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Accumulation of natural and artificial radionuclides in water and hydrobionts of fishing ponds of Dnipropetrovsk region

V. O. Sapronova*, N. L. Hubanova*, N. M. Matviienko, *****
** Dnipro State Agrarian and Economic University, Dnipro, Ukraine*
*** Nature Research Centre, Vilnius, Lithuania*
**** Institute of Fisheries of NAAS, Kyiv, Ukraine*

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Dnipro State Agrarian and Economic University, Serhii Efremov Str., 25, 49600, Dnipro, Ukraine

Tel.: +38-098-051-38-99
E-mail: *svaddau@gmail.com*

Nature Research Centre, Akademijos Str. 2, LT-08412, Vilnius, Lithuania
E-mail: *nataliia.matviienko@gamtc.lt*

Institute of Fisheries of NAAS, Obukhivska Str, 135, 03164, Kyiv-164, Ukraine
E-mail: info.iforgua@gmail.com

#**Corresponding author:**
V. O. Sapronova
svaddau@gmail.com

Abstract. The paper presents the results of radioecological studies conducted in fish farms of the Dnipropetrovsk region. The distribution of radionuclides of natural and artificial origin is an urgent problem for various types of ecosystems, given the different routes of entry of these substances. The level of accumulation of radionuclides in the waters of the Zelenodolsk, Krynychansk and Kryvorizk fish farms was determined in a course of the presented study prior to the 2022 russian invasion of Ukraine. Content indicator of radium-226 in water ranged from 3.8 to 7.4 Bq/kg, thorium-232 – from 2.95 to 44.4 Bq/kg, potassium-40 – from 74.2 to 82.4 Bq/kg. Obtained in the present study results evidence that bottom sediments significantly accumulate the radionuclides. The registered content of radium-226 in them was from 30.1 to 14.8 Bq/kg, thorium-232 – from 9.6 to 41.5 Bq/kg, potassium-40 from 134.8 to 182.2 Bq/kg. The coefficients of accumulation of natural radionuclides in water and bottom sediments was registered as ranging from 1.4 to 5 for radium-226, from 0.82 to 3.3 for thorium-232, from 1.72 to 2.26 for potassium-40. The content of artificial radionuclides in water and bottom sediments determined in the study corresponded with their biochemical properties. In water, their value ranged from 0.13 to 1.8 Bq/kg for cesium-137 and from 0.05 to 0.08 Bq/kg for strontium-90. Taking into account the fact that bottom sediments accumulate a significant proportion of pollutants from water, the determined indicators were significantly higher than those in water, namely, from 5.6 to 10.4 Bq/kg for cesium-137 and from 1.5 to 2, 4 Bq/kg for strontium-90. The coefficients of accumulation of radionuclides of artificial origin in water and bottom sediments ranged from 3.3 to 80 for the content of cesium-137 and from 18.7 to 48 for the content of strontium-90. The levels of accumulation of natural radionuclides in the body of silver carp and carp were studied. The level of potassium-40 in the body of silver carp is lower than that of radium-226 and thorium-232 and ranges from 20.2 to 34.4 Bq/kg in all three fish farms. The same amount of radium-226 and thorium-232 was noted in the silver carp of the Krynychan fish farm which was on the level of 47 Bq/kg. In carp, the levels of natural radionuclides were significantly higher in all three fish farms. The content of cesium-137 was registered as approximately the same in silver carp and carp, with the exception of the Kryvyi Rih fish farm, where its level was significantly lower in the body of carp. Strontium-90 content was found in similar amounts in both types of fish. The concentration of radionuclides did not exceed the permissible levels.

Keywords: fish farming; natural and artificial radionuclides; radium-226; thorium-232; potassium-40; cesium-137; strontium-90; white carp *(Hypophthalmichthys molitrix)*; common carp *(Cyprinus carpio)*.

Накопичення природних та штучних радіонуклідів у воді та гідробіонтах рибогосподарських ставків Дніпропетровської області

Анотація. В роботі представлено результати радіоекологічних досліджень проведених у рибницьких господарствах Дніпропетровської області. Розповсюдження радіонуклідів природного та штучного походження являється актуальною проблемою для різних видів екосистем з огляду на різні шляхи надходження цих сполук. Визначено рівень накопичення радіонуклідів у водах Зеленодольського, Криничанського та Криворізького рибгоспів до початку російської окупації України у 2022 році. Показник кількості радію-226 у воді коливався в межах від 3,8 до 7,4 Бк/кг, торію-232 - від 2,95 до 44,4 Бк/кг, калію-40 – від 74,2 до 82,4 Бк/кг. Донні відклади значно накопичують кількість радіонуклідів, вміст радію-226 в них склав від 30,1 до 14,8 Бк/кг, торію-232 – від 9,6 до 41,5 Бк/кг, калію-40 від 134,8 до 182,2 Бк/кг. Коефіцієнти накопичення природних радіонуклідів в воді та донних відкладах коливалися від 1,4 до 5 за радієм-226, від 0,82 до 3,3 за торієм-232, від 1,72 до 2,26 за калієм-40. Визначений в дослідженні вміст штучних радіонуклідів у воді та донних відкладах відповідав їх біохімічним властивостям. У воді їх показник коливався від 0,13 до 1,8 Бк/кг за цезієм-137 та від 0,05 до 0,08 Бк/кг за стронцієм-90. Враховуючи той факт, що донні відклади акумулюють значну частку полютантів із води, визначені показники були значно вищі за такі у воді, а саме, від 5,6 до 10,4 Бк/кг за цезієм-137 та від 1,5 до 2,4 Бк/кг за стронцієм-90. Коефіцієнти

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накопичення радіонуклідів штучного походження в воді та донних відкладах коливалися від 3,3 до 80 за вмістом цезію-137 та від 18,7 до 48 за вмістом стронцію-90. Досліджено рівень накопичення природних радіонуклідів в організмі товстолобика та коропа. Рівень калія-40 в організмі товстолобика нижчий, порівняно з радієм-226 та торієм-232 і складає від 20,2 до 34,4 Бк/кг в усіх трьох рибгоспах. Однакова кількість радію-226 та торію-232 відмічена у товстолобика Криничанського рибгоспу та складає 47 Бк/кг. У коропа рівень вмісту природних радіонуклідів значно вища у всіх трьох рибгоспах. Вміст цезію-137 був визначений приблизно однаковим і у товстолобика, і у коропа, за виключенням Криворізького рибгоспу, де його рівень є значно меншим в організмі коропа. Вміст Стронцію-90 був виявлений в збіжній кількості в обох видах риб. Концентрація радіонуклідів не перевищувала допустимих нормативами величин.

Ключові слова: рибні господарства; природні та штучні радіонукліди; радій-226; торій-232; калій-40; цезій-137; стронцій-90; товстолобик білий *(Hypophthalmichthys molitrix)*; короп звичайний *(Cyprinus carpio).*

Introduction

Correlation of water pollution and nuclear power usage in the context of climate change increase the importance of control of radioisotopes' transit, level and recovery. Despite the drive to use of sustainable economies, nuclear power generation remains an important issue (Omeje et al., 2024). Radionuclides mixing with water or wastewater can accumulate in and directly affect living organisms (Hossain, 2020; Asaduzzaman et al., 2022; Hunt et al., 2023).

Artificial reservoirs are under the influence of negative effects in a significant number of countries around the world, and, first of all, in the certain regions of Ukraine due to the location of the Chernobyl NPP on its territory (Volkova et al., 2014; Santhanabharathi et al., 2023; Volkova et al., 2023). Significant heterogeneity of radionuclide dose rates in the air, K+ concentration, and estuarine processes contribute to increasing concentrations of radionuclides of natural and artificial origin in the both soil and water resources (Wada et al., 2023). The question of the accumulation of various ecological groups of radionuclides by living organisms and the factors affecting those organisms remain relevant for the past 35 years (Hubanova et al., 2019; Teien et al., 2021).

To obtain safe and high-quality fish and farming animal products, it is necessary to monitor the spread, migration and redistribution of environmental toxicants and radionuclides in artificial and natural reservoirs of the region (Masiuk et al., 2022). The condition of the fish pond is an integral component in obtaining quality fish products in various countries of the world and Ukraine as well (Tahir et al., 2010; Kolar & Gugleta, 2019; Asaduzzaman et al., 2022; Ghajarbeygi et al., 2024). The contribution of ichthyofauna to the total biomass of freshwater reservoirs is significant, and fish play a significant role in the processes of radionuclide migration in ecosystems (Llamazares et al., 2023). Thus, the studying the features of radionuclide accumulation in the organisms of various hydrobiont types is important, first of all, for solving sanitary and hygienic problems. Furthermore, the study of farming animal health is critic item for the better knowledge of the processes of distribution and accumulation of both toxicants and radionuclides in the aquatic environment and various groups of hydrobionts (Masiuk et al., 2023).

The integrative search of detrimental effects of radionuclides and other environmental pollutants is required to clarify the potential risks for both human and animal health.

The purpose of this study was to determine the characteristics of the distribution of radionuclides of natural (226 Ra, 232 Th, 40 K) and artificial (137 Cs, 90 Sr) origin in the water and hydrobionts in fish farms of the Dnipropetrovsk region.

Materials and methods

The research was conducted in the major fish breeding ponds of the region, operating in the mode of special commercial fish farming (Zelenodolsky, Krynychansky and Kryvorizky fish farms) of the Dnipropetrovsk region (Ukraine) in 2021. For the analysis, 7 individuals of silver carp *(Hypophthalmichthys molitrix)* and common carp *(Cyprinus carpio)* were selected as representatives of different trophic levels. Preparations of sampling of water and bottom sediments for measurements were carried out in accordance with

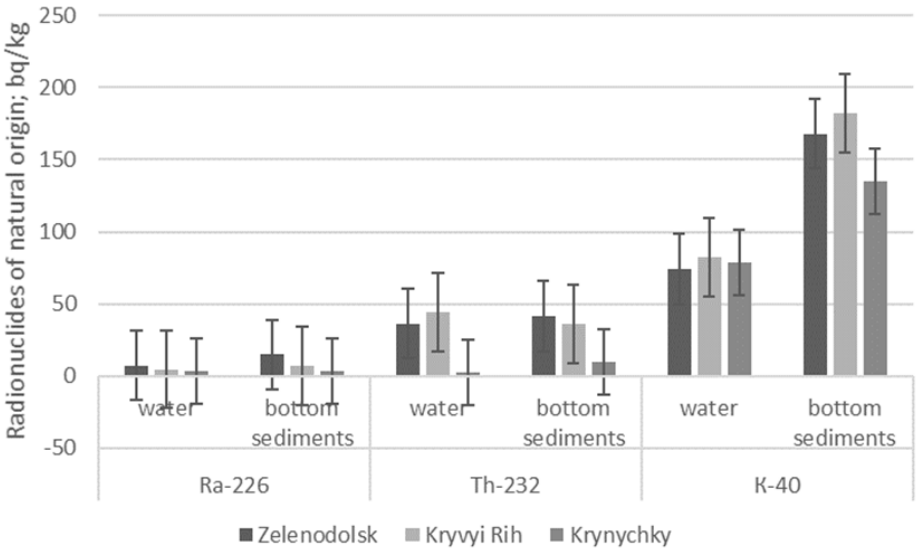

Fig. 1. Content of radionuclides of natural origin in water and bottom sediments.

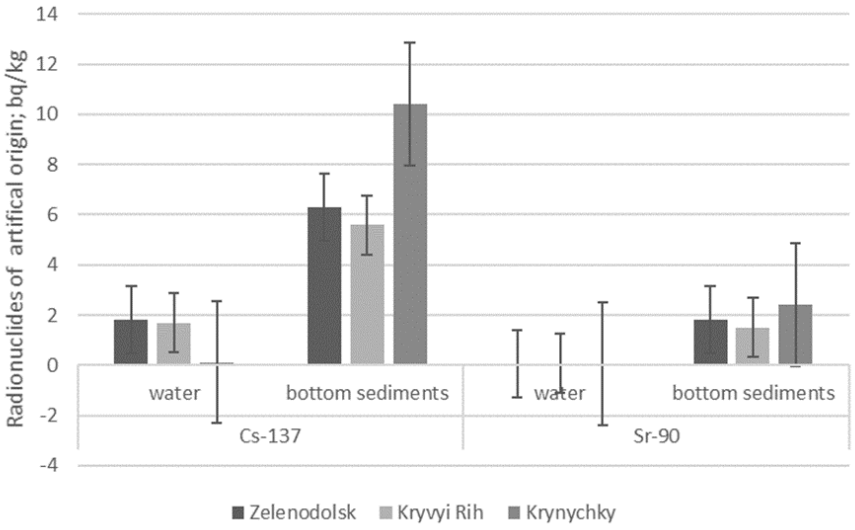

Fig. 2. The content of radionuclides of artificial origin in water and bottom sediments.

the generally accepted methods (Gembal et al., 2023). The content of radionuclides was determined on a SEG-001 "AKP-S" gamma-radiation scintillation spectrometer using the spectrophotometric method in a certified laboratory. Obtained data presented as mean ± standard error of mean (M ± SEM) where statistical significance was accepted as $p < 0.05$.

Results

The accumulation of radionuclides of natural origin in water and bottom sediments has an invariant character with respect to the amount of radium: in water and bottom sediments, the maximum indicator was detected in the Zelenodol fish farm as 7.4 ± 0.12 Bq/kg and 14.8 ± 0.2 Bq/kg correspondingly. The observed trend was the same in the Kryvorizka and Krynychan fish farms. The amount of radium in water and bottom sediments was almost the same in both farms at the levels of 3.1 ± 0.2 Bq/kg and 3.8 ± 0.2 Bq/kg, correspondingly. The maximum rate of thorium was recorded in Kryvorizka fish farm at the level of 44.4 ± 1.2 Bq/kg in water and in the Zelenodol fish farm in the bottom sediments at the level 41.5 ± 1.2 Bq/kg. The minimal results were obtained at the Krynychan fish farm. Potassium content was observed in significantly higher values, especially in the bottom sediments of the Kryvyi Rih fish farm (Fig. 1).

In terms of the number of artificial radionuclides, the maximum level was observed in the bottom sediments of the Krynychan fish farm, both in terms of the content of cesium-137 and strontium-90. The minimum contents of artificial radionuclides were observed in water of the Krynychan fish farm (Fig. 2) and were on the levels of 0.13 ± 0.05 Bq/kg for cesium-137 and 0.05 ± 0.02 Bq/kg for strontium-90 in the the Krynychan fish farm (Fig. 2).

The ratio of the levels of radionuclides of natural origin between bottom sediments and water is given in the form of accumulation coefficients and varies from 1.2 to 5 for radium-226, from 0.82 to 2.21 for thorium-232, from 1.4 to 3.3 for potassium-40 (Fig. 3).

The coefficients of accumulation of artificial radionuclides

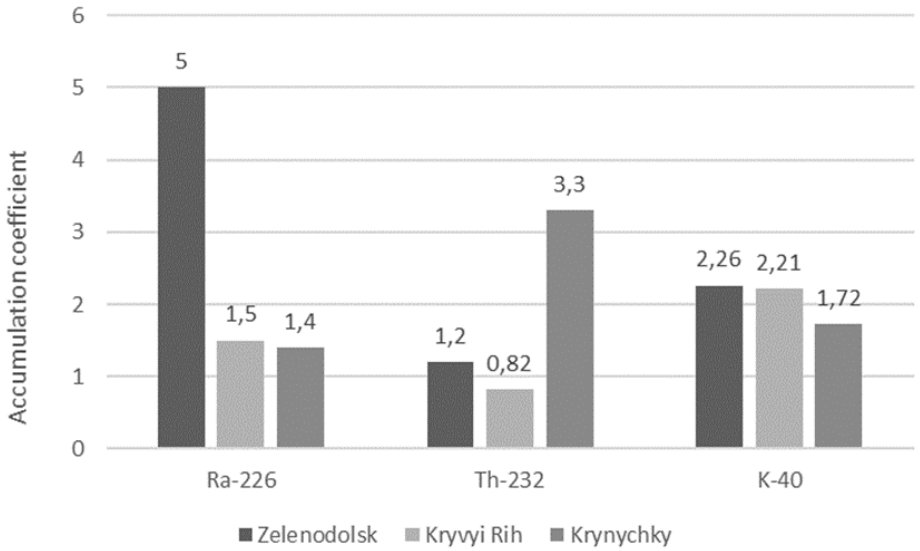

Fig. 3. Accumulation coefficients of natural radionuclides.

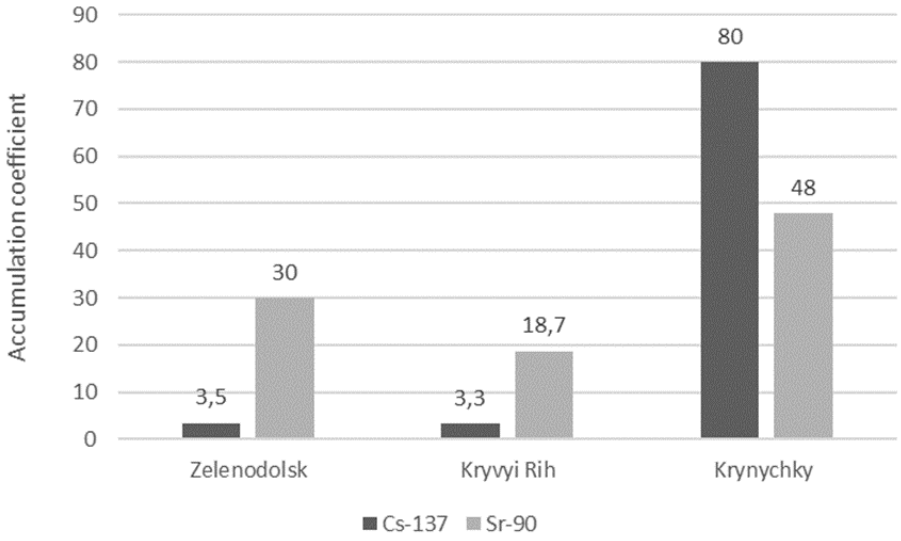

Fig. 4. Accumulation coefficients of artificial radionuclides.

between water and bottom sediments varied for cesium-137 from 3.3 in Kryvyi Rih to 80 in Krynychki and for strontium-90 from 18.7 in Kryvyi Roz to 48 in Krynychki (Fig. 4).

The content of radionuclides of natural origin was minimal for potassium-40 in the silver carp of the Zelenodol Fish Farm, and the maximum was 46.2 ± 2.3 Bq/kg in the common carp of the Kryvorizka Fish Farm; for radium-226, the minimum – 36.2 ± 1.8 Bq/kg was registered in the body of the common carp of the Kryvorizka fish farm, and the maximum indicator is 47.7 ± 2.2 – in the common carp of the Krynychan fish farm. The content of thorium-232 demonstrates the same accumulation character (Fig. 5).

The content of radionuclides of artificial origin was observed in silver carp in a range of 0.8 ± 0.3 to 1 Bq/kg for cesium-137 in Zelenodolsk and Kryvorizke fish farms, correspondingly, and the same amount of cesium-137 in the body of common carp of Zelenodolsk and Krynychan fish farms. The accumulation of strontium-90 by silver carp and common carp was invariant in all fish farms (Fig. 6).

Taking together, obtained results evidence that the level of both natural and artificial radionuclides in the fish farms of Dnipro province is vary and is dependent on unique location.

Discussion

Obtained in the present study results evidence that the presence of radionuclides in the body of fish is vary in respect with its content. However, detected values do not exceed the permissible levels, which is the basis for the further conduction of fishing activities, obtaining the food products, and could be a certain step towards the compliance of the fish products of these farms with the system of analysis of dangerous factors (Gembal et al., 2023).

The results of recent study demonstrated that the dynamics of radionuclide accumulation depends on the biological characteristics of the species, the type of nutrition and the nature of radionuclides (Ilin & Hromyk, 2012; Khan & Yaseen, 2023). The accumulation of cesium could be linked to the peculiarities of physiological and

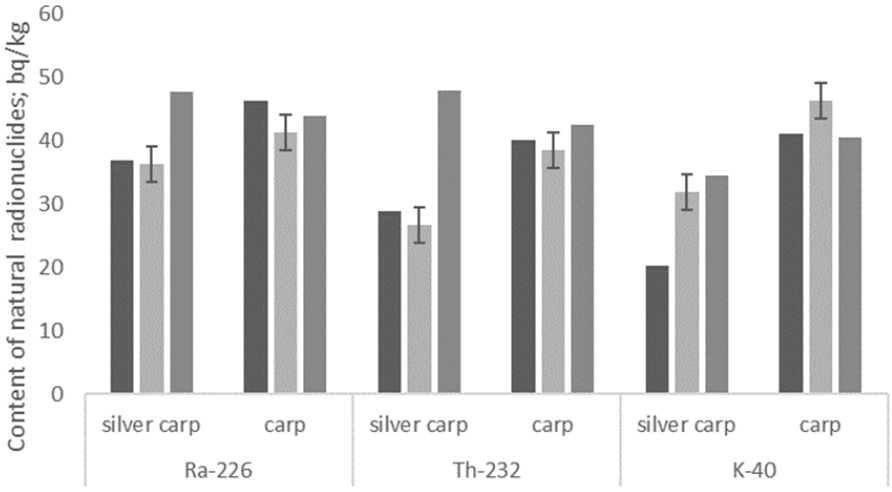

Fig. 5. The content of radionuclides of natural origin in the body of fish.

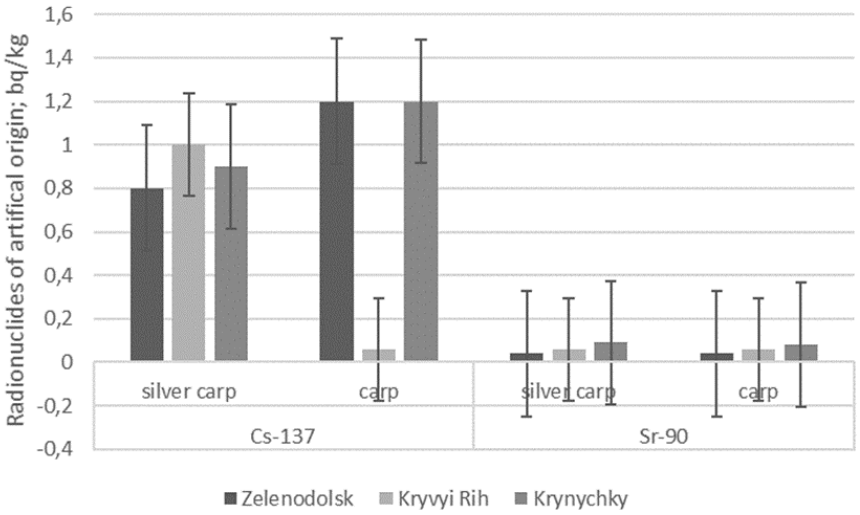

Fig. 6. The content of radionuclides of artificial origin in the body of fish.

biochemical processes in fish organisms, as well as the content of radionuclide in feed resources, which corresponds to the results of other researchers (Kuzmenko et al, 2010). The analysis of the obtained data confirms the fact that the problem of accumulation and distribution of radionuclides of natural and artificial origin exists in both natural reservoirs and in fish farm ponds. The accumulation of radionuclides of natural origin in fish farms has the same tendency, which consists in their intensive cumulation in bottom sediments (Santhanabharathi et al., 2023). The monitoring and detailed control of the content of radionuclides in water ecosystems of the Dnieper region is a necessary activity to prevent secondary water pollution due to bottom sediments.

According to its chemical properties, strontium is an analogue of calcium, which is why it is actively stored in fish skeletons or in the shells of bottom sediments. Accumulation of artificial radionuclides in common carp significantly exceeds such indicators in silver carp, which is related to the type of euryphagous nutrition. Thus, herbivorous species more actively accumulate strontium-90, and carnivores – cesium-137 (Skyba, 2010). A higher specific activity of cesium-137, according to literature data, is characterized by predatory fish, in our studies – by the example of common carp, and relatively low – by herbivores. The radioecological conditions of fish requires significant attention in connection with the formation of trophic chains, therefore, the assessment of the territory according to the landscape-geochemical conditions of radionuclide migration, the study of the patterns of radionuclide migration in different landscape-geochemical conditions, the determination of the paths of surface migration and accumulation of radionuclides require constant observations (Ilin & Hromyk, 2012; Ananieva & Shapovalenko, 2019). The perspective of further research is the study of the influence of the length of the fish farming period on the intensity of its contamination with cesium-137. The distribution and accumulation of toxic substances at the fish farms is an indicator of the environment conditions. Takin into the account the progress in environmental pollution, there is an actual problem to find out molecular markers which can reflect the detrimental effect of local contamination with various toxic agents. Different tissue types accumulate toxicants and develop vary susceptibility in respect with animal health. The cells of intestinal system serve as a first barrier for toxicants and infectious agents (Masiuk et al., 2024). Therefore, the harmful effect of radionuclides should be characterized with tight relation to complex of the other factors which detrimental effect be modulated with the cellular damaging caused by radionuclide exposure.

Conclusion

Obtained in the present study results evidence that the levels of natural radionuclides differ in the main trophic groups of hydrobionts. Furthermore, radionuclide levels were varied in water and bottom sediments as well. The maximum content of potassium-40 was found in the water and bottom sediments of the Zelenodol fish farm – 74.2 and 168 Bq/kg relatively. The content of natural radionuclides in the common carp tissue was detected in a much higher concentration than in the body of silver carp Bq/kg.

The maximum content of artificial radionuclides was observed in the tissues of common carp and silver carp of the Zelenodol fish farm. The detected content of cesium-137 was estimated of 1.2 and 0.8 Bq/kg, correspondingly. The content of strontium-90 detected as similar content for both types of carp at the level of 0.04 Bq/kg. The accumulation coefficients of radionuclide concentrations in the water and bottom sediments confirm their migration according to different ecological groups of hydrobionts and increase from the minimum in water to the maximum in bottom sediments. Despite the presence of radionuclides in the farming fish samples, their levels do not exceed permissible levels, which makes it possible to continue economic activity in the conditions of these enterprises.

Conflict of interests

The authors declare no conflict of interests in respect with this manuscript publishing.

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