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Public Health Risk Conditioned by Chemical Composition of Ground Water

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Abstract. The article studies the public health potential risk originated from water consumption and estimated on the basis of the groundwater chemical composition. We have processed the results of chemical groundwater analysis in different aquifers of Tomsk district (Tomsk Oblast, Russia). More than 8400 samples of chemical groundwater analyses were taken during long-term observation period. Human health risk assessment of exposure to contaminants in drinking water was performed in accordance with the risk assessment guidance for public health concerning chemical pollution of the environment (Russian reference number: P 2.1.10.1920-04-M, 2004). Identified potential risks were estimated for consuming water of each aquifer. The comparative analysis of water quality of different aquifers was performed on the basis of the risk coefficient of the total non-carcinogenic effects. The non-carcinogenic risk for the health of the Tomsk district population due to groundwater consumption without prior sanitary treatment was admitted acceptable. A rather similar picture is observed for all aquifers, although deeper aquifers show lower hazard coefficients.

1. Introduction
In the world the issue of safe drinking water supply is of specific relevance. Water is one of the key environmental components destined to permanent contact with human body. The major part of different substances, both necessary for life and toxic ones enters human body with drinking water. Patterns of human exposure to the factors contaminating the environment, particularly at low rates, are still poorly studied. They can be both direct and indirect. Method of risk assessment allows estimating the real dose hazard for humans taking into account the exposure factor (exposure duration, human age, and dose) [1], [2], [3].

The current study presents the comparative analysis of aquifer water quality and assessment of its potability using the risk assessment method.

The research is performed for Tomsk district (Tomsk Oblast). The area includes 128 settlements. The district is suburban, its territory comprises the administrative center with large industrial enterprises that are responsible for high anthropogenic impact on the environment including underground hydrosphere. The settlements are supplied with water both from central system with preliminary water treatment and individual wells (approximately 19.7% of the district population have individual water sources) [4], [5]. Over the study area four aquifers are distinguished – Neogene-Quaternary, Paleogene, Cretaceous, Paleozoic, the waters of which are used by population to greater or lesser extent for drinking and living needs. According to the result of long-term observation of chemical content in ground water, it is observed that a number of substances are found in increased

concentrations, often exceeding the maximum allowable concentration, which is explained by some subjective and objective factors.

2. Materials and methods

The authors used the data of TOMSKGEOMNITORING Company including the results of ground water analysis sampled from observation wells tapping waters of different stratigraphic units located in the territory of Tomsk district. Stationary monitoring of ground water dynamics of Mesozoic and Cenozoic deposits and Paleozoic formations has been performed since 1962 in the study area.

Taking into account the distribution regularities, the average values of elemental concentration were obtained for water of each unit. In total, more than 8400 chemical analyses of ground water were used [6]. Water analysis was carried out using the standard certified techniques.

The risk assessment of non-carcinogen effect was performed in accordance with the human risk assessment guideline under the exposure of chemicals in the environment – R. 2.1.10. – 1920–04 [7], [8].

The LADD (Life-time Average Daily Dose), mg/kg per day of chemicals consumed through water ingestion was calculated by Eq. (1), hence, we used standard exposure factors

$$LADD = \frac{C \times V \times ED \times EF}{BW \times AT \times 365} \tag{1}$$

where, C - C_{water}, mg/L, means concentration of chemicals in water. The data were averaged for the long-term monitoring.

V – daily ingestion intake of water to human body, to be assumed 2 L/day for adults;

ED – exposure duration, 30 years; EF – exposure frequency – 350 days/year;

BW – body weight (for adults), 70 kg; AT – average time – 30 years; 365 – number of days in a year.

To estimate the chronic health risks, HRIs were calculated by Eq. (2)

$$HRI_{per} = LADD / RfD_{per} \tag{2}$$

where, RfD_{per} - the oral toxicity reference dose for each element or compound [7], [8]

$$HRI = \sum HRI_{per} \text{ for each element or compound} \tag{3}$$

The HRI value less than one is considered to be safe for the consumers.

3. Results and discussion

Four aquifer systems were distinguished, the waters of which were used by population for their domestic needs to different extent. Table 1 lists the data on average chemical composition of ground water.

Table 1. Average chemical composition of ground water.

Substances	Units	Average value in ground water			
		Aquifers			
		Neogene-Quaternary	Paleogene	Cretaceous	Paleozoic
The number of analyses		3450	3707	508	738
pH		7.4	7.4	7.3	7.6
HCO_3	mg/L	268.1	313.9	247.5	381.6
SO_4	mg/L	5.67	5.0	4.2	9.3
Cl	mg/L	4.8	3.0	17.5	6.1
NO_2	mg/L	0.06	0.046	0.043	0.049
NO_3	mg/L	0.79	0.7	0.4	0.7
NH_4	mg/L	0.82	0.8	0.8	0.6

Ca	mg/L	61.7	72.3	42.7	90.1
Mg	mg/L	12.5	15.7	16.3	20.5
Na	mg/L	7.3	9.5	39.5	13.4
K	mg/L	1.2	1.4	3.9	1.3
Si	mg/L	7.7	9.2	10.8	9.7
Σ of salt	mg/L	414.4	485.1	469.1	593.8
Permanganate oxidation	mgO$_2$/L	2.7	2.4	1.9	1.9
F	mg/L	0.22	0.20	0.22	0.21
Al	mg/L	0.2	0.1	0.1	0.1
Fe	mg/L	6.5	4.0	4.8	2.3
Mn	mg/L	0.34	0.2	0.1	0.2
Co	mg/L	0.0019	0.0010	0.0005	0.0019
Ni	mg/L	0.011	0.0083	0,0116	0.0072
Sr	mg/L	0.34	0.4	0.5	0.5
Mo	mg/L	0.0115	0.0044	0.0191	0.0020
Zn	mg/L	0.042	0.0192	0.0115	0.0111
Cu	mg/L	0.027	0.0117	0.0046	0.0055
Hg	mg/L	0.0004	0.0002	0.0005	0.0002

Water of Neogene-Quaternary deposits is fresh, mainly hydrocarbonate calcium, sometimes magnesium-calcium or of blend cation composition. The total dissolved solids in ground water range widely from 136 to 1191 mg/L that can be explained by both natural conditions and anthropogenic effect. Concentrations of sulphate, chloride, sodium, and potassium do not exceed 10 mg/L on the average. The water contains significant amount of silicic acid (up to 39 mg/L). Ammonium ion content in water amounts 0.82 mg/L on average, changing in the range from 0.2 to 3.7 mg/L.

A typical feature of the given water is high contents of iron and manganese, concentrations of which ranges widely (from 0.8 to 29 and from 0.02 to 13 mg/L, respectively). Within the boundaries of Tomsk and Seversk as well as adjacent areas, the deposit waters have changed their chemical composition. They are often chloride-hydrocarbonate, sodium-calcium, very hard, weakly alkaline and alkaline waters with the mineralization value from 0.3 to 1.0 mg/L or more. It is waters of this aquifer that are used by the population as a decentralized water supply.

Water of Paleogene deposits is fresh, with the mineralization value 250-650 mg/L, water medium is neutral and weakly alkaline. By its chemical composition, water is hydrocarbonate, magnesium-calcium, often of blend cation composition. There are ammonium ions everywhere in waters of Paleogene deposits. Their concentrations amount 0.1 – 2.8 mg/L. As is the case with the overlying aquifer system, high concentrations of iron and manganese are typical for waters of Paleogene deposits. Concentration of iron in ground waters of the given deposits ranges widely (from 0.1 to 15 mg/L). Concentration of manganese amounts from 0.02 to 0.6 mg/L. Waters of Paleogene deposits are used for centralized water supply.

Ground water of Cretaceous deposits is generally fresh with the mineralization value from 160 to 810 mg/L, but in some sites there is brackish water with mineralization reaching 1450-4087 mg/L. By its chemical composition waters of Cretaceous deposit are diverse. In the south of the area they are often hydrocarbonate or chloride-hydrocarbonate, calcium or sodium-calcium neutral and weakly alkaline. With the increase in mineralization of Cretaceous deposit waters, there is an increase in chloride and sodium ion concentration in them, anion water composition has become hydrocarbonate-chloride or chloride, cation composition – calcium-sodium or sodium. Low amounts of sulfates (0-14.6 mg/L) and nitrates (1-2 mg/L) are established in the waters of Cretaceous deposit. Ammonium concentrations are also low and change from 0.1 to 2.1 mg/L, but in the brackish water area the

ammonium concentration is generally higher and sometimes reaches 2.5-3.3 mg/L. Cretaceous deposit waters are characterized by significant amount of iron and manganese concentrations.

Water of Paleozoic deposit is fresh (mineralization from 200 to 700 mg/L), moderately hard and hard, neutral and weakly alkaline in the most part of the study area. It is referred to hydrocarbonate type in terms of chemical composition, mostly calcium and magnesium-calcium. Sulfate concentration in waters of Paleozoic deposit often exceeds 10 mg/L. As is the case of overlying aquifer system, water of Paleozoic deposit is saturated with total iron, the average concentration being 2.3 mg/L.

The share of this water in domestic water supply is not great; it is mostly used in the south-eastern part of Tomsk district.

In accordance with the methods of human risk assessment using equations 1-3, the quantitative risk indicators are defined: average daily intake and the chronic health risks, HRI as an indicator of toxic effect under the exposure of chemical elements when consuming ground water without preliminary water treatment (Table 2).

Table 2. The life-time average daily dose of element (LADD) in human organism with ground water consumption and the chronic health risks, HRI.

Element	Aquifer system	RfD per	LADD	HRI	Aquifer system	RfDper	LADD	HRI
		mg/kg×day				mg/kg×day		
Nitrites		0.1	0.002	0.02		0.1	0.001	0.01
Nitrates		1.6	0.02	0.01		1.6	0.019	0.01
Calcium		41.4	1.7	0.04		41.4	2.0	0.05
Magnesium		11.0	0.34	0.03		11.0	0.43	0.04
Fluoride		0.06	0.006	0.1		0.06	0.005	0.09
Aluminum	Neogene-Quaternary	1.0	0.005	0.005	Paleogene	1.0	0.003	0.002
Iron		0.3	0.18	0.59		0.3	0.1	0.37
Manganese		0.14	0.009	0.07		0.14	0.005	0.04
Cobalt		0.02	0.00005	0.003		0.02	0.00003	0.001
Nickel		0.02	0.0003	0.02		0.02	0.0002	0.01
Strontium		0.6	0.009	0.02		0.6	0.01	0.02
Molybdenum		0.005	0.0003	0.06		0.005	0.0001	0.02
Zinc		0.3	0.001	0.004		0.3	0.0005	0.002
Copper		0.02	0.0007	0.04		0.02	0.0003	0.02
Mercury		0.0003	0.00001	0.04		0.0003	0.000005	0.02
Nitrites		0.1	0.001	0.01		0.1	0.001	0.01
Nitrates		1.6	0.01	0.007		1.6	0.02	0.01
Calcium		41.4	1.2	0.03		41.4	2.5	0.06
Magnesium		11.0	0.45	0.04		11.0	0.56	0.05
Fluoride		0.06	0.006	0.1		0.06	0.006	0.09
Aluminum	Cretaceous	1.0	0.0027	0.003	Paleozoic	1.0	0.003	0.003
Iron		0.3	0.13	0.44		0.3	0.06	0.21
Manganese		0.14	0.0027	0.02		0.14	0.005	0.04
Cobalt		0.02	0.00001	0.0007		0.02	0.00005	0.003
Nickel		0.02	0.0003	0.02		0.02	0.0002	0.01
Strontium		0.6	0.014	0.02		0.6	0.014	0.02
Molybdenum		0.005	0.0005	0.1		0.005	0.00005	0.01
Zinc		0.3	0.0003	0.001		0.3	0.0003	0.001

| Copper | 0.02 | 0.0001 | 0.007 | 0.02 | 0.0002 | 0.008 |
| Mercury | 0.0003 | 0.00001 | 0.045 | 0.0003 | 0.000005 | 0.018 |

Notes: RfD per - the oral toxicity reference dose, mg/kg×day [7], [8].
LADD – life-time average daily dose, mg/(kg × day);
HRI - the chronic health risks (risk coefficient).
The priority substances are distinguished.

The priority substances of all aquifers are total iron and fluoride with the risk coefficient for human health being more than 0.05. The priority substance for Neogene-Quaternary deposit water is manganese; for Neogene-Quaternary and Cretaceous deposit water – molybdenum; for Paleozoic deposit water and Paleogene deposit water – calcium and magnesium.

The total risk of non-carcinogen effect with regular water consumption from Neogene-Quaternary aquifer system amounts 1.03; Paleogene – 0.70; Cretaceous – 0.84; Paleozoic – 0.55. The share of different substances in the total value of risk coefficient with regular intake of water to human organism is shown in Figure. The similar pattern is observed in all aquifers. Groundwater from deeper aquifers is characterized by less risk coefficients.
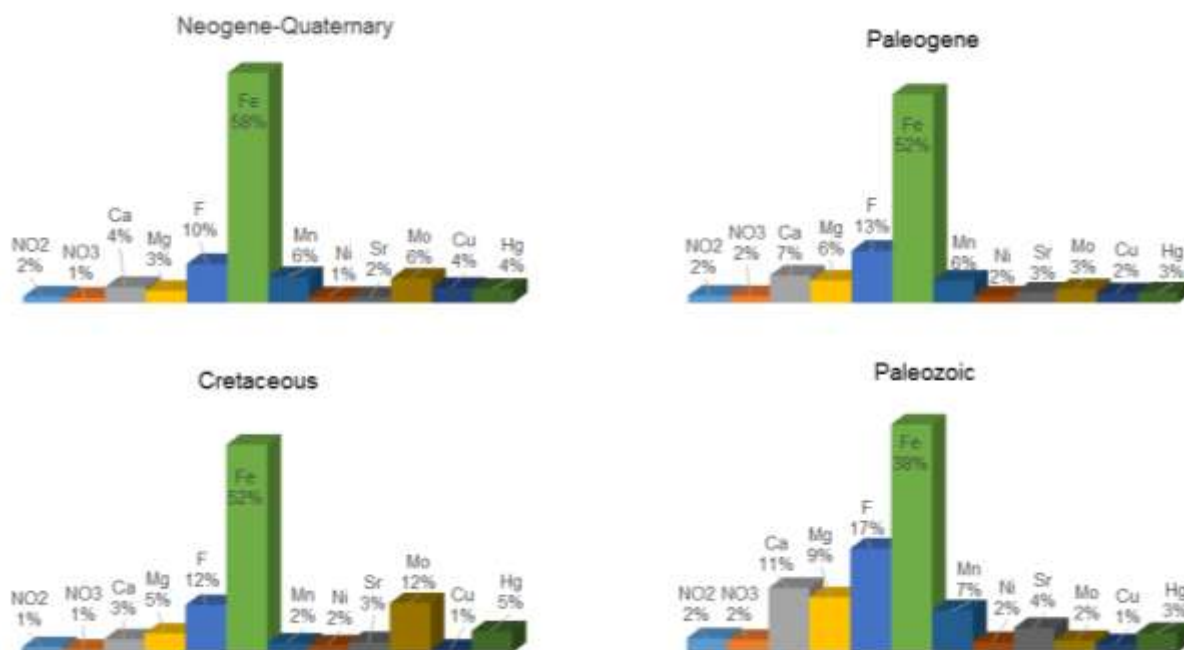

Figure. The share of different substances in total risk coefficient.

4. Conclusion

The non-carcinogen risk for human health in Tomsk region conditioned by ground water consumption from different aquifer systems without preliminary treatment is admissible. However, to produce good drinking water, it is necessary to treat it for removal of elevated chemical concentrations including excess of iron and manganese.

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