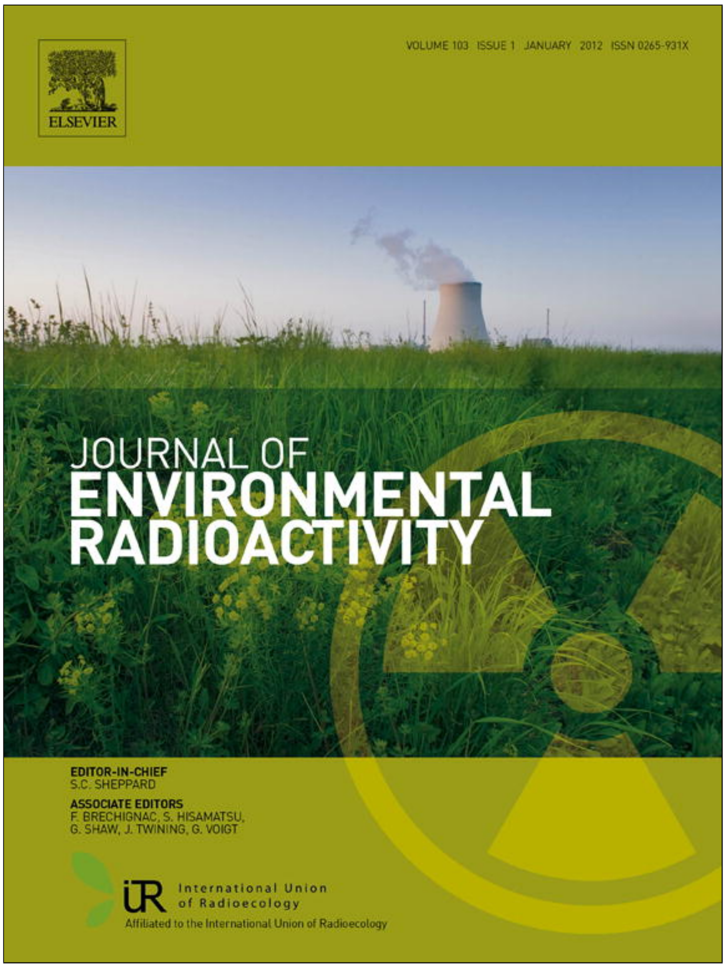
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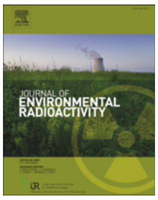

Annual intakes of ^{226}Ra, ^{228}Ra and ^{40}K in staple foodstuffs from a high background radiation area in the southwest region of Cameroon

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ABSTRACT

Concentrations of naturally occurring radionuclides ^{226}Ra, ^{228}Ra and ^{40}K were determined in five most consumed vegetables in a high-level background radiation area (HLBRA) in the southwest region of Cameroon. A total of 25 foodstuff samples collected from Akongo, Ngombas, Awanda, Bikoué and Lolodorf rural districts were analyzed by gamma spectrometry. The average activity concentration values of ^{226}Ra, ^{228}Ra and ^{40}K were respectively 2.30, 1.50 and 140.40 Bq kg^{-1} fresh-weights. The effective dose for individual consumption of the investigated foodstuff types was calculated on an estimated annual intake of such diets in the study area. The estimated total daily effective doses from the ingestion of the investigated foodstuffs for each studied long-life natural radionuclide were respectively 0.41 μSv for ^{226}Ra, 0.84 μSv for ^{228}Ra and 0.71 μSv for ^{40}K. The total annual effective dose was estimated at 0.70 mSv y $^{-1}$. ^{228}Ra (44%) and ^{40}K (36%) were found to be the main sources for internal irradiation which is very likely due to the specific uptake of these radionuclides by the studied plants.

1. Introduction

Public exposure to radiation from natural radioactive decay series of ^{238}U, ^{235}U, and ^{232}Th is due mainly to the fact that the latter dissolve in water and migrate to surface water reservoirs, thereby contaminating foodstuffs through soil–plant transfer which is then ingested into the human body (Chen et al., 2005; Al-Kharouf et al., 2008). Specifically, radionuclides in the naturally occurring ^{238}U and ^{232}Th series contribute about 30–60% to the internal radiation dose (UNSCEAR, 2000). Analysis of the radionuclide contents of foodstuffs and water, bioassay data and knowledge of the metabolic behavior of the radionuclides, provides a basis for dose estimation (UNSCEAR, 1993; UNSCEAR, 2000). Exposure to radionuclides in foodstuffs varies according to soil type, soil chemical characteristics, radionuclide uptake by specific plants and consumption level of specific foodstuffs (Shanthi et al., 2010).

The study area is a high-level natural radiation area situated in the southwest region of Cameroon. Since 1985, some geochemical studies revealed the presence of some radioactive minerals in geological samples from this study area (Maurizot et al., 1986). In a recent study carried out by Ele et al. (2010), soil activity concentrations were assessed by gamma-ray spectrometry and the estimated outdoor annual effective dose equivalent from this area was found to be about 6 times higher than the world average value for outdoor terrestrial radiation of regions with normal background radiation.

The main objective of this study is therefore to determine the activity concentration levels of ^{226}Ra, ^{228}Ra, and ^{40}K in some staple vegetable foodstuffs: *Manihot esculenta* (cassava), *M. esculenta* leaves (cassava leaves), *Xanthosoma sagittifolium* (cocoyam), *Arachis hypogaea* (groundnuts) and *Musa* sp. (plantain), consumed by the people of the southwest region of Cameroon, a high background radiation area, to ensure that food safety is not compromised and that the effective doses from ingestion are within the specified safety limits. These basic radiometric data could be used to set up a foodstuff radiometric control to enhance the activities of the newly established Cameroonian Radiation Protection Regulatory Authority especially with regard to food policy in addition to administrative and regulatory functions.

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2. Materials and methods

2.1. Physiographic state

The study area was identified as a high background radiation area located in the southwest region of Cameroon (Ele et al., 2010; Abiama et al., 2010). Geologically, the lithological formations of this area consist typically of syenites and radioactive source rocks composed of syntectonic syenites that appear to be linked with shear zones. High radiation syenite sources were identified in the Ngombas, Awanda, Bikoué and Madong regions as shown in Fig. 1. Staple foodstuffs from the southwest region of Cameroon were considered for preparation and analysis. Sampling sites were in the rural districts, within the approximately 75 km stretch known as the Akongo–Lolodorf syenitic axis in the southwest of Cameroon. Formations of this study 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. Soils of the study area are of two types namely, ferralitic with deep-red and yellow-red soil color and hydromorphic found in the southwest region of Cameroon. Population density ranges from 8 to 11 persons per square kilometer. The dwellings of the people of this region are spread along the River Lokoundjé which runs through all the localities considered. Over 80% of the population is engaged in agriculture (Sighomnou, 2004). The study area extends over the equatorial climatic zone. 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. Annual rainfall range is 1500–2000 mm and a 70–80% relative humidity recorded throughout the year.

2.2. Foodstuff sample collection and preparation

Sampling was done in the rural districts of Akongo, Ngombas, Awanda, Bikoué and Lolodorf as shown in Fig. 2. From the main village in each district, five representative households were selected for sample collection. Food crops were sampled from material already harvested. Different foodstuff samples weighing 1–2 kg–fresh were collected. The samples from the 5 households were then combined, giving 25 foodstuff samples.

All foodstuff samples were pre-treated according to IAEA (International Atomic Energy Agency, 1989) recommendations. The

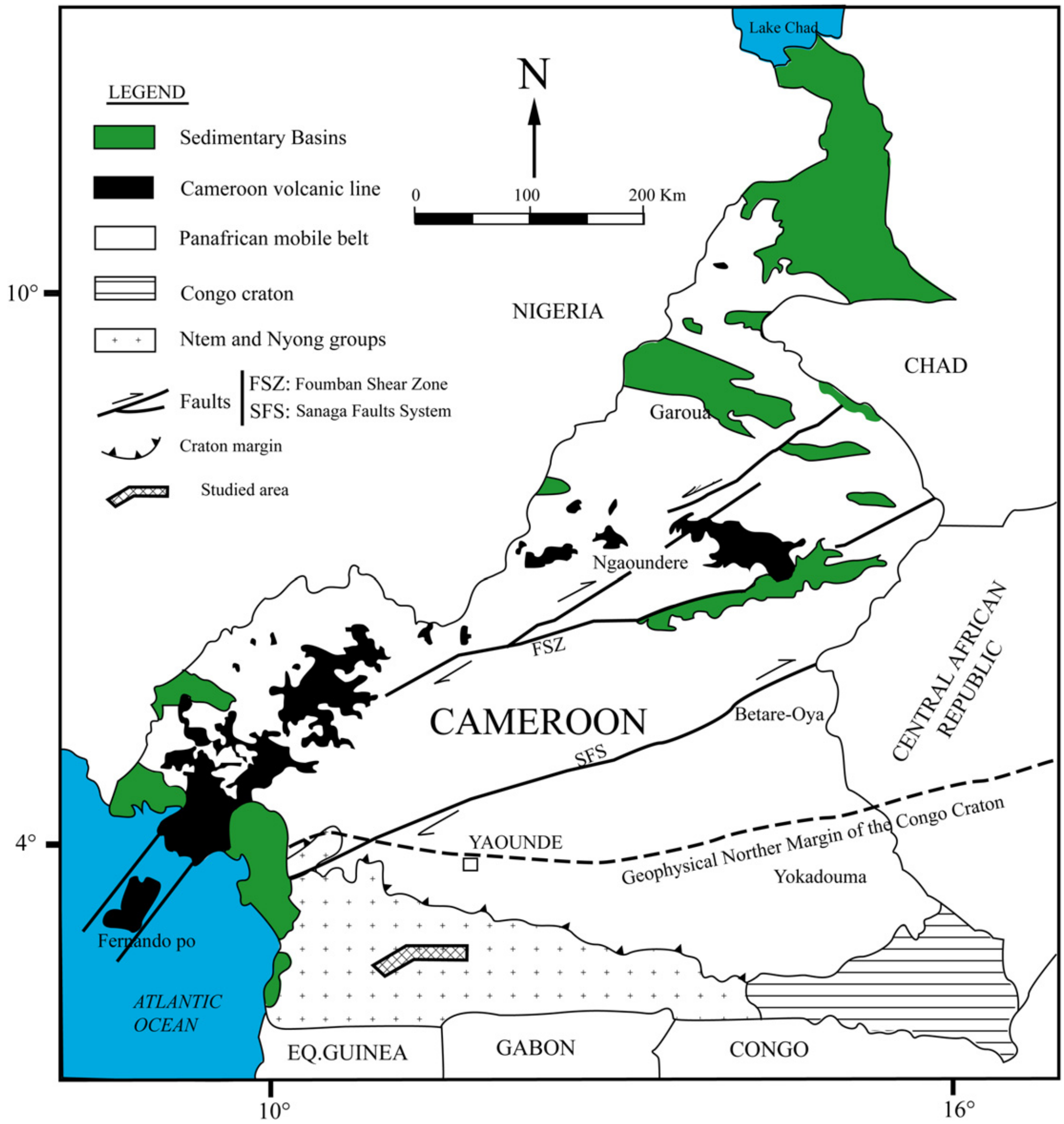

Fig. 1. Geological map of Cameroon showing the study area in the southwest region.

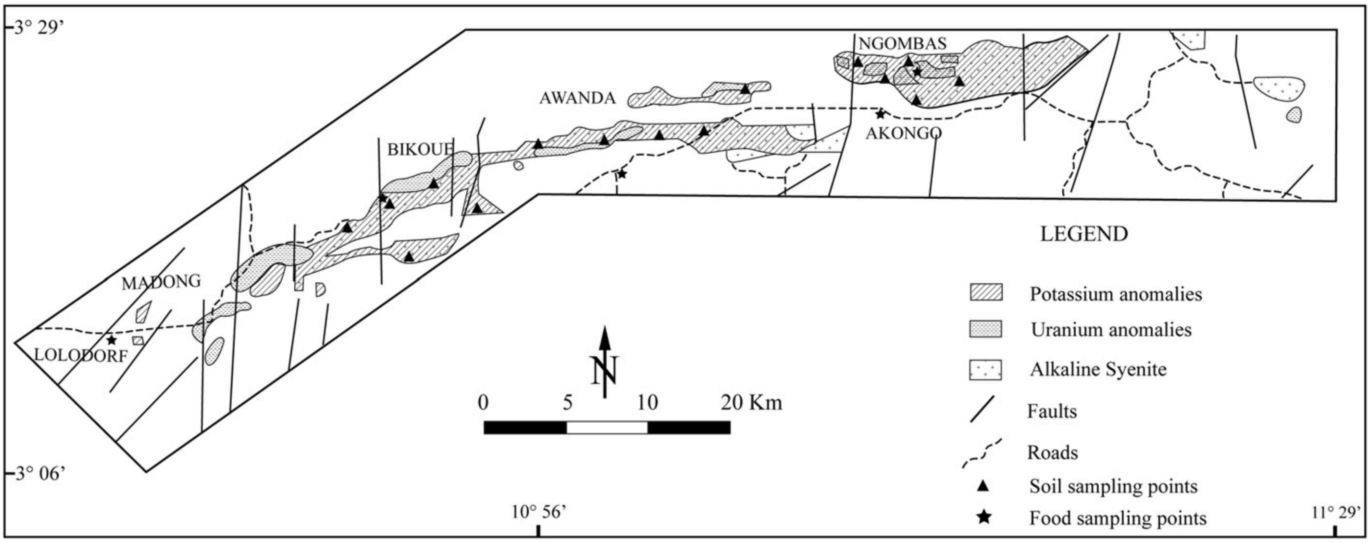

Fig. 2. Soil and foodstuff sampling points in each investigated rural districts.

samples were washed with tap water first and then with distilled water. The cassava root, cocoyam and plantain were peeled and cut, groundnuts shelled and cassava leaves crushed. The prepared samples were weighed and dried at approximately 105 °C until they attained a constant weight. They were then homogenized and ashed at 450 °C to remove organic matter and weighed again, labeled and cataloged. The ashed samples (geometry 50 mL for each) were then kept in hermetically sealed plastic containers for one month in order to allow for the Ra–Rn equilibrium. The geometrical dimensions of these samples were kept similar to those of the reference material.

2.3. Radioactivity measurements

The activity concentration of foodstuff samples was determined using a Canberra low-level gamma counting system. This system consists of a high-resolution p-type HPGe detector (GR3019) with the following physical characteristics (diameter = 55 mm; length = 55 mm; distance from window = 5 mm) and attached to a full featured 16K channel integrated multichannel analyzer (Model DESA 1000). 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 30% relative efficiency. The detector was shielded with a 10 cm thick lead and its peak to Compton ratio was 56:1. Data acquisition and analysis were carried out with the GENIUS 2000 software package. For calibrations, the standard source was placed in the same geometry as the samples. The gamma-transition of 609.3 keV (^{214}Bi) was used to determine ^{226}Ra. The 1460.0 keV gamma-transition of ^{40}K was used to determine the concentration of ^{40}K. The gamma-transition of 911.2 keV (^{228}Ac) was used to determine ^{228}Ra (Shanthi et al., 2010). The counting efficiency of the detector was calibrated using a 50 mL standard multigamma source (9ML01EGRE30).

The gamma spectrum of each foodstuff sample was measured for 86,400 s. The net area under the corresponding peaks in the energy spectrum was computed by subtracting counts due to Compton scattering of higher peaks and other background sources from the total area of the peaks. From the net area of a certain peak, the activity concentrations in the samples were obtained using this equation already used by some authors (Jibiri et al., 2007; Shanthi et al., 2010),

$$c\left(\mathrm{Bq\ Kg}^{-1}\right) = \frac{c_n}{\varepsilon(E)\ x\, P_\gamma\ x\ t\ x\ m_s} \tag{1}$$

where c, is the concentration of the radionuclide in the sample given in Bq kg^{-1}; c_n, the count rate under the corresponding peak; $\varepsilon(E)$, the detector efficiency at the specific γ-ray energy; t, the counting time in seconds; P_γ, the absolute transition probability of the specific γ-ray and m_s, the sample mass (kg). The lower limit of detection (LLD) for ^{226}Ra, ^{228}Ra and ^{40}K was determined from the background radiation level for the same counting time. The measured LLDs for ^{226}Ra, ^{228}Ra and ^{40}K were 0.98, 0.58 and 5.26 Bq kg^{-1}, respectively. Values below these numbers were considered in this work as being below detection limit (BDL) of the detector.

2.4. Calculating effective dose from foods

The typical annual consumptions of investigated foodstuffs from the southwest region of Cameroon are shown in Table 1. The annual effective dose from radionuclides in foodstuffs was computed using the following equation (Samavat et al., 2006; Jibiri et al., 2007):

$$D = D_f \times U \times (C_d \times d \times h), \tag{2}$$

where D, is the annual effective dose (μSv y^{-1}); D_f, the dose coefficient (μSv Bq^{-1}); U, the amount of foodstuff consumed in 1yr (kg–fresh weight y^{-1}); C_d, the radionuclide content of ashed foodstuff (Bq kg^{-1}); d, the ratio of ashed to dried foodstuffs; h, the

Table 1
Annual consumptions of foodstuff types from the southwest region of Cameroon, as fresh weight, from National Agricultural Statistics Bureau and Food and Agriculture Organization (MINADER, 2010; FAO, 1997).

Food group	Food type	Latin names	Annual Consumption (kg y^{-1})
Legume	Groundnuts	*Arachis hypogaea*	30
Fruit	Plantain	*Musa* sp.	100
Leafy vegetable	Cassava leaves	*Manihot esculenta*	50
Tuber	Cassava root	*M. esculenta*	100
	Cocoyam	*Xanthosoma sagittifolium*	60

ratio of dried to fresh foodstuffs and $(C_d \times d \times h)$ is the radionuclide fresh content (Bq kg^{-1}). The recommended dose conversion coefficients used for ^{226}Ra, ^{228}Ra and ^{40}K were 0.28, 0.69, and 0.0062 μSv Bq^{-1}, respectively (UNSCEAR, 2000; ICRP, 1996).

3. Results and discussion

3.1. Foodstuff activity concentration

Concentrations on a fresh weight basis and averaged across crops are shown in Table 2. Analysis of variance showed no statistically significant differences among regions, but differences among crops were significant ($P < 0.05$). The measured ^{226}Ra levels in tuber varied from 0.10 to 4 Bq kg^{-1}–fresh with a mean value of 1.30 Bq kg^{-1}–fresh in cassava, from BDL to 2 Bq kg^{-1}–fresh with a mean value of 0.70 Bq kg^{-1}–fresh in cocoyam. This level in legume varied from BDL to 26 Bq kg^{-1}–fresh with a mean value of 6 Bq kg^{-1}–fresh in groundnuts; in fruits, it varied from BDL to 0.20 Bq kg^{-1}–fresh with a mean value of 0.04 Bq kg^{-1}–fresh in plantain and from BDL to 11 Bq kg^{-1}–fresh with a mean value of 4 Bq kg^{-1}–fresh in cassava leaves. The food groups with notably high values of ^{226}Ra compared to UNSCEAR (2000) were tuber, vegetable and legume, as expected because most of the study area was enriched in ^{226}Ra (Ele et al., 2010).

Concentrations of ^{228}Ra ranged from BDL to 1.10 Bq kg^{-1}–fresh with a mean value of 0.80 Bq kg^{-1}–fresh in cassava, from BDL to 13 Bq kg^{-1}–fresh with a mean value of 6.20 Bq kg^{-1}–fresh in cassava leaves, from BDL to 1 Bq kg^{-1}–fresh with a mean value of 0.40 Bq kg^{-1}–fresh in cocoyam, from BDL to 1 Bq kg^{-1}–fresh with a mean value of 0.20 Bq kg^{-1}–fresh in plantain and BDL in groundnuts. These values were higher than in UNSCEAR (2000), again related the soil of the study area that was recognized to be richer in ^{228}Ra radionuclide.

Concentrations of ^{40}K ranged from 62 to 132 Bq kg^{-1}–fresh with a mean value of 83 Bq kg^{-1}–fresh in cassava, from 95 to 234 Bq kg^{-1}–fresh with a mean value of 160 Bq kg^{-1}–fresh in cassava leaves, from 118 to 193 Bq kg^{-1}–fresh with a mean value of 158 Bq kg^{-1}–fresh in cocoyam, from 162 to 240 Bq kg^{-1}–fresh with a mean value of 195 Bq kg^{-1}–fresh in groundnuts and from 48 to 115 Bq kg^{-1}–fresh with a mean value of 107 Bq kg^{-1}–fresh in plantain.

3.2. Dose calculation

There are no data available on intake by the public from the natural high background radiation area in the southwest region of Cameroon. Dose calculations in this study were done by estimating the annual consumption of the foodstuff types investigated (Table 1) using data from the National Agricultural Statistics Bureau as well as Food and Agriculture Organization (FAO) (FAO, 1997; MINADER, 2010).

Table 2
Average values of activity concentration and daily effective dose for each type of food and each radionuclide.

Plant	Average activity concentration (Bq kg^{-1}–fresh)			Daily effective dose (μSv d^{-1})			
	^{226}Ra	^{228}Ra	^{40}K	^{226}Ra	^{228}Ra	^{40}K	Total
Cassava root	1.30	0.80	83	0.10	0.16	0.14	0.40
Cassava leaves	4.00	6.20	160	0.15	0.59	0.13	0.87
Cocoyam	0.70	0.40	158	0.03	0.05	0.16	0.24
Groundnuts	6.00	0.00	195	0.13	0.00	0.10	0.23
Plantain	0.04	0.20	107	0.003	0.04	0.18	0.22
Total				0.41	0.84	0.71	1.96

The daily effective doses were computed using the average values of activity concentration (Table 2). The total daily effective dose of ^{226}Ra was 0.41 μSv d^{-1} and the high values dose from this radionuclide were 0.10 μSv d^{-1} in cassava, 0.15 μSv d^{-1} in cassava leaves and 0.13 μSv d^{-1} in groundnuts, respectively. The daily dose from cassava was about 61% of the total daily dose calculated for all the investigated food types. The total daily effective dose value of ^{228}Ra was 0.84 μSv d^{-1} and the high values of dose of this radionuclide were 0.16 μSv d^{-1} in cassava root and 0.59 μSv d^{-1} in cassava leaves, respectively. The daily dose from cassava was about 89% of the total daily dose calculated for all the investigated food types.

The total daily effective dose of ^{40}K, was 0.71 μSv d^{-1} represented as follows: 20% in cassava, 18% in cassava leaves, 23% in cocoyam, 14% in groundnuts and 31% in plantain. The total daily effective dose was 1.96 μSv d^{-1} with 21% from ^{226}Ra, 43% from ^{228}Ra and 36% from ^{40}K.

4. Conclusions

This study estimated the activity concentration of natural radionuclides ^{226}Ra, ^{228}Ra and ^{40}K by means of gamma-ray spectrometry in different staple foodstuffs that are regularly consumed by the people of a high background radiation area in the southwest region of Cameroon. The activity concentrations of ^{226}Ra, ^{228}Ra and ^{40}K in each type of food and each radionuclide were much higher than those proposed by UNSCEAR. The highest radionuclide daily effective dose of those measured was that of ^{228}Ra. The cassava plant (*M. esculenta*) was the food type with the highest values of the daily effective dose of both ^{226}Ra and ^{228}Ra radionuclides. This can be explained by the abundance of these radionuclides in the soil, the specific uptake of the latter by the cassava plant and the high consumption. However, the values obtained for the concentration levels of natural radionuclides in the food samples investigated suggest that the dose from the intake of these natural occurring radionuclides is significantly high. Nevertheless, the data shown here represent a small but useful database that allows for further investigations.

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