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Wet deposition and soil content of Beryllium – 7 in a micro-watershed of Minas Gerais (Brazil)

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ABSTRACT

Beryllium-7 (^{7}Be) is a natural radionuclide of cosmogenic origin, normally used as a tracer for several environmental processes; such as soil redistribution, sediment source discrimination, atmospheric mass transport, and trace metal scavenging from the atmosphere. In this research the content of ^{7}Be in soil, its seasonal variation throughout the year and its relationship with the rainfall regime in the Mato Frio creek micro-watershed was investigated, to assess its potential use in estimating soil erosion. The ^{7}Be content in soil shows a marked variation throughout the year. Minimum ^{7}Be values were observed in the dry season (from April to September) and were between 7 and 14 times higher in the rainy season (from October to March). The seasonal oscillations in ^{7}Be soil content could be explained by the asymmetric rainfall regime. A highly linear relationship between rainfall amount and ^{7}Be deposition was observed in rain water. A good agreement between ^{7}Be soil content and ^{7}Be atmospheric deposition was noticed, mainly in wet months. ^{7}Be penetration in soil reaches a 5 cm depth, this could be explained by the soil type in the region. The soils are Acrisol type, characterized by low pH values and clay illuviation in deeper layers of the soil. In some regions of Brazil special attention should be paid if this radionuclide will be used as soil erosion tracer, taking into account the soil origin and its particular properties.

1. Introduction

Beryllium-7 (^{7}Be) is a natural radionuclide of cosmogenic origin. It is produced in the atmosphere by spallation when cosmic rays hit nitrogen and oxygen atoms (Lal et al., 1958). Once formed it diffuses through the atmosphere and is electrostatically adsorbed in atmospheric aerosol particles. It reaches the soil surface via two mechanisms: wet and dry deposition. It is assumed that the wet deposition is the main path leading to the ^{7}Be input (90%) into the soil, dry deposition being negligible (Salisbury and Cartwright, 2005; Ioannidou et al., 2005; Wallbrink and Murray, 1994).

^{7}Be is an important environmental radionuclide, its relatively short half-life of ^{7}Be (53 days), along with its continuous and assessable production rate makes it a potentially powerful tool for surveying environmental processes; such as soil redistribution,

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sediment source discrimination, atmospheric mass transport, and trace metal scavenging from the atmosphere (Kaste et al., 2002; Yoshimori, 2005; Steinmann et al., 1999; Daish et al., 2005; Matissoff et al., 2002; Walling et al., 1999; Blake et al., 1999; Schuller et al., 2006; Sepulveda et al., 2008). Kaste et al. (2011) pointed out that, in order to evaluate the potential of ^{7}Be as a tracer, it is necessary to know its seasonal and spatial depositional variability as well as quantify the relationship between precipitation and surface inventories.

The Mato Frio creek is one of the main tributaries forming the Serra Azul River watershed, near Belo Horizonte, one of the main cities in the central Brazilian plateau. The importance of this watershed is related with a large water reservoir constructed at its lower course, which is the third largest drinking water supply system (2.5 m^3/s) to the metropolitan region of Belo Horizonte (about 4 million inhabitants). Besides supplying water, two other conflicting activities are practiced within the watershed area: vegetable agriculture in the central area and intensive iron ore mining at its headwaters. As regards the Mato Frio creek micro-watershed, it covers an area of about 8 km^2 and has a hilly landscape with steep slopes. Therefore the main farming activity is related with raising livestock, hence both the heavily inclined pasture lands and the constant trampling by cattle promote soil erosion. The sediment load thus added to the watercourses, compounded with those resulting from the ore mining activities, will result in increased sedimentation at the water reservoir downstream with severe volume losses and water quality impairment.

The aim of the research is to investigate the content of ^{7}Be in soil, its seasonal variation throughout the year and its relationship with the rainfall regime in the Mato Frio creek micro-watershed, to assess its potential use to estimate soil erosion.

2. Materials and methods

2.1. Study area

The study area is located within the Mato Frio creek micro-watershed (20 °04′00″ S, 44 °28′00″ W; 20 °08′00″ S, 44 °31′00″ W), about 50 km to the southwest of Belo Horizonte, in the state of Minas Gerais, Brazil (Maia et al., 2006). The micro-watershed is located 908 m asl and has slopes ranging from 6.5% to 15.5%. The climate in the region is characterized by a warm and rainy season from November to March and a cool and dry season from June to August (Neves et al., 2004). Average monthly temperatures vary between 16 °C and 23 °C. Taking into account temperature and rainfall records, the climate can be characterized as high altitude tropical according to the Köppen classification (Soares, 2010).

The soils in the region are Acrisols and Ferrasols, the most important soils in Brazil; covering 40% and 20% of the country, respectively. The Acrisol type is characterized by clay illuviation. In this soil type the clay particles are accumulated in the Bt horizon, causing sand enrichment in the upper layers of soil. This soil is rather acid (pH = 4.5), well-drained and has low fertility. The Ferrasols are a deep soil characterized by the sandy loam texture of the B horizon. This soil type is also acid (pH 4.5–5.0), well-drained with high porosity and has moderate to high fertility (Soares, 2010).

Two parcels, Parcel 1 (P1) and Parcel 2 (P2), on different soil types in the Mato Frio River micro-watershed were selected for this study. Parcel P1 was an Acrisol type and P2 a Ferrasol type, with the intention of exploring differences in the ^{7}Be soil content.

2.2. Rainfall

A rainfall database at the micro-watershed was obtained from the nearest available rain gauge station, located 1 km away from the study sites (www.snirh.gov.br/hidroweb/FAZENDA LARANJEIRAS-JUSANTE, Rainfall Code Station: 2044041, Responsible: ANA, Operating Agency: CPRM, State: Minas Gerais, County: Itaúna, Basin: Rio São Francisco, Micro-watershed: Rios São Francisco, Paraopeba E). The database covers daily rainfall over a period of 39 years, from 1977 to 2015. Additionally, monthly rainfall samples were collected throughout the wet season from October 2015 to May 2016. A standard gauge was used and the ^{7}Be activity concentration was measured by gamma spectrometry.

2.3. Soil

During the period from May 2014 to May 2015 monthly soil samples were taken at 1 cm depth, at both the P1 and P2 parcels. In each sampling time and for each parcel, two soil samples were taken. All soil samples were collected using a scraper plate with a 50 cm × 20 cm collection surface. The soil samples were dried at room temperature for 48 h, sieved through a 2 mm mesh and placed in a Marinelli beaker for gamma spectroscopy analysis.

In October 2015 at parcel P1, the soil profile was sampled at 6 cm depth, cutting the profile in layers of 1 cm thick, with the aim to explore the total ^{7}Be soil content. Following this in the same parcel, from November 2015 to May 2016, monthly soil samples were collected to 5 cm depths, cutting the profile into two layers: 0–2.5 cm depth and 2.5–5.0 cm depth. In each month only one soil profile were collected. The soil samples were collected and processed using the same equipment and procedures as before.

2.4. Gamma spectrometry analysis

The soil and rain water samples were submitted to gamma spectrometry analysis and the ^{7}Be emission pulses were measured at the 477.6 keV energy peak using a Hyper-pure Germanium detector (GX5019, CANBERRA) at the Nuclear Spectrometry Laboratory of the Center for Development of Nuclear Technology (CDTN). This spectrometer has a 1.9 keV resolution and a 50% relative efficiency at the 1.33 MeV gamma energy of ^{60}Co. The samples, weighting around 600 g, were placed in 700 mL Marinelli beaker, and the total counting time varied between 86,000 s and 180,000 s.

The efficiency curve of the Hyper-pure Germanium detector was obtained using the Genie 2000 CAMBERRA Monte Carlo mathematical model software. Compounding it with the detector efficiency curve, the counting efficiency (ε) of the ^{7}Be gamma ray energy in the soil samples was $\varepsilon = 3.3\%$. This methodology had to be used given that no soil reference standard was available at the laboratory. The same procedure has been used in other studies involving gamma spectrometry analysis (Díaz and Vargas, 2008; "Vidmar et al., 1994; García, 2012; Pinto et al., 2013).

Equation (1) has been used to calculate the ^{7}Be activity in the soil and rain water samples (A).

$$A = \frac{N}{\varepsilon m_a t I_\gamma} \quad (1)$$

where $\boldsymbol{N}$ is the net number of counts corresponding to the gamma radiation (γ) per counting time interval t (s), m_a is the mass of the soil sample (kg), I_γ is the absolute transition probability for the measured gamma ray, and ε is the counting efficiency. All the activity measurements were corrected for the ^{7}Be radioactive decay. The final results were expressed in terms of activity per unit mass of soil (Bq kg^{-1}) and of activity per unit of volume of rain (Bq L^{-1}).

It is necessary to check the interference level of ^{228}Ac in ^{7}Be activity measurements by gamma spectrometry in order to establish an analytical protocol for the ^{7}Be determination. Therefore, some soil samples were counted at different time intervals, of