MEDICAL AND BIOLOGICAL ASPECTS RELATED TO ASSESSMENT OF IMPACTS EXERTED BY RISK FACTORS

UDC 613.2: 614.31
DOI: 10.21668/health.risk/2019.4.16.eng

Read online

SANITARY-HYGIENIC CHARACTERISTICS OF HEALTH RISK AND CLINICAL ASSESSMENT OF DAMAGE TO HEALTH DONE TO POPULATION LIVING IN A SPECIFIC GEOCHEMICAL PROVINCE UNDER LONG-TERM EXPOSURE TO ARSENIC INTRODUCED WITH DRINKING WATER

O.Yu. Ustinova[1,3], P.Z. Shur[2,3], A.E. Nosov[3]

[1]Perm State National University, 15 Bukireva Str., Perm, 614990, Russian Federation
[2]Perm State Medical University named after E.A. Wagner, 26 Petropavlovskaya Str., Perm, 614000, Russian Federation
[3]Federal Scientific Center for Medical and Preventive Health Risk Management Technologies, 82 Monastyrskaya Str., Perm, 614045, Russian Federation

In Russia geochemical provinces where arsenic is found are located in Yakutia, Siberia, Transbaikalia region, the Primorye, in the Urals, and Chukotka. Our research goal was to give sanitary-hygienic characteristics of health risk and perform clinical assessment of health damage done to population living in a specific geochemical province under long-term exposure to arsenic introduced with drinking water. We conducted our research in settlements where increased arsenic concentrations were detected in drinking water taken from centralized water supply systems taking into account also hygienic standards for arsenic contents in non-centralized water sources; those increased concentrations were caused by the structure of deep underground layers in the earth crust. We applied a set of sanitary-hygienic techniques and performed clinical examination of 147 people living in a specific geochemical province. We detected excessive arsenic concentrations in drinking water taken from centralized water supply systems; those concentrations were equal to 50–86 MPC whereas arsenic contents didn't exceed 1 MPC in water taken from non-centralized water sources. We revealed that long-term consumption of water with arsenic contents being equal to 2.5 mg/dm^3 and higher caused unacceptable carcinogenic (up to $4.09 \cdot 10^{-2}$) and non-carcinogenic (HQ up to 494.4) population health risk. Potential risk turns into health damage when arsenicosis occurs; it usually happens after 17–19 years of exposure among adults and after 2–3 years among children. There are several basic clinical types of diseases caused by exposure to increased arsenic concentrations; adult people suffer from skin arsenicosis as per poikiloderma type or arsenic melanosis, polyneuropathy, cardiovascular pathology, ands carcinogenesis; children mostly suffer from skin arsenicosis that is usually leucomelanosis. Arsenicosis occurrence is 1.3–9.0 times more frequent among people living in a specific geochemical province who consume water with arsenic concentrations being equal to 2.5 mg/dm^3 and higher in comparison with people who consume drinking water with arsenic contents being within their hygienic standards. Health damage is assessed as grave in 44.4 % cases (oncologic processes, polyneuropathy, and arsenic melanosis); as average, in 46.3 % cases (arsenic dyschromia); and as insignificant, in 9.3 % cases (vegetative-vascular dystonia or autonomous dysfunction, and functional disorders of the nervous system).

Key words: *geochemical province, arsenic, drinking water, health risk, health damage, population morbidity, arsenic melanosis, arsenic polyneuropathy, oncologic processes.*

Millions of people all over the world are chronically exposed to increased arsenic concentrations caused by geochemical peculiarities existing on territories where they live. At present large geochemical provinces of copper and arsenic ores are detected in Italy, the USA,

Olga Yu. Ustinova – Doctor of Medical Sciences, Associate Professor, Head of Human Ecology and Life Safety Department (e-mail: ustinova@fcrisk.ru; tel.: +7 (342) 236-32-64; ORCID: http://orcid.org/0000-0002-9916-5491).

Pavel Z. Shur – Doctor of Medical Sciences, Professor, Academic Secretary (e-mail: shur@fcrisk.ru; tel.: +7 (342) 238-33-37; ORCID: https://orcid.org/0000-0003-2356-1145).

Aleksandr E. Nosov – Candidate of Medical Sciences, Head of In-patient hospital (Therapeutic Occupational pathology Department) (e-mail: nosov@fcrisk.ru; tel.: +7 (342) 236-87-80; ORCID: https://orcid.org/0000-0003-0539-569X).

Sweden, Norway, Japan, Georgia, and Kazakhstan; arsenic and cobalt ores, in Canada; arsenic and tin ores, in Bolivia, Chile, and England; gold and arsenic ores, in the USA and France. In Russia there are arsenic geochemical provinces in Yakutia, Siberia, Transbaikalia, Primorye, Urals, and Chukotka [1].

According to scientific research, drinking water is a primary way for arsenic to be introduced into a human body in geochemical provinces; the leading hygienic problem on such territories is drinking water supply sources being contaminated with arsenic [2–5]. Nowadays the situation with drinking water quality as per arsenic contents is the most serious in Bangladesh and the East Bengal (India) where its concentration in drinking water reaches 50 μg/l or even higher while the WHO recommendations fix this concentration at 10 μg/l maximum. According to official statistic data more than 20 % deaths in rural areas in Bangladesh are caused by consuming drinking water with high arsenic contents [6]. The existing situation in several districts in Dagestan is also rather serious as arsenic contents in drinking water reaches 222–504.1 μg/dm^3 there [7]. In Canada standardized permissible arsenic concentration should not exceed 25 μg/l; in Russia and the USA, 10 μg/l [8, 9].

Data obtained via clinical research performed in various RF regions prove that morbidity among population living in geochemical arsenic provinces is 1.3–3.8 times higher regarding diseases of the endocrine, urogenital, nervous, and cardiovascular system as well as the gastrointestinal tract diseases and skin diseases; mortality caused by oncologic pathologies is also 1.2–4.7 times higher than in the country on average [10]. Experts revealed an authentic correlation between increased arsenic concentrations in drinking water and occurrence of skin diseases, immune system diseases, and cardiovascular pathology in population exposed to them [11].

When arsenic enters a body, it disintegrates or destabilizes more than 200 enzymes that participate in different metabolic cell processes and DNA synthesis; activates peroxidation; binds thiol (sulfhydryl) groups in tissue proteins thus causing multi-system damages involving the cardiovascular and nervous systems, liver, lungs, kidneys, spleen, gastrointestinal tract, and skin, carcinogenesis being the most serious outcome [12, 13].

At the same time our analysis of domestic and foreign literature sources indicates there hasn't been a sufficient scope of complex hygienic and clinic research describing correlations between health disorders among population living in geochemical provinces and long-term consumption of drinking water with increased arsenic concentrations [13].

Our research goal was to give sanitary-hygienic characteristics of health risks and clinically assess damage to health of population living in a specific geochemical province caused by long-term exposure to arsenic introduced with drinking water.

Data and methods. We performed our research in a geochemical province located in Transbaikalia (an urban village) where drinking water from centralized water supply sources contained increased arsenic concentrations while water supplied from non-centralized sources contained the chemical in standardized concentrations[1, 2]. A well for centralized water supply system was usually 100–120 meters deep; non-centralized underground water supply sources (wells at private houses) were usually not deeper than 10–20 meters. We assessed quality of drinking water taken from centralized water supply systems and non-centralized water sources as per data of monitoring research obtained from the Regional

[1] SER 2.1.4.1074-01. Drinking water. Hygienic requirements to quality of water from centralized drinking water supply sources. Quality control. Hygienic requirements to providing safety of hot water supply systems (last amended on April 2, 2018) / approved by the Order by the RF Chief Sanitary Inspector No. 74 on June 28, 2010. Available at: https: //files. stroyinf.ru/Index2/1/4294846/4294846957.htm (date of visit December 01, 2019).

[2] HS 2.2.5.1315-03. Maximum permissible concentrations (MPC) of chemicals in water from water objects aimed at drinking and communal water supply (last amended on July 13, 2017) / approved by the Order by the RF Chief Sanitary Inspector No. 78 on April 30, 2003. Available at: http: //www.dioxin.ru/doc/gn2.1.5.1315-03.htm (date of visit December 01, 2019).

Center for Hygiene and Epidemiology as well as per field observations performed by certified laboratories at the Federal Scientific center for Medical and Preventive Health Risk Management Technologies with their results obtained with licensed equipment. Arsenic concentration was determined in drinking water samples, food products manufactured in the examined province, and biological media (blood) with mass-spectrometry with inductively coupled plasma according to conventional procedures with a ICP-MS spectrometer.

We assessed potential carcinogenic and non-carcinogenic health risks caused by increased arsenic concentrations in drinking water taken from centralized water supply systems according to conventional procedures fixed in the Guide 2.1.10.1920-04[3].

To comparatively assess structure and peculiarities of morbidity (as damage to people's health) among population who consumed drinking water with different arsenic concentrations, we created a test group consisting of 115 people living in houses with centralized water supply and consuming water with increase arsenic concentrations. Our reference group was made up of 21 people who lived in houses without centralized water supply and consumed water with arsenic concentrations in it not deviating from hygienic standards.

80.9 % people in the test group were adults aged from 16 to 81 (their average age was 51.8 ± 3.6); children (aged 5–15) accounted for 19.1 % (their average age was 8.3 ± 1.2). In the reference group adults (aged 16–57) accounted for 46.9 % (their average age was 40.7 ± 7.5; $p = 0.67$ against the test group); children (aged 5–11) accounted for 53.1 % (their average age was 7.2 ± 0.7; $p = 0.71$ against the test group).

A period of time during which adults lived in houses with centralized water supply varied from 6 months to 47 years (on average 22.0 ± 3.1); this period was longer than 10 years for 70.8 % examined people. Children from the test group lived in such houses for a period of time that varied from 9 months to 13 years (on average 6.6 ± 1.5), and 73.3 % of them lived in such houses for more than 5 years. Adults from the reference group lived in their houses for a period of time that varied from 1 to 57 years (on average 21.1 ± 6.6 years; $p = 0.54$ against the test group), and 83.3 % of them lived in their houses for longer than 10 years. Children from the reference group lived in their houses for a period of time that varied from 3 to 15 (on average 6.3 ± 1.5; $p = 0.83$ against the test group), 76.5 % of them lived in their houses for more than 5 years.

There were no authentic differences between the test and reference groups in terms of their socioeconomic and gender characteristics, ethnic structure and medical aid availability ($p = 0.01$–0.03).

Average daily consumption of drinking water by people from both groups varied from 1 to 5 liters and didn't differ between two groups; on average it was equal to approximately 2 liters (1.9 ± 0.2 liters in the test group; 1.9 ± 0.4 liters in the reference group; $p = 1.0$); children consumed from 1 to 2 liters depending on their age and there were no differences between two groups (1.3 ± 0.2 liters in the test group; 1.2 ± 0.3 liters in the reference one; $p = 1.0$).

We performed clinical and functional examinations of people from both groups (clinical examination by a therapist, pediatrician, neurologist, and oncologist; tonometry; EKG) according to conventional procedures and in conformity with ICH GCP[4] and ethical standards fixed in Helsinki Declaration (last edited in 2008).

Data were analyzed with variation and frequency analysis taking into account Pearson's test; authenticity of numerical values was estimated with Fischer's and Student's tests.

Results and discussion. We analyzed monitoring data on quality of water taken from

[3] G 2.1.10.1920-04. Guide on assessing population health risks caused by exposure to chemicals that pollute the environment. Moscow, The RF Public Healthcare Ministry, Federal Center for State Sanitary and Epidemiologic Surveillance, 2004, 143 p.

[4] State Standard52379-2005. Good Clinical Practice: The RF National Standard / approved by the Order by the Federal Technical Regulation and Metrology Agency issued on September 27, 2005. No. 232-st. (ICH E6 GCP). Available at: https://dokipedia.ru/document/5324107 (date of visit December 01, 2019).

centralized water supply system in the examined settlement and revealed persistent arsenic concentration in it varying from 0.002 to 4.3 mg/dm^3 (up to 86 MPC) while it was just above 1 MPC in water taken from non-centralized water sources. Field observation results also confirmed that arsenic occurred in water from centralized water supply systems in increased concentrations which were equal to 2.5 mg/dm^3 (50 MPC) while its contents in water from non-centralized water sources didn't deviate from hygienic standards (less than 0.05 mg/dm^3). We also examined food products that were locally manufactured and determined that arsenic contents in them conformed to hygienic standards; its contents in carrots amounted to 0.0042 ± 0.0003 mg/kg; potatoes, not found; beetroot, not found (MPL is lower than 0.2 mg/kg for vegetables); fish from local water basins, not found (MPL is lower than 1.0 mg/kg for fresh-water fish).

We assessed lifetime cancer risk caused by consuming drinking water with increased arsenic concentration and revealed that it was unacceptable in the test group and amounted to 4.09×10^{-2} for adults and -1.91×10^{-2} for children. Regarding non-carcinogenic risks, we revealed that they were substantially higher than acceptable quotient for arsenic both for adults and children ($HQ = 494.4$ and $HQ = 211.9$ accordingly); it indicated that people ran risks of skin diseases, diseases of the cardiovascular, nervous, and immune systems, and the gastrointestinal tract.

We assessed health risks for people in the reference group and it allowed us to reveal that cancer risks varied from negligible to maximum permissible ones both for adults and children ($1\times10^{-6} < CR < 1\times10^{-4}$); however, hazard quotient for children that described non-carcinogenic risks exceeded its permissible level ($HQ = 1.1$). It indicated that there was a risk of skin diseases ($HI = 1.66$); diseases in the immune, nervous, ($HI = 1.14$–1.66) and cardiovascular systems ($HI = 1.10$), and the gastrointestinal tract ($HI = 1.1$).

Our next task was to reveal damages to health of people living in the examined settlement caused by chronic oral exposure to arsenic; to do that, we performed comparative analysis of the results obtained via chemical-analytical and clinical examinations of people from the test and reference groups.

Chemical and analytical examination of blood serum revealed that arsenic contents median for adults from the test group amounted to 0.0065 mg/l, and to 0.0049 mg/l for children and it corresponded to average country level (0.0017–0.0154 mg/l)[5]. At the same time 7.9 % adults and 18.8 % children in the test group had arsenic in their blood serum in concentrations higher than the hygienic standards; these concentrations varied from 0.0171 mg/l to 0.0636 mg/l in adults' blood and from 0.0162 mg/l to 0.0377 mg/l in children's blood. As for the reference group, only one adult person from it had arsenic in his blood in concentration higher than on average in the country and it was equal to 0.0162 mg/l; all the examined children from the reference group had arsenic in their blood serum in concentrations which were 4.7–15 times lower than average arsenic contents in human blood plasma.

We examined case histories of people from both groups and revealed that each fifth person (18.3 % in the test group and 18.8 in the reference group; $p = 0.88$) had hereditary load with oncologic pathology as it was detected in the closest relatives (the 1st and 2nd degree). Mammary gland, digestive organs, and lungs were the most frequent organs where oncologic processes were localized for both groups; however, we didn't detect any skin cancer cases in family case histories.

We performed retrospect analysis of data on diseases people from both groups had suffered from in the past and revealed that 6.1 % patients from the test group had previously had oncologic diseases (basal cell carcinoma and melanoma, uterine cancer, kidney cancer, mammary gland cancer); only one female patient from the reference group (3.1 %; $p = 0.72$)

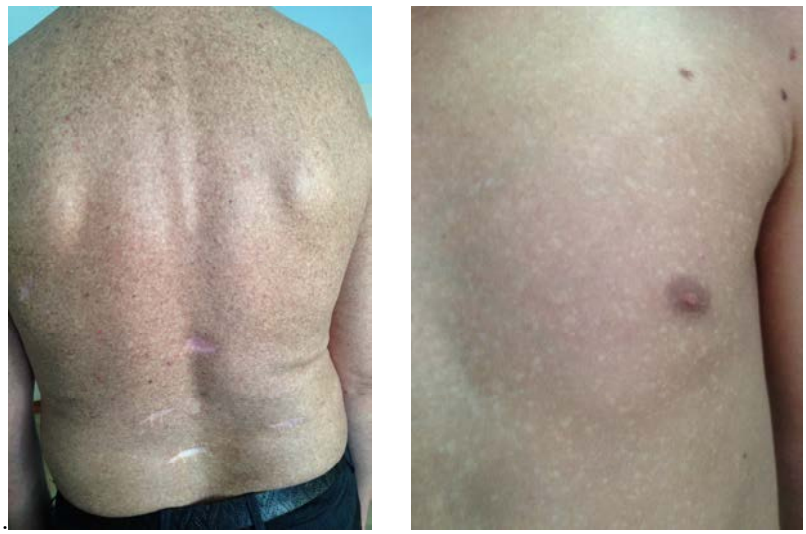
[5] Toxicological chemistry. Metabolism and analysis of toxicants: manual. In: N.I. Kaletina, Moscow, GEOTAR-Media Publ., 2008, 1016 p. (in Russian).

had suffered from basal skin cancer in the past. Overall, oncologic processes occurred 2.0 times more frequently in the test group than in the reference one ($OR = 2.12$; $p = 0.04$).

Patients from the test group most frequently complained about changes in color of their skin, namely occurring hyperpigmentation spots (0.2–0.7 cm) or depigmentation spots (0.3–0.4 cm, more frequently in children) which could be located discretely or everywhere; intense pigmentation of nipples in female patients with their color changing to dark brown or even black; axillary and inguinal folds becoming pigmented and coarse; pigmented spots (more rarely hyperemic ones) with their diameter up to 5.0 cm occurring on the face, neck, breast, and un the occipital region. Dermatological symptoms in adult patients were combined with hyperkeratosis of palms and/or feet in each third case. 44.4 % patients out of 115 people in the test group (9 children and 42 adults) had clinical signs of skin arsenicosis as per poikiloderma type or arsenic melanosis (leukomelanosis) at the moment they were examined (Photo 1).

Most patients stated that the first changes in their skin had occurred 3.5 years prior to our research. Polyneuropathy symptoms were detected in 9.6 % patients during clinical examinations, and ⅔ of them had clinical signs of polyneuropathy combined with damages to skin. There were no complaints about skin pigmentation/depigmentation made by examined people from the reference group; besides, clinical examinations didn't reveal any convincing signs of skin arsenicosis and/or polyneuropathy in them.

To get more precise data on prevalence of a pathology that was co-morbid with skin arsenicosis, we performed clinical and functional examinations of patients and studied their case histories. The examinations revealed that 44.9 % patients from the test group had elevated blood pressure (higher than 140/90 mm Hg); 8.2 % suffered from hypotonia (blood pressure was lower than 100/60 mm Hg). 15.7 % patients suffered from chronic cardiovascular diseases (primary hypertension, ischemic heart disease). Only 43.3 % children had their electrocardiogram conforming to physiological standards whereas 56.7 % had various sinus rhythm disorders. Only 27 % adults had standard ECG. Dysmetabolic and cicatrical changes were prevailing pathologies (39.9 %); 18.6 % patients suffered from functional disorders in the sinus node; 14.4 % had cardiac conduction system pathology. In the reference group only 21.9 % patients had elevated blood pressure, and only 3.1 % suffered from hypotonia; it was 2–3 times less frequent than in the test group ($p = 0.02$). Chronic cardiovascular diseases were diagnosed in 12.5 %



a *b*

Photo 1. Skin arsenicosis as per poikiloderma type (*a*) and leukomelanosis (*b*)

patients from this group and it didn't have any discrepancies with the test one ($p = 0.78$). 55.0 % children from the reference group had standard ECG ($p = 0.69$ against the test group); however, prevailing pathology (40.0 %) was only various sinus rhythm disorders ($p = 0.38$). Adults from the reference group had standard ECG 2.7 times more frequently (71.0 %) than their counterparts from the test one; they suffered from dysmetabolic and cicatrical changes in their cardiac muscle 2 times less frequently (19.4 %; $p = 0.04$); functional disorders in the sinus node (3.2 %) and cardiac conduction system pathology (6.4 %) were rare exceptions for people in the reference group ($p = 0.02$–0.03). Overall, people from the test group suffered from arterial hypertension 2 times more frequently ($OR = 2.14$; $p = 0.03$), and cardiac muscle damages, 9 times more frequently ($OR = 9.23$; $p = 0.01$) than people from the reference one.

20.0 % people from the test group and 18.8 % from the reference one had clinical signs of gastric diseases (chronic gastritis, duodenitis, stomach and duodenum ulcer, enterocolitis) and hepatobiliary diseases (chronic cholecystitis, cholangitis) ($p = 0.92$). The examinations revealed signs of mental and emotional instability, namely astheno-vegetative syndrome and astheno-neurotic syndrome, in 17.4 % people from the test group and 12.5 % people from the reference one ($p = 0.81$).

Overall, damage to health was estimated as grave in 44.4 % cases (oncology, polyneuropathy, arsenic melanosis); average, in 46.3 % cases (arsenic dyschromia); insignificant, in 9.3 % cases (vegetative-vascular dystonia, functional disorders in the nervous system).

Results and discussion. Research results revealed that people who lived in the examined geochemical province and consumed water from deep wells were more significantly exposed to arsenic than their counterparts who consumed water from shallow wells. It is likely due to arsenic ore deposits lying deep. Other authors who have examined peculiarities of geochemical provinces in India and Chile give similar data [3, 4]. According to the obtained results, water taken from a depth of 100 meter and more had arsenic in concentrations that reached 50–86 MPC whereas water taken from a depth of 10–20 meters corresponded to hygienic standards. Hazards caused by deep underground waters are also confirmed by examinations performed on locally produced food such as vegetables watered by local population with water taken from surface water basins and shallow wells as well as fish from local fresh-water basins; arsenic was contained in such products in concentrations that conformed to safety requirements.

Chemical and analytical research revealed that people who consumed drinking water from centralized water supply systems with elevated arsenic contents had arsenic concentrations in their fast-reacting biological media (blood serum) which were authentically higher than arsenic concentrations in blood serum of people who lived in houses without centralized water supply. Besides, we detected that each forth examined person in the test group (26.7 %) had arsenic in his or her blood in concentration which was substantially higher than on average in the country.

We assessed potential health risks caused by elevated arsenic contents in water taken form centralized water supply systems in the examined settlement and revealed that both carcinogenic risks (up to 4.09×10^{-2}) and non-carcinogenic ones (HQ up to 494.4) were unacceptable. As regards non-carcinogenic risks, we detected hazard quotients related to arsenic that were substantially higher than their permissible level both for adults and children ($HQ = 494.4$ and $HQ = 211.9$ accordingly) and it indicated that population ran elevated risks of skin diseases, cardiovascular, nervous, and immune system diseases, and gastric diseases. We should point out that carcinogenic risks for people who consumed water from non-centralized water sources didn't exceed maximum permissible levels; hazard quotients for non-carcinogenic risks were not higher than 1.1 ($HQ = 1.1$).

As per literature data chronic intoxication with arsenic has a diverse clinical picture due to systemic damages to a human body[5] [13]. Also, clinical signs of arsenicosis usually beco-

me apparent under long-term exposure [14–16]. Latent period can last for a long time, up to 60 years after exposure [17]. Our research allowed us to establish that average duration of exposure to arsenic amounted to more than 20 years for adults living in the examined geochemical province, and about 7 years for children; the first clinical signs of the diseases became apparent after 15–17 years for adults and after 4 years for children.

Dermatological signs of arsenicosis and polyneuropathy are the most frequent manifestations of the disease [14, 16]. Our research revealed arsenicosis symptoms in 44.4 % patients who consumed water from centralized water supply systems. These symptoms were hyperpigmentation or depigmentation spots located discretely or everywhere; intense pigmentation of nipple in female patients; axillary and inguinal folds becoming pigmented and coarse; pigmented (less frequently hyperemic) spots occurring on the face, neck, breast, and in the occipital region; 9.6 % patients had polyneuropathy signs. We should point out that people who consumed water from non-centralized water sources didn't have any signs of skin arsenicosis or polyneuropathy. Therefore, people who consumed water with arsenic contents being equal to 50 MPC or even higher had dermatologic or neurologic arsenicosis in each second case.

Chronic intoxication with arsenic can be accompanied with damages to the gastrointestinal tract and in this case gastrointestinal pathology is combined with skin changes and polyneuropathy [18]. In West Bengal 248 patients with chronic intoxication who had been consuming drinking water with elevated arsenic contents for 1–15 years had hepatomegaly in 76.6 % cases; biopsy results revealed that 91.3 % patients suffered from non-cirrhotic portal fibrosis [19]. In other research arsenic was established to be an etiological agent in 5 out of 42 patients with incomplete septal cirrhosis, non-active macronodular cirrhosis, and with frequent bleedings from varicose veins [20]. In our research we revealed clinical signs of gastrointestinal pathologies (chronic gastritis, duodenitis, stomach and duodenum ulcer, enterocolitis) in 18.8 % patients, and hepatobiliary pathologies (chronic cholecystitis / cholangitis), in 20 %.

As per literature data, chronic exposure to elevated arsenic concentrations is accompanied with an increase in cardiovascular pathologies [21–23]. There was a research work accomplished in "arsenicosis – hyperendemic villages" in Taiwan; it revealed a correlation between ischemic heart disease diagnosed in people living there and long-term exposure to arsenic [24]. Results of clinical and pathomorphological research indicate that arsenic causes direct damage to the cardiac muscle, heart rate disorders, and cardiomyopathy [25, 26]. We obtained the same results in our research as we established that adults and children who had been consuming water with elevated arsenic concentrations for a long time (the test group) suffered from arterial hypertension, dysmetabolic changes in the cardiac muscle, and functional disorders in the sinus node and cardiac conduction system 2–9 times more frequently than their counterparts from the reference group.

Carcinogenic effects produced by arsenic are one of the most serious consequences that chronic exposure to it might have [27]. In Bangladesh and India arsenic is associated with skin cancer, lung cancer, liver cancer, kidney cancer, and urinary bladder cancer [28, 29]. The same data have been obtained in South America, Central Africa, and European countries [30]. Though mechanisms of arsenic-related carcinogenesis have not been clearly identified, they probably exert adverse impacts on DNA reparation and methylation; stimulate free radicals production; activate c-myc proto-oncogene; act as co-carcinogen or promoter of tumors or progressing tumor processes [31]. Our research results revealed that chronic exposure to arsenic resulted in 2.0 times more frequent oncology occurrence in people who consumed water with increased arsenic concentrations than in those who consumed water that conformed to hygienic standards.

To sum up our research results, we should note that in specific geochemical provinces where drinking water contains arsenic in ele-

vated concentrations (50–86 MPC), lifetime cancer risk for population who consume this water reaches 4.09×10^{-2} and results in oncologic diseases with various localizations among adults 2 times more frequently than among adult people who consume water that conforms to hygienic standards. Non-carcinogenic health risks for population are unacceptable in such conditions ($HQ = 211.9$ for children; $HQ = 494.4$ for adults) and 2–3 times more frequently result in the diseases of the nervous and cardiovascular system and non-carcinogenic skin pathologies. Overall, damage to health is grave in 44.4 % cases; average, in 46.3 % cases; insignificant, in 9.3 % cases.

Conclusions:

1. In geochemical provinces in Transbaikalia arsenic contents in water taken from deep wells (100 meters and deeper) can reach 50–86 MPC.

2. Chronic consumption of drinking water with arsenic contents being equal to 2.5 mg/dm^3 creates unacceptable carcinogenic (up to 4.09×10^{-2}) and non-carcinogenic (HQ up to 494.4) health risk.

3. Lifetime cancer risk caused by consumption of drinking water with arsenic contents being equal to 50–86 MPC results in 2 times more frequent oncologic pathologies with various localization among adult population.

4. Non-carcinogenic risk is also unacceptable and 2–3 times more frequently results in the diseases of the nervous and cardiovascular system and non-carcinogenic skin pathologies.

5. On average, children have been exposed to increased arsenic concentrations for 4 years; adults, for 15–17 years; damage to their health is estimated as grave in 44.4 % cases (oncology, polyneuropathy, arsenic melanosis); average, in 46.3 % cases (arsenic dyschromia); insignificant, in 9.3 % cases (vegetative-vascular dystonia, functional disorders in the nervous system).

Funding. The research was not granted any sponsor support.

Conflict of interests. The authors declare there is no any conflict of interests.

References

1. Kovshov A.A., Novikova Yu.A., Fedorov V.N., Tikhonova N.A. Diseases risk assessment associated with the quality of drinking water in the urban districts of Russian Arctic. *Vestnik ural'skoi meditsinskoi akademicheskoi nauki*, 2019, vol. 16, no. 2, pp. 215–222 (in Russian).

2. Ratnaike R.N. Acute and chronic arsenic toxicity. *Postgrad med journal*, 2003, vol. 79, no. 933, pp. 391–396. DOI: 10.1136/pmj.79.933.391

3. Matschullat J. Arsenic in the geosphere – a review. *The Science of the Total Environment*, 2000, vol. 17, no. 249, pp. 297–312. DOI: 10.1016/s0048-9697(99)00524-0

4. Gebel T. Confounding variables in the environmental toxicology of arsenic. *Toxicology*, 2000, vol. 144, no. 1–3, pp. 155–162. DOI: 10.1016/s0300-483x(99)00202-4

5. Zaw M., Emett M.T. Arsenic removal from water using advanced oxidation processes. *Toxicol Lett*, 2002, vol. 133, no. 1, pp. 113–118. DOI: 10.1016/s0378-4274(02)00081-4

6. Korolik V.V., Al Sabunchi A.A. Sanitary-hygienic assessment of drinking water and health in Asia. *Zdorov'e naseleniya i sreda obitaniya*, 2013, vol. 239, no. 2, pp. 24–26 (in Russian).

7. Alikberov M.Kh. O riske zdorov'yu naseleniya pri potreblenii vody iz istochnikov khozyaistvenno-pit'evogo vodosnabzheniya v respublike Dagestan [On population health risk related to consuming water from communal and drinking water supply sources in Dagestan]. *Fundamental'nye i prikladnye aspekty analiza riska zdorov'yu naseleniya: materialy vserossiiskoi nauchno-prakticheskoi internet-konferentsii molodykh uchenykh i spetsialistov Rospotrebnadzora*. In: A.Yu. Popova, N.V. Zaitseva eds. Perm, 2017, pp. 14–19 (in Russian).

8. Chowdhury U.K., Biswas B.K., Chowdhury T.R., Samanta G., Mandal B.K., Basu G.C., Chanda C.R., Lodh D. [et al.]. Groundwater arsenic contamination in Bangladesh and West Bengal, India. *Environ Health Perspect*, 2000, vol. 108, no. 5, pp. 393–397. DOI: 10.1289/ehp.00108393

9. Kapaj S., Peterson H., Liber K., Bhattacharya P. Human health effects from chronic arsenic poisoning – a review. *J. Environ. Sci. Health A. Tox. Hazard. Subst. Environ Eng.*, 2006, vol. 41, no. 10, pp. 2399–2428. DOI: 10.1080/10934520600873571

10. Dormancheva E.I. Estimation of morbidity and mortality from malignant diseases in the population of an area with abnormal levels of arsenic. *Vyatskii meditsinskii vestnik*, 2000, no. 1, pp. 68–70 (in Russian).

11. Bogdanova V.D., Kislitsina L.V., Kiku P.F. Sanitarno-gigienicheskaya otsenka kachestva pit'evoi vody v Khasanskom raione Primorskogo kraya [Sanitary-hygienic assessment of drinking water quality in Khasanskiy district of the Primorye]. *Fundamental'naya dal'nevostochnaya nauka – meditsine: materialy nauchno-prakticheskoi konferentsii*. Vladivostok, 2017, pp. 124–126 (in Russian).

12. Cobo J.M., Castineira M. Oxidative stress, mitochondrial respiration, and glycemic control: clues from chronic supplementation with Cr3+ or As3+ to male Wistar rats. *Nutrition*, 1997, vol. 13, no. 11–12, pp. 965–970. DOI: 10.1016/s0899-9007(97)00338-9

13. Hong Y.S., Song K.H., Chung J.Y. Health effects of chronic arsenic exposure. *J. Prev. Med. Public. Health*, 2014, vol. 47, no. 5, pp. 245–252. DOI: 10.3961/jpmph.14.035

14. Guha Mazumder D.N., Haque R., Ghosh N., De B.K., Santra A., Chakraborty D., Smith A.H. Arsenic levels in drinking water and the prevalence of skin lesions in West Bengal, India. *Int. J. Epidemiol.*, 1998, vol. 27, no. 5, pp. 871–877. DOI: 10.1093/ije/27.5.871

15. Lien H.C., Tsai T.F., Lee Y.Y., Hsiao C.H. Merkel cell carcinoma and chronic arsenicism. *J. Am. Acad. Dermatol.*, 1999, vol. 41, no. 4, pp. 641–643.

16. Mazumder D.N., Das Gupta J., Santra A., Pal A., Ghose A., Sarkar S. Chronic arsenic toxicity in West Bengal—the worse calamity in the world. *J. Indian. Med. Assoc.*, 1998, vol. 96, no. 1, pp. 4–7.

17. Abernathy C.O., Liu Y.P., Longfellow D., Aposhian H.V., Beck B., Fowler B., Goyer R., Menzer R. [et al.]. Arsenic: health effects, mechanisms of actions, and research issues. *Environ Health Perspect*, 1999, vol. 107, no. 7, pp. 593–597. DOI: 10.1289/ehp.99107593

18. Poklis A., Saady J.J. Arsenic poisoning: acute or chronic? Suicide or murder? *Am. J. Forensic. Med. Pathol.*, 1990, vol. 11, no. 3, pp. 226–232.

19. Santra A., Das Gupta J., De B.K., Roy B., Guha Mazumder D.N. Hepatic manifestations in chronic arsenic toxicity. *Indian J. Gastroenterol.*, 1999, vol. 18, no. 4, pp. 152–155.

20. Nevens F., Staessen D., Sciot R., Van Damme B., Desmet V., Fevery J., De Groote J., Van Steenbergen W. Clinical aspects of incomplete septal cirrhosis in comparison with macronodular cirrhosis. *Gastroenterology*, 1994, vol. 106, no. 2, pp. 459–463. DOI: 10.1016/0016-5085(94)90605-x

21. Axelson O., Dahlgren E., Jansson C.D., Rehnlund S.O. Arsenic exposure and mortality: a case-referent study from a Swedish copper smelter. *Br. J. Ind. Med.*, 1978, vol. 35, no. 1, pp. 8–15. DOI: 10.1136/oem.35.1.8

22. Lee-Feldstein A. A comparison of several measures of exposure to arsenic. Matched case-control study of copper smelter employees. *Am. J. Epidemiol.*, 1989, vol. 129, no. 1, pp. 112–124. DOI: 10.1093/oxfordjournals.aje.a115100

23. Lewis D.R., Southwick J.W., Ouellet-Hellstrom R., Rench J., Calderon R.L. Drinking water arsenic in Utah: a cohort mortality study. *Environ Health Perspect*, 1999, vol. 107, no. 5, pp. 359–365. DOI: 10.1289/ehp.99107359

24. Tsai S.M., Wang T.N., Ko Y.C. Mortality for certain diseases in areas with high levels of arsenic in drinking water. *Arch. Environ Health*, 1999, vol. 54, no. 3, pp. 186–193. DOI: 10.1080/00039899909602258

25. Benowitz N.L. Cardiotoxicity in the workplace. *Occup. Med.*, 1992, vol. 7, no. 3, pp. 465–478.

26. Goldsmith S., From H. Arsenic-induced atypical ventricular tachycardia. *N. Engl. J. Med.*, 1980, vol. 303, no. 19, pp. 1096–1098. DOI: 10.1056/NEJM198011063031905

27. Everall J.D., Dowd P.M. Influence of environmental factors excluding ultra violet radiation on the incidence of skin cancer. *Bull. Cancer*, 1978, vol. 65, no. 3, pp. 241–247.

28. Guo H.R., Chiang H.S., Hu H., Lipsitz S.R., Monson R.R. Arsenic in drinking water and incidence of urinary cancers. *Epidemiology*, 1997, vol. 8, no. 5, pp. 545–550. DOI: 10.1097/00001648-199709000-00012

29. Hood R.D., Vedel-Macrander G.C. Evaluation of the effect of BAL (2,3-dimercaptopropanol) on arsenite-induced teratogenesis in mice. *Toxicol. Appl. Pharmacol.*, 1984, vol. 73, no. 1, pp. 1–7. DOI: 10.1016/0041-008x(84)90045-0

30. Smith A.H., Arroyo A.P., Mazumder D.N., Kosnett M.J., Hernandez A.L., Beeris M., Smith M.M., Moore L.E. Arsenic-induced skin lesions among Atacameno people in northern Chile despite good nutrition and centuries of exposure. *Environ Health Perspect*, 2000, vol. 108, no. 7, pp. 617–620. DOI: 10.1289/ehp.00108617

31. Rahman M.M., Chowdhury U.K., Mukherjee S.C., Mondal B.K., Paul K., Lodh D., Biswas B.K., Chanda C.R. [et al.]. Chronic arsenic toxicity in Bangladesh and West Bengal, India – a review and commentary. *J. Toxicol. Clin. Toxicol.*, 2001, vol. 39, no. 7, pp. 683–700. DOI: 10.1081/clt-100108509

Ustinova O.Yu., Shur P.Z., Nosov A.E. Sanitary-hygienic characteristics of health risk and clinical assessment of damage to health done to population living in a specific geochemical province under long-term exposure to arsenic introduced with drinking water. Health Risk Analysis, 2019, no. 4, pp. 148–157. DOI: 10.21668/health.risk/2019.4.16.eng

Received: 02.10.2019
Accepted: 03.12.2019
Published: 30.12.2019