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ASSESSMENT OF ^{226}Ra, ^{228}Ra AND ^{210}Pb CONCENTRATION IN MINERAL WATERS FROM PARQUE DAS ÁGUAS DE LAMBARI AND CONTENDAS – MG AND EVALUATION OF THE COMMITTED EFFECTIVE DOSES

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ABSTRACT

The exploration of several Brazilian hydromineral resorts, that have springs of radioactive mineral water consumed by the population support the relevance of the present work. This study is being developed in the IPEN with the aid of the responsible for Parque das Águas de Lambari and Contendas. Thereby, this work aims to determine the activity concentrations of ^{226}Ra, ^{228}Ra and ^{210}Pb to verify the influence of seasonality in these water parks springs. Thereunto, gross alpha and beta measurements were used after radiochemical separation for these radionuclides determination and measurement in a low background proportional detector. The results showed that Parque das Águas de Lambari presented highest concentration values when compared with Contendas. In Parque das Águas de Contendas , the highest concentration values were 77 ± 5 mBq/L and 129 ± 5 mBq/L for ^{226}Rafor Gasosa II springs and ^{228}Ra for Gasosa I spring, respectively, which correspond to the spring season; for ^{210}Pb, 27 ± 2 mBq/L for Magnesiana spring in the same season. In Parque das Águas de Lambari, the highest concentration values for ^{226}Ra was 177 ± 2 mBq/L and for ^{210}Pb, 36 ± 2 mBq/L, both in the Magnesiana spring, for the summer season and 135 ± 5 mBq/L for ^{228}Ra, in Magnesiana spring, for the spring season. The data were analyzed through descriptive and correlational statistical techniques. Therefore, it was possible to evaluate the committed effective doses due to the consumption of these waters and to assess the radiological risk for the radionuclides studied.

Keywords: Mineral Water, Natural Radionuclides, Seasonality, Committed effective doses, Lambari, Contendas.

1. INTRODUCTION

Mineral water, according to the Brazilian Law Nº 7.841 of August 8, 1945 [3], "are those from natural springs or springs artificially captured that have chemical composition or physical or physicochemical properties other than ordinary waters, with characteristics that give them a drug action". In this same law, mineral waters can be classified according to their chemical composition in: oligomineral, radiferous, alkaline-bicarbonated, alkaline-earthy, sulfated, sulphurous, nitrated, chlorinated, ferruginous, radioactive, thorioactive and carbogasous.

The natural radioactivity of the water comes from the radioactive elements dissolved therein and the gases from some radioactive elements diffused from the underground rocks. These radioactive elements can be carried away by underground currents, but not all can be determined in the emergence of the springs [2].

When considering the geochemistry of the natural radionuclides in the aquatic environment, the elements of greatest interest from the point of view of health risk are radium, radon and uranium isotopes, since these have higher solubilities. The thorium isotopes and radionuclides ^{210}Pb and ^{210}Po have particle-reactive behavior and are at lower concentration levels than the previous ones, although, except for the specific cases where there is a high concentration of organic material in suspension [17].

Many studies are conducted in regions of high natural radioactivity to verify the possible biological effects on human health from prolonged exposure to low doses of ionizing radiation. This is mainly due to the incorporation of natural radionuclides from the ^{238}U and ^{232}Th series which have relatively long half-lives. In some places, the levels of ^{238}U and ^{232}Th present in soil and in mineral deposits are high and through physical and chemical mechanisms of dissolution and leaching these radionuclides pass to the groundwater that can emerge with a considerable activity of these elements [17].

As several springs of mineral and thermal waters have relatively high concentrations of ^{226}Ra and ^{222}Rn originally dissolved [13] and are used worldwide due to their therapeutic properties, the estimation of possible adverse effects on human health that may occur because of the ingestion or inhalation of the radioactive substances present in these waters are of great importance in the context of Radiological Protection [8]. Thus, in a number of countries these practices have been evaluated and reviewed as a result of the lack of proven scientific evidence of the dose-effect relationship at low levels of ionizing radiations [8].

High concentrations of ^{222}Rn and its short half-life decay products have been detected in Spas that use radioactive mineral waters and in only a few countries estimates have been made of the doses received by patients attending in these places and individuals occupationally exposed. This concern is a consequence of the high rate of cancer cases observed in the 1980 decade in workers in underground coal and uranium mines due to prolonged exposure to ^{222}Rn [8].

It should be emphasized, however, that in relation to therapeutic practices based on water intake, immersion thermal baths and the use of medical muds, radionuclides ^{238}U, ^{234}U, ^{226}Ra, ^{210}Pb, ^{210}Po, ^{228}Ra, ^{230}Th and ^{232}Th, when present, are of relevant importance, since they contribute in large part to the internal and external irradiation of individuals. However, ^{222}Rn is that often contributes most to the effective dose in man and to the risk of cancer arising from these activities because it is generally present at much higher levels when compared to the other radionuclides.

Since the human diet is the main source of absorption of natural radioactivity and its internal exposure, this practice significantly increases the probability of ingestion of high concentrations of natural radionuclides dissolved therein, mainly of decay products of the radioactive series of uranium and thorium [12].
In several Brazilian hydromineral resorts, springs of radioactive mineral water are commercially exploited and are consumed by the population that believes this practice is

beneficial. For example, in thermal parks like Caxambu, Cambuquira, São Lourenço and Lambari (MG), the waters of the various springs are used for human consumption and are often associated with medicinal use, like diuretic and cathartic waters (with properties of cleaning, purification, facilitating hepato-biliary functions and stimulating intestinal function directly or indirectly), and waters with antiphlogistic properties (anti-inflammatory).

Until today, there are no scientific studies that prove the effectiveness of the use of these radioactive waters in health treatments conducted in spas, and there is only empirical evidence of the benefit of using them in medical chronology.

Therefore, due to the recommendation of these waters as a form of treatment spent in spas, the present work was developed in Centro de Radiometria Ambiental - IPEN, with the aid of those responsible for the spas of Lambari and Águas de Contendas and, with the objective of determine the levels of activity of ^{226}Ra, ^{228}Ra and ^{210}Pb present in the waters of Parque das Águas of Lambari and Águas de Contendas.

2. METHODS

2.1. Study Area

The study area of this work is located in the cities of Lambari and Conceição do Rio Verde, in the Parque das Águas of Lambari and Águas de Contendas, respectively. The cities of Lambari e Conceição do Rio Verde are part of the Water Circuit in the Minas Gerais state (Circuito das Águas do Estado de Minas Gerais), formed by the cities of Baependi, Cambuquira, Campanha, Carmo de Minas, Caxambu, Conceição do Rio Verde, Lambari, São Lourenço, Soledade de Minas e Três Corações [6].

The climate of both cities is classified as tropical climate of altitude. The Parque das Águas of Lambari is located in Lambari downtown and has six mineral water springs coming from Mantiqueira ridge. The mineral water springs are called: Spring 1 - gasosa, Spring 2 - alcalina, Spring 3 - magnesiana, Spring 4 – ligeiramente gasosa, Spring 5 - ferruginosa and Spring 6 - sulforosa. The Parque das Águas of Águas de Contendas is located 7 km from the city and has three mineral water springs called: Spring 1 - gasosa, Spring 2 - ferruginosa and Spring 3 - magnesiana [6].

The mineral water springs of Lambari, Cambuquira and Marimbeiro have been known since the XVIII century, when the inhabitants and doctors of the cities of São Paulo and Rio de Janeiro proved the qualities of the waters in the cure of diseases of digestive and urinary tracts and liver [1].

The springs of groundwater are derived from a rocky substrate composed of granatiferous schists with intercalation of gneisses and muscovite quartzites. In the hydromineral occurrences the rocks are saprolized and covered by alluvial sediments superimposed by a layer of organic clay of approximately 5,0 m [6], [7].

Inside the parks, water abstractions are in fountains and they are relatively close to each other. The springs have different depths and free flow rate.

2.2. Sampling

The water samples were collected during the spring, summer and autumn seasons in nine mineral water springs into the Parque das Águas of Lambari and Águas de Contendas. Two samples of drinking water were also collected in both cities. In autumn sampling, a spring of mineral water outside the Parque das Águas of Lambari was sampled for the analysis, which supplies free water to the local population. Thereby, 34 samples containing 10 L each one were collected in total to carrying out the analytical methods.

Before the sampling, the pH was adjusted to ≤ 2,0 with 50 % HNO_3 for the preservation of the samples and avoid the adsorption of the radionuclides by the polyethylene bottles. In general, the samples preserved in this way remain stable for several months (Smithson, 1990). The temperature measurement was performed *in situ* and pH in the laboratory.

2.3. Analytical Methods

The analytical methods used were gross alpha and beta measurements after sequential radiochemical separation for the radionuclides ^{226}Ra, ^{228}Ra and ^{210}Pb with determination in a low background proportional detector [11], [15].

The analyzes were performed in duplicate, with the water samples from each spring being concentrated from 2 L to 1 L. Stable Ba and Pb carriers and H_2SO_4 (3 mol L^{-1}) were added under heating and stirring for precipitation of $(BaRaPb)SO_4$. The supernatant is then discarded and the precipitate centrifuged.

Nitrile tri-acetic acid – NTA (Titriplex I), superpure water and 7 mL of NaOH (6 mol L^{-1}) were added to the precipitate at basic pH with heating until solubilization. Subsequently, $(NH_4)_2SO_4$ (25 g L^{-1}) was added, at acidic pH, for the precipitation of Ba, ^{226}Ra and ^{228}Ra while ^{210}Pb remained in the supernatant complexed with NTA. The supernatant is reserved.

Therefore, for ^{226}Ra and ^{228}Ra determination, ethylene di-amino-tetra-acetic acid – EDTA (Triplex III) is added to the precipitate, also at basic pH with heating, until its solubilization. Subsequently, $(NH_4)_2SO_4$ (25 g L^{-1}), at acidic pH, was added to the precipitation of $Ba(Ra)SO_4$. The solution was vacuum filtered with glass fiber paper and the chemical yield of the procedure was determined gravimetrically.

^{226}Ra and ^{228}Ra were determined after 21 days of precipitation, by the total alpha and total beta measurement of the $Ba(Ra)SO_4$, respectively, precipitate in a low background radiation proportional gas detector [11].

For ^{210}Pb determination, the supernatant obtained in the previous phase containing the lead complexed with the NTA was used and the Na_2S solution (1 mol L^{-1}) was added to precipitate the ^{210}Pb in the form of sulfide. The supernatant was discarded and the precipitate solubilized with concentrated HNO_3. 30% Na_2CrO_4 was added for the precipitation of $PbCrO_4$, under heating. The solution was vacuum filtered with glass fiber paper and the chemical yield of the procedure was determined gravimetrically.

^{210}Pb was determined after 10 days of precipitation, by the total beta measurement of the precipitate of $PbCrO_4$ in a low background radiation proportional gaseous detector [15].

The detection limit of the radionuclides, using this methodology, is for ^{226}Ra 2.2 ± 0.2 mBq/L, for ^{228}Ra 3.7 ± mBq/L and for ^{210}Pb 4.9 ± mBq/L.

2.3.1. Committed effective doses

Committed effective doses were evaluated due to the ingestion of mineral waters from the Parque das Águas of Lambari and Águas de Contendas containing the natural radionuclides studied in the work, ^{226}Ra, ^{228}Ra and ^{210}Pb. The committed effective doses were integrated in a time interval corresponding to 70 years of the life of an adult, after the incorporation of the radioactive material [10] and were determined by the expression (1):

$$H_e = C_n \, x \, I \, x \, FCD_e \quad (1)$$

Where,
H_e = committed effective dose, in mSv/ y
C_n = concentration of radionuclide n activity in drinking water, in mBq/ L
I = water intake rate, in liters per year, in 730 L/ y [16]
FCD_e = dose conversion factor for radionuclide, n, ingestion, in Sv/ Bq

The values of the dose conversion factors for radionuclides were extracted from the recommendations of the ICRP and CNEN [5], [10].

In cases where the radioactivity quality standards of the waters were exceeded, compliance with the limits established by the Comissão Nacional de Energia Nuclear – CNEN [5] standard for the ingestion of radionuclides of interest was established.

The standard "Basic Guidelines for Radiological Protection" [4] establishes as the primary annual effective dose limit for individuals of the public the value of 1 mSv. Thereby the World Health Organization [17], CNEN-NN-3.01 [4] uses as reference parameter the calculation of the effective dose involved. In this way, compliance with the limits, dose restrictions and reference levels adopted by the International Commission on Radiological Protection [9] can be verified. The dose coefficients adopted for the exposure of individuals to the public were tabulated in the position regulatory framework [5].

3. RESULTS AND DISCUSSION

The values of pH and temperature obtained in the water samples of the Parque das Águas of Lambari and Águas de Contendas for the three seasons of the year under study are shown in Table 1.

For the temperature and pH the range obtained varied from 21°C to 23°C and from 4.70 to 5.41 in Parque das Águas of Lambari and varied from 21°C to 24°C and from 5.09 to 5.97 in Parque das Águas of Águas de Contendas, respectively, considering also the samples of the three seasons of the year collected. This allowed them to be classified as cold natural water springs (below 25°C) [3].

Table 1: pH and temperature (°C) of the mineral waters from Parque das Águas of Lambari and Águas de Contendas

		Spring 2016		Summer 2017		Autumn 2017	
	Samples	pH	T(°C)	pH	T(°C)	pH	T(°C)
Águas de Contendas	Ferruginosa	5.37	22	5.38	21	5.44	21
	Magnesiana	5.97	23	*	*	5,73	22
	Gasosa I	5.09	24	5.33	22	5.21	21
	Gasosa II	5.54	22	5.45	21	5.44	21
	Potável	7.60	22	7.76	26,5	**	21
Lambari	Alcalina	4.79	23	4.97	21	4.82	21
	Magnesiana	4.78	22	5.00	23	4.94	21
	Gasosa	4.70	23	4.97	22	5.41	22
	Ligeiramente Gasosa	4.75	22	5.14	22	4.85	22
	Picante	5.30	23	5.19	23	5.35	21
	Potável	6.95	23	7.22	24	7.30	20
	Fonte Externa	**	**	**	**	5.10	21,5

* Dry spring
** Uncollected sample

However, the collected drinking water gives higher temperature and pH with the range obtained varied from 20°C to 24°C and from 6.95 to 7.30 in Parque das Águas of Lambari and varied from 21°C to 26.5°C and from 7.60 to 7.76 in Parque das Águas of Águas de Contendas, respectively, but their values were not considered because these waters are treated for distribution to the population.

Table 2 shows the concentrations in mBq/L and their respective standard deviations of the radionuclides ^{226}Ra, ^{228}Ra and ^{210}Pb of the mineral waters from Parque das Águas of Lambari and Águas de Contendas collected in the spring of 2016, summer of 2017 and autumn of 2017. It was observed that in both water parks the concentrations of the studied natural radionuclides differed in the three collections performed. In the majority of the samples, the radionuclides with the highest concentrations were ^{226}Ra and ^{228}Ra.

In Parque das Águas of Lambari the highest concentrations values obtained were 189 ± 9 mBq/L in autumn for ^{226}Ra in Gasosa spring, 135 ± 10 mBq/L in spring for ^{228}Ra in Magnesiana spring, and 36 ± 2 mBq/L in summer for ^{210}Pb in Magnesiana spring. On the other hand, the lowest concentrations values obtained for the same water samples were 87 ± 15 mBq/L in summer for ^{226}Ra in Ligeiramente Gasosa spring, 44 ± 5 mBq/L in spring for ^{228}Ra in Gasosa spring, and 9 ± 2 mBq/L in spring for ^{210}Pb in Picante spring.

In Parque das Águas of Águas de Contendas the highest concentrations values obtained were 77 ± 5 mBq/L in spring for ^{226}Ra in Gasosa II spring, 129 ± 11 mBq/L in spring for ^{228}Ra in Gasosa I spring, and 30 ± 2 mBq/L in autumn for ^{210}Pb in Magnesiana spring. On the other hand, the lowest concentrations values obtained for the same water samples were 20 ± 3 mBq/L in spring for ^{226}Ra in Magnesiana spring, 11 ± 5 mBq/L in auttumn for ^{228}Ra in Gasosa II spring, and 11 ± 1 mBq/L in spring for ^{210}Pb in Gasosa I spring.

Table 2: Concentration of ^{226}Ra, ^{228}Ra and ^{210}Pb in mineral water samples from the Parque das Águas of Lambari and Águas de Contendas

		Spring 2016			Summer 2017			Autumn 2017		
	Samples	Ra-226 mBq/L ± δ	Ra-228 mBq/L ± δ	Pb-210 mBq/L ± δ	Ra-226 mBq/L ± δ	Ra-228 mBq/L ± δ	Pb-210 mBq/L ± δ	Ra-226 mBq/L ± δ	Ra-228 mBq/L ± δ	Pb-210 mBq/L ± δ
Águas de Contendas	Ferruginosa	24 ± 4	57 ± 7	15 ± 6	22 ± 1	67 ± 1	15 ± 7	34 ± 3	*	19 ± 1
	Magnesiana	20 ± 3	45 ± 3	27 ± 2	**	**	**	20 ± 4	*	30 ± 2
	Gasosa I	68 ± 2	129 ± 11	11 ± 1	69 ± 5	123 ± 5	14 ± 2	49 ± 3	97 ± 5	24 ± 2
	Gasosa II	77 ± 5	127 ± 5	19 ± 2	45 ± 1	106 ± 6	12 ± 2	60 ± 1	11 ± 5	26 ± 2
	Potável	16 ± 2	*	1 ± 1	13 ± 1	59 ± 4	13 ± 2	21 ± 4	*	33 ± 2
Lambari	Alcalina	151 ± 3	72 ± 5	25.0 ± 0.3	171 ± 5	110 ± 6	14 ± 4	162 ± 2	119 ± 3	20 ± 6
	Magnesiana	141 ± 4	135 ± 10	34 ± 7	177 ± 2	72 ± 1	36 ± 2	164 ± 3	84 ± 5	30 ± 9
	Gasosa	163 ± 4	44 ± 5	26 ± 2	155 ± 3	127 ± 5	27.2 ± 0.4	189 ± 9	34 ± 2	19 ± 3
	Ligeiramente Gasosa	118 ± 15	37 ± 5	20 ± 4	87 ± 15	96 ± 10	32 ± 3	113 ± 14	65 ± 5	18 ± 8
	Picante	101 ± 13	91 ± 5	9 ± 2	118 ± 3	36 ± 4	18 ± 3	104 ± 7	29 ± 11	14 ± 6
	Potável	5 ± 2	87 ± 2	8 ± 1	5.1 ± 0.4	52 ± 6	0.33 ± 0.02	5.9 ± 0.2	50 ± 3	3 ± 4
	Fonte Externa	***	***	***	***	***	***	136 ± 13	59 ± 13	26 ± 1

* Below detection limit
** Dry spring
*** Uncollected sample

^{226}Ra, ^{228}Ra and ^{210}Pb concentrations determined in the drinking water of the Parque das Águas of Lambari ranged from 5 ± 2 mBq/L to 5.9 ± 0.2 mBq/L, 50 ± 3 mBq/L to 87 ± 2 mBq/L and 0.33 ± 0.02 mBq/L to 8 ± 1 mBq/L, respectively. In the Parque das Águas of Águas de Contendas ranged from 13 ± 1 mBq/L to 21 ± 4 mBq/L, < 3.7 ±0.1 mBq/L to 59 ± 4 mBq/L and 1.2 ± 0.8 mBq/L to 33 ± 2 mBq/L, respectively. In the majority of drinking water samples the concentration values obtained were lower than those of mineral water springs, due to the treatment that the water suffers to be distributed to the public supply.

Figure 1 shows the variation of the concentration of the radionuclides studied in the present work in all springs of the two water parks in the three seasons analysis. Thus, it was possible to observe that for the ^{226}Ra and ^{228}Ra radionuclides that presented higher concentration in both water parks, this increase was predominantly observed in the spring season. However, the lowest concentrations for the same radionuclides oscillated between the three seasons under study, and it was not possible to observe a concentration pattern.

Therefore, due to the lack of studies in springs of the Parque das Águas of Águas de Contendas, the comparison of the results was only possible with samples from the Parque das Águas of Lambari, which were also studied by Bonotto [7]. Using alpha spectrometry the above mentioned author determined the concentrations of ^{226}Ra and ^{228}Ra in the water springs of the Parque das Águas of Lambari and obtained a variation of 41.8 ± 41.8 mBq/L at 448.9 ± 156.6 mBq/L and 106.6 ± 4.5 mBq/L at 237.6 ± 5.5 mBq/L, respectively. The values obtained by Bonotto [7] were higher than those determined by the present work in the Parque das Águas of Lambari.

The results obtained for the concentrations of ^{226}Ra and ^{228}Ra radionuclides of the present work were also compared with those obtained by Negrão [14], using the same methodology in the summer of 2011 that studied the mineral water springs of the Parque das Águas of Caxambu. The concentration values obtained by above mentioned author varied from 83 ± 7 mBq/L to 3599 ± 147 mBq/L for ^{226}Ra and from 60 ± 7 mBq/L to 4487 ± 129 mBq/L for ^{228}Ra, which are much larger than those determined by the present study.

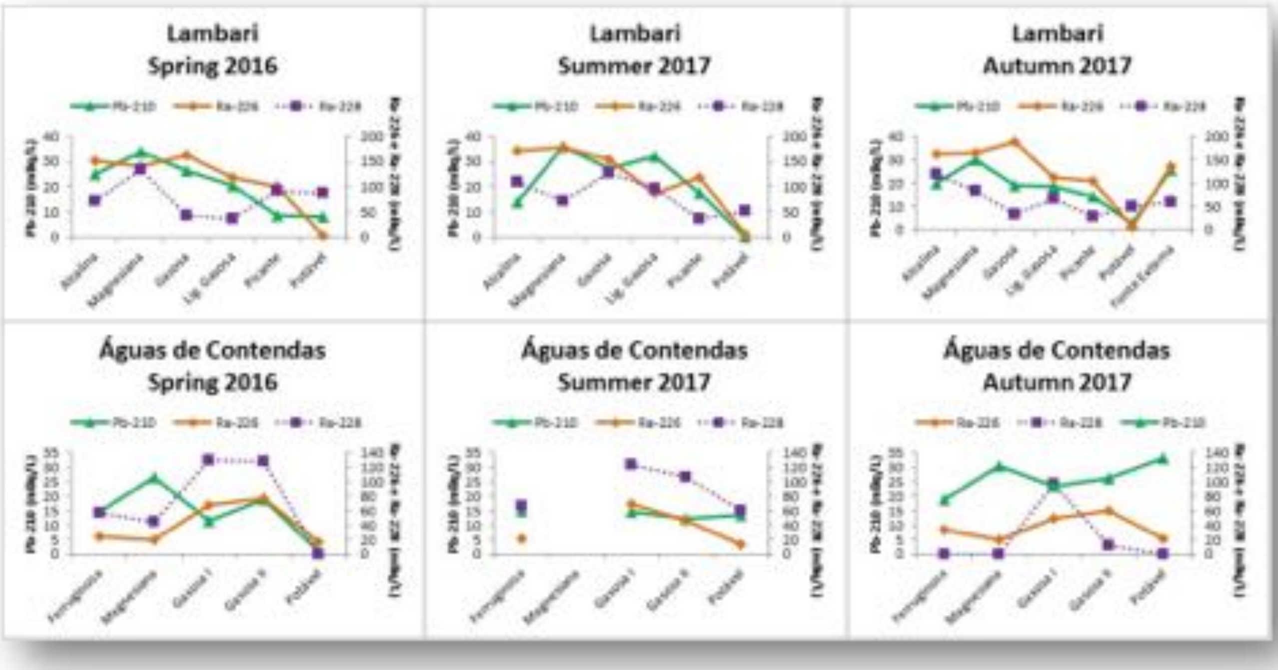

Figure 1: Concentration of ^{226}Ra, ^{228}Ra and ^{210}Pb in water samples from the Parque das Águas of Lambari and Águas de Contendas

Table 3 shows the committed effective dose in mSv/y of the ^{226}Ra, ^{228}Ra and ^{210}P radionuclides of the Lambari and Águas de Contendas mineral water samples collected in the three seasons under study. It was observed that in both water parks the committed effective dose obtained was differed in the both collections performed.

In most of the samples, the radionuclide with the highest value of committed effective dose obtained in Parque das Águas of Lambari was 0,089 mSv/y in summer for ^{226}Ra in Magnesiana spring, and in the Parque das Águas of Águas de Contendas was 0,064 mSv/y in spring for ^{228}Ra in Gasosa II spring. On the other hand, the lowest committed effective dose values obtained for the same mineral water sample in Parque das Águas of Lambari was 0,004 mSv/y in three seasons for ^{226}Ra in Magnesiana and Ferruginosa springs.

Table 3: Committed effective dose for water sample from the Parque das Águas of Lambari and Águas de Contendas

	Samples	Spring 2016 Ra-226 mSv/y	Spring 2016 Ra-228 mSv/y	Spring 2016 Pb-210 mSv/y	Summer 2017 Ra-226 mSv/y	Summer 2017 Ra-228 mSv/y	Summer 2017 Pb-210 mSv/y	Autumn 2017 Ra-226 mSv/y	Autumn 2017 Ra-228 mSv/y	Autumn 2017 Pb-210 mSv/y
Águas de Contendas	Ferruginosa	0.005	0.029	0.007	0.004	0.034	0.0075	0.007	*	0.009
	Magnesiana	0.004	0.023	0.013	**	**	**	0.004	*	0.015
	Gasosa I	0.016	0.056	0.006	0.014	0.062	0.0073	0.010	0.049	0.012
	Gasosa II	0.016	0.064	0.010	0.006	0.061	0.0072	0.012	0.006	0.013
	Potável	0.003	*	0.001	0.003	0.030	0.0067	0.004	*	0.017
Lambari	Alcalina	0.046	0.058	0.012	0.061	0.055	0.0070	0.033	0.060	0.010
	Magnesiana	0.029	0.068	0.017	0.089	0.036	0.0182	0.034	0.042	0.015
	Gasosa	0.037	0.022	0.016	0.078	0.064	0.0155	0.039	0.017	0.010
	Ligeiramente Gasosa	0.024	0.019	0.010	0.044	0.070	0.0162	0.023	0.033	0.009
	Picante	0.021	0.046	0.004	0.059	0.018	0.0089	0.021	0.014	0.007
	Potável	0.001	0.037	0.002	0.003	0.026	0.0002	0.001	0.025	0.001
	Fonte Externa	***	***	***	***	***	***	0.031	0.036	0.013

* Below detection limit
** Dry spring
*** Uncollected sample

The values of committed effective dose obtained for the drinking water for the both water parks were lower than those of majority mineral water springs, due to the treatment that the water suffers to be distributed to the public supply.

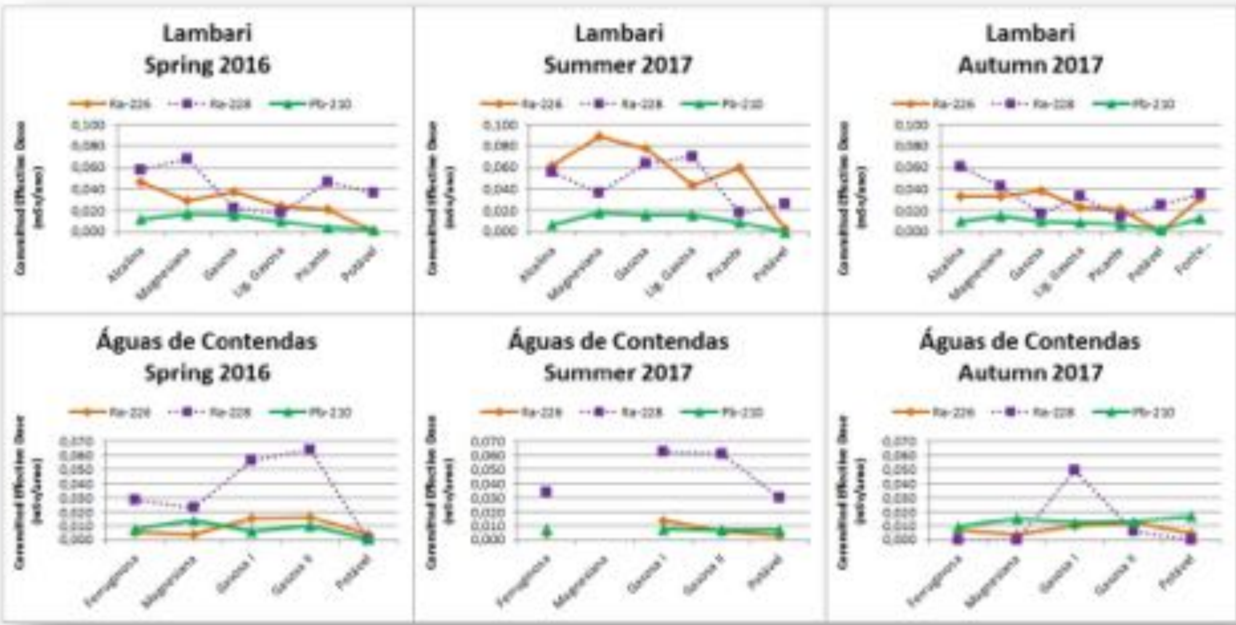

Figure 2: Committed effective dose in the water samples from the Parque das Águas of Lambari and Águas de Contendas

The results obtained for Parque das Águas of Lambari were compared with Bonotto [7] that also studied the mineral waters of this park. In his work, the author found values of ^{226}Ra and ^{228}Ra for the committed effective dose varying from 0.01 mSv/y to 0.09 mSv/y and 0.054 mSv/y to 0.120 mBSv/y, respectively, results that are higher than those determined in the present work. The same can be observed when a comparison is made with Negrão [14] that studied the mineral water springs of the Parque das Águas of Caxambu, where the values for the committed effective dose of ^{226}Ra and ^{228}Ra varied from 0.017 mSv/y to 0.74 mSv/y for ^{226}Ra and from 0.029 mSv/y to 0.90 mSv/y for ^{228}Ra, which are much larger than those determined in the present study.

4. CONCLUSIONS

In this work the natural radionuclides ^{226}Ra, ^{228}Ra and ^{210}Pb concentrations were determined in the springs from Parque das Águas of Lambari and Águas de Contendas, cities that belong to the Circuito das Águas de Minas Gerais.

The radionuclide that presented the highest concentration in Parque das Águas of Águas de Contendas was ^{228}Ra in the majority of the springs and in Parque das Águas de Lambari was ^{226}Ra, also in the majority of the springs.

The highest concentration values for the three radionuclides studied were obtained in the spring in both parks and hence, the highest committed effective dose values were obtained in the same season. However, the comparison of the results obtained in the present work and those obtained by Negrão [14], show that although Lambari has higher concentrations and committed effective dose for radionuclides ^{226}Ra and ^{228}Ra than Águas de Contendas, their values are much lower than those obtained by Bonotto [7] for the waters of Lambari and by Negrão [14] who studied the springs of the Parque das Águas of Caxambu.

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