



Analysis of Lead-210 in Surface Water nearby a Phosphate Mining at Semi-arid Region in Santa Quitéria, Ceará State, Brazil

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Authors' contributions

This work was carried out in collaboration between all authors. Author WSP designed the study, managed the analyses of the study, wrote the protocol, draft and final version. Author AK wrote the protocol and the first draft of the manuscript, final and english version. Authors MVBM and RSA performed sampling collections, chemistry analysis and statistical analysis. Authors JMF and DSGS managed the literature searches, samples collections and chemistry analysis. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To report the activity concentrations (AC) of ²¹⁰Pb in surface waters in a semi-arid region, aiming to record these concentrations before the beginning of a Naturally Occurring Radioactive Material (NORM) mining operation, facilitating subsequent comparisons with the operational phase besides verifying the radioecological characteristics of this radionuclide and the potability of the water used for human consumption by the local population.

Study Design: The water samples were collected in a six points grid associated to places of human consumption, aiming to verify their radioecological characteristics and radiological potability.

Place and Duration of Study: The study site was a semi-arid region associated to a NORM phosphate deposit, between October 2009 and December 2011. No collection occurred in January and February 2010, accounting for 25 collections and 50 analyzes (soluble and particulate) per point.

Methodology: 1 L of water, per point, was collected acidulated and filtered. The filtrate was considered as the soluble fraction and the retained part as the particulate fraction. The ^{210}Pb was separated by coprecipitation and analyzed by total beta counts. Data were analyzed by univariate and multivariate statistical methods and the values found were compared with international potability standards.

Results: The values found were within the international recommendations of ingestion of ^{210}Pb in water (mean value of $0.05 \text{ Bq}\cdot\text{l}^{-1} < \text{recommended of } 0.1 \text{ Bq}\cdot\text{l}^{-1}$). Radionuclide radioecology proved to be complex. The total AC of ^{210}Pb (sum of the soluble and particulate fractions) showed no difference between points, ranging from $0.05 \text{ Bq}\cdot\text{l}^{-1}$ at point 01SQ to $0.10 \text{ Bq}\cdot\text{l}^{-1}$ at point 04SQ. But when the AC of the fractions were analyzed, it could be verified that the AC of the particulate fraction were systematically higher than that of the soluble fraction.

Conclusion: The analyzed water, in relation to the activity concentration of ^{210}Pb , is considered potable and the particulate fraction has higher AC than the soluble fraction. The characterization of the water must be complemented when entering the operation of the phosphate mine to verify the radiological environmental impact assessment of the enterprise.

Keywords: Pb-210; Santa Quitéria; NORM; phosphate mining; individual dose criterion; water potability.

1. INTRODUCTION

Mining of minerals associated with uranium, known as Naturally Occurring Radioactive Material (NORM), exposes the local population and biota to increased radiation exposure. Mining of phosphate [1], titanium [2], rare earths and thorium [3], zirconium and zirconia [4], and cassiterite [5] among others are recognized as causing increased exposure.

Brazil has the world's sixth largest uranium reserves [6]. From the mid-1980s until the mid-1990s, these reserves were mined at the "Osamu Utsami" mine in the city of Caldas, state of Minas Gerais. From the beginning of the 2000s the exploration is being carried out in the waterfall mine known as "Cachoeira", in the city of Caetité, state of Bahia. Aiming at the continuation of uranium exploration, the next deposit in conditions of economic, technical and environmental feasibility is "Jazida Itataia", a phosphate deposit with associated uranium, in the City of Santa Quitéria, state of Ceará [7].

The latter mine, in phase of implantation, possesses phosphate reserves estimated at nine million tons of P_2O_5 with associated uranium estimated in 79,500 tons of U_3O_8 [8]. It is located

in a rather particular ecotone, an ecological transition zone between savanna and cerrado, two Brazilian ecosystems threatened with extinction [9].

One of the possible impacts of phosphate extraction may be the contamination of surface waters with phosphate, heavy metals and radionuclides. In semi-arid regions water management in quantity and quality (potability) is a vital variable for the local population that uses this resource without any treatment. This area has previously been studied, by Pereira et al. [9] focusing on the radioecology of radium (both ^{226}Ra and ^{228}Ra isotopes) in surface waters.

Following Brazilian law [10-13], areas with ore reserves associated with uranium and thorium needs to be accompanied by a radioecology evaluation and of a radiological environmental impact assessment (REIA) based on an environmental radiological monitoring program.

This study aims to evaluate the activity concentrations (AC) of ^{210}Pb in surface waters of the Santa Quitéria region, using statistical analytical tools with univariate and multivariate approaches and the potability of water view from the radiological point.

2. MATERIALS AND METHODS

2.1 Study Area

The study area is situated in the municipality of Santa Quitéria, state of Ceará, Brazilian semi-arid northeast, in the surroundings of the phosphate deposit with associated uranium and thorium (Fig. 1).

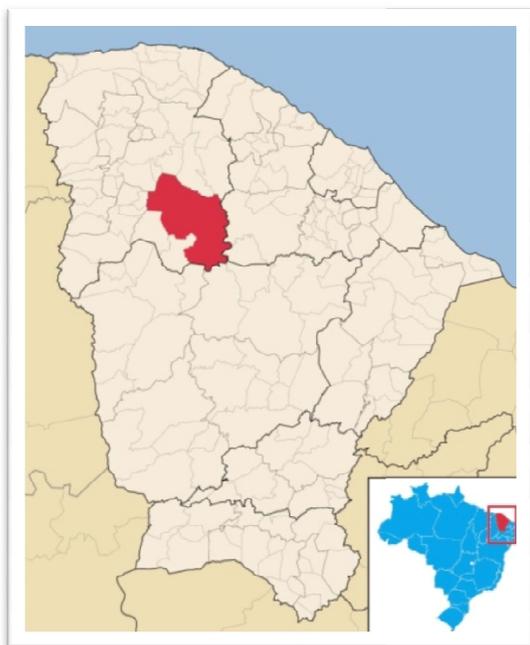


Fig. 1. Location of Santa Quitéria municipality in the state of Ceará, Brazil
(Adapted from Wikipedia)

2.2 Sample Collection and Preparation

The water samples were collected at six different points, (01SQ to 06SQ) as given in Table 1. One liter of surface water was collected at each point every month over a period of 25 months. They were acidified with 1 ml conc. HNO_3 , and then filtered on an acetate filter with porosity $0.45 \mu\text{m}$. The filtrate was considered the soluble fraction and the material retained onto the filter was considered the particulate fraction.

Table 1. Geographical locations of water collecting points in "UTM" coordinates

Points	UTM E	UTM N
01SQ	0408575	9495305
02SQ	0409766	9496141
03SQ	0415241	9496141
04SQ	0413784	9493155
05SQ	0410362	9494800
06SQ	0411850	9494292

2.3 Determination of ^{210}Pb

^{210}Pb was concentrated from water by selective coprecipitation. The precipitate was collected on a filter and then submitted to gross beta counting in a proportional counter, following Godoy et al. [14].

2.4 Sample Design and Data Organization

Data were arranged in a matrix, where the columns represent the combination of collecting points and fractions, and the rows the collection dates, creating a data matrix of 12×25 containing the 300 values of ^{210}Pb activity concentration analyzed for the sampled area.

2.5 Univariate Statistical Analysis

A descriptive statistics of data was performed that furnished the mean values, standard deviation, maximum value, and the number of samples. After that, a one-tailed Z test was carried out to compare the means of activity concentration between the soluble and particulate fractions [15]. Tested hypotheses were:

$H_0 =$ The means of the fractions are statistically identical

$H_1 =$ The means of the fractions are statistically different

Then two analyses of variance (ANOVA) were performed in the data matrix to identify the relationship between the average per point in total fraction and per point in soluble and particulate fraction [15], following the hypotheses:

$H_0 =$ All the means are statistically identical

$H_1 =$ There is at least one mean different

Observing a difference, the Fisher's test was performed for classifying means [15-17].

2.6 Multivariate Statistical Analysis

2.6.1 Principal component analysis

The evaluation of multiple data is always difficult to perform for different reasons. One way to solve these problems is the use of multivariate analysis techniques. Among such techniques, the Principal Component Analysis (PCA) is the most used. This technique employs a matrix arrangement of data and generates from this array a pair of orthogonal axes, where the data

are organized in function of parameters (factors) related on the variance of the data [18-19].

2.6.2 Cluster analysis

This analysis presents multiple data in groups based on data similarities and differences [18-19].

3. RESULTS AND DISCUSSION

3.1 Univariate Statistical Analysis

In the particulate fraction, the ^{210}Pb activity concentrations ranged from $0.0442 \text{ Bq}\cdot\text{l}^{-1}$ at point 03SQ to $0.0292 \text{ Bq}\cdot\text{l}^{-1}$ at point 05SQ, while in the soluble fraction, the highest activity concentration was observed for the same point (05SQ) with the same value $0.0292 \text{ Bq}\cdot\text{l}^{-1}$. Instead, the lowest activity concentration of the soluble fraction appeared at point 04SQ ($0.0099 \text{ Bq}\cdot\text{l}^{-1}$). For the total fraction, the value ranged from 0.05 to 0.10 $\text{Bq}\cdot\text{l}^{-1}$ at points 01SQ and 04SQ. Descriptive statistics is presented in Table 2, Fig. 2 for

soluble and particulate fraction and Fig. 3 for total fraction.

The Z test between all data from soluble and particulate fractions, regardless of the sampling point, with a Z value of 2.01 associated with a P value of 0.02, indicated H_0 as the rejected hypothesis, suggesting differences between the fractions. Thus, the mean activity concentration of the particulate fraction ($0.0334 \text{ Bq}\cdot\text{l}^{-1}$) was considered the highest as that of the soluble fraction ($0.0191 \text{ Bq}\cdot\text{l}^{-1}$).

A different conclusion occurred from the analysis of variance of the total fractions. With F_{cal} equal to 0.29 ($P = 0.92$) H_0 is accepted, suggesting equality between the AC of points. In this case, there are no points with different AC.

The ANOVA for fractions resulted in a different frame. In this case the calculated value of F (F_{cal}) was 1.33, with an associated P value of 0.021. Thus, H_0 was rejected, suggesting differences between the AC of fraction and point. A Fisher's test was thus carried out.

Table 2. Descriptive statistics of AC, for ^{210}Pb in surface waters in the region of Santa Quitéria ($\text{Bq}\cdot\text{l}^{-1}$)

Point	Soluble fraction		Particulate fraction		Total fraction		N
	Mean \pm st. dev.	Max.	Mean \pm st. dev.	Max.	Mean \pm st. dev.	Max.	
01SQ	0.013 ± 0.011	0.041	0.035 ± 0.031	0.118	$0,051 \pm 0,040$	0,159	25
02SQ	0.012 ± 0.011	0.037	0.032 ± 0.031	1.318	$0,093 \pm 0,256$	1,318	25
03SQ	0.020 ± 0.023	0.096	0.044 ± 0.040	0.167	0.080 ± 0.081	0.395	25
04SQ	0.010 ± 0.008	0.032	0.034 ± 0.033	0.114	0.097 ± 0.244	1.244	25
05SQ	0.029 ± 0.033	0.118	0.029 ± 0.028	0.104	0.076 ± 0.115	0.593	25
06SQ	0.019 ± 0.017	0.061	0.032 ± 0.031	0.107	0.067 ± 0.069	0.277	25

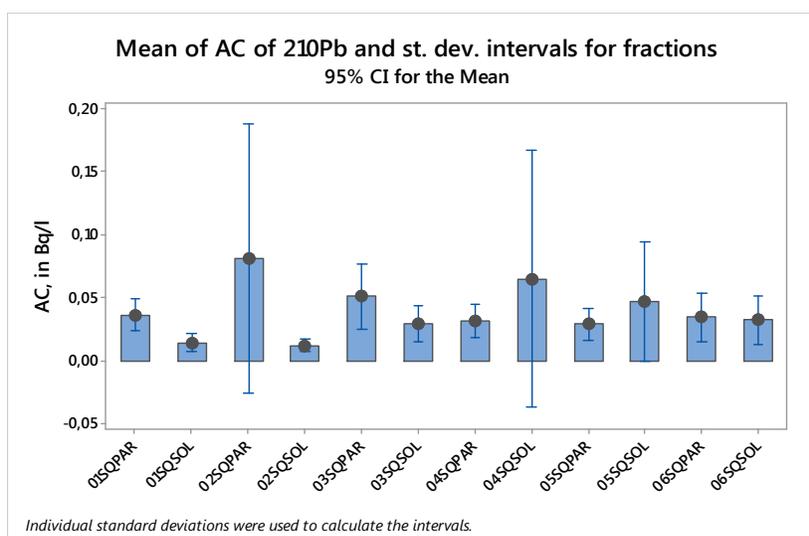


Fig. 2. Mean and intervals (st.dev.) for AC of ^{210}Pb in soluble (SOL) and particulate (PAR) fractions in surface water of Santa Quitéria region

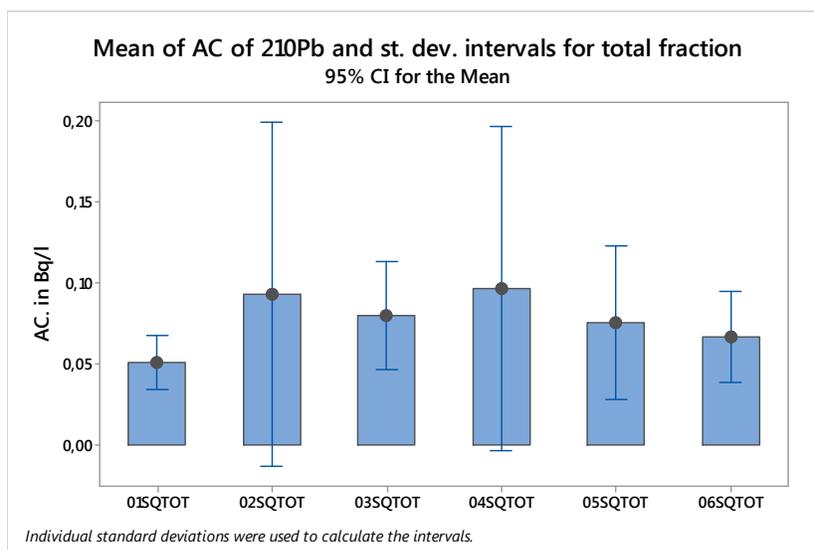


Fig. 3. Mean and intervals (st.dev.) for AC of ²¹⁰Pb in total fractions (TOT) in surface water of Santa Quitéria region

Fisher's test identified different groups, (Table 3) which were ranked according to the activity concentrations. The highest activity concentrations belong to group G1 that includes the particulate fractions of points 03SQ, 01SQ, 04SQ and 02SQ. The intermediate group, G2, includes the particulate fractions of points 06SQ and 05SQ and the soluble fractions of points 05SQ, 03SQ and 06SQ. The group associated with the lowest AC, G3, includes the soluble fractions of point 01SQ, 02SQ and 04SQ. In summary, groups can be organized in function of decreasing activity concentrations as in Table 3.

The Z test showed differences between the particulate and soluble fractions, pointing to the particulate fraction as the one with highest AC. Analyzing the total fraction, no differences

between the points could be observed. When grouping the data by point and fraction, the ANOVA presented differences between the analyzed data, a fact corroborated by the Fisher's test, which grouped the particulate fractions of the points in groups of higher AC than the soluble fractions (Table 3).

3.2 Multivariate Statistical Analysis

3.2.1 Principal component analysis

The principal component analysis showed a clear distinction between the soluble and particulate fractions, as can be seen in Fig. 4. This grouping showed that there is a difference in behavior between both kinds of fraction, confirming the ranking proposed by the Fisher's test and reinforcing the identity suggested by the Z test.

Table 3. Fisher's test for mean ordination

Point and fraction under same line are considered same AC												
Fraction	Particulate						Soluble					
Point	03SQ	01SQ	04SQ	02SQ	06SQ	05SQ	05SQ	03SQ	06SQ	01SQ	02SQ	04SQ
Mean (Bq.l ⁻¹)	0.044	0.035	0.033	0.032	0.030	0.029	0.029	0.020	0.018	0.012	0.011	0.009
Tukeytest	—————						—————					
	G1				G2			G3				
	Grouping G1> G2> G3											

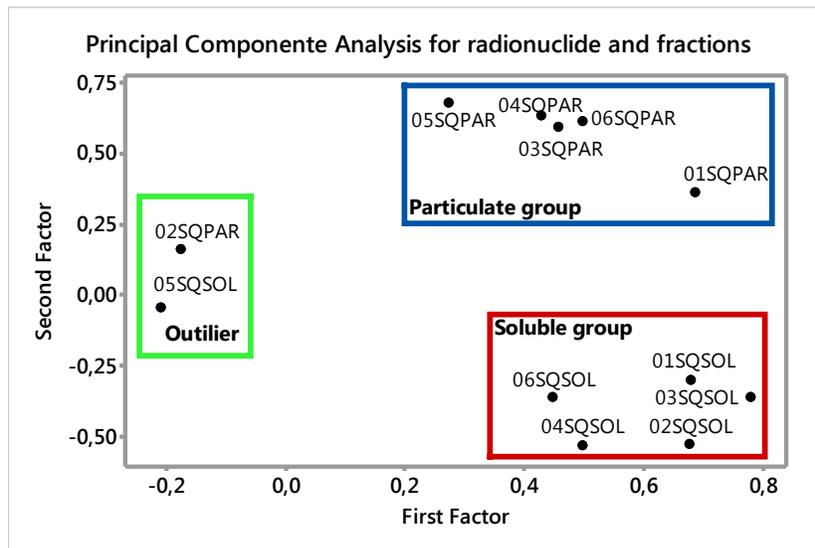


Fig. 4. Principal component analysis of data organized by point and fraction, demonstrating the separation between the soluble and particulate fraction

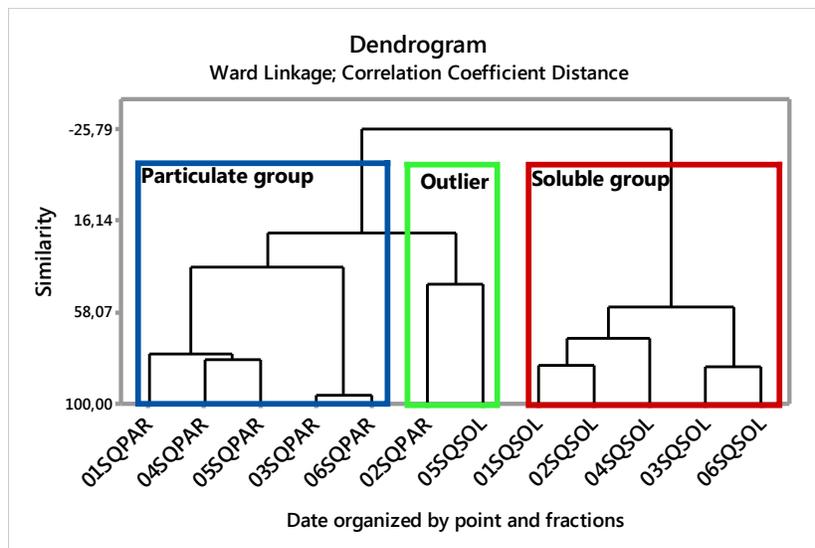


Fig. 5. Dendrogram of the data organized by point and fraction, demonstrating the separation between the soluble and particulate fraction

3.2.2 Cluster analysis

Cluster analysis reinforced the assessment made by PCA and Fisher's tests, refuting once more the Z test conclusion. Thus, different behaviors are observed between the soluble and particulate fractions (PCA and Cluster) with the particulate fractions showing higher activity concentrations than the soluble fractions (Fisher).

The approach used in this study showed the importance of combining univariate and

multivariate analyses for a better understanding of the behavior of radionuclides in the fractions. Indeed, the general assessment of fractions data carried out with the Z test (univariate) showed different behavior between fractions. Analyzing the total fraction by ANOVA, no difference was observed between the points. On the opposite, when ANOVA is used in the data organized by points and fractions, there is evidence of difference between the samples. This last evaluation was also shown by the Fisher's test that organized the data grouping them according

to their concentrations. At this stage, the analysis showed that the particulate fraction displayed higher levels of activity, as already detected by the Z test.

In his turn, the multivariate analysis confirmed the assessment of the Fisher's test, and withstood the Z test conclusion. In both analyzes (PCA and cluster) soluble fractions of collecting points were grouped and the particulate fractions put together in another group.

4. CONCLUSION

The assessment has shown that there are differences in the activity concentrations of ^{210}Pb between the soluble and particulate phases of water samples collected in the region of the Santa Quitéria phosphate deposit. From all this, it can be stated that the radioecology of ^{210}Pb in sampled area is complex, with spatial difference between the points and distribution difference between the fractions, with the particulate fraction showing higher AC than the soluble one.

An increase of sampling must be considered as a tool to increase the reliability both of the statistics and conclusions. A next step to be assessed is the analysis of the differences between the fractions at the collecting points. Another important aspect to be looked at is the geographic variation, comparing the same fractions (soluble or particulate) between the points.

In terms of public health, the World Health Organization (WHO) uses an 'individual dose criterion' (IDC) of 0.1 mSv for one year's consumption of drinking water [1] as the recommended limit of ingestion of radionuclides from water. This organization develops dosimetric models that estimate the concentration of activity that generates this dose for different radionuclides. In the case of ^{210}Pb this value is $0.1 \text{ Bq}\cdot\text{l}^{-1}$ [20]. Considering a linear relationship between ingestion of water and received dose and that the sum of the means of the soluble and particulate fractions is $0.05 \text{ Bq}\cdot\text{l}^{-1}$, it results that the average dose rate resulting from the intake of ^{210}Pb in water is half of the IDC value indicated by WHO.

In specific cases, this value may be higher than the IDC, as observed for point 02SQ, where the sum of the maximum values of AC in the soluble and particulate fractions returns an estimated value of AC of $1.35 \text{ Bq}\cdot\text{l}^{-1}$, that is 13 times the

limit derived of 0.1. But on the whole, the values are considered within the values indicated by the WHO, and the waters may thus be considered as potable from a radiological point of view.

DISCLAIMER

"Some part of this manuscript was previously presented and published in the following conference.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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