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ASSESSMENT OF HEALTH IMPACTS BY CHEMICAL SUBSTANCES, INGESTED WITH DRINKING WATER

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Abstract:

The investigation was conducted with the aim to study regional (local) exposure factors for assessing the intake of chemical substances with drinking water by children (3-6 years old) and adults (18-21 years old) in Kazan, in the Republic of Tatarstan. The analysis of levels of non-carcinogenic risk, using local factors and age differences in the exposure of chemical substances, ingested with drinking water, showed that the use of standard values in the risk assessment methodology led to underestimation of the actual health risk for children and adults by the factors of 1.5 and 1.57 at the median level, and by the factors of 1.9 and 1.98 at the level of 95-th percentile. The HI value, in case of chemicals ingestion with drinking water, indicates a health hazard for children, living in the 2nd and the 4th zones (HI_{me}= 11.8 and 9.9; HI $_{95perc}$= 14.8 and 12.4) and adults (HI_{me}= 5.52 and 6.64; HI $_{95perc}$= 4.42 and 5.59). The main pollutants of drinking water, which cause an increased risk to the health of the population in all zones of Kazan, are oil products, chloroform, nitrates (in NO3) magnesium and fluorides.

Keywords: *health risk assessment, impact factors, drinking tap water, children, adults.*

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INTRODUCTION:

Regulation of drinking water quality is an important direction of public health protection, and prevention of infectious and non-infectious water-related morbidity remains one of the priorities of public policy and has a significant impact on public health. According to WHO, 58% of the global burden of disease in disease-adjusted life years (DALY) are associated with unhealthy water supply, sanitation and hygiene [1]. In the Drinking Water Quality Manual, WHO emphasizes, that a risk-based approach should be used to justify management decisions to ensure drinking-water safety [2].

The current review of publications on risk assessment in Russia and the Republic of Tatarstan (RT) revealed the existence of methodological and toxic metric problems, leading to underestimation of the actual level of health risks of adults and children. The main part of the questions is connected with the uncertainties in the evaluation of the exposition, the absence of regional, national and age differences in the factors of exposure and sensitivity to carcinogens [3, 4]. Most Russian experts, while studying the impact of water factor, still use exposure values by default (for adults: consumption of 2 liters per day for 70 kg of body weight, and for children: 1 l/day for 10 kg). The use and importance of applying age-related exposure factors in risk assessment is constantly discussed in the scientific literature [5, 6, 7]. In the Russian Federation, regional factors of exposure (RFE) for adults (aged 18 and older) and children (aged 1-6 and 7-17) have been studied in several cities and federal districts of Russian Federation. They required systematization [8]. For the first time in the Republic of Tatarstan, the investigations were carried out to study the factors of exposure of drinking water consumption for children 3-6 years old in Kazan city [9]. Modern researches show, that the effects on the health of adults and children from the exposure of the same chemicals have significant differences [10, 11]. The sensitivity of the child population to environmental pollutants differs significantly from adults, due to age, physiological, behavioral and toxic-kinetic features. [12, 13].

The aim of the work is to assess the non-carcinogenic risk for the health of children (3-6 years old) and adults (18-22 years old) in case of ingestion of chemical compounds with drinking tap water, on the basis of standard and regional factors of exposure.

MATERIAL AND METHODS OF RESEARCH:

The study was conducted for children 3-6 years old and adults 18-22 years old, living in 4 districts (zones) of Kazan. This allowed to minimize the uncertainties, connected with specific regional parameters in assessing the exposure of pre-school children, who are less submitted to intra-urban migration. The allocation of studied areas was carried out on the basis of the location of permanent control stations for air pollution, and polyclinics, serving these areas [14]. The assessment of non-carcinogenic risk was carried out based on the values of 95% CI upper limit of the results of studies, performed on the basis of the accredited laboratory of the Federal Hygiene and Epidemiology Centre "Sanitary and Epidemiological Center in the Republic of Tatarstan", according to the guidelines, governing the assessment of population health risks in the Russian Federation [15]. The study of the contaminants impact was conducted on the basis of a chronic daily intake of the substances (by ingestion), with an assessment of the hazard coefficients (HQ) of selected substances, and the total hazard indices (HI) for the substances with unidirectional mechanism of action. Calculation of the average daily dose (ADD) of chemical substances, ingested with drinking water, was carried out according to formula 1 [15].

$$ADD = \frac{(Cw \times V)}{BW \times AT}$$ (1), where

ADD - average daily dose, ingested with drinking water ($mg \cdot kg^{-1} \cdot day^{-1}$);
CW - concentration of the substance in water, ($mg \cdot L^{-1}$);
V - value of water consumption ($L \cdot day^{-1}$);
EF –frequency of exposure ($days \cdot year^{-1}$);
ED - duration of exposure (years);
BW - body weight (kg);
AT - averaging time of exposure, years (for non-carcinogens, AT = ED × 365 days).

Non-carcinogenic risk was assessed on the basis of HQ for each substance, using standard and regional factors of exposure at the median level (Me) - the common range of exposure, and at the level of 95th percentile (P_{95}) - the most reasonable exposure (formula 2).

$\Sigma HQ =$ (2), where

RfD is the reference dose for each of the substances ($\mu g \cdot kg^{-1} \cdot day^{-1}$) [15].

The total hazard indices (HI) were calculated using the formula 3.

$THI = \Sigma HQ$ (3)

For the acceptable level of non-carcinogenic effects, the HI values were taken from 1.1 to 3.0. The range of HI values from 3 to 6 was considered as alarming

level of risk, and HI above 6 - as high level of risk [16].

The study of local exposure factors was carried out in a form of cross-sectional study. 1560 people of two age groups were surveyed, namely: 680 children 3-6 years old and 880 adults 18-22 years old (students of the Institute of Fundamental Medicine and Biology). The questionnaire, including the parameters of the assessment of regional factors of exposure was developed by the employees of the Institute of Fundamental Medicine and Biology of KFU. Due to the fact, that the distribution of quantitative factors of exposure was statistically significantly different from the normal distribution, the median (Me) and 95th percentiles (Perc) were used for their presentation. The comparison of FE values at Me level of children and adults was carried out using nonparametric statistics (the Mann-Whitney (U) test).

RESULTS AND DISCUSSION:

The water supply to Kazan residents is made from the surface water intake area "Volzhsky", underground water intakes and artesian wells. Water intake area "Volzhsky" provides drinking water for 80% of the city's population, including Kirov (the 1stzone) and Vakhitovsky districts (the 3rdzone). The population of the Soviet district (the 2nd zone) uses drinking water of mixed nature ("Volzhsky" water intake area and underground water sources Aki, Azino and Solidarnost). Privolzhsky district of the city (the 4thzone) is provided with mixed water from the water intakes areas "Mirny", "Tankodrom" and "Volzhsky". Detailed information is presented in our article [14]. "19 pollutants were included in the list of main substances, supplied with drinking water. The criterion for the selection of priority chemicals was revealing of compounds, the detection frequency of which in drinking water samples exceeded 5% in all the investigated territories (Table 1) [15]. Residual chlorine, was excluded from the estimation, due to the fact, that currently there are no reference doses for the chronic intake of chloramines "[9, 14].

Table 1: Concentrations of chemical compounds in the drinking water of the city of Kazan in the zones under study (mg/L).

Substances	CAS	Limit of detection	MAC, mg/l	RFD, mg/kg	Upper bound of 95% CI			
					1st	2nd	3rd	4th
Aluminum	7429-90-5	0,05	0,2	1	0,373	0,42	0,4	0,58
Barium	7440-39-3	0,01	4	0,07	0,024	0,034	0,045	0,024
Iron	7439-89-6	0,1	0,3	0,3	0,8	1,71	1,9	0,7
Magnesium	7439-95-4	1	50	11	24,3	63,2	85,05	47,4
Nitrates (in NO3)	14797-55-8	0,2	45	1,6	9,8	24,93	26	58,79
Nitrites (in NO2)	14797-65-0	0,003	3,3	0,1	0,05	0,2	0,4	0,2
Cadmium	7440-43-9	0,0003	0,001	0,0005	0,0007	0,0006	0,0006	-
Manganese	7439-96-5	0,01	0,1	0,14	-	0,131	-	0,02
Lead	7439-92-1	0,05	0,01	0,0035	0,007	0,0036	0,0076	0,004
Strontium		0,01	7	0,6	1,01	0,64	0,92	0,68
Copper	7440-50-8	0,02	1	0,019	0,021	0,017	0,015	0,028
Zinc	7440-66-6	0,2	1	0,3	0,031	0,062	0,09	0,143
Fluorides	16984-48-8	200	1,5	0,06	0,296	0,471	0,57	0,384
Oil products (in total)		0,005	0,1	0,03	0,0172	1,993	0,1	1,01
Chloroform	67-66-3	0,001	0,1	0,01	0,106	0,119	0,147	0,115

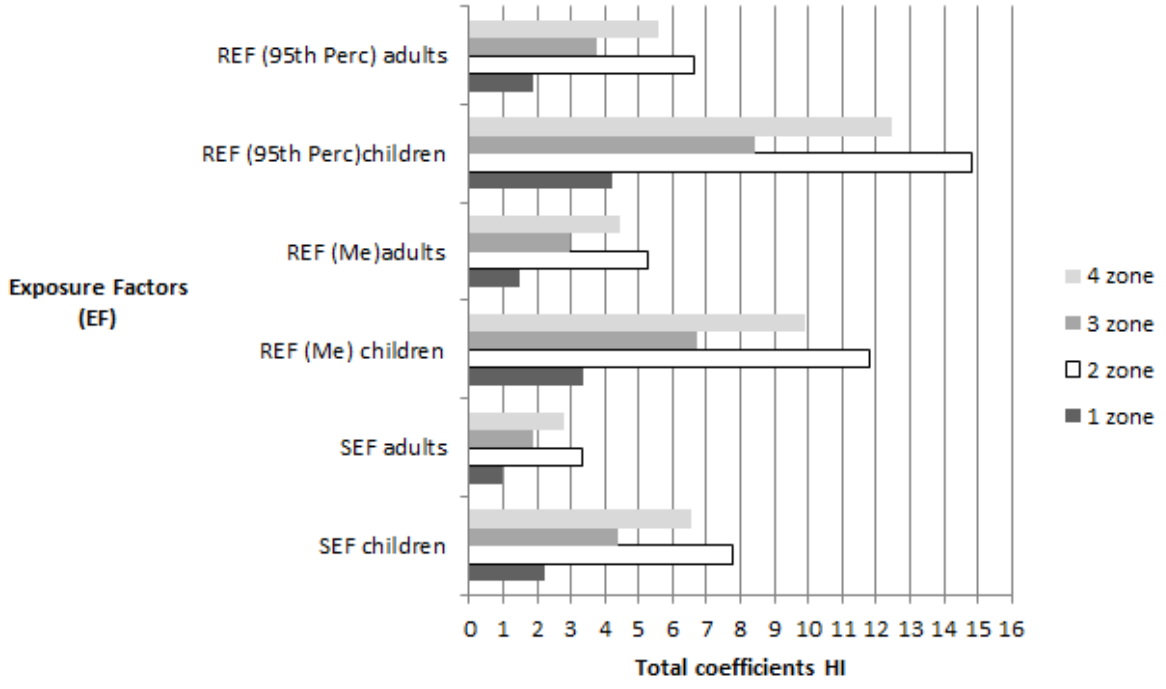
In the cross-sectional questionnaire study, the following exposure factors for children and adults were studied: body weight, the amount of drinking water, consumed per day and duration of the effect (Table 2). It was found, that adults consume more drinking water than children, on average by 1.5 $L \cdot day^{-1}$ (at Me level) and 1.34 $L \cdot day^{-1}$ (at the level 95th percentiles).

The level of drinking water consumption at Melevel and the level of 95th percentile exceeded the value of the standard factor for adults. The body weight of population at Me level and the upper 95% Perc was below the standard value. The duration of the effect of the drinking regime for this group of population was 360 days (Me) and 364 days (95thPerc).

As can be seen in Figure 1, the total level of general toxical effects (HI) in children's population (3-6 years old), with the intake of chemicals with drinking water in all areas is higher than the level of total non-carcinogenic risk of adults (18-21 years old).

Table 2: Regional exposure factors for the child and adult population of the city of Kazan.

Exposure factor	Children aged 3-6 years		Adults 18-22 years		p
	Regional factors		Regional factors		
	Me	95th Percentile	Me	95th Percentile	
Weight, kg	10.3	16.4	57.0	61.2	<0,001
Amount of consumed water, $L \cdot day^{-1}$ (mL/day, ml/kg-day)	1.0 (1000) 97 ml/kg-day	2.0 (2000) 122 ml/kg-day	2.5 (2500) 44 ml/kg-day	3.34 (3340) 55 ml/kg-day	<0,001
Duration of the effect per annum, days	296	364	360	365	<0,001



REF - regional exposure factors at the levels of median (Me) and 95th Perc;
SEF - standard exposure factors.

Fig. 1: The values of the total hazard quotients when using standard and regional exposure factors

The main contribution to HI is made by 5 substances in both groups and cadmium in one zone (at standard exposure factors) in adults (Table 3).

Table 3: Contribution ratio of the hazard quotient of certain chemical substances (HQ) to the total hazard index (HI) for the adult population (aged 18-21 years), %.

№	Substances	HQ with application of standard exposure factors, %				HQ with application of regional exposure factors, % (Me)				HQ with application of regional exposure factors (95th Percentile), %			
		zones											
		1	2	3	4	1	2	3	4	1	2	3	4
1	Magnesium	6,32	4,80	11,11	4,29	6,67	4,76	11,07	4,30	6,35	4,67	11,14	4,29
2	Nitrates (in NO3)	17,89	12,91	23,81	36,07	17,33	12,76	23,49	35,97	17,46	12,80	23,61	35,96
3	Cadmium	9,47	2,40	4,23	0,00	4,00	0,95	1,68	0,00	4,23	1,05	1,86	0,00
4	Fluorides	14,74	6,61	13,76	6,43	14,00	6,48	13,76	6,33	14,29	6,48	13,79	6,26
5	Oilproducts (intotal)	2,11	54,65	4,76	32,86	1,33	54,67	4,70	33,03	1,59	54,67	4,77	32,92
6	Chloroform	30,53	9,91	21,16	11,43	30,67	9,71	21,48	11,31	30,69	9,79	21,22	11,27
	Total 1-6	67,37	75,68	67,72	80,21	62,67	77,14	70,47	79,86	61,90	77,26	69,76	79,96
	Others, %	32,63	24,32	32,28	19,79	37,33	22,86	29,53	20,14	38,10	22,74	30,24	20,04

The sum of these 5 chemicals in adults (excluding cadmium) in selected zones ranges from 61.9% to 80.2%, in children - from 62.5% to 89.9% (Table 4).

Table 4: Contribution ratio of the hazard quotient of certain chemical substances (HQ) to the total hazard index (HI) for the child population (aged 3-6 years), %.

	Substances	HQ with application of standard exposure factors, %				HQ with application of regional exposure factors (Me), %				HQ with application of regional exposure factors (95th Percentile), %			
		zones											
		1	2	3	4	1	2	3	4	1	2	3	4
1	Magnesium	6,33	4,77	11,14	4,29	6,25	4,75	11,21	4,23	6,40	4,73	11,19	4,26
2	Nitrates (in NO3)	17,65	12,89	23,64	35,99	17,56	12,81	23,62	35,95	17,77	12,84	23,57	36,01
3	Fluorides	14,48	6,44	13,86	6,28	14,29	6,45	13,75	6,24	14,22	6,49	13,81	6,27
4	Oilproducts (intotal)	1,81	54,77	4,77	32,92	1,79	54,71	4,78	32,93	1,66	54,73	4,88	33,04
5	Chloroform	30,77	9,79	21,36	11,33	30,65	9,84	21,38	11,28	30,57	9,80	21,31	11,25
	Total 1-5	62,90	77,45	70,00	80,25	89,88	77,35	69,96	80,16	62,56	77,36	69,88	80,31
	Others, %	37,10	22,55	30,00	19,75	10,12	22,65	30,04	19,84	37,44	22,64	30,12	19,69

The rank distribution shows, that the first place in terms of the contribution to the value of HI in children and adults is occupied by oil products with the largest value in the 2nd zone. The second place is occupied by chloroform, the largest contribution of which is found in the 1st and the 3rd zones (with all methodological approaches). The third place belongs to nitrates, the maximum contribution of which is found in the 4th zone in children (35.95% - 36.01%) and adults (35.96% - 36.07%). The fourth place is occupied by fluorides, the highest values of which are found in the 1st and the 3rd zones, in children and adults. The fifth place is determined by the contribution of magnesium, whose contribution varies from 11.07% to 11.21% in the 3rd zone in children and adults. Based on the results of HI analysis of the child population, calculated for substances with a synergistic effect, the main critical organs and systems were identified in all zones (Tables 5, 6).

Table 5: Total hazard indices for substances with synergistic effect (the child population).

Values of total hazard indices	Calculation with application of standard exposure factors				Calculation with application of regional exposure factors (Me)				Calculation with application of regional exposure factors (the 95th perc)			
	1z.	2z.	3z.	4z.	1z.	2z.	3z.	4z.	1z.	2z.	3z.	4z.
HI blood	1,24	2,02	2,39	3,32	2,14	3,63	4,25	5,28	2,68	4,56	5,34	**6,63**
HI kidneys	0,83	5,12	1,27	2,91	1,25	**7,77**	1,93	4,42	1,58	**9,76**	2,42	5,55
HI CVS	0,41	1,03	1,08	2,37	0,63	1,56	1,64	3,60	0,79	1,96	2,06	4,52

Table 6: Total hazard indices for substances with synergistic effect (the adult population).

Values of total hazard indices	Calculation with application of standard exposure factors				Calculation with application of regional exposure factors (Me)				Calculation with application of regional exposure factors (the 95th perc)			
	1st zone	2nd zone	3rd zone	4th zone	1st zone	2nd zone	3rd zone	4th zone	1st zone	2nd zone	3rd zone	4th zone
HI blood	0,60	1,02	1,20	1,49	0,95	1,62	1,89	2,35	1,20	2,04	2,39	2,97
HI kidneys	0,35	2,19	0,54	1,25	0,56	3,46	0,86	1,97	0,71	**4,38**	1,09	2,49
HI CVS	0,18	0,44	0,46	1,02	0,28	0,70	0,73	1,60	0,35	0,88	0,92	2,03

For the child population, the blood circulatory system, renal and cardiovascular systems are exposed to the greatest risk. The HI values for the blood circulatory system in the 2nd, the 3rdand the 4th zones, calculated using regional factors of exposure, and in the 4thzone with standard factors of exposure, correspond to alarming level of risk (3.32 to 5.34). As for the renal system, high level of general toxic effects (HIме = 7.77 and HI95th = 9.76) was defined in the 2ndzone, which was due to the oil products by 73.0% - 83%. Exposure to the cardiovascular system (an alarming level of risk) was determined only in the 4thzone, when using regional factors of exposure. In the adult population of Kazan, an alarming level of risk was found only in the 2nd zone, in case of exposure to renal system (Table 6).

The study contains a number of uncertainties and limitations. The evaluation of the exposure factors includes the analysis of the population survey data for the autumn-winter period 2016-2017, and does not take into account the gender characteristics of drinking water consumption. In addition, we considered only ingestion of chemicals. According to the literature, it is the main route of chemical substances intake from sources of drinking water supply [17, 18].

CONCLUSIONS:

The priority pollutants of drinking water, determining the main contribution (61.9% - 80.0%) to the total amount of non-carcinogenic risk of the child and adult population are 5 substances and cadmium in the 1stzone (with standard exposure factors) in adults. These are oil products (in total), chloroform, nitrates (in NO3), magnesium and fluorides. The results of the research showed, that using standard values of exposure factors underestimates the magnitude of non-carcinogenic risks for the health of adults and children by the factors of 1.5 and 1.57 at the median level, and by the factors of 1.9 and 1.98 at the level of 95-th percentile. The level of total risk for the child population, ingesting the chemical substances with drinking water, exceeds the level of risk for adults by the factors of 2.2 - 2.3, with all methodical approaches. A high level of total risk was found for the population in the 2nd and 4th zones of the city, for which a "mixed" type of drinking water supply was characteristic. This fact requires additional researches. An alarming and high level of risk, in case of exposure of chemicals, ingested with drinking water, with unidirectional mechanism of action in children, was determined for the cardiovascular system, blood circulation and renal systems. Among the adult population of the 4thzone, the critical organ of exposure is the renal system, when assessed at the level of the 95th Perc of the regional factors of exposure. The study shows, that oil products (73.0% to 83%) determine the main contribution to the development of general toxic effects of renal system. For the blood circulation system, general toxic effects are caused by the ingestion of water with nitrates. Elevated concentrations of petroleum products, in our opinion, are connected with the contamination of surface waters by discharges of under-treated sewage from industrial and communal enterprises, and surface run-off from urbanized areas during snow melting [19]. Also, secondary pollution of the aquatic

environment is possible as a result of biological processes, which contribute to the redistribution of petroleum products, included in composition of pollutants of bottom sediments [20]. The obtained results show, that the intake of chemicals with drinking water can be connected with high levels of health risks for children and adults, usually when they are caused by long-term effects at levels below existing regulations.

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