was $I_{pdj}$ = 0.142 (negligible hazard). The potential hazard index associated with anthropogenic contaminants equaled $I_{pdj}$ = 0005 in primary school, $I_{pdj}$ = 0.003 in middle school and $I_{pdj}$ = 0.008 in senior school; its total value for all age groups reached $I_{pdj}$ = 0.016 (negligible hazard). The integral potential hazard index under exposure to all the analyzed environmental factors and factors related to the educational processes equaled $I_{pdk}$ = 0.35 in primary school, $I_{pdk}$ = 0.37 in middle school and $I_{pdk}$ = 0.41 in senior school (average – low hazard) growing by 1.2 times from primary to senior school. The integral potential hazard index for all schoolchildren who attended the type V school equaled $I_{pdk}$ = 0.44 (average – low hazard) and this value is by 2.9 times higher than its safe level ($I_{pd}$ < 0.15).

Overall, the primary meal-related factors with the greatest contributions to the potential hazard index for schoolchildren of all ages include deficiency of micronutrients, especially vitamins C, $B_2$, A, calcium, phosphor and magnesium and excessive quantities of macronutrients (fats and carbohydrates). Among factors related to the educational process, the greatest contributions to the integral potential hazard index are made by excessive daily and weekly educational loads, shorter breaks between classes and additional education, and excessive numbers of schoolchildren in a class. Benzene, toluene, ethylbenzene and chloroform are the most significant anthropogenic contaminants. Although their effects do not exceed permissible levels ($I_{pdj}$ = 0.15–0.16, negligible – low hazard), they make their contribution to the integral potential hazard index for schoolchildren's somatic and mental health given the combined exposure to them together with other risk-inducing factors.

We compared the obtained values of the integral potential hazard index as regards probable health disorders in schoolchildren of all age groups in all the analyzed schools with the scale sets. The comparison revealed that these values ($I_{pdk}$ = 0.40–0.47) were by 2.7–3.1 times higher than the permissible level ($I_{pd} \leq$ 0.15). The first rank place identified as per simultaneous exposure to all the analyzed adverse risk-inducing factors belonged to the type I school with profound studies of natural sciences; the second one, ordinary secondary schools (type IV and V); the third one, type II school; the fourth one, type III school.

**Conclusions:**

1. Basic determinants of negative effects produced by the educational process on schoolchildren's health include elevated intensity and monotony of learning, elevated intellectual loads, shorter breaks and the recovery deficiency index; meal-related factors include excessive fats, carbohydrates and total caloric contents of meals provided at school, protein and micronutrient deficiency; primary chemical factors include elevated levels of metals, aromatic hydrocarbons, aldehydes, and chlorinated organic compounds in biological media.

2. Regardless of schoolchildren's age and a type of a school, the leading risk-inducing factors are organization of the educational process ($I_{pj}$ = 0.45–0.58) and meals provided at school ($I_{pj}$ = 0.41–0.54). The potential hazard index for this indicator groups reaches its peak values ($I_{pj}$ = 0.49–0.58 and $I_{pj}$ = 0.46–0.54 accordingly) in primary school.

3. The highest value of the integral potential hazard index ($I_{pdk}$ = 0.41–0.46) caused by combined exposure to factors of the educational process, meal-related ones and anthropogenic contaminants is detected in senior school regardless of a type of a school.

4. Under combined exposure to environmental factors and factors related to the educational process, the highest values of the integral potential hazard index as regards schoolchildren's somatic and mental health was established for the school with profound studies of natural sciences ($I_{pdk}$ = 0.41); the lowest value was established for the military school ($I_{pdk}$ = 0,33).

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