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Application of the Radiometric Method of Uranium, Thorium, and Potassium in the Cabo Frio Region, Brazil

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ABSTRACT

This paper presents an application of radiometric method through Cabo Frio region, Brazil. The radiometric data collected by aircraft allowed the making of radiometric maps in counts per second of the Uranium, Thorium and Potassium channels by interpolation in the study area. The radiometric maps provide great information about shallow geology. The comparison of the generated maps with the topographic and geological maps allowed setting out the marine deposit, silty-sand-clayey and sandy areas which indicate low count, as well as high count areas, associated in the majority of cases to orthogneiss and garnet situated at high ground region.

Key words: Radiometry, Radiometric Method, Cabo Frio.

1. INTRODUCTION

The municipality of Cabo Frio is one of the oldest Brazilian locations. Geographically, it is located in the southeastern region of Brazil and comprises a territorial area of approximately 410.418 km^2, at a latitude of 22°52′46 ″ south and a longitude of 42°01′07 ″ west [1].

The Cabo Frio region is considered one of the largest economies in the state of Rio de Janeiro, Brazil. It is the main regional center from the diversification of commercial activities and services. Cities such as Arraial do Cabo, Armação dos Búzios, São Pedro da Aldeia, and Araruama are in its surroundings, whose lagoon is part of the territorial extension of Cabo Frio, which in turn has great importance in the salt-producing market [2].

Aeroradiometric surveys are valuable for geological mapping and exploration of mineral resources. With the growth of the economy and the search for new mineral deposits, some methods that use radioactivity have been increasingly used [3].

The advancement of technology has made great progress in aeroradiometric methods. It currently has a fully technological detection system, which facilitates data collection and processing [4].

Although Cabo Frio is one of the most beautiful tourist cities on the Brazilian coast, the city is also a major economic hub due to the existence in its territorial extension of the Araruama Lagoon, known as the largest hypersaline lagoon in the world, thus standing out for its potential in the salt (NaCl) production sector.

The entire Cabo Frio region is covered by aeroradiometric surveys, thus offering an excellent opportunity to analyze the entire subsoil of the area without the need for excavations, which would result in higher costs.

According to Silva [5], the radiometric method can be used as an optimizer and achieves significant results in the investigation of extensive territorial areas and geological structures.

Thus, this paper aims to provide a geological study through the acquisition and interpretation of aeroradiometric data of uranium, thorium, and potassium from the entire Cabo Frio region. For that, section 2 presents the description of the studied region. Section 3 presents the theoretical basis of the radiometric method. Section 4 presents the radiometric maps and their interpretation. Finally, in section 5, we have the main conclusions pointed out.

2. GEOLOGICAL CHARACTERISTICS OF THE CABO FRIO REGION

The region where the project was developed has a geology that can be represented by the simplified geological map described in Figure 1 and Table 1 [6].

From the satellite data of the Topex V18.1 global topography model developed by the Oceanography Institute of the University of San Diego [7], we created a topographic map of the Cabo Frio region, which allows viewing the variety of relief of the region shown in Figure 2 (with 2D view).

The altitude varies from −8 m to close to 62 m. The lowest region, according to Figure 2, is from the northeast to the southeast of the map, and the highest altitude is the northern region.

The area identified by the pink color on the map (Figure 2) shows one of the places with the highest altitude located in the vicinity of

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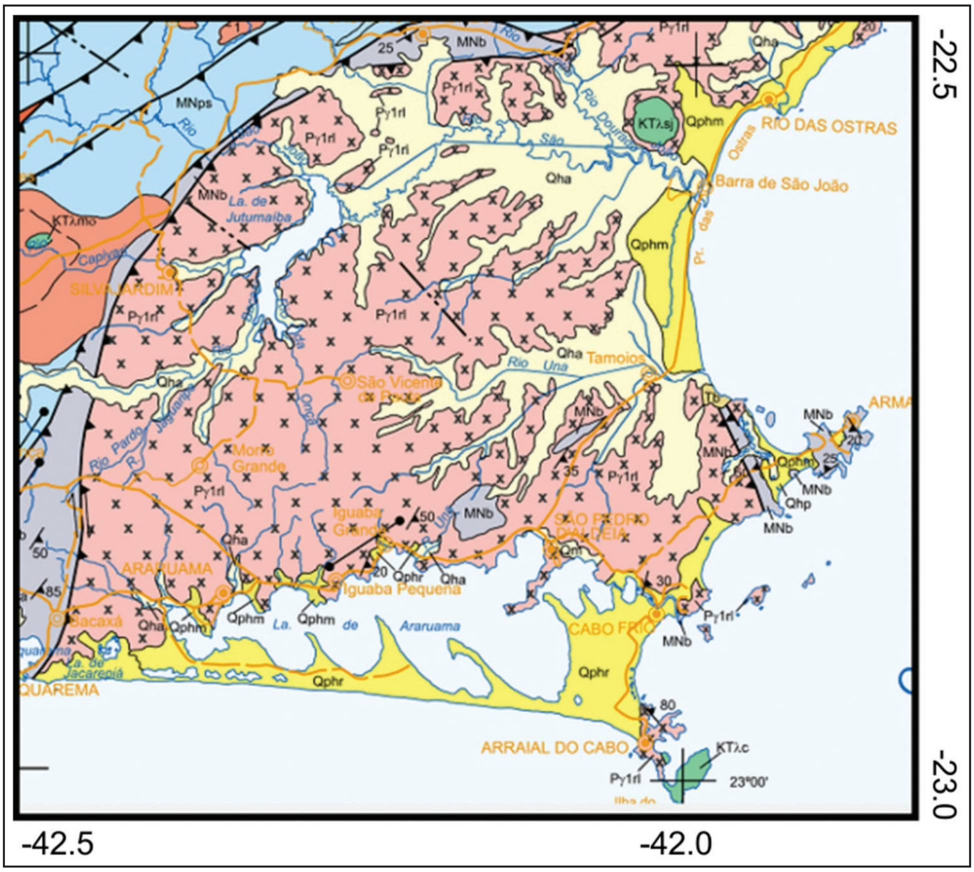

Figure 1: Geologic map of Cabo Frio Region.

Table 1: Geological units.

Geological Units	Name
Qha	Alluvial deposits (Fluvial and marine sand-silty-clay deposits)
Qphm	Fluvial and marine deposits (Sandy-clayey fluvial-marine deposits, rich in organic matter)
Qphr	Dune fields (Quartz, sand, dune fields)
Tb	Barreiras group (Poorly selected detritic deposit with gravel size, sandy-clay sand)
KTλ	Cretaceous/tertiary alkaline rocks (Syenites, alkaline intrusion)
MNb	Búzios complex Kyanite, sillimanite, garnet, biotite, shale, gneiss)
MNps	Paraíba do Sul complex (Grenade, quartz, gneiss)
Pγ1rl	Região dos Lagos complex (Hornblende, biotite, orthogneiss)

the municipalities of Casimiro de Abreu and Rio Bonito. The lower altitude areas are located along the coastal cities of the Lagos region, in which Cabo Frio is included in the study.

3. RADIOMETRIC METHOD

The radioactivity is present in rocks, soils, hydrological systems in emerging areas, groundwater, seas, and atmosphere; it comes from natural radioactive elements. According to Madrucci [8], numerous types of radioactive nuclei are present on Earth, but those that are most relevant to rocks and that occur in abundance in the Earth's crust are uranium (U), thorium (Th), and potassium (K).

The elements U, Th, and K are present in certain minerals in different lithologies. They can provide additional data on the chemical characteristics of the rock [9].

The elements in question are lithophilic, more reactive elements, and are concentrated especially in igneous rocks. In this type of rock, there is a significant variation in radioactivity due to the mineralogical, petrographic, and structural chemical properties [10].

The concentration of uranium, thorium, and potassium in igneous, metamorphic, and sedimentary rocks is present in Tables 2-4 [11].

For Atkins and Jones [12], isotopes of several chemical elements can spontaneously disintegrate, generating the emission of particles and detectable electromagnetic radiation, allowing the location of the material that produced them.

The radiometric method consists of detecting nuclear radiation emissions from rocks that have radioactive minerals. In this case, gamma radiation (electromagnetic wave) is detected through a scintillometer or Geiger counter to obtain the geological, geochemical, and environmental mapping of the region, and it can also be useful to identify soil and subsoil lithologies [13].

The gamma radiation spectrometers normally have 256 (or 512) channels in the 0–3 MeV energy range. Each channel records all the

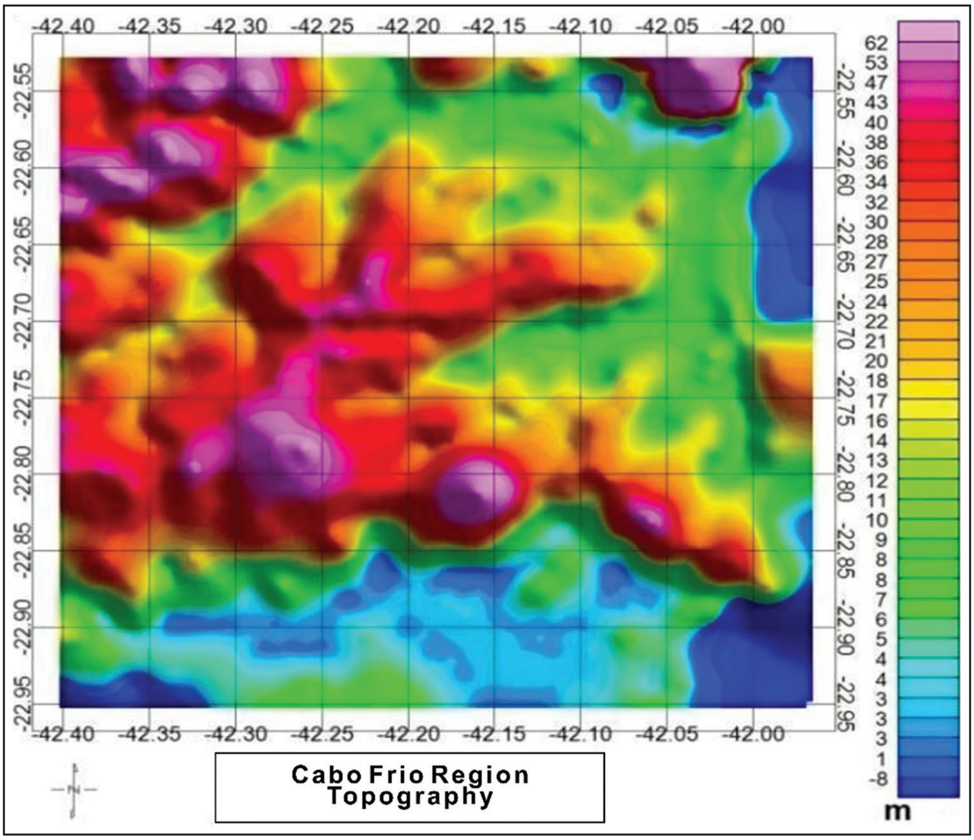

Figure 2: Topographic map of the Cabo Frio region (2D view).

Table 2: Concentration of thorium, uranium, and potassium in igneous rocks [11].

Rock	Th (ppm)	U (ppm)	K (%)
Acid	18.0	3.5	3.34
Intermediate	7.0	1.8	2.31
Basic	3.0	0.5	0.83
Ultrasound	0.005	0.003	0.03

Table 3: Concentration of thorium, uranium, and potassium in metamorphic rocks [11].

Rock	Th (ppm)	U (ppm)	K (%)
Schists	13.5	4.1	2.5
Marble	1.8	1.1	0.4
Amphibolites	4.0	1.0	0.7
Gnaisses	8.0	1.6	2.0

Table 4: Concentration of thorium, uranium, and potassium in sedimentary rocks [11].

Rock	Th (ppm)	U (ppm)	K (%)
Sandstone	10.0	3.0	1.2
Limestone	1.8	1.4	0.3
Leaves and clays	11.0	4.0	2.7

Table 5: Conventional approach for acquisition and processing [3].

WINDOW	NUCLIDE	ENERGY RANGE (Mev)
Total count	-	0.40 – 2.81
K	^{40}K (1460 keV)	1.37 – 1.57
U	^{214}Bi (1765 kev)	1.66 – 1.86
Th	^{208}Ti (2614 keV)	2.41 – 2.81

gamma rays absorbed by the detector with energy in a range of 11.7 keV. The conventional approach for acquiring and processing gamma-ray spectrometric data for measuring U, Th, and K is shown in Table 5 [3].

The aeroradiometric surveys are basically based on the repeated measurement of the gamma radiation flow spectrometry through the assembly of detectors on an aircraft. The acquired data undergo some corrections and are subsequently processed to generate the desired results as presented in concentrations of uranium, thorium, and potassium [3].

The "Low Level" test performed to correct radiometric data is also referred to as the repeatability line. In this test, a measurement ramp needs to be created, usually on the runway at the airport where the aircraft performs flights at prospecting heights that are around 100 m, then collecting for around 2 min. As the test is always carried out on the same ramp, a pattern of radiometric measurements is generated, so the diurnal variation of the test is verified, for example, radon interference. The "High Level" test is also called a calibration test. In this test, a flight direction is maintained for collecting measurements with about 3 min at the height of approximately 800 m. In such a case, it is not necessary for the measurement ramp to be always the same since at this point we consider that the data on the ground do not interfere with the measurements. The background test is what is repeated daily, in this test, radiometric measurements of the environment are made.

This interference is also known as ground measurements. In addition to these corrections, the correction of the Compton Effect can be mentioned, where the electromagnetic wave is scattered, increasing its wavelength and reducing the photon energy [14].

4. PROCESSING AND RESULTS

The surrounding area of Cabo Frio is covered by an aeroradiometric survey carried out by Bandeirante aircraft, with sampling intervals of 100 m, spaced profiles of 1 km, and measurement lines in the North-South direction. The gamma-spectrometer used in the survey was the Geometrics GR-800A with thallium-activated sodium iodide crystals with a volume of 3072 cubic inches.

Aeroradiometric surveys consist of aerial measurements of the natural gamma radiation emitted by the soil and geological formations close to the surface. The spectrometric gamma measurements focused on the radiation emitted by the elements uranium (U), thorium (Th), and potassium (K). The results were recorded as the count per second (cps) of the channels referring to these elements and also the total count (TC).

Subsequently, routine corrections were applied to the raw data of the radiometric method, such as height corrections, Compton Effect, background, among other device-specific corrections. Through the technique of minimum curvature with cells of 250 m, the corrected maps of uranium, thorium, and potassium counts were created with 2D views represented by Figures 3-6. The maps were then correlated to the simplified geological map (Figure 1).

As shown in Figure 3, the highest uranium counts are located in the west and northwest regions of the map and approximately in the center towards the south. They are associated with the alkaline orthogneisses of the Região dos Lagos unit (Pγ1rl) and the gneisses and grenades of the Búzios (MNb) and Paraíba do Sul (MNps) complexes. Large counts are also evident in the northeast area of the map, referring to the alkaline rocks of the Maciço Alcalino do Morro São João unit (KTλsj). Further southeast of the map, high uranium counts can be identified on Cabo Frio Island (KTλc) due to the presence of alkaline rocks, referencing the unit.

The smallest uranium counts can be identified in the regions surrounding the Araruama Lagoon and its southernmost locations on the map, they are associated with the quartz sand deposits present in the Resting Deposit (Qphr) unit and the Sandy-clayey deposits present in the Fluvial and Marine Deposits (Qphm).

There is also the presence of these deposits to the east of the map, close to the Tamoios region and to the northwest in the Juturnaíba Lagoon and its surroundings. These lower radioactive counts occurred mainly around the Araruama Lagoon, which is a region with great potential for the production of salt (NaCl).

As shown in Figure 4, high counts of thorium are found along the Região dos Lagos Complex (Pγ1rl), associated with calc-alkaline orthogneiss rocks, present both in the west and northwest and in the north of the map, comprising a large extent. In the northeast region, the highest counts are associated with the cretaceous/tertiary alkaline rocks present in the Morro São João unit (KTλsj).

Higher thorium counts can also be observed in a small region from the center to the south of the map, near the Araruama lagoon, possibly referring to the Búzios Complex (MNb) unit associated with grenades and gneisses.

The lower thorium counts show the regions of marine fluvial and silty-sandy-clayey deposits that encompass lines of beaches and lagoons present in the Marine and Fluvium-Marine (Qphm) unit to the northeast and east of the map, close to the Tamoios region, besides the Juturnaíba Lagoon (Qha). To the south, more precisely around Araruama Lagoon, areas formed by deposits of quartz sand, which constitute sands of the Dune Field unit (Qphr), also showed low counts.

As shown in Figure 5, the highest counts occurred in the north of Araruama Lagoon dominated by the Região dos Lagos Complex (Pγ1rl). There are also large potassium counts in the alkaline rocks of the KTλsj unit. It is also evident that there is a high

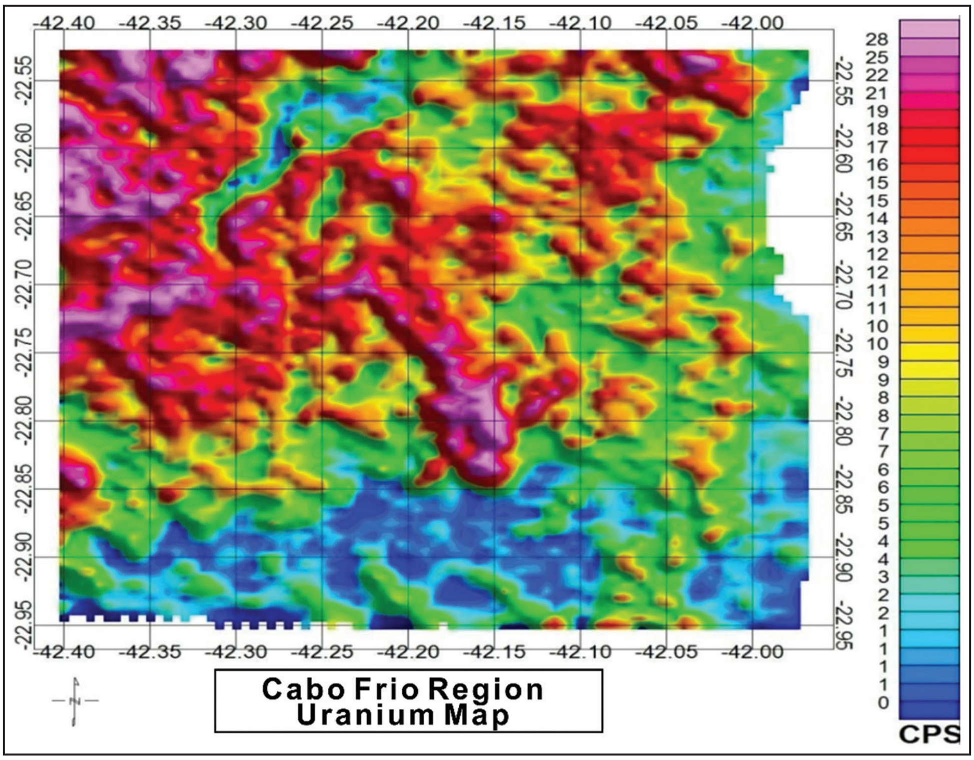

Figure 3: Corrected uranium map of the Cabo Frio region (2D view).

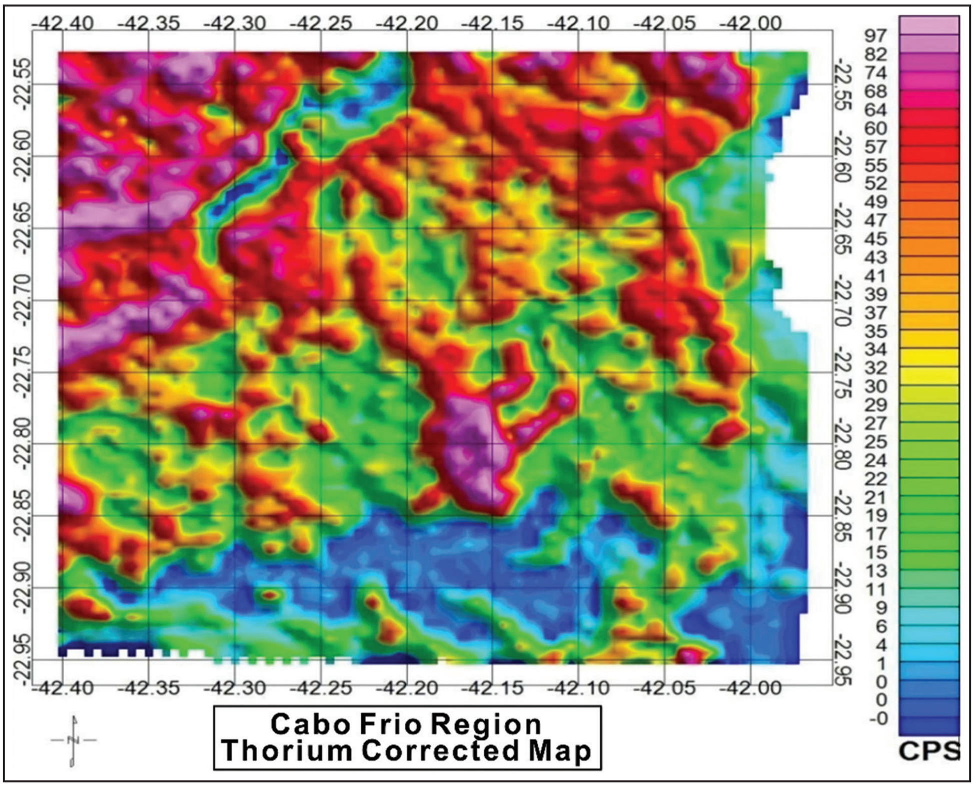

Figure 4: Corrected thorium map of the Cabo Frio region (2D view).

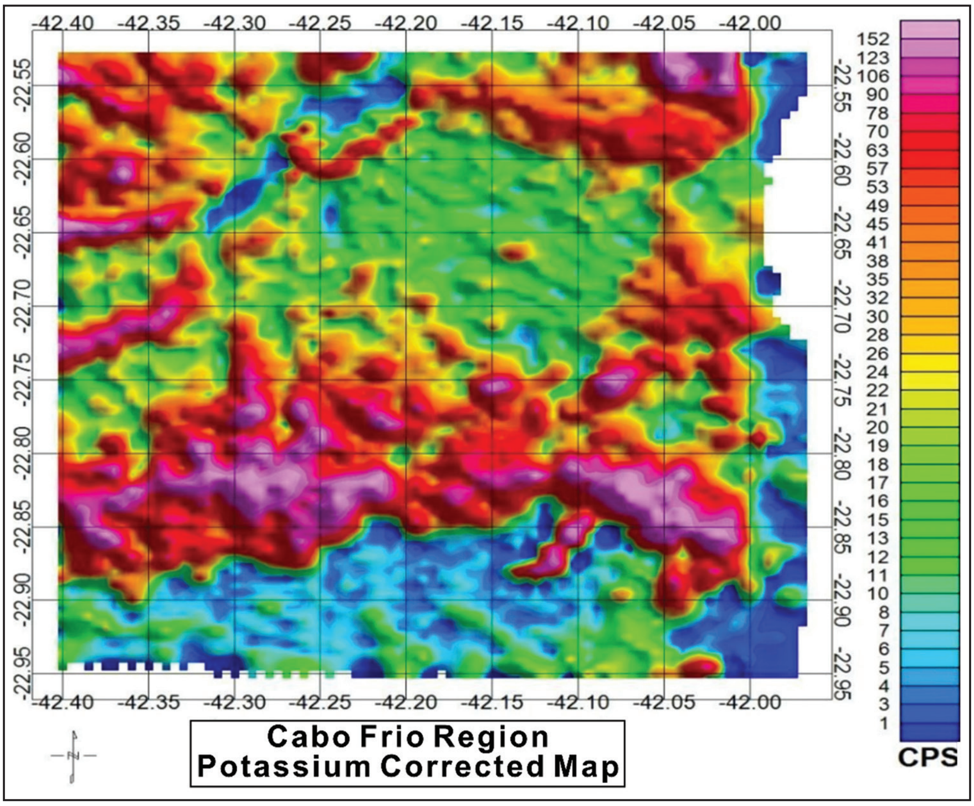

Figure 5: Corrected potassium map of the Cabo Frio region (2D view).

count on the island of Cabo Frio regarding the alkaline rocks of the KTλc unit.

The lowest potassium counts located in the central area to the northeast of the map, close to the Tamoios region, and they are associated with the Qha unit, referring to sediments and river deposits. The south and southeast of Cabo Frio also show small counts associated with the Dune Field (Qphr) and the Fluvial and Marine Deposits (Qphm) units.

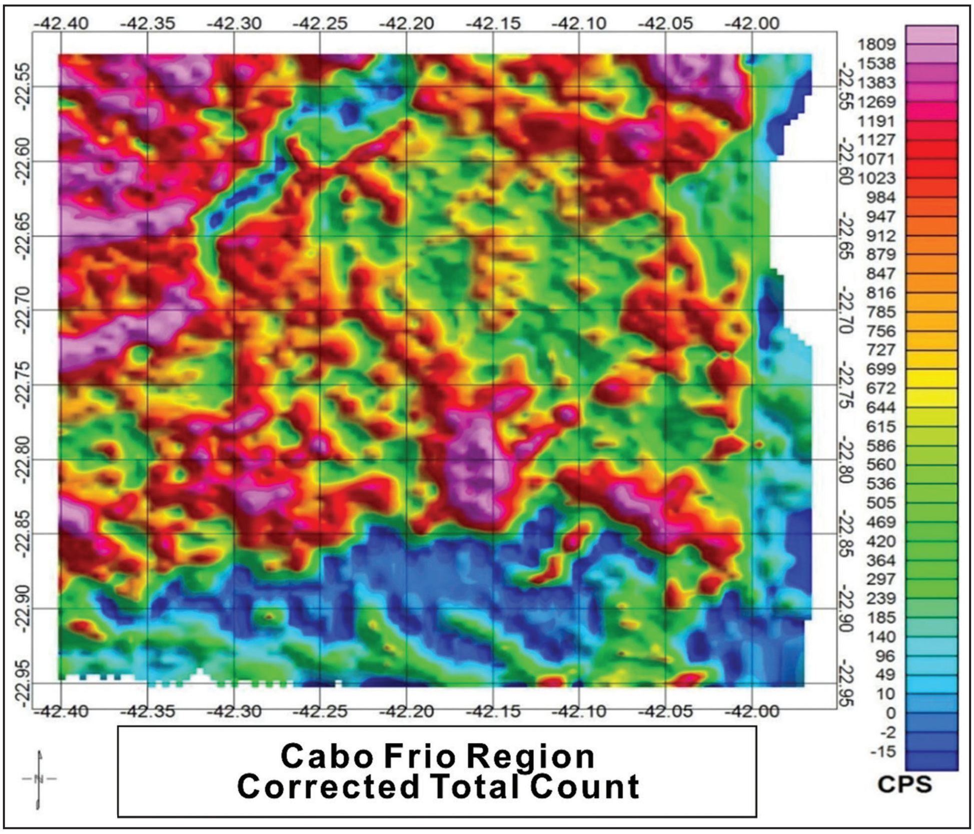

Figure 6: Map of the total count of the Cabo Frio region (2D view).

As shown in Figure 6, the TC map of the Cabo Frio region and all its surroundings show important geological units from across the area, clearly differentiating the regions of high and low counts.

The largest counts are well distributed throughout the map and are located largely in the west and northwest of the map, associated with the gneisses of the Região dos Lagos Complex (Pγ1rl) Paraíba do Sul Complex (MNps) and the grenades and gneisses from the Búzios Complex (MNb). The alkaline rocks of Morro São João (KTλsj) have a high count to the northeast of the map, and the grenades and gneisses associated with the MNb unit (Búzios Complex) also stand out with a large count from the central to the south near the Araruama Lagoon. In the southeastern region, the Pγ1rl unit can also be identified, which is very present in large part of the map. The KTλc unit associated with the alkaline rocks of the island of Cabo Frio to the southeast of the map also has a large count.

The lowest counts are located in regions well spread on the map, in the northeastern region, there is the presence of silicon-sand-clayey and clay-marine deposits from the Qphm unit. In the southern and southeastern areas of Cabo Frio, around the Araruama Lagoon, they are the deposits of quartz and sand associated with the Dune Fields (Qphr) and with a small presence also from the Fluvial and Marine Deposits (Qphm) again, which results in lower counts. Near Tamoios region, there are also low counts referring to the sandy and silty-clayey fluvial and marine fluvial deposits associated with the Alluvial Deposits (Qha) unit. These lower counts showed that the entire Araruama Lagoon and its sandy deposits always presented low counts.

5. CONCLUSIONS

In this paper, the theoretical bases of radioactivity and the aeroradiometric method were presented, describing the main elements responsible for the emission of natural radioactivity (uranium, thorium, and potassium). These bases were of great importance in the use and application in the radiometric study of the Cabo Frio region.

It was used a large aerogeophysical database in Geosoft's xyz and gdb formats. It was possible to apply these data in the radiometric method of uranium, thorium, and potassium to investigate the area studied.

Maps of natural radioactivity in the uranium, thorium, and potassium channels of the Cabo Frio region were prepared. It was possible to highlight the main geological formations of the covered area and their radiation emissions.

Through these maps, it was possible to distinguish the areas with silty-sandy-clayey-sand-marine deposits and quartz-sandy that indicate low counts, as well as the regions with high counts, mostly associated with orthogneisses and garnets in general present in regions of higher altitudes.

From the radiometric maps, it was possible to make the correlation with the geologic map of the Cabo Frio region. This comparison provided the identification of areas with lower radiometric counts, usually present on the banks of lakes, rivers, and seas. Thus, the regions with the greatest potential for salt production have low radioactive counts.

The obtained maps provide a radiometric basis that can be used in other studies such as geological, geochemical, and environmental, thus contributing to the understanding of all soil and subsoil in the Cabo Frio region.

For future work, it is suggested that local surveys be carried out to validate the results obtained by the method used. It is also recommended to reprocess the maps with the conversion of counts per seconds (cps) to percentage (%) and ppm for the concentrations of uranium, thorium, and potassium for a better assessment of the geology of the Cabo Frio region.

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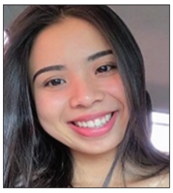

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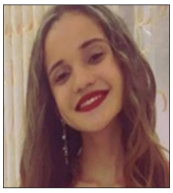

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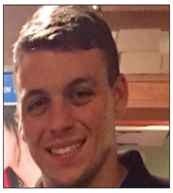

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