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Survey of Gamma Dose Rate in Air Inside Some Dwellings of the Commune of Yopougon, Abidjan, Côte d'Ivoire

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Abstract
To determine the radon potential level and estimate the related exposure of the public, combined gamma dose rate and radon measurements were performed in 15 dwellings in Yopougon, the largest and inhabited commune of Côte d'Ivoire. Indoor gamma dose rates were measured using a gamma survey meter. Radon concentration measurements were performed using LR-115 films detectors (SSNTDs) for three months. The mean indoor gamma dose rate in air was 20 nSv/h whereas the mean radon concentration indoor was found to be 93.04 Bq/m^3. The relationship between indoor radon measurements and gamma dose rates was also investigated. A very weak correlation between the two variables was observed.

Keywords: Correlation investigation, Côte d'Ivoire, indoor gamma dose rate, indoor radon, LR-115, surveymeter

INTRODUCTION

Radon, a radioactive gas, is present in all buildings and underground locations as its immediate precursor, radium-226, is ubiquitous in the Earth's crust. Radon is a significant source of radiation exposure of the public. Since it was recognized as a human lung carcinogen from epidemiological (WHO, 1986; IARC, 1988; ICRP, 1993) and pooled case-control studies of residential exposures (ICRP, 2010), comprehensive radon surveys in dwellings and workplaces, as well as management strategies, were implemented in many countries through national radon programs. Combined studies of gamma dose rate and radon concentration inside houses (Sundal and Strand, 2004; Iqbal *et al*., 2012; Clouvas *et al*., 2013; Quarto *et al*., 2016) were also carried out. In general, a weak correlation was found between these two variables (Sundal and Strand, 2004, Clouvas *et al*., 2013, Quarto *et al*., 2016).

As Côte d'Ivoire is a non-nuclear country, the study of environmental radioactivity is recent. Therefore, there is no natural radiation mapping and not even national reference level. Environmental radioactivity investigation began with the measurement of radionuclides in the soil by alpha and gamma spectrometry (Koua *et al*., 2009a) as well as the estimation of the gamma dose rate outdoor (Koua *et al*., 2009b). The ambient gamma dose rate outdoor was also measured in Abobo, another commune of the district of Abidjan where the average value found was 10 nGy/h (Kouadio, 2008).

In order to broaden this systematic survey of the exposure to natural radiation, radon concentration study using Solid State Nuclear Tracks Detectors (SSNTD) was initiated. In this context, various measurements of radon in homes were conducted, notably in the district of Abidjan (Agba, 2009, Agba *et al*., 2015; N'guessan, 2014, N'guessan *et al*., 2016; Nonka, 2015; Vanié, 2015). The aim of these measurements was to determine the radon potential level and estimate the related exposure of the public in this district, which alone shelters 33% of the population living in Côte d'Ivoire.

In this study, we present the results of a pilot study. Measurements were carried out in 15 houses located in Yopougon (Nonka, 2015; Vanié, 2015) and the correlation between gamma dose rate and radon concentration in these dwellings was discussed.

MATERIALS AND METHODS

Study area: The area of this study is Yopougon which lies in the North-West part of the District of Abidjan, between the latitudes 5°20'56″ N and longitudes 4`°00'56″ W. It is the largest and one of the most inhabited communes of Côte d'Ivoire.

The climate is divided in four distinct seasons: a long dry season (from December to April), a heavy rainy season (from April to July), a small dry season (from July to September) and a small rainy season (from October to December). The temperature varies from 22 to 35°C with a mean about 28°C. The mean moisture is

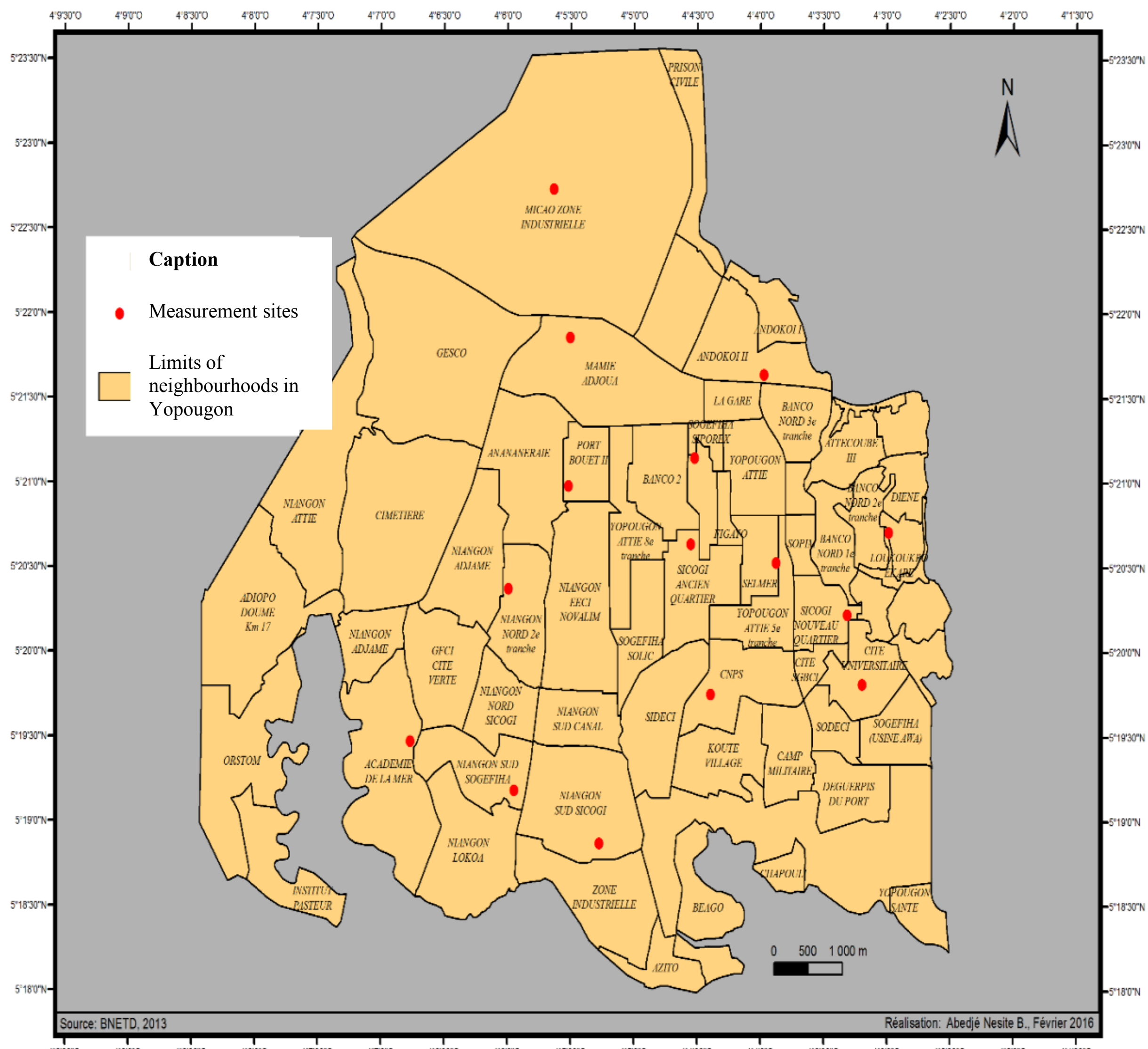

Fig. 1: Map of Yopougon showing the selected measurement sites

Table 1: Basic information on sites, gamma dose rate and radon gas concentration in the commune of Yopougon

Sites	Code	GPS	Gamma dose rate (µSv/h)	Radon concentration (Bq/m^3)
Siporex	SI	21' 8.833" N 4' 31.125" W	30	81.9±1.7
Sicogi ancien quartier	AQ	20' 38.298" N 4' 32.988" W	10	75.6±1.6
Selmer	SE	20' 31.651" N 3' 52.496" W	10	101.6±1.2
Nouveau quartier	NQ	20' 13.206" N 3' 18.643" W	30	106.5±1.5
Niangon sud sogefiha	NS	19' 11.016" N 5' 56.693" W	30	66.8±1.9
Academie de la mer	AM	19' 28.256" N 6' 45.951" W	20	80.4±1.7
Niangon sud sicogi	SS	18' 52.215" N 5' 16.360" W	20	60.2±1.8
Cnps	CN	19' 45.127" N 4' 23.422" W	20	95.4±2.3
Niangon nord	NN	20' 22.419" N 5' 59.453" W	40	26.3±1.1
Mamie adjoua	MA	21' 51.444" N 5' 30.180" W	40	89.4±1.5
Micao zone industrielle	ZI	22' 44.040" N 5' 37.978" W	30	99.6±1.7
Andokoi II	AN	21' 38.426" N 3' 58.204" W	10	173.3±1.5
Millionnaire	MI	20' 42.519" N 2' 59.063" W	30	151.9±2.2
Toit rouge	TR	19' 48.590" N 3' 11.519" W	20	64.9±1.6
Port bouet II	PB	20' 58.859" N 5' 31.039" W	30	121.8±2.1
Range			10 - 40	26.3-173.3
Median			25	89.4±1.5
Arithmetic mean			20	93.04

90%. The geology of the commune is formed of sedimentary rocks from tertiary to quaternary age.

Fifteen dwellings were selected throughout the commune and the sites were located using a GPS (Fig. 1). The basic information on the sites is given in Table 1.

The surveys are performed at the same period and at the same location during the small rainy season, from September to November 2015.

Indoor Gamma dose rates and radon measurements: The indoor gamma dose rate measurements in the identified sites were carried out using a highly sensitive NaI scintillator-based gamma dosimeter (RadEye PRD, ThermoFisher, USA) at 1 m above the ground. Several readings were taken at different points in each area and the average gamma exposures were determined. This device can detect gamma rays in the energy range from 60 keV to 1.3 MeV and the dose rate measurement range is 0.01 to 250 µSv/h. During the measurement, beyond 95% of cosmic radiation was removed.

The indigenous radon measurement sensor was composed of a non-strippable LR 115 type 2 film (Dosirad, France) cut into 2.5×2.5 cm^2 and sticked on an envelope. The detectors were deployed inside the dwellings, away from windows and doors. After three months of exposure, the SSNTDs were retrieved for chemical etching in a 2.5 N NaOH solution bath at a temperature of 60°C during 120 min (Agba, 2009). The tracks recorded onto the film were counted using a digital imaging system which comprise an optical microscope and a CCD camera connected to a monitor, then converted to radon concentration.

Statistical analysis: The relationship between the indoor gamma dose rate and radon concentration was analyzed using the student's t-test. The normality of the log transformed experimental data was tested by the KOLMOGOROV-SMIRNOV test.

RESULTS AND DISCUSSION

The results of indoor ambient gamma dose rates and indoor radon concentration were summarized in Table 1.

Indoor gamma dose rates: The gamma absorbed dose rates varies in the range 10-40 nSv/h, with a mean value of 20 nSv/h. The highest values, 40 nSv/h, are recorded on the sites MA, NN and the lowest at AQ, SE. The mean value observed in Yopougon (20 nSv/h) was very low compared to the average value, 229 nSv/h, obtained in the Province of Naples (Quarto *et al*., 2016). In this region of Italy, materials which are very rich in uranium and thorium traces are widely used in house construction. This make the natural radiation exposure particularly significant whereas buildings in Yopougon were made of sand and cement. Moreover, Yopougon lies on the sedimentary costal area which was reputed to have low natural background radiation exposure.

The mean dose rates were also lower than the world average value (46.8 nSv/h) of the normal background area (UNSCEAR, 2000).

Figure 2 shows the frequency distribution of gamma dose rate in air inside the monitored dwellings. The experimental gamma radiation dose rate data indicates a normal-like distribution.

Indoor radon concentration: The indoor radon concentrations measured in the selected dwellings range from 26.3 Bq/m^3 to 173.3 Bq/m^3 with a mean value of 93.04 Bq/m^3. The lowest value was obtained on the NN site. This concentration value was quite particular as it was obtained from the 1st floor of a good, ventilated house while all others in the study were carried out in low rise residential dwellings.

The arithmetic mean value, 93.04 Bq/m^3, was higher than the world average indoor value (UNSCEAR, 2009) which is approximately 40 Bq/m^3. However, it must be noticed that the value derived from our survey is closed to the arithmetic mean radon concentration, 90 Bq/m^3, found in Thessaloniki (Clouvas *et al*., 2013) and lower than the average value reported for the Province of Naples, in south Italy. However, this result must be considered with caution due to the limited number of measurements performed in Yopougon.

Inside more than 66% of the monitored houses, the radon concentration was below 100 Bq/m^3, the lower value recommended by ICPR 126 (ICRP, 2010). For the remaining 34%, their concentrations do not exceed the recommended upper value (300 Bq/m^3) of the derived reference level (ICRP, 2014).

The indoor radon concentration frequency distributions (Fig. 3) exhibit an approximately log-normal distribution.

Correlation analysis: To analyze the correlation between the ambient gamma dose rate and the radon concentration in the surveyed dwellings, we calculated the Pearson-Bravais coefficient. The Kolmogorov-Smirnov normality test with 95% confidence and the cumulative frequency distributions curve confirm that the two variables are normally distributed. These results are indicated in Table 2 and illustrated by Fig. 4 and 5.

Hence, one can calculate the BRAVAIS-PEARSON coefficient for the linear correlation coefficient. When all the values in Table 1 were considered to plot gamma dose rate vs radon concentration indoor (Fig. 6), we found a correlation coefficient, R = -0.28 and a corresponding coefficient of determination R^2 = 0.0786.

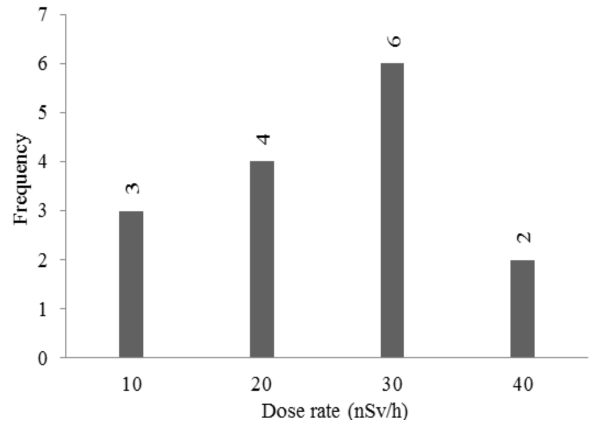

Fig. 2: Frequency distribution of gamma dose rate in dwellings of Yopougon

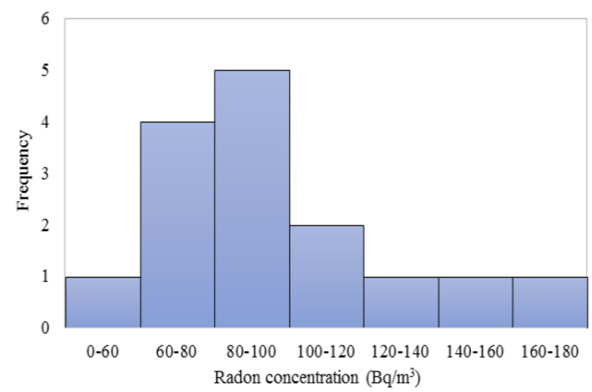

Fig. 3: Frequency distribution of Randon concentration in dwellings of Yopougon

Table 2: Kolmogorov-Smirnov test

Variable	Observed probability (d_{obs})	Empirique probability (d_{tab})
Radon concentration	0.156	0.338
Gamma dose rate	0.172	0.338

d_{obs}<d_{tab}: The variables exhibit normal distribution behavior

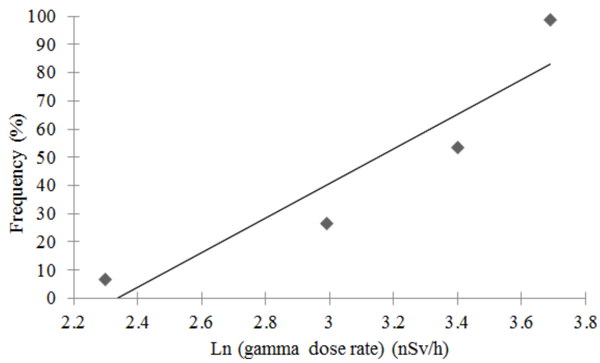

Fig. 4: Frequency distribution of Ln (gamma dose rate) in dwellings of Yopougon

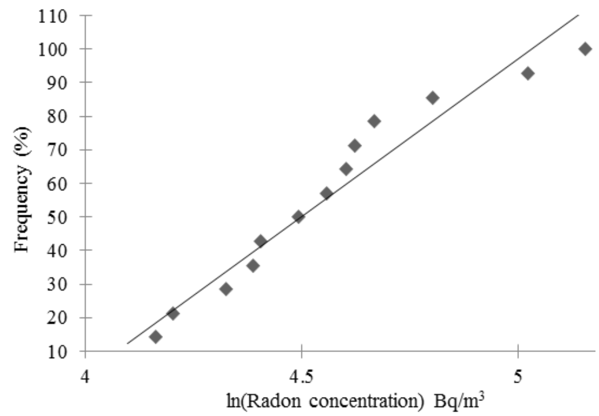

Fig. 5: Frequency distribution of Ln (Radon concentration) in dwellings of Yopougon

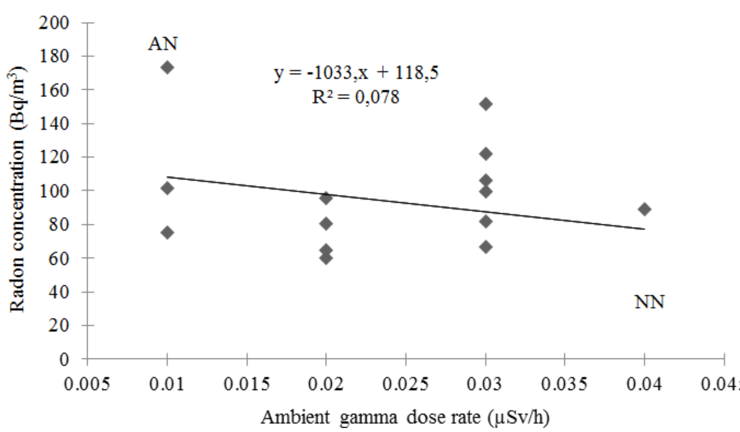

Fig. 6: Correlation between the gamma dose rate and radon concentration with points NN and AN

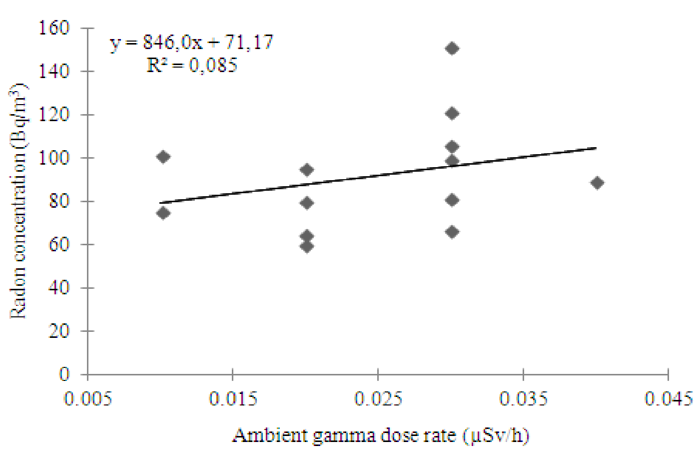

Fig. 7: Correlation between the gamma dose rate and radon concentration without points NN and AN

A negative linear relationship between these two variables was observed. It means that gamma dose rate and radon concentration evolve in opposite directions, contrary to what was reported by Iqbal (Iqbal *et al*., 2012).

In case of rejection of the two extreme points, "NN" and "AN" respectively with abnormally very low and high concentrations, the new correlation coefficient is R = 0.29 and R^2 = 0.0854 (Fig. 7). The linear correlation became positive but, it remains very weak. Such behavior was found in the study of Italy (Quarto *et al*., 2016). Here, only 8.54% of the variation in radon concentration was explained by the variation of the ambient gamma dose rate, as stated by the coefficient of determination R^2.

In our model, we considered only one parameter (the gamma dose rate) to explain the variations in radon concentration in dwellings assuming all other things being equal. However, the radon concentration may be affected by several factors such as atmospheric conditions (wind speed, atmospheric pressure, humidity, temperature, etc.), building types, building materials, the underlying geology, etc. This approximation could explain the low value of the coefficient of determination R^2.

CONCLUSION

This preliminary study revealed a weak positive linear correlation between ambient gamma dose rate and radon concentration inside the surveyed houses in the commune of Yopougon. Nevertheless, it remained low (R = 0.29). About only 8.54% change in radon concentration was explained by the variation in the ambient gamma dose rate in our model (R^2 = 0.085). To improve the correlation, the following factors must be considered in later studies:

- Increase the number of the monitored dwellings
- More geological data
- Characteristics of the monitored dwellings (habitat types, construction materials, ventilation, construction period, etc.)

This pilot study should be extended to the other communes of the district of Abidjan for indoor gamma dose rate mapping in the most inhabited parts of the country and later nationwide.

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