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7 YEARS OF MONITORING OF ^{40}K IN SURFACE WATER SAMPLES FROM OLT RIVER, ROMANIA

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Abstract:

The aim of this study was to determine naturally occurring radionuclide ^{40}K in surface water samples from Olt River, Romania. A monitoring study during 7 years (2012-2018) was accomplished. A number of 728 surface water samples were collected and analysed.
Several hundred pollution sources were identified for the Olt River basin in Romania. This study is of particular importance since it is the first effort to evaluate the activity concentrations of ^{40}K in surface water from Romania for such a long period.
For this reason, two sampling points along the Olt River were chosen, the first one upstream of the discharge point of the magistrate channel "Deversor Olt" (reference location) and respectively the second sampling point downstream of the liquid effluents discharges point (indicator location).
The radioactivity concentration of ^{40}K was determined from the 1460.8 keV photopeak. The method used was high resolution gamma ray spectrometry performed with a hyperpure germanium detector.
An activity concentration for ^{40}K, no more than 2.14 ± 0.32 Bq l^{-1}, is observed, but the values recorded for the background location had a slight, but not significant difference compared with the values recorded in the second sampling point.

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1. INTRODUCTION

Primordial radionuclides (radionuclides of natural origin) are present in the environment in all media (water, soil, flora, fauna), and even in the human body. ^{238}U and ^{232}Th series and ^{40}K are the main external sources of external irradiation for the human body (UNSCEAR 2000). Only 1% of the total effective dose experienced by individuals is due to the artificial

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radionuclides, while the most important part is from natural decay series (83%) and ^{40}K (16%) (Bhuiyan et al., 2019; Chau et al., 2011; Asaduzzaman et al., 2015).

The assessment of the natural radioactivity in rivers is necessary because it concerns the most abundant radionuclide (^{40}K) liable to produce radiation protection issues (Sac et al., 2012).

The water is one of the most important component of the environment, and it represents a transferring vector of the radionuclides between the environmental compartments. The chemistry of the environmental radionuclides differs from one element or from one matrix to another and has variations in time related to the time of emission.

Generally, ^{40}K is in mineral form and is a component of various rocks and dusts, so that it can accumulate in soils and minerals and as a soluble electrolite in water (Külahcı and Çiçek, 2019). Rivers can carry this mineral form on long distance.

The Olt River Basin has a surface of 24050 km^2 and is situated in the central and south part of Romania. It springs from Hamasu Mare Mountains, situated in the Oriental Carpathians. A series of tributary rivers are situated near the main course: the Negru River, the Cibin River and the Lotru River. Due to its sources of supply, the Olt River has a well-balanced hydrological regime and its physico-geographical characteristics are very diverse due to its length and altitude variation (from an average of 750 m in the upper area to around 16 m in the confluence area) (Borza and Petrescu, 2016).

Several hundred pollution sources were identified for the Olt River basin in Romania. (Antoniu, 1969) However, on the basis of waste water flows and toxic character of the waste (nature, complexity, and intensity) only nine pollution zones were stated to exert a significant effect on river quality (Figure 1). (Antoniu, 1969)

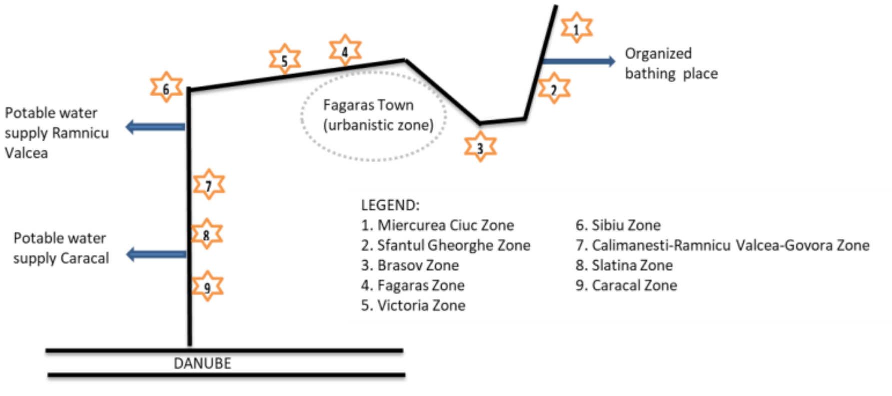

Figure 1. Major water uses and sources of pollution in the Olt River Basin

Liquid effluents from Industrial Platform - Ramnicu Valcea (major producer in the chemical industry, which uses the electrolytic enrichment technique in its technological processes) and from the Experimental Pilot Plant for Tritium and Deuterium Separations (PESTD) are discharged in Olt River.

The process used in PESTD is based on a combined method for liquid-phase catalytic exchange and cryogenic distillation. Its main objective is to complete the technology for detritiation of the heavy water resulted from the CANDU type reactors. (Duliu et al., 2018).

The use of the water close to PESTD for irrigation and for home use is the essential factor which requires the permanent analysis of the radioactive content and its variation in time.

Since the current environmental distribution of radioactivity includes naturally occurring radioactive materials and man-made radioactive materials, it is important to establish the existing levels, so that future changes may be properly attributed to PESTD operations or other causes.

Along with the phosphate fertilizers used in agriculture, radioactive metals such as uranium, thorium, radium and potassium enter the environment. Radioactive pollutants are an important research topic.

Radioactive emissions into the environment during the operational phase of PESTD may affect the current environmental distribution of radioactivity in the area surrounding the plant. The Preoperational Environmental Monitoring Program (PEMP) is set to measure this current environmental distribution prior to plant operation and thus to establish a reference level for evaluating the impact of plant operation. The PEMP also provides an opportunity to establish sampling and analytical techniques which may be used in the operational program.

In this regard it should be noticed that until present time, the experiments performed for PESTD were made with heavy and tritiated water whose gamma radionuclides concentrations were below the exempting level for nuclear facilities as established by the Romanian National Regulations (CNCAN 2000).

All the liquid effluents (from PESTD and Industrial Platform) are collected in a Mixing Chamber, named ”Camera de amestec” and then being discharged into the Olt River.

For this study, two locations were selected. One is upstream of the wastewater discharged point (reference locations) and the second location is downstream of the same point (indicator locations). Sampling points were established taking into account the distance and the orientation from the future effluent, the presence of population, the degree of use of surface water from the Olt River for agricultural activities (Figure 2).

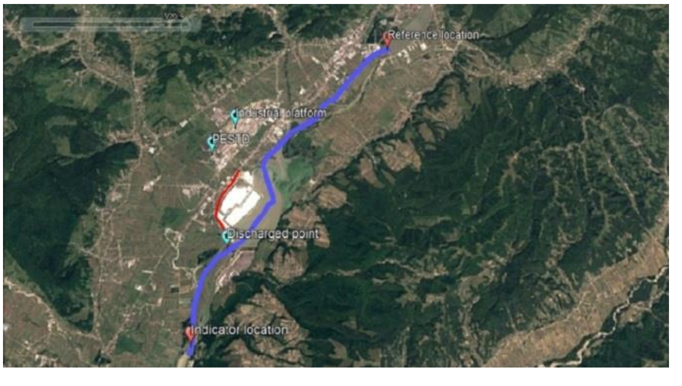

Figure 2. Map of the study area. Coloured line: Olt River (coloured blue), Deversor Channel (coloured red)

The geographical coordinates of these sampling points were marked and designed to be representative of the concentrations of ^{40}K in surface water (Table 1).

Table 1. Geographic site of sampling location

Site	Sampling location		Distance from the Discharged point (km)
	Latitude °(N)	Longitude °(E)	
Reference location	45°4’16.77”	24° 21’45.55”	3
Indicator location	44° 58’53.78”	24° 16’52.39”	9
Discharge point	45° 0’28.14”	24° 17’35.95”	-

2. MATERIALS AND METHODS

2.1. Sampling methodology and preparation

Each week, during the entire monitoring period of seven years, 5 litters of water were collected right from underneath the water surface from each established location. Thus, 728 surface water samples were obtained. The sampling, conservation and manipulation of the surface water samples was carried out in accordance with international standards (ISO 5667-1 Water quality — Sampling — Part 1: Guidance on the design of sampling programmes and sampling techniques).

The initial volume was reduced to about 150 ml by evaporation on a sand bath (ISO 10703:2007 Water quality — Determination of the activity concentration of radionuclides — Method by high resolution gamma-ray spectrometry). After evaporation, the resulting sample was sealed in a Sarpagan-type plastic box with the same shape as the one used for calibration.

2.2 Gamma spectrometry measurement

For gamma measurements, a coaxial HPGe detector (65% relative efficiency) was used. The energy resolution (FWHM) of HPGe detector is 1.85 keV at 1332 γ-^{60}Co transition.

The quantitative and qualitative analysis was achieved by using a Multi-Channel Analyser (DSPEC plus). The spectra were analysed by the GammaVision software. All gamma measurements were taken after calibrating the MCA with ^{241}Am, ^{60}Co, ^{133}Ba and ^{137}Cs sources.

The detector was housed in a cylindrical lead shield in order to eliminate the contribution of naturally occurring background radionuclides in the environment. In addition, the natural background gamma spectrum was subtracted from the peak area in order to have more accurate results.

Samples were placed symmetrically on top of the detector and were analysed for 25200 sec.

^{40}K is included in the isotope mixture of natural potassium (^{39}K, ^{40}K, ^{41}K) with an isotopic abundance of 0.0119 % and decays with a half-life of $1.29 \cdot 10^{9}$ years to ^{40}Ca (β-decay) or ^{40}Ar (electron capture), respectively.

^{40}K concentration was measured from its 1460.83 (10.66 %) keV γ-line.

The activity concentration of ^{40}K in surface water samples was obtained using the Eq (1): (SR EN ISO 10703, 2016).

$$\text{Activity concentration} = \frac{n_g - n_b}{P \cdot \varepsilon \cdot V \cdot f \cdot t} \; [\text{Bq l}^{-1}] \qquad (1)$$

where n_g is number of counts in the gross area of the peak, in the sample spectrum; n_b is number of counts in the background of the peak, in the sample spectrum; P is the probability of the emission of gamma radiation, per decay; ε is the efficiency of the detector , with the actual measurement geometry; V is the volume of the surface water sample in litters, t is the sample spectrum counting time, in seconds; f is the correction factor considering all necessary corrections according to Eq (2).

$$f = f_d \cdot f_{cl} \cdot f_S \qquad (2)$$

where f_d is the factor to correct the decay to a reference date, f_{cl} is the correction factor for coincidence losses, f_s is the factor to correct summing-up effects by coincidences.

Minimum Detectable Activities (MDA's) are calculated using a coverage factor of 1.645, corresponding to a 95% confidence level, and reported as <VALUE.

2.3 Annual Effective Dose Calculation

The human body is exposed to various types of radiation that are emitted from sources in the environment at any moment. Dose estimation is required because of the biological effects of radiations.

The annual effective dose due to the intake of ^{40}K in drinking water (AED_{dw}) can be calculated from the Formula given by (Parhoudeh et al., 2019; ICRP, 1996):

$$AED_{dw} = A \cdot DCF \cdot CRW \qquad [Sv\ y^{-1}] \tag{3}$$

where A is the activity concentration of ^{40}K in the ingested sample (Bq l^{-1}), DCF is the ingested dose conversion factor for ^{40}K ($4.2 \cdot 10^{-8}$ Sv Bq^{-1} for infants, $1.3 \cdot 10^{-8}$ Sv Bq^{-1} for children and $6.2 \cdot 10^{-9}$ Sv Bq^{-1} for adults) and CRW is the annual ingested volume of drinking-water which depends on a given age (150 l a^{-1} for infants, 350 l a^{-1} for children and 500 l a^{-1} for adults) (UNSCEAR, 2000; European Directive 2013/51 Euratom).

3. RESULTS AND DISCUSSION

This study was carried out over a period of 7 years (2012-2018).

The water samples collected from Olt River were measured in order to determine a wider range of radionuclides of interest, as well as: ^{99}Mo, ^{226}Ra, ^{235}U, ^{51}Cr, ^{7}Be, ^{137}Cs, ^{65}Zn, ^{60}Co. For all radionuclides, with the exception of ^{40}K, the activity concentration was below the detection limit.

Table 2 and table 3 presents the results of the activity concentrations in surface water samples (Bq l^{-1} ± SD) collected in Olt River (upstream and downstream from Discharged Point) in January-December 2018-2012.

Table 2. Activity concentration of ^{40}K in surface water samples (Bq l^{-1} ± SD) collected in the Olt River in January-December 2018-2015

Week of the year	Activity concentration of ^{40}K of the surface water samples (Bq l^{-1}) ± SD							
	2018		2017		2016		2015	
	Reference location	Indicator location	Reference location	Indicator location	Reference location	Indicator location	Reference location	Indicator location
1	0.72 ± 0.11	0.85 ± 0.14	0.63 ± 0.11	0.84 ± 0.23	1.01 ± 0.10	< 0.44	0.68 ± 0.23	0.76 ± 0.21
2	0.50 ± 0.10	0.42 ± 0.10	0.52 ± 0.10	0.79 ± 0.23	0.85 ± 0.28	0.56 ± 0.28	0.79 ± 0.21	0.69 ± 0.23
3	0.37 ± 0.11	0.48 ± 0.11	1.08 ± 0.20	0.94 ± 0.26	1.25 ± 0.10	1.32 ± 0.17	0.90 ± 0.23	0.90 ± 0.23
4	0.19 ± 0.10	0.44 ± 0.10	0.61 ± 0.13	1.03 ±0.23	0.98 ± 0.27	0.87 ± 0.23	0.77 ± 0.21	1.03 ± 0.24
5	0.24 ± 0.11	0.35 ± 0.10	1.11 ± 0.15	0.88 ± 0.28	< 0.43	0.75 ± 0.22	0.86 ± 0.22	1.11 ± 0.24
6	0.23 ± 0.11	0.38 ± 0.10	1.01 ± 0.12	0.69 ± 0.12	1.28 ± 0.17	1.38 ± 0.17	1.21 ± 0.41	1.01 ± 0.23
7	0.37 ± 0.11	0.29 ± 0.11	0.88 ± 0.12	0.54 ± 0.21	1.43 ± 0.13	1.32 ± 0.13	1.08 ± 0.24	0.96 ± 0.22
8	0.38 ± 0.10	0.69 ± 0.14	0.86 ±0.10	0.73 ± 0.20	0.73 ± 0.23	0.77 ± 0.27	1.18 ± 0.25	0.99 ± 0.22
9	0.52 ± 0.12	0.58 ± 0.11	0.75 ±0.11	0.53 ± 0.12	0.86 ± 0.27	0.85 ± 0.23	0.79 ± 0.23	0.70 ± 0.24
10	0.17 ± 0.08	0.67 ± 0.12	1.00 ±0.14	0.99 ± 0.13	0.58 ± 0.27	0.92 ± 0.23	0.86 ± 0.22	0.75 ± 0.24
11	0.14 ± 0.10	0.44 ± 0.16	1.21 ±0.20	1.14 ± 0.14	0.64 ± 0.26	0.75 ± 0.22	0.97 ± 0.22	1.34 ± 0.27
12	< 0.12	< 0.11	1.25 ±0.22	1.36 ± 0.14	0.60 ± 0.23	0.69 ± 0.23	0.96 ± 0.22	0.99 ± 0.24
13	1.12 ± 0.23	1.07 ± 0.21	0.94 ± 0.21	0.85 ± 0.22	< 0.43	0.70 ± 0.23	0.91± 0.21	0.83 ± 0.21
14	0.83 ± 0.22	0.49 ± 0.21	1.14 ± 0.15	0.93 ± 0.13	0.77 ± 0.23	0.91 ± 0.27	0.86 ± 0.20	1.10 ± 0.24

15	0.59 ± 0.21	0.92 ± 0.20	0.85 ± 0.13	0.91 ± 0.13	0.98 ± 0.23	0.62 ± 0.22	0.69 ± 0.22	1.00 ± 0.23
16	1.17 ± 0.23	0.74 ± 0.20	0.90 ± 0.12	0.76 ± 0.12	0.94 ± 0.17	1.02 ± 0.18	0.93 ± 0.21	1.11 ± 0.24
17	0.94 ± 0.19	0.74 ± 0.20	1.19 ± 0.15	0.97 ± 0.13	0.69 ± 0.24	0.89 ± 0.23	0.90 ± 0.21	0.80 ± 0.23
18	0.46 ± 0.21	0.56 ± 0.19	0.81 ± 0.12	1.08 ± 0.14	0.80 ± 0.27	0.93 ± 0.28	0.78 ± 0.21	1.14 ± 0.26
19	0.81 ± 0.22	0.77 ± 0.22	0.63 ± 0.12	0.83 ± 0.12	0.65 ± 0.26	0.87 ± 0.23	1.04 ± 0.23	1.07 ± 0.23
20	0.37 ± 0.22	0.71 ± 0.19	0.57 ± 0.10	0.94 ± 0.13	0.56 ± 0.22	0.79 ± 0.23	0.95 ± 0.22	0.91 ± 0.23
21	0.44 ± 0.20	0.50 ± 0.24	0.82 ± 0.12	0.64 ± 0.12	0.96 ± 0.27	0.80 ± 0.23	1.02 ± 0.23	0.86 ± 0.25
22	0.44 ± 0.21	0.34 ± 0.21	0.75 ± 0.11	0.79 ± 0.12	0.62 ± 0.23	0.80 ± 0.22	1.03 ± 0.23	0.81 ± 0.20
23	0.82 ± 0.23	0.48 ± 0.19	0.84 ± 0.12	0.75 ± 0.11	0.56 ± 0.26	0.59 ± 0.23	0.92 ± 0.21	0.99 ± 0.22
24	0.44 ± 0.21	0.50 ± 0.22	0.95 ± 0.13	1.01 ± 0.14	0.77 ± 0.22	0.74 ± 0.23	0.93 ± 0.21	0.96 ± 0.22
25	0.37 ± 0.24	0.74 ± 0.22	0.77 ± 0.12	0.94 ± 0.13	0.95 ± 0.27	1.03 ± 0.28	0.88 ± 0.21	0.87 ± 0.20
26	0.27 ± 0.18	0.94 ± 0.25	0.91 ± 0.13	0.92 ± 0.13	0.75 ± 0.19	0.75 ± 0.02	0.96 ± 0.24	1.05 ± 0.23
27	0.68 ± 0.22	0.37 ± 0.22	0.90 ± 0.13	1.01 ± 0.14	0.90 ± 0.23	0.66 ± 0.28	0.98 ± 0.22	0.89 ± 0.22
28	0.67 ± 0.21	0.58 ± 0.23	0.81 ± 0.12	0.83 ± 0.14	0.96 ± 0.23	0.55 ± 0.26	0.69 ± 0.20	1.06 ± 0.26
29	0.41 ± 0.23	0.32 ± 0.20	0.82 ± 0.16	0.85 ± 0.14	0.65 ± 0.22	0.58 ± 0.27	1.07 ± 0.23	0.93 ± 0.21
30	0.48 ± 0.22	0.37 ± 0.21	0.75 ± 0.14	0.94 ± 0.16	0.61 ± 0.22	0.63 ± 0.23	1.14 ± 0.24	1.39 ± 0.28
31	0.44 ± 0.22	0.39 ± 0.21	0.78 ± 0.13	0.48 ± 0.09	0.62 ± 0.22	0.85 ± 0.22	1.06 ± 0.23	0.99 ± 0.22
32	0.58 ± 0.25	0.63 ± 0.22	0.82 ± 0.13	0.73 ± 0.12	0.69 ± 0.27	1.08 ± 0.18	1.32 ± 0.27	1.22 ± 0.25
33	0.67 ± 0.21	0.53 ± 0.22	0.82 ± 0.13	0.79 ± 0.13	0.71 ± 0.28	0.75 ± 0.22	1.04 ± 0.24	1.49 ± 0.30
34	0.53 ± 0.23	0.69 ± 0.21	0.88 ± 0.14	0.80 ± 0.13	1.00 ± 0.28	0.96 ± 0.27	1.37 ± 0.29	0.96 ± 0.22
35	0.68 ± 0.22	0.53 ± 0.20	1.06 ± 0.18	0.91 ± 0.15	0.88 ± 0.23	0.74 ± 0.23	1.11 ± 0.25	1.04 ± 0.25
36	0.45 ± 0.19	0.59 ± 0.25	0.83 ± 0.13	0.89 ± 0.14	0.84 ± 0.23	0.69 ± 0.27	1.39 ± 0.29	1.27 ± 0.28
37	0.50 ± 0.24	0.37 ± 0.19	0.75 ± 0.13	0.81 ± 0.13	0.65 ± 0.23	0.54 ± 0.23	0.81 ± 0.22	0.89 ± 0.21
38	0.37 ± 0.22	0.47 ± 0.20	0.83 ± 0.13	0.91 ± 0.14	0.71 ± 0.22	0.90 ± 0.23	1.19 ± 0.25	0.94 ± 0.23
39	0.55 ± 0.20	0.71 ± 0.20	0.37 ± 0.08	0.55 ± 0.10	0.87 ± 0.22	0.91 ± 0.27	1.04 ± 0.23	0.98 ± 0.25
40	0.59 ± 0.21	0.71 ± 0.19	0.79 ± 0.14	0.76 ± 0.11	0.95 ± 0.28	0.85 ± 0.27	1.22 ± 0.27	1.20 ± 0.28
41	0.58 ± 0.21	0.43 ± 0.20	0.84 ± 0.12	0.77 ± 0.12	0.71 ± 0.23	0.47 ± 0.27	1.27 ± 0.27	0.95 ± 0.22
42	0.36 ± 0.21	0.37 ± 0.21	0.82 ± 0.12	0.82 ± 0.15	0.45 ± 0.27	0.48 ± 0.27	0.85 ± 0.24	1.12 ± 0.24
43	0.58 ± 0.19	0.68 ± 0.20	0.65 ± 0.11	0.80 ± 0.12	0.74 ± 0.24	0.68 ± 0.22	1.16 ± 0.27	0.90 ± 0.29
44	0.37 ± 0.22	0.38 ± 0.21	0.83 ± 0.12	0.97 ± 0.13	0.71 ± 0.22	0.58 ± 0.26	0.83 ± 0.22	0.93 ± 0.21
45	0.44 ± 0.26	0.33 ± 0.21	0.86 ± 0.12	0.79 ± 0.12	0.65 ± 0.22	0.68 ± 0.26	0.73 ± 0.18	0.80 ± 0.22
46	0.31 ± 0.20	0.37 ± 0.22	0.96 ± 0.13	0.86 ± 0.13	0.73 ± 0.22	0.62 ± 0.27	1.03 ± 0.23	0.73 ± 0.20
47	< 0.31	< 0.36	0.77 ± 0.11	0.77 ± 0.11	0.68 ± 0.23	0.58 ± 0.22	0.84 ± 0.20	0.89 ± 0.23
48	0.41 ± 0.23	0.33 ± 0.21	0.67 ± 0.12	0.90 ± 0.13	0.75 ± 0.22	0.85 ± 0.27	0.83 ± 0.26	0.77 ± 0.22
49	0.33 ± 0.20	0.46 ± 0.22	0.65 ± 0.13	0.83 ± 0.13	0.57 ± 0.23	0.69 ± 0.28	0.75 ± 0.20	0.93 ± 0.21
50	0.41 ± 0.24	0.44 ± 0.24	0.91 ± 0.14	0.83 ± 0.13	0.59 ± 0.21	0.55 ± 0.21	1.12 ± 0.25	1.03 ± 0.25
51	0.34 ± 0.20	0.37 ± 0.24	0.60 ± 0.11	0.76 ± 0.12	0.66 ± 0.27	0.70 ± 0.22	1.15 ± 0.25	0.82 ± 0.20
52	0.70 ± 0.22	0.49 ± 0.20	0.62 ± 0.11	0.78 ± 0.23	0.64 ± 0.27	0.78 ± 0.23	0.81 ± 0.20	1.05 ± 0.23
Range	0.14 - 1.17	0.29 - 1.07	0.37 - 1.25	0.48 - 1.36	0.45 ± 1.43	0.47 ± 1.38	0.68 - 1.39	0.69 - 1.49
Average	0.49 ± 0.19	0.53 ± 0.19	0.83 ±0.13	0.84 ± 0.15	0.77 ± 0.23	0.77 ± 0.23	0.97 ± 0.23	0.98 ± 0.23

Table 3. Activity concentration of ^{40}K in surface water samples (Bq l^{-1} ± SD) collected in the Olt River in January- December 2014-2012

Week of the year	Activity concentration of ^{40}K of the surface water samples (Bq l^{-1}) ± SD					
	2014		2013		2012	
	Reference location	Indicator location	Reference location	Indicator location	Reference location	Indicator location
1	1.371± 0.23	1.03 ± 0.21	< 0.28	< 0.38	1.56 ± 0.25	< 0.40
2	1.48 ± 0.24	1.41 ± 0.23	1.65 ± 0.26	1.52 ± 0.24	1.47 ± 0.24	< 0.34
3	1.41 ± 0.23	1.24 ± 0.21	1.25 ± 0.23	1.66 ± 0.26	1.45 ± 0.24	1.56 ± 0.25
4	1.16 ± 0.20	1.23 ± 0.21	1.38 ± 0.23	1.10 ± 0.26	0.57 ± 0.18	1.38 ± 0.23
5	1.30 ± 0.22	1.34 ± 0.22	1.74 ± 0.27	1.54 ± 0.26	1.32 ± 0.22	1.57 ± 0.25
6	1.49 ± 0.24	1.46 ± 0.24	0.81 ± 0.24	1.40 ± 0.23	1.38 ± 0.23	1.35 ± 0.23
7	1.61 ± 0.25	1.33 ± 0.22	1.53 ± 0.24	1.71 ± 0.27	1.29 ± 0.21	< 0.19
8	1.20 ± 0.20	1.59 ± 0.25	1.21 ± 0.23	1.46 ± 0.24	1.24 ± 0.21	1.59 ± 0.25

9	1.18 ± 0.20	1.50 ± 0.24	1.34 ± 0.22	1.22 ± 0.27	< 0.16	1.66 ± 0.26
10	1.62 ± 0.26	1.33 ± 0.22	1.62 ± 0.26	1.41 ± 0.23	0.50 ± 0.18	1.69 ± 0.27
11	1.12 ± 0.25	0.89 ± 0.24	0.94 ± 0.20	1.26 ± 0.22	< 0.30	1.70 ± 0.27
12	0.62 ± 0.18	1.00 ± 0.22	1.33 ± 0.22	1.58 ± 0.25	1.16 ± 0.20	1.58 ± 0.25
13	0.49 ± 0.02	1.21 ± 0.25	1.54 ± 0.25	1.50 ± 0.24	1.48 ± 0.24	< 0.27
14	0.99 ± 0.23	1.02 ± 0.23	1.22 ± 0.25	1.04 ± 0.23	1.67 ± 0.26	1.67 ± 0.26
15	0.82 ± 0.21	0.70 ± 0.25	1.59 ± 0.25	1.30 ± 0.22	1.56 ± 0.36	1.34 ± 0.22
16	0.88 ± 0.23	0.57 ± 0.19	< 0.19	1.13 ± 0.22	0.79 ± 0.27	1.28 ± 0.21
17	1.11 ± 0.24	1.58 ± 0.25	1.09 ± 0.20	0.65 ± 0.19	1.37 ± 0.23	1.67 ± 0.26
18	1.06 ± 0.23	1.42 ± 0.23	1.08 ± 0.23	0.92 ± 0.24	1.36 ± 0.23	1.19 ± 0.20
19	1.82 ± 0.28	2.08 ± 0.31	1.47 ± 0.26	0.72 ± 0.19	1.57 ± 0.26	1.27 ± 0.22
20	1.79 ± 0.27	1.52 ± 0.24	0.78 ± 0.21	0.89 ± 0.22	1.31 ± 0.33	1.46 ± 0.35
21	2.14 ± 0.32	0.37 ± 0.23	1.26 ± 0.24	1.47 ± 0.26	1.50 ± 0.24	1.12 ± 0.21
22	1.44 ± 0.23	1.96 ± 0.30	1.35 ± 0.27	1.52 ± 0.27	1.59 ± 0.25	1.96 ± 0.30
23	0.99 ± 0.23	1.09 ± 0.21	1.39 ± 0.28	2.08 ± 0.33	1.65± 0.26	1.49 ± 0.24
24	1.26 ± 0.24	0.39 ± 0.20	1.45 ± 0.23	1.62 ± 0.25	1.17 ± 0.31	1.49 ± 0.24
25	1.60 ± 0.26	1.12 ± 0.23	1.68 ± 0.26	2.00 ± 0.39	1.42 ± 0.24	1.21 ± 0.21
26	1.33 ± 0.22	1.17 ± 0.21	1.61 ± 0.25	1.77 ± 0.27	1.25 ± 0.22	1.20 ± 0.22
27	1.47± 0.24	1.57 ± 0.25	1.33 ± 0.23	1.58 ± 0.26	1.54 ± 0.21	0.55 ± 0.18
28	0.90 ± 0.20	1.60 ± 0.25	1.50 ± 0.24	1.16 ± 0.20	0.64 ± 0.18	0.93 ± 0.18
29	1.59 ± 0.25	1.63 ± 0.26	1.19 ± 0.20	1.41 ± 0.24	1.56 ± 0.21	1.50 ± 0.20
30	1.39 ± 0.23	1.32 ± 0.22	1.35 ± 0.22	1.60 ± 0.26	0.93 ± 0.19	0.75 ± 0.18
31	1.40 ± 0.23	1.24 ± 0.22	1.70 ± 0.26	1.11 ± 0.23	1.29 ± 0.18	0.47 ± 0.25
32	1.45 ± 0.23	1.67 ± 0.26	1.47 ± 0.24	1.18 ± 0.21	0.96 ± 0.18	1.25 ± 0.22
33	1.45 ± 0.23	1.86 ± 0.28	1.10 ± 0.23	0.97 ± 0.21	1.46 ± 0.24	1.42 ± 0.23
34	1.38 ± 0.23	1.49 ± 0.24	1.57 ± 0.25	1.24 ± 0.22	1.61 ± 0.25	1.24 ± 0.36
35	1.28 ± 0.21	1.26 ± 0.21	0.94 ± 0.21	<0.33	1.28 ± 0.22	0.72 ± 0.28
36	1.61 ± 0.25	1.18 ± 0.20	0.75 ± 0.28	0.85 ± 0.21	1.61 ± 0.37	1.60 ± 0.25
37	1.26 ± 0.22	1.44 ± 0.24	1.48 ± 0.25	1.37 ± 0.25	0.79 ± 0.29	0.93 ± 0.33
38	1.20 ± 0.20	1.64 ± 0.26	0.42 ± 0.22	0.75 ± 0.21	1.05 ± 0.24	0.82 ± 0.23
39	1.61 ± 0.25	1.37 ± 0.22	1.45 ± 0.26	1.30 ± 0.23	1.35 ± 0.26	0.95 ± 0.23
40	1.54 ± 0.25	1.38 ± 0.23	1.29 ± 0.24	0.52 ± 0.21	1.12 ± 0.27	0.14 ± 0.06
41	1.56 ± 0.25	1.51 ± 0.24	1.29 ± 0.24	<0.33	1.13 ± 0.24	1.97 ± 0.30
42	1.56 ± 0.25	1.18 ± 0.21	0.89 ± 0.22	0.83 ± 0.21	0.70 ± 0.20	0.93 ± 0.23
43	1.13 ± 0.20	1.55 ± 0.25	1.19 ± 0.23	1.18 ± 0.20	0.55 ±0.18	0.78 ± 0.16
44	0.74 ± 0.19	1.00 ± 0.22	1.44 ± 0.23	1.16 ± 0.20	1.02 ±0.22	1.43 ± 0.23
45	0.83 ± 0.23	1.39 ± 0.09	1.45 ± 0.23	1.45 ± 0.23	1.63 ± 0.26	1.36 ± 0.22
46	0.50 ± 0.18	1.15 ± 0.28	1.18 ± 0.21	0.76 ± 0.24	1.42 ±0.24	1.72 ± 0.27
47	1.05 ± 0.23	0.96 ± 0.22	1.21 ± 0.24	1.59 ± 0.26	1.66 ±0.26	1.47 ± 0.24
48	0.94 ± 0.25	0.94 ± 0.22	1.28 ± 0.23	1.19 ± 0.23	1.43 ±0.23	1.42 ± 0.23
49	0.47 ± 0.22	1.13 ± 0.26	1.54 ± 0.25	1.35 ± 0.22	1.44 ± 0.24	1.72 ± 0.27
50	0.94 ± 0.22	1.19 ± 0.25	1.67 ± 0.26	1.76 ± 0.27	1.44 ± 0.24	1.52 ± 0.25
51	0.49 ± 0.19	0.87 ± 0.21	1.37 ± 0.22	1.44 ± 0.23	1.11± 0.20	1.38 ± 0.23
52	0.88 ± 0.24	1.04 ± 0.23	1.52 ± 0.24	1.53 ± 0.25	1.43 ± 0.24	1.06 ± 0.19
Range	0.47 - 2.14	0.37 - 2.08	0.42 - 1.74	0.52 - 2.08	0.50 - 1.67	0.14 - 1.97
Average	1.23 ± 0.23	1.27 ± 0.23	1.28 ± 0.24	1.25 ± 0.70	1.24 ± 0.71	1.24 ± 0.24

Considering surface water as a source of drinking water, because the Olt River represents a source of drinking water supply for the city of Ramnicu Valcea, effective dose estimation is calculated.

The range of effective doses do the intake of ^{40}K were from $3.12 \cdot 10^{-3}$ mSv/year to $8.03 \cdot 10^{-3}$ mSv/year in reference location and from $3.35 \cdot 10^{-3}$ mSv/year to $8.00 \cdot 10^{-3}$ mSv/year in indicator location for infants; $2.25 \cdot 10^{-3}$ mSv/year to $5.80 \cdot 10^{-3}$ mSv/year in reference location and from $2.42 \cdot 10^{-3}$ mSv/year to $5.78 \cdot 10^{-3}$ mSv/year in indicator location for children; $1.54 \cdot 10^{-3}$

mSv/year to 3.96·10^{-3} mSv/year in reference location and from 1.65·10^{-3} mSv/year to 3.94·10^{-3} mSv/year in indicator location for infants (Table 4).

Table 4. Results of annual effective dose from ^{40}K over the year

Year	Annual effective dose (mSv/year)					
	Reference location			Indicator location		
	Infants (1 year)	Children (10 years)	Adult	Infants (1 year)	Children (10 years)	Adult
2018	3.12·10^{-3}	2.25·10^{-3}	1.54·10^{-3}	3.35·10^{-3}	2.42·10^{-3}	1.65·10^{-3}
2017	5.25·10^{-3}	3.79·10^{-3}	2.59·10^{-3}	5.34·10^{-3}	3.84·10^{-3}	2.62·10^{-3}
2016	4.84·10^{-3}	3.50·10^{-3}	2.39·10^{-3}	4.77·10^{-3}	3.45·10^{-3}	2.35·10^{-3}
2015	6.13·10^{-3}	4.43·10^{-3}	3.02·10^{-3}	6.16·10^{-3}	4.45·10^{-3}	3.04·10^{-3}
2014	7.73·10^{-3}	5.59·10^{-3}	3.81·10^{-3}	8.00·10^{-3}	5.78·10^{-3}	3.94·10^{-3}
2013	8.03·10^{-3}	5.80·10^{-3}	3.96·10^{-3}	7.84·10^{-3}	5.67·10^{-3}	3.86·10^{-3}
2012	7.82·10^{-3}	5.66·10^{-3}	3.86·10^{-3}	7.82·10^{-3}	5.66·10^{-3}	3.86·10^{-3}

The effective dose is strongly dependent on the drinking water consumption amounts. The dose conversion factor depends on the radionuclide and on the age of the individual (IAEA, 2014).

The activity concentrations of ^{40}K in water samples collected from Olt River are much lower than the average concentration in Egypt, Nigeria, Malaysia and Bangladesh (Table 5) (Morsy et al. 2012; Agbalagba and Onoja 2011; Almayahi et al. 2012; Bhuiyan et al. 2019). Though, the activity concentration of ^{40}K of the current study is found to be comparable to the study of Amal Hussain Al-Ghamdi (2019) in the Al-Baha Region even if the samples are from different types of water: surface water and ground water, respectively.

Table 5. Comparison of radioactivity of water samples with the others areas of the world

Location	Type of water	Activity concentration of ^{40}K Bq l^{-1}		References
		Mean	Standard deviation	
Bangladesh	Surface water	46.8	25.44	Bhuiyan *et al*., 2019
Egypt	Lake water	119.2	8.34	Morsy *et al*., 2012
Nigeria	Lake water	97	29	Agbalagba and Onoja , 2011
Malaysia	River water	118.5	11.5	Almayahi *et al.*, 2012
Saudi Arabia	Ground water	2.84		Al-Ghamdi, 2019
Iran	Drinking water	6.42	4.54	Parhoudeh *et al*., 2019
Turkey	Lake water	6.68		Külahcı and Çiçek, 2019
Iran	Surface water	132.6-148.87		Zare *et al.*, 2015
Romania	River water	0.98	0.28	Our study

A monitoring programme is usually set up in order to estimate the impact of the radioactivity on the population health. The expected activity concentrations are normally far below the levels corresponding to the dose limits for the population and many data obtained are below the limit of detection of the method (Engelbrecht and Schwaiger, 2008).

Following the distribution of the activity concentration of ^{40}K (Figure 3) in space (the two sampling locations), the values recorded along 7 years of monitoring are within 2.14 ± 0.32 – 0.14 ± 0.10 Bq l^{-1} for reference location and 2.08 ± 0.33 – 0.14 ± 0.06 Bq l^{-1} for indicator location.

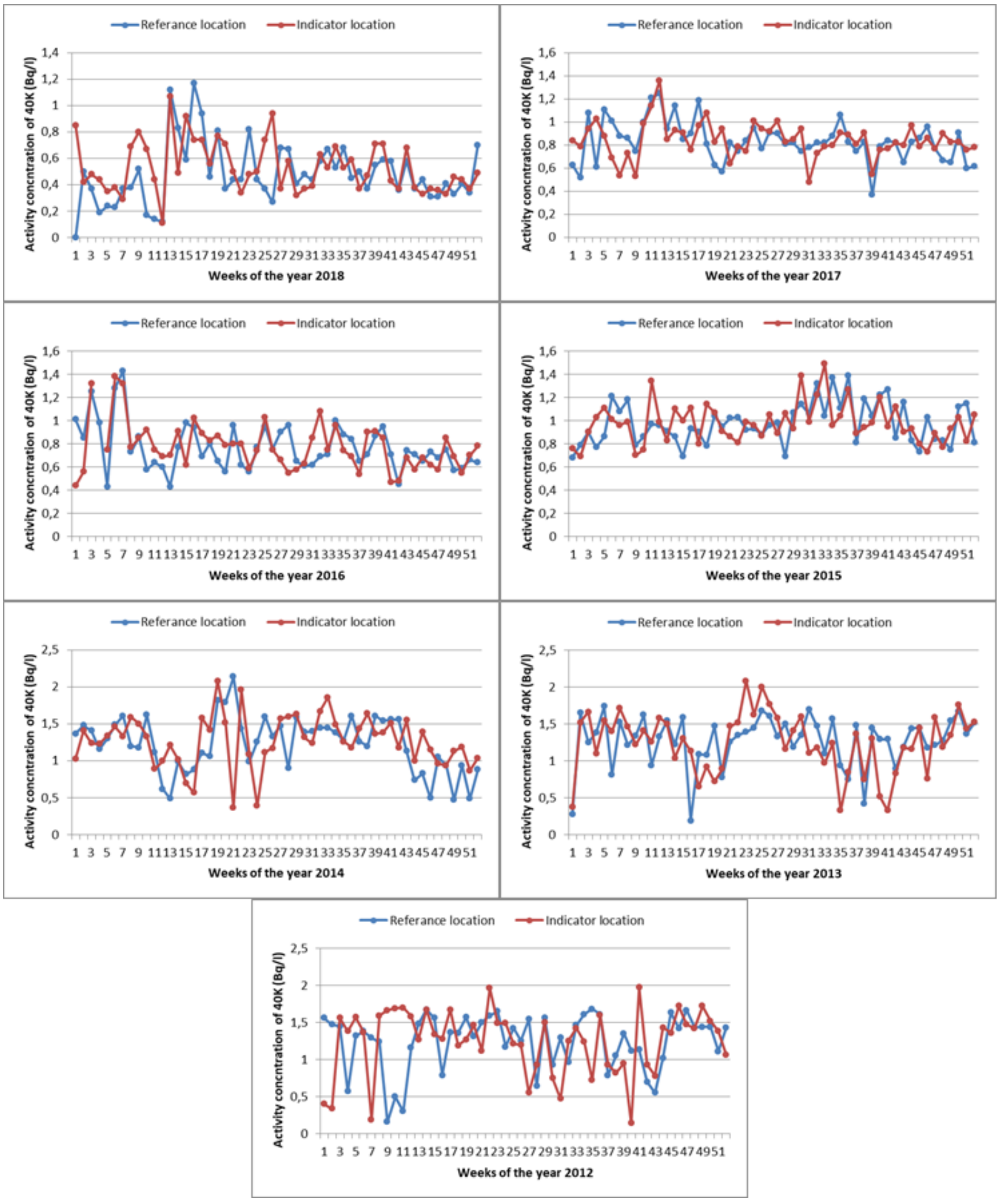

Figure 3. The activity concentration levels of ^{40}K in surface water sampled from Olt River, Romania, within the period from 2012 to 2018. Values below detection limit are included

Also, the activity concentration values measured in the reference locations are predominantly lower than the values measured in the indicator location, taking into account the relative error in measurements.

Following the distribution of the activity concentration of ^{40}K in time (2012-2018), we observe a decrease. If in 2013, at the indicator location, the average activity concentration was 1.25 ± 0.70 Bq l^{-1}, in 2018 the value decreases to 0.53 ± 0.19 Bq l^{-1}.

Log-transformed activity concentration of ^{40}K in samples of surface water used to estimate the time-dependent trends. Linear regressions were calculated from the period from 2012 to 2018. For both locations, the activity concentrations tended to decrease in all samples during the monitored period (Figure 4).

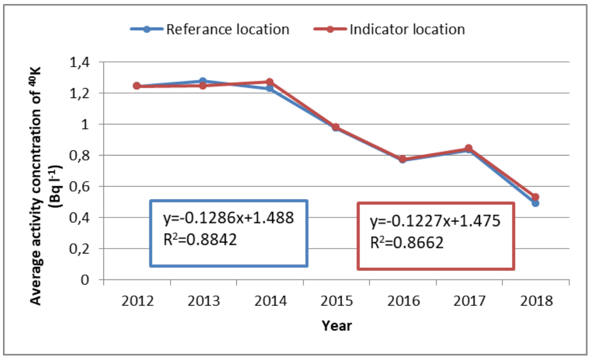

Figure 4. Linear regression of activity concentrations of ^{40}K

4. CONCLUSIONS

We have used the high resolution HPGe gamma detector to determine the activity concentration of ^{40}K in surface water samples collected from Olt River. The monitoring period was between 2012-2018, during which 728 water samples were collected. ^{40}K activities ranged from 0.14 Bq l^{-1} to 2.14 Bq l^{-1}, all samples concentration activities were below the recommended limit 10.0 Bq l^{-1} of ^{40}K reported by WHO 2006 (Al-Ghamdi, 2019; WHO, 2006).

Worldwide annual exposures to natural radiation sources would generally be expected to be in the range 1-10 mSv, with 2.4 mSv being the present estimate of the central value. Results demonstrated clearly that, during 2012-2018, annual effective dose in Olt River surface water is lower than average worldwide exposure to ^{40}K which is 0.17 mSv (UNSCEAR, 2000). More than that, in UNSCEAR 2017 Report, the average annual effective dose from ^{40}K is equal to 0.2 mSv a^{-1} in the Techa River.

The existing pollution due to the economic activities developed in the studied area, does not call into question any radioactive contamination with ^{40}K.

Following the distribution of the activity concentration for ^{40}K, upstream and downstream from the discharge point Deversor-Olt Channel, no significant modification can be observed, not in time (along the years) or in space (the two sampling locations) so that the situation should come under attention.

The data obtained in this study is a baseline which can be used to evaluate possible future changes. Further detailed radioecological investigations and realistic estimation of dose assessment for the rivers especially for the purposes of agriculture irrigation, fishery, tourism/recreation, and water supply could be needed.

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