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Assessment of radiological risk due to natural radioactivity in soils from landscaped spaces at the University Jean Lorougnon Guede, Daloa, Côte d'Ivoire

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Abstract
Located in a mining region, the University of Daloa had no data on the radioactivity of its frequented spaces. The objective of this study was to assess the risk of cancer due to natural radioactivity in landscaped spaces of the university. A total of twenty-one (21) samples were collected. Analysis of these samples by gamma spectrometry has shown low activity concentration of K-40 in all samples and activity concentrations of ^{226}Ra (^{238}U) and ^{232}Th higher than IAEA recommended values of 37 $Bq.\,kg^{-1}$ for ^{226}Ra (^{238}U) and ^{232}Th respectively. Concentrations of ^{222}Rn also calculated in samples were seen to be also lower than UNSCEAR guideline of 100$Bq.\,m^{-3}$.
The dose rate and effective dose due to exposure to radioactivity in soil samples were found to be respectively higher and lower than the UNSCEAR recommended values of 57nGy/h and 1 mSv/y. Assessment of radiological risk due to exposure to natural radioactivity has shown external risk indexes in all samples lower than UNSCEAR recommended limit of 1.

Keywords: Natural radioactivity, activity concentration, dose rate, effective dose, risk index

1. Introduction

As its name implies, radioactivity is the act of emitting radiation spontaneously. This phenomenon originates from natural and artificial sources. Natural radioactivity from naturally occurring radioactive materials (NORMs) is widely spread in the Earth's environment and therefore does not spare any human being in terms of radiation exposure. Natural radioactive concentration mainly depends on geological and geographical condition and appears at different level in soils of each different geological region (UNSCEAR,2000) [1]. Soil radionuclide activity concentration is one of the main determinants of the natural background radiation. When rocks are disintegrated through natural process, radionuclides are carried to soil by rain and flows (Taskin, Karavus, Ay, Topuzoglu, Hindiroglu and Karahan, 2009) [2].

Natural radioactivity is the main contributor to human radiation dose which is equivalent to 2.4 mSv per person makes up approximately 80% of the total radiation dose a person is exposed in a year (IAEA, 1996) [3]. It comes mainly from the naturally occurring radioactive isotopes of ^{238}U and ^{232}Th and their progeny as well as ^{40}K (UNSCEAR, 1993; Shetty, and Narayana, 2010) [4, 5]. The dose from natural exposure is generally low; but it could be increased with anthropogenic activities in the region. However, this low dose can have effects on the health of population such as the risk of malformation transmitted to the offspring when the germs are destroyed and the risk of induced-cancer in case of the destruction of genetic cells.

The University Jean Lorougnon GUEDE (UJLoG) is located in the Haut-Sassandra region, which is a mining area in Cote d'Ivoire and where the main activity of the population is agriculture. In recent years, works to expand the university and urbanize the city of Daloa have raised fears of increasing the natural radioactivity of the landscaped spaces at the UJLoG. Unfortunately, no data on the university's radioactivity exists.

It was therefore necessary to carry out this study which the main objective is to assess the radiological risk associated with the exposure of people occupying the landscaped spaces at UJLoG.

2. Materials and Methods

2.1 Description of the study area

The study was carried out at UJLoG, located in the department of Daloa, a town located in the Haut-Sassandra region in the west-central part of Côte d'Ivoire between 6° and 7° N latitude and 7° and 8° W longitude. In 2023, UJLoG had nearly 6,000 students, 421 teacher-researchers and 149 administrative and technical staff members. Geologically, the soil substrate belongs to the old Precambrian basement composed of granites. These soils, leached and deep (20 m) are due to the abundant rainfall and the rapid weathering of the rocks. The soils of the region are mostly ferritic (Manéhonon, Koutoua, Sopie, Tionta and Yatty, 2020) [6]. The study area is shown by fig 1 below.

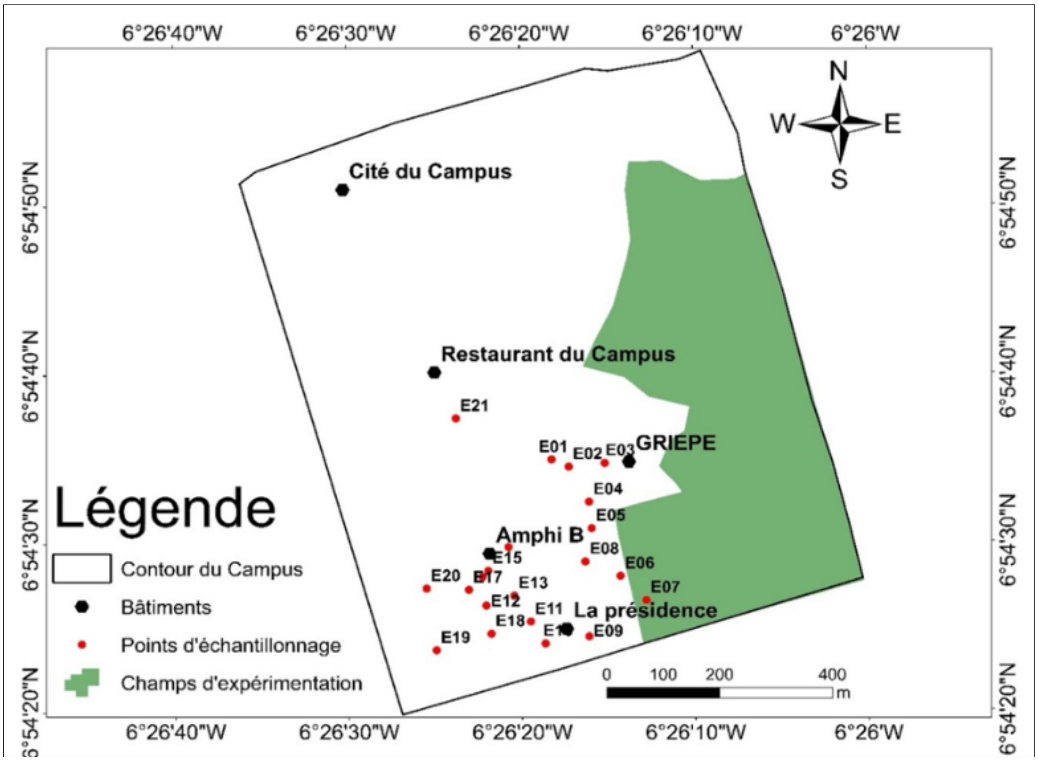

Fig 1: Study area with soil sampling points

2.2 Collection and sample preparation

A total of twenty-one (21) soil samples were collected at different locations throughout the university using the simple sampling technique during the dry season. The samples were taken from a depth of 10 cm and then collected in plastic containers that were thoroughly cleaned to avoid contamination of the samples. Then using a global positioning system (GPS), the positions of the samples were taken and then labelled in order to differentiate between them. After collection, the samples were taken to the laboratory of the Radiation Protection and Nuclear Safety and Security Authority (ARSN) in Abidjan for analysis.

At the ARSN laboratory, the samples were dried and left to rest for more than 21 days in order to ensure the secular equilibrium. Then they were crushed in a mortar and sieved using a 500 µm diameter sieve. The powder obtained is put into Marinelli beakers of one liter capacity. The samples were then placed in the spectrometer (detector) for analysis.

2.3 Sample analysis

All samples were analyzed by the gamma spectrometer HPGe model: GX4520, serial number b 21003 which has a coaxial geometry with a diameter of 63.1 mm and a length of 62.3 m, with a resolution of 2 keV (FWHM) for gamma rays from Co-60 to 1332 keV. Placed in the detector, each sample was counted for 10 hours or 36000 seconds. The identification of radionuclides was performed using the energies of the emitted gamma rays found in the Genie 2000 software database.

2.4 Activity concentration of the radionuclides

Activity concentrations of the main natural radionuclides ^{40}K, ^{232}Th and ^{226}Ra (^{238}U) present in the samples were calculated by the equation below (Alam, Chowdhury, Kamal, Ghose, Anwaruddin, 1999; Awudu, Darko, Schandorf, Hayford, Abekoe, Ofori-Danson, 2010) [7, 8].

$$A_{sp} = \frac{N_{sam}}{\varepsilon(E_\lambda)\times P_E\times t_c\times M_{sam}} \quad (1)$$

Where N_{sam} is the net count of the sample in a gamma energy peak E_λ, M_{sam} is the mass of the sample, $\varepsilon(E_\lambda)$ is the photopic yield, P_E is the storage factor of the radionuclide, t_c is the counting time.

Since ^{232}Th and ^{226}Ra (^{238}U) are not directly gamma emitters, their activities are calculated from those of their emitted gamma daughter nuclei. Thus, ^{232}Th activity was calculated from ^{228}Ac and ^{212}Pb. That of ^{226}Ra (^{238}U) was calculated from ^{214}Pb and ^{214}Bi assuming the secular equilibrium established between father and daughter radionuclides. The concentration of ^{40}K was directly determined.

2.5 Concentration of radon, dose rate and annual effective dose
To estimate the hazard associated with exposure to natural radionuclides in spaces at UJLoG, the concentration of radon gas (^{222}Rn) was determined using the following equation (Darko, Adukpo, Fletcher, Awudu, and Otoo) [9].

$$A_{Rn} = A_{Ra}\left[1 - e^{-\lambda_{Rn}.T_d}\right] \quad (2)$$

Where: A_{Ra} is the ^{226}Ra concentration in the sample, T_d the decay time between sampling and counting and λ_{Rn} the radon decay constant.
The absorbed dose rate in air at one meter above the ground surface, defined as a direct connection between the radioactivity concentrations of naturally occurring radionuclides and their exposure, was calculated using the equation below (UNSCEAR, 2000) [1]:

$$\dot{D} = 0.92A_{Ra} + 1.1A_{Th} + 0.08A_K \quad (3)$$

Where: $\dot{D}$ (nG_γ.h^{-1}) is the dose rate, A_{Ra}, A_{Th} and A_K are respectively concentrations of ^{226}Ra (^{238}U), ^{232}Th and ^{40}K.
Similarly, the annual effective dose was calculated using the following formula (UNSCEAR, 2000; Al-Hamameh and Awadallah, 2009) [1, 10].

$$DE = \dot{D} \text{ x } 8760 \text{ x } 0.2 \text{ x } 0.7 \text{ x } 10^{-6} \quad (4)$$

Where: DE is the annual effective dose, $\dot{D}$, the dose rate, 0,7 is the conversion coefficient of absorbed dose to effective dose received by adults for one year (8760 hours) and 0.2 the outdoor occupancy factor.

2.6 Risk estimation
In order to estimate the radiological risks associated with the natural radioactivity of the soil, the external risk index denoted H_{ex} introduced by Beretka and Mathew was calculated. The value of H_{ex} should be less than 1 in order to keep the risk negligible. Thus, the index is expressed using a model proposed by Krieger (UNSCEAR, 2000; Kpeglo, Lawluvi, Faanu, Awudu, Deatanyah, Wotorchi, Arwui, Reynolds & Darko, 2011) [1, 11].

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (4)$$

Where: H_{ex} is external risk index, A_{Ra}, A_{Th} and A_K are respectively concentrations of ^{226}Ra (^{238}U), ^{232}Th and ^{40}K.

3. Results and Discussion
3.1. Activity concentrations of ^{40}K, ^{232}Th and ^{226}Ra (^{238}U)
Activity concentrations of main natural radionuclides are indicated in Table 1 below. The activity concentration of ^{40}K ranged from 44.088±2.376 Bq.kg^{-1} to 119.554±5.597 Bq.kg^{-1} with a mean of 62.405±3.215 Bq.kg^{-1}. The activity concentrations of ^{226}Ra (^{238}U) and ^{232}Th ranged from 34.090±1.239 $\text{Bq.kg}^{-1}$to 52.328±1.870 Bq.kg^{-1} and from 45.937±1.728 Bq.kg^{-1} to 73.997±3.141 Bq.kg^{-1}, respectively with averages of 43.542±1.578 $\text{Bq.kg}^{-1}$and 63.328±2.408 Bq.kg^{-1}, respectively. Activities varied from one point to another in the study area and these variations could result from the non-uniform distribution of radionuclides that are present in the Earth's crust. It was noted that rocks contain high levels of radioactive elements. However, the study area is located in a rock-rich region with rapid alteration. So, this rapid weathering of rocks could explain the low concentrations of radionuclides in samples. The comparison of the measured radionuclide concentrations with IAEA limits of radionuclide concentrations in environment showed concentration of potassium ^{40}K in all the samples lower than the recommended value of 400 Bq.kg^{-1}. Also, results showed concentrations of ^{232}Th and ^{226}Ra (^{238}U) measured in samples higher than IAEA limits of 37 Bq.kg^{-1} and 22 Bq.kg^{-1} for ^{232}Th and ^{226}Ra (^{238}U) respectively (AIEA, 1989)[12]. And these highest concentrations of ^{232}Th and ^{226}Ra (^{238}U) could be explained by the presence of rocks in the study area.

Table 1: Activity concentrations ^{40}K, ^{232}Th and ^{226}Ra (^{238}U)

Sample Code	Activity concentration of radionuclides (Bq/kg)		
	A_{K-40}	A_{Ra-226}	A_{Th-232}
E01	54.789±2.962	45.300±1.637	64.822±2.811
E02	63.068±3.128	36.771±1.306	56.749±2.298
E03	107.687±5.036	45.918±1.607	64.346±2.336
E04	78.110±3.849	45.906± 1.612	68.432±2.818
E05	88.047±4.308	47.628±1.676	64.868±2.326
E06	52.273±2.869	48.444±1.728	64.296±2.757
E07	58.514±3.101	43.065±1.738	69.302±2.483
E08	46.347±2.525	41.124±1.498	60.825±2.474
E09	56.243±2.954	38.972±1.420	50.509±2.140
E10	60.911±3.185	50.581±1.827	71.910±2.731
E11	49.358±2.729	50.128±1.714	70.099±2.486
E12	51.829±2.777	45.962±1.824	70.477±2.501
E13	52.079±2.801	52.328±1.870	73.997±3.141
E14	54.072±2.986	44.598±1.638	68.568±1.109
E15	44.088±2.376	39.853±1.411	63.407±2.623
E16	56.218±2.961	39.213±1.408	58.999±2.546
E17	68.456±3.479	42.551±1.531	59.684±2.247
E18	119.554±5.597	51.461±1.868	70.253± 2.960
E19	44.733±2.376	34.090±1.239	45.937±1.728
E20	50.441±2.659	35.166±1.299	55.993±1.985
E21	53.699±2.848	35.314±1.295	56.413±2.062
Range	44.088 - 107.687	34.090 - 52.328	45.937 - 73.997
Average	62.405±3.215	43.542 ±1.578	63.328±2.408
IAEA	400	37	22

3.2. Concentration of radon, dose rate and annual effective dose

Concentrations of ^{222}Rn are shown in Table 2. They ranged from 34.090±1.239 $Bq.m^{-3}$ to 52,328±1,870 $Bq.m^{-3}$ with an average of 43.541±1.578 $Bq.m^{-3}$. This slight variation in concentration from one point to another in the study area may result from the non-uniform distribution of ^{226}Ra, the parent radionuclide of ^{222}Rn in rocks. The comparison of the mean radon concentration value obtained in this study with the value recommended by UNSCEAR, 100$Bq.m^{-3}$, showed that radiological hazard associated with exposure to natural radionuclides in spaces at UJLoG is low.

The dose rate and absorbed effective dose are presented in Table 2. They ranged from 85.472±10.861 nGy/h to 134.186±16.807 nGy/h and from 0.105±0.013 mSv/year to 0.165±0.020 mSv/year respectively with averages of 114.711±14.513 nGy/h and 0.141±0.018 mSv/year, respectively. The results showed dose rate values higher than the UNSCEAR recommended value, 60 nGy/h. However, the annual effective doses were below the UNSCEAR limit value of 1 mSv/y [1]. The low effective dose values found in the samples indicate that landscaped spaces at UJLoG would be safe.

Table 2: Concentration of radon, dose rate and annual effective dose of samples

Sample Code	Radon A_{Rn}(Bq/m^3)	Dose rate $\dot{D}$(nGy/h)	Annual effective Dose (mSv/an)
E01	45.300±1.637	117.363±15.677	0.144±0.019
E02	36.771±1.306	101.299±12.722	0.124±0.016
E03	45.918±1.607	121.641±14.360	0.149±0.018
E04	45.906±1.612	123.758±15.541	0.152±0.019
E05	47.628±1.676	122.217±14.663	0.150±0.018
E06	48.444±1.728	119.476±15.942	0.147±0.020
E07	43.065±1.738	120.533±15.572	0.148±0.019
E08	41.124±1.498	108.450±14.270	0.133±0.018
E09	38.972±1.420	95.13±12.595	0.118±0.015
E10	50.581±1.827	130.508±16.496	0.160±0.020
E11	50.128±1.714	127.175±15.891	0.156±0.019
E12	45.962±1.824	123.956±15.960	0.152±0.020
E13	52.328±1.870	133.705±17.646	0.164±0.022
E14	44.598±1.638	120.781±13.061	0.148±0.016
E15	39.853±1.411	109.940±14.366	0.135±0.018
E16	39.213±1.408	105.472±13.893	0.129±0.017
E17	42.551±1.531	110.275±13.722	0.135±0.017
E18	51.461±1.868	134.186±16.807	0.165±0.021
E19	34.090±1.239	85.472±10.861	0.105±0.013
E20	35.166±1.300	97.980±12.258	0.120±0.015
E21	35.314±1.295	98.839±12.479	0.121±0.015
Range	34.090 – 52.328	85.472 – 134.186	0.118 – 0.165
Average	43.541±1.578	114.711±14.513	0.141±0.018
UNSCEAR	100	60	1

3.3. External risk index

The external risk indexes due to the exposure to natural radioactivity in soil at UJLoG are presented in Table 3. They ranged from 0.279±0.035 to 0.438±0.058 with a mean of 0.375±0.047. These results showed risk index values obtained in all samples lower than the UNSCEAR recommended value of external risk index, 1. This shows that landscaped spaces at UJLoG are safe for the people.

Table 3: External risk index of soil samples at UJLoG

Sample Codes	External risk index H_{ex}	Sample Codes	External risk index H_{ex}
E01	0.384±0.051	E12	0.407±0.052
E02	0.332±0.042	E13	0.438±0.058
E03	0.395±0.047	E14	0.397±0.043
E04	0.405±0.051	E15	0.362±0.047
E05	0.397±0.048	E16	0.345±0.046
E06	0.390±0.052	E17	0.360±0.045
E07	0.396±0.051	E18	0.435±0.055
E08	0.356±0.047	E19	0.279±0.035
E09	0.312±0.041	E20	0.322±0.040
E10	0.427±0.054	E21	0.324±0.041
E11	0.416±0.052		
Range	0.279 – 0.438		
Average	0.375±0.047		
UNSCEAR	1		

4. Conclusion

The main objective of this work was to assess the radiological risk due to natural radioactivity in the landscaped spaces at UJLoG. To do this, soil samples taken from these spaces were analyzed by a gamma spectrometry technique. The results of the analysis showed a large variation in terrestrial radionuclide concentrations due to rapid weathering of rocks in the soil of the region and building construction materials at UJLoG. Assessment of the annual effective doses yielded dose values below the dose limit recommended by UNSCEAR. Also, assessment of the radiological risk due to exposure to natural radioactivity from soils at UJLoG gave external risk index lower than 1, the reference value established by UNSCEAR. This shows that the spaces set up at UJLoG are safe for the population.

5. Acknowledge

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6. Conflict of Interest

The authors have no conflict of interest.

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