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Modern Assessment of Health Impacts and Outcomes of Chemicals in Drinking Water.

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ABSTRACT

Results of the non-carcinogenic health risk assessment for the population living in 4 different districts (zones) of the city of Kazan are given in the article. The risk assessment was carried out for the peroral route of ingestion with the account of standard and regional exposure factors, determined according to the data of the questionnaire survey of the adult population aged 18-22 years. Risk level analysis with application of regional factors and age differences in exposure to the chemicals ingested with drinking water showed that application of standard values resulted in underestimation of the actual health risk by a factor 1.57 at the median level, and by a factor 1.98 at the 95-th Percentile level for the adult population.
Keywords: Health risk assessment, exposure factors, drinking tap water, adult population

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INTRODUCTION

Quality of drinking water is a problem of high concern in regard to human health in the developing and developed countries all over the world and has a great influence on the public health. An estimated 13% of the world population lacked access to improved drinking-water sources in 2008, and in 2015 (according to WHO data) 6.6 billion people, or 91 per cent of the global population, used an improved drinking water source [1], and almost 10% of the total burden of disease worldwide could be prevented by improving drinking-water supply, sanitation, hygiene, and the management of water resources [2]. Chemicals in water supplies can be related to health risks, generally when associated with long-term exposures. Health impacts from chemical contaminants in the drinking water include various forms of cancer, unfavorable reproductive outcomes, circulatory diseases, nervous diseases and other health disorders [3].

At present, the risk analysis methodology is a generally accepted and primary tool in international organizations (UN Commission on Environment, WHO, FAO/WHO, the European Union, International Standards Committee, WTO, and etc.) and governmental organizations of all developed countries (Canada, Australia, Great Britain, USA and others.)

So far, it is evident that a solution to the problem of implementing an integral hygienic assessment of the drinking water quality is impossible without scientific justification and development of new methods of its safety assessment with due account for carcinogenic and non-carcinogenic effects of the chemical substances, which must be consistent with the current knowledge in the field of general scientific methodology for the population health risk assessment. Review of publications on practical application of the risk analysis methodology in different regions of Russia showed the high perspectiveness of such studies for determination of feasibility, priority and effectiveness of curative measures. Used in Russia methodology of health risk assessment is based on the use of standard exposure factors in accordance with the guidelines P 2.1.10.1920-04. Traditional approaches to risk assessment are aimed primarily at the adult population, when many experts still use default values for exposure: for assessing screening levels (consumption for adults makes 2 liters / day for a body weight of 70 kg [4, 5]. A review of publications on the risk assessment in Russia and in the Republic of Tatarstan revealed the presence of methodological and toxicometric problems resulting in underestimation of the actual level of the health risk for the adult and child population. The major part of issues is associated with uncertainties in exposure assessment, absence of regional and age differences in the exposure factors and sensitivity to carcinogens [4, 6]. The exposure assessment is a key stage for the population health risk assessment on exposure to harmful environmental factors. At present, a large body of research was carried out abroad, on the basis of which national and international data bases of the exposure factor values used when assessing the health risk were formed. The most large scale data bank on different exposure factors is given in the guidelines of American Environmental Protection Agency (US EPA), which regularly reviews and corrects them with the account of new data on the public opinion polls [7]. As of today, improvement of methodological approaches to the collection and processing of information on the regional exposure factors (EF) in different population groups, that is, in-depth study of the factors associated with water and air micro environmental effect are perspective trends of the health risk research. Such exposure factors as the values of consumption of water and various foodstuffs are to be corrected in presence of specific regional peculiarities. In the Russian Federation, the regional exposure factors for the adult (aged 18 and older) and the child population (aged 1-6 and 7-17) are studied in certain cities/towns of the Central, Siberian, Ural and the Northwestern Federal Districts of Russia. However, the data on Russian values of the exposure factors for the population in different regions of the country obtained by the population questionnaire survey require systematization. In the Volga (Privolzhsky) Federal District, such studies were not carried out. In the Republic of Tatarstan, the studies on the exposure factors of the drinking water consumption for children aged 3-6 years were carried out for the first time [8].

The aim of the work is to carry out the assessment of non-carcinogenic risk for the adult population health on per oral route of chemicals ingested with drinking tap water on the basis of standard and regional exposure factors.

MATERIALS AND METHODS

The assessment of the non-carcinogenic risk on per oral route of chemicals ingested with drinking water was carried out for the population aged 18 - 22 years living in 4 districts (zones) of the city of Kazan.

The research areas were allotted on the basis of arrangement of permanent stations for monitoring the atmospheric air pollution. The selected areas have significant differences in the present ecological and hygienic situation with heavy metals in soil and snow cover [9].The risk assessment was carried outaccording 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].

Risk assessment normally includes data collection and analysis, exposure assessment, toxicity assessment, and risk characterization. The calculation of an average daily dose (ADD) of chemicals ingested with drinking water (average daily dose, (mg·kg^{-1}·day^{-1}) was carried out according to Equation 1 [10].

$$ADD = \frac{(Cw \times V \times EF \times ED)}{BW \times AT \times 365} (1),$$

where ADD is an average daily doseingested with drinking water (mg·kg^{-1}·day^{-1}); CW – the substance concentration in water (mg·L^{-1}); V – the of consumption (L·day^{-1}); EF is the exposure frequency (days·year^{-1}), ED is the exposure duration (years); BW is the bodyweight (kg), and AT is the average time in days (for non-carcinogens, AT = ED × 365 days).

The assessment of noncarcinogenic risk was carried out on the basis of hazard quotients (HQ) for each substance (Equation 2) and total coefficients HI (Equation 3).

$$\Sigma HQ = \frac{ADD}{RfD} \quad (2) \quad HI = HQ \ (3),$$

Where RfD is the reference dose (safe exposure level) for each of the substances (µg·kg^{-1}·day^{-1}). The oral reference doses (mg·kg^{-1}·day^{-1}) were obtained from the US EPA's Integrated Risk Information System.

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 [11]. 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 [11].

The non-carcinogenic risk was assessed with application of standard and regional exposure factors at the median level (Me) – usual exposure range, and the 95-th percentile (maximum reasonable exposure).

Information on regional factors of exposure was obtained in a cross-sectional study of 680 students (from 18 to 22 years of age) of the Medical and Biological Faculties of the Kazan Federal University. 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: age (years), the body weight/mass (kg), the amount of drinking water taken (L/day, mL/day), exposure time (days/year). The response rate for participating in the questionnaire was 100%. 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.10.0".

RESULTS

Water supply to the citizens of Kazan is carried out from the"Volzhsky" surface water intake, the underground water intakes and the artesian boreholes. "Volzhsky" water intake provides 80% of the city population including Kirovsky (1st zone) and Vakhitovsky districts (3rd zone) with drinking water. The population of the Soviet district (2nd zone) uses drinking water of a mixed character ("Volzhsky" water intake and the underground water sources Aki, Azino and Solidarnost). The Volga (Privolzhsky) district of the city (4th zone) is provided with mixed water from the water intakes "Mirny", "Tankodrom" and "Volzhsky". The increase of the iron concentration at the level of 3–5 MPC is specific to underground waters of the Republic (the city of Kazan – the water intake "Mirny"). Analysis of an average content of certain metals (HM) in the sources of the central water supply of the city of Kazan for the period from 2010 to 2015 revealed significant differences between them in the content of zinc and magnesium, which were above the standards in the underground water sources. Average long-term concentrations of the rest studied substances in different sources were not much different from each other, not exceeding the hygienic regulations (apart from iron). However currently, the focus on the standard coefficients of exceedance of standards, when assessing water bodies, holds good not for all substances including heavy metals (HM), because they don't permit to assess actual danger for a human being, taking into consideration only strictly deterministic relationship of the pollution level and the health hazard [12, 13]. In real life, this relationship is complex and difficult to prove due to a great number of the accompanying factors (population heterogeneity, insufficient assessment precision of the concentration effect because of their temporal variations, additional effect of unaccounted factors, but its presence could not be denied nowadays. A probabilistic approach to assessment, which is better used in the methodology of the risk assessment, is more rational. The statistically significant differences of the chemical parameters of water in the water abstraction points from different city zones are determined only as far as the total hardness of water, which, however, according to the literature data, determines to a great extent the risk for the population health from the presence of HM in the water [12].

Local exposure factors obtained in the cross-sectional study showed that the adult population consumed 2.5liters/day at the median level (Me) (Table.1). Whereas at the level of 95% CI, this indicator was 3.45 liters/day, which is 1.73times higher than the value of a standard factor for the adults. The body mass of the population was 57.0 kg at the level of Me, and 61.2 kg (standard value – 70.0 kg) at the level of upper 95% Pers. The exposure time of the water schedule for this group of population made 360 days (Me) and 364 days (95thPerc).

Table 1: Local and standard exposure factors in adult population in the city of Kazan

Exposure factor	Adults 18-21 years		Adults
	Regional factors		Standard (recommended) factors [10]
	Mean	95th Percentile	
Weight, kg	57.0	61.2	70.0
Amount of consumed water (L/day, mL/day)	2.5 (2500)	3.34 (3340)	2.0 (2000)
Duration of the effect per annum, days	360	365	365

19 pollutants are on the list of priority substances ingested with drinking water (Table 2). The key criteria for the choice of priority chemical compounds were the ratio of unsatisfactory samples in hygienic studies, the detection rate of which in the drinking water samples exceeded 5% in all territories under study. The residual chlorine, sulphates and chlorides were excluded from calculations due to the fact that at present reference doses (RfD) are not determined during chronic ingestion. The assessment of non-carcinogenic risk established that the hazard quotients (HQ) of the substances contained in the drinking water from the utility and drinking water supply system of the city of Kazan when applying standard exposure factors for the adult population exceeded the allowable level (HQ =1.0) in oil products (HQ =1.82) in the 2nd zone, and in nitrates (HQ =1.01) in the 4th zone. HQ calculated with application of regional exposure factors (Me) were above the allowable risk level in nitrates (HQ = 1.59) in the 4th zone, and in oil products (HQ = 2.87 and 1.46) in the 2nd and the 4th zones. The calculation of the hazard quotients for the adult population with application of regional exposure factors (95th Percentile) showed that the allowable level was surpassed in oil products (HQ=3.63 and 1.84) in the 2nd and the 4th zones, and in nitrates (HQ =2.01) in the 4th zone (Table 3).

Table 2: 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

Table 3: Hazard quotients (HQ) for substances with synergistic effects

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
Aluminum	0,01	0,01	0,01	0,02	0,02	0,02	0,02	0,03	0,02	0,02	0,02	0,03
Barium	0,01	0,01	0,02	0,01	0,01	0,02	0,03	0,01	0,02	0,03	0,04	0,02
Iron	0,07	0,16	0,17	0,06	0,12	0,25	0,27	0,10	0,15	0,31	0,35	0,13
Magnesium	0,06	0,16	0,21	0,12	0,10	0,25	0,33	0,19	0,12	0,31	0,42	0,24
Nitrates (in NO3)	0,17	0,43	0,45	1,01	0,26	0,67	0,70	1,59	0,33	0,85	0,89	2,01
Nitrites (in NO2)	0,01	0,05	0,11	0,05	0,02	0,09	0,17	0,09	0,03	0,11	0,22	0,11
Cadmium	0,09	0,08	0,08	0,00	0,06	0,05	0,05	0,00	0,08	0,07	0,07	0,00
Manganese	0,00	0,03	0,00	0,004	0,00	0,04		0,01	0,00	0,05	0,00	0,01
Lead	0,05	0,03	0,06	0,03	0,09	0,04	0,09	0,05	0,11	0,06	0,12	0,06
Strontium	0,05	0,03	0,04	0,03	0,07	0,05	0,07	0,05	0,09	0,06	0,08	0,06
Copper	0,03	0,02	0,02	0,04	0,05	0,04	0,03	0,06	0,06	0,05	0,04	0,08
Zinc	0,00	0,01	0,01	0,01	0,00	0,01	0,01	0,02	0,01	0,01	0,02	0,03
Fluorides	0,14	0,22	0,26	0,18	0,21	0,34	0,41	0,28	0,27	0,43	0,52	0,35
Oilproducts (intotal)	0,02	1,82	0,09	0,92	0,02	2,87	0,14	1,46	0,03	3,63	0,18	1,84
Chloroform	0,29	0,33	0,40	0,32	0,46	0,51	0,64	0,50	0,58	0,65	0,80	0,63
HI	**0,95**	**3,33**	**1,89**	**2,80**	1,50	5,25	2,98	4,42	**1,89**	**6,64**	**3,77**	**5,59**

The results of the non-carcinogenic risk assessment on per-oral route of chemicals ingested with drinking water showed that the value of total risk (HI) only in the 1st city zone (for all values of the exposure factors) conformed to the allowable level. In the 2nd zone, irrespective of the values of exposure factors (standard or regional factors at the level of Me or the 95th Percentile), the total hazard indices indicate the alarming and unacceptable risk levels (HI =3.33; 5.25 and 6.64).The total hazard index (HI) on combined per-oral route of chemical compounds and elements ingested with drinking water in the rest zones of the city of Kazan exceeds the allowable risk level for the adult population(HI >1) and is dangerous for health (Table 3).Under conditions of the combined effects, the total hazard indeximplies the risk of developing unfavorable effects on a critical organ (system).The main priority organs and systems – targets for chemical substances ingested with drinking water, when applying standard values of the exposure factors in the 2nd – 4th zones, are the blood system (HI from 1.02 to 1.49), kidneys (1.25 and 2.19) - in the 2nd and 4th zones and the cardiovascular system – in the 4th zone. The revealed differences are expressed in the value of exposure and the value of non-carcinogenic risk level, which is higher in case of the regional exposure factors at the level of the 95th Percentile. In all territories under study an increased (1.4-2.1 folds) consumption of drinking water per 1 kg of the body weight/mass as compared with standard values was observed. The highest levels of the total risk (HI) and the risk for the given critical systems were identified in the 2nd zone. The priority pollutants of drinking water forming the increased non-carcinogenic risk for the adult population health in all zones of the city of Kazan are oil products and nitrates.

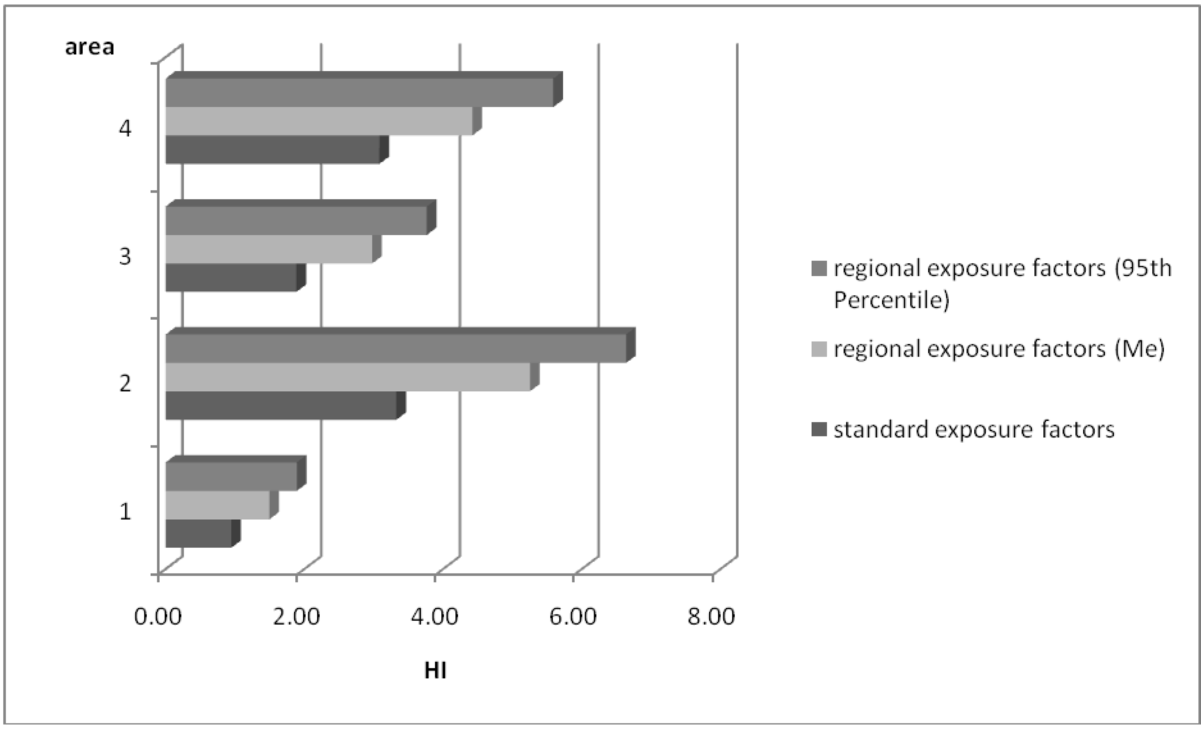

Figure 1: The values of the total hazard quotients when using standard and regional exposure factors

Thus, the analysis of the risk levels with application of standard exposure factors of the chemicals ingested with drinking water results in underestimation of actual noncarcinogenic risk for the adult population of the city of Kazan by a factor of 1.57 at the median level, and by a factor of 2 at the level of the 95th Percentile. There are some uncertainties and limitations in this study. This study includes analysis of the population questionnaire survey data for the autumn-winter period of the years 2016-2017 and doesn't take into account gender peculiarities of the drinking water consumption. Besides, we assessed only the per-oral route of ingestion, this route being the main one on ingestion of chemicals from the water supply sources [14]. In our opinion, ingestion of oil products is associated with pollution of the surface water supply source (the Volga River) and requires detailed study. The pollution of waters with suspended matters and oil products is shown to be caused by discharge of effluents from industrial and public utility enterprises, as well as the surface runoff from the urbanized territory [15]. Thus, in this paper, the risk assessment of the chemicals ingested with drinking water in the city of Kazan is preliminary.

CONCLUSION

Analysis of literature showed that the available methods of assessing the drinking water quality were largely limited to comparison of the levels of actual content of various chemicals with their hygienic regulations; and this fact not always reflects adequately the biological patterns of influence on the human body. Methods based on the population health risk assessment are the most comfortable to solve this problem. The advantage of these methods is their ability to identify unfavorable effects, both qualitative and quantitative. The assessment of non-carcinogenic risk on per-oral route of chemicals ingested with drinking water revealed differences in the risk level for the population in case of various water supply sources(mixed and surface water bodies).Analysis of the risk levels with application of local factors and age differences in exposure of the chemicals entering the body orally with drinking water showed that the use of standard values in the risk assessment methodology results in underestimation of the actual health risk for adults population by a factor of 1.57 (at the level of Me) and by a factor of 1.99 (the 95-th percentile). Therefore, application of regional data on the exposure factors, peculiar to certain population, increases accuracy and reliability of the risk assessed. The factors used in calculations of exposures and risks should reflect peculiarities of the populations under study and accepted scenarios of the effect.

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