# A Comparative Study of Ground and Airborne Gamma Measurements in Saquarema (RJ): Implications for Determination of Radiogenic Heat of Basement Rocks beneath tropical soil cover.

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**Abstract**

In the present work we report results of a comparative study of ground and air borne radiometric measurements in the region of Saquarema in the state of Rio de Janeiro. The results obtained indicate that the effects of systematic bias in air borne surveys can be minimized on the basis of a limited number of ground measurements in suitably selected localities. The proposed method does not have universal validity, because of the highly heterogeneous composition of soil cover at the surface. However, the method provides a convenient means for better utilization of the results of air borne gamma measurements. It also has the potential for estimating radiogenic heat of basement rocks on the basis of measurements in soil cover.

## Introduction

Knowledge of the distribution of radioactive elements is of considerable interest in understanding dynamics of processes occurring in near surface environments. It is also of interest in studies of the subsurface geothermal field because of the liberation of heat in radioactive processes. Gamma ray spectrometric techniques are commonly used for measurements of concentrations of natural radio elements (Uranium, Thorium and Potassium) in terrestrial environments (Winkelmann, et al., 2001; Dickson, 2004). However, there are considerable differences in the techniques used for data acquisition that have direct influence on the final results. An example is the systematic differences between results of gamma spectrometric measurements by air-borne and ground surveys are rarely in agreement with ground.

The main objective of this work is to present an estimate for the value of the surface radiogenic heat flow through airborne gamma-ray spectrometer data, U (ppm), Th (ppm) and K (%), and compare them with values of soil samples measured in-situ. A comparative study of ground and airborne measurements was carried out for this purpose for developing a set of correction factors that can be used for obtaining estimates of radiogenic heat production of basement rocks.

## Geologic Context and Soil Cover in study area

The region selected for study in the present work is situated to the east of the Guanabara Bay, approximately 100 km of distance from the capital of the state (Rio de Janeiro). The climate is sub-tropical with annual median temperatures of 22.5°C and annual median precipitation of 1700 mm and has a long dry season. According to geologic studies the Saqurema region is located within the Mantiqueira Province, specifically in the Cabo Frio Terrain which is located on the southeastern extremity of the Ribeira fold belt. This terrain has a number of NE – SW structures composed of thrusts and folds generated during the Brasiliano Orogeny. The units that constitute the basement rocks are orthogneisses and orthoamphibolites of Região dos Lagos Complex of Paleoproterozoic age (Viana, et al., 2008). The geologic context of the study area is illustrated in the map of Figure (1).

Outcrops of geologic formations are rare in the study area, as intense weathering processes have lead to the formation of thick soil cover. According to the soil classification system of Embrapa (1999) the predominant type is the Argis soil which is characterized by low clay activity and argilic horizon B. Other types present in the area include Pod soil, Glei soil, Neo soil, Organo soil.

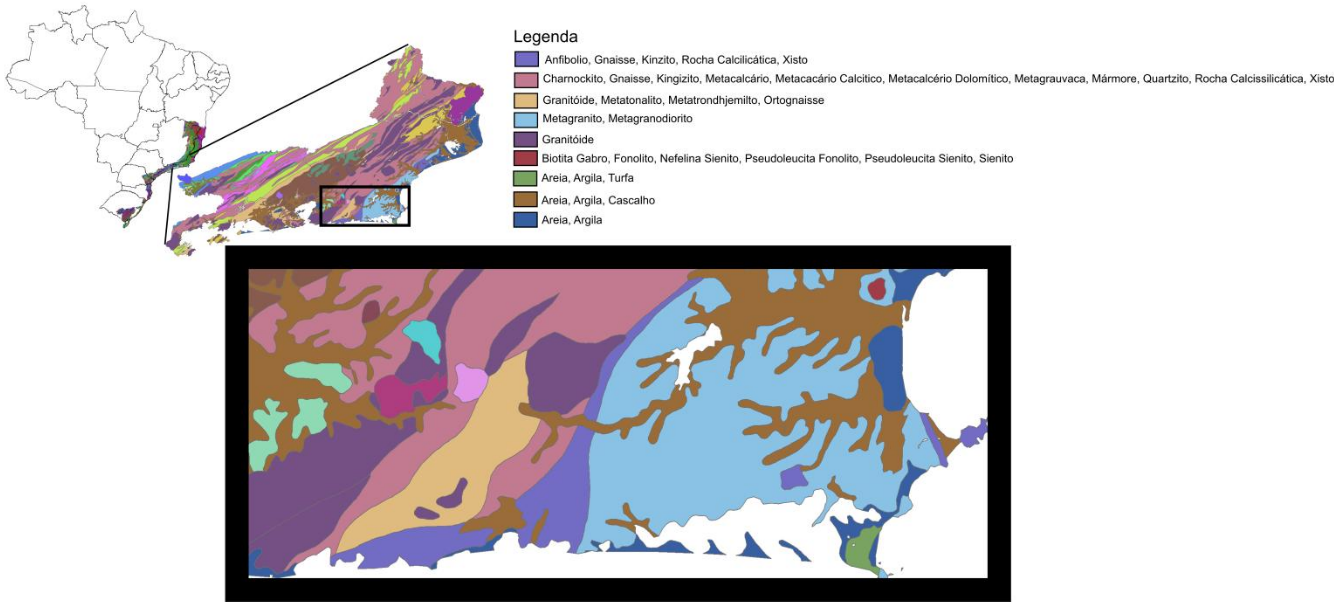


**Figure 1. Geological map of the search.**

## Database

The database employed in the present work includes results of both ground and air borne surveys. The ground survey was carried out in the northwestern parts of the Saqurema district. Sixteen sampling points were selected depending on the local surface conditions and vegetation cover. The locations of the sampling points are indicated in the map of Figure (2).

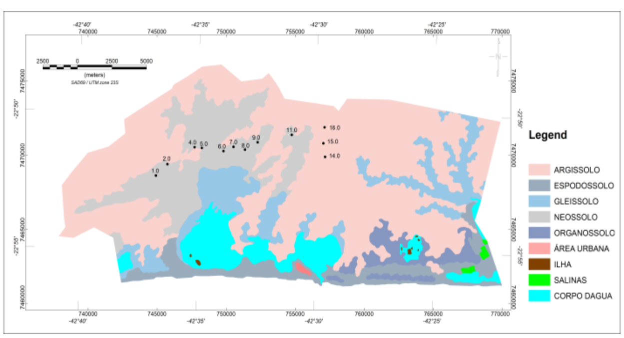


Figure (2) Map of Saquarema district selected for ground survey. The numbers indicate sampling points.

Data obtained as part of air borne radiometric survey carried out in 1978, within the framework of the São Paulo – Rio de Janeiro Project, was also used in the present work. The data sets acquired include measurements of geomagnetic field and intensity of gamma radiation emitted by the radioactive elements of Uranium, Thorium and Potassium. These are recorded in separate channels, along with information on flight altitude and atmospheric conditions. The flight lines were set in north – south direction, has a spacing of 500m and altitude of 100m. Quality control tests were carried out not only prior to data acquisition, but also during and after the surveys.

## Methodology

Ground gamma-ray spectrometry survey was carried out using an Exploranium GR-320 portable detector. The main components of this equipment include a NaI crystal and an associated electronic system that allows automatically maintaining the position of energy channels with respect to peaks of U (ppm), Th (ppm) and K (%). The field procedure consisted of two steps. First the detector was kept in contact with the ground during the measurement period. The second set of measurements was made by placing the detector at a height of approximately one meter above the ground level. , In this configuration the instrument detects gamma rays from an area within approximately a 10m radius. The sampling time was 100s.

Most of the data processing in the present work has been carried out using the computational package GEOSOFT, Oasis Montaj. Initially the raw data were corrected for the perturbing effects of technical survey operations (LAG and Heading effects and altitude variations). In addition, procedures were adopted for filtering, levelling and micro levelling operations, as per standard data processing techniques. Following this stage a suitable grid system was set up and homogenized data sets derived from the raw data sets for the chosen grid system, using suitable interpolations schemes. The grid size used for interpolations is 125m, which is in accordance with Nyquist criteria. The procedures employed included the method of bicubic splines – BIGRID for radiometric data sets.

The radiometric data refer to intensities of gamma rays emitted in radioactive decay of Uranium, Thorium and Potassium. The original data, recorded in units of counts per second (cps), were transformed into values of relative abundances using conversion factors specific to each flight path (BARMP, 1997). These factors depend on the sensitivity and geometry of detectors used and the survey altitude. Finally the values were corrected using calibration data for the particular survey operations.

Following this stage radioactive heat production values were calculated from the abundances of radioactive elements. The procedures adopted are derived from the work of Hamza and Beck (1972) and Hamza (1973). The relevant equation used for this purpose is:

$$H = 10^{-11}\left(9.51C_U + 2.56C_{Th} + 3.5C_K\right) \quad (1)$$

where H is the rate of heat production in units of W/kg, and $C_U$, $C_{Th}$ and $C_K$ are the concentrations of the radioactive elements. It is common practice to express concentrations of Uranium and Thorium in units of parts per million (ppm) and that of Potassium in units of percent (%). The numbers in equation (1) are conversion factors derived from radioactive decay schemes of individual isotopes, described in the earlier work of Hamza (1973). The volumetric heat production values (A) were calculated as the product of heat production per unit mass (H) and the density (ρ) of source material. For mean soil density of 1.5 x $10^3$ kg/m$^3$, the relation volumetric heat production, in units of μW/m$^3$, is:

$$A = 0.1428\, C_U + 0.0383\, C_{Th} + 0.0522\, C_K \quad (2)$$

**Result and Discussion**

**Ground Surveys**

The results of measurements carried out at ground level are illustrated in Figure (3). Note the rather smooth variation of U and K relative to that of Th.

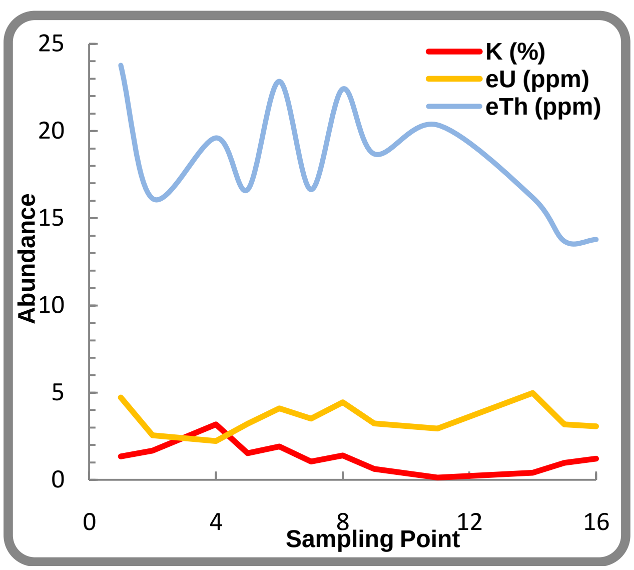


Figure (3) Results of ground measurements at 16 points.

The results of measurements carried out at level of one meter above ground level are illustrated in Figure (4). In this case also the variation of U and K are rather smooth relative to that of Th.

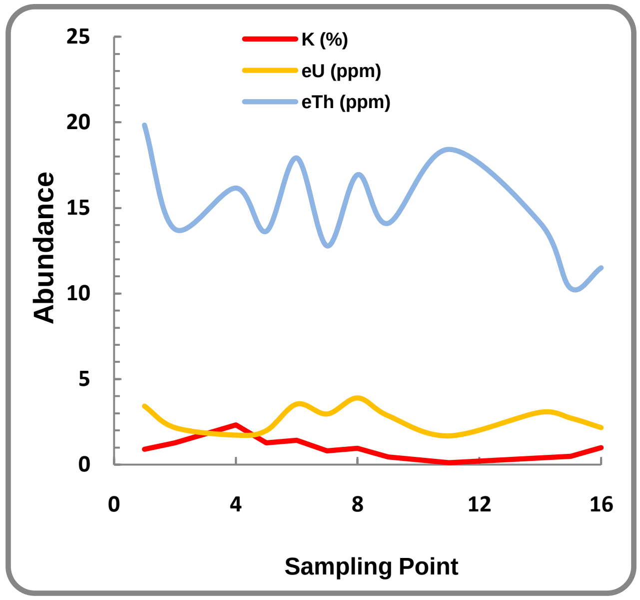


Figure (4) Results of measurements at one meter above ground level.

The difference between measurements at ground level and those at one meter above ground are illustrated in Figure (5). Again the differences in abundances are rather small for results of Potassium and Uranium, relative to that for Thorium. It is possible that this is a consequence of the differences in penetrating power of high energy gamma rays originating from the Thorium series.

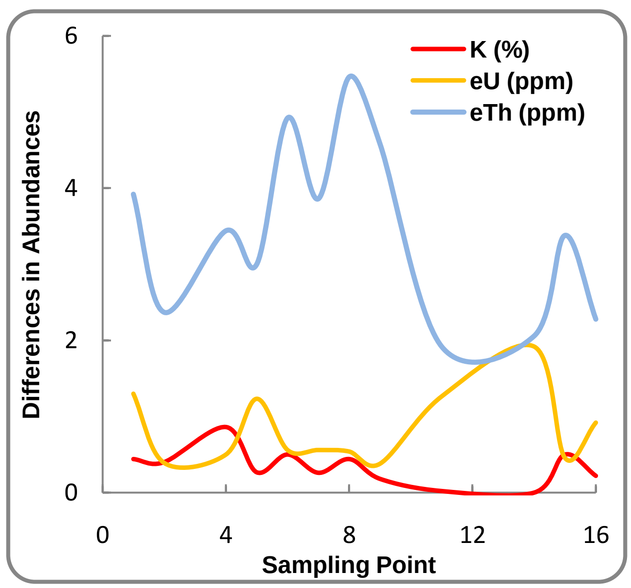


Figure (5) Differences between experimental data at ground level and at one meter above ground level.

### Airborne Surveys

The results of air borne gamma measurements are displayed in the form of maps of in Figures 6, 7 and 8, for the distributions of Thorium, Uranium and Potassium respectively. The concentrations in these maps are expressed in units of ppm for eU and eTh and in % for Potassium. An outstanding feature in these maps is the relatively high concentrations of Thorium and Uranium in the northwestern parts of the study area. The belt of low concentrations in the southern parts of the study area corresponds to areas covered by lakes and coastal water bodies.

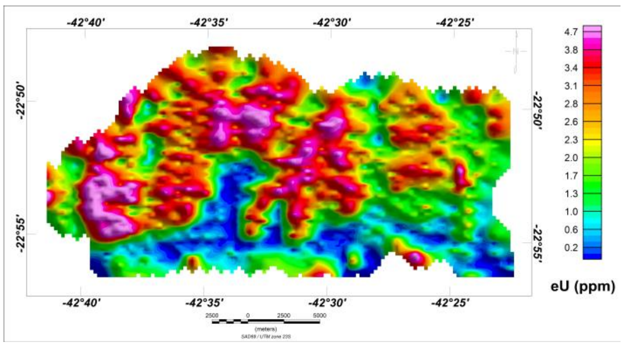


Figure (6). Map of concentration of thorium.

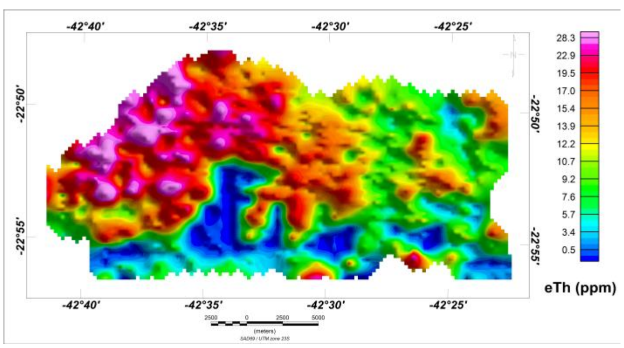


Figure (7). Map of concentration of uranium.

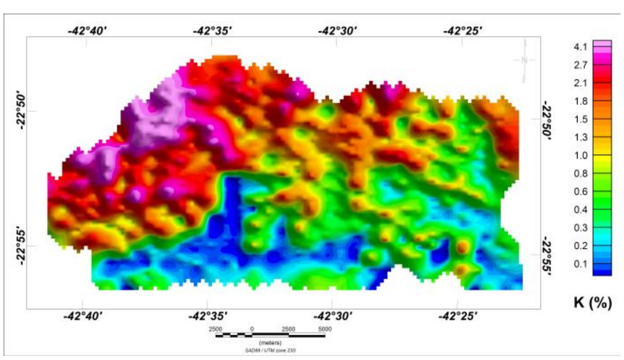


Figure (8). Map of concentration of potassium.

The average values of the radioelement abundances are 2.2±1.6ppm for Uranium, 12.5±8.2 ppm for Thorium and 1.2±1.1 % for Potassium. Figure (9) shows the ternary diagram indicating the relative concentrations of the three radionuclides.

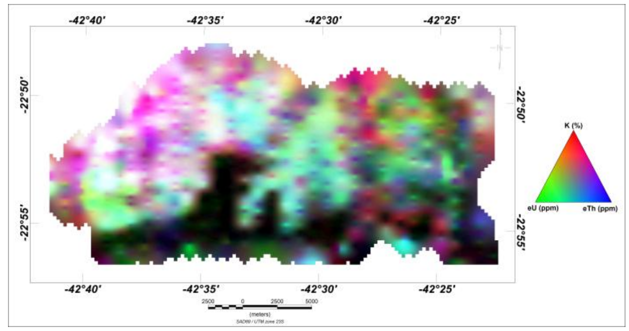


Figure (9). Ternary diagram of eU, eTh and K in the study area.

### *Radiogenic Heat Production*

Radiogenic Heat Production values were calculated using equation (1) for both ground and airborne radiometric data. In these calculations the soil layer at the surface is assumed to have a density of 1500 kg/m$^3$. The spatial distribution of airborne radiogenic heat production is illustrated in the map of Figure (10). Relatively high values of radiogenic heat production are observed in the north western parts of the study area. This trend is similar to those observed in maps of Uranium and Thorium (see figures 6 and 7). The mean value of heat production for airborne data is 0.86±0.5 μW/m$^3$.

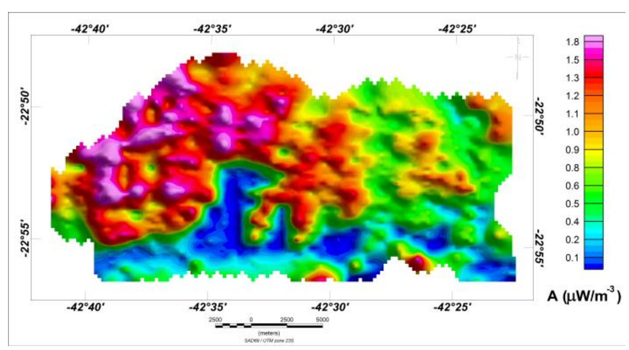


Figure (10). Map of distribution of radiogenic heat production.

### Analysis and Conclusions

Comparison of radioelement abundances obtained in ground and air borne surveys point to systematic differences in the final results. The spatial distribution of such differences is illustrated in figure (11). The differences are relatively low for Uranium and Potassium. In the case of Thorium the differences seem to point to changes that appear as oscillatory. It is possible that such differences arise from inability of the calibration procedures in accounting for the effects of relatively high degrees of geometrical spreading of high energy gamma rays.

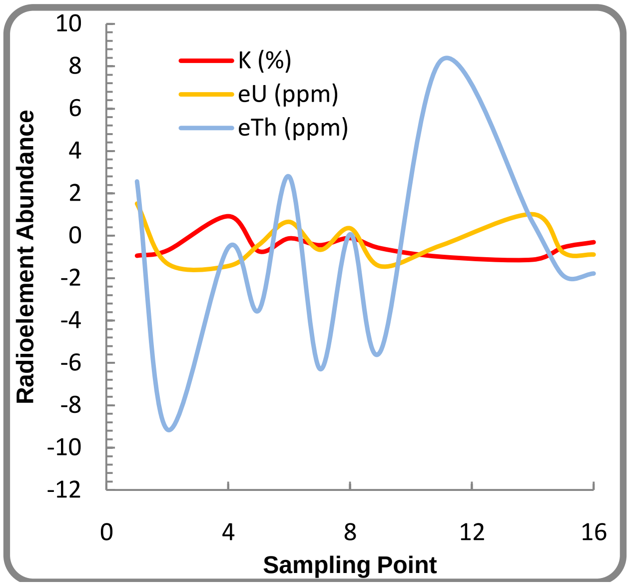


Figure (11). Map of differences in radioelement abundances between ground and air borne surveys.

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