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Spatial assessment of gross alpha, beta, and gamma radiation as a pre-operational environmental baseline for the Unconventional Hydrocarbon Industry: the case of São Francisco basin - Brazil

Gustavo Filemon Costa Lima[1], Danilo Chagas Vasconcelos[2], Carlos Alberto de Carvalho Filho[3], and Rubens Martins Moreira[4]

[1]*gustavofilemon2@gmail.com, PhD student at the Nuclear Technology Development Center(CDTN); Federal Center for Technological Education of Minas Gerais (CEFET-MG)*
[2]*danilochagasvas@gmail.com, Nuclear Technology Development Center(CDTN)*
[3]*cacf@cdtn.br, Nuclear Technology Development Center(CDTN)*
[4]*rubens@cdtn.br, Nuclear Technology Development Center(CDTN)*

1. Introduction

The exploration of unconventional hydrocarbon reservoirs, worldly known as shale gas reservoirs, is polemic and controversial. At first, the unconventional natural gas industry emerges as an alternative and intermediary source to shift the world energy matrix from fossil fuels to renewable green resources. The perspective in the natural gas industry is enormous, given that the development of the hydraulic fracturing technique allowed the exploration of unconventional gas reservoirs in many parts of the world (as Argentina, China, Europe, USA, Canada…) [1], [2]. The U.S. Energy Information Administration prospects that natural gas will become the second most principal energy source globally in the following decades [1]. The North American case shows that the spectacular increase in shale gas production makes this resource a "disruptive technology, threatening profitability and continued development of other energy sources" [3]. On the other hand, hydraulic fracturing (namely as "fracking") is commonly associated with several environmental hazards such as surface waters/groundwater contamination, seismic-induced risks, air pollution, and territorial conflicts. Several studies regarded the practice of fracking as an impending source of potentially toxic elements (PTEs), organic pollutants, and naturally occurring radioactive materials (NORM to rivers, lakes, and aquifers (e.g. [4-8]).

It is worldly known that Brazil has many unconventional hydrocarbon reservoirs. In the case of São Francisco, two research surveys attempted to amplify the geological knowledge of those resources, the first one in the 60 to 80's decades coordinated by national institutions and another after 2005 when the Brazilian government reformed the hydrocarbons monopoly politics [9]. Nowadays, many studies highlight the potential of the Indaiá and the Borrachudo hydrological sub-basin as an unconventional gas player inside the São Francisco geological basin. However, in the last decade, the Brazilian public prosecutor's office decided to suspend these research endeavors under the pretext of lack of environmental support to guarantee safety and clarity concerning this disrupting practice [10].

In this context, the GASBRAS R&D project is working to provide essential guidelines and develop an environmental baseline considering the expected return of the unconventional hydrocarbon activities in Brazilian territory. Therefore, the aim of this research is: (1) Provide overall settings of gross Alpha, Beta, and Gamma radiation in the Indaiá and the Borrachudo sub-basins; (2) Understand the spatial behavior of Alpha, Beta and Gamma in surface waters, groundwater, and rocks; (3) Define recommendations for environmental baselines in the context of the unconventional hydrocarbon industry in Brazil.

2. Methodology

Indaiá and Borrachudo sub-basins areas cover approximately 4.480 km², located inside the São Francisco craton domain. The geological context of the São Francisco basin is characterized by the polycyclic history of Proterozoic deposition represented by the Paranoá-Espinhaço Superior sequence; the Neoproterozoic Macaúbas Group, and the pelitic-carbonatic system from Bambuí Group [9], [11]. The Areado Group (siliciclastic rocks), the Mata da Corda Group (ultramafic rocks), and quaternary deposits are the strata overlying the Bambui Group.

Eleven samples of groundwaters and thirteen samples of surface waters were appraised for gross alpha, beta, and gamma. In addition, five samples of rocks were measured gamma values. The gross alpha and beta values were analyzed using a gas flow proportional counter in the Nuclear Technology Development Center (CDTN/CNEN), whereas the gamma values were evaluated *in situ* using a portable scintillometer (low Bg model). The alpha and beta values were with the standards defined by the ministry of health (MS) [12]. The geoprocessing procedures were performed using the QuantumGIS 3.6.2 (QGIS).

3. Results and Discussion

The descriptive statistics of alpha, beta, and gamma measured in surface waters, groundwater, and rocks are exposed in Table I. The mean values of gross alpha, beta, and gamma for surface waters are 0.09 Bq L^{-1}, 0.27 Bq L^{-1}, and 97.73 counts per second, respectively. All maximum alpha and beta values are below the MS threshold which is 0.5 Bq L^{-1} and 1 Bq L^{-1} for total alpha and beta, respectively.

Table I Descriptive statistics of environmental compartments in the Indaiá and the Borrachudo basins

Statistical summary of gross Alpha, Beta and Gamma in Surface Waters						
Variable	**Mean**	**Standard Deviation**	**Median**	**Minimum**	**Maximum**	**Coefficient of Variation**
Alpha^a	0.09	0.06	0.12	0.02	0.19	62.40
Beta^a	0.27	0.07	0.28	0.18	0.40	26.36
Gamma^b	97.73	23.70	100	60	140	24.25
Statistical summary of gross Alpha, Beta and Gamma in Groundwater						
Alpha^a	0.09	0.06	0.12	0.02	0.19	62.40
Beta^a	0.27	0.07	0.28	0.18	0.40	26.36
Gamma^b	95.91	35.69	75.00	60.00	180.00	37.22
Statistical summary of Gamma in rocks						
Gamma^b	104	26.79	110	60	125	25.76

[A]Values in Bq L^{-1}; [B]Values in counts/s (cps).

The headwaters of the Borrachudo River shows higher gamma values in the waters, reaching a peak of 140 counts/s and 180 counts/s in the surface water and groundwater, respectively (**Fig 1**).

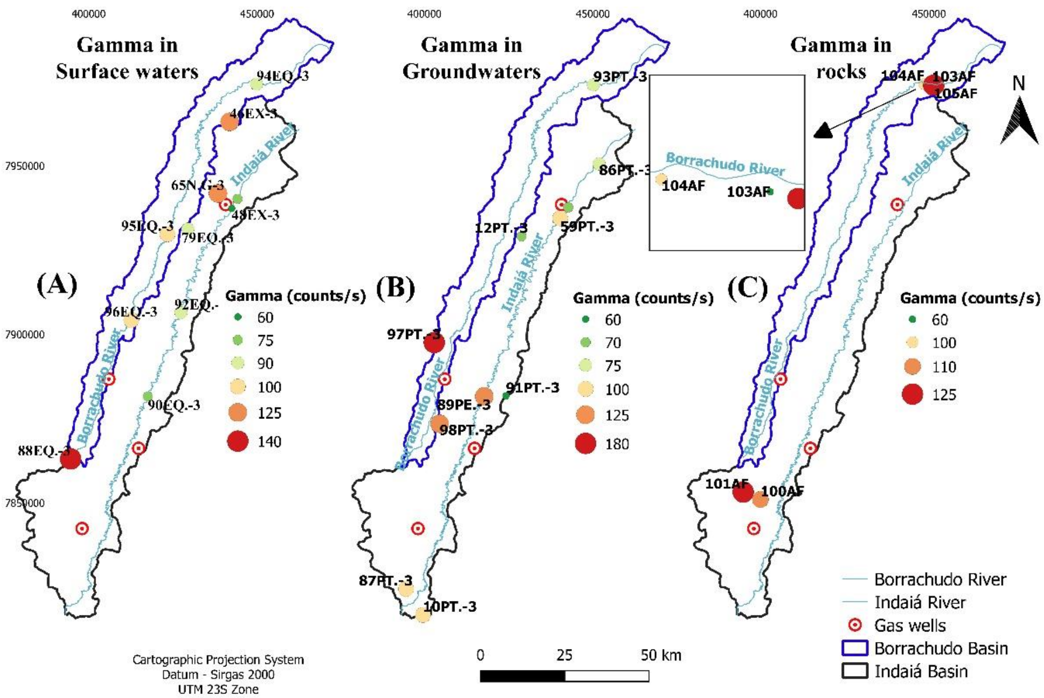

Figure 1 Gamma values in counts/s in the Indaia Basin and Borrachudo Basin. (A) Gamma in Surface waters; (B) Gamma in groundwater; and (C) Gamma in rocks.

Fig 2 shows gross alpha and beta in the Indaiá Basin and Borrachudo Basin. Higher levels of alpha can be observed in the south of both basins, reaching values of 190 Bq L^{-1} in surface and groundwaters. Beta values are also concentrated in the upstream segments.

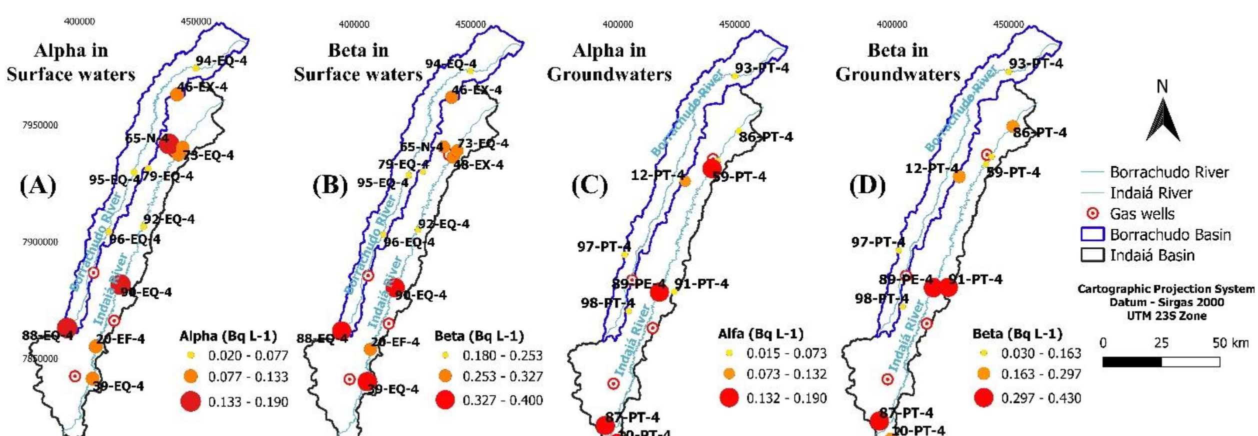

Figure 2 Gross alpha and beta values in the Indaia Basin and Borrachudo Basin. (A) Gross Alpha values in Surface waters; (B) Gross Beta values in surface water; (C) Gross alpha values in groundwater, and (D) Gross beta values in groundwater.

4. Conclusions

This research characterizes the gross alpha, beta, and gamma in the unconventional hydrocarbon system of the Indaiá and the Borrachudo basins. In all measured variables, the upstream parts of Indaiá and Borrachudo show higher concentrations. Assessing alpha, beta, and gamma's spatial aspects before the operational stage can be fundamental to implementing an unconventional hydrocarbon industry grounded on environmental sustainability principles. The radiological characteristics of these basins should be monitored in all stages.

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