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RADON IN SOIL GAS: DISTRIBUTIONS AND CORRELATIONS WITH THE LITHOLOGIES AND PEDOLOGIES OF RMBH - METROPOLITAN REGION OF BELO HORIZONTE - MINAS GERAIS - BRAZIL

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ABSTRACT

The concentration of radon in the soil gas is an important indicator to predict the radon geologic potential, usually indicated by Geological Radon Potential - GEORP, which is defined as the percent number of dwellings with indoor air radon concentration above the U.S.EPA action limit. The objective of this work was to investigate the distribution of radon concentration in soil gas and its relation with the pedologies and lithologies in the RMBH. The radon concentrations in soil gas were determined by using an *Alpha*GUARD monitor at 150 measurement points over the lithologies and pedologies of the area. The concentrations ^{226}Ra were determined by gamma spectrometry (HPGe) and U and Th by ICP-MS. The permeabilities of the soil were determined by using the RADON-JOK permeameter. Regarding pedologies, the perferric Red Latosols had the highest concentrations, with arithmetic mean to 60.6 ± 8.7 kBq.m^{-3}. Regarding lithologies, areas where the bedrocks are predominantly schists and metagraywackes showed the highest radon concentrations, with arithmetic mean to 46.5 ± 9.9 kBq.m^{-3}. The areas of lithology or pedology, in which the average radon concentrations are the highest also exhibit higher GEORP, e.g. for the perferric Red Latosol pedology shows GEORP of 26,5%. In this pedology, over 50% of the measurement points shows radon concentrations above of 50.0 kBq.m^{-3}, that, by the "Swedish Criteria" classifies the area as high radon risk. The correlation with GEORP is even more significant when the radon concentration in soil gas is combined with soil permeability, through the Soil Radon Index indicator.

1. INTRODUCTION

The radiation is present in all geological environments. The emission of ionizing radiation by rocks and soils is controlled by its contents of elements as uranium, thorium, potassium and radium. Therefore, the distribution of these radionuclides in soil mainly depends on the radioactive content of the source rocks and pedogenic processes that originated these soils. Thus, the humans are permanently exposed to natural radiation, from primordial and cosmogenic elements. Rocks, soils, sediments and ores have significant concentrations of uranium and thorium, and these materials will also contain radionuclides generated in radioactive chains.

The ^{222}Rn radioisotope (or simply radon) is a chemically inert gas generated from ^{226}Ra decay, which is generated by ^{238}U decay. The half-life of ^{222}Rn is 3.82 days and issues alpha particles whose energy is around 5.49 MeV. Thus, built with local materials from rocks and soils may accumulate significant radon in these environments, because these are gaseous radioisotopes and their half-lives allow its transportation of soils and construction materials for environments of human togetherness. The average annual effective dose received by the world population is estimated in 2.40 mSv, which radon and its decay products of short half-life contribute with approximately 1.15 mSv [20]. On average, is estimated that about 95% of radon concentration existing indoor dwellings is due for subsoil, 5% of building materials and less than 1% is released from the water consumed [11].

The soils are created through lithologics processes interactions that result in different arrangements called horizontal and vertical profiles. Thus, the physical and geochemical features of soil profiles are important in the availability and migration of radon. The most important factor in the availability of radon concentration in soil gas is the content of uranium and radium in rocks [2, 10, 20]. According to the literature, the most common sources of radon gas in soils are granitic rocks and metamorphic rocks, black shales, phosphatic rocks and some carbonate rocks. The granitic rocks commonly focus on specific minerals uranium during its initial crystallization. However, the uranium in metamorphic rocks are moved and concentrated due of the temperature, pressure and fluid migration during metamorphism [15].

In Korea, the radon concentrations in soil gas are strongly associated with granitic gneisses and banded gneisses, however, low concentrations of radon in soil gas usually occur in schist soils, calcareous schist and phyllite. Similarly, soils developed from granitic gneisses showed higher radon concentrations in soil gas [1]. Were determined the radon concentrations in soil gas and indoor dwellings in Angera, northern Italy, where were observed high indoor radon concentrations in dwellings, and these areas can be considered “risk areas”. In this work, observed that older buildings were built in areas consisting of igneous and metamorphic rocks such as rhyolite and tuff, enriched in uranium minerals. In addition, faults and permeability of the soil also showed positive correlation for determining the radon concentration within those rooms [17].

In Sweden, the Swedish Radiation Protection Authority conducted an extensive program of determining the indoor radon concentrations in dwellings, particularly those built on aluminous schists. Thus, local risk maps were based on geological criteria, like soils rich in uranium and thorium and very permeables soils. In this context, was established a criterion for risk assessment, known as "Sweden Criteria" or "Åkerblom Criteria", which establishes classification based on radon concentrations in soil gas. This criterion states that soils showing radon concentrations in soil gas below 10.0 kBq.m^{-3} (270 ρCi.L^{-1}) are considered "low risk", and do not require special buildings. The radon concentrations in soil gas whose concentration is between 10.0 and 50.0 kBq.m^{-3} (270-1,350 ρCi.L^{-1}) are classified as "normal risk" and require protective actions in dwellings. However, soils showing concentrations above 50.0 kBq.m^{-3} (1.350 ρCi.L^{-1}) are classified as "high risk" and require buildings with safety criteria against radon [4]. Other authors state that in typical soils, the radon concentrations in soil gas ranging from 4.0 to 40.0 kBq.m^{-3} [12].

The Metropolitan Region of Belo Horizonte (RMBH), Minas Gerais, Brazil, has 34 municipalities, covering an area of approximately 9.460 km², equivalent to 1.6% of the total area of Minas Gerais [23]. The part of RMBH is located over a granite embasement area, the granite gneissic Complex, suggesting the passive existence of radon prone areas. A study conducted in dwellings of this region showed that the variation in concentrations of radon gas within dwellings in the RMBH is largely due the local geological setting [18].

In this context, the main objective this work is to study the distribution of the concentration of radon gas in soils RMBH relating the results and observations with corresponding lithologies and pedologies in the region.

2. MAPPING GEOGENIC RADON

Aiming to prevent the population is exposed to high levels of radon concentration, some governmental or linked to research centers have identified higher risk areas through mapping geogenic sources indicative of risk of radon. Thus, these maps serve as a management tool for authorities assisting them in making decisions on priority areas [5]. Therefore, the environmental mapping with respect to the concentration of radon is to determine the potential risks of this gas inside dwellings and other indoor environments and assess areas available for new construction.

2.1. Geological Radon Potential - GEORP

The indicator Geological Radon Potential (GEORP) is the percentage of dwellings located in a given area which have indoor radon concentrations that exceed action levels set by regulators. Thus, the GEORP depends on a number of variables and parameters features of the soil: emanation coefficient, equivalent concentration of uranium, climatic features and type of buildings [9]. This work used data relating to the indoor radon concentrations in dwellings of RMBH [18]. The index GEORP was calculated based on the percentage of dwellings that exceeded the action limit suggested by United States Environmental Protection Agency (U.S.EPA), whose value is 148.0 $Bq.m^{-3}$[19]. Therefore, for each lithology and pedology estimated the percentage of dwellings that had concentrations of radon in the air above this limit action.

2.2. Soil Radon Index – SRI

The SRI is an indicator used to estimate the potential risk of given area. This indicator consists of an dimensionless value calculated from measurements of radon concentrations in soil gas to a depth of 0.7 m and permeability of this soil [6]. Thus, the SRI statistical allows a prediction of indoor radon concentration using these variables and may characterize a given area on the radon risk in dwellings, according to the equation below:

$$SRI = \frac{C - C_0}{- \log (P) + \log (P_0)} \qquad (1)$$

where “C” is the radon concentration in soil gas (kBq.m^{-3}), “P” is the permeability of the soil (m²); “C_0” and “P_0” are 1.0 kBq.m^{-3} and 1.0 x 10^{-10} m², respectively. Thus, the SRI is directly proportional to the radon concentration in soil gas and is utilized as methodology for risk assessment of radon in homes in the Czech Republic [13].

3. MATERIALS AND METHODS

Were performed 150 measurements of radon concentration in soil gas of RMBH, 90 measurements of permeability and 150 determinations of radionuclide concentration in soil samples, specifically ^{226}Ra, uranium and thorium concentrations. Thus, measurements were made in order to obtain a relationship between the distributions of radon in soil with geological factors: the lithologies and pedologies of RMBH.

3.1. Radon Concentration in Soil Gas

The radon concentrations in soil gas were determined using the *Alpha*GUARD® detector model PQ2000 PRO, SAPHYMO GmbH, Germany. This detector is an ionization chamber, where a volume of air is ionised by alpha particles emitted during the decay of radon and thoron. For the determination of radon concentration in soil gas, the *Alpha*GUARD® is used in continuous flow mode at intervals of 1.0 minute, where a metallic probe is inserted into the ground at a depth of 0.7 meters. Thus, the soil gas are sucked by a pump and forced to flow continuously through a capillary tube into the open circuit detector. The pump remains on for 10.0 minutes are recorded where the radon total activity concentrations (^{222}Rn and ^{220}Rn) in Bq.m^{-3}. After the shutdown of the pump, the count goes for over 10.0 minutes where it is assumed that the atoms of ^{220}Rn have already suffered decay and hence will not influence the concentration values measured thereafter. Thus, the equipment remains counting for a while at least five minutes. After the counting time, the equipment is uncoupled from the probe and the pump switched on again in order to fill the ionization chamber of the machine with ambient air and dilute the radon contained in the device. The Figure 1 shows the scheme mounting the measuring circuit in the field.

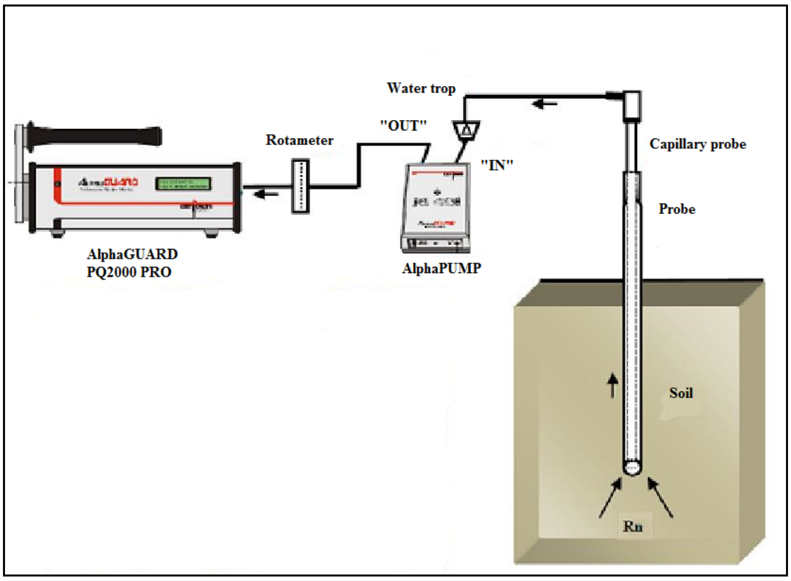

Figure 1: Scheme mounting the measuring circuit in the field.

3.2. Soil Permeability Measurements

The soil permeability to its natural gas is the most important characteristic physics of soils to determining the potential risk from radon in dwellings. Therefore, the permeability of the soil was determined by using the RADON-JOK permeameter, RADON V.O.S, Czech Republic.

The principle of operation of the equipment RADON-JOK is the removal of soil gas through negative pressure. Accordingly, a metallic probe is inserted to a depth of about 0.7 meter (the same depth in the sample used for the determination of radon concentration in soil gas) is introduced into the soil and through the gas are sucked by a constant pressure through the action of a bellows which expands as it is driven by one or two weights about 1.0 kg each one. Thus, the permeability (k) is calculated based on the flow rate of air through the tube, whose inner diameter and length are known, and the amount of gas sucked in to fill the chamber, also known volume. The Figure 2 shows a schematic of the circuit assembly to measure the permeability of soil in the field. In detail, shows the end of the probe where the soil gas are sucked.

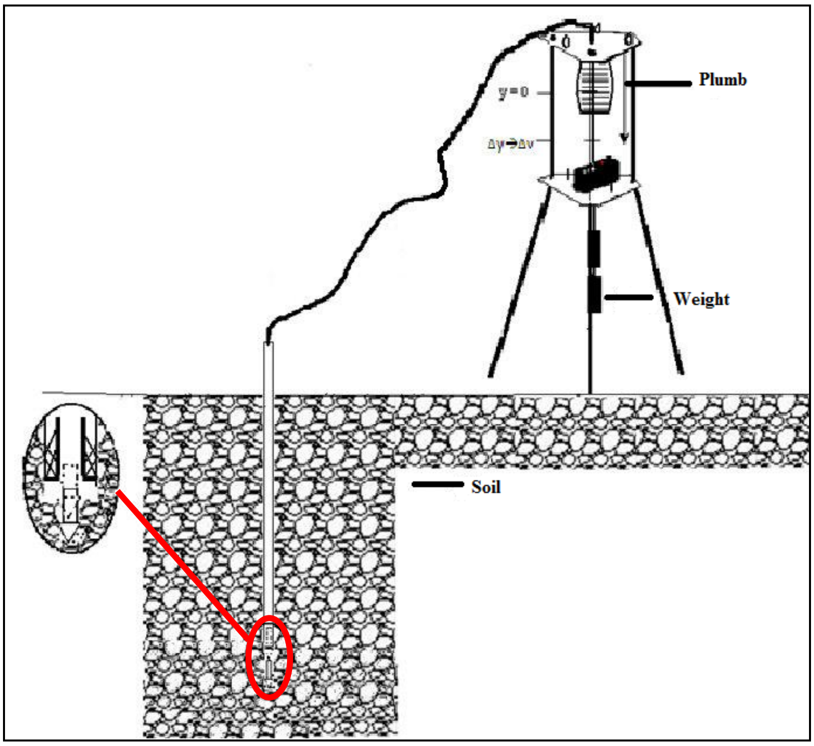

Figure 2: Scheme circuit assembly permeability measurement in the field.

3.3. ^{226}Ra, U and Th Concentrations

The soil samples were collected from RMBH about 0.70 meters deep and after crushed, the samples were put in Marinelli's sealed of 0.5 liters, where they remained for four weeks to establish secular radioactive equilibrium between ^{226}Ra and their children of short half-life. After this time, the samples were analyzed by gamma spectrometry hyperpure germanium detector Canberra, with efficiency of 15% and coaxial geometry.

The determination of uranium and thorium were performed by using the Mass Spectrometer with Inductively Coupled Plasma (ICP-MS), model ELAN DRC-e, PerkinElmer, Service Reactor and Analytical Techniques of CDTN. For the ICP-MS analysis, about 100 g of the sample were prepared for analysis range was separated and taken to an oven at approximately 100 °C for 12 hours to further reduce the moisture. After drying, this amount was pulverized again and finally mixed again to be placed in a polyethylene bottle and sent for laboratory analysis.

4. RESULTS AND DISCUSSIONS

4.1. Radon Concentration in Soil Gas

The radon concentrations in soil gas determined in the RMBH showed large variation, which was expected because of different geological settings and other physical parameters that influence radon concentrations: concentration of ^{226}Ra in soil, moisture content, permeability, barometric pressure, weather, season and others. The Figure 3 shows the set of all the results of the concentrations of radon gas in the soil on a Boxplot chart, highlighting descriptive statistic parameters: median (2nd quartile), average, 1st and 3rd quartiles and outliers points. However, the analysis of the graph shows points of extreme values which are the points of interest in this study since they have important information from rock types and pedological features.

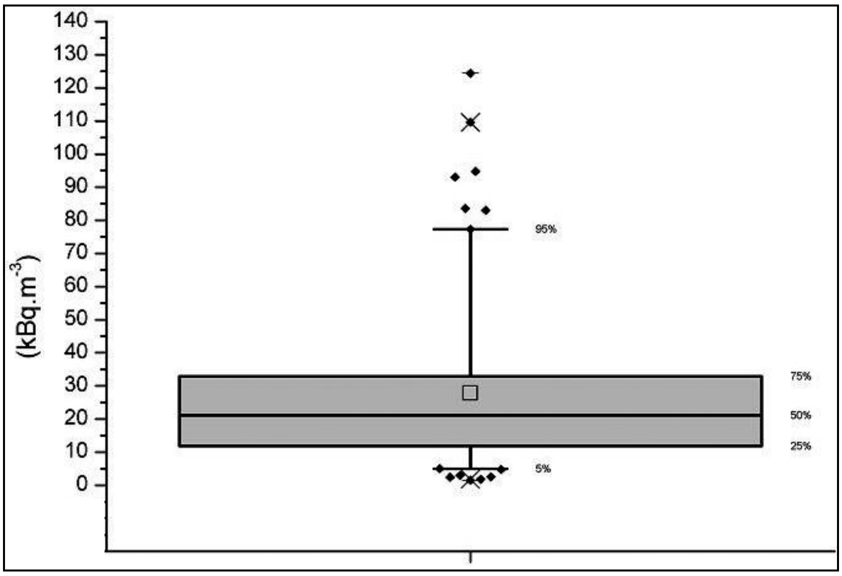

Figure 3: Radon concentration in soil gas.

4.1.1. Lithologies, Pedologies and Permeabilities

The areas classified as rocks "igneous" and "igneous metamorphic" showed average radon concentration in soil gas is smaller compared to other classes of rocks. This fact can be justified based on their ranges of values of permeability of the soil, which varied in the range of 10^{-13} m² (less permeable) to 10^{-11} m² (more permeable). However, the metamorphic and sedimentary rocks showed higher radon concentration in soil gas. It is observed that regions composed by metamorphic rocks, as gneiss, orthogneiss, granulite gneiss, migmatite, schist and metagraywackes. Specifically, the higher radon concentrations were observed in the areas on schist and metagraywackes rocks, which showed radon concentration average of 46.5 ± 9.9 kBq.m^{-3}, nearly 60% above the average of the other metamorphic rocks. In this work, was used the statistical hypotheses testing, it was found that the difference between the average radon concentration in soil gas is statistically significant when compared with other classifications lithology. The Table 1 shows the radon concentrations of radon in soil gas classified by rock types within the lithological classes: igneous, metamorphic and sedimentary rocks.

Table 1: Radon concentrations of radon in soil gas classified by rock types within the lithological classes

Litology (Classes of rocks)	Litology (Rocks types)	Arithmetic Mean [^{222}Rn] in soil gas (kBq.m^{-3})	Geometric Mean [^{222}Rn] in soil gas (kBq.m^{-3})	N^{a}
Igneous	Granodiorite, granite, tonalite	20,7±2,3	20,2	04
Igneous, Metamorphic	Granite, granite gneiss, granodiorite	10,2±3,6	8,3	03
	Serpentinite, metagabbro	9,4±5,8	6,0	03
Metamorphic	Gneiss	29,5±3,0	19,8	77
	Granulite gneiss, migmatite	28,2±7,2	25,5	05
	Schist, metagraywackes	46,5±9,9	39,5	07
	rock metapelitic	6,8±2,2	5,0	04
	Orthogneiss	30,7±19,2	28,2	04
	Schist rock metamafic, metagraywackes	14,1±3,7	11,7	04
Metamorphic, Sedimentary (or Sediment)	Phyllite, dolomite, shale	24,4±8,1	23,0	02
Sedimentary	Calcarenite, calcissiltite	19,7±4,1	18,7	04
	Siltstone, shale	32,7±4,6	31,2	05

a. N = number of measurements

The Table 2 shows the results of analysis of variance (single factor) for the rock types of rocks. This analysis showed that variation in the radon concentrations in soil gas is not significantly influenced by the rock types, being $F_{measured}$ value smaller than $F_{critical}$ value.

Table 2: Analysis of variance for the rock types of rocks

Variation source	SS[a]	DF[b]	Estimate of the variance	F[c]	P-value	$F_{critical}$
Between lithologies	6819,4973	11	619,9543	1,1228917	0,3508728	1,8792399
Within the lithologies	59075,251	107	552,10515			
Total	65894,749	118				

a. SS = sum of squares
b. DF = degrees of freedom
c. $F = F_{calculated}$ (SS/DF)

Regarding the pedologies, the Red Argisol, Red Yellow Argisol, Haplic Cambisol, Red Yellow Latosol and Red Latosol classes showed intermediate concentrations; around 22.0 kBq.m^{-3}.These values are according the range of average concentration suggested in the literature, as Eisenbud and Gesell [12]. The activity concentrations of ^{226}Ra ranged from 12.4 ± 2.5 to 23.7 ± 3.4 Bq.kg^{-1}, according with average values for typical soils, in accordance with UNSCEAR [20]. However, the average radon concentrations ranged from 13.6 ± 3.0 kBq.m^{-3} to Litolic Entisols, until 60.6 ± 8.7 kBq.m^{-3} for Perferric Red Latosols. The ^{226}Ra activity concentration showed values of 12.4 ± 2.5 Bq.kg^{-1} for the Litolic Entisols and 50.3 ± 13.0 Bq.kg^{-1} for Perferric Red Latosols. Thus, were found the highest values of radon concentration in soil gas and content of ^{226}Ra in soils to Perferric Red Latosols (Figure 4).

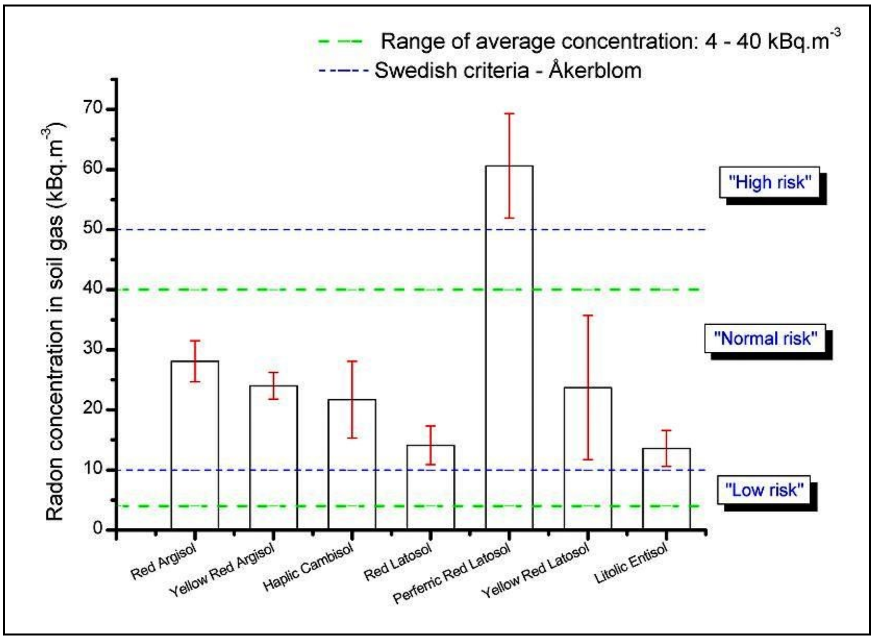

Figure 4: Radon distribution in soil gas classified by pedologies and risk criterions.

Table 3: Radon concentrations in soil gas classified by pedologies

Pedology	Arithmetic Mean [^{222}Rn] in soil gas (kBq.m^{-3})	Geometric Mean [^{222}Rn] in soil gas (kBq.m^{-3})	[^{226}Ra] in soil (Bq.kg^{-1})	N	Range of soil permeability (K) (m²)	SRI[a]
Red Argisol	28,1±3,4	25,8	21,6±0,3	14	(10^{-12}- 10^{-11})	18,5 (9,0 - 28,0)
Yellow Red Argisol	24,0±2,2	18	23,7±3,4	65	(10^{-14}- 10^{-11})	16,1 (0,3 - 76,3)
Haplic Cambisol	21,7±6,4	12,7	18,1±3,4	15	(10^{-14}- 10^{-11})	17 (0,1 - 75,3)
Red Latosol	14,1±3,2	13	15,3±6,1	04	(10^{-11})	13 (5,9 - 20,4)
Perferric Red Latosol	60,6±8,7	51,4	50,3±13	15	(10^{-14}- 10^{-11})	49 (7,0 - 108,6)
Yellow Red Latosol	23,7±12	16,3	21,7±0,5	04	(10^{-12}- 10^{-11})	15 (2,0 - 29,0)
Litolic Entisol	13,6±3	12,1	12,4±2,5	05	(10^{-12}- 10^{-11})	7,5 (4,7 - 10)

a. According with equation 1. Table shows the average SRI and upper and lower values between parenthesis.

The Table 4 shows the results of analysis of variance (single factor) for pedologies. This analysis showed that the variation in the radon concentration in soil gas is significantly influenced by the soil classes, with the value $F_{calculated}$ greater than the value $F_{critical}$.

Table 4: Analysis of variance for the pedologies

Variation source	SS[a]	DF[b]	Estimate of the variance	F[c]	P-value	$F_{critical}$
Between pedologies	19583,86	6,0	3263,977	7,589835	7,28E-07	2,1791
Within the pedologies	49025,22	114	430,0458			
Total	68609,08	120				

a. SS = sum of squares
b. DF = degrees of freedom
c. F = $F_{calculated}$ (SS/DF)

4.2. U, Th and ^{226}Ra Concentrations

The ^{226}Ra activity concentration indicates a degree of constant spacing in relation to the ^{238}U activity concentration, that is, the ratio is 0.50 to ^{226}Ra/^{238}U the whole. Part of this removal can be justified by the radioactive disequilibrium due to the higher solubility in water and radio, mainly due to the passage of ^{234}U by recoil during alpha emission by ^{238}U atoms when they are present near the surface of the mineral grains, or that is, in the solid phase of the soil.

Regarding the dispersion between ^{220}Rn and ^{232}Th concentrations, it was observed that although the decay series of ^{232}Th radioactive equilibrium are obtained in a relatively short time, is not expected radioactive equilibrium between ^{220}Rn and ^{232}Th, since the extraction process of ^{220}Rn measurement by using an *Alpha*GUARD is a strong factor imbalance due to the decay of ^{220}Rn during their transport to the detector, because its half-life relatively very short, about 55.0 seconds. However there is a growing tendency to ^{220}Rn with the values of ^{232}Th.The Figure 5 shows the correlation between ^{226}Ra and ^{238}U concentrations and dispersion between ^{220}Rn and ^{232}Th concentrations in soil samples from RMBH.

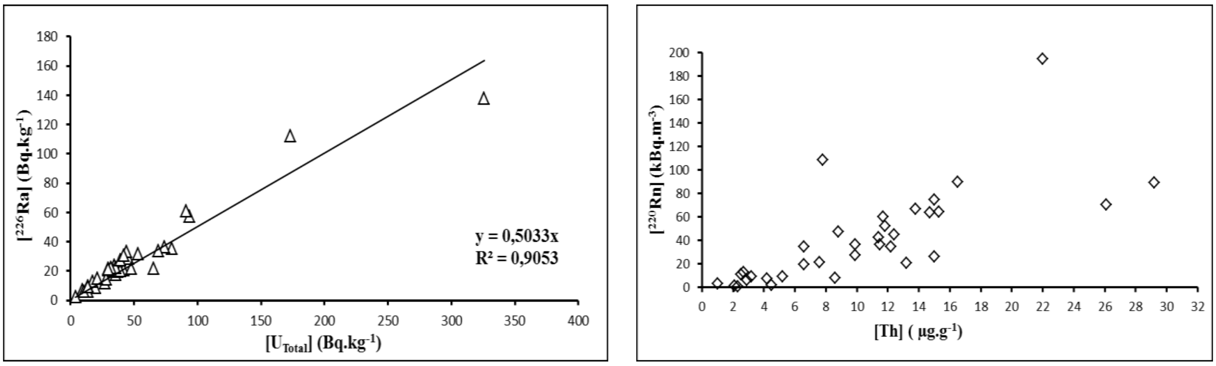

Figure 5: Correlation between the concentrations of ^{226}Ra and ^{238}U in soil samples from RMBH (left) and Dispersion of concentrations of ^{220}Rn and the concentration of ^{232}Th in soil samples from RMBH (right).

4.3. GEORP and SRI

The global GEORP for RMBH was calculated and found 18.8%. This means that of the 500 dwellings monitored located in RMBH, approximately 94 showed indoor radon concentrations above the limit of 148.0 Bq.m^{-3} established by U.S.EPA [19]. Analyzing the results sorted by lithology, it is observed that soils with rocky basement is composed of sedimentary rocks showed the highest values GEORP, SRI, shows the indoor radon concentrations and in soil gas, according with the greater permeability of these soils. It can be argued, albeit preliminarily, that these areas may be more susceptible to radon in relation to the others areas. It is noteworthy that although the results presented for regions with basement corresponds to rocks classified as "metamorphic, sedimentary (or sediment)" showed higher values. On the other hand, soils on rocks "igneous" and "igneous metamorphic" showed lower indoor radon concentration and in soil gas, and also besides lower GEORP and SRI indicators. However, due the few determinations in these areas, it is uncertain to submit any conclusive statement.

Regarding the classes of rocks classified as "metamorphic", notes that even the radon concentration in soil gas being the highest, the indoor radon concentration in dwellings for these areas are showed lower and also a lower GEORP. The SRI showed since despite its great range of variation (0.1 to 108.6), and its proved to be intermediate with respect to classes of sedimentary rocks and igneous classes. Table 5 shows the indoor radon concentrations, in soil gas, ^{226}Ra content in soils and SRI and GEORP indicators classified by lithologies (classes of rocks).

Table 5: Indoor radon concentrations, in soil gas, ^{226}Ra content in soils and SRI and GEORP indicators classified by lithologies

Lithology (Classes of rocks)	Arithmetic Mean [^{222}Rn] in the air (Bq.m^{-3})	Arithmetic Mean [^{222}Rn] in soil gas (kBq.m^{-3})	N (air)	N (soil)	SRI	GEORP (%)
Igneous	119,3 ± 18	20,7 ± 2,3	25	04	14 (12,3 - 20,1)	12,0
Igneous, Metamorphic	116,0 ± 31,6	13,0 ± 3,7	11	04	7,5 (0,6 - 13,6)	18,0
Metamorphic	113,0 ± 6,4	28,8 ± 2,5	408	102	19,0 (0,1 - 108,6)	17,4
Metamorphic, sedimentary (or sediment)	180,0 ± 60,0	24,4 ± 8,1	3	02	23,4 (15,3 - 31,5)	66,0
Sedimentary	135,0 ± 19,0	27,8 ± 3,5	53	10	26,8 (11,3 - 43,3)	20,7

The radon concentration indoor dwellings, in soil gas, SRI and GEORP were distributed by pedologies. The perferrics Red Latosols showed the highest values of SRI and GEORP, which agrees with the results obtained for the radon concentration in these soil gas. Although the Red Latosols also exhibit high values, these will not be posted because they lack a greater improvement in the number of measurements. It is noteworthy that the Cambisol, Red Argisol and Litolic Entisol pedologies showed indoor radon concentrations and in the soil gas below their averages: 108.0 Bq.m^{-3} to indoor air and 26.3 kBq.m^{-3} to soil gas. These results can be seen in Table 6.

Table 6: Radon concentrations in soil gas, in the air, ^{226}Ra content in soils and SRI and GEORP indicators classified by pedologies

Pedology	Arithmetic Mean [^{222}Rn] in the air (Bq.m^{-3})	Arithmetic Mean [^{222}Rn] in soil gas (kBq.m-^{3})	N (air)	N (soil)	[^{226}Ra] in soil (Bq.kg^{-1})	SRI	GEORP (%)
Red Argisol	142,2±23	28,1±3,4	60	14	21,6±0,3	18,5 (9,0 - 28,0)	18,3
Yellow Red Argisol	113,2±8,4	24,0±2,2	252	65	23,7±3,4	16,1 (0,3 - 76,3)	16,5
Haplic Cambisol	98,1±9,3	21,7±6,4	63	15	18,1±3,4	17 (0,1 - 75,3)	16,0
Red Latosol	137±11,5	14,1±3,2	16	04	15,3±6,1	13 (5,9 - 20,4)	37,5

Perferric Red Latosol	130±17	60,6±8,7	68	15	50,3±13	49 (7,0 - 108,6)	26,5
Yellow Red Latosol	80,8±7,0	23,7±12	20	04	21,7±0,5	15 (2,0 - 29,0)	05
Litolic Entisol	101,1±11,1	13,6±3,0	21	05	12,4±2,5	7,5 (4,7 - 10)	19,0

5. CONCLUSIONS

The distribution of radon concentration in soil gas of RMBH showed that about 17% of the measurements points, in the different lithologies and pedologies, showed radon concentrations in soil gas exceeding 40.0 kBq.m^{-3}, a value suggested as reference (maximum concentration of radon gas in soils typicals) by Eisenbud and Gesell [12]. Therefore in comparison with the values suggested by Åkerblom [4], approximately 70% are in the range from 10.0 to 50.0 kBq.m^{-3} is considered "normal risk," and 13% correspond to concentrations greater than 50kBq.m^{-3}, which classify areas as "High Risk".

With respect to lithology, rocky areas whose foundation is composed of metamorphic gneiss, orthogneiss, granulite gneiss, migmatite, schist and metagraywackes showed high relative radon concentrations to other rocks, especially the rocks types of schist and metagraywackes, which showed a concentration of 46.5 ± 9.9 kBq.m^{-3}, about 60% above the average of other metamorphic rocks. Areas predominantly rocky basement of sedimentary rocks also showed significant amounts of radon concentration in soil gas. The analysis of variance carried out to lithologies showed that variation in the radon concentrations in soil gas is not significantly influenced by these rock types.

Regarding pedologies, the Perferric Red Latosols showed radon concentrations in soil gas quite significant. The range was 13.6 kBq.m^{-3} to 124.4 kBq.m^{-3}. Thus, approximately 53% of the points discussed in this pedology can be classified as "High Risk", according to the Swedish classification criteria. However, Litolic Entisols showed the lowest radon concentrations, about 13.6 ± 3.0 kBq.m^{-3}. It is important that pedology Perferric Red Latosol and areas is dominated by schist and metagraywackes lithologies showed radon concentrations in soil gas higher. Overlaying said pedology their respective lithology these coincide geographically. Such geographic coincidence suggests the need for specific studies to determine whether the high levels of concentration of radon in the soil would be due to lithology and/or soil conditions. Analysis of variance performed for the soil classes showed that variation in the concentrations of radon gas in the ground is strongly influenced by soil conditions of the area. However, it requires a greater number of samples in these areas for any conclusive statement.

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