Hygienic Evaluation of the Quality of Drinking Water and Risks for Health of the Population

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Abstract. According to WHO, approaches based on the assessment of health risks are promising and should be used to justify management decisions to ensure the safety of drinking water. A review of publications on risk assessment in Russia showed that the main part of the methodological issues is related to the uncertainties in the evaluation of exposure, the lack of regional, national and age differences in exposure factors and sensitivity to carcinogens. In the Republic of Tatarstan, research was conducted for the first time on the regional factors of the exposure of drinking water consumption for adolescents aged 15-17 and adults (18-21) years in Kazan, Republic of Tatarstan. We studied the content of 19 priority chemical pollutants, including three carcinogens, in the drinking water of Kazan for 2010-2016. The HI value for oral intake of chemicals with drinking water indicates a health hazard for the adolescent population living in zones 2 and 4 (HIm = 9.8 and 8.8, HI 95percent = 8.1 and 7.6), and adults (HIm = 7.4 and 7.8, HI 95percent = 6.8 and 6.5). The priority pollutants of drinking water in all zones that determine the main contribution (71.6% - 87.6%) are petroleum products (29.7% - 54.0%), chloroform, nitrates, magnesium, as a total amount of non-carcinogenic risk of adolescent and adult population and fluorides.

1. Introduction

The problem of good quality water availability is one of the priorities in the sphere of creating sanitary and epidemiological welfare of the population in Russian Federation [1]. The public health problem on using poor-quality drinking waters is global [2]. The obtained results indicate existing carcinogenic hazards for the population health. The current review of publications on risk assessment in Russia and the Republic of Tatarstan (RT) revealed the existence of methodological and toxicometric problems leading to underestimation of the actual level of health risks for the adult and child population. The main part of questions is connected with the uncertainties in the exposure evaluation, the absence of regional, national and age differences in exposure factors and sensitivity to carcinogens [3-9]. In Russian Federation, the regional exposure factors (REF) for the adult (aged 18 and older) and the child population (aged 1-6 and 7-17) were studied in certain cities/towns and federal districts of Russia, and they require systematization. Hygienic assessment based on the risk assessment methodology plays a major role in making management decisions on the drinking water quality problem at the regional level [7]. Hygienic studies on assessment of possible unfavorable impact and health risk levels for the population of the city of Kazan associated with intake of drinking waters [8,9] are relevant.

Aim of the research – to assess the non-carcinogenic risk for the health of adolescent and adult population on peroral intake of chemical compounds with drinking tap water on the basis of standard and regional exposure factors.

2. Materials and Methods

The values of HQ in the range from 0,11 to 1,0, and HI – from 1,1 to 3,0 were taken for the allowable level of non-carcinogenic effects. Information on local exposure factors was obtained in the cross-sectional study when questioning 930 adolescents (from 13 to 15 years of age). A questionnaire developed by the researchers of the Institute of Fundamental Medicine and Biology of the Kazan (Volga Region) Federal University included the following information on the exposure factors: the child body weight (kg), the height (cm), the amount of drinking water taken (l/24hrs), the number of water procedures (hand washing) - (times/24hrs), taking a shower (a bath) – times /week, the duration of water procedures (min/24hrs), exposure time (days /year), spending time outdoors (hrs/24hrs), spending time indoors (hrs/24hrs). A standard formula for calculating an average daily dose and regional exposure factors on peroral ingestion of chemicals with drinking water was used: I= (Cw*V*EF*ED)/(BW*AT*365), where CW – the substance concentration in water, mg/l, V- the amount of water taken, l/24hrs, EF – the exposure frequency, days/year, ED – the exposure duration, years, BW- the body weight, kg, AT - the exposure averaging time, years.

Non-carcinogenic risk (ingestion route: per os) is assessed by calculating the hazard quotient (HQ): HQ = I/RfD, where I – average daily dose of a substance on peroral route, mg/kg, RfD - reference (safe) dose. To assess the total effect of chemical substances the total hazard index is used: HI = HQ1 + HQ2 + ... + HQn, where HQq, HQ2, HQn – hazard quotients of the 1st, 2nd ... n –the chemical substances. The HI is usually calculated only for the substances having effect on the same body organs and systems. The approach based on safe (reference) doses and total hazard indices (THI) was used for the non-carcinogenic risk assessment. The study of the contaminant toxicity was carried out on the basis of chronic daily ingestion of a substance (the peroral route). Characteristics of general toxic effects were made based on hazard quotients (HQ) of certain substances and hazard indices (HI) for the substances with synergistic effect. Calculation of an average daily dose (ADD) of chemical substances ingested perorally with drinking water was carried out according to formula 1 [10]. Total hazard quotients (HI) were calculated according to formula 3. $THI = \Sigma HQ$ (3) The values of HI in the range from 1,1 to 3,0 were taken for the allowable level of non-carcinogenic effects. The range of HI values from 3 to 6 was regarded as an alarming risk level and HI higher than 6 – as a high one [10]. The investigation of regional exposure factors was performed in the cross-sectional study. 1560 persons of two age groups: 680 children aged 12-16 years underwent the questionnaire survey. A questionnaire including the assessment parameters of regional exposure factors (EF) was developed by the researchers of the Institute of Fundamental Medicine and Biology of the Kazan (Volga Region) Federal University. Owing to the fact that distribution of the quantitative EF was statistically significant different from normal distribution, the median (Me) and the 95th percentile (Perc) were applied for their presentation. Statistical analysis of the obtained data was implemented in operating system Windows 2010, with the use of standard application program packages Excel 2010 and «Statistica v.6.0».

3. Results

The non-carcinogenic risk assessment on ingestion of chemical substances with drinking water was carried out for the adolescents aged 12-16 years, living in 4 districts (1-Vakhitosky, 2-Sovetsky/Soviet, 3-Kirovsky, 4-Privolzhsky/Volga Region) of the city of Kazan, and that fact allowed minimizing uncertainties associated with specific regional parameters in exposure assessment. The research areas were selected on the basis of arrangement of permanent stations for monitoring the atmospheric air pollution and the children's polyclinics (No. 1, 2, 3, 4) providing services to these districts with the purpose of subsequent complex assessment of the multi-environmental risk. The risk assessment was carried out according to the data of the Regional Information Fund (RIF) of social and

hygienic monitoring and results of the research carried out on the basis of an accredited laboratory of the Federal State-Funded Healthcare Institution "The Center of Hygiene and Epidemiology in the Republic of Tatarstan" in keeping with Guidelines P 2.1.10.1920-04 [10].

The major negative impact on the human health is associated with chemical impurities in the tap water, both of natural (nitrates, nitrites), and industrial origin (metal compounds, oil products) and other substances. The presence of chlorine compounds and by-products, which are formed in the process of the drinking water treatment, remains an urgent problem. According to data of the World Health Organization (WHO) the approaches based on the health risk should be applied for justification of management decisions on provision of the drinking water safety [5].

Table 1. Regial exposure factors for the child and adult population of the city of Kazan.

	Children aged 15-17 years		Adults 18-22 years		p
	Regional factors		Regional factors		
Exposure factor	Me	95th Percentile	Me	95th Percentile	
Weight, kg	50	54.5	59.0	62.3	<0,001
Amount of consumed water, Lday−1 (mL/day, ml/kg-day)	1.9 (1900) 38 ml/kg-day	2.1 (2100) 38.5 ml/kg-day	2.5 (2500) 44 ml/kg-day	3.35 (3350) 54 ml/kg-day	<0,001
Duration of the effect per annum, days	360	365	360	364	

The following exposure factors for the adolescent and adult population: the body weight, the amount of drinking water taken daily, and the exposure time were investigated in a cross-sectional study. The level of the drinking water intake at the median (Me) and the 95-th Perc levels exceeded the value of standard factor for the adults. The body weight of the population at the level of Me was below the standard value. The exposure time of the water intake schedule for this population group made 360 days (Me) and 364 days (95-th Perc).

The major contribution to the HI value at the median (Me) and the 95-th percentile levels is also made by 5 substances in both groups at standard exposure factors: (magnesium, nitrates (in NO3), fluorides, chloroform, oil products (in total)). The total of these substances (excluding cadmium) in the zones under study made 59.11% - 89.51% in adolescents, and 55.1% - 89.6%. in adults (Table 2,3).

Table 2. The ratio of the contributions of hazards of chemical substances (HQ) of drinking water to the overall hazard index (HI) for adolescents in Kazan in the study zones (%).

		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											
№	Substances	1	2	3	4	1	2	3	4	1	2	3	4
1	**Magnesium**	5.5	4,32	11.22	3,71	5,05	4,57	11.20	3,82	5,08	4,73	11,32	3,89
2	**Nitrates (in NO3)**	14,01	23,58	12,82	32,64	14,01	23,58	12,82	32,64	14,11	23,80	12,41	33,23
3	**Fluorides**	11,28	13,79	6,46	5,68	11,28	6,46	13,79	5,68	11,36	6,10	13,99	5,78
4	**Cadmium**	1,71	0,98	3,20	0	3,20	1,74	0,98	0	3,22	1,74	0,93	0
5	**Oil products (in total)**	1,31	4,83	54,70	29,91	1,31	51,70	4,70	29,70	1,32	54,0	4,83	30,4
6	**Chloroform**	24,24	21,33	9,79	10,21	24,24	8.79	21,33	10,21	24,42	9.25	21,33	10,40
	Total 1-6	63,82	69,27	92,04	82,17	59,11	76,52	89,51	82,29	59,53	76,52	84,56	83,78
	Others, %	36,17	30,72	7,95	17,82	40,88	23,47	10,48	17,70	40,46	22,76	13,38	16,21

Table 3. The ratio of the contributions of hazards of chemical substances (HQ) of drinking water to the general hazard index (HI) for adults in the city of Kazan by study areas.

		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											
№	Substances	1	2	3	4	1	2	3	4	1	2	3	4
1	**Magnesium**	5.05	4.73	11.0	3.82	5,05	11.32	4.46	3.82	5.08	4.93	11.42	3.92
2	**Nitrates (in NO3)**	13.7	14.43	11.25	31.88	14.01	23.58	12.82	32.64	14.5	24.04	12.12	33.23
3	**Fluorides**	10.16	6.61	6.04	5.09	11.28	6.51	6.46	5.68	11.60	6.51	13.93	6.94
4	**Cadmium**	3.02	1.02	0.90	0	3.20	1.74	0.90	0	3.42	1.79	0.95	0
5	**Oil products (in total)**	1.11	49.07	4.03	29.0	1.31	51.67	4.83	29.91	1.39	52.70	4.94	30.59
6	**Chloroform**	24.24	9.00	21.02	10.0	24.29	9.79	21.33	10.21	24.72	9,51	21,53	10,52
	Total 1-6	57.28	84.86	54.24	79.79	59.11	83.38	82.65	82.29	60.71	89.68	64.89	85.2
	Others, %	42.72	15.14	45.76	20.21	40.88	23.47	10.48	17.70	39.29	8.32	35.11	14.8

Table 4. Critical organs and systems of adolescents based on the assessment of non-carcinogenic risk in the entry of chemicals with drinking water.

Values of total hazard indices	Calculation with application of standard exposure factors				Calculation with application of regional exposure factors (Me)				Calculation with application of standard exposure factors (95th Percentile)			
	zones											
	1	2	3	4	1	2	3	4	1	2	3	4
CNS	0.12	0.15	0.12	0.10	0.08	0.11	0.09	0.09	0.87	1.16	0.96	0.89
Blood	0.18	0.35	0.35	0.14	0.14	0.29	0.24	0.36	1.44	2.94	2.37	3.52
Kidneys	0.12	0.73	0.14	0.39	0.08	0.13	0.52	0.30	0.87	1.33	5.38	3.06
Hormone	0.13	0.15	0.13	0.10	0.09	0.12	0.09	0.08	0.94	1.21	0.95	0.77
HI ccc	0.05	0.14	0.14	0.32	0.04	0.11	0.10	0.24	0.44	1.40	1.08	2.49
CVS	0.10	0.05	0.05	0.11	0.08	0.04	0.04	0.08	0.79	0.42	0.99	0.85
Liver	0.11	0.13	0.10	0.10	0.08	0.10	0.08	0.08	0.78	1.04	0.86	0.87

The priority pollutants in contribution to the HI value are oil products with the highest value in adolescents and adults from the 2nd and the 4th zones (51.70% and 30.4%; 53.70% and 30.59%) in the 2nd and the 4th zones (51.70% and 29.7%; 54.0% and 30.4%). Nitrates (in NO3) in the 2nd and the 4th zones (Me - 23.58% and 32.64%; the 95th Perc - 23.80% and 33.23%; Me – 23.58% and 32.64%; the 95th Perc - 24.04% and 33.23% in the adult population rank second. Chloroform, the highest contribution of which was identified in the 1st and the 3rd zones (Me – 24.24% and 21.33%) in adolescents, and (24.29% and 21.33%) in adults correspondingly, ranks third. The contribution of fluorides, high indices of which are identified in the 1st and the 3rd zones in adolescents and in adults (13.28% and 13.79% correspondingly), ranks fourth. Magnesium, the contribution value of which ranges from 11.20 % to 11.32 % in the 3rd zone in population groups under study (Table 4,5), ranks fifth.

The assessment of exposure factors does not take into account the gender peculiarities of the drinking water intake and comprises analysis of the population questionnaire survey data for the autumn-winter period of the years 2015-2017. According to literature data, the peroral route is the main one on ingestion of chemicals from the water supply sources, and we used this approach on the basis of this fact [2,11-20].

Table 5. Critical organs and systems of adults based on the evaluation of non-carcinogenic risk in the intake of chemicals with drinking water.

Values of total hazard indices	Calculation with application of standard exposure factors				Calculation with application of regional exposure factors (Me)				Calculation with application of standard exposure factors (95th Percentile)			
	zones											
	1	2	3	4	1	2	3	4	1	2	3	4
CNS	0.08	0.10	0.08	0.08	0.07	0.08	0.08	0.07	0.76	1.01	0.84	0.78
Blood	0.13	0.27	0.23	0.33	0.12	0.25	0.21	0.30	1.26	2.54	1.90	3.08
Kidneys	0.08	0.12	0.49	0.28	0.07	0.11	0.45	0.26	0.77	4.72	1.17	2.68
Hormone	0.08	0.11	0.08	0.07	0.08	0.10	0.08	0.07	0.82	1.06	0.83	0.67
HI ccc	0.04	0.10	0.09	0.23	0.03	0.09	0.09	0.21	0.39	1.23	0.94	2.18
CVS	0.07	0.03	0.03	0.07	0.06	0.03	0.03	0.07	0.69	0.33	0.69	0.74
Liver	0.07	0.09	0.07	0.08	0.06	0.08	0.07	0.07	0.69	0.91	0.75	0.76

4. Discussion

The central nervous system, the blood, the kidneys, the cardiovascular system, the hormone system and the liver are at the highest risk among the population cohort under study. The values of HI for the blood system in the 2nd, 3rd and 4th zones, calculated with application of regional EF and in the 4th zone at standard EF correspond to the alert risk level (3.08). The high level of general toxical effects for the kidneys (HIме = 2.54 and HI95th = 3.08) is identified in the 2nd zone, 54.0 % of which are due to oil products. In the adult population of the city of Kazan, the alert risk level is identified only in the 2nd zone on impact on the kidneys HI95th =4.42 and the blood in the 4th zone HI95th = 3.08 (Tab.4,5). At the level of the 95-th percentile, the values of the highest risk for the organs and systems are higher in adolescents than in the adults.

5. Conclusions

The priority pollutants of drinking water determining a major contribution (55.91% - 80.0%) to total value of non- carcinogenic risk for the adolescent and the adult populations are the following 6 substances: oil products, nitrates, chloroform, fluorides, magnesium and cadmium.

The kidneys, the blood system, the cardiovascular system, the endocrine system, the CNS, and the liver have the highest risk of developing unfavorable effects on peroral route of the chemicals' ingestion with drinking water both in adolescents, and adults.

The level of total risk for adolescents on ingestion of chemicals with drinking water exceeds the risk level for the adults by a factor of 1.06 – 1.22 under all methodological approaches.

The high level of total risk is identified for the cohort under study in the 2nd and the 4th city zones, for which a "combined" type of the drinking water supply is typical, and it requires additional studies. In the adult population of the city of Kazan, the alert risk level is identified only in the 2nd zone on impact on the kidneys (HI95th = 4.42), and on the blood in the 4th zone (HI95th =3.08). The oil products have general toxic effect for the kidneys, and nitrates, which are ingested with water - for the blood. In our opinion, the ingestion of oil products is associated with pollution of surface waters with effluents from industrial and public utility enterprises, and the surface runoff from the urbanized territory [11,12,15]. Consequently, our studies of chemicals' ingestion with drinking water at the level below the existing exposure regulations can be ascribed to high levels of health risks for the adolescent and adult populations.

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