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RESEARCH PAPER

Gross Alpha and Beta Radioactivity Evaluation in Drinking Water: Results from the Calabria Region, Southern Italy

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Abstract

In this article, authors report experimental results obtained for the assessment of gross alpha and beta radioactivity in drinking waters, coming from the Calabria region, southern Italy. The measurements, performed with the Perkin-Elmer Tricarb 4910 TR Liquid Scintillation Counter (LSC) setup, were compared with reference values derived from Italian regulations (the Italian Legislative Decree n. 28/2016) to evaluate the existence of possible health risks for the population due to the ingestion of gross alpha and beta radioactivity in the analyzed drinking waters. Experimental results underline that both specific activities in the investigated drinking waters varies widely. In particular, for gross alpha, the activity concentration ranges from a minimum value lower than the LSC minimum detectable activity (MDA), 0.04 Bq L^{-1}, for the site IDs 13, 28, 34, 35, 38, 44, 53, to a maximum of (0.16 ± 0.03) Bq L^{-1} for the site ID 22; for gross beta, the specific activity varies from a minimum value lower than the LSC MDA, 0.20 Bq L^{-1}, for all the sampling sites except for the site IDs 5, 6, 9, 13, 15, 18, 19, 25, 27, 29, 33, 34, 40, to a maximum of (0.34 ± 0.07) Bq L^{-1} for the site ID 15. Obtained results represent a main reference for the investigated area, and they are useful to determine the associated radiological health risks for the population.

Article Highlights

- **The assessment of gross alpha and beta radioactivity in drinking waters, coming from the Calabria region, southern Italy, was performed.**
- **Experimental results were compared with reference values derived from the Italian Legislative Decree 28/2016 in order to evaluate the existence of possible health risks for the population.**
- **Obtained results represent a main reference for the investigated area, and they are useful to determine the associated radiological health risks for the population.**

Keywords Gross alpha · Gross beta · Drinking water · Ingestion · Radiological risk · Dose

Introduction

Natural radioactivity in the environment is due to the presence of cosmogenic and primordial radionuclides in the Earth's crust and it provides the greatest contribution to the dose received by the population (Torrisi et al. 2010; Caridi et al. 2016a; Tzortzis et al. 2003). Cosmogenic radioisotopes are produced by the interaction of cosmic-rays with atomic nuclei in the atmosphere; the origin of primordial radionuclides goes back to the formation of the Earth, when they were formed by the process of nucleo-synthesis (Torrisi et al. 2008; Caridi et al. 2016b; Von Gunten 1995).

Although environmental aspects of natural radioactivity were discussed in numerous publications (Cooper et al. 2003; Caridi et al. 2016c, 2021) the presence of natural radioisotopes in drinking water as a hazard factor to the public was not addressed in sufficient detail (Atwood 2010; Vallejos et al. 2015). Water-quality assurance is one of the most important issues in environmental programs to protect public health,

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because safe drinking water must not represent any significant risk to health over a lifetime consumption, including different sensitivities that may occur between life stages (Alabdula'aly et al. 2010; Kansaana et al. 2012). Drinking waters contain natural radionuclides in various concentrations depending on their origin (Moreno et al. 2014; Baeza et al. 1995); the activity concentrations of gross alpha or beta in drinking water, in particular, could guide in determining whether the water can be used for human consumption (AOAC 1990; Oluyide et al. 2019). This led to an increased demand for data, with the aim of addressing public concern pertaining to the quality of drinking water since most of Italian people use groundwater as fetched directly from wells for domestic use (Caridi et al. 2019; Velis et al. 2017). Gross alpha is more of a concern than gross beta for natural radioactivity in water as it refers to the radioactivity of Th, U, Ra as well as Rn and its descendants (EML 1990; Ashton et al. 2012; Osmond et al. 1976).

The Italian Legislative Decree n. 28/2016 constitutes the current national legislative reference regarding the quality of drinking water, in relation to radioactivity. In particular, it regulates the methods of controlling radioactive substances by means of indicator parameters and indicates the related parameter values: Indicative Dose (DI), 0.1 mSv year^{-1}; activity concentration of radon, 100 Bq L^{-1} and tritium-specific activity, 100 Bq L^{-1}. The Legislative Decree n. 28/2016 also establishes that the determination of the Indicative Dose (ID) is consequent to a preliminary screening, based on the measurement of the gross alpha and beta activity concentration: if the values of 0.1 Bq L^{-1} for the gross alpha and 0.5 Bq L^{-1} for the gross beta-specific activities, respectively, are not exceeded, it can reasonably be assumed that the Indicative Dose value of 0.1 mSv year^{-1} is also respected. If this is not the case, an analytical study must be carried out which allows the dose to be calculated on the basis of the activity concentration of the radionuclides present in the investigated sample (Caridi et al. 2020).

In the present study, a campaign of measurements to control the gross alpha and beta activity concentration in drinking water from public supplies in the Calabria region, southern Italy, is reported. The purpose was to contribute to data compilation concerning the presence of α- and β-emitting radionuclides in drinking waters in the investigated region and to determine the associated radiological health risk for the population.

Therefore, the data reported in this paper were compared with the abovementioned reference values and the associated health risk was calculated.

Materials and Methods

The investigated area is located in the southern part of Italy (Fig. 1). In particular, in the Calabrian districts of Reggio Calabria, Catanzaro, Crotone and Vibo Valentia, 54 municipalities, with springs, wells and related fountains and tanks were identified and monitored, as reported in Table 1, for a total of 250 drinking water samples collected during the 2019. The sampling collection was done for different seasons of the year, according to the local weather conditions, that in some periods put severe limitations on access to the monitoring stations.

All samples were collected into 1 L of acidified polyethylene holders, tightly sealed and labeled, to avoid radionuclide precipitation and adsorption on walls of the containers.

For the measurements, a Perkin-Elmer Tricarb 4910 TR Liquid Scintillation Counter (LSC) was employed (Perkin-Elmer Tri-Carb 4910 Manual 2009). Its energy range was 0–2 meV (β particles) and 0–10 meV (α particles). Its minimum acceptable efficiency was 60% for ^{3}H (0–18.6 keV) and 95% for ^{14}C (0–156 keV). Its average Background was 17 CPM for ^{3}H and 26 CPM for ^{14}C. It worked in Normal Count Mode/Low activity—High Sensitivity Mode, with the external standard ^{133}Ba to take into account chemical and optical quenches and to determine the counting efficiency through the Transformed Spectral Index of the External Standard with Automated Efficiency Control (TSIE/AEC) (Caridi et al. 2016d).

For gross alpha and beta assessment, the activity concentration was measured as follows: 200 mL of sample, acidified with 20 µL of ultra-pure HNO_3 (67–69%), were preconcentrated at a volume of 20 mL and pH about of 1.85. Of this total volume only 8 mL were taken and mixed with 12 mL of Perkin Elmer ULTIMA GOLD AB scintillating cocktail, stored in a 20 mL plastic vial and, after a rest time of 3 h, counted for 1000 min together with a background (UNI EN ISO 9696–9697 2019).

The activity concentration (Bq L^{-1}) was calculated using the following formula (Caridi et al. 2016e, 2017):

$$C = \frac{N}{\varepsilon t V} \tag{1}$$

where N indicates net counts, ε the counting efficiency, V the sample volume (L) and t the live time (s).

In the case of exceeding gross alpha or beta, an analytical study must be carried to calculate the ID parameter (Caridi F. et al. 2020). The Indicative Dose is a measure of the effect on the body of the radioactivity taken by ingestion: it was obtained by qualitative and quantitative analysis of the radionuclides present in the sample and was calculated using the dose coefficients reported in the Italian Legislation D.Lgs. n. 230 and s.m.i. 1995. These coefficients, together

Fig. 1 A map of the investigated zone

with the assumption of an annual ingestion of water of 730 L, allow to calculate the derived activity concentrations for the individual radionuclides, corresponding to an effective committed dose of 0.1 mSv per year (Italian Legislation D. Lgs. n. 28 2016).

The ID parameter was therefore determined by:

$$ID(\text{mSv}) = \sum_{i=1}^{n} \frac{C_i(\text{mis.})}{C_i(\text{der.})} x(0.1\text{mSv}) \quad (2)$$

where n indicates the number of radionuclides that contributed at the ID, C_i(mis.) and C_i(der.) the measured and derived specific activities of the i-th radionuclide, respectively.

The ID was less than or equal to the parameter value of 0.1 mSv if the following condition was satisfied:

$$\sum_{i=1}^{n} \frac{C_i(\text{mis.})}{C_i(\text{der.})} \leq 0.1 \quad (3)$$

Results and Discussion

Figure 2 shows the average value of the gross alpha and beta activity concentrations in the analyzed samples, for each sampling site. Values lower than the minimum detectable activity (MDA) (0.04 Bq L^{-1} and 0.20 Bq L^{-1} for gross alpha and gross beta, respectively) were not reported (UNI EN ISO 9696–9697 2019).

It is evident that both specific activities in the investigated drinking waters varies widely. In particular, for gross alpha, the activity concentration ranges from a minimum value lower than the LSC MDA for the site IDs 13, 28, 34, 35, 38, 44, 53, to a maximum of (0.16 ± 0.03) Bq L^{-1} for the site ID 22; for gross beta, the specific activity varies from a minimum value lower than the LSC MDA for all the sampling sites except for the site IDs 5, 6, 9, 13, 15, 18, 19, 25, 27, 29, 33, 34, 40, to a maximum of (0.34 ± 0.07) Bq L^{-1} for the site ID 15.

This variation indicates that the origin of these drinking waters is not the same and that they come from different depths and pass through different geological layers.

Table 1 The investigated municipalities

Site ID	Municipality	District
1	Antonimina	Reggio Calabria
2	Ardore	
3	Bivongi	
4	Bova	
5	Bovalino	
6	Campo Calabro	
7	Canolo	
8	Caraffa del Bianco	
9	Casignana	
10	Caulonia	
11	Ciminà	
12	Cittanova	
13	Cosoleto	
14	Delianuova	
15	Fiumara	
16	Galatro	
17	Gerace	
18	Giffone	
19	Gioia Tauro	
20	Mammola	
21	Martone	
22	Melicucco	
23	Monasterace	
24	Oppido M	
25	Palmi	
26	Placanica	
27	Polistena	
28	Portigliola	
29	Reggio Calabria	
30	Roccella J	
31	S. Agata del Bianco	
32	S. Eufemia d'Aspromonte	
33	S. Giorgio Morgeto	
34	S. Pietro di Caridà	
35	S. Procopio	
36	S. Stefano d'Aspromonte	
37	Scido	
38	Scilla	
39	Siderno	
40	Sinopoli	
41	Villa S. Giovanni	
42	Catanzaro	Catanzaro
43	Crotone	Crotone
44	Cutro	
45	Isola di Capo Rizzuto	
46	S. Mauro Marchesato	
47	S. Severina	
48	Scandale	
49	Briatico	Vibo Valentia
50	Filandari	
51	Nicotera	
52	Ricadi	
53	Simbario	
54	Vibo Valentia	

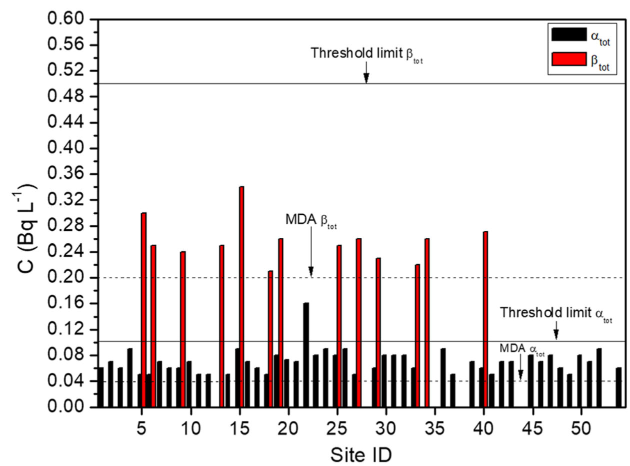

Fig. 2 The average value of the gross alpha and beta activity concentrations in the analyzed samples, for each sampling site

This irregular distribution of the activity concentration may depend on the U and Th content in rocks or solid aquifers in the areas where are located and the residence time of waters/rocks-soils in contact as well. In particular, the maximum values were obtained for municipalities located in an area where the geological setting is the "Calabrian-Peloritan arc" (Atzori et al. 1984). Its rocks are acidic intrusive igneous and metamorphic, characterized by the highest natural radioactivity.

Obtained results are in good agreement with those reported in the literature from other parts of world (Davila Rangel et al. 2001; Turhan 2020; Ogundare et al. 2015; Ho et al. 2020), on the basis of similar geological considerations.

All the gross alpha and beta activity concentration values turn out to be lower than 0.1 Bq L^{-1} and 0.5 Bq L^{-1}, respectively, except for the gross alpha-specific activity in the sampling site ID 22 (see Fig. 2). Thus, in this case an analytical study was carried out to calculate the Indicative Dose through the Eq. (2) on the basis of the activity concentration of the radionuclides present in the investigated sample (Caridi et al. 2020).

In particular, we measured an activity concentration of (0.07 ± 0.02) Bq L^{-1}, (0.09 ± 0.03) Bq L^{-1} and lower than

0.04 Bq L^{-1} for ^{238}U, ^{234}U and ^{226}Ra, respectively, and then an Indicative Dose of 0.005 mSv $year^{-1}$, much lower than the parameter value of 0.1 mSv $year^{-1}$ (Italian Legislation D. Lgs. n. 28 2016).

All obtained values, due to ingestion of α- and β-emitting radionuclides in drinking water to any individual in the population living in the Calabria region, are then lower than the screening and parameter values reported by the Italian Legislative Decree n. 28/2016, thus excluding any possible radiological health risk.

Conclusions

In this article, results from the gross alpha- and beta-specific activity measurements, performed during the 2019, to preliminarily assess the radiological health risk due to the presence of α- and β-emitting radionuclides in drinking water of the Calabria region, are reported. Reported results have a more immediate and easy-to-comment graphic layout, even for evaluations.

The gross alpha and beta activity concentrations were measured by means of the Perkin-Elmer Tricarb 4910 TR Liquid Scintillation Counter (LSC). Obtained results show that the specific activities in drinking water in the investigated 54 municipalities are well below the screening levels indicated by the current Italian legislation (0.1 Bq L^{-1} for the gross alpha and 0.5 Bq L^{-1} for the gross beta, respectively) except for the gross alpha-specific activity in the sampling site ID 22. In this case, an analytical study was carried out and the calculated Indicative Dose was of 0.005 mSv $year^{-1}$, fully compliant with the parameter value set by the current Italian legislation (0.1 mSv $year^{-1}$). Therefore, it can be argued that the water examined is safe for drinking and other domestic purposes, and no remedial actions are demanded.

However, even though these results show low values of gross alpha and beta activity concentrations and doses in perfect compliance with the official institutional indications, it has to be underlined that periodical screening could be necessary to guarantee the safety of drinking water. Therefore, more measurements and investigations are needed, for the sake of public health.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

Alabdula'aly AI, Maghrawy HB (2010) Radon emanation from radium specific adsorbents. Water Res. 44:177–184

AOAC (Association of Official Analytical Chemists) (1990) Fifteenth ed. Official Methods of Analysis of the Association of Official Analytical Chemists, Washington

Ashton K, Heckler A, Jones C (2021) Water for life—investigating water as a global issue. Publication of Geography Teachers' Association of Victoria Inc. (Global Education Project Victoria), Australia

Atwood DA (2010) Radionuclides in the environment. Encyclopedia of Inorganic Chemistry, JohnWiley & Sons, Chichester

Atzori P, Ferla P, Paglionico A, Piccarreta G, Rottura A (1984) Remnants of the Hercynian orogen along the Calabrian Peloritan Arc (Southern Italy): a review. J Geol Soc London 141:137–145

Baeza A, Del Rio M, Jimenez A, Miro C, Paniagua J (1995) Influence of geology and soil particle size on the surface-area/volume activity ratio for natural radionuclides. J Radioanal Nucl Chem 189(2):289–299

Caridi F, D'Agostino M, Marguccio S, Belvedere A, Belmusto G, Marcianò G, Sabatino G, Mottese A (2016a) Radioactivity, granulometric and elemental analysis of river sediments samples from the coast of Calabria, south of Italy. Eur Phys J plus 131:136

Caridi F, Marguccio S, D'Agostino M, Belvedere A, Belmusto G (2016b) Natural radioactivity and metal contamination of river sediments in the Calabria region, south of Italy. Eur Phys J plus 131:155

Caridi F, D'Agostino M, Belvedere A, Marguccio S, Belmusto G (2016c) Radon radioactivity in groundwater from the Calabria region, south of Italy. J Inst 11(5):P05012

Caridi F, D'Agostino M, Belvedere A, Marguccio S, Belmusto G, Gatto MF (2016d) Diagnostics techniques and dosimetric evaluations for environmental radioactivity investigations. J Inst 11(5):C10012

Caridi F, Marguccio S, Belvedere A, Belmusto G, Marcianò G, Sabatino G, Mottese A (2016e) Natural radioactivity and elemental composition of beach sands in the Calabria region, south of Italy. Environ Earth Sci 75(7):1–7

Caridi F, Belmusto G (2019) Overview of the technologies for assessment of natural radioactivity in drinking water. J Inst 14:T02002

Caridi F, D'Agostino M (2020) Evaluation of drinking water radioactivity content and radiological risk assessment: a new methodological approach. J Inst 15:P10016

Caridi F, Messina M, D'Agostino M (2017) An investigation about natural radioactivity, hydrochemistry and metal pollution in groundwater from Calabrian selected areas, southern Italy. Environ Earth Sci 76:668

Caridi F, Di Bella M, Sabatino G, Belmusto G, Fede MR, Romano D, Italiano F, Mottese AF (2021) Assessment of natural radioactivity and radiological risks in river sediments of Calabria (southern Italy). Appl Sci 11(4):1729

Cooper JR, Randle K, Sokhi RS (2003) Radioactive releases in the environment. Impact and Assessment. John Wiley & Sons, Chichester

Davila Rangel JI, Lopez del Rio H, Rodriguez BL, Solache-Rios BM (2001) Gross alpha and gross beta radioactivity in drinking water from Zacatecas and Guadalupe cities, Mexico. J Radioanal Nucl Chem 247:425–428

EML (Environmental Measurements Laboratory) (1990) EML Procedures Manual. Department of Energy, New York

Ho PL, Hung LD, Minh VT, Chinh DV, Thanh TT, Tao CV (2020) Simultaneous determination of gross alpha/beta activities in groundwater for ingestion effective dose and its associated public health risk prevention. Sci Rep 10:4299

Kansaana C, Darko EO, Schandorf C (2012) Determination of natural radioactivity in saline water and salt from Panbros salt industry limited in the Accra metropolis, Ghana. Int J Sci Technol 2(3)

Italian Legislation (1995) D. Lgs. n. 230 and successful modifications

Italian Legislation (2016) D. Lgs. n. 28

Moreno V, Bach J, Baixeras C, Font L (2014) Radon levels in groundwaters and natural radioactivity in soils of the volcanic region of La Garrotxa. Spain J Environ Radioact 128:1–8

Ogundare FO, Adekoya OI (2015) Gross alpha and beta radioactivity in surface soil and drinkable water around a steel processing facility. J Rad Res Appl Sci 8(3):411–417

Oluyide SO, Tchokossa P, Orosun MM (2019) Natural radioactivity and radiological impact assessment of soil, food and water around iron and steel smelting area in Fashina village, Ile-Ife, Osun state. Nigeria J Appl Sci Environ Manage 23(1):135–143

Osmond JK, Cowart JB (1976) The theory and uses of natural uranium isotopic variations in hydrology. At Energy Rev 14:621–679

Perkin-Elmer Tri-Carb 4910 TR Low Activity Liquid Scintillation Counter Manual (2009)

Torrisi L, Caridi F, Margarone D, Giuffrida L (2008) Nickel plasma produced by 532-nm and 1064-nm pulsed laser ablation. Plasma Phys Rep 34(7) 547–554

Torrisi L, Visco AM, Campo N, Caridi F (2010) Pulsed laser treatments of polyethylene films. Nucl Instr Meth Phys Res B 268(19):3117–3121

Turhan S (2020) The natural radioactivity in drinking water by gross alpha and beta measurements and radiological quality assessment. Radiochim Acta 108(6):491–498

Tzortzis M, Tsertos H, Christofides S, Christodoulides G (2003) Gamma-ray measurements of naturally occurring radioactive samples from Cyprus characteristic geological rocks. Radiat Meas 37(3):221–229

UNI EN ISO 9696–9697:2019

Vallejos A, Andreu JM, Sola F, Pulido-Bosch A (2015) The anthropogenic impact on Mediterranean karst aquifers: cases of some Spanish aquifers. Environ Earth Sci 1–14

Velis M, Conti KI, Biermann F (2017) Groundwater and human development: synergies and trade-offs within the context of the sustainable development goals. Sustain Sci 12:1007–1017

Von Gunten HR (1995) Radioactivity: a tool to explore the past. Radiochim Acta 70(71):305–316