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Radiological Screening of Bottom Sediments of The Tisza River: High Mountain Part

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Abstract
The results of the radiological study of the sediments from the sources of the Tisza River in the highlands of the Carpathians are presented. For the first time, data were obtained on the structure of sediments' natural activity and its transformation during the altitude lowering of the riverbed lowering for 400 m. The sediment samples were taken from 12 sampling points and investigated under low-background gamma spectrometry experiments. The content of natural, in particular, daughter isotopes of the U / Th series, ^{40}K, and artificial (^{137}Cs) radionuclides in the sludge was controlled. They can serve as markers of the studied areas' spatial, geochemical, and anthropogenic characteristics. Standards of the content of the radionuclides - marks along the Tisza riverbed and in the vicinity of its tributary rivers have been established. Significant changes in the range of U/Th components under the lowering of the Tisza riverbed are shown, indicating geochemical anomalies in these areas. The cluster and factor analysis methods were used to study the stability of statistical indicators based on the radionuclide content in the highlands of the Tisza River and the nature of latent factors that determine their statistical equivalency and grouping conditions. The radiological research data in the sediments' samples allows for estimating the abundance of chemical elements U, Th, and K as important geochemical and geothermal characteristics of its catchment area. The importance and prospects of radiological monitoring from the origin and in all the Carpathian basins of the Tisza River are discussed, given its importance for the formation of water resources in Eastern Europe.

Keywords
Carpathians, Tisza River, sediments, low-background measurements, radioisotopes, distribution, standards, geochemical indicators, U/Th/K abundance.

Introduction

Radiological studies are known to provide valuable information on the ecological status, the structure of terrestrial radioactivity, and the isotopic and chemical composition of environmental objects. In addition, one can use them to establish geochemical parameters and the nature of anthropogenic activities in the study areas. Studies of the structure of natural radioactivity are especially relevant for the mountainous regions of the Carpathians, which are a kind of natural barrier to the movement of air flows in Europe (Maňkovská et al.,2008; Kubica et al., 2017).

Mountainous areas for a long time accumulate products of both global origin and technogenic activity in large nearby regions. The mountain ranges of the Carpathians have a dominant function in the formation of water and air regimes of Transcarpathia and Eastern and Central Europe. The Ukrainian Carpathians are the region where the largest rivers in Europe originate: the San, which flows into the Vistula (Baltic Sea basin), and the Dniester and its right tributaries: Tysmenytsia, Stryi, Svicha, Limnytsia, Bystrytsia Solotvynska and Bystrytsia Nadvirnyanska (Black Sea basin) and the other Tisza River (Sendzimir et al., 2015).

This work concerns the study of the natural radioactivity of silt samples in the mountainous areas of the sources and confluence of the Black and White Tisza, Transcarpathia. Issues are considered: sampling schemes, research regulations, and radionuclides, which can serve as labels for processes of natural and technogenic origin. Furthermore, the conditions of low-background gamma-spectrometry of silt samples of the Tisza River and the method of multidimensional statistical analysis are discussed, which allows for establishing the nature of factors influencing the patterns of their spatial distribution in mountainous areas.

Object and methodology of research

The subject of the study was bottom sediments, which were taken at fixed sampling points along the Tisza riverbed. This paper presents the results of processing 12 samples related to mountain areas of river sources. Mountain river sediments (muds) are an effective accumulating environment, the isotopic and microelement composition of which is formed and renewed under the influence of factors of different nature: from soils of their catchment areas (watershed) – adjacent and distant upstream, current weather conditions such as wind rose, precipitation frequency and intensity, and seasonal indicators (Ionete et al., 2015).

River sediments capture the features of both regional - geochemical, economic, and global factors. The latter is due to the intensive interaction of mountains with air currents, which carry long-distance products of tectonic, climatic, and technogenic activity. In addition, a feature of mountain rivers is a significant amount of solid runoff, which is transported by riverbeds in the form of pebbles and blurred clay (suspended silt and sand particles). Therefore, the substance that makes up the bottom sediments of mountain rivers is a mixture of clastic (products of the destruction of rocks, volcanic rocks) and silty (organic and mineral colloidal materials) components.

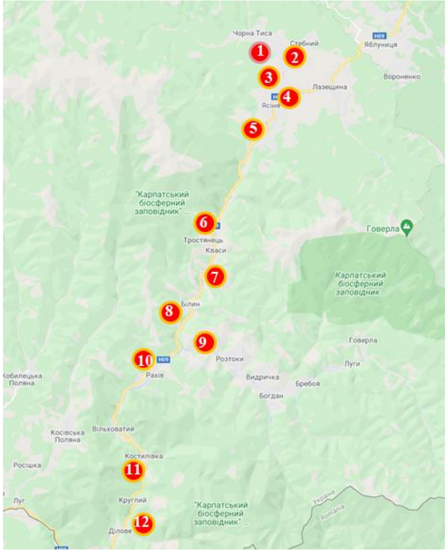
The first has the same radioisotope composition as the original rocks of the catchment basin, and an imbalance in the genetic chains of isotopes of natural series is possible due to their exfoliation in water at the phase boundary due to a significant specific surface area. On the other hand, the silty component is a good sorbent, its chemical and isotopic composition is formed and changes under the influence of river water.

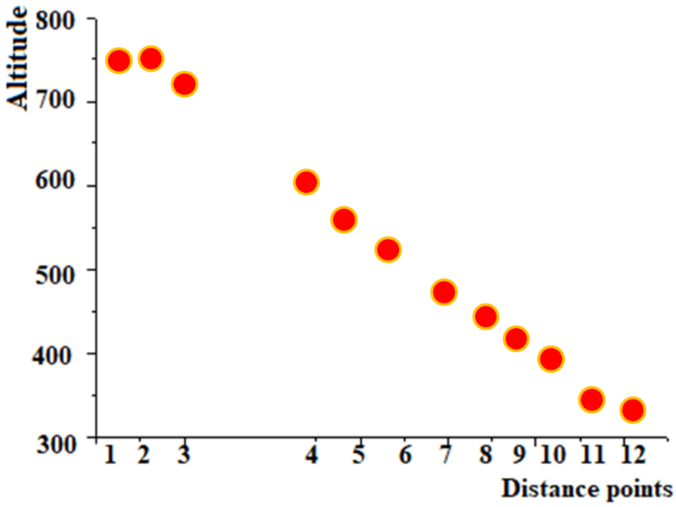
The choice as the object of study of the Tisza River is explained by the fact that almost the entire territory of Transcarpathia is the basin of its catchment area. However, this is only 25.6% of its total runoff. Other catchment volumes are formed in Romania (51%), Slovakia (13.4%), and Hungary (10%).

A sampling of bottom sediment samples along the Tisza River was carried out to comply with such experiments' standard requirements (Svatiuk et al., 2021). Thus, silt samples for rapid water flow were taken in areas with a stable dynamic equilibrium between suspended particles and bottom sediments (Blistanova et al., 2016; Kendall et al., 2006). In the absence of changes in the type of bottom sediments, the granulometric composition of the sample across the river's width is taken through one vertical velocity.

Coordinates of sampling points, Fig. 1a) were determined by GPS navigation and fixed by marks installed on the shore. The distance between them was 3 - 7 km; the first point was at the source of the river in the mountains (the village of Black Tisa), and the last – was near the town of Dilove, Rakhiv. The difference in height for these sampling points above sea level was 300 m, Fig. 1b). The proposed sampling scheme allows for recording the role of spatial and anthropogenic factors in forming radioecological indicators of the Tisza water basin. The weight fraction of each sample of silt mud (wet sample) was more than 1500 - 3000g; sampling was carried out using dredges. Samples were packed, transported, and stored in airtight containers. The packages contained all the information on the sampling conditions.

For measurements, the obtained samples were dried at a temperature of 110°C in an oven to an air-dry state, ground to obtain a homogeneous mass, and placed in an airtight container for at least 30 days, see (Svatiuk et al., 2021) before the beginning of low-background measurements. This condition is standard to ensure the quasi-equilibrium conditions of natural series radionuclides: for $2^{238}U$, it is 7-8 half-lives of volatile ^{222}Rn stability of its indicators relative to the content ^{214}Pb and ^{214}Bi (Ji et al., 2015). Then, it can be assumed that ^{226}Ra and ^{238}U are in equilibrium. Sediment samples weighing 1 to 1.5kg were placed in a Marinelli cap for gamma-spectroscopic measurements.





a) *б)*

Fig. 1 Sampling scheme of the bottom sediments of the sources of the Tisza River: a) their geographical location, b) the height of the sampling points above sea level. The inequality interval between sampling points has complied

The studies were performed on a spectrometric complex "ORTEC" with HPGe-detector with a volume of 150 cm^3. The resolution was not worse than 2.1 keV (^{60}Co), with an efficiency of 15%. The detector channels' resolution, efficiency, and drift were constantly monitored during the measurements. The total error in measuring the specific activity of radionuclides did not exceed 3-5%.

Low-background measurement conditions were provided by a system of passive, multilayer 4π-protection against radiation of elements of the laboratory premises and an additional set of measures to reduce it. The measurements themselves were performed in house-like protection containing successive layers of Pb (95 mm), Cd (1 mm), Fe and Cu (8 mm each), and Al (3 mm). The set of active measures to improve background conditions included ventilation and temperature regimes for controlled air convection. This condition reduces the content of gaseous isotopes $^{220,222}Rn$ in the room, which condense well on cooled surfaces without natural and forced ventilation. The nature of radon intake has both local (room materials, rocks, sewage) and global origins. Radon appearance is associated with wind flows and precipitation in the latter case. In addition, an air dehumidifier gives a constant (40-50%) degree of humidity during the measurements. During the measurements, air ventilation was also in the upper outer protection and the outer lower protection of the laboratory.

The quality of conditions and stability of low-background parameters allows one to adjust the measurement time in 2500 - 54000 s and optimize its value. These experiments permitted it to stop at a value of 5000s, which considers both the stability of background conditions and the reliability of establishing the specific activities of the studied radionuclides.

Experiment and discuss the results

The subject of the investigation was the content of radionuclides of natural and artificial origin in the sediment samples of the Tisza River. The coordinates of the sampling points are given in Table 1.

Table 1. Geolocation characteristics of sediment sampling points of the Tisza riverbed: high mountain areas.

Sampling point	Settlement	Altitude, meters above sea level	GPS-coordinate
P1	The source of the river Tisza	730	48°18'59.9"N 24°18'27.6"E
P2	vl. Black Tisza 1	739	48°18'48.1"N 24°18'62.3"E
P3	vl. Black Tisza 2	702	48°18'35.2"N 24°20'55.3"E
P4	vl. Yasinya (beginning)	661	48°16'66.5"N 24°21'56.8"E
P5	vl. Yasinya (end)	614	48°13'22.7"N 24°19'12.3"E
P6	vl. Kvasiv (beginning)	543	48°10'37.5"N 24°17'09.3"E
P7	vl. Kvasiv (end)	496	48°32'22.0"N 24°15'14.3"E
P8	vl. Bilin	488	48°60'29.0"N 24°15'32.0"E

P9	village of Roztoky	450	48°04'46.3"N 24°15'23.8"E
P10	village of Rakhiv	429	48°04'46.9"N 24°14'63.9"E
P11	vl. Kostylivka	354	48°01'65.0"N 24°10'21.9"E
P12	vl. Dilove	346	47°57'84.0"N 24°11'42.8"E

The choice of label isotopes to characterize the structure of natural activity is an essential component of establishing natural and technogenic indicators of the studied samples. It is known that the main contribution to terrestrial radioactivity is made by the daughter products of the decay of natural uranium and thorium, as well as ^{40}K, table 2. Isotope-labels ^{214}Bi and ^{214}Pb are well detected in low background experiments and can be used to determine standards for radioactive series U (^{238}U). In the case of the equivalent of Th (^{232}Th), it is possible to study the isotopes-labels ^{212}Pb, ^{212}Bi, and ^{228}Ac. Given the presence of genetically related U / Th isotopes of volatile components such as ^{220,222}Ra, as mentioned above, at least monthly sealing of test specimens is required to ensure the radioactive equilibrium of genetically related daughter radionuclides. As shown in Table 2, not all radionuclides can be reliable markers of the U / Th series due to the low energies of emitted gamma rays or the outputs of their characteristic lines. As mentioned above, the presence of these radionuclides in laboratory materials and the possibility of fluctuations in their parameters under low-background measurements should also be considered.

Table 2 Nuclear physical constants of radionuclides of natural and artificial origin: Eγ –the energy of characteristic γ-lines, n, % - their yields (Nelson et al., 2015).

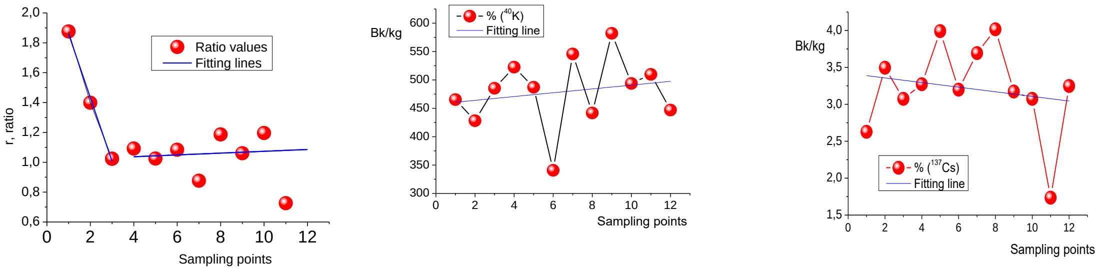
№	Radionuclide Basics	Daughter radionuclides	$T_{1/2}$	E_γ, кеВ keV	n, %
1	**^{232}Th**	^{228}Ac	6.15 год	338,32	11,27%
				911,204	25,8%
				968,971	15,8%
2		^{212}Pb	10.64 год	238,632	43,6%
				300,087	3,30%
3		^{212}Bi	60.6 хв	727,33	6,67%
4		^{208}TI	3.05 хв	583,191	85,0%
				2614,533	99,754%
5	**^{238}U**	^{226}Ra	1600 років	186,211	3,64%
6		^{214}Pb	26.8 хв	295	18,42%
				351	35,60%
7		^{214}Bi	19.9 хв	609,312	45,49%
				1120,287	14,92%
				1764,494	15,30%
8	**^{40}K**		$1.26\cdot10^9$ років	1460	11%
9	**^{137}Cs**		30 років	661	85%

The analysis of the data obtained testifies to sufficient stability of radiological indicators of siltstones. Thus, for the uranium series, the fluctuations of the specific content of the isotope ^{226}Ra near the average value, 81.8 Bq / kg, were within 3%, for ^{214}Pb, respectively, - 44.3 Bq / kg (15.4%), for ^{214}Bi - 43 .0 Bq / kg (23.3%). For thorium isotopes, these indicators are as follows: ^{228}Ac - 35.2 Bq / kg (13.5%); ^{212}Pb -37.2 Bq / kg (11.1%); ^{212}Bi, - 38.7 Bq / kg (14.5%) and for ^{208}Tl - 11.8 Bq / kg (15.6%). The content of ^{40}K is reliably identified in the sediments; its average value is 479.2 Bq / kg, and fluctuations in its content relative to all 12 sampling points were within 4.2%.

Note that the average values of relative specific activities of uranium/thorium series isotopes, respectively, ^{214}Pb / ^{214}Bi and ^{212}Pb / ^{212}Bi, are equal to each other in the range of 5-7%, which indicates a sufficient degree of quasi-equilibrium of daughter radionuclides U / Th series. Therefore, data on the specific activity of their daughter radionuclides, respectively, ^{214}Bi and ^{212}Pb, can be used to determine the content of uranium and thorium components in the samples. Anthropogenic human activity can be studied by the content in the environmental samples of radionuclides of man-made origin as ^{137}Cs, ^{90}Sr, or daughter isotopes ^{235}U, or ratios ^{234}U / ^{238}U, ^{236}U / ^{238}U as indicators of the presence of nuclear facilities or storage facilities for spent nuclear materials (Veerasamy et al., 2020). In our measurements of the specific content of the isotope ^{137}Cs, its average content was 81.8 Bq / kg, and fluctuations in values were within 3%.

Figure 2 presents the spatial distribution of some isotopes as markers of natural and artificial characteristics for selected sampling points of the Tisza riverbed. As shown in Fig. 2b), high mountain sources, points 1 and 2, offer a low content of technogenic radionuclides (^{137}Cs) in the silt. On the other hand, as one can see, there is a tendency for their accumulation in the sediments of the lower river horizons.

This fact indicates their exogenous origin. Visible changes in their value are observed only in the confluence of the tributaries of the Tisza: the river Lazenschyna (point 4), at the junction of the Black and White Tisza (point 7), near the tributaries Viseu, Iza (all Romania) and Kosovo, Shopurka and Apshitsa, (Ukraine), sampling points 12. As can be seen, there is a reduction, see points 6 and 9, 11, or increase, points 5 and 8, in the ^{137}Cs content, depending on the degree of technogenic activity. The content of ^{40}K in sediments shows greater resistance to spatial distribution from the upper to the lower sampling points, undergoing changes only in the vicinity of the tributaries of these rivers to the Tisza riverbed. The behaviour of the relative content of uranium/thorium components of silt is interesting: the trend towards their decrease for mountainous areas and the relative stability of *r* for the lower horizons of the Tisza riverbed. This dependence may indicate geochemical anomalies in the content of these components in the highlands of the Tisza.



a) *b)* *c)*

Fig. 2 Spatial distribution of radionuclide content in sediments along the Tisza River: a) relative content of uranium / thorium series components, r = 214Bi/212Pb; b) - the content of 40K, and artificial 137Cs, all in Bq/kg.

Statistical processing of low-background measurements has its peculiarities. This is because each sample of silt can be characterized by its own $\{A_i\}$ set of the activities of nuclides of natural and artificial origin, Table 1. Therefore, values of $\{A_i\}$ serve as statistical parameters for all 12 samples of sediments. Then the results of nuclear physical measurements can be presented as an array of multidimensional random variables formed by the influence of various factors: fluctuations in the composition of silt, sampling conditions, dehumidification, and conditions of low background measurements. Therefore, the patterns of distribution of these radionuclides in sediments and the correlations between them can be established by multidimensional statistical analysis (Davis., 2002; Yu et al.,2001). The first stage of such research is the way from statistical arrays $\{A_i\}$ to dimensionless standardized parameters a_i according to the rule:

$$a_i = \frac{A_i - \overline{A}_i}{\sigma_i}$$

Here $\overline{A}_i$ is the average value, σ_i – dispersion of specific activities of specifically 9 radionuclides according to the results, Table 1 according to the measurement results of all 12 samples of silt. Table 3 shows the following standardized values of specific activities for each of the sampling points, and Table 4 – shows the matrix of paired correlations, the structure of which is important for establishing the nature of the latent factors that form their content in the samples of silt 12 sampling points of the Tisza River.

Table 3 Standardized values of specific activities of nuclides of natural and technogenic origin for 12 sampling points, Fig.1

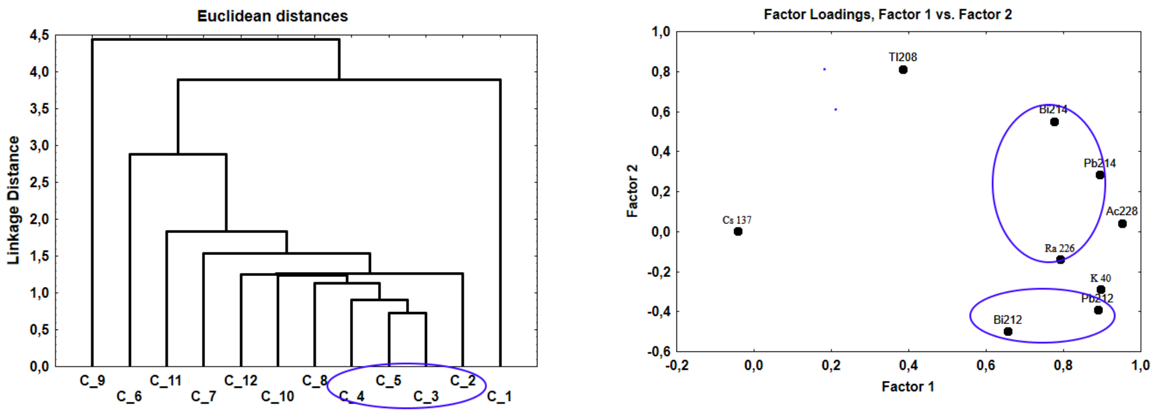
	^{226}Ra	^{214}Pb	^{214}Bi	^{228}Ac	^{212}Pb	^{212}Bi	^{208}TI	^{40}K	^{137}Cs
1	**0,077**	0,715	1,580	-0,062	-0,675	0,078	0,466	-0,21	-1,675
2	-0,606	-0,336	-0,281	-1,188	-1,072	-1,009	-0,923	-0,76	0,305
3	1,119	0,106	-0,270	0,345	0,019	-0,422	0,288	0,09	-0,65
4	0,948	0,484	0,146	-1,285	0,286	-0,400	0,250	0,64	-0,203
5	-0,854	0,197	-0,105	-0,351	0,440	-,422	0,551	0,12	1,437
6	-1,725	-2,052	-1,982	-1,145	-1,550	-0,443	-1,487	-2,06	-0,373
7	0,497	-0,758	-0,497	1,171	0,585	0,709	0,523	0,99	0,758
8	-0,559	0,212	0,255	0,141	-0,103	-1,009	-0,989	-0,56	1,493
9	1,445	1,772	1,415	1,471	2,088	2,319	1,913	1,53	-0,430
10	-0,341	-0,341	-0,260	0,903	-0,018	0,600	-0,594	0,22	-0,656
11	0,4935	-2,4166	-0,270	-1,3719	-0,7622	0,1812	1,2038	-1,027	-0,277
12	-0,5178	0,0506	0,6701	0,1523	-0,1034	-0,7294	-0,5362	0,0787	-0,3621

Significant correlations between the studied radionuclides' content in table 4 are highlighted in bold. As can be seen, the table illustrates the considerable correlations within the daughter isotopes of the natural U / Th series, which also extend to ^{40}K. At the same time, for technogenic ^{137}Cs, such dependencies are absent. Correlation dependences are also weakened for daughter radionuclides U/Th series, which are separated by 3-4 acts of α-decays as ^{228}Ac - ^{212}Pb, ^{226}Ra - ^{214}Pb, in the presence of branding due to β-decays (Pop et al., 2019), or because of low yield of analytical lines in ^{212}Bi, ^{226}Ra. The last case needs a good statistic for their identification.

Table 4 Matrix of pair correlations of distribution of nuclides of natural and artificial origin in the sediments of the Tisza River, according to Table 3

	^{226}Ra	**^{214}Pb**	**^{214}Bi**	**^{228}Ac**	**^{212}Pb**	**^{212}Bi**	**^{208}TI**	**^{40}K**	**^{137}Cs**
^{226}Ra	1,000	**0,710**	0,598	0,498	**0,729**	0,550	**0,781**	**0,840**	-0,298
^{214}Pb	**0,710**	1,000	**0,927**	0,388	**0,725**	0,459	**0,771**	**0,717**	-0,135
^{214}Bi	0,598	**0,927**	1,000	0,396	0,548	0,433	**0,688**	0,612	-0,270
^{228}Ac	0,498	0,388	0,396	1,000	**0,700**	**0,762**	0,567	**0,663**	-0,047
^{212}Pb	**0,729**	**0,725**	0,548	**0,700**	1,000	**0,751**	**0,857**	**0,913**	0,149
^{212}Bi	0,550	0,459	0,433	**0,762**	**0,751**	1,000	**0,736**	**0,696**	-0,320
^{208}TI	**0,781**	**0,771**	**0,688**	0,567	**0,857**	**0,736**	1,000	**0,866**	-0,163
^{40}K	**0,840**	**0,717**	0,612	**0,663**	**0,913**	**0,696**	**0,866**	1,000	-0,002
^{137}Cs	-0,298	-0,135	-0,270	-0,047	0,149	-0,320	-0,163	-0,002	1,000

These data make it possible to investigate the degree of correlation proximity for the studied sampling points along the Tisza riverbed and the role of latent factors in the radiological clustering parameters of its silt. Since the characteristics of terrestrial radioactivity are due to technogenic, natural influences and the geochemical state of the studied areas is appropriate to use cluster analysis to determine their effects. In fig. 3, a) data on clustering or statistical proximity of sampling points for uranium/thorium radionuclide content are given. As can be seen, the analysis shows a significant identity or the degree of geochemical proximity of mountain areas of the Tisza River from its sources to the village Yasinya (points 2-5). The confluence m of the Black and White Tisza (point 7) violates this geographical, which is already being restored near point 8 (the village of Bilin). The influence of anthropological factors and the presence of numerous tributaries (see also Fig. 2 affect both the content of investigated isotopes in the sediments samples and the statistical characteristics of sampling points. The following riverbed sampling points 9-12 have a lower degree of geochemical proximity, i.e., greater values of linkage distances, due to the collective impacts from natural and artificial factors.



a) b)

Fig.3. The results of statistical analysis of radiological indicators of the Tisza River sediments:
a) Dendrograms of cluster analysis assess the statistical proximity of sampling points along the Tisza riverbed by radionuclides of the U / Th series. A lower value of the aggregation parameter indicates a greater degree of statistical proximity to the sampling points.;
b) - 2D graphs of factor loads, demonstrating the different nature of the statistical grouping of radionuclides of natural and artificial origin in the silt of the Tisza River when choosing two factors scheme with the weight of factors 1 with 59% and other 17.3%

Fig. 3 b) demonstrate the role of latent factors on the characteristic of statistical clustering of radionuclides of natural and technogenic origin. Thus, factor 1 may be responsible for the nuclear physical properties of the studied isotopes of natural U/Th radioactive series and ^{40}K. As can be seen, this grouping occurs separately for daughter radionuclides of the U and Th series, and there is a correlation between the contents of the ^{40}K isotope and daughter isotopes of the Th series. This feature was mentioned earlier (Svatiuk et al., 2021) after the same investigation of the sediments of the Borzhava River (Transcarpathia). It was explained by the accumulation of actinides in the compositions of potassium minerals and monazites. The chemical element Th has less chemical mobility than U, and therefore there are better conditions for the quasi-equilibrium of its daughter isotopes in microcrystalline composites in sediments. This fact explains the greater statistical relationship in the Tisza River sediments of their contents and ^{40}K, see table 3. Moreover, as can be seen, the different mobility of the chemical elements U and Th leads to the different signs of factor 2, which may be responsible for the geochemical characteristics of the region, hydrodynamic parameters of mountain rivers, climatic, spatial, and seasonal patterns of the study region. Interestingly, factors 1 and 2 influence the distribution of artificial ^{137}Cs in silt samples is minimal because their values are close to zero.

The radiological studies of the distribution of daughter isotopes of natural series allow us to estimate the content of their parent chemical elements U, Th, and K and establish the geochemical characteristics of the Tisza River mountain areas. It is known that thorium, uranium, and potassium show a strong concentration in the surface layers of the Earth and are enriched in the continental crust (Yaroshevsky et al., 2006). Therefore, data on their content are essential both for understanding the fundamentals of the formation of Carpathian mountains and for a number of applications: assessment of erosion of the surface layers of adjacent areas, meteorological and geothermal indicators of the territories, et al. The Th / U ratio can serve as a tracer of hydrothermal processes; respectively, K / Th may be used as a proxy of the action of surface weathering processes. Note that these elements exist in minor or trace levels in all soil, sediments, or rock formations; their distribution for different areas can vary by order of magnitude to their reference values (U, Th K% (Wasserburg et al., 1964). This peculiarity is also a problem with their content definition in natural objects. In practice, the abundance of thorium, uranium, and potassium can be estimated by two independent methods; a physical method based on heat-flow measurements and another one in studying the structure of terrestrial radioactivity, as was made in this paper (Dikiy et al., 2017). The first is related to the release of energy in the matter during nuclear transformations of daughter radionuclides of natural U/Th series and ^{40}K. Thus, in the case of mineral formations of the Earth's crust with a density ρ (2.7E+3 kg/m^3), the heat generation H_0 depends on the content of these radioisotopes with the concentrations c_K (% K), c_U (ppm U), c_{Th} (ppm Th). With known coefficients of heat generation of these isotopes (H (^{238}U) = 9,38E-5 W/kg., H (^{235}U) = 5,69E-4 W/kg, H (^{232}Th) = 2,69E-5 W/kg, H (^{40}K) = 2.79E-5 W/kg formulas for determining H_0 have the following form (Goodge et al., 2017)):

$$H_o = 10^{-2} * \rho * (9.67c_U + 2.63c_{Th} + 3.48c_K)$$

or

$$H_o = \rho \cdot 0.9928C_U \cdot H(^{238}U) + 0.0071C_U \cdot H(^{235}U) + C_{Th} \cdot H(Th) + 1.19 \cdot 10^{-4} C_{K40} \cdot H(^{40}K) \qquad (2)$$

Another method is based on data on the specific activities of A_E of basic radionuclides U, Th natural series, and ^{40}K in environmental samples using their content in ppm or at. %, See (Converting Atomic Percent to Weight Percent and Vice Versa, 2016). To estimate the specific concentrations of the chemical element *E*, i.e. f_E, in ppm is to use the following formula (Tzortzis et al., 2004):

$$f_E = \frac{M_E T_{1/2}^{(E)} C}{N_A \lambda_E} A_E,$$

Here $T_{1/2}^{(E)}$ is the half-life of the basic radioisotope: ^{238}U for the element U, ^{232}Th for Th, and ^{40}K for K, the fractional content of which in the studying sample with atomic mass ME (kg/mol) is lE, N_{Av}, - Avogadro's number ($6.023 \cdot 10^{23}$ atom/mole). The constant C has a value of 106 for U, Th, and 100 for K, then f_E is set in mg/kg or ppm (the part per million), 1% = 10000 ppm. Recommended values according to IAEA TEC DOC no. 1363 (Guidelines for Radioelement Mapping Using Gamma-Ray Spectrometry Data, 2003)systematized according to research and calculations according to formula (3) are 1 ppm U = 13.35 Bk / kg of ^{238}U, 1 ppm Th = 4.06 Bk / kg of ^{232}Th, 1 ppm K = 313.0 Bk / kg of ^{40}K.

Studies show that the Th/U ratio increases with decreasing riverbed of the Tisza, sampling points 1-3, Fig.2 a). Their values vary between 1.75 and 3.17 (in ppm) using the recommended ratios (Guidelines for Radioelement Mapping Using Gamma-Ray Spectrometry Data, 2003), or from 1.9 to 2.95 ppm according to (3), see also (Yaroshevsky et al., 2006). The same K / Th ratio is presented at % changes on a smaller scale, respectively, 2788 and 2010.

Conclusion

For the first time, the results of radiological studies of the Tisza River sediments in the Carpathians' highlands were obtained and presented. The sediments are informative for studying the quality of water resources and the ecological condition of significant adjacent areas of the Tisza river basin. In addition, data on abundance and the nature of the spatial distribution of radionuclides of natural and artificial origin along the river bed were obtained. The content of uranium-thorium components of sediment at the beginning of the river sources, the nature of their change during the transition from high to lowland areas, and under the influence of tributaries of other rivers and man-made rivers activity are obtained. Such information is essential for the control of the geochemical and geothermal characteristics of the studied mountain areas. It is shown that the obtained standards of the content of daughter radionuclides in silt samples can be used for certification and study of the degree of statistical proximity of different mountain areas, establishing latent indicators that lead to the formation of natural activity along the Tisza riverbed.

The obtained results are necessary for the development of methods of water resource control in the Eurocarpathian region, for which the Tisza River is an essential formative factor. An open question is the influence of global factors in the particular meteorological or tectonic activity of mountains on the content of these indicators. To solve it and establish the seasonal features of changes in radiological indicators of silt, it is necessary to organize monitoring of the riverbed with periodic sampling, which can be solved only within the framework of the target European program.

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