PERIÓDICO TCHÊ QUÍMICA
ARTIGO ORIGINAL

DISTRIBUIÇÃO DE RADIONUCLÍDEOS EM ÁGUAS NATURAIS DO NORTE DO CAZAQUISTÃO E AVALIAÇÃO DAS DOSES DE RADIAÇÃO DA ÁGUA USA PELA POPULAÇÃO

DISTRIBUTION OF RADIONUCLIDES IN NATURAL WATERS OF NORTHERN KAZAKHSTAN AND ASSESSMENT OF WATERBORNE DOSES IRRADIATION OF POPULATION

РАСПРЕДЕЛЕНИЕ РАДИОНУКЛИДОВ В ПРИРОДНЫХ ВОДАХ СЕВЕРНОГО КАЗАХСТАНА И ОЦЕНКА ВОДООБУСЛОВЛЕННЫХ ДОЗ ОБЛУЧЕНИЯ НАСЕЛЕНИЯ

SALIKOVA, Natalya S.[1*]; TLEUOVA, Zhulduz O.[2]; KURMANBAYEVA, Aigul S.[3]; KHUSSAINOVA, Razya K.[4]; KAKABAYEV, Anuarbek A.[5];

[1,2] Abay Myrzakhmetov Kokshetau University; Department of Ecology, Life Safety and Environmental Protection; 189A Auezov Str., zip code 020000, Kokshetau – Republic of Kazakhstan

[3,4,5] Sh. Ualikhanov Kokshetau State University; Department of Geography, Ecology and Tourism; 76 Abay Str., zip code 020000,Kokshetau – Republic of Kazakhstan

** Corresponding author*
e-mail: natsal66@mail.ru

Received 20 September 2020; received in revised form 26 October 2020; accepted 10 November 2020

RESUMO

A população da Terra está diariamente exposta à radiação externa e interna. Suas doses variam em uma ampla faixa, dependendo dos níveis de radiação cósmica e do conteúdo de radionuclídeos naturais e antropogênicos na litosfera, hidrosfera, atmosfera e biosfera. A radiação ionizante e os radionuclídeos de origem natural e artificial inevitavelmente causam a exposição humana, o que aumenta a probabilidade de consequências negativas para a saúde. Se a dose de radiação for baixa e a exposição durar por um longo período de tempo (baixa potência), o risco é significativamente reduzido, pois neste caso a probabilidade de reparo dos tecidos danificados aumenta. No entanto, existe o risco de consequências de longo prazo, como o câncer, que pode se manifestar em anos ou mesmo décadas. O objetivo do estudo é estudar os fatores naturais da formação de radioatividade em águas naturais do norte do Cazaquistão e avaliar as doses de exposição da população relacionadas à água. O principal método para estudar este problema é o método radiométrico através da utilização do radiômetro. A análise radioquímica seletiva foi usada para determinar os radionuclídeos de urânio, tório, rádio, chumbo, césio e estrôncio. No decorrer do estudo, 166 fontes de água foram estudadas e sistematizadas nos últimos 5 anos. O objeto do estudo abrange as fontes de água potável para a população das regiões de Ayyrtau, Tayinshinsky, Esilsky, bem como a área de Musrepov, região do Norte do Cazaquistão. Foram investigados 4 tipos de fontes de água potável: água de furos, água de poços, água da torneira, água de furos usados para abastecimento de água centralizado. Ao calcular a dose de exposição interna, usamos os dados da análise radioquímica anual de várias fontes de água doce em quatro distritos da região do Norte do Cazaquistão de 2011 a 2016. Também foram realizadas conservação e recultivo de minas e depósitos de rochas nas áreas de Musrepov e Ayyrtau.

Palavras-chave: *fontes de água potável, monitoramento de radiação, atividade específica, dose de radiação interna.*

ABSTRACT

The population of the Earth is exposed to external and internal radiation every day. Radiation doses differ over a wide range of cosmic radiation levels and the content of natural and anthropogenic radionuclides in the lithosphere, hydrosphere, atmosphere and biosphere. Ionizing radiation and radionuclides of natural and artificial origin inevitably causes exposure, increasing the probability of adverse health effects. Suppose the dose of radiation is low and is exposed for a long period of time (low power). In that case, the risk is significantly reduced, since the likelihood of repair of damaged tissues increases. However, there is a risk of long-term consequences, such as cancer, which can manifest in years or even decades. The paper aims to research the natural factors in the formation of radioactivity in the natural waters of Northern Kazakhstan and assess water-related doses to the population. The leading research methods for this issue are radiometric and radiochemical methods of analysis. Selective radiochemical analysis was used to determine the radionuclides of uranium, thorium, radium, lead, cesium and strontium, and a radiometer was used to determine radonuclides. During the study, 166 water sources over the past 5 years were analysed and systematized. The research object was drinking water sources of the population of Ayyrtau, Tayinsha, Yesil districts, and Musirepov district of the North Kazakhstan region. Four types of drinking water sources were investigated: well water, borehole water, spring water, borehole water used for centralized water supply. When calculating the dose of internal exposure, the data of the annual radiochemical analysis of various fresh water sources of four districts of the North Kazakhstan region from 2011 to 2016 were used.

Keywords: *drinking water sources, radiation monitoring, specific activity, internal radiation dose.*

АННОТАЦИЯ

Население Земли ежедневно подвергается как внешнему, так и внутреннему облучению. Его дозы различаются в широком диапазоне в зависимости от уровней космического излучения и содержания естественных и антропогенных радионуклидов в литосфере, гидросфере, атмосфере и биосфере. Ионизирующие излучения и радионуклиды естественного и искусственного происхождения неизбежно вызывают облучение человека, увеличивающее вероятность возникновения негативных для здоровья последствий. Если доза облучения является низкой и воздействует длительный период времени (низкая мощность), риск существенно снижается, поскольку в этом случае увеличивается вероятность восстановления поврежденных тканей. Тем не менее риск долгосрочных последствий, таких как рак, который может проявиться через годы и даже десятилетия, существует. Цель исследования заключается в изучении природных факторов формирования радиоактивности природных вод Северного Казахстана и оценке водообусловленных доз облучения населения. Ведущим методом исследования данной проблеми является радиометрический метод с использованием радиометра. Для определения радионуклидов урана, тория, радия, свинца, цезия и стронция применили селективный радиохимический анализ. В ходе исследования было изучено и систематизировано 166 источников воды за последние 5 лет. Объектом исследования стали источники питьевой воды населения Айыртауского, Тайыншинского, Есильского района, а также района г. Мусрепова Северо-Казахстанской области. Было исследовано 4 типа источников питьевой воды: вода скважин, вода колодцев, водопроводная вода, вода скважин, используемая для централизованного водоснабжения. При расчете дозы внутреннего облучения были использованы данные ежегодного радиохимического анализа различных источников пресной воды четырех районов Северо-Казахстанской области с 2011 г. по 2016 г.

Ключевые слова: *источники питьевой воды, радиационный мониторинг, удельная активность, доза внутреннего облучения.*

1. INTRODUCTION:

Every day from water and food people receive certain doses of radiation. On average, approximately 2/3 of the effective equivalent dose of radiation received by a person from natural sources of radiation comes from radionuclides that enter the body with food, water and air. Only a small part of this dose falls on radioactive isotopes such as carbon-14 and tritium, formed under the influence of cosmic radiation (Wilson *et al.*, 2015; World Health Organization, 2017). Everything else comes from sources of terrestrial origin. On average, a person receives about 180 mSv/year due to potassium-40, which is absorbed by the body along with non-radioactive potassium isotopes necessary for the life of the body. However, a person receives a more substantial dose of internal radiation from the nuclides of the radioactive series of uranium and, to a lesser extent, from the radionuclides of the thorium series. One of the most important sources of natural radioactivity in exposure of the population is the radioactivity of drinking water, determined by the content of uranium, thorium, radium, lead and radon (Grobe *et al.*, 2009; Berdymbaeva, 2012; Vogiannis and Nikolopoulos, 2015; Yan, 2019).

The territory of Kazakhstan is the world's largest uranium-ore geochemical province. Two uranium provinces – North Kazakhstan and Betpak-Dala, are located in Northern, Central and Southern Kazakhstan and are characterized by outcrops of pre-Mesozoic formations on the surface. Among the latter, rocks with high uranium and thorium contents are widespread, as well as local near-surface insolation-evaporitional accumulations of uranium typical of arid zones.

The lack of necessary information on the specific activity of drinking water can lead to the use of water sources in these areas with increased radioactivity as sources of drinking water (World Nuclear Association, 2020).

The formation of the radionuclide composition of groundwater in Northern Kazakhstan depends on natural factors: on the type of water (river, underground); lithologic-petrographic composition of rock complexes; the nature of groundwater circulation in areas of intense and difficult water exchange; ion-salt composition of water; from acid-base and reductive-oxidative conditions. The content of radionuclides in groundwater depends not only on their content in rocks, but also to a small extent is determined by their physicochemical properties that determine the migration ability of the radionuclide (degree of ionization, ability to complexation, solubility of the compounds formed by them, the form of the nuclide associated with ions) (Likhodumova and Salikova, 2013; Kaz *et al.*, 2016; Liu *et al.*, 2020). Granitoids are among the natural factors affecting the radioecological state of Northern Kazakhstan; their massifs contain elevated dispersed concentrations of radionuclides of uranium, thorium and daughter products of their decay. Almost a quarter of the country`s uranium reserves are concentrated in the region. In the region, the uranium content, according to Volkovgeologiya (1994), ranges from less than 0.5 to 12.4 mg/kg with a background content of 2.1 mg/kg. The largest anomalies of uranium are located in the south of the region, where massifs of the Kokshetau low mountains are located, composed mainly of granitoids – the most radioactive rocks in nature.

As of the beginning of 1992, 17 deposits of uranium ore were explored in the North Kazakhstan region, which constitute the bulk of the resources of the North Kazakhstan uranium ore province (NKUOP) by reserves. For uranium deposits development, the Tselinnyy Mining and Chemical Complex was formed with its main base in Stepnogorsk, Akmola Region. Of the 17 deposits, 15 belong to hydrothermal and 2 to infiltration in the sediments of the Mesozoic palaeovalleys (Sofronova, 2012; Karibayev, 2014). As of 01.01.2001, there were 9 deposits on the state balance. Grachevka and Semizbai deposits are classified as exploited, and Kosachin, Shokpak, Kamyshovo, Akkan-Burlyk, Viktorovskoe, Fevralskoe, Burlyk deposits are being used. As of the beginning of 1992, 17 deposits of uranium ore were explored in the North Kazakhstan region, which constitutes the bulk of the resources of the North Kazakhstan uranium ore province (NKUOP) by reserves. For uranium deposits development, the Tselinnyy Mining and Chemical Complex was formed with its main base in Stepnogorsk, Akmola Region. Of the 17 deposits, 15 belong to hydrothermal and 2 to infiltration in the sediments of the Mesozoic palaeovalleys (Gavrylko, 2014; Karibayev, 2014). As of 01.01.2001, there were 9 deposits on the state balance. Grachevka and Semizbai deposits are classified as exploited, and Kosachin, Shokpak, Kamyshovo, Akkan-Burlyk, Viktorovskoe, Fevralskoe, Burlyk deposits are being used.

Granitoids are among the natural factors affecting the radioecological state of the North Kazakhstan region, their massifs contain increased dispersed concentrations of uranium radionuclides and daughter products of its decay (Panin, 2005). As a result of the desalination of rocks containing radioactive elements, the hydrosphere of the region is saturated with radionuclides, therefore, there is a danger of increased radiation risk for the population of the North Kazakhstan region. In this regard, the study of drinking water as a source of internal radiation factor, additional to external, and, accordingly, additional radiation risk to the health of the population of Northern Kazakhstan, is relevant (Bersimbaev and Bulgakova, 2015).

A comprehensive research of the environmental situation in the territory of Northern Kazakhstan and analyzing the possible causes of high morbidity and mortality in the region's population is impossible without researching the radiation factor. In this regard, investigating the content and mechanisms of radionuclide intake into various natural components and environments is of particular interest. Natural sources of ionizing radiation to the total radiation doses to people in most cases are the main (Bersynbaev and Bakhtin, 2012; Mazhitova and Pashkov, 2017). In this regard, there is a need to analyze the content of natural radionuclides in natural environments and, in particular, in groundwater used as drinking water. One of these quality indicators is the content (specific activity) of radionucl ides (Yapiyev *et al*., 2019).

Therefore, the aim of this study was to study radionuclides in the natural waters of Northern Kazakhstan, as well as to assessment of waterborne doses irradiation of population.

2. MATERIALS AND METHODS:

To establish the conformity of the quality of drinking groundwater with the current standards in the field of radiation safety, 726 samples of groundwater were analyzed by the content of ^{238}U, ^{232}Th, ^{226}Ra, ^{210}Pb, ^{137}Cs, ^{90}Sr, ^{222}Rn (Appendices No. 1-4 to the Order..., 2011; Decree of the Government…, 2015a; Decree of the Government…, 2015b; Order of the Minister of Health…, 2019). Water sampling was carried out following Appendix No. 1-4 to the Order of the Chairman of the State Sanitary and Epidemiological Surveillance Committee dated 08.09.2011, No. 194 "On approval of guidelines for radiation hygiene" (Methodological recommendations for sanitary control … 2011): when using standard containers made of polymeric materials, it is necessary to rinse with water from the source at least 3 times before use (Appendices No. 1-4 to the Order..., 2011). When calculating the required volume of water, it is necessary to rely on the approved indicators in the normative documentation, which considers the method for determining a specific indicator and the number of determined indicators. According to the Appendices No. 1-4 to the Order of the Chairman ot the State Sanitary Doctor of the Republic of Kazakhstan No. 194 "On approval of guidelines for radiation hygiene" (2011) the recommended volume of water sampling from surface and underground sources of drinking water is 10 liters. This volume includes the required amount of water needed during the re-analysis, the type of analysis, the volume of water taken. Evaluation of the total indicators of α- or β-activity required at least 1 liter of samples. To assess the radionuclide composition and specific activity of natural radionuclides (^{226}Ra, ^{224}Ra, ^{238}Ra, ^{238}U, ^{234}U, ^{210}Pb, ^{210}P, ^{210}Bi, ^{230}Th, ^{232}Th, ^{228}Th) at least 11 liters were required. To check the specific activity of 137Cs, 90Sr and 40K (if necessary, 238Ru and 241Am) minimum 4 liters were required. To determine the specific activity of 222Rn 1 liter of sample was required.

When sampling, it is necessary to drain the water for a certain time to establish constant characteristics. If the current water source is operational, regardless if it is artesian water or tap water, then the drain time is set within 5 minutes. For newly introduced sources or sources after repair, this time was set individually and depended on the degree of contamination of the water supply channel. There were no established time frames for draining, since the fixation of the stability of water characteristics is only visually recognized. Water can be taken traditionally from wells and open reservoirs, such as rivers, lakes, water storage reservoirs and other bodies of water. After selection, water was placed in an airtight container for the time required for the deposition of small fragments of sand, soil, silt. Again, the time was set subjectively in each case, but not less than 2-3 hours. After the required time, nitric acid was added to the sample in an amount necessary to achieve a pH of 1. This allowed to eliminate the process of sorption of trace amounts of radionuclides on the inner surface of the container. The container was labeled and a selection certificate was added, which indicated the date, time of selection, and all the necessary information about the source. Appendix 1 to the guidelines contains recommended information for display in the certificate. The analysis period should not exceed 14 days for the selected samples. The test report indicated the shelf life of the sample. If this conditions were violated, analysis was not carried out.

For determining ^{222}Rn, a radiometric method was applied to water with the use of a Ramon-02 radiometer. Selective radiochemical analysis was used to determine the radionuclides of uranium, thorium, radium, lead, cesium, and strontium. Specific activity of ^{238}U, ^{232}Th was determined by the photometric method with the use of a KFK-3 photocolorimeter, ^{226}Ra, ^{210}Pb, ^{137}Cs, ^{90}Sr – sedimentation analysis with the use of the low-background setup UMF-2000, entered in the register of the State Automotive Inspection of the Republic of Kazakhstan. All measurements were performed according to the methods included in the register of the GSI RK, the latest edition is presented in (Order of the Chairman of the State Sanitary … 2011).

The methodology for assessing the internal doses of radionuclides entering the human body with drinking water Ewater (mSv/year) was calculated according to the Decree of the Government of the Republic of Kazakhstan "On approval of hygiene standards" Sanitary and epidemiological requirements for radiation safety" (Decree of the Government of the Republic of Kazakhstan … 2015a) according to the formula (Equation 1):

$$E_{water} = \sum(\varepsilon_{wateri} \cdot C_{wateri} \cdot 2 \cdot 365) \qquad \text{(Eq. 1)}$$

Where ε_{wateri} is the dose coefficient of the *i* isotope for water, mSv/Bq; C_{wateri} is the specific activity of the *i* radionuclide in a water sample, Bq/kg; *2* is the statistically average amount of water consumed by a person per day, kg/day; *365* is the conversion factor, days/year.

3. RESULTS AND DISCUSSION:

3.1. Characteristics of radiation hazardous areas

Considering all radiation factors, 5 radioecological potentially hazardous zones were identified: Priyesil, Zerendy-Balkashino, Chagaly, Akkol-Schuchinsk and Stepnogorsk-Zaozernyy. Exploration of uranium deposits was carried out in the region and it was mined until the middle of 1990s. During mining and evaluation of ore occurrences, extensive dumps of radioactive rocks were formed, most of which are currently reclaimed.

There are five radiation hazardous zones on the territory of Northern Kazakhstan (Beletskaya, 1974, Abdulkabirova, 1975): Priyesil; Zhalgyztau (Zerendy-Balkashino); Saumalkol (Chagaly); Taldykol (Akkol-Schuchinsk); Aisary (Stepnogorsk-Zaozernyy). On the map of dose loads in the southern part of the region there are areas with increased (up to 5.6 mSv/year) radiation dose values.

To calculate the exposure ammount, the dose factors were used (Table 1). In terms of the degree of possible technogenic radiation load, the Akmola region is the most dangerous in Kazakhstan (along with the East Kazakhstan and Pavlodar regions, where this danger is caused by the presence of the Semipalatinsk Test Site). Currently, the degree of radiation hazard within it is determined by the following main regional and local factors:

- high content of uranium and thorium in rocks;
- the high content of radon in groundwater, in the surface layer of atmospheric air (and, accordingly, in residential buildings);
- increased groundwater radioactivity;
- the formation of areoles of technogenic radioactivity in places of mining.

There is a small amount of total thorium in the region, averaging 7 mg/kg; its increased content (49 mg/kg) was noted near the highly active, rare-metal Orlinogorsk granitoid massif. Radium is in a diffuse state in the region. In very low concentrations, it is found in aqueous solutions, from which it is extracted as a result of adsorption, coprecipitation and capture by living matter. Some researchers consider the accumulation of radium to be a species trait of plants. The highest concentration of strontium-90 (30 Bq/kg, or 0.093 Ci/km^2) within the study area was noted in the largest (2000 km^2) Volodarsk anomalous zone.

Alpha radiation within the studied area ranges from 100 to 18025 imp/s·kg. The largest anomalies – with high alpha activity – are recorded in the southern part of the region, to the north of alpha activity is much less. The intensity of beta radiation within the study area ranges from 0 to 781 imp/s·kg. There are 9 anomalies and 3 anomalous points. An analysis of the obtained materials allows us to conclude that the radiation pollution of the territory is mainly due to natural sources (Salikova *et al*., 2011). The most dangerous objects are those from which the human dose norm from anthropogenic radiation should not exceed 1 mSv/year. These objects include industrial enterprises that involve radioactive natural materials (radioactive ore) in their technological process.

An unfavorable radiological condition is noted in the city of Sergeyevka, in Ornek village and other settlements located in the near-valley part of Ishim, where there are outcrops of indigenous acidic magmatic rocks. A relatively unfavorable radiological situation is also noted in the areas of development of fracture of the platform cover, in the vicinity of Yavlenka village, near the northern border of the ancient platform (Lipchanskaya, 2014). However, as already noted, so far there are few works devoted to the results of the research of radiation intensity or safety of the territory of Northern Kazakhstan. Based on the research results and taking into account the data of other authors, a radiation intensity map was compiled (Bensman *et al*., 2012).

The territory of the eastern half of the republic, especially the territory of the Akmola and North Kazakhstan regions, is characterized by the greatest radon emanations. About 30 anomalies and 15 anomalous points with an increased concentration of uranium, thorium, ^{226}Ra, ^{228}Ra, ^{40}K and other elements, were found in the northern half of the region. 2 anomalies of strontium and 2 anomalous cesium points of unknown origin were located. Perhaps they were formed due to global western disturbance and the deposition of products of the Kyshtym accident in the Urals. In general, anomalies of radionuclides characterize a satisfactory ecological state of almost the entire water catchment area of small rivers in the region.

In the predominant part of the region, the annual dose level is 2-3 mSv/year. The zone territories located in the southern border zone (Saumal, Priyesil, Zerenda-Balkashino) include areas with a dose load of up to 4 mSv/year. In the northern part of the region, granites and other crystalline rocks of a folded basement are overlain by the thickness of aleuric-clay deposits, which increases in the northern and northeastern directions 1000-1500 m or more. The absence of acidic magmatic rocks on the surface, the sluggish tectonic regime and the thick stratum of sedimentary rocks of the platform cover play the role of a protective shield against emanation of the decay products of the radioactive elements of the folded basement. Table 2 describes radiation hazardous areas.

In the city of Petropavlovsk, the gamma background is low, it ranges from 3 μR/h to 45-50 μR/h. The increased background radiation (17 anomalies with gamma activity from 50 μR/h to 800 μR/h) is created by granite slabs lining the steps near some shops, granite blocks embedded in the foundation of multi-storey buildings and other elements. The presence of natural radioactive objects in these zones, creates an increase of radiation risk. Most of these zones do not pose a real radiation hazard, since on average the radiation dose does not exceed 1 mSv/year. Only in certain local areas can it exceed the annual dose load of 1 mSv/year. The total area of such zones is 489.1 thousand km2 or 57.1 of the total area of all zones. These low radiation hazard areas are mainly located in the western region of Kazakhstan. Areas of medium radiation hazard are also identified here.

The most significant concentrations of radionuclides were found in the Orlinogorsk granite massif in the Zhaman-Sopka area. According to the analysis results conducted by Stepgeology JSC, the most critical radiological condition is noted in the village of Gorny, located in the vicinity of the granite quarry at the foot of Orlinaya. There is no homogeneous gamma background and ranges from 18-25 μR/hour to 40-80 μR/hour. 25 points with an abnormally high gamma-ray background were detected – approximately of 60-80 μR/hour. High levels of radiation were detected inside some rooms.

Of the radioactive elements contained in groundwater, the most hazardous to health is the presence of emanations of radon and its daughter decay products (Isupov *et al.*, 2016). An increased radon content is noted in groundwater near the village of Gorny at the foot of Zhaman-Sopka. The highest content was 2795 Bq/kg, which is more than 45 times the maximum permissible value, and 1663.9 Bq/kg was recorded in the central well, which exceeds the MPC (1100 Bq/kg) by 15.1 times. In other wells, radon concentrations range from 113.7 to 1037.0 Bq/kg (1.03-9.43 MPC). High ^{222}Rn activities are also recorded in Saumalkol village of the Ayyrtau region, where the concentrations are 506-1073 Bq/kg, in the wells of Raisovka village – 333 Bq/kg (Musirepov district), Ikobercy village – 303 Bq/kg (Akzhar district), and some other settlements in the North Kazakhstan region (the village of Ruzayevka, the village of Urnek, the town of Strelnikovo, the sanatorium Arka). The content of 222Rn in the water of the listed settlements exceeds the established intervention level of 60 Bq/kg. In the waters of open reservoirs, the radon content is much lower and ranges from 0.29 to 0.59 Bq/kg (0.003-0.005 MPC) (Vodopyanova and Mazhitova, 2012).

Radionuclides in high concentrations are also contained in other drinking wells located in the southern part of the region. In the northern part of the region, radioactive groundwater was discovered in the Petropavlovsk region. The radium concentration and radon concentration is of therapeutic value and allows their use in balneological purposes (Larikova, 2012). Thus, the variety of natural conditions contributed to the formation of zones with different levels of radiation conditions in the region: in a significant part of the region (northern regions), the radiological situation is approaching normal; Some territories in the south of the region have increased radiation background due to the wide development of granite massifs and numerous deposits of uranium ores.

3.2. Description of the specific activity of drinking water in the reservoirs of Northern Kazakhstan

Researches have shown that the underground waters in Northern Kazakhstan are distinguished by a variety of chemical composition and content of radioactive elements, which is due to the location of the region on the border of the northern part of the Kazakh small hills and the southern part of the West Siberian plain (Panin, 2005). The radionuclide composition of natural waters varies over a wide range (Table 3).

The absence of the effect of artificial radioactivity on the formation of the radioactive background of groundwater has been established. Technogenic radionuclides are detected in single samples and do not exceed 0.05 IL for ^{137}Cs and 0.02 IL for ^{90}Sr. Excess levels of intervention are observed in the content of ^{238}U (Aiyrtau and Ualikhanov districts), in the content of ^{226}Ra (Yesil and Timiryazev districts), in the content of ^{222}Rn (areas: Aiyrtau, Akzhar, Yesil, G. Musirepov, Shal akyn).

Radon is highly soluble in water and its content in groundwater is unlimited. The formation of aquifers washing uranium-containing granitoids in the zones of fracture and karst contributes to its increased groundwater content in the south of the North Kazakhstan region. Groundwater sedimentary rocks of uranium of the northern part of the North Kazakhstan region have minimal radon content. However, in the northern region of the region, granites and other crystalline rocks of a folded basement are overlain by the thickness of aleuric-clay deposits, the thickness of which increases in the northern and northeastern directions to 1,500 m or more. The thick stratum of sedimentary rocks prevents the emanation of radon to the Earth surface and contribute to its concentration in groundwater.

When calculating the dose of internal exposure, we used the data of the annual radiochemical analysis of various freshwater sources of four regions of the North Kazakhstan from 2011 to 2016. The sources of drinking water such as wells, boreholes, springs, and water supply were calculated. The values of specific activities of drinking water of various sources of the G. Musirepov district for 2011 are presented in the Table 4.

The values of specific activities of drinking water of various sources of the G. Musirepov district for 2012 are presented in the Table 5. As can be seen from the data of Table 5, the specific activity of radionuclides (^{238}U, ^{232}Th, ^{226}Ra, ^{210}Pb) in drinking water of all investigated sources does not exceed the established levels of intervention (IL). Table 6 shows the specific activity of drinking water in the G. Musirepov district for 2013.

The highest specific activity is inherent in uranium-238, with the maximum value of the radionuclide observed in the water of the boreholes. The second place in the specific activity of uranium-238 is water wells. A rather high specific activity is noted for lead-210 in water wells. Table 7 shows the specific activity of drinking water in the G. Musirepov district for 2014. Table 8 presents the specific activity of drinking water in G. Musirepov district for 2015.

The highest specific activity is typical for well water for all analyzed radionuclides. A low specific activity was noted for the thorium-242 isotope in all samples of the analyzed water from various drinking water sources. Despite the absence of obvious sources of anthropogenic interference, the presence of lead-210 isotope in all water samples is observed. Table 9 shows the specific activity of drinking water in the G. Musirepov district for 2016. During this period, the water of wells, boreholes, and the water of springs was examined. The presence of radioactivity in the water of springs and other water samples of all the analyzed radionuclides is noted. Approximately equal concentrations of radium-226 are observed in all sources of drinking water. Despite strict sanitary and epidemiological control and borehole water used for centralized water supply, it contains radionuclides radium-226, uranium-238, and lead-210. The presence of granite uranium-containing radionuclides naturally explains the presence in the analyzed waters of the isotopes of uranium-238 and its decay product – radium-226. Thorium-232, as less mobile in natural waters, exhibits low radioactivity in all water samples.

Based on the data presented in Tables 4-9, the effective equivalent dose of the population exposure from radionuclides in drinking water of G. Musirepov district was calculated, mSv/year (Table 10). As we can see from the data of Table 10, the drinking water of all the analysed sources does not significantly irradiate the population of the G. Musirepov region for the entire studied period of 2011-2016. According to the calculated data, the exposure of the population to the drinking water consumption of the considered region ranged from 0.024 mSv/year (borehole water used for centralized water supply, 2016) to 0.123 mSv/year (borehole water, 2013). In Tables 11-14, the presented data of radiation monitoring of drinking water of the Yesil district for 2011-2016.

As can be seen from the data, the specific activity of radionuclides (^{238}U, ^{232}Th, ^{226}Ra, ^{210}Pb) in drinking water of all the studied sources does not exceed the established IL. The highest specific activity of uranium-238, radium-226 radionuclides, is observed in water samples from wells and boreholes in Yavlenka, Pokrovka. Noted low specific activity of thorium-232 radionuclide in all water samples from all sources of water supply. In tap water, the highest specific activity is characteristic of the uranium-238 radionuclide. Among all drinking water sources, the highest specific activity for radionuclides is ^{238}U, ^{232}Th, ^{226}Ra, ^{210}Pb, which is typical for water samples from wells. In 2016, in one of the wells of Korneyevka village, the ^{238}U radionuclide content is almost 3 times higher than the specific activity of this radionuclide in the water of other wells, selected at other sampling points of this settlement. In the whole region, borehole water shows the highest radioactivity.

The effective equivalent dose of exposure to the Yesil district population from radionuclides from drinking water, mSv/year, is presented in Table 15. As can be seen from the data of Table 15, the drinking water from all the analysed sources does not have a significant internal exposure of the population of the Yesil district for the entire studied period 2011, 2014-2016. According to the calculated data, the exposure of the population to the consumption of drinking water in the considered district ranged from 0.024 mSv/year (well water used for centralized water supply, 2015) to 0.084 mSv/year (well water, 2015). Radiological research in the Ayyrtau region was carried out starting in 2012 (Tables 16-19).

As can be seen from the Tables, the specific activity of radionuclides (^{238}U, ^{232}Th, ^{226}Ra, ^{210}Pb) in drinking water of all the analysed sources does not exceed the established IL. The highest radioactivity of drinking water was found in the waters of boreholes in the villages of Saumalkol, Lobanovo, Yeletskoye, Daukara, located in the zone of uranium deposition. The effective equivalent dose of radiation exposure, Ew, of the Ayyrtau region population from radionuclides from drinking water, mSv/year, is presented in Table 20. As can be seen from the data of Table 20, the drinking water of all analysed sources does not have a significant internal exposure of the population of the Ayyrtau region for the entire studied period 2012, 2014-2016. According to the calculated data, the exposure of the population to the drinking water consumption of the considered region ranged from 0.024 mSv/year (borehole water, 2014) to 0.078 mSv/year (borehole water, 2015) (Table 21).

As can be seen from the data of Table 25, the specific activity of radionuclides (^{238}U, ^{232}Th, ^{226}Ra, ^{210}Pb) in drinking water of all the analysed sources does not exceed the established IL. Calculation of the value of the effective equivalent exposure dose for the consumption of water from borehole (Equation 2):

$$E_{water} = 0.26 \cdot 0.000045 \cdot 2 \cdot 365 + 0.00023 \cdot 0.01 \cdot 2 \cdot 365 + 0.00028 \cdot 0.016 \cdot 2 \cdot 365 + 0.00069 \cdot 0.0355 \cdot 2 \cdot 365 = 0.031 \text{ mSv/year.} \quad \text{(Eq. 2)}$$

The values of specific activities of drinking water of various sources of the Taiynsha district for 2013 are presented in Table 22. As can be seen from the data of Table 22, the specific activity of radionuclides (238U, 232Th, 226Ra, 210Pb) in drinking water of all the analysed sources does not exceed the established IL. Water from these wells is suitable for drinking and domestic purposes. The highest radioactivity in drinking water was found in a borerhole used for centralized water supply in Petrovka. Thorium-232 radionuclide is practically not found in most of the water samples.

As can be seen from the data in Table 23, the specific activity of radionuclides (238U, 232Th, 226Ra, 210Pb) in drinking water of all the analysed sources does not exceed the established IL. Water from these sources is suitable for use in domestic and drinking purposes. On average, drinking water sources showed the greatest radioactivity in well water (almost 3 times the specific activity in wells exceeds the average value of specific activity in wells).

As can be seen from the data in Table 24, the specific activity of radionuclides (238U, 232Th, 226Ra, 210Pb) in drinking water of all the studied sources does not exceed the established IL. Water from these sources is suitable for use in domestic and drinking purposes. In this work it was found that the greatest radioactivity was shown by samples of drinking water from boreholes used for drinking water supply (almost 2 times higher than the specific activity of water samples of wells and 3 times higher than the specific water samples of boreholes) (Table 25). We noticed that the greatest radioactivity was shown by samples of drinking water taken from wells.

As can be seen from the data of Table 26, the drinking water of all the analysed sources does not have a significant internal exposure of the population of the Tayinsha district for the entire studied period of 2012-2016. Water from the examied sources can be used for domestic and drinking purposes. According to the calculated data, the irradiation of the population with drinking water consumption in the considered region ranged from 0.026 mSv/year (borehole water, 2014) to 0.099 mSv/year (well water used for centralized water supply in 2013).

3.3. The content of individual radionuclides in groundwater of the North Kazakhstan region

The main sources of radionuclides entering groundwater are acidic magmatic rocks of the Kokshetau massif, widely developed in the south of the region and in the regions adjacent to it. Particularly high enrichment with rare metals is distinguished by granites of the Zolotonosha massif located at the junction of the Ishim disjunctive zone with the Saumalkol split. Along with potassium and flint, also tantalum, tin, beryllium, niobium, rubidium, zirconium, and uranium enter the water along this zone. On this territory, local accumulations of natural radionuclides develop and uranium deposits form, in which uranium minerals are represented by uraninite, coffinite, brannerite, and nasturan (Karibayev, 2014). These minerals belong to 4-valent form uranium compounds, which are considered inactive (Kulikov, 1990).

The areas of Ayyrtau, Ualikhanov, Shal akyn, and Yesil located within the indicated granitoid massifs are characterized by increased values of groundwater radioactivity (Figures 1-3).

Thorium, even if it is contained in rocks exceeds the uranium content, will be detected in groundwater in concentrations several orders of magnitude lower than uranium. Due to the tendency to hydrolysis and adsorption on suspended particles and colloids, a significant part of thorium is deposited from the water column in the form of suspensions and colloids, as a result of which the thorium migration capacity is small and isotope is found in groundwater in small quantities (Langmuir and Herman, 1980). The oxidizing groundwater conditions contribute to the transition of uranium from a 4-valent sparingly soluble form to a 6-valent migratory active (Federal-Provincial-Territorial…, 2017), which leads to the detection of uranium in groundwater in activities exceeding the established IL. In the underground waters of Northern Kazakhstan, the Th/U ratio ranges from 0.001 to 0.07.

The acid-alkali conditions of groundwater are important, in acidic waters the content of uranium and radium will be significantly higher (by 3 orders of magnitude) than in near-neutral ones. The content of radium and uranium is also limited by the concentration of sulfate ions, the lower their concentration relative to the total mineralization, the more radium and uranium will be detected in groundwater. The results of our previous research confirm this: the ratio of sulfate to total mineralization in groundwaters of Yesil, Aiyrtau, Ualikhanov districts is lower (0.09-0.14) than this ratio in the regions of Akzhar and G. Musirepov (0.2) (Yapiyev *et al*., 2017).

According to (Chalov, 1975), the 226Ra/238U ratio is a qualitative indicator of the migration ability of radionuclides in natural waters. In our case, the ratio 226Ra/238U significantly exceeds the equilibrium one and varies between 0.01-0.8, which indicates a predominant migration of radium and possible complexation of uranium with related elements.

4. CONCLUSIONS:

Granitoids are among the natural factors influencing the radioecological state of Northern Kazakhstan, their massifs contain increased dispersed concentrations of radionuclides of uranium, thorium and daughter products of their decay in all objects of the environment, including in surface and underground waters. There is a potential danger of increasing the total dose of the population exposure from natural sources due to the intake of natural and man-made radionuclides with drinking water into the human body.

The content of radionuclides in the analysed water bodies used for drinking water supply, in most cases, do not exceed the established levels of intervention and do not exceed the values of the total alpha and beta activity established by the requirements of radiation safety. Such a content of radionuclides does not pose a radiation hazard when drinking water. It was found that the population of the considered regions of the North-Kazakhstan region receives the largest dose of radiation when drinking water from wells (0.123 mSv/year), the lowest dose – when drinking tap water (0.024 mSv/year), which is (1-13%) from the total exposure dose to the population of Northern Kazakhstan.

The researched area population does not use sources with increased radioactivity that were conserved and banned for use. In accordance with the principles of radiation safety – the principle of regulation and the principle of optimization, systematic radiation monitoring of underground drinking water sources is necessary to timely identify and eliminate sources with increased radioactivity from drinking water supply.

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Table 1. *Intervention level and the values of dose factors when radionuclides enter the human body with water*

Radionuclide	$\varepsilon_{water\,i}$	IL^{water} Bq/kg
^{238}U	$4.5*10^{-5}$	3.1
^{232}Th	$2.3*10^{-4}$	0.6
^{226}Ra	$2.8*10^{-4}$	0.5
^{210}Pb	$6.9*10^{-4}$	0.2

Table 2. *Characteristics of radiation hazardous areas*

Name of region, zone	Area of the zone, ths. km^2	The number of deposits of ore occurrences U and Th	Types of formations rocks *	The area of radioactive formations, ths. km^2	Radium areolas, ths. km^2	Exceeding doses relative to the background, mSv/year	Rank
North-Kazakhstan region							
Priyesil	5.5	10	G, S	0.85	1.0	0.1	III
Zhalgyztau	0.9	-	G, V	0.15	0.16		I
Saumalkol	6.4	9	-	-	0.5	1.2 (>3.0)	II
Taldykol	1.0	1	-	-	0.24		II
Aisary	3.1	1	-	-	-		II
Akmola region							
Priyesil	7.4	4	G, S	3.2	1.8		III
Zerendy-Balkashino	11.2	15	G, V	4.0	3.14	>3.0 (>4.1)	I
Chagaly	2.9	6	G, V	2.7	0.08		
Akkol-Schuchinsk	8.5	9	G, V, S	2.3	1.3	0.9 (2.0)	II
Stepnogorsk-Zaozernyy	6.8	8	G, V	1.5	0.2	1.3 (2.4)	II

*Note: * G – granites, granitoids and weathering crust, S – shale rocks, V – volcanic (effusive) acidic rocks*
Source: Kayukov et al., 2014

__Table 3__. The specific activity of radionuclides in groundwater, Bq/kg

Administrative district	^{238}U	^{232}Th	^{226}Ra	^{210}Pb	^{137}Cs	^{90}Sr	^{222}Rn
Intervention Level, IL	3	0.6	0.49	0.2	11	4.9	60
Ayyrtau	0.2-10.4	0.01-0.16	0.006-0.38	0.018-0.14	0.07-0.53	0.01-0.04	4-1073
Akzhar	0.3	0.009	-	-	-	-	3-303
Akkayin	0.4-2.19	0.01-0.08	0.04-0.19	0.01-0.04	0.007-0.04	0.007-0.09	3-58
G. Musirepov	0.01-2.92	0.005-0.014	0.008-0.13	0.025-0.1	-	0.03	3-333
Yesil	0.007-2.6	0.002-0.08	0.008-1.98	0.004-0.07	-	-	2-2795
Zhambyl	0.59-0.88	0.03-0.12	0.027-0.04	0.038	-	-	4-20
Kyzylzhar	0.18-3	0.01-0.03	0.018-0.13	0.003-0.04	-	-	3-22
Mamlyut	0.95-2.65	0.02-0.07	0.03-0.05	0.013-0.06			3-31
M. Zhumbayev	0.1-1.7	0.01-0.023	0.014-0.2	0.01-0.05	-	-	4-31
Taiynsha	0.1-1.54	0.004-0.05	0.05-0.44	0.033-0.2	-	-	3-65
Timiryazev	0.11-1.3	0.01-0.014	0.04-0.64	0.045-0.056	-	-	8-42
Ualikhanov	0.01-5.45	0.01-0.1	0.01-0.34	0.01-0.041	0.01-0.05	0.01-0.05	4-31
Shal akyn	0.2-1.13	0.0023-0.018	0.012-0.08	0.02-0.04	-	-	4-136

Note: the values of specific activities are presented in the range from minimum to maximum for the period 2011-2016.

***Table 4.** Specific activity of drinking water in the G. Musirepov district for 2011.*

Sampling point	Source	The specific activity of radionuclides, Bq/kg			
		^{238}U	^{232}Th	^{226}Ra	^{210}Pb
Birlik	water supply	0.4	0	0.09	0.05
Zolotonosha	well	0.49	0.014	0.04	0.03
Saradyr	borehole	0.45	0.02	0.03	0.03
Saradyr	borehole	0.33	0.012	0.13	
Shukurkol	borehole	0.18	0.005	0.064	
Starobelka	borehole	0.94	0.005	0.03	0.04
Druzhba	borehole	1.01	0	0.08	
Peski	borehole – water supply	0.18	0.014	0.2	0.04
average value for boreholes		0.582	0.0084	0.067	0.035
average value for water supply		0.4	0	0.09	0.05
average value for wells		0.49	0.014	0.04	0.03
average value for boreholes, used for centralized water supply		0.18	0.014	0.2	0.04

Table 5. The specific activity of drinking water in the G. Musirepov district for 2012

Sampling point	Source	The specific activity of radionuclides, Bq/kg			
		^{238}U	^{232}Th	^{226}Ra	^{210}Pb
Zharkol	well	2.92	0.01	0.026	0.04
Berezovka	borehole	0.45	0	0.01	0.057
Novoishimskoe	borehole	0.47	0	0.01	0.067
Novoselovka	borehole	0.28	0	0.008	0.025
Kyrymbet	borehole	1.15	0	0.04	0.1
average value for boreholes		0.5875	0	0.017	0.062
average value for wells		2.92	0.01	0.026	0.04

Table 6. *The specific activity of drinking water in the G. Musirepov district for 2013*

Sampling point	Source	The specific activity of radionuclides, Bq/kg			
		^{238}U	^{232}Th	^{226}Ra	^{210}Pb
Zolotonosha	well	1.18	0.01	0.003	0.04
Chernozubovka	well	1.2	0.02	0.05	0.01
Vozvyshenka	well	1.58	0.02	0.3	0.01
Nezhenka	well	1.15	0	0.12	0.05
Chernozubovka	well	0.82	0.02	0.04	0.47
Shak pak	borehole	1.4	0.018	0.19	0.07
Privolnoe	borehole – water supply	0.05	0	0.05	0.08
average value for wells		1.186	0.014	0.1026	0.116
average value for boreholes		1.4	0.018	0.19	0.07
average value for boreholes, used for centralized water supply		0.05	0	0.05	0.08

Table 7. *The specific activity of drinking water in the G. Musirepov district for 2014*

Sampling point	Source	The specific activity of radionuclides, Bq/kg			
		^{238}U	^{232}Th	^{226}Ra	^{210}Pb
Birlik	borehole	0.23	0.009	0.026	0.07
Chervonnoye	water supply	0.12	0.014	0.031	0.013
Budennoye	water supply	0.24	0.014	0.009	0.07
Nezhenka	borehole	0.26	0.07	0.25	0.1
Peski	borehole	0.28	0.02	0.16	0.013
Stavropolka	borehole	0	0	0.018	0.026
Peski	borehole – water supply	0.09	0.012	0.2	0.05
Birlik	borehole – water supply	0.26	0.016	0.01	0.07
Kokozhar	borehole – water supply	0.13	0.022	0.1	0.08
Sarybulak	borehole – water supply	2.25	0.03	0.04	0.11
Salkynkul	borehole – water supply	0.15	0.016	0.06	0.05
Yalty	borehole – water supply	0.2	0.012	0.027	0.06
average value for boreholes		0.1925	0.02475	0.1135	0.052
average value for water supply		0.18	0.01	0.02	0.04
average value for boreholes, used for centralized water supply		0.51333	0.018	0.0728	0.07

Table 8. *The specific activity of drinking water in the G. Musirepov district for 2015*

Sampling point	Source	The specific activity of radionuclides, Bq/kg			
		^{238}U	^{232}Th	^{226}Ra	^{210}Pb
Shukyrkol	borehole	0.38	0.02	0.08	0.04
Sarybulak	borehole	1.3	0.02	0.18	0.04
Raisovka	borehole	1.22	0.03	0.19	0.09
Golopyatovo	borehole	0.58	0.04	0.04	0.07
Zhanasu	borehole	0.2	0.05	0.14	0.07
Yalty	borehole	0.32	0.02	0.04	0.01
Mukur	well	0.49	0.02	0.03	0.022
Kyrymbet	borehole	0.22	0.021	0.04	0.026
Budennoye	water supply	0.37	0.03	0.09	0.08
Novoishimskoye	water supply	0.32	0.01	0.04	0.07
average value for water supply		0.345	0.02	0.065	0.075
average value for boreholes		0.6029	0.0287	0.10143	0.0494
average value for wells		0.49	0.02	0.03	0.022

Table 9. *The specific activity of drinking water in the G. Musirepov district for 2016*

Sampling point	Source	The specific activity of radionuclides, Bq/kg			
		^{238}U	^{232}Th	^{226}Ra	^{210}Pb
Andreyevka	well	0.24	0.023	0.05	0.07
Yefimovka	well	0.2	0.025	0.05	0.07
Chernobayevka	well	0.47	0.018	0.04	0.014
Chernobayevka	spring	0.54	0.025	0.04	0.08
Tselinnoe	borehole – water supply	0.25	0.028	0.03	0.009
Druzhba	borehole	0.09	0	0.03	0.009
Toksan bi	borehole	0.13	0.018	0.04	0.07
Litvinovka	borehole	0.6	0.013	0.04	0.09
Chistopole	borehole	0.37	0.016	0.04	0.09
Sivkovka	borehole	0.31	0.018	0.04	0.023
average value for wells		0.30333	0.022	0.0467	0.0513
average value for springs		0.54	0.025	0.04	0.08
average value for boreholes, used for centralized water supply		0.25	0.028	0.03	0.009
average value for boreholes		0.3	0.013	0.038	0.0564

Table 10*. Effective equivalent dose of radiation exposure, E_{w}, of the population of G. Musirepov district from radionuclides in drinking water, mSv/year*

Year	Water sources				
	boreholes	borehole – water supply	springs	water supply	Wells
2011	0.052	0.069	-	0.057	0.042
2012	0.054	-	-	-	0.123
2013	0.123	0.052	-	-	0.121
2014	0.060	0.070	-	0.033	-
2015	0.070	-	-	0.066	0.037
2016	0.048	0.024	0.070	-	0.049

Table 11. *The specific activity of drinking water in the Yesil district for 2011*

Sampling point	**Source**	**The specific activity of radionuclides, Bq/kg**			
		^{238}U	**^{232}Th**	**^{226}Ra**	**^{210}Pb**
Yesilskoye	water supply	0.007	0	0.016	0.07
Gornoye	spring	0.9	0.002		
Yavlenka	borehole	0.74	0.08	0.07	
Yavlenka	borehole	0.33	0.023	0.034	0.014
Gornoye	borehole	1.9	0.005		
Gornoye	borehole	1.06	0.002		
Zarechnoye	borehole	0.23	0	0.008	0.004
Yasnovka	borehole – water supply	0.06	0.002	0.046	0.07
Amangeldinskoye	borehole – water supply	0.17	0	0.018	0.026
average value for boreholes		0.852	0.022	0.0373	0.009

Table 12. *The specific activity of drinking water in the Yesil district for 2014*

Sampling point	**Source**	**The specific activity of radionuclides, Bq/kg**			
		^{238}U	**^{232}Th**	**^{226}Ra**	**^{210}Pb**
Yavlenka	water supply	0.13	0.012	0.013	0.04
Yavlenka	water supply	0.2	0.009	0.014	0.026
average value for water supply		0.165	0.0105	0.014	0.033

Table 13. *The specific activity of drinking water in the Yesil district for 2015*

Sampling point	**Source**	**The specific activity of radionuclides, Bq/kg**			
		^{238}U	**^{232}Th**	**^{226}Ra**	**^{210}Pb**
Pokrovka	borehole	0.34	0.02	0.18	0.02
Yavlenka	well	1.22	0.04	0.04	0.09
Yavlenka	well	0.34	0.04	0.05	0.08
Amangeldinskoye	borehole – water supply	0.34	0.01	0.03	0.01
Yavlenka	water supply	0.3	0.02	0.03	0.05
Yavlenka	water supply	0.32	0.02	0.03	0.04
Yavlenka	water supply	0.32	0.02	0.03	0.03
Petrovka	water supply	0.17	0.01	0.05	0.04
Tarangul	water supply	0.36	0.01	0.04	0.02
average value for boreholes		0,34	0.02	0.18	0.02
average value for wells		0.78	0.04	0.045	0.085
average value for boreholes, used for centralized water supply		0.34	0.01	0.03	0.01
average value for water supply		0.294	0.016	0.036	0.036

Table 14. *The specific activity of drinking water in the Yesil district for 2016*

Sampling point	Source	The specific activity of radionuclides, Bq/kg			
		^{238}U	^{232}Th	^{226}Ra	^{210}Pb
Maltsevo	spring	0.69	0.02	0.04	0.04
Amangeldinskoye	borehole	0.13	0.028	0.03	0.021
Korneevka	borehole	0.49	0.016	0.15	0.05
Yasnovka	borehole	0.51	0.018	0.03	0.018
Korneyevka	borehole	1.58	0.03	0.04	0.09
Sovetskoye	borehole	0.107	0.02	0.03	0.07
Novo-Uzenka	borehole	0.3	0.02	0.04	0.07
Korneevka	borehole	2.3	0.023	0.04	0.05
average value for spring		0.69	0.02	0.04	0.04
average value for boreholes		0.774	0.022	0.051	0.053

Table 15. *Effective equivalent dose of radiation exposure, E_w, of the population of the Yesil district from radionuclides coming from drinking water, mSv/year*

Year	Watersources				
	boreholes	borehole – water supply	springs	water supply	wells
2011	0.044	0.035	0.030	0.039	-
2012	-	-	-	-	-
2013	-	-	-	-	-
2014	-	-	-	0.027	-
2015	0.061	0.024	-	0.038	0.084
2016	0.066	-	0.054	-	-

Table 16. *The specific activity of drinking water in the Ayyrtau district for 2012*

Sampling point	Source	The specific activity of radionuclides, Bq/kg			
		^{238}U	^{232}Th	^{226}Ra	^{210}Pb
Aryk-Balyk	borehole	0.68	0	0.14	0.03
Aryk-Balyk	borehole	0.68	0	0.17	0.04
Arka resort	borehole	0.23	0.014	0.018	0.13
Arka resort	borehole	0.32	0.023	0.006	0.09
Rodniki	borehole	0.44	0.016	0.012	0.07
Kumtuken	borehole	0.66	0	0.016	0.01
Krasnogorka	borehole	0.06	0	0.008	0.018
Aryk-Balyk	borehole - water supply	0.63	0	0.14	0.04
average value for boreholes		0.4385714	0.007571	0.052857	0.055429
average value for boreholes, used for centralized water supply		0.63	0	0.14	0.04

Table 17. *The specific activity of drinking water in the Ayyrtau district for 2014*

Sampling point	Source	The specific activity of radionuclides, Bq/kg			
		^{238}U	^{232}Th	^{226}Ra	^{210}Pb
Orlovka	borehole	0	0.016	0.026	0.0013
Kirillovka	borehole	0	0	0.026	0.026
Alzhanka	borehole	0.035	0	0.026	0.05
Yeletskoye	borehole	0.046	0	0.007	0.04
N.Burluk	borehole	0.035	0	0.004	0.05
N.Burluk	borehole	0.023	0	0.011	0.026
Yakshi-Yangistau	borehole	0.08	0.009	0.001	0.04
Lobanovo	borehole	0	0	0.026	0.05
Saumalkol	borehole	0	0.007	0.013	0.07
Kirillovka	borehole - water supply	0.53	0.035	0.038	0.04
Saumalkol	borehole - water supply	0.023	0.014	0.018	0.12
Gorny	borehole - water supply	0.014	0.012	0.023	0.03
average value for boreholes		0.02433	0.00356	0.016	0.0393
average value for boreholes, used for centralized water supply		0.189	0.02033	0.026	0.0633

Table 18. *The specific activity of drinking water in the Ayyrtau district for 2015*

Sampling point	Source	The specific activity of radionuclides, Bq/kg			
		^{238}U	^{232}Th	^{226}Ra	^{210}Pb
Saumalkol	borehole	2.24	0.03	0.03	0.05
Saumalkol	borehole	0.85	0.02	0.02	0.09
Saumalkol	borehole	0.87	0.03	0.04	0.14
Saumalkol	borehole	0.45	0.02	0.12	0.09
Saumalkol	borehole	0.26	0.02	0.04	0.03
Saumalkol	borehole	0.85	0.05	0.04	0.04
Saumalkol	borehole	0.68	0.03	0.08	0.04
Saumalkol	borehole	1.02	0.02	0.03	0.05
Zarya	borehole - water supply	0.59	0.04	0.13	0.05
Karlygash	borehole - water supply	0.22	0.03	0.03	0.09
average value for boreholes		0.9025	0.0275	0.05	0.0663
average value for boreholes, used for centralized water supply		0.405	0.035	0.08	0.07

Table 19. *The specific activity of drinking water in the Ayyrtau district for 2016*

Sampling point	Source	The specific activity of radionuclides, Bq/kg			
		^{238}U	^{232}Th	^{226}Ra	^{210}Pb
Yeletskoye	borehole	0.15	0.018	0.03	0.005
Kumtuken	borehole	0.4	0.03	0.04	0.03
Kumtuken	borehole	0.21	0.016	0.04	0.07
Daukara	borehole	0.69	0.02	0.03	0.07
Lobanovo	borehole	1.45	0.02	0.04	0.09
Novoukrainka	borehole	0.4	0.028	0.03	0.04
Kirillovka	borehole	0.2	0	0.03	0.003
Yeletskoye	borehole	0.15	0.018	0.03	0.022
Yeletskoye	borehole	0.64	0.028	0.03	0.03
average value for boreholes		0.477	0.0198	0.033	0.04

Table 20. *Effective equivalent dose of radiation exposure, E_w, of the population of the Ayyrtau region from radionuclides coming from drinking water, mSv/year*

Year	**Water sources**				
	boreholes	**borehole – water supply**	**springs**	**water supply**	**wells**
2011	-	-	-	-	-
2012	0.054	0.069	-	-	-
2013	-	-	-	-	-
2014	0.024	0.047	-	-	-
2015	0.078	0.071	-	-	-
2016	0.046	-	-	-	-

Table 21. *The specific activity of drinking water of the Tayinsha district for 2012*

Sampling point	**Source**	**The specific activity of radionuclides, Bq/kg**			
		^{238}U	**^{232}Th**	**^{226}Ra**	**^{210}Pb**
Madeniyet	borehole	0.32	0.01	0.027	0,033
Letovochnoye	borehole	0.2	trace	0.005	0,038
average value for boreholes		0.26	0.01	0.02	0.04

Table 22. *The specific activity of drinking water of the Tayinsha district for 2013*

Sampling point	**Source**	**The specific activity of radionuclides, Bq/kg**			
		^{238}U	**^{232}Th**	**^{226}Ra**	**^{210}Pb**
Petrovka	borehole - water supply	1.41	0.014	0.05	0.08
Chkalovo	borehole	0.38	0	0.05	0.05
Kellerovka	borehole	0.39	0.01	0.03	0.05
Podlesnoye	borehole	0.36	0	0.03	0.04
Madeniet	borehole	0.45	0	0.03	0.04
Akkuduk	well	0.45	0	0.01	0.05
average value for boreholes		0.395	0.0025	0.035	0.045
average value for wells		0.45	0	0.01	0.05
average value for boreholes, used for centralized water supply		1.41	0.014	0.05	0.08

Table 23*. The specific activity of drinking water of the Tayinsha district for 2014*

Sampling point	**Source**	**The specific activity of radionuclides, Bq/kg**			
		^{238}U	**^{232}Th**	**^{226}Ra**	**^{210}Pb**
Bolshoy Izyum	well	0.18	0.007	0.04	0.05
Ivan-gorod	well	0.20	0.018	0.29	0.03
Kellerovka	well	0.24	0.022	0.013	0.06
Ozernoye	well	0.24	0.022	0.025	0.028
Kalinovka	well	0.08	0.009	0.04	0.029
Amandyk	well	0.17	0.012	0.04	0.003
Zolotorunnoye	well	0.20	0.008	0.04	0.008

Taldykul	well	0.12	0.01	0.026	0.01
Bolshoy Izyum	well	0.10	0.002	0.026	0.05
Kozashar	well	0.20	0.002	0.04	0.039
Lyubimovka	borehole	0.08	0.012	0.0013	0.07
Makashevka	borehole	0.046	0.007	0.004	0.026
Letovochnoye	borehole	0.046	0.007	0.04	0.05
Podlesnoye	borehole	0.07	0.012	0.026	0.04
Ilichevka	borehole	0.08	0	0.018	0
average value for wells		0.173	0.0112	0.058	0.0307
average value for boreholes		0.0644	0.0076	0.0179	0.0372

Table 24. *The specific activity of drinking water of the Tayinsha district for 2015*

Sampling point	Source	The specific activity of radionuclides, Bq/kg			
		^{238}U	^{232}Th	^{226}Ra	^{210}Pb
Amandyk	well	0.63	0.02	0.04	0.09
Petrovka	well	0.49	0.03	0.07	0.08
Amandyk	well	0.66	0.03	0.04	0.01
Petrovka	well	0.75	0.04	0.1	0.005
Petrovka	well	0.68	0.02	0.03	0.05
Ak-kuduk	well	0.32	0.01	0.04	0.07
Petrovka	well	0.51	0.02	0.07	0.09
Vishnevka	water supply	0.58	0.03	0.14	0.02
Petrovka	water supply	1.28	0.02	0.08	0.013
Ilichevka	borehole	0.84	0.02	0.04	0.017
Ilichevka	borehole	0.66	0.02	0.05	0.08
Ilichevka	borehole	0.4	0.02	0.04	0.08
Ilichevka	borehole	0.1	0.02	0.04	0.07
Krasnokamenka	borehole	0.2	0.01	0.03	0.02
Kellerovka	borehole	0.13	0.005	0.05	0.02
Dragomirovka	borehole	0.41	0.02	0.06	0.01
average value for wells		0.58	0.02	0.06	0.06
average value for water supply		0.93	0.025	0.11	0.0165
average value for boreholes		0.391	0.0164	0.044	0.0424

Table 25. *The specific activity of drinking water of the Tayinsha district for 2016*

Sampling point	Source	The specific activity of radionuclides, Bq/kg			
		^{238}U	^{232}Th	^{226}Ra	^{210}Pb
Bolshoy Izyum	well	0.28	0.04	0.05	0.01
Petrovka	well	0.29	0.03	0.05	0.005
Aymak	borehole	0.32	0.03	0.06	0.012
Aymak	borehole	0.21	0.03	0.05	0.003
Letovochnoye	borehole	0	0.04	0.05	0.017
Letovochnoye	borehole	0.22	0.04	0.05	0.008
Ilichevka	borehole	0.02	0.04	0.05	0.03
Ilichevka	borehole	0.24	0.03	0.05	0.01
average value for boreholes		0.168	0.035	0.052	0.0133
average value for wells		0.285	0.035	0.05	0.0075

Table 26. *Effective equivalent dose of radiation exposure, E_w, of the population of the Tayinsha district of radionuclides from drinking water, mSv/year*

Year	Water sources				
	boreholes	borehole – water supply	springs	water supply	wells
2011	-	-	-	-	-
2012	0.031	-	-	-	-
2013	0.043	0.099	-	-	0.042
2014	0.026	-	-	-	0.035
2015	0.046	-	-	0.066	0.063
2016	0.029	-	-	-	0.029

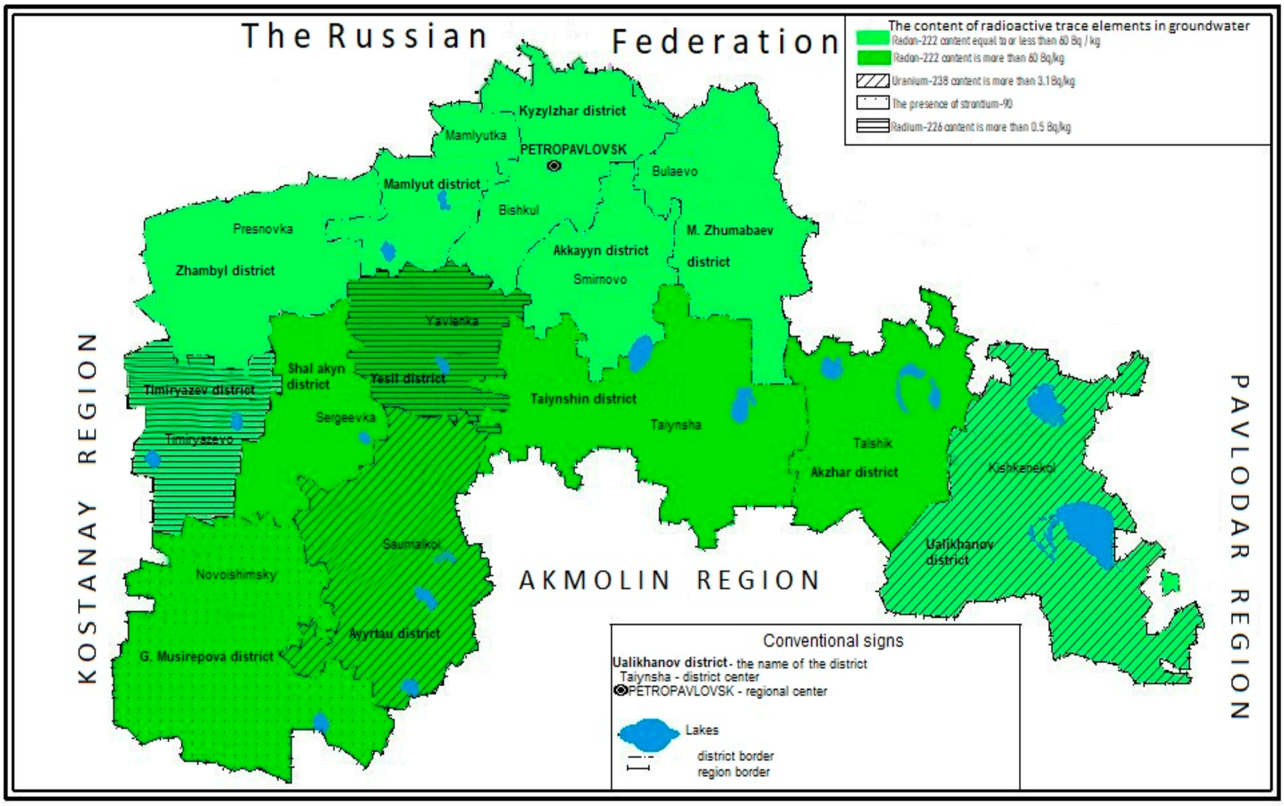

Figure 1. *The content of radioactive trace elements in groundwater*

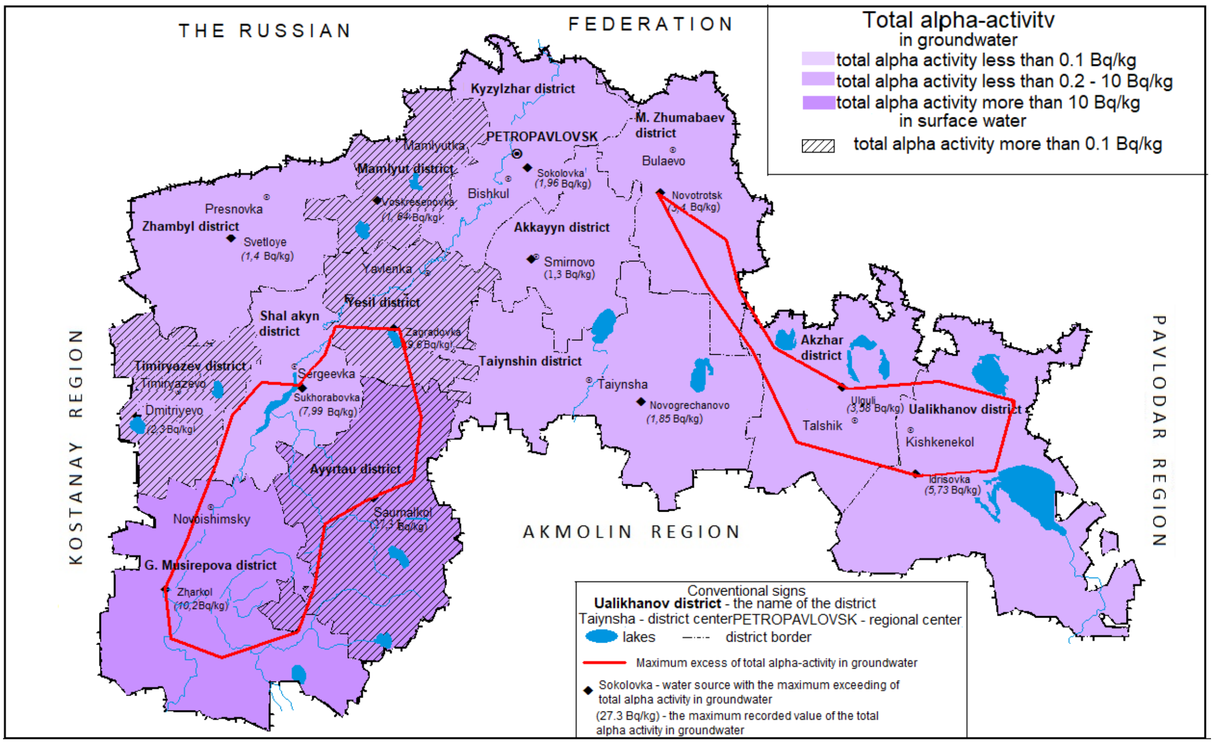

Figure 2. *Total alpha-activity in groundwater*

Figure 3. *Total beta-activity in groundwater*