Journal of Materials and Environmental Science
ISSN : 2028-2508
e-ISSN : 2737-890X
CODEN : JMESCN

J. Mater. Environ. Sci., 2022, Volume 13, Issue 01, Page 129-138

http://www.jmaterenvironsci.com

Measurements of natural radioactivity and exposure rates in soil samples from Ouagadougou, Burkina Faso

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Received 09 Oct 2021,
Revised 24 Jan 2022,
Accepted 26 Jan 2022

Keywords
- ✓ Radionuclide,
- ✓ Natural radioactivity,
- ✓ soil sample,
- ✓ activity concentration,
- ✓ dose.

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Abstract

Natural radioactivity could be found in various degrees in all media in the environment (water, soils, vegetation, food), and depending on the activity and concentration of radionuclides dealt with, the principal concern is the consequence of exposure to low doses and low dose rates. In this work, we present a study on the measurements of natural radioactivity levels and the external exposure rates in 10 soil samples collected from the city of Ouagadougou in Burkina Faso, using a high-resolution gamma-ray spectrometry with HPGe detector. The specific activity concentrations of the identified radionuclides ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs range respectively from 23.14 ± 1.28 Bq/kg to 52.07 ± 2.59 Bq/kg, 14.83 ± 1.26 Bq/kg to 47.87 ± 3.59 Bq/kg, 114.37 ± 6.83 Bq/kg to 370.93 ± 18.12 Bq/kg and 0.33±0.17 Bq/kg to 7.09±0.39 Bq/kg. From the primordial radionuclides ^{238}U, ^{232}Th and ^{40}K activity concentrations in the soil samples, the absorbed gamma dose rates and the annual effective doses in air were calculated to assess public terrestrial radiation exposures. The absorbed dose rates varied from 27,17 ± 1,71 nGy/h to 55,01 ± 6,937 nGy/h while the annual effective doses ranged from 33.32 ± 2.10 µSv to 67.46 ± 08.50 µSv. The measured values for the terrestrial radioactivity are lower than the worldwide averages given by UNSCEAR (2000).

1. Introduction

Radioactivity is a natural phenomenon, which has always existed in the environment. It is originated from two main sources: high-energy cosmic rays that originate in outer space and terrestrial radionuclides that occur in the Earth's crust [1]. Terrestrial radionuclides are present in different degrees in all environment components. The principal contribution to external exposure comes from gamma radiations emitted by radionuclides present in the soils originated in each area, mainly ^{40}K and the ^{238}U and ^{232}Th families [2]. Significant amount of man-made radionuclides may also present in the environment. ^{137}Cs is found globally in the environment as a result of anthropogenic sources, such as nuclear weapon tests, and nuclear accidents [3].

Determination of natural radioactivity in soil is important since it is an indicator of radioactive accumulation in the environment, which can increase population's exposure to radiation and impact human health. In addition, the area immediately surrounding Ouagadougou is underlain entirely by granite, which is known generally to have high levels of radioactivity.

The aim of this study is to evaluate the natural radioactivity levels and to estimate the external exposure rates in some soil samples from Ouagadougou, Burkina Faso using a high-resolution gamma-ray spectrometry with HPGe detector. The measurement results reported in this paper can be used to

provide radiological information on the studied region as well as to serve as a reference data to evaluate any future change of radiation levels.

2. Materials and Methods

2.1 Study location

Ten (10) composite soil samples were collected in different locations from Ouagadougou (Burkina Faso) with GPS site localization (see **Figure 1**).

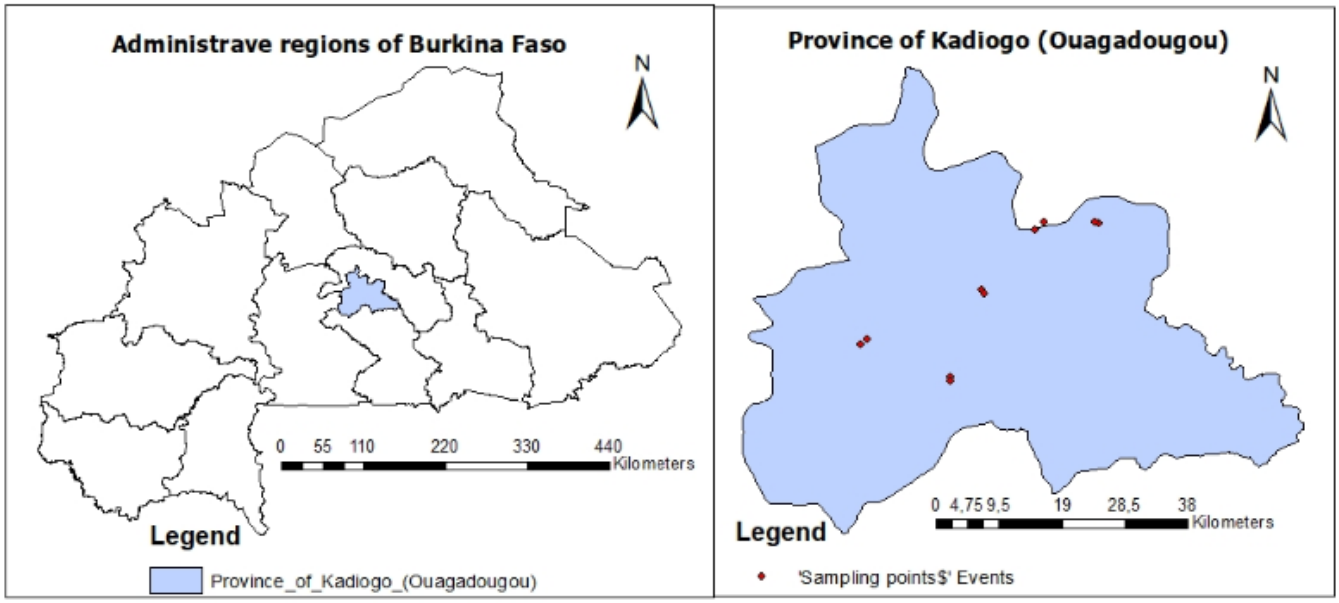

Figure 1. Geographical location of sampling points

Table 1 below summarized the GPS coordinates of each sampling location.

Table 1. Sampling points coordinates

Sample code	GPS coordinates	
	Latitude (N)	Longitude (W)
E1	12.4713056°	1.34127778°
E2	12.473250°	1.34658333°
E3	12.3818056°	1.50127778°
E4	12.3772222°	1.49686111°
E5	12.2632222°	1.54338889°
E6	12.2584167°	1.54336111°
E7	12.3147778°	1.65733333°
E8	12.3067222°	1.666250°
E9	12.4743333°	1.4160°
E10	12.4636667°	1.42847222°

2.2 Sampling and Sample preparation

After clearing the surface grass on each sampling area using a shovel, composite soil samples have been randomly collected in surface (1-15 cm of depth) using a soil auger. About 1 kg of soil sample was collected and each composite sample is formed by combining five (5) single samples collected at different points in which the GPS point and four (4) others at 3 meters distance around.

In the laboratory, sample materials were oven dried at 80°C for about 24 h. The dried samples were grounded with mortar and pestle and then sieved through a metal screen with 600 µm mesh size. Water for washing the tools and paper towels were used during sampling and sample preparation in order to avoid the cross-contamination between samples. The fine grain materials were homogenized, sealed in 120 ml standard plastic containers weighted and well identified for radioactivity measurements. The dry weights were stored for at least 4 weeks before counting to allow the achievement of equilibrium for ^{238}U and ^{232}Th with their respective progeny decay products [4].

2.3 Instrumentation and Calibration

The samples were analyzed using gamma-ray spectrometer at the Laboratory of the National Radiation Protection Agency (NRPA), Yaoundé (Cameroon), consisting of a CANBERRA coaxial HPGe detector cooled with an electrical cryocooler (see **Figure 2**).

Figure 2. Gamma ray spectrometry of NRPA

A 10 cm lead shield prevents the detector from high background counts due to external sources. Energy calibration was done using a set of standard sources of ^{155}Eu and ^{22}Na which have respectively their mean photo peaks at 86.547 keV and 105.308 keV and at 511 keV and 1,274.537 keV. Efficiency calibration was performed using Laboratory Sourceless Object Calibration Software (LabSOCS). The samples were counted for 36,000 s. Prior to sample measurements, the background gamma ray was measured with an empty standard plastic container (the same as those used for sample preparations) under identical measurement conditions. ^{238}U, which does not emit gamma rays, was quantified by measuring the activity of its short-lived gamma emitting decay product ^{234m} Pa (766.37 and 1,000.03 keV) and ^{228}Ac (911.20 and 968.97 keV) was used for the ^{232}Th activity concentrations. The natural abundance of ^{235}U is only 0.72% from the total uranium content and hence it is not considered in our study [5]. ^{40}K and ^{137}Cs activity concentrations were directly determined by their own gamma rays respectively at 1,460.83 keV and 661.65 keV.

- ***Activity concentration measurements***

The concentration of specific activity, $A_E(Bq/kg)$, of a nuclide with a single photo-peak at energy "E" was calculated by **Eqn. 1** [4].

$$A_E = \frac{N_E}{\varepsilon_E \cdot t \cdot \gamma_d \cdot M} \qquad \textbf{Eqn. 1}$$

Where N_E is the net peat area after subtraction of the background, ε_E is the detection efficiency at energy *E*, ***t*** is the live time counting, γ_d is the number of gamma per disintegration of this nuclide for a transition at energy E and M is the mass in kg of the measured sample.

The combined standard uncertainty, $u_c(A_E)$, is determined by **Eqn. 2** [6].

$$u_c(A_E) = A_E\sqrt{(\frac{u(N_E)}{N_E})^2 + (\frac{u(\varepsilon_E)}{\varepsilon_E})^2 + (\frac{u(t)}{t})^2 + (\frac{u(\gamma_d)}{\gamma_d})^2 + (\frac{u(M)}{M})^2} \qquad \textbf{Eqn. 2}$$

Where $(u(N_E)/N_E)$ etc. are the uncertainties in the parameters, expressed as relative standard deviations. For a multi gamma rays emitting nuclide, the weighted average activity is used to estimate the activity concentrations, A_W, according to **Eqn. 3** [5; 7].

$$A_W = \frac{\sum_{i=1}^{N} \frac{A_{Ei}}{(\sigma_i)^2}}{\sum_{i=1}^{N} \frac{1}{(\sigma_i)^2}} \qquad \textbf{Eqn. 3}$$

Where A_{Ei} is the specific activity for a photo-peak "i" at energy "E", σ_i is the standard deviation of A_{Ei}, *N* is the number of significant photo-peaks of the identified nuclide.

In case of weighted average activity, the combined standard uncertainty, $u_c(A_w)$, is determined by **Eqn. 4** [7].

$$u_c(A_W) = \frac{1}{\left[\sum\left[\frac{1}{u_c(A_{Ei})}\right]^2\right]^{1/2}} \qquad \textbf{Eqn. 4}$$

Where $u(A_{Ei})$ are the uncertainties in the parameters, expressed as standard deviations.

- ***External exposure rates***

Absorbed dose rates in air $D(nGy/h)$ from various concentrations of terrestrial radionuclides in soil were calculated using **Eqn. 5** [1; 4].

$$D = 0.462C_U + 0.604C_{Th} + 0.0417C_K \qquad \textbf{Eqn. 5}$$

In **Eqn. 5**, C_U, C_{Th} and C_K are respectively the average specific activity concentrations of ^{238}U, ^{232}Th and ^{40}K in the investigated soil samples.

The annual effective dose $E(mSv)$ was determined using **Eqn. 6** [1; 4].

$$E = D(nGy.h^{-1}) \cdot 8{,}760(h) \cdot 0.2 \cdot 0.7(Sv.Gy^{-1}) \qquad \textbf{Eqn. 6}$$

In **Eqn. 6**, 0.7 Sv.Gy^{-1} is the conversion coefficient from absorbed dose in air to effective dose received by adults, 0.2, the outdoor occupational factor and 8,760 h, the total number of hours in a year.

3. Results and Discussion

3.1 Activity Concentration

The primordial radioelements of the telluric radioactivity ^{238}U, ^{232}Th, and ^{40}K together with ^{137}Cs, which is an artificial nuclide were mainly identified (see **Figure 3**) and quantified.

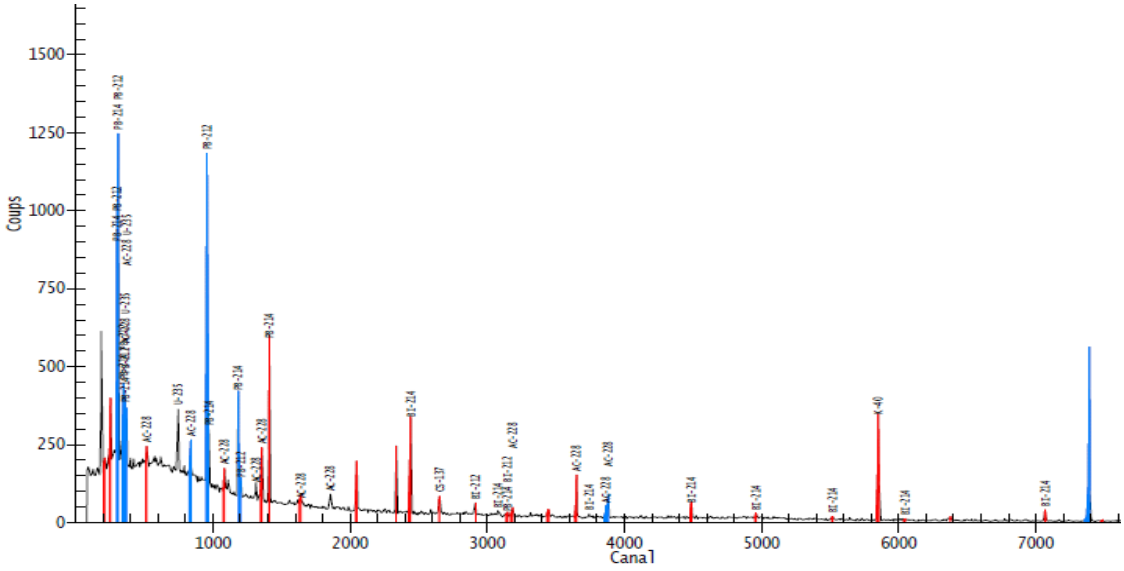

Figure 3. Natural gamma-ray spectrum of sample E2

The concentration of specific activities of the identified radionuclides were summarized in **Table 2**. In our study, it appeared a relative variation of activity concentrations from place to place as well as within the same sampling location. **Table 3** summarized specific activity concentrations measured from different parts of the world for comparison.

Table 2. Activity concentration rates of samples

Sample code	Activity concentration (Bq/kg)			
	^{238}U	^{232}Th	^{40}k	^{137}Cs
E1	45.17 ± 2.27	32.20 ± 2.57	272.64 ± 13.83	7.09 ± 0.39
E2	25.15 ± 1.39	36.17 ± 3.16	370.93 ± 18.12	3.22 ± 0.32
E3	29.25 ± 1.6	36.40 ± 3.15	177.52 ± 9.61	0.14 ± 0.09
E4	26.11 ± 1.35	14.83 ± 1.26	147.48 ± 7.92	< AMD
E5	23.14 ± 1.28	21.15 ± 1.97	312.00 ± 15.59	1.24 ± 0.27
E6	26.12 ± 1.39	20.72 ± 1.77	176.99 ± 9.51	2.57 ± 0.34
E7	39.26 ± 2.00	34.57 ± 3.55	161.84 ± 9.21	1.89 ± 0.38
E8	46.17 ± 9.70	47.87 ± 3.59	114.37 ± 6.83	1.37 ± 0.17
E9	24.05 ± 1.31	17.99 ± 1.69	205.96 ± 10.80	0.33 ± 0.17
E10	52.07 ± 2.59	32.22 ± 2.61	129.65 ± 7.64	0.45 ± 0.22

Table 3. Activity concentrations measured worldwide for comparison

Region / Country	Activity concentration (Bq/kg)				Reference
	238U	232Th	40K	137Cs	
Algeria	30	25	370	-	UNSCEAR, 2000
Egypt	37	18	320	-	UNSCEAR, 2000
Jamaica	87.01 ± 12.70	42.92 ± 4.98	200.76 ± 21.50	3.20± 0.60	Miller et al., 2018 [8]
Niger delta, Nigeria	-	29.70 ± 4	412.5 ± 20.00	-	Agbalagbaa et al., 2012 [9]
North west of Saudi Arabia	43.79 ± 3.12	27.59 ± 1.64	161.82 ± 8.16	-	Zarie and Al-Mugren, 2010 [4]
Dhaka city, Bangladesh	-	16 ± 4	574± 111	7 ± 2	MIAH FK et al., 1998 [10]
Central province, Saudi Arabia	12.91	17.79	200.90	4.76	Al-Kheliewi and Al-Mogabes, 2001 [11]
Ouagadougou, Burkina Faso	33.65 ± 2.49	29.41 ± 2.53	206.94 ± 10.91	2.03 ± 0.26	Present study, 2020
Worldwide average	35	30	400	-	UNSCEAR, 2000

- The activity concentrations of ^{238}U ranged from 23.14 ± 1.28 Bq/kg to 52.07 ± 2.59 Bq/kg with a mean value of 33.65 ± 2.49 Bq/kg. ^{238}U activity concentrations in samples E1 in the Eastern of the city, in E7 and E8 in the Western and in E10 in Northern were higher than the median value of 35 Bq/kg given by UNSCEAR (2000). This indicated some variations in geological formations in the space of Ouagadougou. Sampling locations of E1 and E10 are closed to the Laongo natural site made up of granite mass outcropping on the ground whereas E7 and E8 are near to the Pissy granite quarry. The variations in mass activities observed reinforce the assertion that higher radiation levels are associated with igneous rocks, such as granite, and lower levels with sedimentary rocks [12]. We observe also that the mean value of ^{238}U is higher than the value of 12.91 Bq/kg reported by Al-Kheliewi and Al-Mogabes [11], but lower than those reported by Miller et al [8] and Zarie and Al-Mugren [4].

- The activity concentration of ^{232}Th ranged from 14.83 ± 1.26 Bq/kg to 47.87 ± 3.59 Bq/kg with a mean value of 29.41 ± 2.53 Bq/kg which is higher than the values reported by MIAH FK et al. [10] and Al-Kheliewi and Al-Mogabes [11], but within the values reported by Agbalagbaa et al. [9] and Zarie and Al-Mugren [4]. As thorium is present in the granites, this may justify the slightly high activity concentrations in samples E1, E7, E8 and E10 in the same range as the concentrations of ^{238}U. This confirmed the statement that in sand samples, ^{232}Th and ^{238}U concentration distributions were parallel and show that both are interdependent [13].

- ^{40}K activity concentration ranged from 114.37 ± 6.83 Bq/kg to 370.93 ± 18.12 Bq/kg with a mean value of 206.94 ± 10.91 Bq/kg. Sampling locations of E4, E8 and E10 are clearings then lower concentrations may be due to strong runoff of water whereas in sampling locations E1, E2, E5, E7 and E9 that are cultivable areas, the intake of organic manure may justify the slightly higher concentrations of ^{40}K. It appeared low concentrations of 40K in all samples compared to the median value of 400 Bq/kg given by UNSCEAR (2000). It appears also that the mean value of ^{40}K is lower than the results

reported by Agbalagbaa et al. [9] and MIAH FK et al. [10] but is within those reported by Miller et al. [8] and Al-Kheliewi and Al-Mogabes [11].

- The activity concentrations of ^{137}Cs ranged from 0.33 ± 0.17 Bq/kg to 7.09 ± 0.39 Bq/kg with a mean value of 2.03 ± 0.26 Bq/kg. It appeared relatively low activities and quasi-homogeneous concentrations all along the sampling areas. In the Center of the city, the sample E3 showed the lowest concentration of ^{137}Cs while the mass activity in sample E4 was below the detection limit. Lower concentrations in the Center locations may be linked to human actions by turning of the soil or to the effects of erosion resulting from runoff water. The anthropogenic radionuclide ^{137}Cs, was deposited in the soil presumably as a result of fallout of radioactivity from the atmosphere following nuclear weapon testing in the fifties and sixties around the world [3], mainly from the French nuclear tests in Algeria between 1960 and 1966 [14]. The results of this study show that, the ^{137}Cs mean activity concentration is lower than those reported by Miller et al. [8], MIAH FK et al. [10] and Al-Kheliewi and Al-Mogabes [11].

3.2 External exposure rates

From the activity concentrations of the primordial radionuclides ^{238}U, ^{232}Th and ^{40}K in the soil samples, the absorbed gamma dose rates and the annual effective dose in air in regions of sampling were computed and the results are shown in **Table 4** together with the measured ambient dose rates in air at 1 m above the ground accomplished using RadEye PRD portable radiation survey meter.

Table 4. External exposure rates from samples with measured ambient dose rates in air at sampling points

Sample code	External exposure		Measured ambient dose rates (µSv/h)
	Absorbed dose rates (nGy/h)	Annual effective dose (µSv)	
E1	51.68 ± 3.17	63.38 ± 3.89	0.06 ± 0.01
E2	48.93 ± 3.30	60.01 ± 4.05	0.06 ± 0.02
E3	42.90 ± 3.04	52.61 ± 3.73	0.06 ± 0.01
E4	27.17 ± 1.71	33.32 ± 2.10	0.05 ± 0.01
E5	36.47 ± 2.43	44.73 ± 2.98	0.05 ± 0.01
E6	31.96 ± 2.10	39.19 ± 2.58	0.05 ± 0.01
E7	45.76 ± 3.45	56.12 ± 4.23	0.07 ± 0.02
E8	55.01 ± 6.93	67.46 ± 8.50	0.07 ± 0.02
E9	30.56 ± 2.07	37.48 ± 2.54	0.05 ± 0.01
E10	48.92 ± 3.09	59.99 ± 3.79	0.06 ± 0.01

We observe on **Table 4** that the absorbed dose rates in air due to the primordial radionuclides varied from 27.17 ± 1.71 nGy/h to 55.01 ± 6.94 nGy/h with a mean value of 41.94 ± 3.13 nGy/h. The ambient

dose rates directly measured in air at the sampling locations ranged from 0.05 ± 0.01 µSv/h to 0.07 ± 0.02 µSv/h, with an average of 0.06 ± 0.01 µSv/h.

For needs of comparison to the worldwide averages given by UNSCEAR (2000), we present in **Table 5** below, the external exposure rates measured in different countries. The ratio of the calculated value to the measured value in this study is 0.50 taking into account of the conversion coefficient of 0.7 $Sv.Gy^{-1}$ from absorbed dose in air to effective dose received. This ratio obtained is comparable with the ratio of 0.60 reported for Albania by UNSCEAR (2000) but far lower than the value of 1.20 reported for the United States.

Table 5. External exposure rates measured worldwide for comparison

Region / Country	Absorbed dose rates in air (nGy/h)	Annual effective dose (µSv)	Reference
Algeria	70	-	UNSCEAR, 2000
Egypt	32	-	UNSCEAR, 2000
Sudan	53	-	UNSCEAR, 2000
Niger delta, Nigeria	54.6	70	Agbalagbaa et al., 2012 [9]
North west of Saudi Arabia	43.64 ± 2.91	53.53 ± 3.56	Zarie and Al-Mugren, 2010 [4]
Babylon city, Iraq	23.61	29	Karim et al., 2016 [15]
Ouagadougou, Burkina Faso	41.94 ± 3.13	51. 43 ± 3.84	Present study, 2020
Worldwide average	60	70	UNSCEAR, 2000

The calculated annual effective doses in air due to external exposure to natural terrestrial sources of radiation ranged from 33.32 ± 2.10 µSv to 67.46 ± 08.50 µSv with an average of 51.43 ± 3.84 µSv. This average of annual effective dose is lower than the value of 70 µSv given by UNSCEAR (2000) and Agbalagbaa et al. [9], higher than the value reported by Karim et al. [15] but it is within those reported by Zarie and Al-Mugren [4]. Good agreement was obtained by recent works [16-18].

Conclusion

Specific activity concentrations of terrestrial radionuclides ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in soil samples along the space of Ouagadougou in Burkina Faso have been determied using a gamma-ray spectrometer. The mean values of the primordial radionuclides ^{238}U, ^{232}Th and ^{40}K activity concentrations were respectively 33.65 ± 2.49 Bq/kg, 29.41 ± 2.53 Bq/kg and 206.94 ± 10.91 Bq/kg. The external exposure rates in air due to the primordial radionuclides were then evaluated with a mean value of 41.94 ± 3.13 nGy/h for the absorbed dose rates while the mean value of the annual effective doses was 51.43 ± 3.84 µSv. These values were all of them lower than the worldwide averages given by UNSCEAR (2000). So, the space of Ouagadougou can be considered as a normal natural background radiation area. The study showed a spatial distribution of the anthropogenic radionuclide ^{137}Cs with a mean activity concentration of 2.03 ± 0.26 Bq/kg. This low level of ^{137}Cs activity is presumably distributed across the space of Ouagadougou. Additional study with a sampling method customized to ^{137}Cs activity concentration with increased sampling density is required to improve the quality of the contamination distribution.

Acknowledgement : The authors wish to thank International Science Program (ISP) for funding our research group and allowing to conduct these works.

Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest. *Compliance with Ethical Standards:* This article does not contain any studies involving human or animal subjects.

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