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Article

Trace elements and radioactivity measurements in some terrestrial food crops in Jos-plateau, north central, Nigeria

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ABSTRACT **Some crops of important nutritive requirements have been collected from farmlands located in Bitsichi an old tin mining town in north central region of Nigeria. The food crops were analyzed in order to determine trace element concentrations level using Neutron Activation Analysis (NAA). The activity concentrations due to natural radionuclides in the food samples and soil samples collected within the root zone of the crops were also determined using gamma-ray spectrometry (GRS). The NAA results obtained showed higher concentration of Potassium among the essential elements in all the crops. Calcium concentration in both maize and Guinea corn was below detection limit and also Zn in Green beans, sweet potato and cassava. The trace elements; Sc, Hf, Sm, and Th, were below detection limit in all the crops except in Green beans. Rubidium (Rb) and lanthanum (La) were below detection limits only in Cabbage. The activity concentrations of the natural radionuclides in the food samples were found to vary between 83 and 129 Bq kg^{-1} for ^{40}K, 19 and 30 Bq kg^{-1} for ^{226}Ra and 27 to 41 Bq kg^{-1} for ^{232}Th. In the soil samples the activity concentrations varied between 177 and 271 Bq kg^{-1} for ^{40}K, 53 and 96 Bq kg^{-1} for ^{226}Ra and 73 to 176 Bq kg^{-1} for ^{232}Th. Results of activity concentration levels of the radionuclides obtained in similar crops collected for control measurements were found to be very low compared to those from the study area. The effective dose due to intake of the food crops considered in the study area was estimated based on the measured activity concentrations of ^{226}Ra and ^{232}Th in the food crops. It was found to vary between 0.01 mSv y^{-1} (Acha) and 1.35 mSv y^{-1} (Cassava) with a cumulative total dose estimated as 2.5 mSv y^{-1}. The mining activities in the area are seen to have influenced the concentration of these trace elements and radionuclides in the food crops. However, they are seen not to pose any serious internal health burden due to ingestion given the realities of food choice by individuals in the study area.**

Keywords: food crops / trace elements / radioactivity / ingestion dose / Jos-plateau / Nigeria

RÉSUMÉ **Éléments traces et mesures de la radioactivité dans quelques récoltes vivrières terrestres du plateau de Jos dans le centre-nord du Nigéria.**

Quelques récoltes d'aliments importants ont été effectuées dans des champs situés à Bitsichi, une ville minière d'étain dans la région nord central du Nigéria. Les récoltes vivrières ont été analysées afin de déterminer le niveau de concentration d'oligoélément en utilisant l'analyse par activation neutronique (AAN). Les concentrations de radioactivité des radionucléides naturels dans les échantillons alimentaires et des échantillons de sol rassemblés dans la zone des récoltes ont été également déterminées par spectrométrie gamma (GRS). Les résultats d'activation neutronique ont montré que la concentration la plus élevée parmi les éléments

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essentiels dans toutes les récoltes était celle du potassium. La concentration en calcium dans le maïs et le maïs de Guinée était au-dessous de limite de détection comme celle du Zn dans les haricots verts, la patate douce et le manioc. Les éléments traces ; Sc, Hf, Sm et Th, étaient au-dessous de limite de détection dans toutes les récoltes excepté dans les haricots verts. Le rubidium (Rb) et le lanthane (La) étaient au-dessous des limites de détection seulement dans le chou. Les concentrations en activité des radionucléides naturels dans les échantillons alimentaires sont comprises entre 83 et 129 Bq kg^{-1} pour ^{40}K, 19 et 30 Bq kg^{-1} pour ^{226}Ra et 27 à 41 Bq kg^{-1} pour le ^{232}Th. Dans les échantillons de sol, les concentrations d'activité varient entre 177 et 271 Bq kg^{-1} pour ^{40}K, 53 et 96 Bq kg^{-1} pour ^{226}Ra et 73 à 176 Bq kg^{-1} pour ^{232}Th. Les niveaux de radioactivité des radionucléides des récoltes dans une zone témoin sont beaucoup plus bas comparés à ceux de la zone d'étude. La dose efficace due à l'ingestion des récoltes vivrières considérées dans la zone d'étude a été estimée sur la base des concentrations en activité de ^{226}Ra et du ^{232}Th. Elle est évaluée entre 0,01 mSv y^{-1} (Acha) et 1,35 de mSv y^{-1} (manioc) pour une dose totale cumulative estimée en tant que 2,5 mSv y^{-1}. L'extraction minière dans la zone a influencé la concentration de ces éléments traces et des radionucléides dans les récoltes vivrières. Cependant, elles ne posent pas de problème sérieux de santé lié à l'ingestion de ces récoltes guidées par les réalités locales dans le choix de la nourriture par les habitants de cette zone d'étude.

1. Introduction

The Jos area is located on a granite plateau about 1100 m above sea level in the north central part of Nigeria (Badejoko, 1975). Jos Plateau is known for mining and milling of tin and columbite. The geological formation and mineral distribution of the Jos-plateau is shown in Figure 1. The mining operation in this area started around 1904. This activity disturbed about 320 km^2 of cultivable land much of which was needed for food production because of the growing population (Alexander and Kidd, 2000). This operation involves physical excavation of soil with heavy machineries which gave rise to different heaps of laterite and ditches in these areas. Though the mining operation in large quantity has ceased, due to low market value as the country presently earns less than 0.5% of its foreign exchange from tin, local mining of tin which involves digging of pits and trenches is still going on in some areas (Alexander, 1996; Pasquini and Alexander, 2005). Some of the areas that were affected by these mining operations include: Bukuru, Bitsichi, Gana Ropp, Dorowa-Babuje, Dorowa Tsoho etc., but the large scale mining activities took place in Bitsichi in Barkin Ladi local government council of Jos Plateau. The radioactive nature of tin ore and its tailings was only realized in 1974, but before then, the tailings were treated as non-radioactive and were used for building construction and agricultural purposes (Babalola, 1984). The source of this high radioactivity has been the subject of many scientific investigations over the years and now it has been established that the by-products of mining and milling were very high in thorium than uranium content (Babalola, 1984; Oresegun and Babalola, 1990; Farai and Sanni, 1992; Oresegun and Babalola, 1993). Due to the level of ecological devastation and non restorative measures

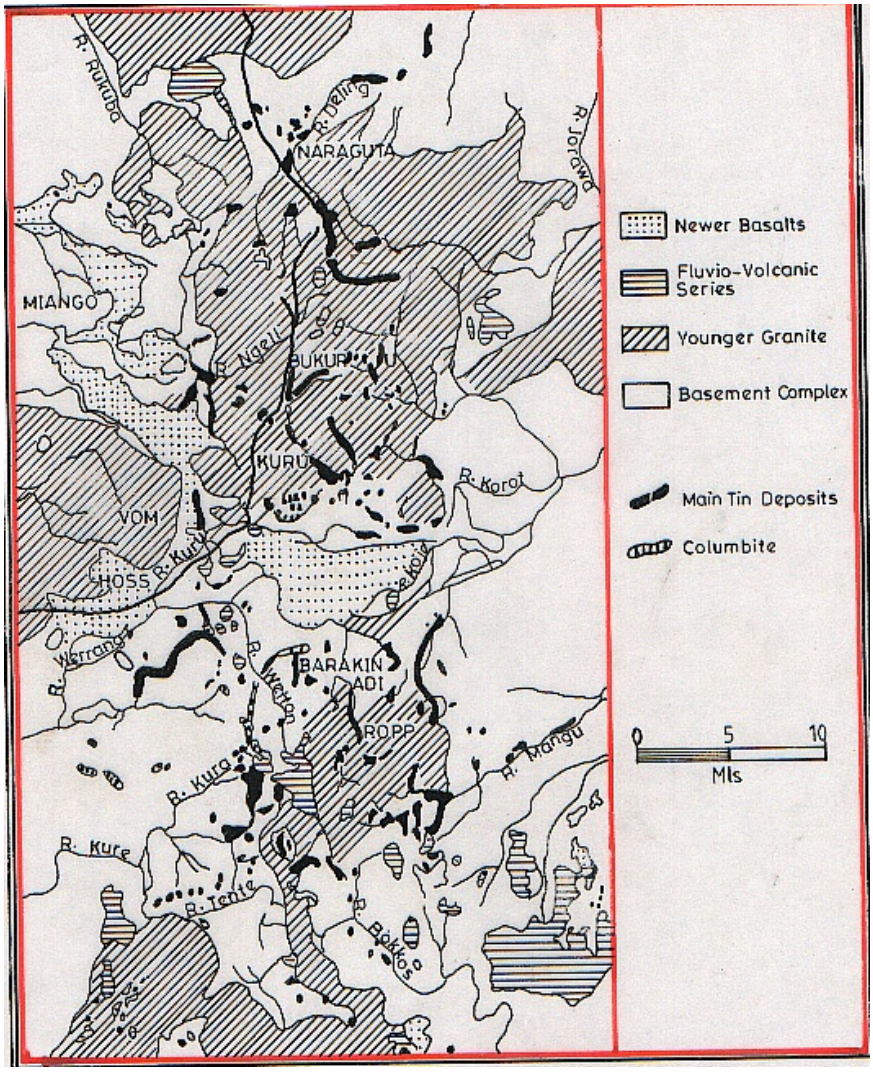

Figure 1 – ***The geological formations and mineral distributions of Jos-plateau, Nigeria.***
Les formations géologiques et les distributions minérales du plateau de Jos au Nigéria.

such as reclamation approaches by constituted authorities this area has attracted the attention of environmentalist especially in Bitsichi (Alexander and Kidd, 2000). In this area, farmers complained of low farm produce yield as compared to areas where mining did not take place an indication that suggest that the operations

may have affected the soil integrity on which crops are eventually grown due to food security and economic pressures. However, not much has been done to ascertain the concentration of the trace elements and natural radionuclides in the food crops grown in these areas following the level of reported scientific studies above.

The concentration or quantity of nutritive elements in crop depends on the soil on which the crop is grown. One essential feature of soil is the ability to retain and accumulate for long time elements and radionuclides coming from the outside. Therefore, for years, a contaminated soil becomes a source through which radionuclides, trace elements and heavy metals enter agricultural products and subsequently enter the food chain from the soil by plant root uptake (Mc Donald *et al.*, 1999; Breuninger *et al.*, 2002; Hernandez *et al.*, 2004). The long established tin mining operation in Jos plateau may have directly or indirectly affected the concentration of trace elements, heavy metal and radionuclide in food crops planted around these areas. In addition to high level of external ionizing radiation, individuals living in high background radiation areas can be exposed internally especially through the intake of foodstuffs. It has therefore become imperative to assess the radiological implication due to consumption of different food crops in the area with the following objectives to:

(1) determine the trace element concentrations level in the food crops using neutron activation analysis (NAA);
(2) determine the activity concentrations due to ^{40}K, ^{226}Ra and ^{232}Th in the food and soil samples by gamma-ray spectrometry;
(3) deduce the intake dose due to the different radionuclides in the food crops.

2. Materials and methods

2.1. Sampling

Samples of cassava (*Manihot esculenta*), guinea corn (*Sorghum bicolor L*), acha (hungry rice) (*Digitaria exillis stapf*), cabbage (*Brassica oleracea capitata*), maize (*Zea mays*), sweet potatoes (*Ipomoea batatas*) and green beans (*Phaseolus vulgaris*) were collected directly from some farm lands around the old mining sites in Bitsichi town to ensure that they are site specific samples. Soil samples were equally collected from the spots where the food samples were taken. Effort was made to ensure that at least two samples each of these food crops were collected across the farmlands, since it was not possible to have a farmland where all the crops are grown. The sample size, however, was considered reasonably well enough for the purpose of the study. The map of Jos plateau showing the location of the sampling site is shown in Figure 2. All the food samples were washed and

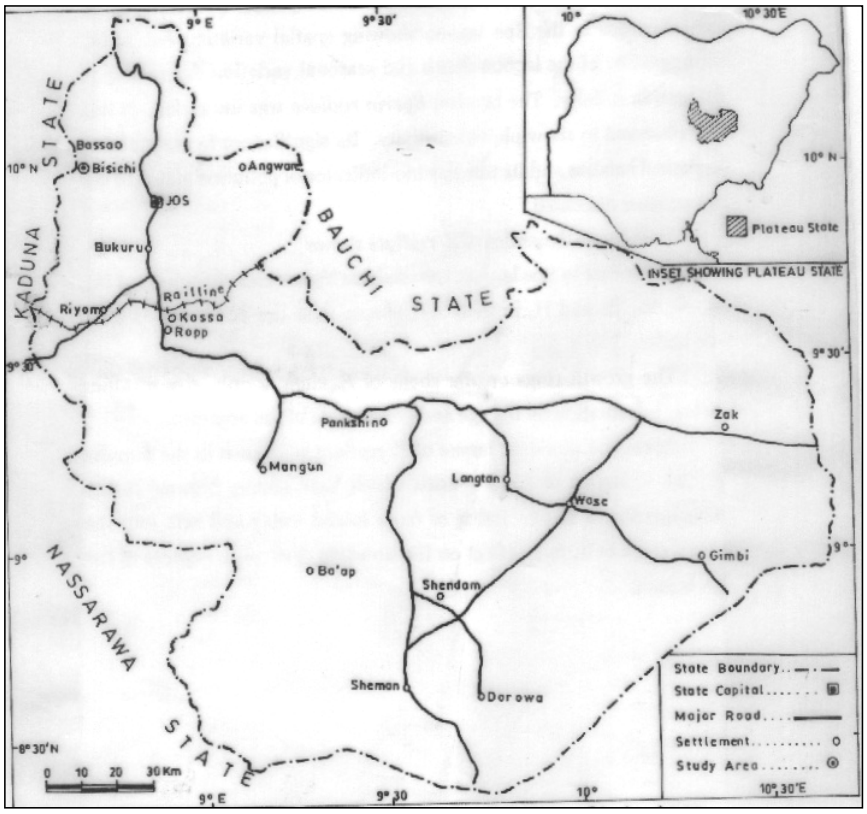

Figure 2 – ***The map of Jos-plateau showing the location of the sampling site.***
Carte du plateau de Jos montrant l'emplacement du site de prélèvement.

the non-edible parts removed. They were oven dried at a temperature of about 70 °C until they reached a constant weight. They were then grounded properly in a wooden mortar for homogenization. The soil samples were also oven dried at a temperature of about 100 °C until they reached a constant weight.

2.2. Sample preparation and encapsulation for NAA

The samples were grounded and sieved with a 300 µm sieve. About 200 mg of each of the food samples was measured and encapsulated. The encapsulation material used in this work is polyethylene. For quality assurance, before encapsulation the polyethylene and the rabbit capsules used during encapsulation were cleaned by soaking in 1:1 HNO_3 for three days and washed with de-ionized water and then

dried in the oven for about 2-3 h at 50 °C. A blank count was carried out on the polyethylene and rabbit capsules to ensure no contamination and none of the element of interest was detected (in other words they were below the limit of detection).

2.3. Sample preparation for radioactivity measurement

After crushing, the samples (both food and soil samples) were weighed and sealed in plastic containers (8 cm × 6 cm) and kept for at least one month to allow for the secular equilibrium of ^{222}Rn and its progeny with ^{226}Ra. Before the sealing, the containers were washed, dried and certified to be non-radioactive.

2.4. Analytical procedure

2.4.1. Neutron activation analysis (NAA)

The NAA analysis was carried out at the Center for Energy Research and Training (CERT) at Ahmadu Bello University, Zaria, Nigeria. The Nigerian Research Reactor-1 (NIRR-1) is a miniature Neutron Source reactor (MNSR) and has a tank in-pool structure configuration with nominal thermal power rating of 31 kW. It is a low power nuclear reactor, which has highly enriched uranium as fuel, light water moderator and beryllium as reflector. The associated facility for radioactivity measurement is a gamma-ray data acquisition system comprising a horizontal dip-stick High-Purity Germanium (HPGe) detector with relative efficiency of 10% at 1332.5 keV gamma-ray line, the MAESTRO emulation software compatible with the ADCAM® Multichannel analyzer (MCA) card, associated electronics modules all manufactured by EG&G ORTEC and a personal computer. The efficiency curves of the detector system have been determined by standard gamma-ray sources in the energy range of 59.5–2 254 keV. The certified reference biological materials IAEA-359 and IAEA-336 were used for the identification of gamma-ray product radionuclides through their energies and quantitative analysis of their concentrations. The gamma-ray spectrum analysis software WINSPAN 2004 was used for the data processing. For irradiation of the samples, two schemes were adopted based on the half-life of product radionuclides. Both schemes were adopted because we are interested in both the short-lived and the long-lived radionuclides. For the elements leading to short-lived activation products the samples were each packed and sealed in 7 cm^3 rabbit capsules and irradiated each for about 2 min in turn in an outer irradiation channel B4 where the neutron spectrum is ‘soft’. For elements leading to long-lived activation products, samples wrapped in polyethylene films were packed and sealed in a stack inside the 7 cm^3 rabbit capsules and irradiated for 6 h in any of

the small inner irradiation channels (A1, B1, B2, and B3) to take advantage of the maximum value of thermal neutron flux in the inner channels. After irradiation, radioactivity measurement of induced radionuclides is performed by the PC based gamma-ray spectrometry set up. Following the short regime the first round of counting was performed for 10 min (S1) after waiting for 2–15 min. Samples were placed in a Plexiglas sample holder designated as 'H2' which corresponds to source-detector geometry of 5 cm. The second round of counting was also carried out for 10 min following short irradiation regime (S2) after waiting period of 3–4 h. Samples were counted on a Plexiglas holder designated as 'H1' corresponding to source-detector geometry of 1 cm. Usually, the neutron flux for short irradiation regime S1 and S2 is 10^{11} n/cm^{2}s but for this work (being biological samples) the neutron flux was raised to 5×10^{11} n/cm^{2}s in order to increase the detection sensitivity for analysis of elements using procedures S1 and S2. For long irradiation regime, the first round of counting was carried out for 30 min, following long irradiation (L1) using holder 'H1' after a waiting time of 4–5 days. The second round of counting was performed for 60 min (L2) after waiting (cooling) time of 10–15 days.

2.4.2. Radioactivity analytical procedure

The natural radionuclide concentration in the soil and food samples was carried out in this work using gamma-ray spectrometry. This system consist of a 3" × 3" NaI (Tl) detector well shielded in a 6 cm lead shield, the MAESTRO emulation software compatible with ADCAM® Multichannel analyzer (MCA) card, associated electronics modules (amplifier and power supply modules) all made by EG&G ORTEC and personal computer. The detector has a resolution of about 8% at 0.662 MeV of ^{137}Cs which is capable of distinguishing the gamma ray energies used for the measurements. The photopeak at 1.460 MeV was used for the measurement of ^{40}K while those at 1.760 MeV peak from ^{214}Bi and 2.614 MeV from ^{208}Tl were used for the measurement of ^{226}Ra and ^{232}Th, respectively. These peaks are clean, reasonably strong with very low continuum and were considered appropriate because of the poor resolution of the NaI(Tl) detector used in this work. Calibration of the detector system was achieved by determining its gamma ray counting efficiencies over the energy range 0.662 to 2.615 MeV using a certified reference source soil sample traceable to source number 48722–356 by Analytic Inc. Atlanta, Georgia. For the food samples the IAEA certified reference source traceable to source number IAEA-152 was used. The counting time of 8 h and 10 h were used respectively for the soil and food samples respectively. The net area count after background corrections in each photopeak was used in the computation of the activity concentration of each of the radionuclide in the food and soil samples using the MAESTRO emulation software. The activity

concentrations of the radionuclides in the soil samples in Bq kg^{-1} were calculated using the following equations (Jibiri and Ajao, 2005; Jibiri and Bankole, 2006):

$$C\ (\text{Bq kg}^{-1}) = \frac{C_k}{A_k} A \tag{1}$$

C_k is the activity concentration of the radionuclide in the standard reference sample (Bq kg^{-1}), A is the net area count after background correction in the spectrum of the radionuclide in the sample and A_k is the net area count after background correction under the spectrum of the radionuclide in the standard reference sample. The standard reference soil sample used was prepared from Rocketdyne Laboratories California; USA which is traceable to a mixed standard gamma source (Ref. No. 48722-356) by Analytic Inc. Atlanta, Georgia. A uniform mass of 200 g was used for the soil samples while for the food samples the mass used ranged between 80 and 200 g. Due to the different mass used for the food samples the activity concentrations was obtained using the expression (Olomo, 1990; Akinloye and Olomo, 2000):

$$C\ (\text{Bq kg}^{-1}) = \frac{C_n}{\varepsilon P_\gamma M_s} \tag{2}$$

where C is the activity concentration of the radionuclide in the sample, C_n is the count rate under each photopeak due to each radionuclides, ε is the detector efficiency of the specific γ-ray, P_γ is the absolute transition probability of the specific γ-ray and M_s is the mass of the sample (kg).

3. Results and discussion

3.1. Concentration levels

Table I presents the results of the major and trace element analysis in the food samples while the results of the activity concentrations due to natural radionuclides in the soil and food crops are presented respectively in Tables II and III. As could be observed from Table III, radioactivity measurements on cabbage and green beans were not reported, this is due to the fact that the reasonable quantity of mass required for radioactivity measurements was not obtained after preparation. From Table I, potassium has higher concentration among the major elements in all the food crops. The highest potassium content of 30 400 ± 608 ppm was obtained in cabbage while the lowest value of 6 824 ± 328 ppm was obtained in sweet potato. Calcium concentration was below detection limit in both maize and Guinea corn; also was Zn in green beans, sweet potato and cassava. The real trace elements; Sc, Hf, Sm, and Th, were below detection limit in all the crops except in green beans. Rubidium (Rb) and lanthanum (La) were below detection limits only in Cabbage. The crops with seeds such as beans and corn showed higher absorption of the trace

TABLE I

The analytical result of trace elements in the food crops.
Résultats analytiques des elements traces dans les récoltes vivrières.

Elements	Food crop types					
	Green beans	Sweet potato	Cassava	Guinea corn	Maize	Cabbage
Na (ppm)	86.2± 4.9	766 ± 18	36.6 ± 3.4	67.0 ± 4.6	30.7 ± 2.9	794 ± 18
K (ppm)	18310± 458	6824 ± 328	6938 ±278	7930 ± 293	11590 ± 406	30400 ± 608
Mg (ppm)	1668± 458	453 ± 131	478 ± 94	2879 ±127	4603 ± 180	1754 ±163
Ca (ppm)	1922 ± 242	826 ± 132	602 ±122	BDL	BDL	3828 ± 306
Al (ppm)	785 ± 10	102 ± 4	181 ± 6	144 ± 4	228 ± 6	189 ± 6
Zn (ppm)	BDL	BDL	BDL	75.0 ± 17.8	82.7 ± 18.9	88.4 ± 18.8
Mn (ppm)	35.3 ± 0.5	17.5 ± 0.4	11.3 ± 0.3	25.5 ± 0.4	60.9 ± 5.8	57.2 ± 0.6
Rb (ppm)	85.5 ± 10.3	44.3 ± 10.1	37.5 6.7	41.7 ± 8.5	20.7 ± 4.6	BDL
Sc (ppm)	0.17 ± 0.03	BDL	BDL	BDL	BDL	BDL
Hf (ppm)	0.54 ± 0.12	BDL	BDL	BDL	BDL	BDL
La (ppm)	1.21 ± 0.09	0.73 ± 0.13	0.57 ±0.07	0.29 ± 0.05	0.38 ± 0.06	BDL
Sm (ppm)	0.17 ± 0.01	BDL	BDL	BDL	BDL	BDL
Th (ppm)	1.10 ± 0.17	BDL	BDL	BDL	BDL	BDL
Cl (ppm)	882 ± 36	2184 ± 57	337 ± 22	317 ± 20	874 ± 34	1943 ± 53
Br (ppm)	1.29 ± 0.11	1.18 ± 0.18	0.62 ±0.09	0.66 0±.12	0.32 ± 0.07	0.98 ± 0.17

BDL – Below detection limit. ± indicates uncertainty from counting statistics.

TABLE II

The activities of the radionuclide in soil samples.
Activité des radionucléides dans les échantillons de sol.

Activity concentration (Bq kg^{-1})			
Crop farms	^{40}K	^{226}Ra	^{232}Th
Acha (Hungry rice)	271 ± 17	96 ± 16	107 ± 3
Cassava 1	287 ± 17	74 ± 15	177 ± 6
Cassava 2	132 ± 9	65 ± 14	97 ± 3
Guinea corn	132.± 8	76 ± 14	73 ± 3
Maize	177 ± 12	53 ± 12	97 ± 3

elements compared to tubercles such as potato and cassava. This observation has been similarly reported (Njafang *et al.*, 2006). The activity concentrations of the natural radionuclides in the food samples was found to vary between 83 Bq kg^{-1} in sweet potato and 129 Bq kg^{-1} in cassava for ^{40}K, 19 Bq kg^{-1} in cassava and 30 Bq kg^{-1} in acha for ^{226}Ra and 27 Bq kg^{-1} in acha and 41 Bq kg^{-1} in sweet potato

TABLE III

The activities of the radionuclide in food samples and effective dose due to ingestion.
Activité des radionucléides dans les échantillons alimentaires et dose efficace liée à l'ingestion.

Activity concentration (Bq kg^{-1})				
Food samples	^{40}K	^{226}Ra	^{232}Th	Annual Effective dose due to ingestion (mSv y^{-1})
Acha	87 ± 6	30 ± 8	27 ± 1	0.01
Cassava	129 ± 9	19 ± 6	29 ± 1	1.35
Guinea corn	87 ± 6	27 ± 6	27 ± 1	0.61
Maize	102 ± 6	19 ± 6	40 ± 1	0.29
Sweet potato	83 ± 6	27 ± 10	41 ± 2	0.24

for ^{232}Th. The activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in the food crops from this area were about 10 orders of magnitude higher than those obtained in other parts of the country. For instance in tuber products the radionuclide levels varied from 10.6 to 46.4 Bq kg^{-1} for ^{40}K, 0.5 to 2.7 Bq kg^{-1} for ^{238}U and from BDL –1.4 Bq kg^{-1} for ^{232}Th (Akinloye and Olomo, 2000) while in cereal crops the values of the radionuclides varied from 36.4 to 186.9 Bq kg^{-1} for ^{40}K, 0.2 to 1.4 Bq kg^{-1}for ^{238}U and from 0.3 to 1.8 Bq kg^{-1} for ^{232}Th (Arogunjo, 2003). The ^{40}K value of sweet potato in this study is also lower than that of the value 136 ± 2 Bq kg^{-1} reported in Spain (Hernandez *et al.*, 2004). Furthermore, samples of the food crops similar to the ones considered in the study were collected from Kaduna State for control radioactivity measurements. Kaduna State was chosen because it is located in the north central region of the country as the study area and it also has no history of tin mining activities. The natural environmental radioactivity levels in the State have been reported to be within the world average normal range (Farai and Jibiri, 2000). The result of the activity concentrations of the radionuclides in the food crops from Kaduna State (control site) is presented in Table IV. Results are lower than those from the study area. It is also envisaged that trace elements values will equally be lower in their concentration values. This therefore suggests that the mining activities may have influenced their levels in crops in the study area. Also fertilizer largely used to improve soil fertility is also seen to have enhanced the quantity of these radionuclides in the soil and consequently through uptake are made available to the plants. For the soil samples the activity concentrations varied between 177 and 271 Bq kg^{-1} for ^{40}K, 53 and 96 Bq kg^{-1} for ^{226}Ra and 73 to 176 Bq kg^{-1} for ^{232}Th. In all the soil samples analyzed the concentration of ^{232}Th is higher than that of ^{226}Ra (^{238}U).

TABLE IV
The activities of the radionuclide in food samples (control site).
Activités des radionucléides dans les aliments de la zone témoin.

Activity concentration (Bq kg^{-1})			
Food samples	^{40}K	^{226}Ra	^{232}Th
Acha	24 ± 3	6± 1	6 ± 2
Cassava	94 ± 3	2 ± 1	2 ± 1
Sweet potato	113 ± 3	BDL	7± 2
Guinea corn	38 ± 2	BDL	6 ± 2
Maize	38 ± 3	3 ± 1	5 ± 2
Millet	38 ± 3	3 ± 1	BDL

3.2. Effective dose from ingestion

Radiation doses obtained due to the intake of food is calculated from the amount of radionuclide deposited on foodstuff, the activity concentration of a particular radionuclide in food per unit deposition, the consumption rate of the food products and the dose per unit activity ingested**.** Thus the effective dose due to the intake of these food crops can be calculated using the formula (Breuninger *et al.*, 2002; RIFE, 2005):

$$D_i = (U_{Ra}C_{Ra} + U_{Th}C_{Th}) \times W \times 10^{-3} \quad (3)$$

where, D_i = effective dose from intake of a particular food, U_{Ra}(0.28 μSv Bq^{-1}) and U_{Th} (0.230 μSv Bq^{-1}) are the dose per unit activity for ^{226}Ra, and ^{232}Th respectively (ICRP 1996; RIFE, 2005), C_{Ra}, and C_{Th} are the activity concentration of ^{226}Ra, and ^{232}Th respectively, W is the consumption rate (kg y^{-1}) and 10^{-3} is a factor that converts micro to milli. The indigenes of Bitsichi (the study area) fall within the Northern region of Nigeria where grains and tubers are staple food of nutritive importance (Olayemi, 1998; Maziya-Dixon *et al.*, 2004). Presently, no site specific consumption data exist in the study area and as such we have adopted the country's mean annual consumption rate per capita values (Tab. V) to enable us calculate the effective dose due intake of the food stuffs using equation (3). Potassium-40 was not considered in the effective dose calculation in this study because as an isotope of an essential element, it is under homeostatic control depending on the physiological behavior of the essential trace element Potassium rather than on its intake (Akinloye and Olomo, 2000; Jibiri and Ajao, 2005), hence the dose from ^{226}Ra and ^{232}Th are only considered as they are known to contribute between 40% and 60% respectively of the internal dose resulting from food product intake. The results of the calculation are also presented in Table III. The total estimated annual

TABLE V
The mean annual consumption (MAC) values per kilogram per person.
Consommation annuelle moyenne par kg et par personne.

Food Type	MAC kg/Person[§]
Maize	20.67
Millet	36.24
Rice	26.35
Guinea corn	44.70
Other cereals	0.60
Cassava	115.46
Sweet potatoes	14.35
Yam	75.15
Other roots	6.50
Wheat	18.55
Beans	0.02

[§] Data was collected from the Federal Office of Statistics(FOS), Nigeria/FAO 2006.

dose due to intake of the food crops ranged between 0.01 (Acha) and 1.35 mSv y^{-1} (Cassava) with a cumulative total dose estimated as 2.5 mSv y^{-1}. Although not all crops were sampled such as rice though not grown in the area, the total effective dose estimated in this study is seen to represent a reasonable range due to intakes in the area. Nevertheless, it represents a useful small database that will allow more thorough investigations in future works in the area. The small database is also seen to be useful to the newly established Nigerian Nuclear Regulatory Authority (NNRA) in their food policy, administration and regulatory functions.

4. Conclusion

The major, trace elements and natural radionuclide concentrations have been determined in crops of important nutritive requirements in an old tin mining area in Bitsichi town in Jos-plateau, Nigeria. The major trace elements Na, K, Mg, Cl were detected in all the food crops except Ca that was below detection in the cereal crops. The real trace elements Sc, Hf, Sm and Th were all below detection in the crops except in Green beans. Rubidium (Rb) and lanthanum (La) were found to be below detection limits only in Cabbage. The activity concentrations of the natural radionuclides in the food samples was found to vary between 83 Bq kg^{-1} in sweet potato and 129 Bq kg^{-1} in cassava for ^{40}K, 19 Bq kg^{-1} in cassava and 30 Bq kg^{-1} in acha for ^{226}Ra while 27 Bq kg^{-1} in acha and 41 Bq kg^{-1} in sweet potato for ^{232}Th. The activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in the food crops from this area were found to be higher than those obtained in other parts of the country

and in the similar crops from the control site. The total estimated annual dose due to intake of the food crops ranged between 0.01 (Acha) and 1.35 mSv y^{-1} (Cassava) with a cumulative total dose estimated as 2.5 mSv y^{-1}. The mining activities in the area are seen to have influenced the concentration of these trace elements and radionuclides in the food crops. However, they are seen not to pose any serious internal health burden due to ingestion given the realities of food choice by individuals in the study area.

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