European Journal of Applied Sciences – Vol. 10, No. 1
Publication Date: February 25, 2022
DOI:10.14738/aivp.101.11419.
Brigui, O. J., Agbo, D. D. A., & Monnehan, G. A. (2022). Assessment of Natural Radioactivity in Gravel Samples Collected from Abidjan District in Côte d'Ivoire. European Journal of Applied Sciences, 10(1). 126-134.

Assessment of Natural Radioactivity in Gravel Samples Collected from Abidjan District in Côte d'Ivoire

BRIGUI Olkalé Jean-Claude
Laboratoire des Sciences de la Matière, de l'Environnement et de l'Energie Solaire, UFR des Sciences des Structures de la Matière et Technologie, Equipe de physique Nucléaire et Radioprotection
Université Félix Houphouët Boigny, Abidjan, Côte d'Ivoire

AGBO Djama Djoman Alfred
Laboratoire des Sciences de la Matière, de l'Environnement et de l'Energie Solaire, UFR des Sciences des Structures de la Matière et Technologie, Equipe de physique Nucléaire et Radioprotection
Université Félix Houphouët Boigny, Abidjan, Côte d'Ivoire

MONNEHAN Georges Alain
Laboratoire des Sciences de la Matière, de l'Environnement et de l'Energie Solaire, UFR des Sciences des Structures de la Matière et Technologie, Equipe de physique Nucléaire et Radioprotection
Université Félix Houphouët Boigny, Abidjan, Côte d'Ivoire
Autorité de Radioprotection, de Sûreté et Sécurité Nucléaires
Abidjan, Côte d'Ivoire

ABSTRACT

Gravel is one of the reference materials used in the construction sector and in particular in Côte d'Ivoire. In this study, which appears to be one of the first works on construction materials in Côte d'Ivoire, radiological measurements are carried out on ten (10) samples of gravel from the district of Abidjan in order to evaluate the activity concentration of natural radionuclides (226Ra, 232Th and 40K). The measurements are made using the nuclear technique based on gamma spectrometry with a GeHP detector. The average activity concentrations in the samples were 5.98± 0.24 Bq.kg^{-1}, 4.17± 1.65 Bq.kg^{-1} and 177.18± 3.50 Bq.kg^{-1} for 226Ra, 232Th and 40K respectively. These values, which were the first results obtained, show that the natural radioactivity in these gravels is comparable to what is usually measured in the same samples on a world scale, whose average limit values are 35 Bq.kg^{-1}, 30 Bq.kg^{-1} and 400 Bq. kg^{-1} (UNSCEAR, 2000). Therefore, the radioactivity in these gravels does not pose an immediate health risk to the public. Long-term effects can be avoided by simple precautionary measures.

Keywords : Gamma spectrometry Technique, gravel samples, District of Abidjan, activity concentration

INTRODUCTION

Populations are subjected to environmental ionizing radiation from a wide variety of sources. A part from the direct irradiation due to cosmic rays, human been is subjected to an irradiation due to radioelements of natural origin contained in the ground, the rocks or the building materials. Most of this radioactivity is due to elements of the uranium-238, thorium-232 and potassium-40 series [1]. These radionuclides can cause adverse effects on human health, particularly through external exposure to gamma radiation, ingestion or inhalation due to their ionizing radiation on the body [2].

According to [3], the term "gravel" typically refers to pieces of crushed stone often basalt, sandstone, or lime stone that are categorized by size, composition, color, or shape. Today; pea gravel, river rock, and stone dust can all be considered gravel. There are many of applications for these stone products in construction. The authors in [3] reported that from acting as fill material or pipe bedding to making up foundations and roads, gravel is a versatile material that comes in many shapes and sizes. Gravel is one of the reference materials in the construction sector in Côte d'Ivoire. It is an important part in the different construction works. The risks associated with construction materials can become important in the case of high levels of radionuclides or chronic exposure over many years. This study is a preliminary assessment and aims to assess the levels of naturally occurring radioactivity in samples of gravel used in the Abidjan District in the various construction sectors.

MATERIALS AND METHODS

Study area

The District of Abidjan is located between latitudes 5°10 and 5°38 North and longitudes 3°45 and 4°21 West. Covering an area of 2119 km^2, the District of Abidjan has a population density of 2221 inhabitants / km^2. Its population is estimated at 4,707,404 with a growth rate of 3.7% [4]. Geologically, it belongs to the coastal sedimentary basin (figure 1).

Materials

Sampling and preparation equipment

The materials analyzed during this work are ten (10) samples of gravel. The equipment used in the field for sample collection includes a Garmin (etrex) brand GPS to determine geographic coordinates, shovels for manual collection and polythene sample bags. The laboratory equipment used for sample preparation consists of a METTLER TOLEDO brand electronic balance (Model: XP2001S, SNR; B044082756,12V / 2.25A) for different mass measurements of the samples. There are also Marinelli beakers (SG 500) for the conditioning of the samples, an oven for drying the samples, a ball mill and a sieve of 2 millimeters mesh.

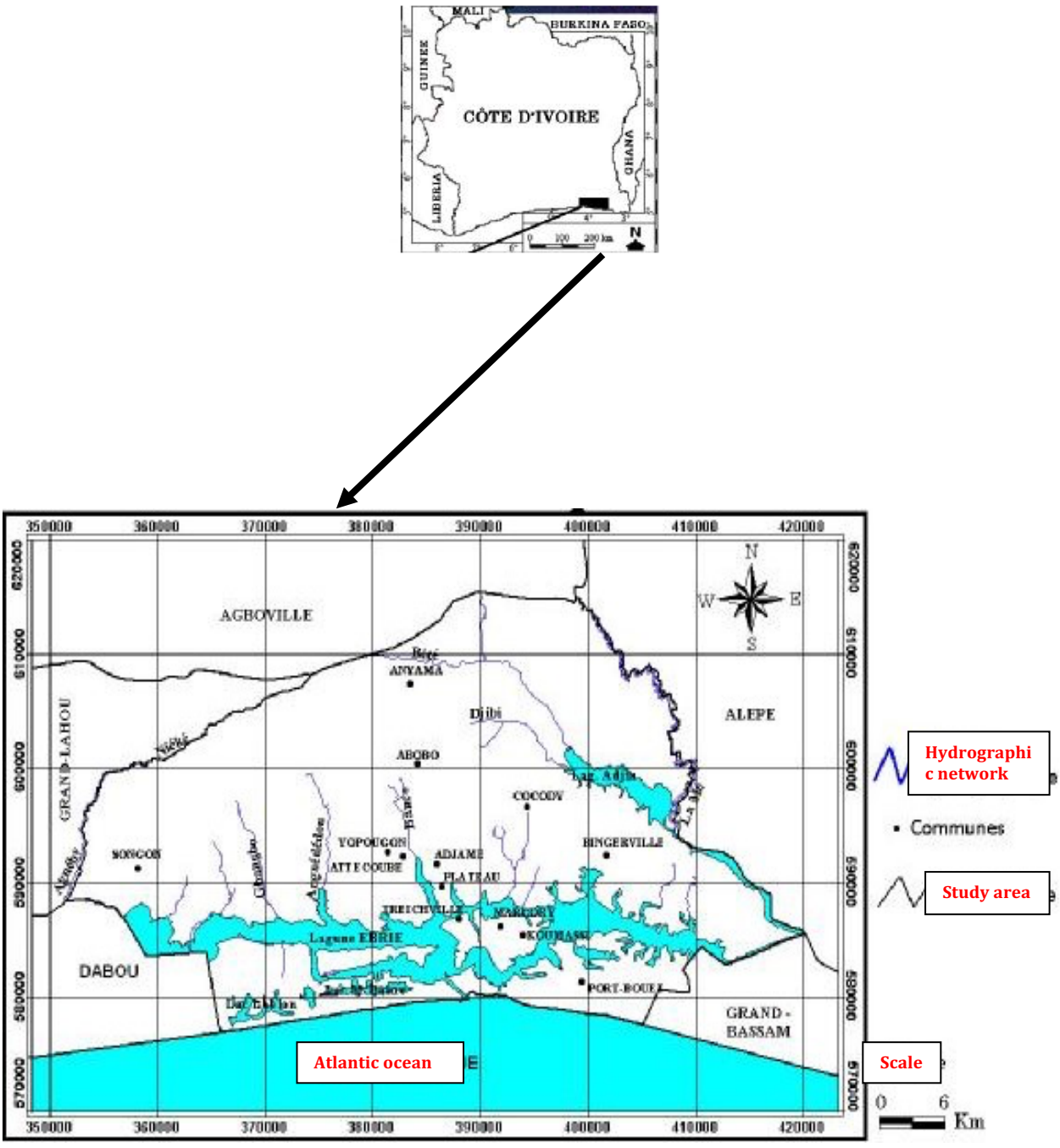


Figure 1: Map of the study area (District of Abidjan)

Equipment analysis

The radioactivity of the sand samples is measured using the gamma ray spectrometer installed at the laboratory of the Radiation Protection Institute (RPI) of GAEC (Ghana). The measurement chain includes the measurement chamber, a liquid nitrogen cooling system (77 K), a High purity Germanium (*HPGe*) coaxial detector model GX 4020-7500 SL (Canberra brand) and with a resolution of 2 keV at 1332 keV (^{60}Co).There are also a high voltage power supply (4000V) essential for the collection of the quantity of electric charges deposited in the detector, a cylindrical lead shielding 10 cm thick making it possible to reduce contributions of ambient

radiation, a multichannel analyzer (MCA) connected to a computer.There are also an acquisition and processing software "GENIE 2000 Camberra" with calibration sources composed of: ^{241}Am (59.5412keV), ^{109}Cd (88, 04keV), ^{139}Ce (165,864keV), ^{113}Sn (391.69keV), ^{137}Cs (661.56keV), ^{57}Co (122keV; 136keV, 474keV), ^{60}Co (1173keV, 237keV, 1332.50 keV), ^{88}Y (898.042keV, 1836.063keV).

Methods

Samples collection

The nineteen sand samples are collected from the main suppliers and construction sites. Each sample is a combination of five (5) incremental samples taken at random from five points in the gravel stock from a depth of approximately 15 cm. Approximately 2 kg of each sample is collected and packaged in contamination-free polyethylene bags, adequately labeled in situ to allow their exact identification at the laboratory for preparation.

Preparation methods

In the laboratory, all samples are dried at 105° C in an oven until all moisture has been removed. A constant dry weight of the samples is obtained after approximately 24 hours. The samples are then crushed and sieved (at 2mm) in order to get rid of the unwanted fractions. After their reduction to a homogeneous powder, the samples are conditioned in Marinelli type geometry (SG 500), sealed against radon for 30 days before the measurements in order to allow a secular equilibrium. This equilibrium corresponds to at least seven half-lives of ^{222}Rn (3.81d) between the radionuclides ^{226}Ra and ^{232}Th and their respective descendants**.**

Radioactivity measurement

The radioactivity measurement of the samples was carried out at the Ghana Atomic Energy Commission (GAEC) laboratory (RPI). One kilogram (1 kg) dry mass sand samples are measured for 10 hours (36,000 s) using the gamma ray spectrometer installed in the laboratory. During the measurement, the detector (HPGe) mounted on the cryostat is cooled with liquid nitrogen (77 K) in order to decrease the resistivity of the material and reduce the thermal background noise. The detector is also surrounded by a cylindrical lead castle of 10 cm thick to attenuate the background noise in the measured spectrum due to natural ambient radioactivity. Spectra analysis are performed using "Genie 2000, CAMBERRA" software. Each spectrum belonging to a given sample gives the number of hits recorded per second as a function of the energy of the gamma rays emitted by the radionuclides. Background measurements of the laboratory are also carried out in order to obtain net counts for each sample. Thus, an empty Marinelli beaker is measured in order to detect the background noise generated by the ambient natural radioactivity. The background noise is then subtracted from the activities of each radionuclide in the measured samples. The energy and efficiency calibrations of the detector are carried out with a standard multi-source with energies between 60 and 2000 keV. This make it possible to take into account the desired radionuclides and reduce the counting losses linked to the coincidence summing and self-absorption effects of gamma rays. The energy and efficiency calibrations of the detector, respectively, identify the radionuclides detected in the samples; and we can determine their concentrations [5].

Activity concentration

The activity concentrations of radionuclides in the sand samples are calculated using the equation below

$$C = \frac{N_{net}}{\varepsilon.P.t_c.m_s} \quad (1)\ [6]$$

Where: N_{net}, ε, t_C(s), m_s(kg), p (%) are, respectively, the number of net hits below the photoelectric peak for each sample, the detection efficiency for a specific gamma energy, the count time, dry mass of the sample and probability of detection. The ^{40}K radioactivity is measured directly from the gamma ray emitted at 1460.8 keV (10.7%). The radioactivity of ^{226}Ra and ^{232}Th is measured from their descendants in secular equilibrium by making average of their respective activities. Thus, the gamma rays of ^{214}Pb at 295.2 (19.3%) keV and 351.9 (35.8%) kev and the gamma rays of ^{214}Bi at 609.3 (46.1%) keV and 1764.5 (15.1%) keV are used for the measurement of ^{226}Ra. The ^{232}Th radioactivity is measured using the 911.2 (26.6%) keV line of ^{228}Ac and the 583.2 (30.5%) keV line of ^{208}Tl. The minimum detectable activity (MDA) of the measurement system is calculated using the following equation:

$$MDA = \frac{\sigma\sqrt{B}}{\varepsilon_\gamma.P_\gamma.t_c.m_e} \quad (2)\ [7]$$

Where: σ, B, ε_γ, P_γ, t_c (s), m_s (kg) are, respectively, the statistical coverage factor (equal to 1.645 at the 95% confidence level), the background noise, the efficiency of the detector (HPGe), the probability of emission of gamma rays, the counting time and the dry mass of the sample. The calculated MDAs are 0.12 Bq.kg^{-1} for ^{229}Ra, 0.11 Bq.kg^{-1} for ^{232}Th, and 0.15 Bq.kg^{-1} for ^{40}K.

Radium equivalent

The distribution of radionuclides ^{226}Ra, ^{232}Th and ^{40}K in terrestrial materials is not uniform, the risk induced by the radioactivity existing in a building material is evaluated by different models including the equivalent radium (R_{aeq}). R_{aeq} is defined as the weighted sum of the activities of ^{226}Ra, ^{232}Th, and ^{40}K, according to equation (3).

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (3)\ [8].$$

Where : R_{aeq} (Bq. Kg^{-1}) represents the equivalent radium number; C_{Ra}, C_{Th} and C_K activity concentrations (Bq. Kg^{-1}) of ^{226}Ra, ^{232}Th, and ^{40}K, respectively. The constants 1, 1.43 and 0.077 are risk conversion coefficients established on the basis that 370 Bq.kg^{-1} of ^{226}Ra, 259 Bq.kg^{-1} of ^{232}Th and 4810 Bq.kg^{-1} of ^{40}K, respectively, produce the same flow gamma dose. The maximum recommended value of R_{aeq} is 370 Bq.kg^{-1} for a safer use of the material [9]

RESULTS AND DISCUSSION

Table 1 : Activity Concentrations of^{226}Ra, ^{232}Th and ^{40}K in the gravel samples

Samples codes	Activity Concentration (Bq.kg^{-1})					
	^{26}Ra		^{232}Th		^{40}K	
GRA-1	12.67	± 1.24	5.07	± 1.75	220.50	± 5.60
GRA-2	2.84	± 0.02	3.58	± 1.24	127.51	± 3.27
GRA-3	3.13	± 0.04	6.70	± 3.44	107.62	± 1.29
GRA-4	8.47	± 0.24	4.95	± 1.60	115.96	± 2.08
GRA-5	5.20	± 0.27	3.71	± 1.39	112.75	± 1.76
GRA-6	5.75	± 0.27	3.22	± 1.67	124.63	± 2.99
GRA-7	2.34	± 0.02	5.60	± 2.77	142.23	± 1.76
GRA-8	7.25	± 0.09	2.10	± 0.98	285.68	± 4.42
GRA-9	5.62	± 0.06	2.10	± 0.50	144.46	± 6.58

GRA-10	6.55	± 0.19	4.63	± 1.12	390.42	± 5.23
MIN	**2.34**	± **0.02**	**2.10**	± **0.50**	**107.62**	± **1.29**
MAX	**12.67**	± **1.24**	**6.70**	± **3.44**	**390.42**	± **5.23**
MOY	**5,98**	± **0,24**	**4,17**	± **1,65**	**177,18**	± **3,50**

Table 2: Comparison of averages values of activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the gravel samples of some countries

Country	Materials	Activity Concentration (Bq.kg^{-1})			Référence
		^{226}Ra	^{232}Th	^{40}K	
Cote d'ivoire	**Gravier**	**5.98**	**4.17**	**177.85**	**PT**
Bangladesh	**Gravier**	14.20	25	158.40	[9]
KenyaMustapha	**Gravier**	11	**5**	**802**	[10]
Cuba	**Gravier**	17	16	208	[11]
France	**Gravier**	31.31	**5.07**	92.54	[12]
Brasilia	**Gravier**	10.30	NA	933	[13]
USA	**Gravier**	33.33	**33.33**	14.80	[14]
Cameroon	**Gravier**	19	**26**	304	[15]
	Range	5.98-33.33	**NA-33.33**	14.8-933	

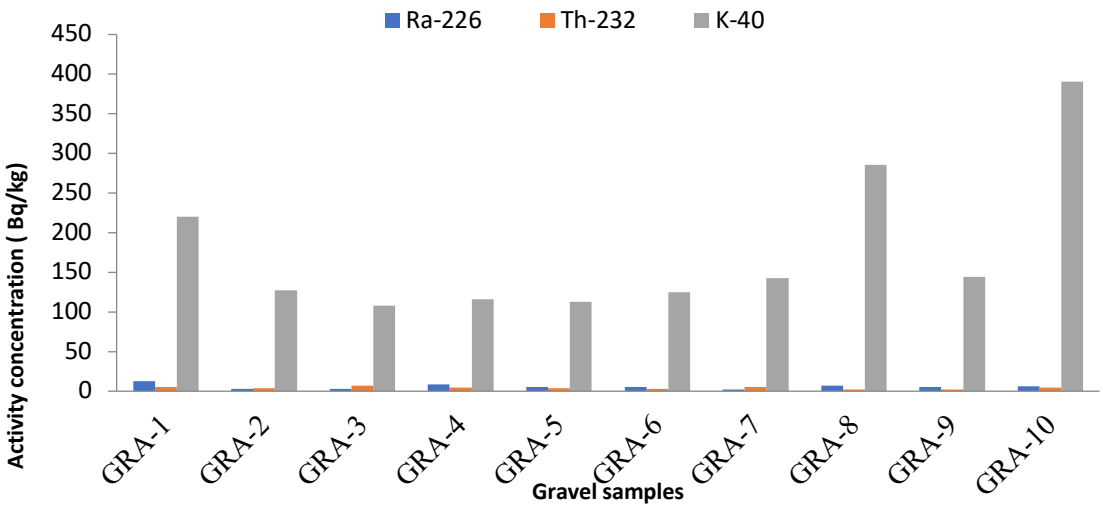


Figure 1 : Activitiy concentration of ^{226}Ra, ^{232}Th and ^{40}Kin the gravel samples

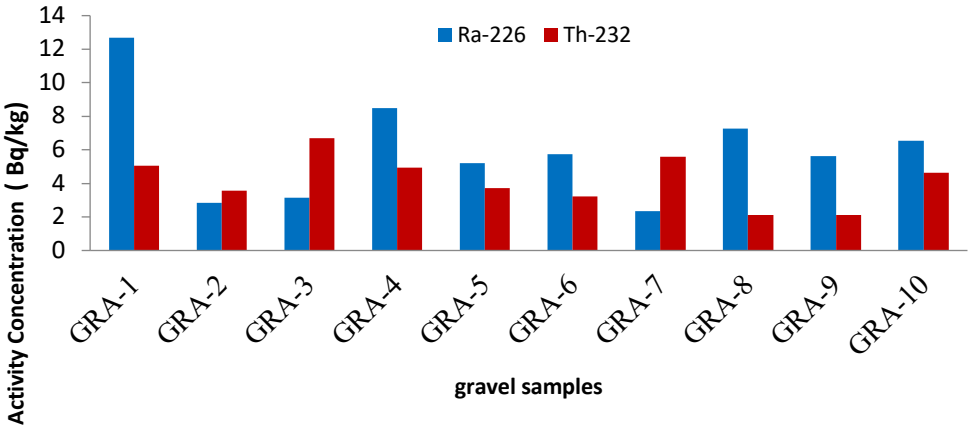


Figure 2: activity concentrations of ^{226}Ra and ^{232}Th in gravel samples

In the **table 1,** the activity concentration in the gravel samples show that the values varies from 2.34± 0.02 to 12.67± 1.24 Bq.kg^{-1}, 2.1± 0.98 to 6.7±3.44 Bq.kg^{-}1 and 107.62± 1.29 to 390.42± 5.23 Bq.kg^{-}1 respectively for ^{226}Ra, ^{232}Th and ^{40}K. These concentrations are superior to the limit detection for all samples. The figure 1 shows the concentrations distribution of three radionuclides. The lower values of activity concentration of ^{226}Ra, ^{232}Th and ^{40}K were observed in the samples GRA-7, GRA-8 and GRA-9, GRA-3 and the higher were registered in the samples GRA-1, GRA-3 and GRA-10 respectively. According to the contribution of the three radionuclides to the total radioactivity of the samples (Figure 1), 40K is the main contributor. The concentration of 40K is higher compared to 226Ra and of 232Th. The results of activity concentrations of the analyzed samples with the values put forward at the world level by UNSCEAR, the average values of radionuclides 226Ra (5.98± 0.24 Bq. kg^{-1}), 232Th (4.17± 1.65 Bq. kg^{-1}) and 40K (177.18± 3.50 Bq.kg^{-1}) are below the limits of 35, 30 and 400 Bq.kg-1 respectively. Therefore, the use of these gravels in construction could not provide serious radiation effects to the population living in the study area. In addition, the equivalent radium (Raeq) corresponding to the different concentrations estimated using the equation varies from 17.78 Bq.kg^{-1} in GRA-2 to 43.23Bq.kg^{-1} in GRA-10. The average value of the measurements is 25.58 Bq.kg^{-1}. The Figure 3 presents the distribution of Raeq in the samples analyzed, we report that these values are relatively similar for most of the samples. The three samples GRA-10, GRA-1 and GRA-8 have higher values than the average value. These differences in radium equivalent values are related to the concentrations of the radionuclides and can be explained by the geological characteristics of the samples. All Raeq values are below the exposure limit figured at 370 Bq.kg^{-1} (UNSCEAR 2000). This further means that the radiological health effects to populations from gamma radiation of these gravel samples remain negligible.

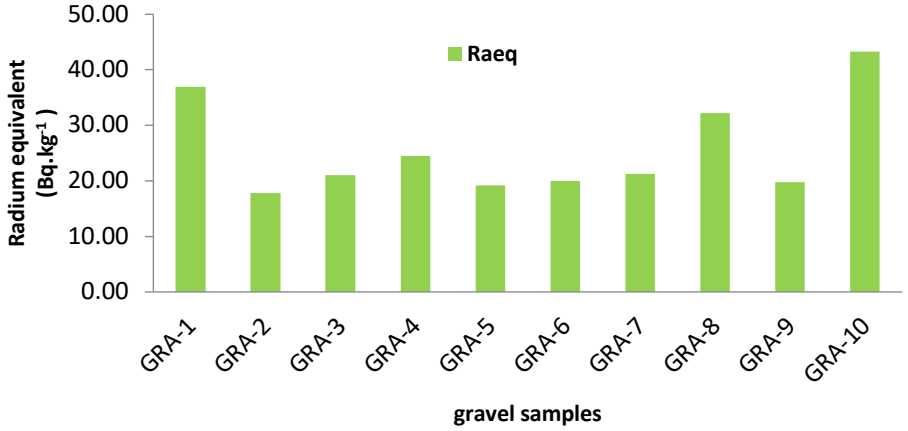


Figure 3: Radium equivalent distribution of gravel samples

CONCLUSION

This present study carried out and discussed using the nuclear technique based on gamma spectrometry by means of a GeHP detector show average activity concentrations of 5.98± 0.24 Bq. kg^{-1}, 4.17± 1.65 Bq. kg^{-1} and 177.18± 3.50 Bq.kg^{-1} respectively for 226Ra, 232Th and 40K. These values obtained show that the activity concentration in these gravels are inferior to what are usually measured in the same samples on a global scale with average limit values of 35 Bq. kg^{-1}, 30 Bq. kg^{-1} and 400 Bq. kg^{-1}. The values of Ra_{eq} are inferior to the limit value of exposure 370 Bq.kg^{-1}. The radioactivity in these gravels does not, in any case, present an immediate health risk to the public. Long-term effects can be avoided by simple precautionary recommendations

ACKNOWLEDGEMENT

The authors are grateful to Ghana Atomic Energy Commission (GAEC) for facilities everything

References

[1] M. J. Willson. Anthropogenic and Naturally Occurring Radioactive Materials Detected on Radiological Survey of Properties in Monticello, Utah. Environmental Health Physics,26th Midyear Topical Meeting, 1993. (24-28): 564.

[2] https://www.reliablecontracting.com/how-gravel-is-used-in-construction/

[3] UNSCEAR, Sources and Effects of Ionizing Radiation, Report to General Assembly, with Scientific Annexes. United Nations, New York,2000.

[4] Recensement Général de la Population et de l'Habitat(RGPH) en Côte d'Ivoire, 2014.

[5] Prince J.H.; Comments on Equilibrium, Transition Equilibrium, and Secular Equilibrium in Serial Radioactive Decay, Journal of Nuclear Medicine 1979. (20):162-164

[6] Darko E. O. Faanu A., RazakA., Emi-Reynolds G., Yeboah J., OpponO. C., Akaho E.H. K; Public exposure hazards associated with natural radioactivity in open pit mining in Ghana. Radiation Protection Dosimetry. 2010.138 (1):45-51

[7] Curie L.A.; Limits for qualitative detection and quantitative determination. Anal.Chem.1968: (40): 586-593.

[8] Beretka, I, Mathew P.I; National radioactivity of Australian building materials waste and products, Health Phys. 1985. (48):87-95).

[9] Chowdhury M.L., Alain M.N. and Ahmed A.K.S., Concentration of radionuclides in building and ceramic materials of Bangladesh and evaluation of radiation hazard, Journal of Rationalistic Nuclear Chemistry. 1998. 231 (1-2:117-122

[10] Mustapha A.O. Pated J.P. and Rathore I.V.S. Assessment of Human Exposures to Natural Sources of Radiation in Kenya. Radiation Protection Dosimetry. 1999. 82(4):285-292.

[11] Brigido Flores, O. et al. Natural radionuclide content in building materials and gamma dose rate in dwellings in Cuba, Journal of Environmental Radioactivity, 2008. (99):1834-1837.

[12] Samir Dziri. Etudes expérimentales et simulations Monte Carlo en spectrométrie gamma: Correction des effets de cascade et de matrice pour des mesures environnementales. Thèse (2013) p.144

[13] Malanca A. and Gaidolfi L., Preliminary radiological survey in some towns of the northeastern Brazilian wilderness, Nucleus Journal. 1996. 33(3)(:139-144

[14] Ingersoll, G.J. 1983. A survey of radionuclide contents and radon emanation rates in building materials in USA. Health Physics. 1983. 45:363-368.

[15] M.Ngachim, M. Garavaglia, C. Giovani and M.G. Kwato Njocck**,** Assessment of natural radioactivity and associated radiation hazards in some Cameroonian building materials. Radiation measurements. 2007. 42 (1)):61-67