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Radiometric Characteristics of Rio Das Ostras-Brazil

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ABSTRACT
This paper presents an analysis of natural radiation data of uranium, thorium and potassium from soil in the city of Rio das Ostras, Brazil. The aerial radiometric data were interpolated using the minimum curvature method with cells of 250 meters, generating radiometric maps by count per second of Potassium, Thorium, Uranium, Total Count and Ternary. After making the maps, comparisons were made with topographic, geological and land cover maps. In general, the highest radioactive counts were associated with granites and gneisses of the Região dos Lagos Complex and Paraíba do Sul Complex. The Morro São João Alkaline Massif with 270 cps radiometric signature of potassium channel, and the Granite Sana with 300 cps were well evidenced.

Keywords
Natural Radioactivity; Radiometry; Rio das Ostras.

1. INTRODUCTION
After heating a uranium rock on a new photographic film, Becquerel noticed something interesting: the film was found with something that came out of the rock, and at the time, they called it rays or radiation. It was noticed that other elements that had mass values close to uranium also had the same property [1].According to Navarro *et al*. (2008) [2], it was thought, at the beginning, that these were rays equivalent to the X-rays observed by Roentgen, but analyzis by Marie and Pierre Curie made it possible to discover three new elements (thorium, polonium and radio). Then the phenomenon was called radioactivity, those who possessed it were called radioactive elements and Becquerel won a Nobel Prize in physics. Today, it is known that radiation can be used as an aid in scientific research and as a qualitative and quantitative analytical method [3].Radiometry is a technique based on the measurement and subsequent interpretation of electromagnetic radiation, in this paper it was used to measure radiation from rocks and minerals in soil and subsoil. The counts of specific channels of gamma radiation from the shallow subsoil and soil with high levels of uranium, thorium and potassium are measured. After that, these counts can be interpreted through maps that allow the study of the soil with environmental or mineral applications [4]. The city of Rio das Ostras has a great prominence in tourism in the state of Rio de Janeiro, Brazil. It has an estimated population in 2017 of 140 thousand inhabitants and an area of approximately 230 km², with approximately 18% of Atlantic forest cover [5]. Rio das Ostras is located in the Region dos Lagos of the state of Rio de Janeiro, being situated on a coastal plain. It has characteristics and geological formations similar to other cities located in this same region, and its soils are classified mainly as alluvial soils [6]. This region not only cultivates coffee and sugar cane, but also has dunes, forests and others. Land-use maps consequently indicate the growth of the city due to the decrease in green area [5].Radiometric methods are excellent ways to investigate extensive territorial areas such as the city of Rio das Ostras and its subsurface geological structures. Thus, this paper aims to promote the study of Rio das Ostras soils through the interpretation of aerial radiometric data. Therefore, this research can facilitate the understanding of the local geology and the identification of land cover.In this paper, section II presents the characteristics of Rio das Ostras, Brazil; section III describes the radiometric method; in section IV, maps and data interpretation are presented; and, finally, the main conclusions are summarized in Section V.

2. CHARACTERISTICS OF THE STUDY AREA

2.1 City's description
The city of Rio das Ostras is part of the Coastal Region and is surrounding by Araruama, Arraial do Cabo, Armação dos Búzios, Cabo Frio, Casemiro de Abreu and Macaé, being located in the state of Rio de Janeiro, Brazil (Figure 1) [7].

Figure 1: Location of Rio das Ostras [8]

2.2 Region's geology

According to the Department of Mineral Resources of Brazil, Rio de Janeiro had its region mapped on a scale of 1: 50,000 through the Geologic Chart of Rio de Janeiro that was accomplished in the 70s and 80s. The city is located on the eastern coastal strip (Figure 2) [9] [10].

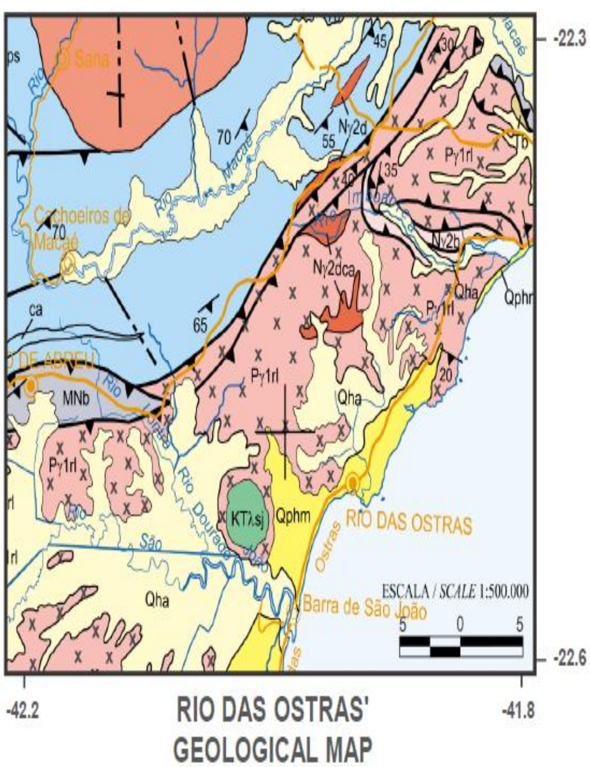

Figure 2: Geological map of the Rio das Ostras region [11]

The geological map of the Rio das Ostras region is characterized by the following geological units:

Qha	Fluvio/Lagoonal Deposits (0 – 1.6 Ma) Fluvial and marine fluvial deposits of sand and clays with gravel layers associated with talus deposits, and lake and mangrove sediments.
Qphm	Lagoonal/Marine Beach Deposits (0 – 1.6 Ma) Fluvial-marine deposits of sand and clays rich in organic matter, including current to old beach lines, as well as mangroves.
KTλ	Cretaceous/Tertiary Alkaline rocks (65 – 135 Ma) Alkaline Rocks. Morro dos Gatos Massif (KTλmo) and Morro São João Massif (KTλsj) stand out.
Nγ2d	Desengano Suite (560 – 6507 Ma) Coarse-grained granite, garnet, muscovite and biotite. Santa Terezinha Granite (Nγ2ds); Carapebus Granite (Nγ2dca); Serra da Concórdia Granite (Nγ2dsc).
MNps	Paraíba do Sul Complex (650 – 1600 Ma) Garnet, biotite and gneiss. Shale horizons are common.
MNb	Búzios Complex (650 – 1600 Ma) Cyanite, garnet, biotite, shale and gneiss interspersed with garnets.
Pγ1rl	Região dos Lagos Complex (2100 - 2200 Ma) Biotites and orthogneisses.
εγ5	Post-tectonic granitoids (500 -545 Ma) Biotite and fine to medium granulation granitoids. They occur as tabular bodies, dikes, stocks and small batholiths, cutting regional rocks.

2.3 Region's topography

The city relief has flat regions and mountains. According to Figure 3, the altitude varies from sea level to almost 600 m.

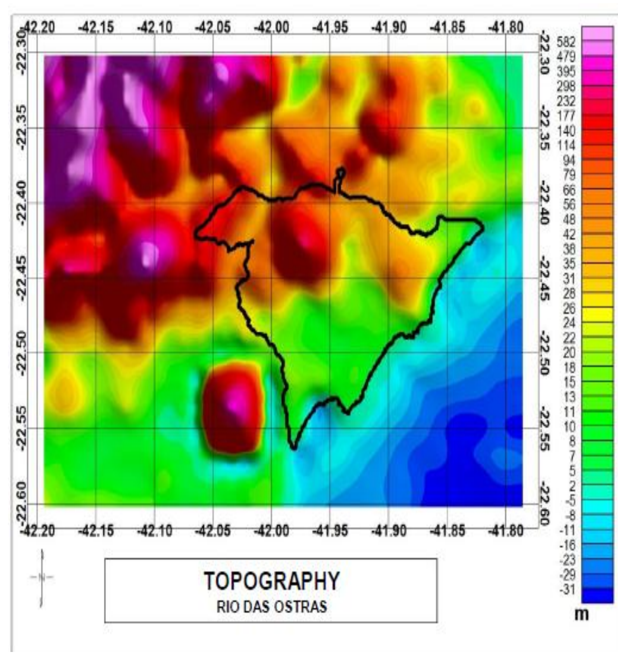

Figure 3: Topographic map of Rio das Ostras

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2.4 Land-use

According to Figure 4, the decrease in the area constituted by forest is notorious due to the increase in urban occupation, population density and environmental exploitation.

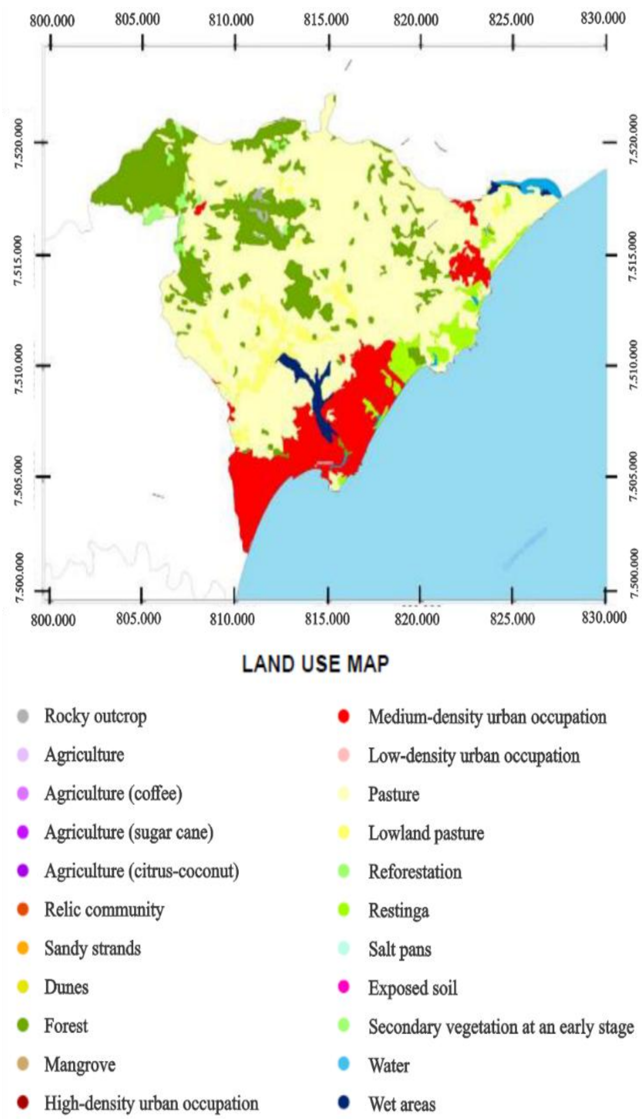

Figure 4: Rio das Ostras land-use map [6]

3. GAMMA SPECTROMETRY

The gamma spectrometry detects gamma rays from radioactive isotopes such as potassium (K), bismuth (Bi), uranium (U) and thorium (To). Figure 5 outlines the method showing the radiation input until the data is obtained. The wave of gamma rays is perceived by the scintillator (detector) containing sodium iodide crystals. This salt is capable of emitting a light pulse of 4200 angstrom and energy equivalent to a photon of gamma radiation. Then the electrons enter the photomultiplier tube, where they multiply when hitting electrodes and when passing through a potential difference, they are accelerated to the meter and the data is computed [2] [12]. In aerial gamma spectrometry, the data is obtained by aircraft-mounted detectors that fly over the surface forming a path called measurement line, perpendicularly to these. Another path is drawn with more spaced lines called control lines for the purpose of corrections [13].

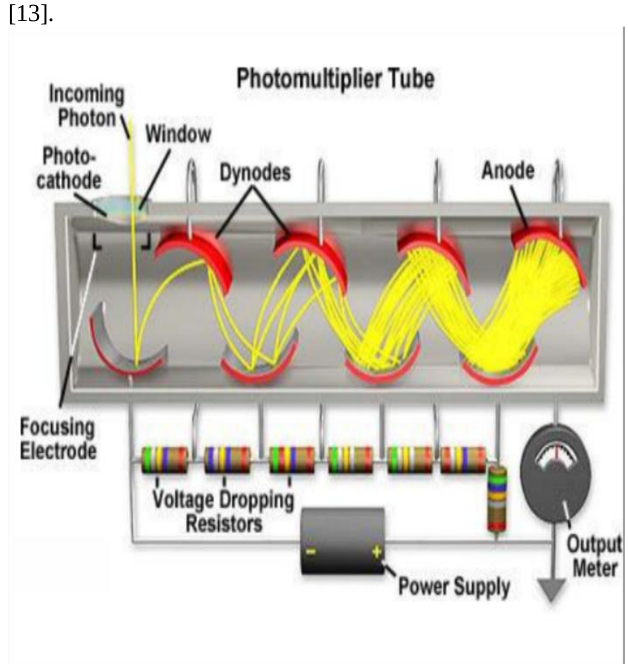

Figure 5: Gamma spectrometry scheme [12]

Due to the incostant concentration of radon found naturally in the atmosphere, there are two types of detectors, upward looking, which are inside a thermally insulated box and have the ability to identify 0.41-2.81 MeV in total, which comprises the elements: 1.37-1.57 (potassium), 1.66-1.86 (uranium) and 2.41-2.81 (thorium). This is placed on the second detector, the downward looking, which is able to detect only the energy range between 1.66-1.86 MeV emitted by the bismuth (Bi) from the radioactive decay of the atmospheric radon. Both detectors are isolated vertically by a sheet of lead [13]. Table 1 shows the radio elements and the energy perceived by each type of detector.

Detector Type	Detector Range (MeV)	Chan nel	Channel power range (MeV)	Peak (MeV)
upward looking	0.41 - 2.81	K^{40} U^{238} Th^{232}	1.37 – 1.57 1.66 – 1.86 2.41 – 2.81	1.46 1.76 2.61
downward looking	1.66 – 1.86	Bi	1.66 – 1.86	
		TC	0.41 – 2.81	-
		COS MIC	3 - 8	-

Table 1: Radio elements and their respective MeV detection energy ranges associated with the type of detector [13]

The correction of the data must be carried out in accordance with the standards of the International Atomic Energy Agency (IAEA). It must be considered: the time taken for the equipment to calculate and record the measured data (“dead time”); the calculation of the effective flight height, as it does not remain constant along the route due to surface irregularities; the interference in measuring the radiation of one element caused by the radiation of another element, a phenomenon known as the Compton Effect; the removal of background radiation, the sum of cosmic radiation and the influence of the aircraft; background removal of radon according to the measured amount of bismuth in the upward and downward detectors; altimetric correction, calculation performed to cancel erroneous deformations in the surface relief [13].

4. DATA PROCESSING AND INTERPRATATION

From the collected data, the radiation count and topography maps were made using the Oasis Montaj software. Six maps were made: total radiation count, topography, thorium count, potassium count, uranium count and ternary map.
Figure 6 shows the total count map:

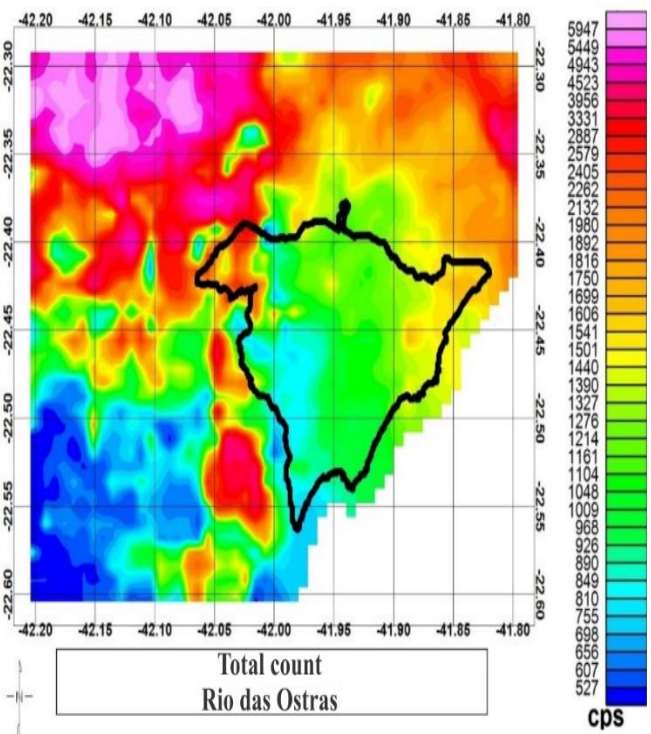

Figure 6: Total radiation count

The total count map includes all the radiation collected in the range of 0.41 - 2.81 MeV. Figure 6 shows that Granite Sana in the northwest part of the map and Morro São João, which is formed by alkaline rocks, located southwest of the municipality stand out with the highest total radioactivity counts in the region. The lowest counts were observed in the stretches of mangroves, sands, beaches and around the rivers: Rio Macaé on the northern limit of Rio das Ostras, Rio Dourado and Rio São João on the western limit of the municipality. Comparing of total count map with the land use map, it appears that the southern limit of the municipality (dominated by urbanization) and the northwestern tip of the municipality (dominated by dense forests) had their radioactive counts mitigated, since it is known that both closed forest and asphalt or buildings are able to obstruct part of the soil's natural radioactivity.Figure 7 shows the map of the potassium radiation count.Most of the municipality had a potassium count between 28 and 46 cps (greenish region). The highest counts in the municipality occur in the north of the municipality in the Desengano Suite associated with granites and in the northeast part of the municipality associated with the gneisses of the Região dos Lagos Complex with around 150 cps.

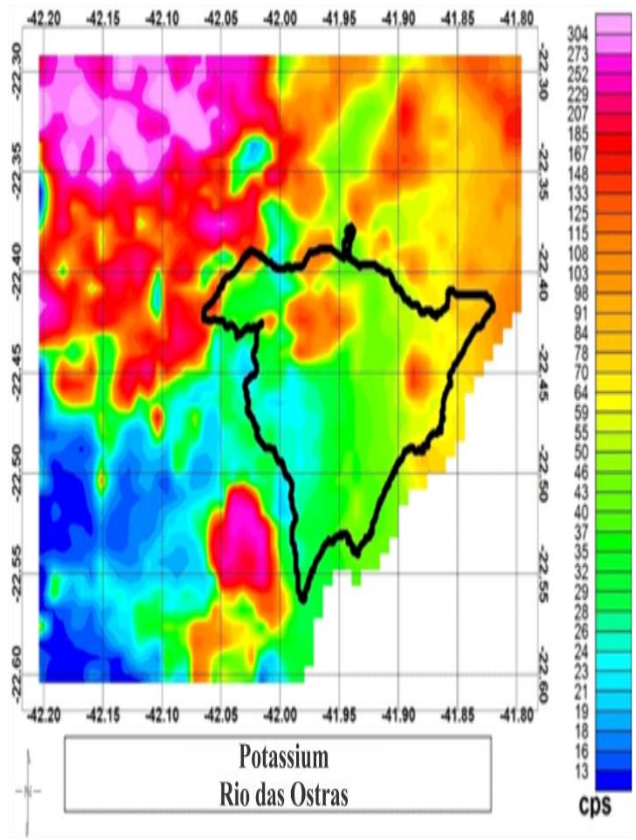

Figure 7: Potassium radiation count

According to the topographic map, the regions with the highest potassium count are at the highest altitude. Outside the municipality, Granito Sana stands out with a great count. Besides it, Morro São João stands out because it is formed by alkaline rocks, reaching an additional 300 cps. Low counts are evident in sandbank regions, river beds, dunes and beaches.
Figure 8 shows the radiation map of the thorium.

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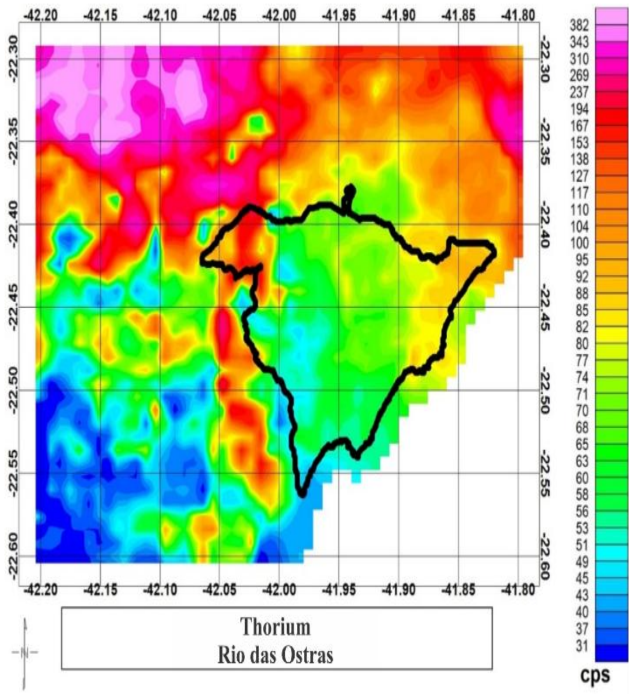

Figure 8: Thorium radiation count

Thorium count in most parts of the municipality was measured between 56 to 77 cps (greenish region). The highest counts occur in the northwest of the municipality in the União Biological Reserve due to garnet and gneisses of the Paraíba do Sul Complex with over 200 cps, and also in the northeastern part of the municipality associated with the gneisses of the Região dos Lagos Complex with around 150 cps. Granite Sana in the northwest of the map proved to be the region with the highest thorium count reaching almost 400 cps. Low counts are also evident in sandbank regions, river beds, dunes and beaches.
Figure 9 shows the uranium radiation count:

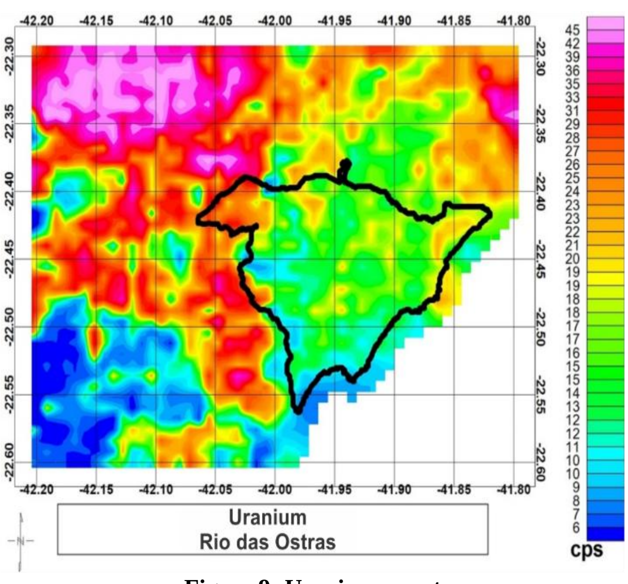

Figure 9: Uranium count

The uranium count map presents the most scattered and low count values ranging from 6 cps to 45 cps. The highest counts in the municipality occur in the northwest of the municipality in the Union Biological Reserve due to garnet and gneisses of the Paraíba do Sul Complex with around 30 cps. The low counts in sandbanks, river beds, dunes and beaches are also noteworthy.
Figure 10 shows the ternary map in a CMY system (Cyan, Magenta and Yellow)

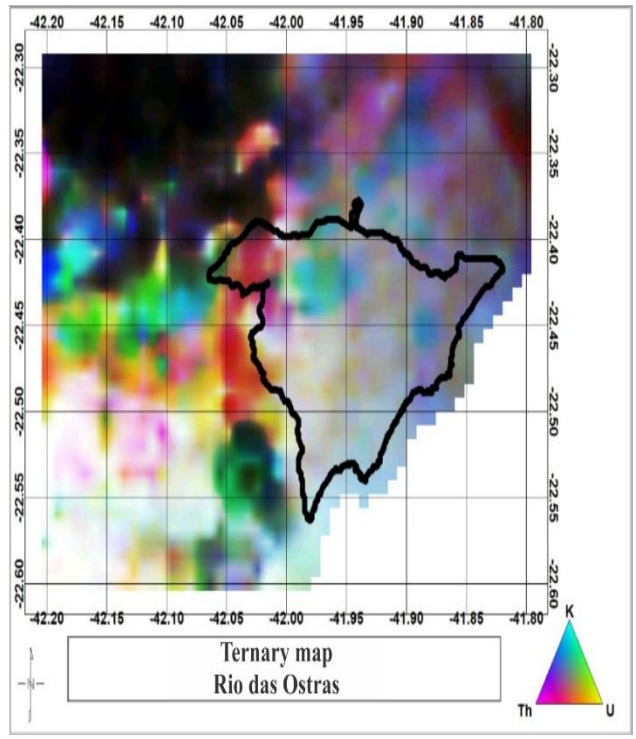

Figure 10: Ternary map of uranium, thorium and potassium.

In this type of map, a color triangle relates the potassium, thorium and uranium counts to the colors cyan, magenta and yellow, respectively. The white regions represent low counts of the three elements and the black regions represent high counts of the three. It should be noted that the lower half of the map is whitish, containing a low count of the 3 elements. The northwest region is dominated by thorium because of its magenta color. To the north and northeast of the municipality, there is a predominance of potassium. There is a simple predominance of potassium only in the central strip of the municipality and on the banks of the Rivers Lontra and São João, which are located to the west of the municipality. Granite Sana and Morro São João stand out as bodies dominated by higher counts and are also located in regions of higher altitudes. Finally, analyzing the land use map in figure 4, it can be perceived that the regions of low radiation in the ternary map coincide with the region of urban occupation, which contributed to mitigate the detected counts.

5. CONCLUSION

In this paper, the basis of the radiometric method and its application in the city of Rio das Ostras was described. The study region was described using topographic, geological and land use maps. The analysis of radiation data from the city's soil was performed using the aerogeophysical database (Project Code 1038) made available by CPRM - Geological Service of Brazil, of thorium, potassium and uranium. The processing of natural radioactivity data allowed the elaboration of maps for each element, the total count map, and the ternary map. These maps were compared to the geological, topographic, and land use maps. In general, the regions that had the highest radiation index were the highest altitude regions, such as Sana located in the city of Macaé, due to the granite formation, and also Morro São João due to its alkaline rocks. In contrast, in the region studied, lower radioactive counts were observed in the coast, mangroves and sandbeds of the São João, Macaé, Dourado and Imboassica rivers. Finally, the maps may be useful for geological and environmental studies, in addition they can contribute to the study of soils in the region.

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