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Gamma radiation of the street corners from South zone of Natal city, Rio Grande do Norte, Brazil

Campos[a] T.F.C., Motoki[b] K., Pastura[c] V.F.S., Sichel[b] S.E., Fonseca[b] E. M.

[a]Natural Radioactivity Laboratory of Federal University of Rio Grande do Norte, 59064-741 Natal RN; [b]Geosciences Institute of Fluminense Federal University, 24210-346 Niterói RJ; [c]Nuclear Engineering Institute, 21941-610 Rio de Janeiro RJ

Email: thomas.campos@ufrn.br

ABSTRACT

This research had the objective of studying the absorbed dose of the street corner intersections from the South zone of Natal city, Brazil. This city grew up on dune lands, on siliciclastic rocks from Barreiras Formation, these dunes are quartz-sand and have heavy mineral layers bearing uranium and thorium (monazite, xenothymeo, thorianite, ilmenite, rutile, zircon, magnetite and columbite-tantalite). Not all streets in Natal city have paving, in the part with more movement they have asphalt covering over cobblestone, in the less busy have cobblestone covering, and in the quiet streets are in natural dune sand. In situ Gamma radiation measurements were performed with three portable spectrometers model RS-230 with BGO crystal, about 1 meter above the ground. The absorbed dose ranged from 11 to 150 ηGy/h (MG: 40; Median: 39; SD: 18). In gamma spectrometry measure, Uranium varied between 0.1 to 6.2 Eq.A. ppm (MG: 1.6; Median: 1.4; SD: 1), Thorium between 0.7 to 32 Eq.A. ppm (MG: 6; Median: 5; SD: 3.3), Potassium ranged between 0.1 to 3.9 Eq.A. % (MG: 1.2; Median: 1.2; SD: 0.7). The values of the absorbed dose of external radiation measured in the studied street corners show values lower than the world average of 59 ηGy/h, and annual effective dose is also lower than the global average value of 0.48 mSv/a. Areas with higher U-K contents correspond to areas with asphalt/cobblestone capping, while areas with higher Th contents correspond to sandy streets and dunes in protected areas. This fact denote a lower radiometric risk to the population.

Keywords: Natural radioactivity, Radiation hazards, Sand dunes, Natal-Brazil.

1. INTRODUCTION

All living organisms on the planet are exposed to the Earth's natural radiation. The exposure to natural ionizing radiation is a constant and inexorable life feature. The background radiation comes from soils, air, food, outer space and even our own bodies. The ionizing radiation present in the environment is mainly due to the primordial natural radionuclides activity, namely U-238, Th-232, K-40, associated to natural occurrence radioactive materials (NORM) in the Earth's crust [1, 2, 3]. The external exposures to NORM arise from terrestrial radioisotopes present at trace levels in soil, sediments and building materials. Consequently, geological formation, the soil type and bulk materials of buildings (bricks, concrete, cement, aggregates) in a given area control the natural radioactivity and the external exposure associated with gamma radiation. These factors strongly influence the dose distribution of natural terrestrial radiation [2, 3].

The natural radiation is the biggest contributor to the dose absorbed by the world population, therefore, it is vitally important to evaluate the dose of gamma radiation from natural sources. The U-238, Th-232 and K-40 concentrations varies widely and depends on their location [2, 3]. Most of the external gamma dose rate (95%) above typical soils comes from primordial radionuclides embedded in the soil [4, 5]. The objective of this research was to investigate the natural radioactivity of street corner intersections from the South zone of Natal city, Rio Grande do Norte, Brazil, through the analysis of the absorbed dose rate in the air, obtained by *in situ* gamma ray spectrometry, in order to determine the activity equivalent concentration of U-238, Th-232 and K-40 and the fatality cancer hazard index.

2. GEOLOGICAL ASPECTS

The studied area is the South zone from Natal city, Rio Grande do Norte, Brazil (05º 47' 42" S, 35º 12' 34" W) and has 896,708 inhabitants (2021 census; Fig. 1). Geologically, Natal city grew up over dune terrain, which is composed of unconsolidated sedimentary rocks and more rarely consolidated, they are composed of very friable material and easily transported by wind action.

These unities are: Vegetated coastal wind deposits (N4elv), Un-vegetated coastal wind deposits (N4eln) and Beach littoral deposits (N4lp) (Fig. 2).

Figure 1: *Geographical location of Natal city, Rio Grande do Norte, Brazil.*
Source: GeoMapApp (www.geomapapp.org; [6]).

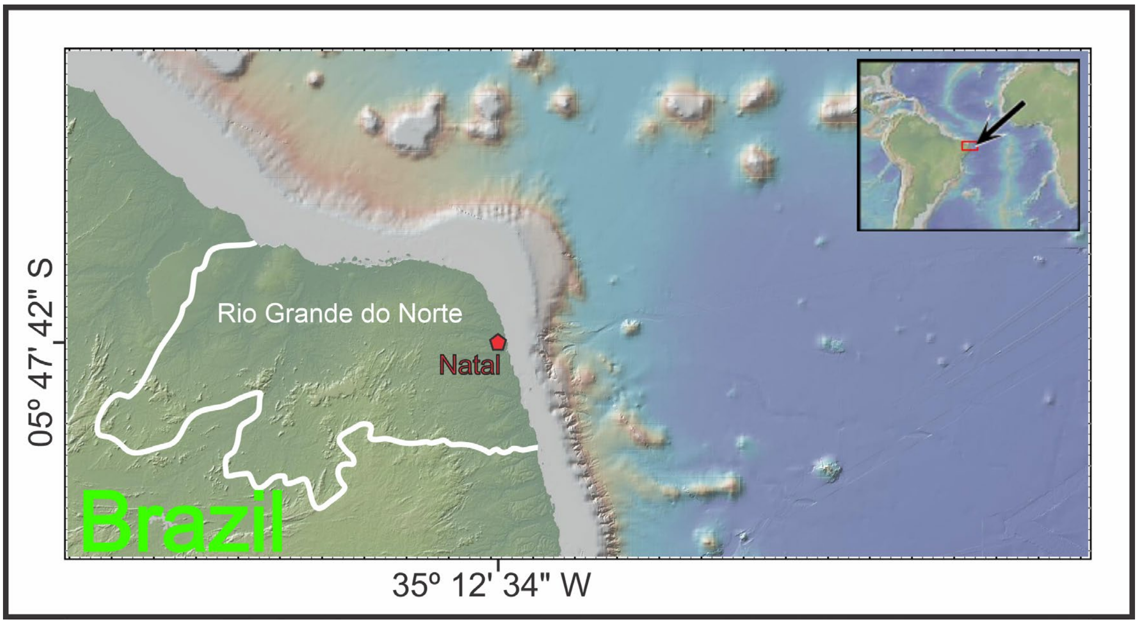
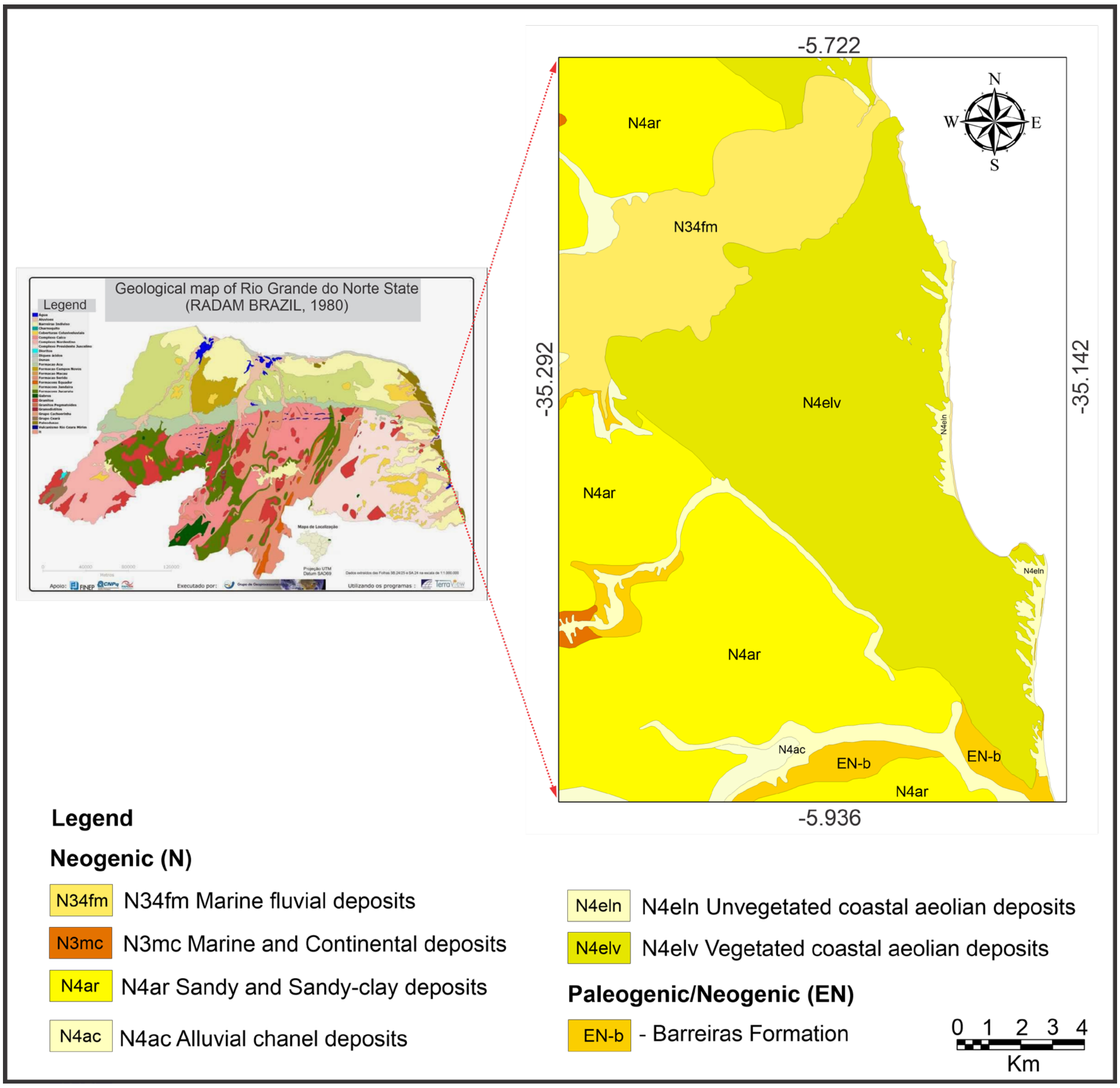


Figure 2: *Geological map of Natal city, Rio Grande do Norte, Brazil.*
Source: [7, 8]



3. MATERIALS AND METHODS

The measurement stations were randomly chosen, located at the intersection of street corners from the South zone of Natal city.

For *in situ* surface gamma radiation measurements were used three portable gamma radiation spectrometers model RS-230® with BGO crystal (Radiation Solution Inc., Canada). These instruments are factory calibrated, with a 5-year stability guarantee and does not require a radioactive source for field calibration. The measurements were performed by a researcher-collector who suspended the RS-230 spectrometer 1 meter above the ground and far from any masonry construction [9].

At each station, *in situ* gamma spectrometry was performed with the protocol of 5 measurements with 3 minutes duration and with an interval of 10 minute between them [9]. The data average of each station was calculated and taken as the absorbed dose rate of the sampled station [9]. For civil security reasons, measurements were only carried out in the southern area of Natal city. This research took place during the year 2019.

For the analysis of natural and artificial radioactivity, several health risk indexes have been used by research organizations [3, 9, 10, 11, 12, 13, 14, 15], in order to arrive at a better and safer conclusion about the health status of an irradiated environment or irradiated person, whose maximum limits recommend that the gamma radiation of natural radionuclides in a given area generates an Annual Equivalent Effective Dose below of 1 mSv/y, namely:

- External Absorbed Dose (AD_{Ext}) [3]

$$AD_{Ext}\ (nGy/h) = 0.462 \times A_{U,} + 0.604 \times A_{Th} + 0.417 \times A_K \quad (1)$$

Where: A_U, A_{Th} and A_K are the activity concentrations of U-238, Th-232 and K-40, and 0.462, 0.604 and 0.0417 are the conversion factors dose for radionuclides, respectively.

- External Annual Effective Dose (AED_{Ext}) [3]

$$AED_{Ext}\ (mSv/y) = AD_{ext} \times OF_{ext} \times T \times f \quad (2)$$

Where: AD_{ext} the external absorbed dose (ηGy/h); OF_{ext} the external occupancy factor (20%); T is the annual duration time in hours (24 h x 365 day) and *f* is the conversion coefficient (0.7 for adults adopted by [3]. Maximum value allowed: 1 mSv/y.

- Gamma Activity Index (GAI) [13, 14, 15]:

$$GAI = C_U / 370 + C_{Th} / 200 + C_K / 3000 \qquad (3)$$

Where: C_U, C_{Th}, C_K are the Activity concentrations (Bq/kg) of U-238, Th-232 and K-40. Maximum value allowed: 1 Bq/kg.

- Radium Equivalent Activity (RaEq) [13, 14, 15]:

$$RaEq = C_U + 1.43 \text{ x } C_{Th} + 0.077 \text{ x } C_K \qquad (4)$$

Where: C_U, C_{Th}, C_K are the Activity concentrations (Bq/kg) of U-238, Th-232 and K-40. This formula is based on the estimation that 1 Bq/kg of U, 0.7 Bq/kg of Th and 13 Bq/kg of K produce the same dose of Gamma radiation. Maximum value allowed: 370 Bq/kg.

- External Hazard Index (HI_{Ext}) [3]:

$$HI_{Ext} = C_U / 370 + C_{Th} / 259 + C_K / 4810 \qquad (5)$$

Where: C_U, C_{Th}, C_K are the activity concentrations (Bq/kg) of U-238, Th-232 and K-40. Maximum value allowed: 1 Bq/kg.

- External Fatality Cancer Hazard (FCH_{Ext}) [10]:

$$FCH_{Ext} = AED_{Ext} \text{ x } LT \text{ x } FH \qquad (6)$$

Where: AED_{Ext} is the External Annual Effective Dose, LT is the estimated life time of 70 years, FH is the Fatality Hazard Factor for Cancer by Sievert = 0.06 for the public recommended by [3].

According to [9] for the purpose of some calculations foreseen in gamma radiation dosimetry, the following equivalences between the activity concentrations of U (ppm), Th (ppm) and K (%)

and the respective value in Bq/kg should be used:

$$1\ ppm\ of\ U = 12.35\ Bq/kg\ of\ U\text{-}238 \tag{7}$$

$$1\ ppm\ of\ Th = 4.06\ Bq/kg\ of\ Th\text{-}232 \tag{8}$$

$$1\ \%\ of\ K = 313\ Bq/kg\ of\ K\text{-}40 \tag{9}$$

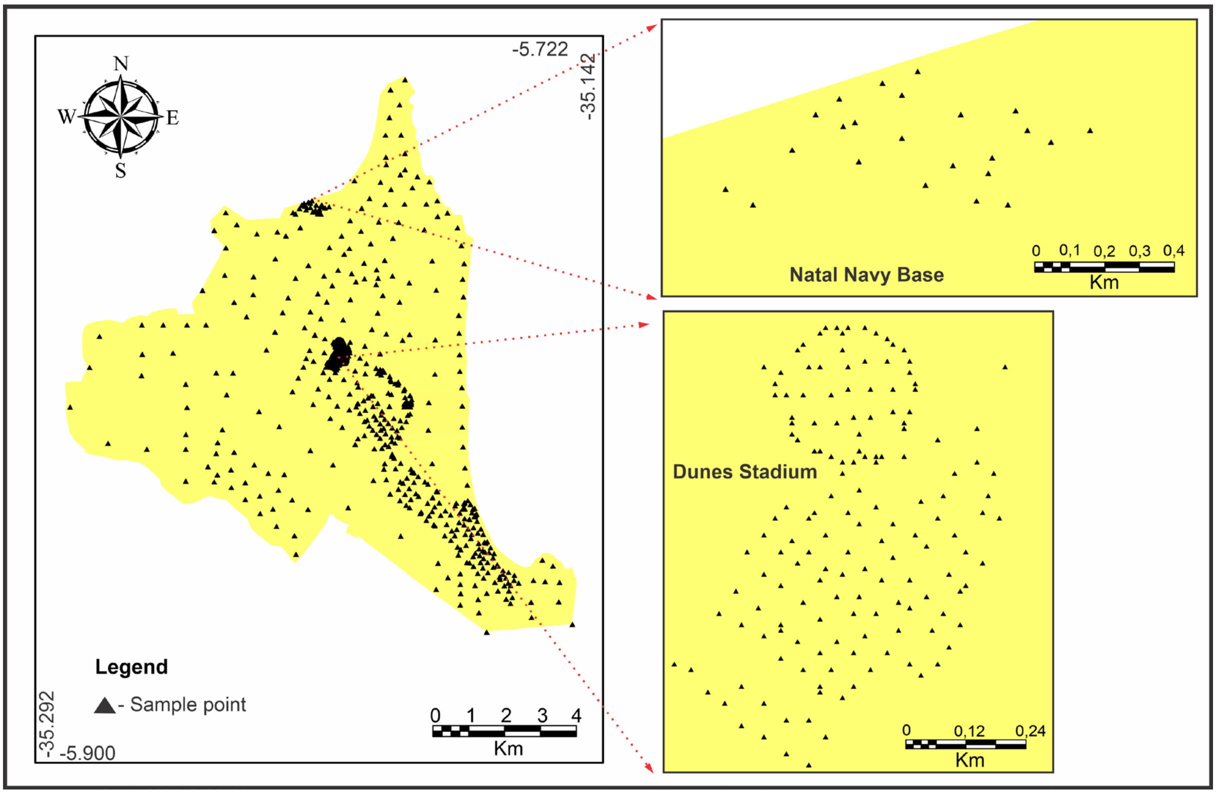
Attention is drawn to the fact that the international community is adopting as a policy of protection against radiation the motto that “there is no minimum threshold of dose of radioactive exposure that is safe”. This motto, designated by the English acronym of LNT (Linear no-threshold), carries with it the assumption that an unsafe dose of radiation is always received. Consequently, we should always consider radiation exposure values as low as possible as a policy to protect against ionizing radiation. This policy is called ALARA (As Low As Reasonably Achievable).

4. RESULTS AND DISCUSSION

Data collection totaled 630 points, were measured in the street corner intersections from the South zone of Natal city, Rio Grande do Norte, Brazil (Figure 3). The natural gamma radiation level showed great variation, due to the street paving type, where: the busy streets have asphalt capping on cobblestone, with little traffic have granite cobblestone capping and quiet streets have no capping and outcrop sands of old dunes.

The statistical summary of the gamma radiation variation is given in Table 1 and its distribution interpolated by the “Natural Neighbors” method and respective histogram are given in Figures 4, 5, 6, 7, 8, 9, 10, 11 and 12.

Figure 3: *Map of gamma radiation sampling points of the street corner intersections from the South Zone from Natal city, Rio Grande do Norte, Brazil.* The areas with the highest sampling density are expanded and are the Natal Navy Base and the Dunes Stadium.



The data analysis allows suggest that about 90% of the Absorbed Dose in the Air from the external gamma radiation of the studied street corners denote an average radiometric potential lower than the world average value 59 ηGy/h [3], but with a peak of 150 ηGy/h (Fig.4). The areas with the highest levels of U and K correspond to the areas with asphalt/cobblestone capping, while the areas with the highest levels of Th correspond to the sand streets and dune's pathway of the protected areas (Fig. 5, 6 and 7). However, in the Natal Navy Base area we have positive peaks for K and very lower values for Th (Fig. 3, 6 and 7). While in the area of the Dunes stadium we have positive peaks for U and very lower values for K (Fig. 3, 5 and 7). We associate these two facts with the different NORM compositions of the bulk materials (bricks, concrete, cement, aggregates) used in buildings [14].

Table 1: Statistical summary of the variation of natural gamma radiation (n: 630) of the street corner intersections from the South Zone of the Natal city, Rio Grande do Norte, Brazil.

	Max*	**Min***	**Med***	**GM***	**SD***	**CI (?)**
Equivalent activity U (ppm)	6.19	0.09	1.42	1.60	0.99	0.08
Equivalent activity Th (ppm)	31.62	0.70	5.20	5.95	3.27	0.26
Equivalent activity K (%)	3.87	0.10	1.20	1.19	0.72	0.06
External Absorbed Dose (ηGy/h)	149.70	11.50	38.59	39.87	17.53,	1.37
Annual Effective Dose (mSv/y)	0.18	0.01	0.05	0.05	0.02	0.002
Gamma activity index (Bq/kg)	1.15	0.07	0.30	0.31	0.14	0.01
Ra Equivalent Activity index (Bq/kg)	310.70	20.53	79.09	82.79	36.27	2.83
External Hazard index (Bq/kg)	0.13	0.01	0.03	0.03	0.01	0.001
Fatality Cancer Hazard index	0.77	0.06	0.20	0.21	0.09	0.007

* Max: Maximum; Min: Minimum: Med: Median: GM: Geometric mean; SD: Standard Deviation;
CI: Confidence interval at 95% level.

The mean Annual Effective Dose (Fig. 8) is lower than the global mean value of 0.6 mSv/year [3]. While 91.43% of the calculated fatality cancer risk (Fig. 12) is below the global average of 0.29 [3].

The fatality cancer risk over a 70-year lifetime was calculated. However, it was not possible to assess the health problems in the population, because of the lack of reliable and standardized statistics on morbidity and mortality in the Natal population. The present study was limited to inferring the levels of natural background gamma radiation.

In turn, the Radium Equivalent Activity and External Hazard index turned out to be below the accepted global average limits, respectively of 370 Bq/kg and 1 Bq/kg (Figs. 10 and 11). While 98.68% of the Gamma Activity Index is below the global average allowed limit of 1 Bq/kg. The measured external hazard index values were lower than the external hazard index of the other municipalities in Rio Grande do Norte, Brazil [15-20].

Figure 4: *Gamma radiation spectrometry of the street corner intersections from the South zone of Natal city, Rio Grande do Norte, Brazil: A) The Absorbed Dose interpolative distribution (Natural Neighbors Method) (ηGy/h); B) Absorbed Dose Histogram (ηGy/h).*
Geological legend as in Figure 2.

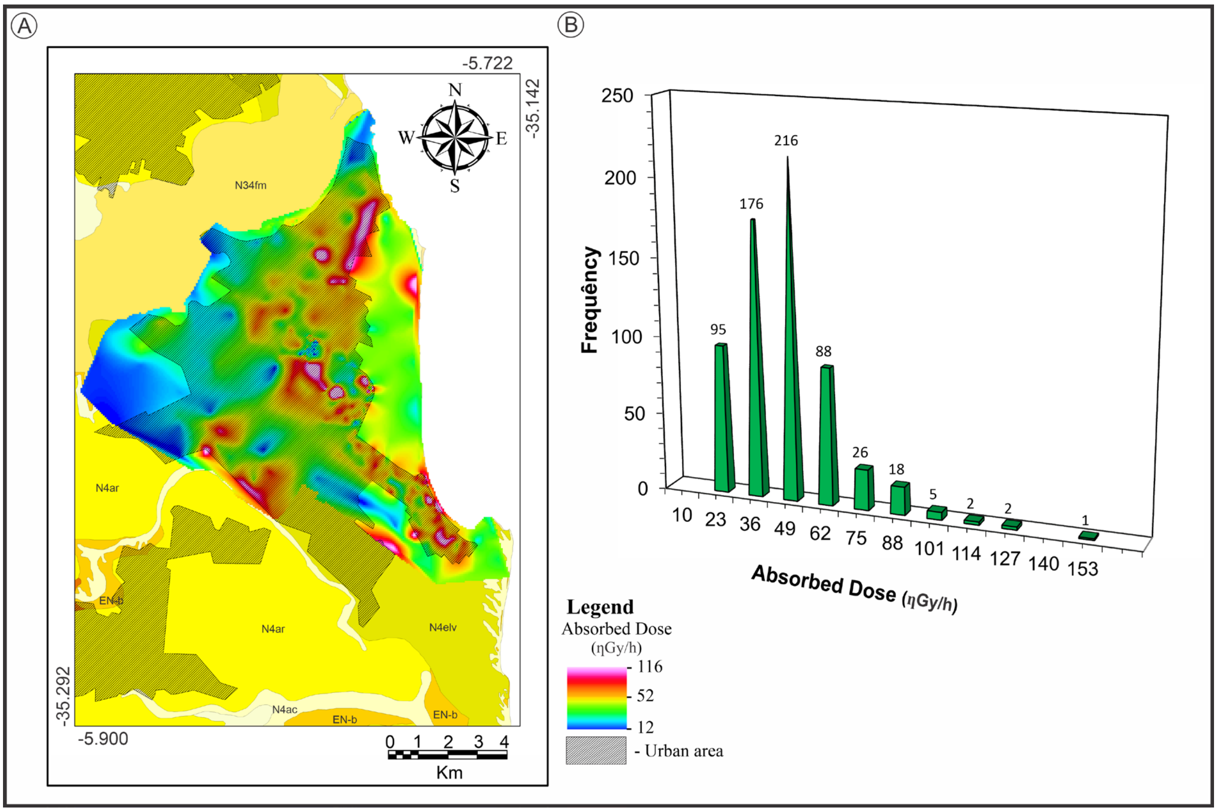


Figure 5: *Gamma radiation spectrometry of the street corner intersections from the South zone of the Natal city, Rio Grande do Norte, Brazil: A) Uranium Equivalent Activity interpolative distribution (Natural Neighbors Method) (ppm); B) U Equivalent Activity histogram (ppm).* Geological legend as in Figure 2.

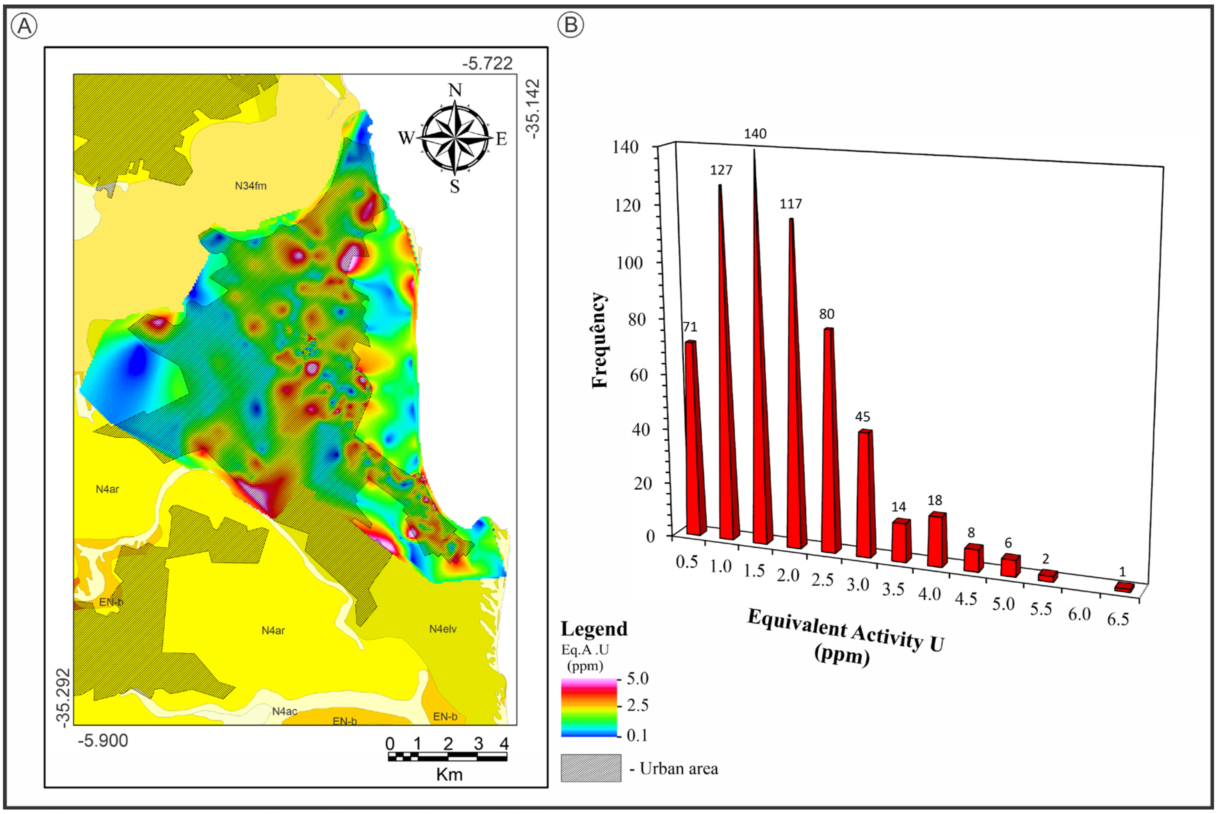


Figure 6: *Gamma radiation spectrometry of the street corner intersections from the South zone of the city zone of Natal, Rio Grande do Norte: A) Interpolative distribution (Natural Neighbors Method) of the Thorium Equivalent Activity (ppm); B) Th Equivalent Activity histogram (ppm).* Geological legend as in Figure 2.

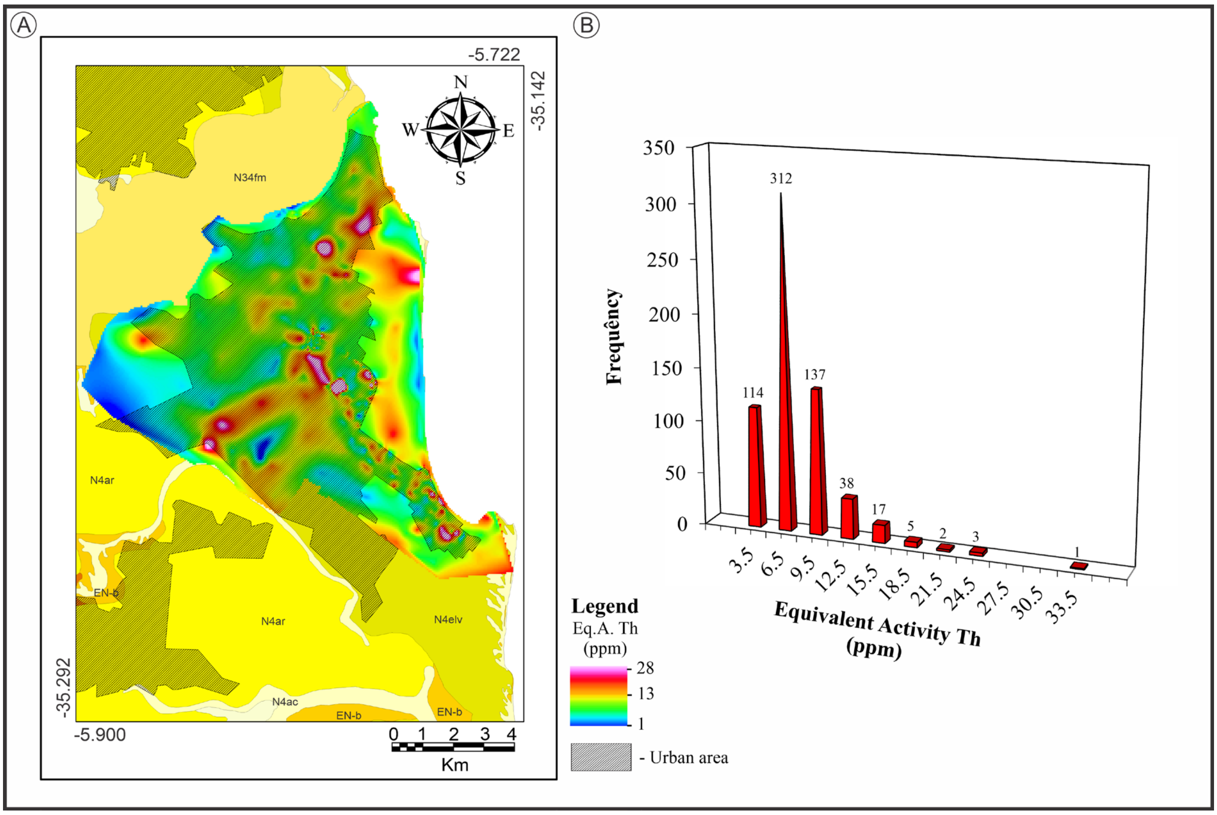


Figure 7: *Gamma radiation spectrometry of the street corner intersections from the South zone of the Natal city, Rio Grande do Norte, Brazil: A) Potassium Equivalent Activity interpolative distribution (Natural Neighbors Method) (%); B) K Equivalent Activity histogram (%). Geological legend as in Figure 2.*

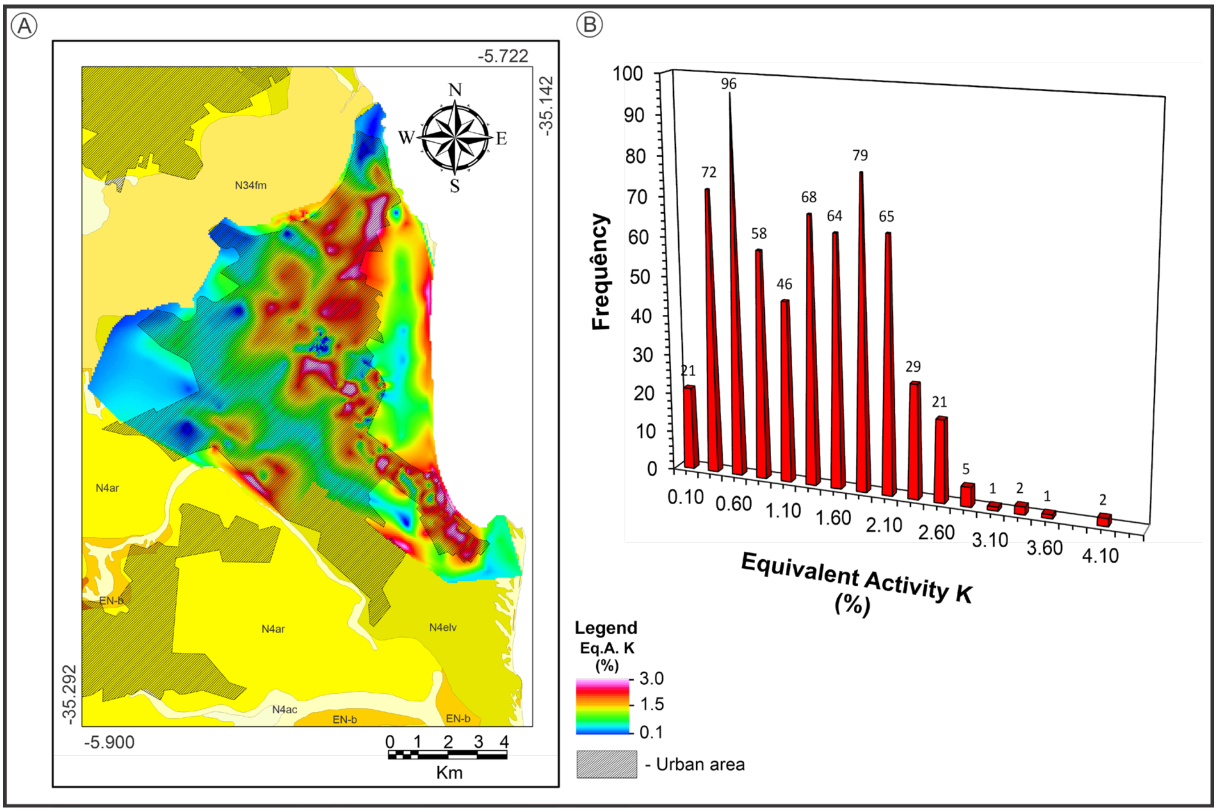


Figure 8: *Gamma radiation spectrometry of the street corner intersections from the South zone of the Natal city, Rio Grande do Norte, Brazil: A) Annual Effective Dose interpolative distribution (Natural Neighbors Method) (mSv/a); B) Annual Effective Dose histogram (mSv/a).* Geological legend as in Figure 2.

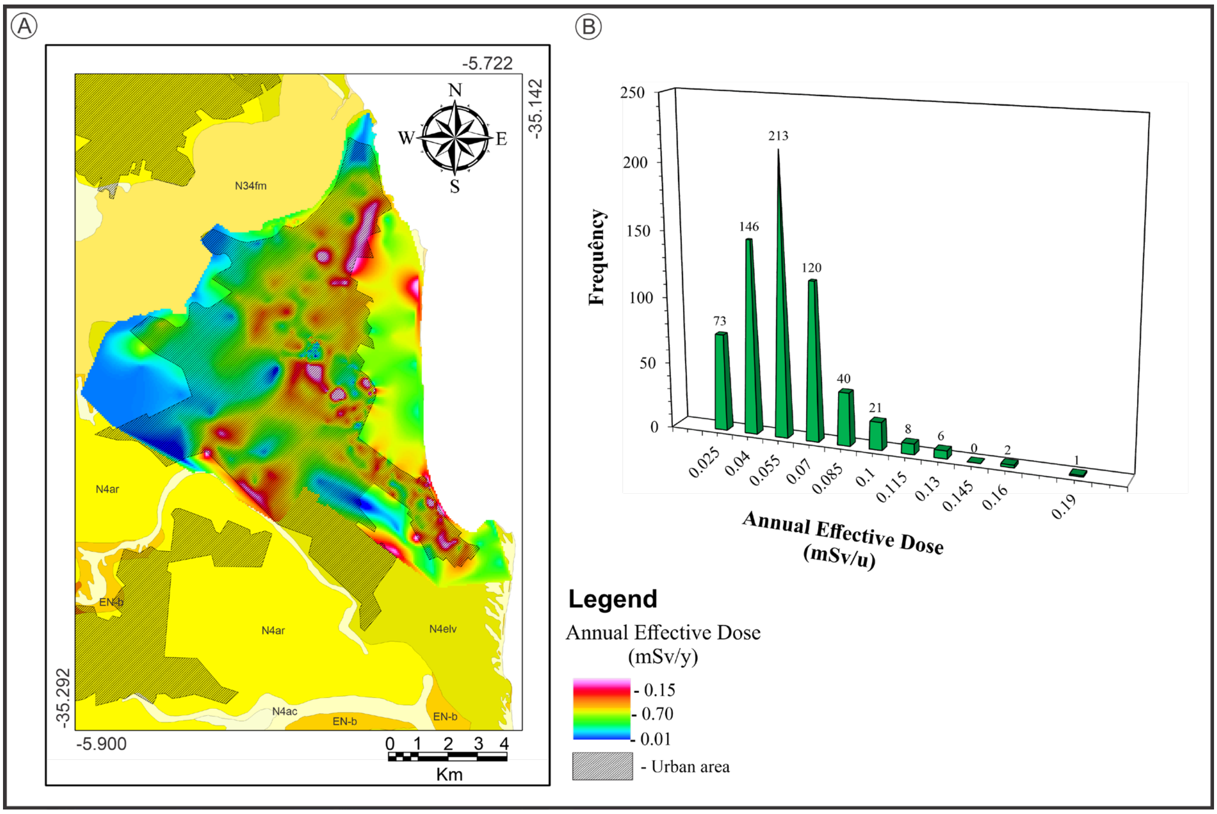


Figure 9: *Gamma radiation spectrometry of the street corner intersections from the South zone of the Natal city, Rio Grande do Norte, Brazil: A) Gamma Activity Index interpolative distribution (Natural Neighbors Method) (Bq/kg); B) Gamma Activity Index histogram (Bq/kg).*
Geological legend as in Figure 2.

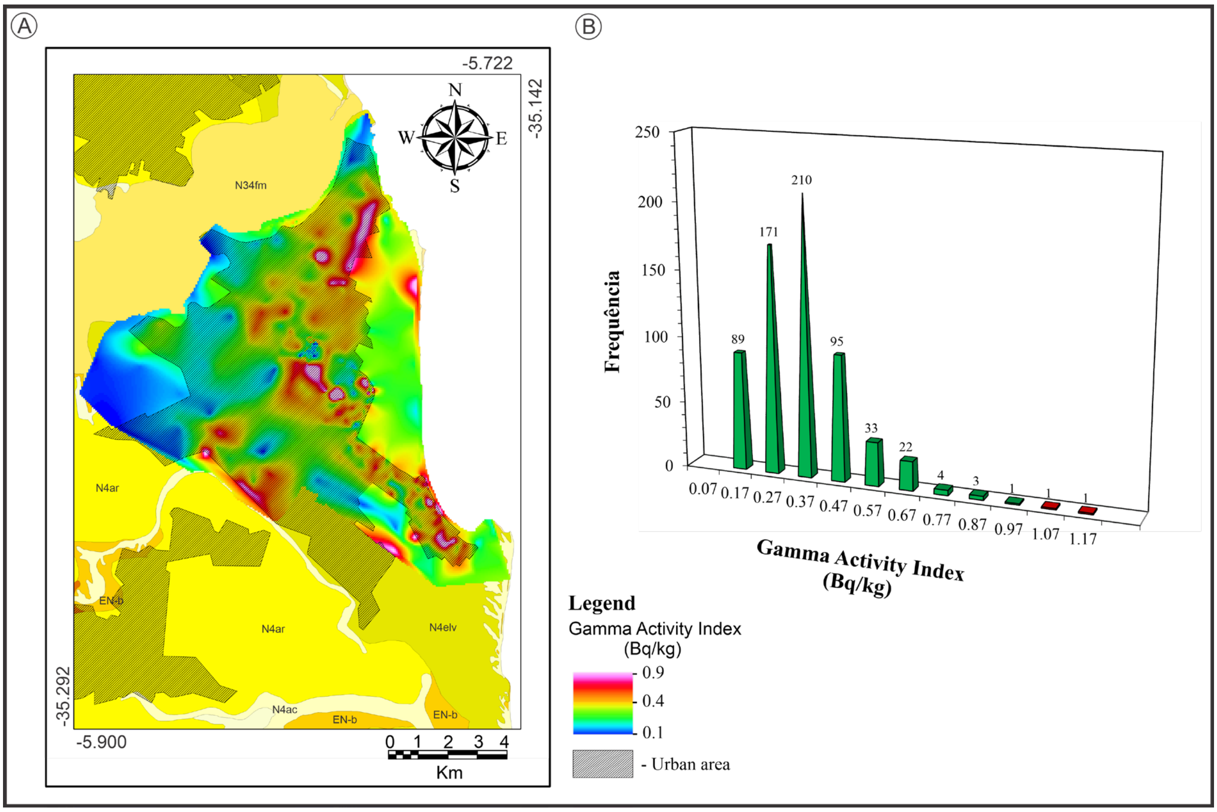


Figure 10: *Gamma radiation spectrometry of the street corner intersections from the South zone of the Natal city, Rio Grande do Norte, Brazil: A) Radium Equivalent Activity interpolative distribution (Natural Neighbors Method) (Bq/kg); B) Radium Equivalent Activity histogram (Bq/kg).* Geological legend as in Figure 2.

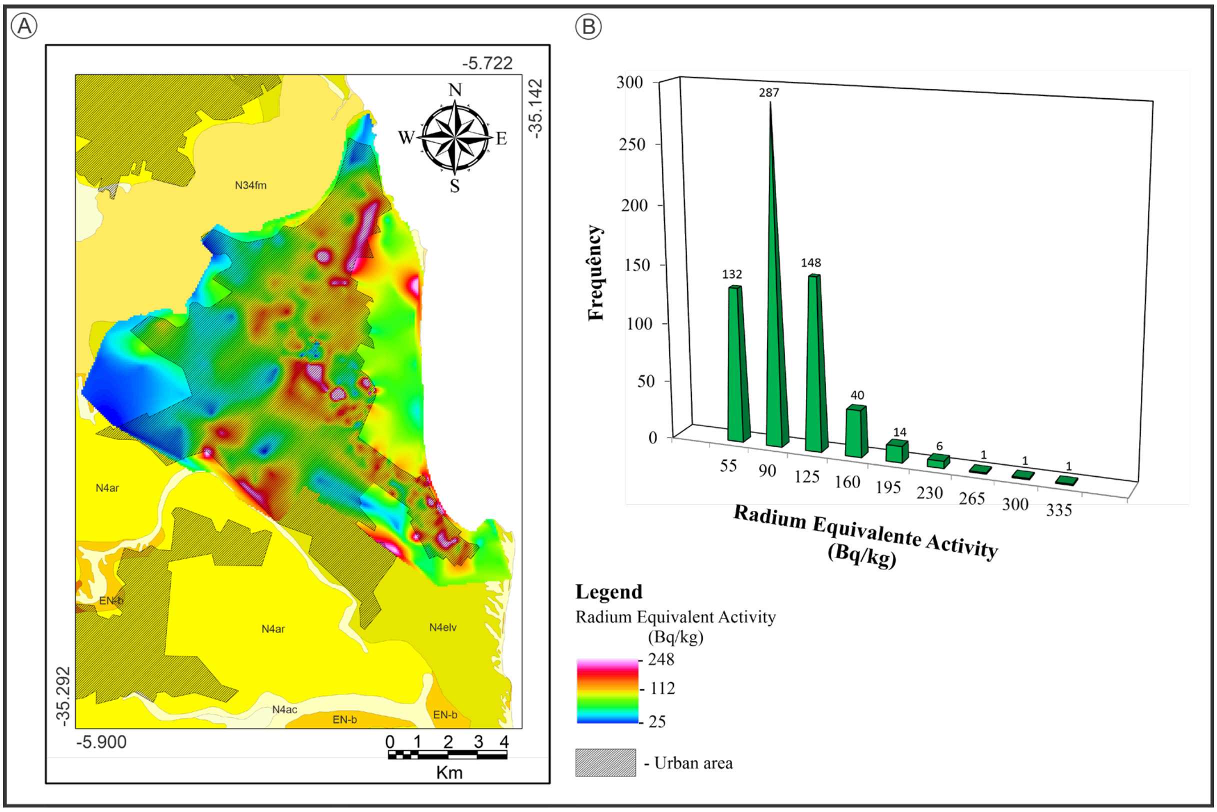


Figure 11: *Gamma radiation spectrometry of the street corner intersections from the South zone of the Natal city, Rio Grande do Norte, Brazil: A) External Hazard interpolative distribution (Natural Neighbors Method) (Bq/kg); B) External Hazard Histogram (Bq/kg).*
Geological legend as in Figure 2.

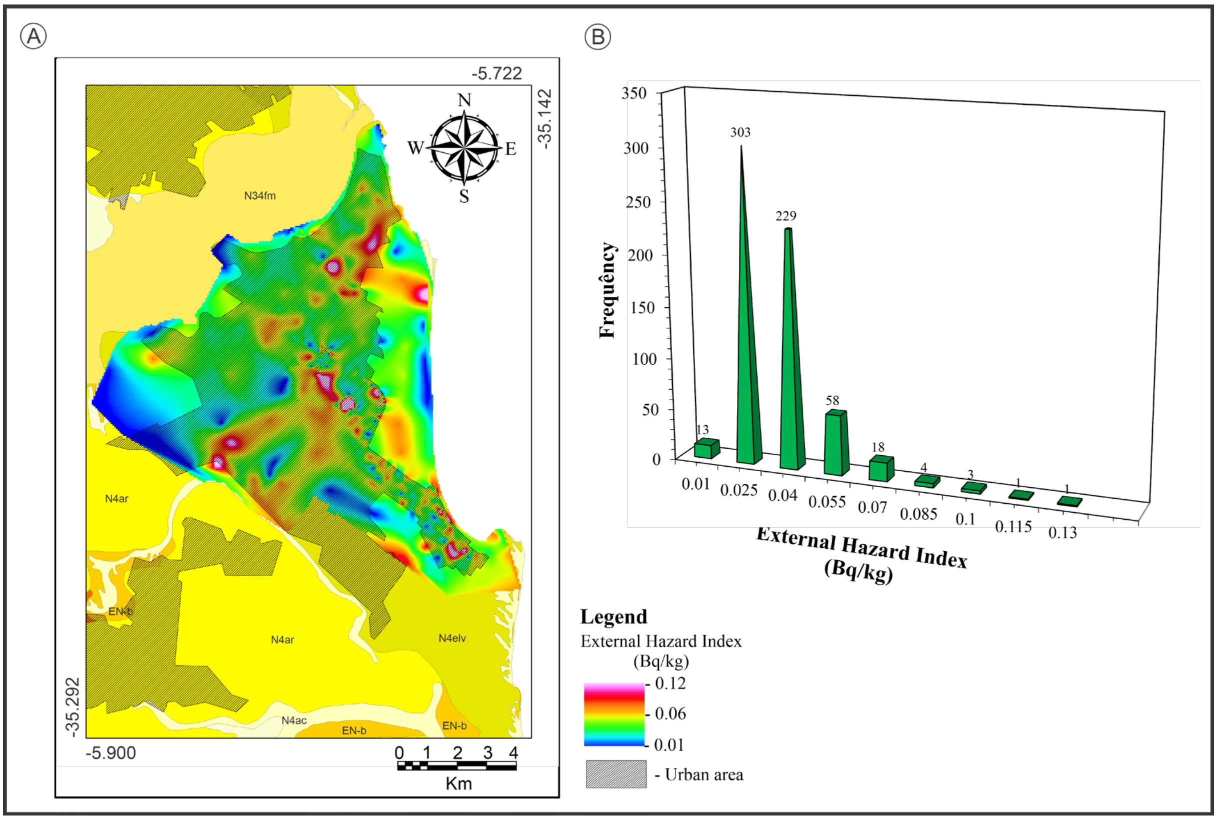
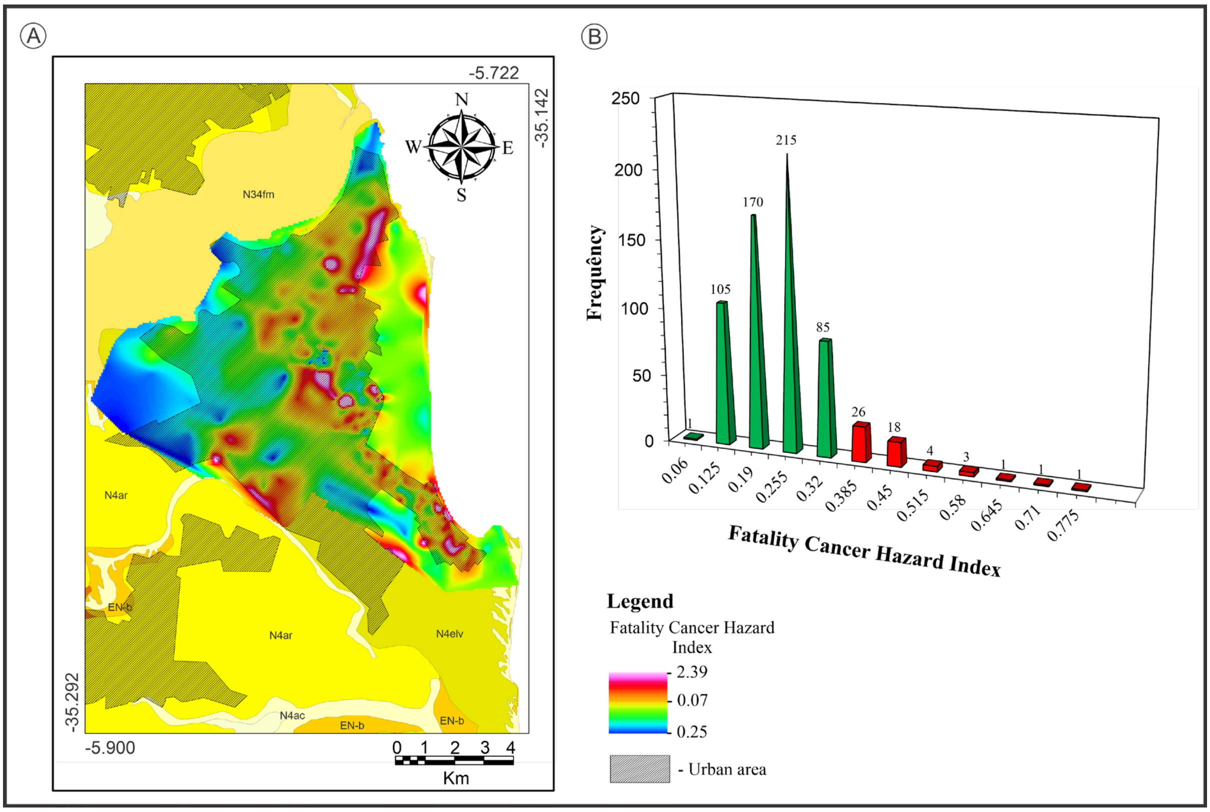


Figure 12: *Gamma radiation spectrometry of the street corner intersections from the South zone of the Natal city, Rio Grande do Norte, Brazil: A) Fatality Cancer Hazard Index at 70 years of life interpolative distribution (Natural Neighbors Method); B) Fatality Cancer Hazard Index histogram.* Geological legend as in Figure 2.



5. CONCLUSION

The *in situ* spectrometric measurements of gamma radiation were performed on the street corner intersections from South zone of Natal city (Brazil) and our data show that:

- The External Absorbed Dose ranged from 11 to 150 ηGy/h (MG: 40; Median: 39; SD: 18);
- Uranium ranged from 0.1 to 6.2 Eq.A. ppm (MG: 1.6; Median: 1.4; SD: 1);
- Thorium ranged from 0.7 to 32 Eq.A. ppm (MG: 6; Median: 5; SD: 3.3);
- Potassium ranged from 0.1 to 3.9 Eq.A. % (MG: 1.2; Median: 1.2; SD: 0.7);
- Annual Effective Dose ranged from 0.01 to 0.18 mSv/y (GM: 0.05; Median: 0.05; SD: 0.02);
- Gamma Activity Index ranged from 20.53 to 310.70 Bq/kg (GM: 0.31: Median: 0.30; SD: 0.14);
- External Hazard Index ranged from 0.01 to 0.13 Bq/kg (GM: 0.03; Median: 0.03; SD: 0.01;
- Fatality Cancer Hazard Index ranged from 0.06 to 0.77 (GM: 0.21; Median: 0.20: SD: 0.09)

The 99.84 % of values of the Absorbed Dose and the 100% of the Annual Effective Dose of external radiation measured on the street corner intersections from South zone of Natal city show values lower than the world average of 143 ηGy/h and 0.48 mSv/y, respectively, indicated by the UNSCEAR [3]. While the Radio Equivalent Activity and External Risk indexes showed values below the global average limits, respectively of 370 Bq/kg and 1 Bq/kg and Gamma Activity Index with 98.68% of values below the global average limit allowed of 1 Bq/kg [3]

Areas with higher U and K contents correspond to streets with asphalt/cobblestone capping, while areas with higher Th contents correspond to sandy streets and dune's pathways in protected areas.

Ours data are comparable to the recommended values and they fall within the safety limits. This fact denote a lower radiometric risk to the population and the harmful effects of radiation are not caused to the public and tourists who roam the streets of the Natal city.

The health risk indexes from street corner intersections were lower than the other municipalities in Rio Grande do Norte, Brazil [17-22].

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REFERENCES

[1] UNSCEAR (United Nations Scientific Committee on Effect of Atomic Radiation). Sources and Effects of Ionizing Radiation: ANNEX A: Dose assessment methodologies. (2000), United Nations, New York: United Nations Scientific Committee on the Effects of Atomic Radiation 2000.

[2] BEIR VII (Biological Effects of Ionizing Radiation). Health risks from exposure to low levels of ionizing radiation. Washington, DC: National Academy of Sciences; 2006.

[3] UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation). ANNEX B: Exposures from natural radiation sources (2000). United Nations, New York: United Nations Scientific Committee on the Effects of Atomic Radiation 2000.

[4] Klein C, Hurlbut CS. Manual of mineralogy. 20th ed. NewYork: Wiley; 1985.

[5] Kuzin, M. & Egorov, N., 1976. Field Manual of Minerals. MIR Publishers, Moscow.

[6] Ryan, W. B. F., S.M. Carbotte, J. Coplan, S. O'Hara, A. Melkonian, R. Arko, R.A. Weissel, V. Ferrini, A. Goodwillie, F. Nitsche, J. Bonczkowski, and R. Zemsky (2009), Global Multi-Resolution Topography (GMRT) synthesis data set, Geochem. Geophys. Geosyst., 10, Q03014, doi:10.1029/2008GC002332.

[7] Angelim, L.A.A., Medeiros, V.C., Nesi, J.R. 2006. Programa Geologia do Brazil –PGB. Projeto Geologia e Recursos Minerais do Estado do Rio Grande do Norte. Mapa geológico do Estado do Rio Grande do Norte. Escala. 1:500.000. Recife: CPRM/FAPERN, 2006.

[8] Serviços Geológicos do Brasil/CPRM Carta Geológica Folha Natal SB-25-V-C-V Escala 1:100.000 CPRM, 2012

[9] IAEA (International Atomic Energy Agence). Guidelines for radioelement mapping using Gamma ray spectrometry data. IAEA, Vienna, 2003. IAEA-TECDOC-1363, ISBN 92–0–108303–3, ISSN 1011–4289.

[10] ICRP (International Commission on Radiological Protection). The recommendations of the International Commission on Radiological Protection. Ann ICRP. 1991; 21(1–3). ICRP Publication 60. New York: Pergamon Press; 1991.

[11] ICRU (International Commission on Radiation Units and Measurements). Conversion Coefficients for Use in Radiological Protection against External Radiation. ICRU Report 57. ICRU Publications: Bethesda, MD., 1997.

[12] ICRU (International Commission on Radiation Units and Measurements). Quantities, units and terms in radioecology. ICRU Report 65. Journal of ICRU 1 (2) 2001.

[13] EC (European Commission). Report on Radiological Principles Concerning the Natural Radioactivity of Building Materials, 1999. Radiation Protection Report 112, 1999).

[14] Beretka J, Matthew PJ. Natural radioactivity of Australian building materials, industrial wastes and by-products. Health Phys. 1985 Jan; 48(1):87-95. doi: 10.1097/00004032-198501000-00007.

[15] NEA-OECD (Nuclear Energy Agency - Organization for Economic Co-operation and Development). Exposure to radiation from the natural radioactivity in building materials: report by a group of experts of the OECD Nuclear Energy Agency. 1979, OECD.

[16] Trevisi, R., Leonardi, F., Risica, S. Nuccetelli, C.. 2018. Updated database on natural radioactivity in building materials in Europe. Journal of Environmental Radioactivity, 187, 90-105, ISSN 0265-931X, doi.org/10.1016/j.jenvrad.2018.01.024.

[17] Malanca, A., Pessina, V. & Dallara, G., 1993. Assessment of natural radioactivity in the Brazilian state of Rio Grande do Norte. Health Physical 65(3): 298-302.

[18] Malanca, A.; Repetti, M. & Gazzola, Z. 1995. A radiological investigation on the monazite sands of the Atlantic Brazilian shore. Nuclear Geophysical 9: 453-459.

[19] Malanca, A., Gaidolf, L., Pessina, V. & Dallara, G., 1995. Distribution of ^{226}Ra, ^{232}Th and ^{40}K in solis of Rio Grande do Norte (Brazil). Journal of Environmental Radioactivity 30:55-67.

[20] Campos, T.F.C., Petta, R.; Malanca, Al., Pastura, V. F. S., Sichel, S.E.;, Motoki, A. O Gás Radônio Doméstico e a Radioatividade Natural Em Terrenos Metamórficos: o Caso do

Município de Lucrecia (Rio Grande do Norte, Brazil). Revista de Geologia (Fortaleza). , v.26, p.85 - 93, 2013.

[21] Campos, T.F.C., Petta, R., Malanca, A., Pastura, V. F. S., Sichel, S.E., Motoki, A. O gás radônio e a radiação natural em terrenos metagraníticos e pegmatíticos: o caso do município de Lages Pintadas (Rio Grande do Norte, Brazil). Revista de Geologia (Fortaleza). , v.26, p.45 - 52, 2013

[22] Campos, T. F. C.; Petta, R. A.; Pastura, V. F. S.; Sindern, S.; Nascimento, P. S. R. Environmental and safety education campaign on the radioactivity and the radioactivity and the risk of malignity in the pegmatites Borborema province: Preventive measure to avoid contamination with U and Th. Estudos Geológicos (UFPE), v.19, p.77 - 92, 2009.