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VARIATION OF MONTHLY INVENTORIES OF ^{7}Be FALLOUT IN THE SOILS OF THE SUB-BASINS 3 AND 4 IN MATO FRIO RIVER, A TRIBUTARY OF SERRA AZUL RIVER

Alexander D. Esquivel[1] and Rubens M. Moreira[2]

[1] Centro de Investigaciones Hidráulicas e Hidrotécnicas (CIHH / UTP ï PA)
Universidad Tecnológica de Panamá, Extensión Tocumen, Pabellón C
Vía Domingo Díaz al lado de Pazco, S.A.
alexander.esquivel@utp.ac.pa

[2] Centro de Desenvolvimento da Tecnologia Nuclear (CDTN / CNEN - MG)
Av. Presidente Antônio Carlos 6.627
31270-901 Belo Horizonte, MG
rubens@cdtn.br

ABSTRACT

In this study 72 soil samples collected right at the surface were analyzed. They were collected at two work parcels located within the basin of the Mato Frio Creek (total drainage area = 10.6 km²) located in the municipality of Itaúna, except for a small fraction in its northern part, which is located in the municipality of Serra Azul. Both municipalities are in the State of Minas Gerais, Brazil. The sampling period covers the time span from May 2014 to May 2015, with the purpose of observing on a monthly basis the variation in the activity of the radionuclide Beryllium-7 (^{7}Be, E_γ = 477.6 keV) along a one year hydrologic cycle, stressing the dry and rainy seasons. The objective of this investigation was to establish a baseline for the alteration pattern of the ^{7}Be content in the soil in order to use these results for future estimates of rates of erosion or accreation in areas of interest within this basin. In order to measure the ^{7}Be activity in the collected samples, a gamma spectrometer was used, composed of a hyperpure germanium detector with a relative efficiency of 50%. The results indicate a net trend towards a marked variation in the activity of ^{7}Be in relative to the period of year within which the samples were collected, which in turn results in a reduction or increase in the values of the ^{7}Be monthly inventory in the topsoil.

1. INTRODUCTION

Beryllium-7 (^{7}Be) is a cosmogenic radionuclide having a relatively short half-life ($T_{½}$ = 53.3 days) and a 477.6 keV gamma energy; resulting spallation reactions of cosmic rays with atoms of oxygen and nitrogen in the upper troposphere and lower stratosphere [16]. This radionuclide enters the soil in two ways: through wet deposition (rain and snow), which is the main input source, and through dry deposition (gravity), which accounts for less than 10% of the total [2,15].

The deposition and concentration of ^{7}Be on the surface of the earth, depends on the rate of production (intensity of cosmic rays) that varies with the latitude, altitude and solar activity; likewise, other factors must be taken into account such as: washout of the air masses by precipitation, vertical mixing between and within the stratosphere and troposphere, and increased movement and mixing of air masses within the troposphere [8]. Previous research in different regions and environments have shown that the flux of ^{7}Be by wet deposition is directly related to the amount of precipitation [6,7,8], so that seasonal patterns are strongly associated with the variability of rainfall deposition [3,4,6,7,9].

In the present work, the surface activity density (Bq.m^{-2}) of ^{7}Be contained in the topsoil, and its variation, were analyzed with respect to seasons of the year and the rainfall regime, during the monitoring period from May 2014 to May 2015. From these measurements could be appraised factors affecting the low and high values in the monthly inventory of ^{7}Be in the working plots in Mato Frio Creek watershed.

2. MATERIALS AND METHODS

2.1. Study Area

The watershed of the Mato Frio Creek, is located between parallels 20°04'00" and 20°08'00" South, and between the meridians 44°28'00" and 44°31'00" West. It is almost completely contained within the municipality of Itaúna, except for a small fraction in its northern part, which is located in the municipality of Serra Azul [14]. Two sampling plots were established within this study area, both measuring 50 m x 30 m, with average slopes of 6.5% (Plot II) and 15.5% (Plot I), respectively. The land use in this area is mostly limited to livestock; therefore, at some places the soil is exposed to the effects of weathering. The topography in the watershed is quite hilly; the plots were placed in smoothly inclined sites at the top of hills, but quite near to strongly inclined slopes.

Plots selected for this research are located within the sub-basins 3 (20°5'56.43" S and 44°29'34.06" W) and 4 (20°5'46.18" S and 44°29'26.44" W) of the Mato FrioCreek; at each site were collected six samples of soil, the spacing between each sampling position was 20 meters. The sampling depth was restricted to 1 cm, since appropriate equipment for accurate collection at larger depths was missing. But actually this is not of utmost importance because, due to its limited half-fife and strong adsorption, ^{7}Be does not migrate a large vertical distance downward during its lifetime. The monitoring time span at this stage of the investigation was 13 months. A reference site is located (20°6'13.19" S and 44°29'4.38" W) next to the plots under study (average distance of 1,025.56 m). One important advantage of this area is its proximity to the pluviometric station Fazenda Laranjeiras (code: 02044041), at precipitation data relatively to the Mato Frio river watershed is daily, monthly, and yearly recorded. The average elevation of the three sites was 903.17 m Records of annual rainfall data for the last five years were available for this watershed; an average value of 1,243 mm for the period between th**e** years 2010-2014.

The climate in this region is characterized by a warm and rainy season between November and March; and the dry season between June and August [12]. The coolest months are June, July and August; the warmer months are January, February and March. The rainy season in the region where the plots are has started in the month of October and ends in April.

2.2. Sampling procedures

The methodology for preparing soil samples was as follows:

- Samples of 1 kg of soil were placed and uniformly distributed in plastic trays, and air dried at room temperature for a period of 48 hours to eliminate the humidity contained in the collected soil;
- Once dried, each complete sample was disaggregated and milled;
- After being completely disintegrated and milled, the samples were sieved and the fraction passing the 2 mm sieve were collected; the soil fraction of above 2 mm, was not used for counting.
- From the fraction smaller soil than 2 mm in each sample 0.616 kg were weighed and loaded in a 700 mL Marinelli vessel for counting.

2.3. ^{7}Be Activity Analysis

To determine the activity of ^{7}Be in prepared soil samples, their gamma emission of 477.6 keV energy was counted. This measurement was performed using a high-energy hyperpure Ge CANBERRA detector, Model GX5019 at the the Radiometric Measurements Laboratory (LMR), of the Reactor Service and Analytical Techniques (SERTA) Service, CDTN. The ensemble is composed of a hyper pure germanium detector with associated electronics and microcomputer, software Genie 2000 (Genie 2000 Basic Spectroscopy Software) CANBERRA for the acquisition and analysis of gamma spectra, photomultiplier and pre-amplifier, 2002CSL model, with 4096 channels. The relative efficiency of the detector is 50% with a resolution of 1.9 keV at the 1.33 MeV energy of ^{60}Co. The set point of the photomultiplier was adjusted to 3000 V. Two time intervals for counting the samples were used: 180,000 s for low activity and 86,400 s for high activity.

3. RESULTS AND DISCUSSION

3.1. Rainfall Pattern

Analyzing the precipitation data of Fig. 1, the first thing that can be observed is the decrease in the volume of rainfall in the year 2014 relatively to previous years; however, the overall behavior has not altered; it can be observed that major rainfall amounts occur in the period from October to April. From May to September, a remarkable decrease in rainfall events is noticed and it occurs only sporadically and in much lower amounts then in the previous period

Considering that the flow of ^{7}Be during wet deposition is directly related to the amount of rainfall [6,7,8], higher ^{7}Be surface activity densities (Bq.m^{-2}) are expected to occur between the months of October to April in the topsoil at the work parcels located within the watershed of Mato Frio Creek. The precipitation amount during the period analyzed in this study was 1,066.3 mm.

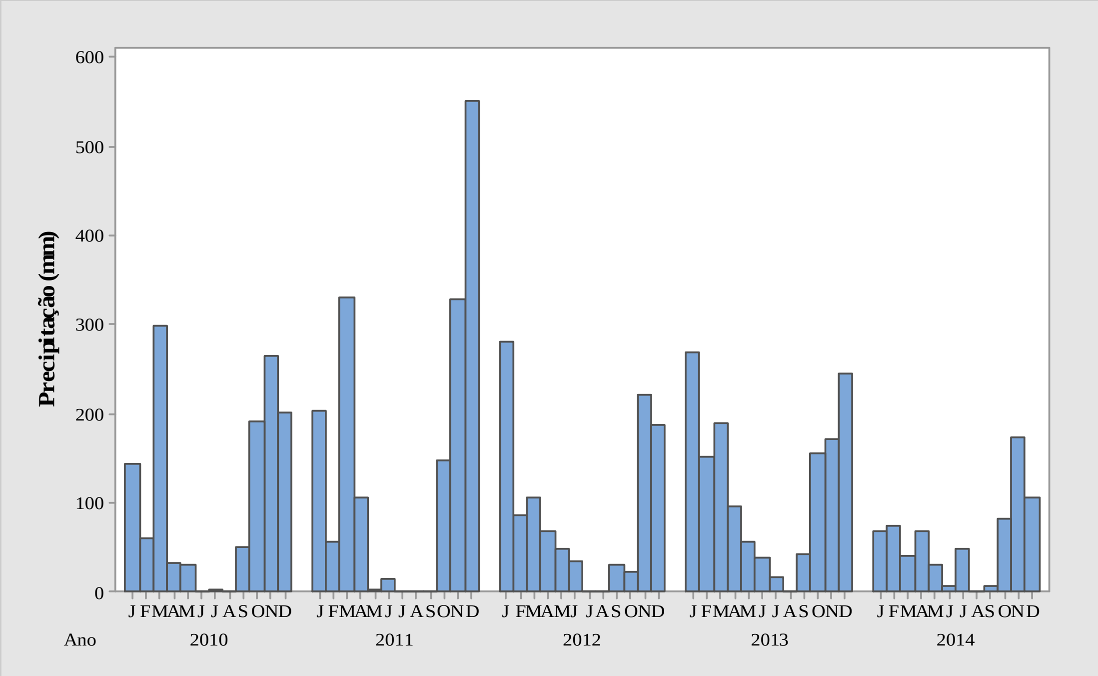

Figure 1: Annual Rainfall: Fazenda Laranjeiras Station (02044041)

3.2. Measurement of ^{7}Be Activity

To reliably measure the emission energy range of the ^{7}Be radionuclide using the high-energy CANBERRA GX5019 detector two important parameters had to be determined, so that results of a representative character would be obtained. With the help of the Monte Carlo mathematical model of the program "Geometry Composer" associated with the Genie 2000 software CANBERRA, it became possible to define the counting efficiency for the energy gamma radiation ***Ů***(%) and the absolute emission probability for the measured gamma ray, ***Pɔ*** (%) [5,13]. Once the necessary parameters to calculate the ^{7}Be specific activity (Bq.kg^{-1}) were obtained, the following equation was used:

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

Where:

- *A* is the activity of radionuclide (Bq.kg^{-1}).
- *N* is the number of liquid counts of the measured gamma ray (ɔ).
- m_a is the mass of the sample (kg).
- *t* is the counting time (s).
- ***Ů***it is the counting efficiency at the gamma ray (ɔ) energy.
- *Iɔ* is the absolute probability of transition to the measured gamma ray (ɔ).

The maximum values registered for the ^{7}Be specific activity were 33.95 ± 4.59 Bq.kg^{-1} in Plot 1, and 22.02 ± 0.15 Bq.kg^{-1} in Plot 2. During the months of July and August 2014, the concentration of ^{7}Be in the soil samples analyzed were below the detection limit of the high-energy detector used in the analysis.

3.3. ^{7}Be Monthly Inventory

Monthly soil samples to a depth of 1 cm were taken in six (6) points within each of the plots along a period of 13 months. Daily rain records for the period January 2010 to May 2015 were obtained.

In Fig. 2, the monthly inventory ^{7}Be is displayed for months between May 2014 and May 2015. Its calculation has been obtained using the following formuila:

$$I_m = I_{me} - I_{am} e^{-\lambda T} \qquad (2)$$

Where I_m is the real monthly inventory, I_{me} is measured inventory, I_{am} is the inventory of the previous month, λ is the decay constant of ^{7}Be and T is the time between the monthly inventory and the previous month [11].

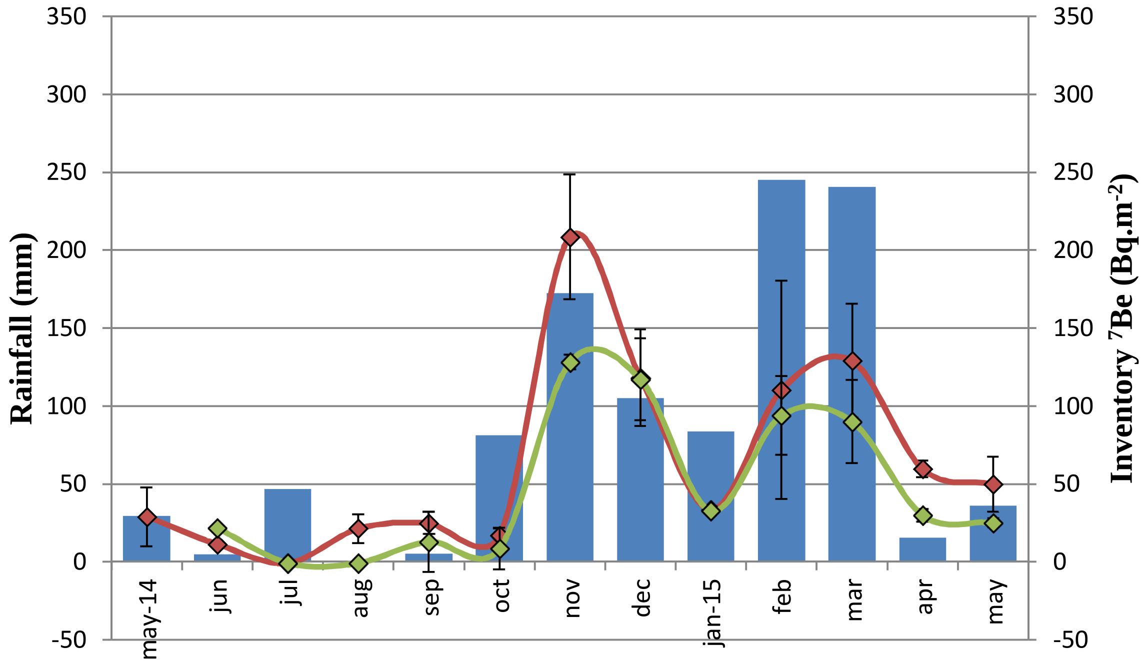

Figure 2: 7Be Inventory monthly May 2014 to May 2015

In Fig. 2, a relationship between can be noticed between the ^{7}Be inventory in the soil, the amount of precipitation and the season of the year. During winter (June to August) the registered values are low; this can be explained by the following: dry deposition in the area is low; the winter months are the coldest in the region which inhibits vertical transport between air masses near the ground and troposphere [4].

With the onset of spring (September to November), there is an increase in the amount of ^{7}Be retained in the soil, also, the rainfall is higher so that washout in the atmosphere increases, and with it the wet deposition the ^{7}Be. The behavior during summer (December to March) maintains the same trend of higher radionuclide activities and representative rain records.

Here it is also important to stress that these high ^{7}Be concentrations coincide with two important situations. First, the rainy season in the region begins in October and ends in April, therefore washout from the atmosphere is constant as is also the radionuclide entry by wet deposition. Second, the warmest months extend from January to March; these favor the vertical transport between the air masses in the troposphere, which is reflected in high levels of ^{7}Be in the air near the earth surface and its transport to the soil by rain [1,4].

With the arrival of autumn (late March to May) the concentration of ^{7}Be retained in the soil is considerably reduced; as well as the rainfall which limits the contribution of radionuclide by wet deposition. At the end of May the ambient temperature begins to decrease, producing an effect of stability in air masses in the troposphere, which inhibits the vertical transport to ground level, reducing the amount of ^{7}Be available to enter the soil by dry deposition [4].

Although the behavior of ^{7}Be in the two plots shows the same trend, it can be inferred that values in the second Plot are lower. This may be due to the effect of air currents on dry and wet deposition [4], the physicochemical properties of the soil [9], and the influence of the vegetation cover [10].

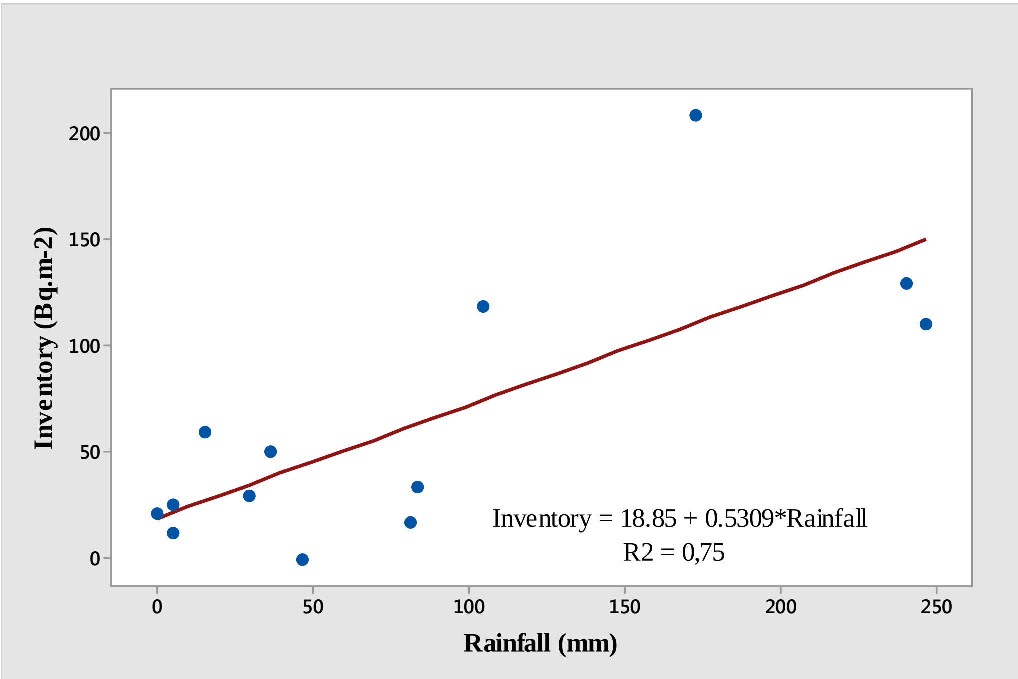

Figure 3: Linear regression between ^{7}Be inventory and rainfall in Plot 1

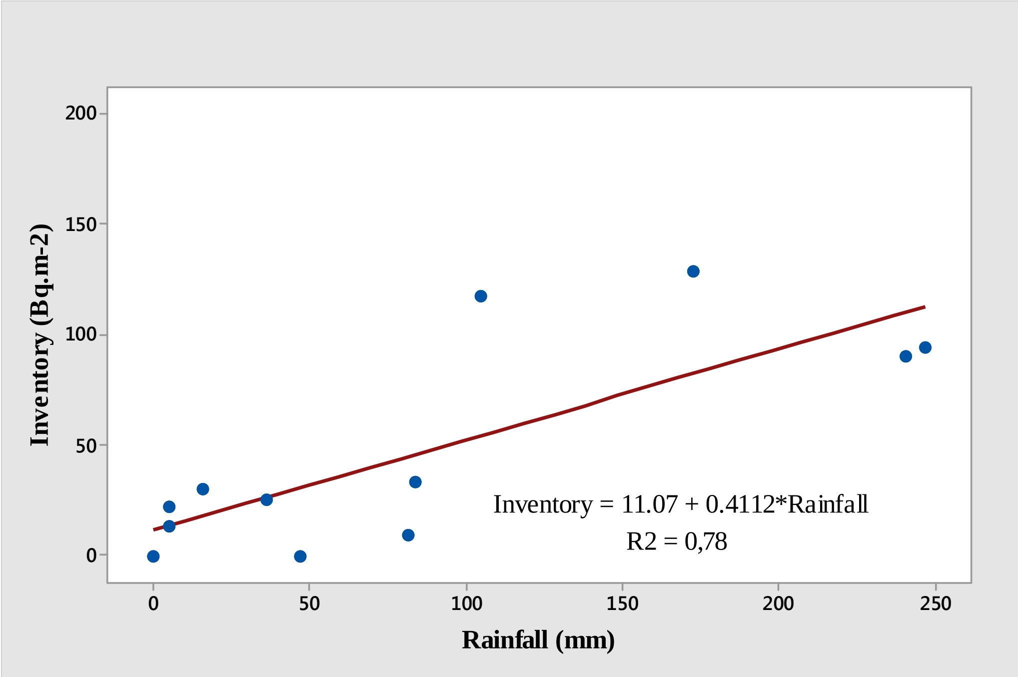

Figure 4: Linear regression between ^{7}Be inventory and rainfall in Plot 2

Linear regression between ^{7}Be inventory and precipitation in Plots 1 and 2 were calculated (Figs. 3 and 4), the correlation coefficients were R^2 = 0.75 and 0.78, respectively. Comparing these results with those obtained in the work of Marestoni et al., (2009), a difference of values is observed, which may be related to the variability shown by the ^{7}Be content in the soil versus the monthly rainfall registered. Nevertheless, the above values indicate a statistically significant relationship between these two variables.

4. CONCLUSIONS

This study demonstrated the correlation between the amount of ^{7}Be retained in the soil and rainfall; likewise, it confirmed that the monthly inventory of ^{7}Be is a function of the rain, and how this pattern is manifested at a very hilly landscape. The ^{7}Be concentrations obtained are the basis for developing a more detailed investigation aiming at determining the rate of soil erosion and sediment deposition in the watershed of the Mato Frio Creek. Its necessary to conduct a more detailed study of the physicochemical features of the soil in the plots, so that conclusions may be reached about the causes of the observed variation in ^{7}Be concentrations, despite they being following the same trend.

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REFERENCES

1. Andrello, A.C.; Appoloni, C.R., ñMeasurements of the Fallout Flux of Beryllium-7 and its Variability in the Soil,ò *Brazilian Archives of Biology and Technology*, Vol. 53, pp. 179-184 (2010).

2. Benitez N, C.R.; Buesseler, K.O., ñPhosphorus 32, phosphorus 37, beryllium 7, and lead 210: Atmospheric fluxes and utility in tracing stratosphere/troposphere exchange,ò *Journal of Geophysical Research*, **Vol. 104**, pp. 11,745-11,754 (1999).

3. Caillet, S.; Arpagaus, P.; Monna, F.; Dominik, J., ñFactors controlling 7Be and 210Pb atmospheric deposition as revealed by sampling individual rain events in the region of Geneva, Switzerland,ò *Journal of Environmental Radioactivity*, **Vol. 53**, pp. 241-256 (2001).

4. Feely, H.W.; Larsen, R.J.; Sanderson, C.G., ñFactors that cause seasonal variation in beryllium-7 concentrations in surface air,ò *J. Environ. Radioactivity*, **Vol. 9**, pp. 223-249 (1989).

5. García O., J., ñDeterminación de ^{210}Pb y otros Radionúclidos,ò *Radiocronología de Sedimentos Costeros Utilizando ^{210}Pb: Modelos, Validación y Aplicaciones*, pp. 21-28 (2012).

6. Juri A., J.; Di Gregorio, D.E.; Velasco, H.; Huck, H.; Rizzotto, M.; Lohaiza, F., ñShort-term seasonal variability in ^{7}Be wet deposition in a semiarid ecosystem of central Argentina,ò *Journal of Environmental Radioactivity*, **Vol. 100**, pp. 977-981 (2009).

7. Juri A., J.; Lohaiza, F.; Velasco, H.; Rizzotto, M.; Di Gregorio, D.; Huck, H., ñAssessment of ^{7}Be content in precipitation in precipitation in a South American semi-arid environment,ò *Science of the Total Environment*, **Vol. 441**, pp. 111-116 (2012).

8. Kaste, J.M.; Norton, S.A.; Hess, C.T., ñEnvironmental chemistry of beryllium-7,ò *Journal Reviews in mineralogy and geochemistry*, **Vol. 50**, pp. 271-289 (2002).

9. Kaste, J.M.; Elmore, A.J.; Vest, K.R.; Okin, G.S., ñBeryllium-7 in soils and vegetation along an arid precipitation gradient in Owens Valley, California,ò *Geophysical Research Letters*, **Vol. 38**, L09401 (2011).

10. Mabit, L.; Benmansour, M.; Walling, D.E., ñComparative advantages and limitations of the fallout radionuclides ^{137}Cs, ^{210}Pb$_{ex}$ and ^{7}Be for assessing soil erosion and sedimentation,ò *Journal of Environmental Radioactivity*, **Vol. 99**, pp. 1799ï 1807 (2008).

11. Marestoni, L.D.; Appoloni, C.R.; Andrello, A.C.; Martins, E.L., ñ^{7}Be Fallout for Superficial Soil Erosion Assessment,ò *2009 International Nuclear Atlantic Conference - INAC*, *ISBN:* 978-85-99141-03-8 (2009).

12. Neves, B.V.B.; Dutra, L.V.; Drumond, M.M.; Rodrigues, P.C.H.; Versiani, B.R., ñInfluência do desmatamento na evapotranspiração: Estudo na micro-bacia do ribeirão Serra Azul - MG com apoio do geoprocessamento,ò *VII Simpósio de Recursos Hídricos do Nordeste*, (2004).

13. Pinto, M.V.; Pires, L.F.; Bacchi, O.O.S.; Arthur, R.C.J.; Bruno, I. P.; Reichardt, K., ñSpatial variability of ^{7}Be fallout for erosion evaluation,ò *Radiation Physics and Chemistry*, **Vol. 83**, pp. 1ï 7 (2013).

14. Vasconcellos, R., *Caracterização do fluxo subterrâneo das águas na porção sudoeste da bacia representativa de Juatuba*, Belo Horizonte-Brasil (2010).

15. Wallbrink, P.J.; Murray, A.S., ñFallout of ^{7}Be in South Eastern Australia,ò *J. Environ. Radioactivit*y, **Vol. 25**, pp. 213-228 (1994).

16. Yoshimori, M.; Hirayama, H.; Mori, S., ñProduction of ^{7}Be Nuclei in the Earthôs Upper Atmosphere from Galactic Cosmic Rays and Solar Energetic Particles,ò *Proceedings of the 28th International Cosmic Ray Conference*, Japan, July 31-August 7, pp. 4273-4276 (2003).