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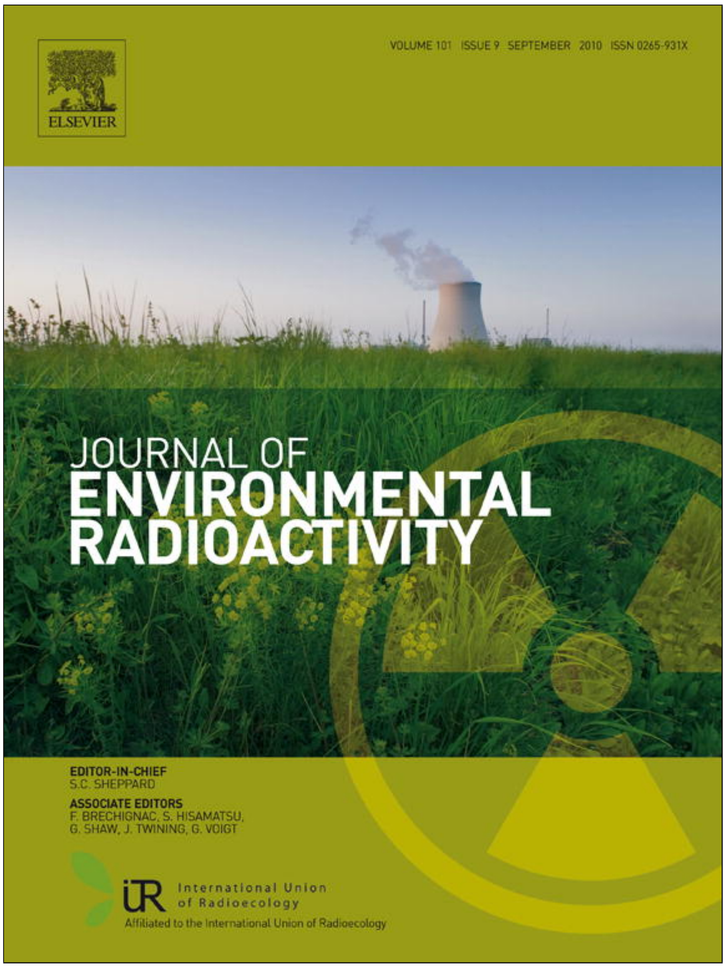

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Technical note

High background radiation investigated by gamma spectrometry of the soil in the southwestern region of Cameroon

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ABSTRACT

The aim of this work is to determine the radioactivity concentration of ^{226}Ra, ^{232}Th and ^{40}K in sub-surface (0–5 cm) soil samples collected from Awanda, Bikoué, Ngombas in the southwestern region of Cameroon, to assess their contribution to the external dose exposure relative to the United Nation Scientific Committee on Effects of Atomic Radiation (UNSCEAR) data. An HPGe p-type detector coupled to a multi-channel analyzer was used to perform measurements and data processing. The activity concentrations of ^{226}Ra varied from 0.06 ± 0.01 to 0.27 ± 0.02 kBq kg^{-1} with a mean value of 0.13 ± 0.01 kBq kg^{-1} wet weight. The activity concentrations of ^{232}Th varied from 0.10 ± 0.01 to 0.70 ± 0.05 kBq kg^{-1} with a mean value of 0.39 ± 0.03 kBq kg^{-1} wet weight, and ^{40}K concentrations varied from 0.37 ± 0.02 to 1.53 ± 0.11 kBq kg^{-1} with a mean value of 0.85 ± 0.07 kBq kg^{-1} wet weight, respectively. The mean value of outdoor annual effective doses were estimated to be 0.48 mSv y^{-1}, 0.39 mSv y^{-1} and 0.38 mSv y^{-1} from Ngombas, Awanda and Bikoué, respectively. The studied areas can be said to have a high background radiation level.

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1. Introduction

Naturally occurring radionuclides are present in the earth's crust since its origin. The members of the radioactive decay chain of ^{232}Th (14%), ^{235}U and ^{238}U (55.8%) along with ^{40}K (13.8%) are responsible for doses from natural radiation. The ratio of ^{235}U to ^{238}U is less than 1% hence the contribution of ^{235}U to the environmental dose is very small (Joshua et al., 2009; Bennett, 1997; Bruzzi et al., 1997; UNSCEAR, 1993). These primordial radionuclides have sufficiently longer half-lives and decay to attain the stable state emitting ionizing radiations. In most places on the earth, the natural radioactivity varies only within narrow margins, but in some places there are wide deviations from normal levels because of the abundance of minerals with high radioactivity (UNSCEAR, 2000; Mohanty et al., 2004).

The southwestern region of Cameroon was suspected to have uranium ore deposits. Between 1978 and 1985 a previous reconnaissance work was carried out in this area by the French Office of Geological and Mining Research commonly known by its French appellation "Bureau de Recherches Géologiques et Minières (BRGM)". Financing of this study was assumed by the Cameroon Government whose objective was to evaluate the mineral potential of the southwestern region of Cameroon. The technical aspect was effected in three steps. The first step consisted of helicopter-borne radiometric survey. Seventeen points of high radiation anomaly were detected along the Lokoundjé River Basin (1150 km^2). These high radiation syenite sources were identified in Ngombas (11°06′E; 3°25′N), Awanda (10°59′E; 3°22′N), Bikoué (10°51′E; 3°21′N) and Madong (10°44′E; 3°17′N). The second step consisted of identifying areas of high uranium abundance using a portable NaI spectrometer. It was found that background radiation from Ngombas was relatively higher than those from Awanda and Bikoué. The third step consisted of Geochemical studies to understand the chemical constitution of elements in the studied areas. Some radioactive minerals such as zircon, apatite, monazite, allanite, coffinite, thorite, uranothorite and uraninite were found in rocks. Fig. 2 shows the BRGM spatial distribution map of uranium and potassium anomalies of this studied area (Maurizot et al., 1986). It is worth noting that there are no thorium anomalies on the map. There are also no data on the radionuclide enrichment and gamma dose rates in air from geological samples in the investigated area. Measurement of natural radioactivity due to gamma rays in rocks and soils and, consequently, the determination of the dose rate allows for the implementation of precautionary measures

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whenever the dose is found to be above the recommended limits. It is necessary to monitor the release of radioactivity into the environment to be able to protect the people appropriately.

The objective of this work is to determine radioactivity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in surface (0–5 cm) soil samples collected from Ngombas, Awanda and Bikoué in the southwestern region of Cameroon, to assessing their contribution to the external dose exposure relative to the UNSCEAR data.

2. Materials and methods

2.1. Physiographic state

This study was carried out on the approximately 75 km Akongo-Lolodorf syenitic axis in the South of the Republic of Cameroon. The formations of this studied area are mainly Palaeoprotozoic belonging to the Nyong Group and are cross-cut by the Pan-African intrusive shown in Fig. 1. Ferrallitisation is the most important pedogenic process in Cameroon. The soils of the studied area consist of two types namely, ferralitic soils with deep-red and yellow-red soil colour and hydromorphic soils found in the southwestern region of Cameroon (Sighomnou, 2004). The studied region extends over the equatorial climatic zone. The mean temperature of the zone varies from 25 to 26 °C with two rainy and two dry seasons. The dry season is caused by a tropical continental (TC) air mass blowing from the Sahara Desert between December–February and July–August. The rainy season is brought about by a tropical maritime (TM) air mass blowing from the Atlantic Ocean between September–November and March–June. Annual rainfall range is 1500–2000 mm, with a relative humidity of 70–80% recorded throughout the year. The studied areas are in rural districts, with population density from 8 to 11 persons per square kilometer and over 80% of the population is engaged in agriculture (Sighomnou, 2004).

2.2. Sample collection and preparation

Fifteen surface soil samples were collected from Ngombas, Awanda and Bikoué in the southwestern region of Cameroon (Fig. 2). Our sampling points are located in inhabited or agricultural areas. At each sampling location, an area of about 1 m^2 was marked out. The humus layer of soil which contains decayed organic matter was removed using a flat-blade shovel. Soil samples were taken to a depth of about 5 cm at each corner of the identified 1 m^2 area and at its centre. The five soil subsamples obtained were then mixed thoroughly to make a composite sample and extraneous material such as plant roots were removed from the mixture. The sample of about 500 g was then packed in a plastic bag.

Fifteen rock samples were collected near the soil sampling point. All rock samples were chiselled out of fixed rocks. Approximately 1 kg material of each rock was collected and packed in a plastic bag. Identification of the rock samples was done at the Institute of Geological and Mining Research, Yaounde, Cameroon. Typical lithologic formations from studied areas are constituted by intrusive rocks, specifically alkaline syenites (Maurizot et al., 1986). Syenite is a coarse-grained intrusive rock, of similar general composition as granite but with the quartz either absent or present in relatively small quantities (< 5%) (Foucault and Raoult, 1997).

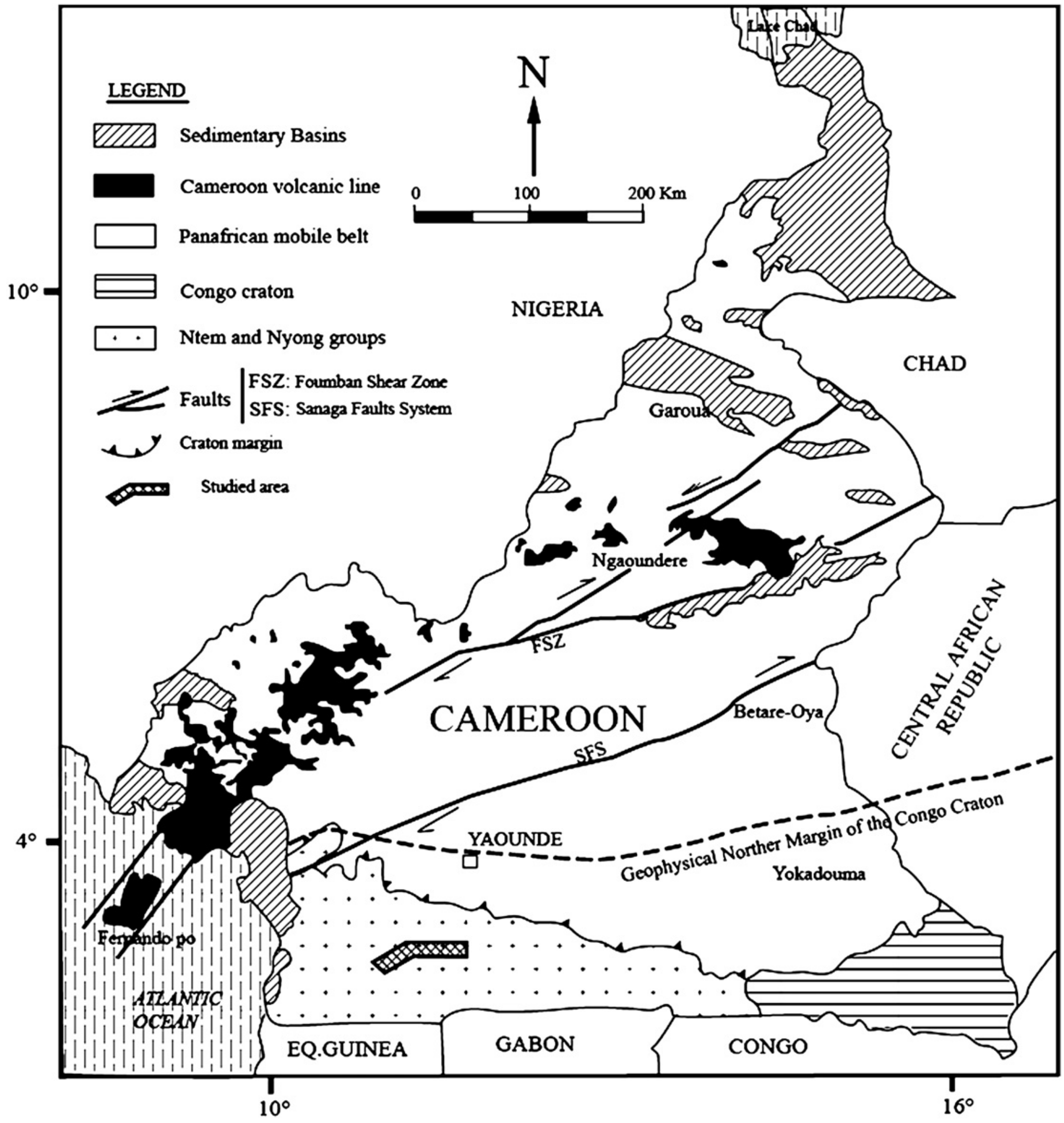

Fig. 1. Geological map of Cameroon showing the localisation of the studied area.

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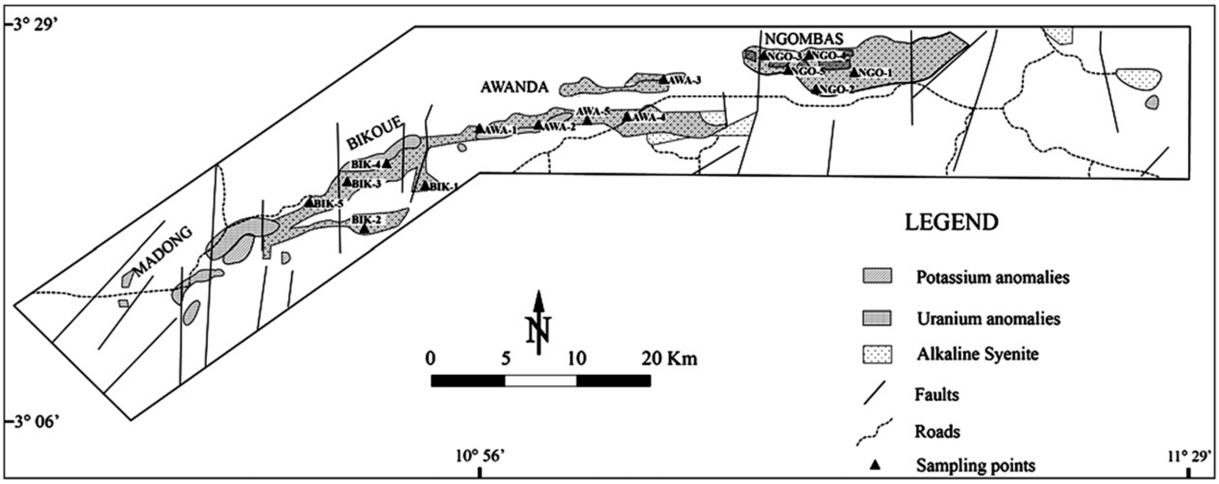

Fig. 2. BRGM's airborne radiometric anomalies map with sampling points from this study: 1 – Ngombas; 2 – Awanda; 3 – Bikoué.

In the laboratory, all samples were dried in a drying oven at 200 °C for 12 h. Each soil and rock sample was ground into fine powder. Finally all samples were sieved using a 2 mm mesh screen to obtain a homogenous sample for measurement (International Atomic Energy Agency, 1989). Each sieved sample was sealed in a 50-ml cylindrical plastic container (SG 50, standardized by the CEA). The sealed samples were stored for about 30 d before carrying out gamma analysis to allow ^{226}Ra and its short-lived progenies to reach equilibrium.

2.3. Radioactivity measurements

The activity concentration of soil samples were measured using a Canberra low-level gamma counting system (SAGA 0930-7), with a high-resolution HPGe detector (p-type, GR3019) coupled to a multichannel analyzer (Model DESA). The detector was shielded with a 5 cm thick lead. The energy resolution of the 1332 keV line from ^{60}Co was found to be 1.93 keV at full width of half maximum (FWHM) with a relative efficiency of 30%. The data acquisition and analysis were carried out with the use of the GENIUS 2000 software package.

The counting efficiency of the detector was calibrated using a 50 ml standard volume source (N°71,863/3). All spectrometric measurements of this work were carried out in the "Unité de Surveillance de l'Environnement (USE)" (Environment Watch Unit). The gamma-transitions of 609.3 keV (^{214}Bi), 768.4 keV (^{214}Bi), 1120.3 keV (^{214}Bi), 1238.0 keV (^{214}Bi) and 1764.0 keV (^{214}Bi) were used to determine the concentrations of ^{226}Ra. The gamma-transitions of 238.0 keV (^{212}Pb), 338.0 keV (^{228}Ac), 583.1 keV (^{208}Tl), 911.2 keV (^{228}Ac), 968.3 keV (^{228}Ac), and 974.2 keV (^{228}Ac) were used to determine the concentration of ^{232}Th. The 1460.0 keV gamma-transition of ^{40}K was used to determine the concentration of ^{40}K. The gamma spectrum of each sample was measured for 54,000 s.

2.4. Dose rate

The absorbed gamma dose rate in air at 1 m above the ground surface (D in nGy h^{-1}) for the uniform distribution of radionuclides (^{238}U, ^{232}Th, ^{40}K) in the ground was computed by the following equation of UNSCEAR (1993, 2000),

$$D = 0.462A_{Ra} + 0.621A_{Th} + 0.0417A_{K} \quad (1)$$

where, A_{Ra}, A_{Th} and A_K are the in situ concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1}, respectively. Dry weight based concentration was converted to the in situ concentration by using 0.81 of wet/dry ratio of UNSCEAR (2000). To estimate the annual effective dose rates to human body, a conversion factor of 0.7 Sv Gy^{-1} and outdoor occupancy factor of 0.2 were used.

According to UNSCEAR (2000), the worldwide average of the annual effective dose is 0.48 mSv, with the results for individual countries being generally within the 0.3 – 0.6 mSv range. The world average value of annual outdoor effective dose for regions of natural radiation background is 0.07 mSv y^{-1}. The worldwide annual exposures to natural radiation sources would generally be expected to be in the 1–10 mSv range, with 2.4 mSv being the present central value estimate.

3. Results and discussion

3.1. Activity concentrations

The results of activity concentration measurements in the soil and rock samples on a dry weight basis are shown with their counting errors in Tables 1 and 2, respectively. The activity

Table 1
Soil sample concentrations of Ra, Th, and K, per unit dry weight and dose rate per unit wet weight.

Location	Sample I.D.	^{226}Ra (kBq kg^{-1})	^{232}Th (kBq kg^{-1})	^{40}K (kBq kg^{-1})	Dose rate (nGy h^{-1})[a]
Ngombas	NGO-1-S	0.08 ± 0.01	0.21 ± 0.01	0.49 ± 0.03	150 ± 6
	NGO-2-S	0.16 ± 0.01	0.32 ± 0.02	0.58 ± 0.05	241 ± 11
	NGO-3-S	0.17 ± 0.01	0.63 ± 0.05	0.63 ± 0.05	403 ± 25
	NGO-4-S	0.33 ± 0.03	0.84 ± 0.06	0.60 ± 0.04	567 ± 32
	NGO-5-S	0.29 ± 0.02	0.91 ± 0.06	0.46 ± 0.03	581 ± 31
Awanda	AWA-1-S	0.15 ± 0.01	0.30 ± 0.02	0.86 ± 0.06	234 ± 11
	AWA-2-S	0.20 ± 0.02	0.43 ± 0.03	0.92 ± 0.07	323 ± 17
	AWA-3-S	0.10 ± 0.01	0.65 ± 0.03	0.84 ± 0.06	395 ± 15
	AWA-4-S	0.10 ± 0.01	0.52 ± 0.04	0.85 ± 0.06	327 ± 20
	AWA-5-S	0.12 ± 0.01	0.43 ± 0.03	0.97 ± 0.07	296 ± 15
Bikoué	BIK-1-S	0.14 ± 0.01	0.86 ± 0.06	1.50 ± 0.10	536 ± 31
	BIK-2-S	0.10 ± 0.01	0.12 ± 0.01	1.73 ± 0.12	157 ± 7
	BIK-3-S	0.24 ± 0.02	0.28 ± 0.02	1.89 ± 0.13	294 ± 13
	BIK-4-S	0.10 ± 0.01	0.23 ± 0.02	1.66 ± 0.12	211 ± 11
	BIK-5-S	0.14 ± 0.01	0.49 ± 0.03	1.74 ± 0.13	358 ± 16
	Mean	0.16 ± 0.01	0.48 ± 0.04	1.05 ± 0.27	338 ± 19
	Range	0.08 ± 0.01–0.33 ± 0.03	0.12 ± 0.01–0.91 ± 0.06	0.46 ± 0.03–1.89 ± 0.13	150 ± 6–581 ± 31

[a] Estimated with Gy h^{-1}/Bq kg^{-1} by UNSCEAR, 2000 assuming 0.81 as dry/wet ratio of soil.

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Table 2
Rock sample concentrations of Ra, Th, and K per unit dry weight from studied location.

Location	Sample I.D.	^{226}Ra (kBq kg^{-1})	^{232}Th (kBq kg^{-1})	^{40}K (kBq kg^{-1})
Ngombas	NGO-1-R	2.72 ± 0.20	0.89 ± 0.06	2.51 ± 0.19
	NGO-2-R	0.70 ± 0.05	1.29 ± 0.09	2.36 ± 0.17
	NGO-3-R	3.77 ± 0.19	0.63 ± 0.04	0.54 ± 0.04
	NGO-4-R	5.68 ± 0.40	0.99 ± 0.07	1.77 ± 0.01
	NGO-5-R	7.26 ± 0.36	1.42 ± 0.10	2.23 ± 0.16
Awanda	AWA-1-R	0.13 ± 0.01	0.09 ± 0.01	2.21 ± 0.16
	AWA-2-R	0.84 ± 0.06	0.61 ± 0.04	1.64 ± 0.12
	AWA-3-R	0.48 ± 0.04	5.50 ± 0.40	1.56 ± 0.11
	AWA-4-R	0.061 ± 0.004	0.41 ± 0.03	1.47 ± 0.10
	AWA-5-R	0.08 ± 0.01	0.32 ± 0.02	1.74 ± 0.12
Bikoué	BIK-1-R	0.07 ± 0.01	1.13 ± 0.08	0.86 ± 0.06
	BIK-2-R	0.57 ± 0.04	1.18 ± 0.09	1.34 ± 0.10
	BIK-3-R	0.10 ± 0.01	0.26 ± 0.02	0.75 ± 0.05
	BIK-4-R	0.78 ± 0.06	0.27 ± 0.02	0.80 ± 0.06
	BIK-5-R	0.49 ± 0.03	0.57 ± 0.04	0.96 ± 0.07
	Mean	1.58 ± 0.16	1.04 ± 0.12	1.52 ± 0.11
	Range	0.061 ± 0.004–7.26 ± 0.36	0.09 ± 0.01–5.50 ± 0.40	0.54 ± 0.04–2.51 ± 0.19

concentrations of ^{226}Ra ranged from 0.08 ± 0.01 to 0.33 ± 0.03 kBq kg^{-1} in soils and from 0.061 ± 0.004 to 7.26 ± 0.36 kBq kg^{-1} in rocks with means of 0.16 ± 0.01 kBq kg^{-1} and 1.58 ± 0.16 kBq kg^{-1}, respectively. The soil samples collected at Ngombas, Awanda and Bikoué had ^{226}Ra activity concentration that is more than 3–5 times higher than the world average value of 35 Bq kg^{-1} (UNSCEAR, 2000), respectively. The high concentration of ^{226}Ra observed in soil samples can be explained by the presence of uranium bearing radiogenic heavy minerals. Most of the sampled points are located in zones identified with uranium anomalies by BRGM in the studied area shown in Fig. 2.

The activity concentrations of ^{232}Th ranged from 0.12 ± 0.01 to 0.91 ± 0.06 kBq kg^{-1} in soils and from 0.09 ± 0.01 to 5.50 ± 0.40 kBq kg^{-1} in rocks with means of 0.48 ± 0.04 kBq kg^{-1} and 1.04 ± 0.12 kBq kg^{-1}, respectively. The activity concentrations of ^{232}Th in soil samples from Ngombas, Awanda and Bikoué are about 16, 13 and 11 times more than the world average value of 30 Bq kg^{-1} (UNSCEAR, 2000), respectively. The very high concentration of ^{232}Th indicates the presence of thorium bearing minerals in the soil samples.

The activity concentrations of ^{40}K ranged from 0.46 ± 0.03 to 1.89 ± 0.13 kBq kg^{-1} in soils and from 0.54 ± 0.04 to 2.51 ± 0.19 kBq kg^{-1} in rocks with means of 1.05 ± 0.27 kBq kg^{-1} and 1.52 ± 0.11 kBq kg^{-1}, respectively. The ^{40}K mean activity concentrations in soil samples from Awanda and Bikoué are about two and three times higher than the world average value of 400 Bq kg^{-1} (UNSCEAR, 2000), respectively. The radioactivity content in rocks is more important than that in soils and ^{40}K contributes highly to the total activity in geological samples from the study area.

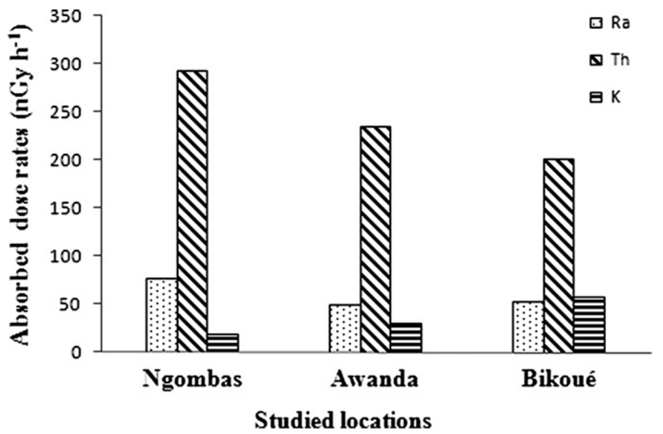

Fig. 3. The average absorbed dose rates of ^{226}Ra, ^{232}Th and ^{40}K from studied locations.

3.2. Absorbed dose rates in air

The values of absorbed dose rates D in air on wet weight basis are listed in Table 1. The absorbed dose rates due to the presence of ^{226}Ra, ^{232}Th and ^{40}K, in soil samples in the studied area vary between the range from 150 ± 6 to 581 ± 31 nGy h^{-1} with a mean value of 338 ± 19 nGy h^{-1}, which is much higher than the world average value of 56 nGy h^{-1} (UNSCEAR, 1988). The absorbed dose rate values in soils from Ngombas, Awanda and Bikoué are 388 ± 24 nGy h^{-1}, 315 ± 16 nGy h^{-1} and 311 ± 18 nGy h^{-1}, respectively. Fig. 3 displays the average absorbed dose rates of ^{226}Ra, ^{232}Th and ^{40}K from soil samples in the three studied locations in the southwestern region of Cameroon. Thorium contributes highly in the external exposure dose rate than radium and potassium in the studied areas.

3.3. Annual effective dose equivalent

The results from the calculation of annual effective dose values on a wet weight basis are, respectively, 0.48 mSv y^{-1}, 0.39 mSv y^{-1} and 0.38 mSv y^{-1} for Ngombas, Awanda and Bikoué. These three values are, respectively, 7, 6 and 5 times higher than the world average value of 0.070 mSv y^{-1} for outdoor terrestrial radiation of regions of normal background radiation (UNSCEAR, 2000). The mean value of outdoor annual effective dose equivalent estimate from this study is 0.41 mSv.

4. Conclusions

The natural radioactivity and related radiation dose rates in soil from the southwestern region of Cameroon were assessed by gamma-ray spectrometry. The average values of the activity of ^{226}Ra, ^{232}Th and ^{40}K in different locations are much higher than that proposed by UNSCEAR. The mean value of the absorbed dose rate in air was found to be 0.48 mSv y^{-1}, 0.39 mSv y^{-1} and 0.38 mSv y^{-1}, respectively, for Ngombas, Awanda and Bikoué. The mean value of outdoor annual effective dose equivalent estimate of 0.41 mSv from this study is about 6 times higher than the world average value of 0.070 mSv y^{-1} for outdoor terrestrial radiation of regions with normal background radiation (UNSCEAR, 2000). The localities of Ngombas, Awanda, Bikoué in the southwestern region of Cameroon, can be said to have a high natural background radiation, due to the high concentration of thorium in soils.

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