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RADON EXHALATION RATE MEASUREMENT IN AMAZON FOREST SOIL

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Abstract Measurements of terrestrial residual gas emissions are important for investigations of atmospheric, biological, and geophysical processes. Terrestrial high-frequency flows of the radioactive noble gas ^{222}Rn are useful for evaluating the performance of regional atmospheric models through the use of validated radon flux maps. In this sense, this work aims to validate a laboratory method for determining soil parameters that can influence the flow of ^{222}Rn in samples collected at the Amazon Tall Tower Observatory (ATTO). Specifically, the pH and humidity values were determined for three soil types. Although more observations are still necessary, we concluded that, in comparison with works reported in the literature, the exhalation rate is in good agreement for tropical forest soils. However, no clear correlation could be observed between the ^{222}Rn exhalation rate and soil humidity or pH.

Keywords: Radon Flux, Amazon Soil, Validation

INTRODUCTION

The soil is the main source of all life-supporting ingredients, directly or indirectly. It is also the primary contributor to the natural background radiation dose received by humans [1]. High-quality and long-term measurements of terrestrial gas emissions are important for investigations of atmospheric, biological, and geophysical processes. Soil is the upper part of the Earth's crust and is formed due to the deformation of rocks by physical and chemical processes, including weathering, decomposition, addition of organic matter, and water movement. It contains not only organic and inorganic matter but also various natural radionuclides, namely uranium (^{238}U), thorium (^{232}Th), their decay products and potassium (^{40}K), as inherent soil contents. The distribution of primordial radionuclides and their radiological effects are important factors for human health [2]. Radon gasses (^{222}Rn) and thoron (^{220}Rn) are decay products of radium (^{226}Ra) and thorium (^{232}Th), respectively [1]. As ^{238}U and ^{232}Th exist in all types of soils and rocks on the Earth's surface, after generation, these gasses escape from the soil matrix. This escape consists of a two-step process, emanation, and exhalation. In emanation, ^{222}Rn and ^{220}Rn atoms escape from solid mineral grains to air-filled pores, and in the exhalation process, they are transported to the atmosphere through convection and diffusion process. The exhalation rate is a pre-indicator of natural radioactivity levels; this rate is the emission of ^{222}Rn per unit area per unit time and depends on various factors such as the concentration of parent radium content in soil and rocks, emanation power or fraction of ^{222}Rn released from the mineral, geographical location, soil or rock porosity, grain size, water saturation degree, variable atmospheric conditions such as wind speed, temperature, and soil moisture content [2]. This work aimed to characterize the different types of soil found in the region of the High Tower Amazon Observatory (ATTO) and determine the ^{222}Rn exhalation rates. By understanding how soil parameters influence ^{222}Rn exhalation, researchers can infer information about gas dynamics in the tropical forest, its implications for the carbon cycle, and greenhouse gas emissions.

METHODS

A. Study area

Soil samples were collected from 3 distinct ecosystems existing at the ATTO site: the Terrace, an area next to the Uatumã river that is periodically flooded (Igapó Forest), the Plateau, a region of dense and non- flooded forest (Terra Firme Forest), and the Campina, an area of transition between the river terraces and the plateau [3].

B. Determination of pH and moisture

For pH determination, soil samples were placed in a 100 mL plastic beaker, and then 25 mL of 1 mol L^{-1} potassium chloride (KCl) solution was added and stirred with a glass rod. After one hour of settling, the samples were stirred again with a glass rod, and then pH readings were taken. This procedure was also performed for the pH determination in water medium [4]. For moisture determination, a soil sample was collected, and the wet mass of the sample was recorded. The soil sample was dried in a hot air oven at 105 °C until constant weight to obtain the dry weight. The moisture content is calculated by the difference in mass between the two weighing.

C. Radon (^{222}Rn) measurements

For ^{222}Rn measurements, a RAD7 detector (manufactured by Durridge Co., Inc.) was used, which is capable of detecting alpha particles by converting radiation into an electrical signal, distinguishing the energy of each particle, allowing the identification of isotopes (^{218}Po and ^{214}Po of ^{222}Rn and ^{216}Po of ^{220}Rn) produced by the decay of radon.

The calibration of RAD7 was performed at Durridge's internal facilities using a radon chamber with a radium source (^{226}Ra) to provide a known flux of ^{222}Rn. According to the RAD7 User Manual, reproducibility is generally better than 2%, and calibration accuracy is in the range of 5% [5]. The radon (^{222}Rn) exhalation rate was calculated following the formula given by Equation (1).

$$E0 = C\lambda effV \,/\, 1 - e^{-\lambda efft} \qquad \text{Eq.1}$$

The approach used in this study followed De Martino et al. [6], applying a nonlinear curve fitting to the experimental data C versus t, in the form $y = a\,(1 - e^{-bx})$, where $a = E0/\lambda eff \times V$ and $b = \lambda^{eff}$, where E0 is the exhalation rate, λeff is the effective decay constant, and V is the effective volume.

FINDINGS AND ARGUMENT

In Table 1 it is possible to see a variation from 0.92 to 12.7% in the organic matter content of the soil. The Campina soil sample had the lowest value, followed by terrace and plateau, with the higher. Studies show that in forest soils the organic matter content is generally between 1 and 5% [6], the current study shows a corresponding value in the Campina region, nevertheless, Plateau and Terrace were above this value.

Table 2 shows the soil pH measurements in water (H_2O) and potassium chloride (KCl), and also the delta pH values (ΔpH), which is the numerical difference in the pH values measured in KCl and H_2O (pH KCl - pH H_2O). The pH of the Terrace sample presented values similar to that observed in the Plateau sample, for the value observed for Campina sample, the pH was lower. In a KCl all the values were lower than in water, but the pattern remains the same, with higher values in Terraço and Plateau and lower in Campina. The ΔpH variation showed negative values in all three regions. When this difference is negative, the colloid has a negative net charge (cation exchange capacity), and when it is positive, it has a positive net charge (anion exchange capacity) [7].

Three different types of soil were analyzed from the Amazon region - site ATTO, in which the ^{222}Rn exhalation rate was presented according to Fig. 1 that shows an example of the nonlinear exponential regression fit used for determining the exhalation rate from the activity concentration values as a function of time [8].

Table 1: Moisture, organic matter, and loss on ignition - Soil samples collected at ATTO.

Samples	Temperature	Mean (% loss)	Standard Deviation
	105 °C (after 24h)	0.89	0.16
TERRAÇO	550 °C (after 4h)	7.72	0.09
	1000 °C (after 2h)	1.74	0.11
CAMPINA	105 °C (after 24h)	0.09	0.02
	550 °C (after 4h)	0.92	0.04
	1000 °C (after 2h)	0.27	0.30
PLATEAU	105 °C (after 24h)	1.27	0.15
	550 °C (after 4h)	12.7	0.64
	1000 °C (after 2h)	3.35	0.08

105ºC (Moisture); 550ºC (Organic matter); 1000ºC (Loss on ignition)

Three different types of soil were analyzed from the Amazon region - site ATTO, in which the ^{222}Rn exhalation rate was presented according to Fig. 1 that shows an example of the nonlinear exponential regression fit used for determining the exhalation rate from the activity concentration values as a function of time [8].

The samples were collected during August 2023. The highest ^{222}Rn exhalation rate was found in the Terraço region, with the value from 32±7 mBq/cm² s. The Plateau and Campina region presented close values of 18±2 mBq/cm² s and 12±6 mBq/cm² s, respectively. The values found are close to the literature where samples analyzed in Atlantic Forest soils showed an exhalation rate of 13.5±1.6 mBq/cm² s to 20±2 mBq/cm² s [9].

Table 2: pH Amazon Soil - ATTO site

Samples	pH (H_2O)	pH (KCl)	Δ pH
	4.01	3.65	-0.36
TERRAÇO	4.07	3.68	-0.39
	4.09	3.64	-0.45
	3.57	3.06	-0.51
CAMPINA	3.69	3.07	-0.62
	3.65	3.08	-0.57
	4.03	3.60	-0.43
PLATEAU	4.05	3.78	-0.27
	4.05	3.78	-0.27

ΔpH=pH KCl – pH H_2O

CONCLUSIONS

In this study, three types of soil from the Amazon region were analyzed - ATTO site, in which the exhalation rate of ^{222}Rn showed the different soils present different exhalation rates. In comparison with works reported in the literature, the exhalation rate was in good agreement for tropical forest soils. No clear correlation could be observed between ^{222}Rn exhalation rate and humidity, or soil pH and more observations are still necessary.

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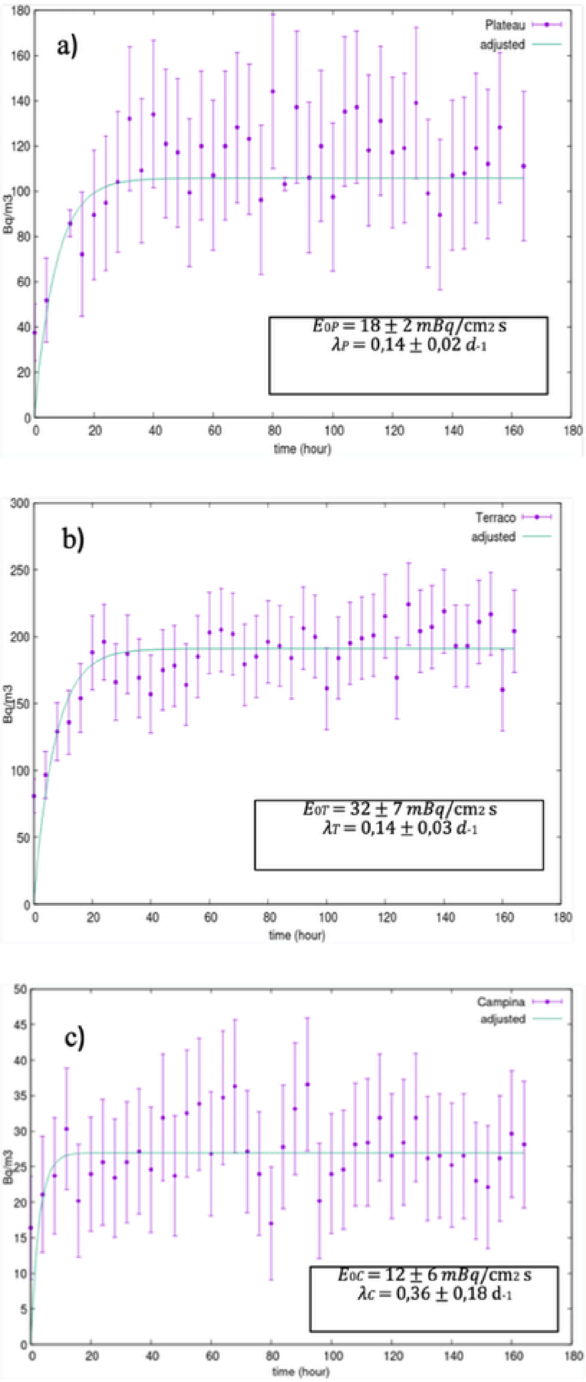

Figure 1: Graphs of 222Rn exhalation rates (E0C) as a function of time in three different regions (Campina, Terraço and Plateau) with the respective effective constant decay (λ).

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