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ORIGINAL RESEARCH ARTICLE

A Study of Natural Radionuclides in Frequently Consumed Foodstuffs in Ode-Irele, Ondo State, Nigeria

Abimbola Isaac Odudu[1], Damilare Stephen Adepehin [2*], Emmanuel Daniel Onoja [2], Ifunanya Peace Muogbo[3], Ugochukwu Williams Nsolibe[3] and Matthew Inalegwu Amanyi[2]

[1]Department of Physics, Adeyemi College of Education, Ondo, Ondo State, Nigeria.
[2*] Department of Physics, Federal University of Health Sciences, Otukpo, Benue State, Nigeria
[3]Department of Physics Education, Federal College of Education (Technical) Umunze, Anambra State, Nigeria

ABSTRACT

Identifying the natural radionuclides in frequently consumed foodstuffs has attracted research interests from many researchers. In this study, we reported the quantities of natural radionuclides in frequently consumed foods in the community of Ode-Irele in Ondo State, Nigeria. Data obtained for this study were analysed using the gamma-ray spectrometer. Careful examination of six (6) different foodstuffs obtained at random for four (4) different times from the community's local market was done: all of them were discovered to be rich in Th-232, U-238 and K-40. The activity concentrations of the foodstuffs ranged from 58.21±5.93 $Bqkg^{-1}$ to 1.91±0.41 $Bqkg^{-1}$ with a mean value of 11.74±1.22 $Bqkg^{-1}$ for Th-232, 41.82±9.48 $Bqkg^{-1}$ to 3.12±0.39 $Bqkg^{-1}$ with a mean value of 12.38±2.27 $Bqkg^{-1}$ for U-238 and 1854.12±126.83 $Bqkg^{-1}$ to 134.72±12.62 $Bqkg^{-1}$ with mean value of 280.22±30.08 $Bqkg^{-1}$ for K-40. The minimum and maximum dose rates discovered from the foodstuffs are respectively 8.03$nGyh^{-1}$ and 132.35$nGyh^{-1}$. The mean value of all absorbed dose rates (28.99$nGyh^{-1}$) was found to be less than the world average limit of 55.0$nGyh^{-1}$. Comparison of the annual committed effective doses determined from the mean of the natural radionuclides (0.155$mSvy^{-1}$) in the foodstuffs to the global recommended limit (1$mSvy^{-1}$), showed that the frequently consumed foods by the people in the community posed no important radiation-related risk to them.

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INTRODUCTION

Naturally occurring radionuclides such as ^{232}Th,^{238}U and ^{40}K present in foodstuffs have significant effects on the human health when taken in very high quantity (Pearson *et al*. 2016). Oral consumption of^{238}U for instance, can lead to high chances of the lung cancer and damage of the kidney cells (Abojassim *et al*., 2014). The damage done by ^{238}U is traceable to decays of uranium to emit alpha particles ($^4_2\alpha$) which are dangerous to human health both externally and internally (Abojassim *et al*., 2014). ^{232}Th is a naturally occurring radioactive element in rocks, soil and some of the foodstuffs we consume. Findings from Jibiri and Abiodun (2012) made it known that when too much of ^{232}Th is consumed, it can result in lung lung cancer. The isotope of potassium (^{40}K) is considered harmless to humans based on its very small content in the volume of potassium which was discovered to be naturally present. It constitutes just 0.012% of the sum total of the isotopes of potassium. Despite the harmless nature of this isotope, literature has it recorded that the ^{40}K decays by emitting beta particles with no indication of gamma elements (Khan *et al*., 2020). Consumption of ^{40}K in large quantities can snowball into damage to cells resulting from ionization during radioactive disintegration (Sowole and Amodu, 2019). The distribution of radionuclides in different parts of the plant from which the foodstuffs we consume were obtained depends on the environmental contributions to the geological, geophysical and geographical attributes (Chiozzi *et al*., 2000).The earth contains different levels of radioactivity due to chain delay of naturally occurring radioactive materials (NORMs) (^{238}U, ^{232}Th and ^{40}K). Some foodstuffs we consume contain a very small amount of natural radionuclides (Khan *et al*., 2020). For instance, Brazil nut and banana contain some naturally occurring radionuclides, such as potassium, radium and carbon (Zagatto *et al*., 2008).

Correspondence: Damilare S. A. Department of Physics, Federal University of Health Sciences, Otukpo, Benue State, Nigeria. ✉ damilare.adepehin@fuhso.edu.ng; Phone: +234-8133874616
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Zagatto *et al.* (2008) showed that products of the radioactive disintegration of the aforementioned elements are present in most foods we eat. Still, because of the negligible contents of these radiations in foods, they are believed incapable of posing related risks to consumers. A more accurate way of measuring natural radionuclides in locally consumed foodstuffs especially in areas where radioactive disasters recently happened is to examine the water, food items and the air people breathe in around the environment (Murakami and Oki, 2014). Just as the purchased foodstuffs can harbour a lot of natural radionuclides, food crops and vegetables are grown locally and can so carry a lot of NORMs due to the radioactive nature of the soil and the environment (Murakami and Oki, 2014).

Foodstuffs consumed locally are either purchased from the community market or grown in the locality for subsistence reasons (McMahon *et al*., 2015). Findings the from literatures show that the accumulation of these radioactive materials in foodstuffs, even when the contents are small, puts consumers at long-lasting radioactive risk (Tawalbeh *et al*., 2012). Naturally occurring radioactive materials (NORMs) which are taken in by the foodstuffs we eat constitute a large percentage of radiations present in the body system: some of which are present in doses donated to different organs which remained affected over a very long period of time (Fathabadi *et al*., 2017). Fathabadi *et al.* (2017) opined that the concentration of NORMs might be high in locally produced foodstuffs because their cultivation may be from areas where the concentrations of natural radionuclides is very high in the atmosphere and the soil. The foodstuffs consumed by people in an area have different effects from the same foodstuffs in another area (El-Gamal *et al*., 2019). The peculiarity of the NORMs in the environment and the soil of a particular area determines the extent to which people will be affected by the consumption of local foodstuffs (El-Gamal *et al*., 2019). The consumption of NORMs can also result from a complete food chain in which radionuclides absorbed by plants are taken to the leaves which are eaten by animals we feed on. After habouring some quantities of harmful radionuclides in their organs, these animals become very harmful to human health when eaten. This explains why foodstuffs should be well-assessed before people can purchase them for consumption (Fathabadi *et al*., 2017). Supplementation of foodstuffs in a local community with radiation-free items can also serve as a better way to improve people's health, especially in communities where NORMs have been released into the environment due to some unplanned incidents (McMahon *et al*., 2015).

Food items produced in local communities are often rich in naturally occurring radionuclides due to the general belief that locally-made foodstuffs are the best for human consumption (Yablokov *et al*., 2009). The Chernobyl incident in large parts of Ukraine released a lot of natural radionuclides into the atmosphere (McMahon *et al*., 2015). The focus of the work of McMahon *et al.* (2015) was on providing foodstuffs to supplement the contaminated consistently consumed foodstuffs in Narodichi, a rural area of Ukraine; it later became evident that reduction in the supplement led to an increase in some NORMs-related diseases like anaemia, cough, cold, bronchitis and cancer. These diseases were reduced to the nearest minimum when supplementation was increased. It is imperative for organizations responsible for food control to educate people on the harmful effects of consuming radiation-rich foodstuffs (McMahon *et al*., 2015). Adopting food supplementation will reduce the concentration of NORMs in local areas where people are susceptible to radiation-related diseases (McMahon *et al*., 2015). NORMs such as U-238, Th-232 and K-40 can contaminate our foodstuffs due to natural disintegration; as the elements disintegrate to half their original atoms for as long as when the earth has been in existence (Merli *et al*., 2015). Merli *et al*., (2015) established that some of the products obtained from animals might be rich in NORMs. Pork, Chicken, Eggs, Beef and Milk purchased from the market should be well assessed by relevant authorities to be sure that they are NORMs-free because there exist various alternatives of different qualities to these products everywhere (Cengiz, 2020).

It is known that almost every household in every community consumes one or more of these products from animals; we therefore need to be well informed of the aftermath effects of their consumption, if there are any (Cengiz, 2020). Cancers of the lung, liver, kidney, breast, blood and bones do not just happen overnight in patients diagnosed with the diseases (Sowole and Amodu, 2019). It must have been situations resulting from the unnoticed accumulation of radiations in the body over a long period of time. In summary, natural radionuclides get into our foods through roots uptake, crops deposition and biological accumulation. Soil has a very high percentage of natural radionuclides. This is why plants, during conduction take water containing natural radionuclides from the soil through the roots to other parts like the stem and leaves which human sometimes consumes Paatero 1 and Paatero 2, (2021).

The air we breathe in is not totally free from natural radionuclides. There are many activities, such as pollution (contamination of the environment with harmful substances) resulting from burning fossil fuel which makes the air impure. Some of these NORMs can settle on crops: if the content is too high, it can pose a radiation risk to consumers (Adedokun *et al*., 2019). Naturally occurring radioactive materials accumulate in some animals that feed on plants, roots of plants, soil and water which contains radioactive elements. Whenever some animals ingest NORMs in plants and humans also feed on them, it can put the lives of such persons at risk, especially when the content keeps increasing over a long period. Fishes in water may consume water which contains NORMs which can find their ways into human bodies when consumed (Zehringer, 2016). Zehringer (2016) stressed that radiological activities in foods are usually guided and monitored by certain organizations saddled with the responsibility of the maintenance of food security in different parts of the country to prevent the public from consuming foods and any other substances presumed to be capable of posing radiological abnormalities to people. The National Agency for Food and Drug Administration and Control (NAFDAC) in Nigeria and the Food and Drug Administration (FDA) in the United States, are some of the agencies that test foods and make sure they are free from contaminants such as radiations, before allowing producers release them to the public (Lordford *et al*., 2013). Lai (2009) emphasized that food security is one of the important goals of the United Nations Food and Agriculture Organization. It speaks volume about social and economic access to safe, nutritious and sufficient food for every living being at all times to meet their dietary and food preferences for an active and healthy lifestyle (Lai, 2009).

Most of the research done on foodstuffs consumed for the past two decades has focused only on the nutritional constituents but little or no attention has been on the number of radionuclides (naturally occurring radioactive material, NORMs) inherent in such foodstuffs consumed particularly in local communities like the study area. This research work is aimed at determining the activity concentrations of twenty-four food samples purchased from different selling points for four different days in the local market of the study area through gamma-ray spectrometry, determining the minimum and maximum dose rates of the foodstuffs, relating the mean dose rates to the world average limit and comparing the annual committed effective doses obtained from the average of the natural radionuclides to the global recommended limit. These research findings are expected to assist food regulatory bodies put a measure to determine the percentage of natural radionuclides in foodstuffs before allowing wholesalers to sell to retailers who sell in small quantities to the consumers. This will help to reduce radiation-related risks that consumers are exposed to from the consumption of unregulated foodstuffs. In doing this, cells damaging diseases like cancers of the lung, liver, kidney and bones will be reduced.

MATERIALS AND METHODS

Study Area

The community of Ode-Irele is bounded by latitudes $6°29'18°N$ and longitudes $4°52'12.78°E$. The Ode-Irele community located in Ondo State, southwest of Nigeria in West Africa, has fertile soil, supporting the major farming occupation in the community. This community is generally characterized by two major tropical seasons: the dry and rainy seasons.

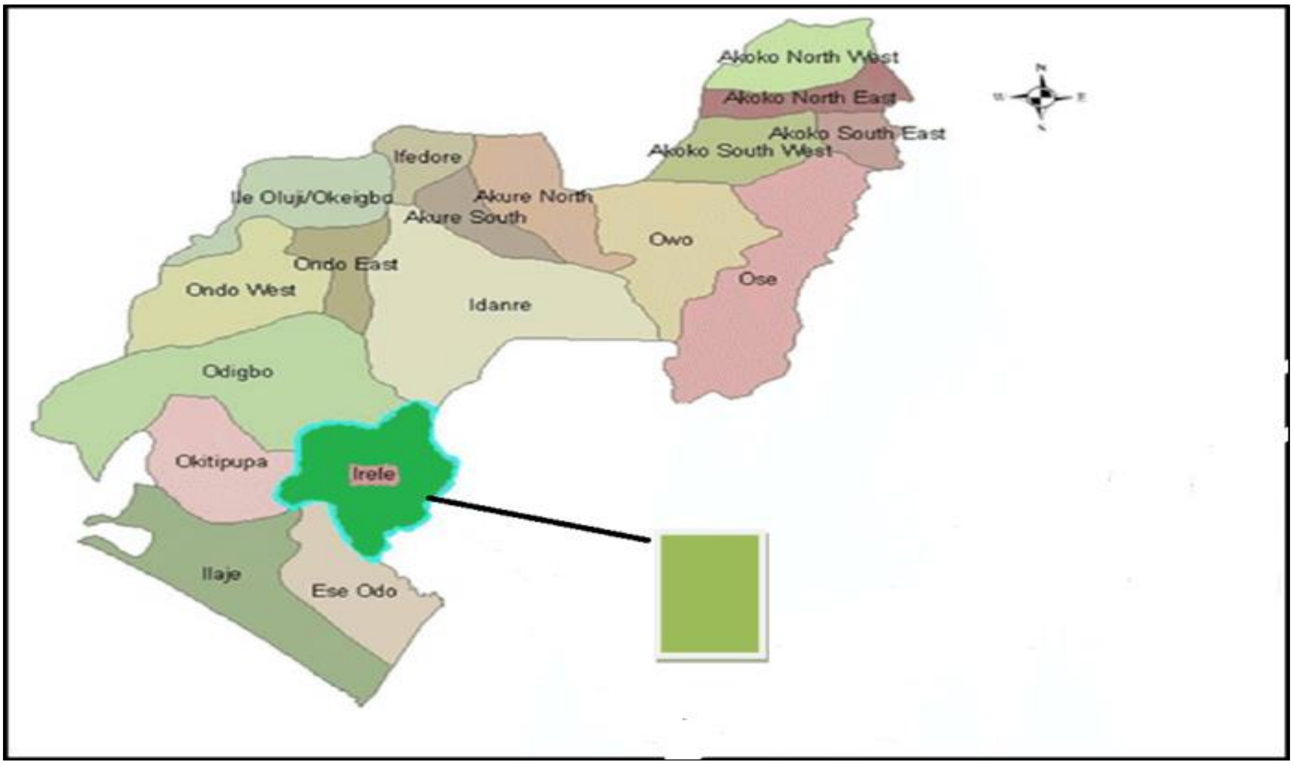

Figure 1: Map of Ondo state showing Irele town

Study shows that some naturally occurring radioactive materials (NORMs) exist in the soil of the community. Still, a considerably high percentage of natural radionuclides can be found in Gbeleju-Loda in the suburb of the Ode-Irele community. The work done on NORMs by (Ilori *et al.* 2018) revealed that a high percentage of NORMs are noticed in the environment due to the effectsofthe Bitumen. Other areas of the community have soil with very low NORMs, and this is evident in the nutritious and harmless farm produce from the district. This community is the administrative headquarter of the Irele Local Government Area. It is located 10 kilometres by road west of the town of Okitipupa, according to Omosule (2011).The occupants of this town were the Ikales,with the same language and culture. One major source of income for the people in this community for the past ten decades has been majorly farming and partly fishing because of the limited numbers of rivers. Most of the food items like 'garri', corn, cassava flour (pupuru), plantain flour, and palm oilconsumed by the people in the community are locally produced. Figure 1 below shows the map of the Ondo state from which the community of Ode-Irele is identified.

Sample collection and preparation

Twenty-four food samples used for this research work were obtained from the local market of the Ode-Irele community. This was done by obtaining six food samples randomly from different traders for four different market days. The targeted food samples used for this research were cassava flour (pupuru), beans, corn, garri, plantain flour and rice. Some of the samples that were not fully in their powdered forms like the rice, beans, corn and garri were pulverized and sieved to get them in powder form and given codes as shown in table 1. The samples were weighed 165g and sealed in small plastic containers, then stored for four (4) weeks before counting to allow secular equilibrium to be reached. Gamma-ray spectrometry analysis was carried out to determine the Activity Concentration (A), Gamma Dose Rate (GDR), and Annual Committed Effective Dose (ACED).

Gamma Spectrometry analysis

A gamma-ray scintillation spectrometry system was used to measure the natural radionuclides content of the soil samples. The Gamma-ray spectrometer used for this research is the Canberra 7.6cm x 7.6 cm Nal (Tl) detector (Model No. 802-series). The spectroscopic system is connected to Canberra series 10 plus Multichannel Analyses (MCA) (Model No. 1104) through a preamplifier base, which enables data acquisition, storage and display of the acquired spectra. The resolution of the detector is about 8% at 0.662 MeV 137Cs which is capable of distinguishing the gamma-ray energies used for the measurements.

The efficiency calibration of the system was done using a reference soil sample prepared from Rocket dyne Laboratories, California, USA. The reference soil sample is traceable to a mixed standard gamma source (No. 48722-356) by Analytics Inc., Atlanta, Georgia. The net count under each photo peak was related to the specific activity of the radionuclide using the calibration factors obtained for ^{238}U, ^{228}Th and ^{40}K by the following relation (Tzortzis *et al.,* 2003):

$$A_{Ei} = \frac{N_{Ei}}{M_E \times t \times Y \times M_S} \qquad (1)$$

Where A_{Ei} is the specific activities in Bq/kg of a nuclide *i*. N_{Ei} is for peak at energy E,M_E is the detection efficiency at energy, t is the counting of lifetime, Y is the gamma-ray yield per disintegration of specific nuclide for transition at energy *E, and* M_S is Mass in kg of the measured sample.

Each sample was put on the shielded Nal (TI) detector and counted for an accumulating period of 36,000 seconds (10 hours), and a correction was made for the background radiation level. The determination of ^{238}U and ^{232}Th were based on the measurements of photo-peaks from 214Bi (1.76 MeV) and 208TI (2.62 MeV), respectively. The primary decay of ^{40}K (1.46 MeV) was measured directly, just like the work of Chiozzi *et al.,*(2000). The lower limits of detection (LLD) of ^{238}U, ^{232}Th and ^{40}K were determined from the background radiation. The LLD obtained were 4.0, 4.8 and 17.0 Bqkg^{-1} for ^{238}U, ^{228}Th and ^{40}K, respectively (IAEA, 1989).

Features of the Gamma-Ray spectrometer

The work of (Aryal, 2022) revealed the various features and functions of the gamma-ray spectrometer. One of the key functions of the gamma-ray spectrometer is its usage in measuring super high frequencies of radioactive materials emitted during mega-joules energy scenarios such as a high explosion. It compares the intensity of the gamma-ray to the photon energy.

The Gamma-ray spectrometer has the following parts;

The Detectors: These are made up of two major types.

The scintillation sensitive detector: This is capable of responding to ionizing radiations incident on the surface. It is also being applied as one NaI crystal that accepts impurities such as thallium (Tl) to become NaI(Tl). The resulting NaI(Tl) glows improve into a sensitive electric signal through photoelectricity. After that, the photoelectric signals can be converted to detectable signals by a computer. **The semiconductor sensitive detector** works like the radiation sensitive detector. It helps in the conversion of small γ-ray pulses to detectable signals. The forbidden gap which exists between the conduction band and conduction band is the gap to be covered by a promoted electron for it to properly conduct electricity. Hitting a semiconductor with γ –rays will promote electron from valence band to the conduction band and as the conductivity changes, signals can be produced. Example is the doping of pure germanium with lithium to become Ge(Li)

The Electronics Processor: This part of Gamma-ray spectrometer (GRS) process the signals detected into more friendly data that can be analyzed. Example is sorting of pulse.

The Amplifier: This reads out data for audibility
Generally, Gamma-Ray spectrometers are useful in the following areas;

- Structural analyses of nuclear events
- Nuclear changes from one form to another
- Analysis of nuclear reactions
- Research involving space. Example is the detection of water on different planets
- Analyses of elements and isotopes
- GRS provide raw data on the categorization and the availability of chemical elements.

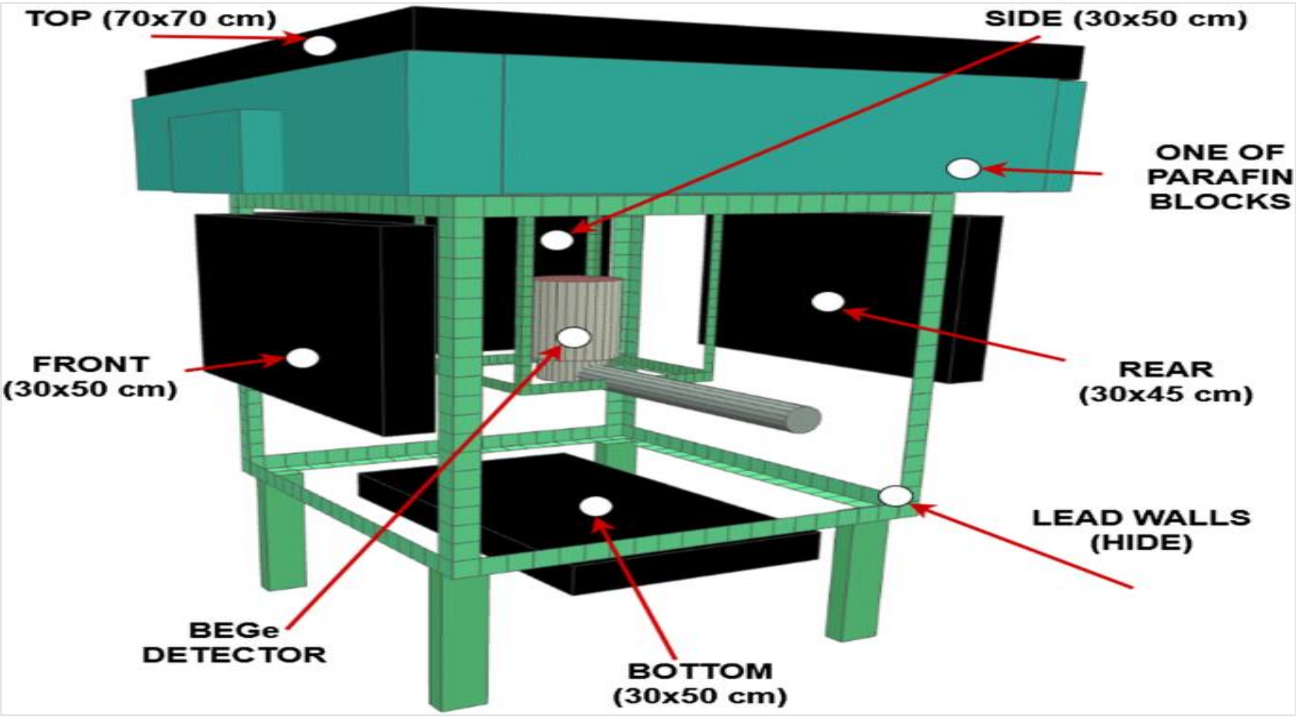

Figure 2: Features of the Gamma-Ray Spectrometer (Jodlowski *et al.*, 2016)

Activity Concentration
The activity concentration is the determination of the standard concentration that effectively measures an identified species in physically combined substances (mixtures) (Adeleye *et al.*, 2020). The chemical ability of the species is determined solely by the activity of the solution (Tzortzis *et al.,* 2003). The activity concentration is measured in Becquerel per Kilogram (BgK^{-1}).

Absorbed Dose Rate (ADR)
The dose rate refers to the intensity of the radionuclides stored in every part of the tissue situated at every location of the body (Inoue *et al.*, 2020). Inoue at al. (2020) emphasized that the ADR is the basis upon which damages done to the tissues or organs of humans can be estimated. This refers to the energy absorbed from radiation per unit mass of a tissue or an organ (Joel *et al.*, 2020). It is expressed in Joules per kilogram (JKg^{-1}). Joules per Kilogram is also known as Gray (Gy). 1 JKg^{-1} = 1Gy, and when a number (n) is given per Gray, we can write that 1n JKg^{-1} = 1nGy (UNSCEAR, 1993).

Therefore, the absorbed dose rate is the energy absorbed (RE) per unit tissue or organ per unit time.

$$ADR = \frac{Radiation\ Energy\ (RE)}{Mass\ of\ tissue/organ\ (M)\ x\ time(T)} \quad (2)$$

The dose rate can be investigated by calculating the variation of activity concentrations of the primordial radionuclides in the soil and the consequent variability of the absorbed dose rate. In the air, the gamma dose rate is measured at one meter above the ground level, and the formula to calculate it is given in equation 2 (UNSCEAR, 2000)

$$ADR(\frac{nGy}{h}) = 0.604A_{Th} + 0.462A_{Ra} + 0.042A_K \quad (3)$$

D = Absorbed dose rate (nGy/h), A_{Th}, A_{Ra} and A_K were activity concentrations of Th-232, U-238 and K-40 ($Bqkg^{-1}$), respectively.

Annual Committed Effective Dose
NORMs ingested by human decreases gradually over time by disintegration through natural means (Nicolov *et al.*, 2020). The ingested radiations are thereafter given out through urine and faeces (body metabolism). The Committed Effective Dose (CED) is the NORMs dose which will be ingested for a determined period of 50 years after ingestion is taken just for the first calendar

year (Chandrashekara *et al*., 2016). This is being utilized as the standard for estimating the effects of internal vulnerability to NORMs by what we consume. The annual committed effective dose (ACED) is the estimated outdoor conversion coefficient of the measurement of the concentrations from Th-232, U-238 and K-40. According to (Lordford*et al.* 2013), the ACED can be determined using equation (3) below.

$$ACED = A_{Ei}\ x\ DCF\ x\ CR \qquad (4)$$

Where ACED = annual committed effective dose, A_C = activity concentration of the radionuclides, DCF = dose conversion factor for ingestion of natural radionuclides and CR = consumption rate of intake of the radionuclides from the foodstuffs. The ACED is expressed in Sievert (Sv) or in millisievert (mSv)

$$\text{ACED} = \frac{CED}{Number\ of\ years}\ \text{in svyr}^{-1}\ \text{or msvyr}^{-1} \qquad (5)$$

RESULTS AND DISCUSSION

Activity concentrations in the foodstuff samples

The activity concentration of samples G1, G2, G3 and G4 were discovered to be the highest when Th-232, U-238 and K-40 were compared. The activity concentration was found to be the highest in G1 for all the considered NORMs. Orosun *et al.* (2018) revealed that high activity concentration could be attributed to the very high contents of the NORMs in the soil from which the food samples were harvested. The P2, R3 and R4 recorded the lowest activity concentration. This can sometimes be attributed to low percentage of NORMs in the ground from which the samples were harvested. Table 1 below shows the activity concentration for all the twenty four (24) food samples.

Table 1: Activity concentration (Ac) of Th-232, U-238 and K-40 for the samples.

Market Day	Sample Name	Sample Code	Th-232 ($Bqkg^{-1}$)	U-238 ($Bqkg^{-1}$)	K-40 ($Bqkg^{-1}$)
1	Beans	B1	4.06±0.48	17.46±3.18	257.72±20.07
	Cassava flour (pupuru)	PU1	2.63±0.33	12.75±2.75	205.48±16.66
	Corn	C1	3.47±0.43	3.95±0.88	206.37±16.38
	Garri	G1	58.21±5.93	41.82±9.48	1854.12±126.83
	Plantain flour	PF1	4.15±0.53	BDL	261.94±20.86
	Rice	R1	2.55±0.32	BDL	154.63±13.10
2	Beans	B2	4.01±0.39	16.30±3.55	257.72±20.11
	Cassava flour (pupuru)	PU2	1.91±0.41	12.91±2.44	201.38±14.65
	Corn	C2	3.23±0.43	3.75±0.99	208.47±15.36
	Garri	G2	49.02±5.02	40.80±9.01	785.22±78.11
	Plantain flour	PF2	5.15±0.43	4.15±0.62	249.94±12.21
	Rice	R2	2.90±0.29	BDL	164.25±12.21
3	Beans	B3	4.02±0.48	17.01±2.49	246.68±18.11
	Cassava flour (pupuru)	PU3	2.43±0.11	12.01±2.11	201.34±14.24
	Corn	C3	3.13±0.23	3.54±0.54	202.42±14.48
	Garri	G3	54.26±6.01	39.47±8.98	902.12±89.68
	Plantain flour	PF3	4.25±0.49	BDL	230.64±19.98
	Rice	R3	2.60±0.32	3.47±0.43	134.72±12.62
4	Beans	B4	4.01±0.28	16.55±2.49	232.67±19.89
	Cassava flour (pupuru)	PU4	2.63±0.21	12.62±2.44	203.11±15.02
	Corn	C4	3.13±0.25	3.62±0.61	205.72±14.98
	Garri	G4	52.25±5.20	38.84±0.56	1096.23±92.45
	Plantain flour	PF4	4.95±0.45	4.02±0.58	252.54±21.21
	Rice	R4	2.72±0.25	3.12±0.39	163.28±12.10
	Average ± S.D		11.74±1.22	12.38±2.27	280.22±30.08

BDL: Below Detection Limit, $Bqkg^{-1}$: Becquerel per Kilogram

The daily average activity concentration with standard deviation was determined to get a clearer picture of all the foodstuffs. The deviation revealed the highest and the lowest values of the (Ac) that can be obtained. Table 2 shows the daily average activity concentration

Table2: Daily Average Activity Concentration

Days	Daily Average Activity concentration (Ac) of Th-232, U-238 and K-40		
Days 1	Th-232(Bqkg^{-1}) ± 1.34 12.51	U-238(Bqkg^{-1}) ± 2.72 12.66	K-40(Bqkg^{-1}) ± 35.65 490.05
Day 2	Th-232(Bqkg^{-1}) ± 1.16 11.04	U-238(Bqkg^{-1}) ± 2.77 12.99	K-40(Bqkg^{-1}) ± 25.44 311.16
Day 3	Th-232(Bqkg^{-1}) ± 1.27 11.78	U-238(Bqkg^{-1}) ± 2.43 12.58	K-40(Bqkg^{-1}) ± 28.19 319.65
Day 4	Th-232(Bqkg^{-1}) ± 1.11 11.62	U-238(Bqkg^{-1}) ± 1.18 13.13	K-40(Bqkg^{-1}) ± 29.28 358.93

Determination of Absorbed Dose Rate

The absorbed dose rate was discovered to be the highest in G-food samples and lowest in R-food samples. This can be due to the high percentage of three naturally occurring radioactive materials (NORMs) considered in this study. It may also be attributed to the high content of the NORMs in the soil from which the G-samples were harvested. The low dose rate in R-samples may be attributed to the low activity concentration in the samples. Table 3 shows the absorbed dose rate for all twenty-four (24) food samples, and Table 4 shows the summary of the absorbed dose rate in similar samples for all the four (4) days.

Table3: Absorbed Dose Rate for the Samples

Market Day	Sample Name	Absorbed Dose Rate (nGyh^{-1})
1	Beans	21.33
	Cassava flour (pupuru)	16.11
	Corn	12.58
	Garri	132.35
	Plantain flour	13.51
	Rice	8.03
2	Beans	20.77
	Cassava flour (pupuru)	15.57
	Corn	12.44
	Garri	81.44
	Plantain flour	15.52
	Rice	8.64
3	Beans	26.84
	Cassava flour (pupuru)	15.48
	Corn	12.03
	Garri	88.90
	Plantain flour	12.26
	Rice	13.03
4	Beans	19.84
	Cassava flour (pupuru)	15.95
	Corn	12.20
	Garri	95.53
	Plantain flour	15.46
	Rice	9.94
	worldwide mean value	55.0

Table 4: Summary of Absorbed Dose Rate in Similar Food Samples

Days	ADR B Sample (nGyh^{-1})	ADR PU Sample (nGyh^{-1})	ADR C Sample (nGyh^{-1})	ADR G Sample (nGyh^{-1})	ADR PF Sample (nGyh^{-1})	ADR R Sample (nGyh^{-1})
1	21.33	16.11	12.58	132.35	13.51	8.03
2	20.77	15.57	12.44	81.44	15.52	8.64
3	26.84	15.48	12.03	88.90	12.26	13.03
4	19.84	15.95	12.20	95.53	15.46	9.94

Table 5: Annual Committed Effective Dose for the Samples

	Sample Name	Annual Committed Effective Dose (mSvy^{-1})		
		Th-232	**U-238**	**K-40**
1	Beans	0.056	0.046	0.096
	Cassava flour (pupuru)	0.073	0.067	0.154
	Corn	0.016	0.004	0.025
	Garri	1.349	0.185	1.158
	Plantain flour	0.019	-	0.033
	Rice	0.047	-	0.077
2	Beans	0.056	0.043	0.094
	Cassava flour (pupuru)	0.053	0.069	0.147
	Corn	0.015	0.003	0.025
	Garri	1.136	0.181	0.476
	Plantain flour	0.024	0.004	0.030
	Rice	0.054	-	0.079
3	Beans	0.056	0.045	0.089
	Cassava flour (pupuru)	0.068	0.064	0.147
	Corn	0.015	0.003	0.026
	Garri	1.257	0.175	0.547
	Plantain flour	0.019	-	0.028
	Rice	0.047	0.012	0.065
4	Beans	0.056	0.044	0.085
	Cassava flour (pupuru)	0.073	0.067	0.148
	Corn	0.015	0.003	0.025
	Garri	1.211	0.017	0.665
	Plantain flour	0.023	0.004	0.031
	Rice	0.050	0.011	0.079
	Mean	**0.241**	**0.044**	**0.180**

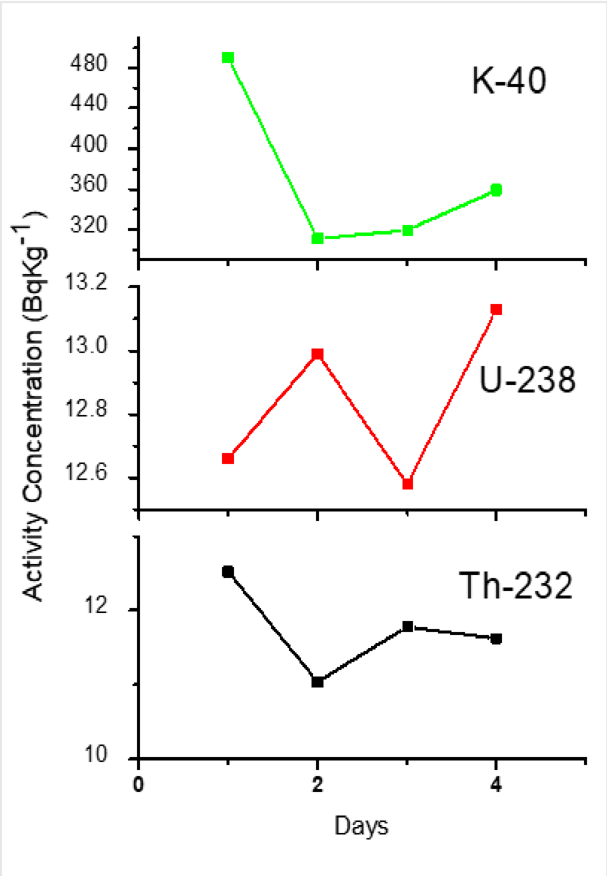

Figure 3: Daily Relationships of the NORMs Activity Concentration

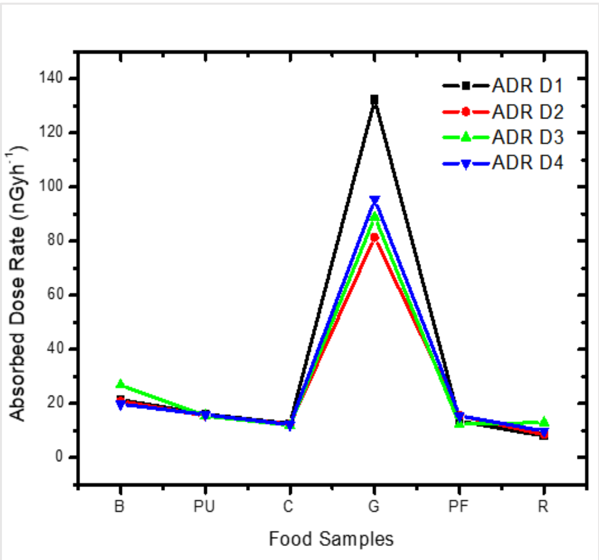

Figure 4: Relationship Between the ADR and the Food Samples Purchased for 4 Days

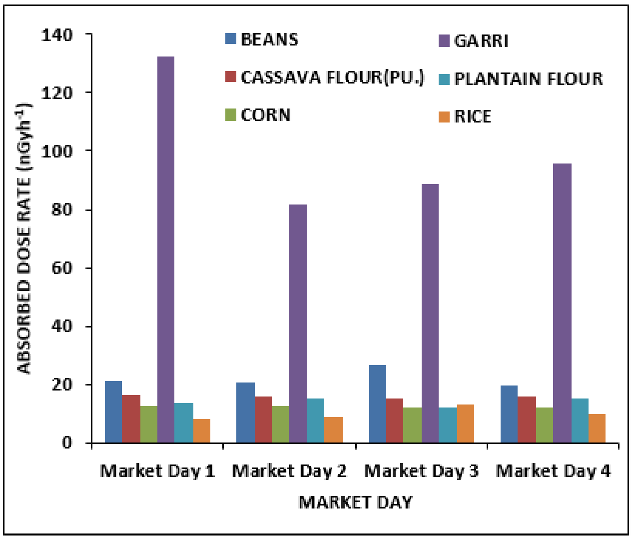

Figure 5: Absorbed dose rate values of radionuclides to the consumers

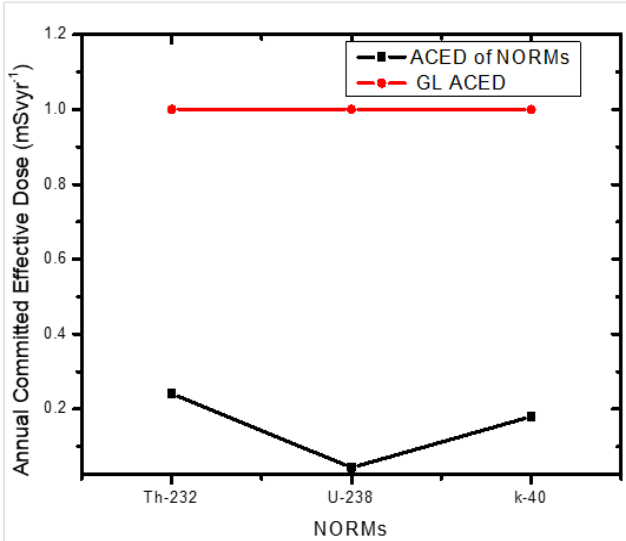

Figure 6: Comparison of the ACED to the Global Limit

Table 1 revealed that the highest value of activity concentration of Th-232 was discovered in sample G1 (58.21±5.93 Bqkg^{-1}), and the lowest was discovered in sample PU2 (1.91±0.41Bqkg^{-1}) with an average value of (11.74± 1.22Bqkg^{-1}). This shows that the activity concentration of Th-232 is below the value of the activity concentration of Th-232 global limit, which is50 Bqkg^{-1} (UNSCEAR, 2000). The highest activity concentration value of U-238 was recorded in sample G1 (41.82±9.48Bqkg^{-1}) and the lowest value in sample R4 (3.12±0.39Bqkg^{-1}) with an average value of (12.38 ± 2.27Bqkg^{-1}). This value is below the activity concentration value of U-238 global limit, which is 33 Bqkg^{-1}. The highest value of the activity concentration of K-40 was discovered in sample G1 (1854.12±126.83 Bqkg^{-1}) and the lowest value in sample R3 (134.72±12.62Bqkg^{-1}) with an average value of (280.22 ± 30.08Bqkg^{-1}). The activity concentration of K-40 is below the value of the activity concentration of K-40 global limit, which is 420 $Bqkg^{-1}$. Figure 3 showed that the activity concentrations of K-40 for days 1, 2, 3 and 4were the highest in all ofthe food samples. The high concentration of K-40 in some of the foodstuffs purchased per day might be responsible for this. It is worth mentioning that the activity concentration of K-40 increases on the first day of sampling. The value surprisingly dropped on day 2 and then gradually increased from day 3 to 4. This fluctuation may be due to the difference in concentrations of K-40 in each of the different soil locations from which the food samples obtained for each were harvested before processing. The low activity concentration of U-238in the first day surprisingly increased in day 2, dropped in day 3 and increased on day 4. This instability in the activity concentration of U-238 for all the four days of sampling may be due to the reason earlier stated. The activity concentrations of Th-232 for all four days were the lowest. This may be attributed to the low concentration of Th-232 in all the twenty-four food samples collected. The concentration of Th-232 is not the same for every location in the study area. Therefore, the activity concentrations for all four days fluctuate based on the percentage of Th-232 in each food sample. This is similar to the work of Shooshtari *et al*., (2017).

The activity concentration of Ra-226 was analyzed in foodstuffs purchased from the market of Ramsar in Iran. Shoostari *et al.* (2017), however, discovered that the activity concentration of NORMs in the foodstuffs considered is less than the acceptable value by UNSCEAR (1993) and concluded that no significant radiation hazard from Ra-226 was posed on the inhabitants of Ramsar from the consumption of the foodstuffs. Canbazoglu and Dogru (2013) studied the activity concentrations of fruits and vegetables commonly consumed by the people in the region of Elazig in Turkey. They, however, discovered that the activity concentration of fruits and vegetables taken by the people of Elazig is less than the global limit and therefore poses no health hazard to inhabitants. Jwanbot *et al*., (2013) examined the activity concentration of soil samples and consumable crops grown in Barkin Ladi Local Government Area, Plateau, North Central, Nigeria. Jwanbot and the other co-authors compared the activity concentration of the soil to that of the food crops. They concluded that the crops did not absorb some percentage of the activity concentration of the soil.

Figures 4 and 5 revealed that the average absorbed dose rate for all food samples, with the exception ofgarri, gives almost the same values for all the four days of sampling. The drop in the ADR of garri follows the trend ADR D1>ADR D4>ADR D3>ADR D2. This may be due to the differences in the concentration of K-40 in each of the four different garri samples, G1, G2, G3 and G4. K-40 may be high in the sample purchased on day 1 and low in the sample purchased on day 2 due to respective high and low concentrations of the radionuclides in G-samples for the two days. The determined absorbed dose rate values for the samples are shown in table 3. The minimum value was obtained from rice (8.03$nGyh^{-1}$) and the highest from garri (132.35$nGyh^{-1}$). The mean value of all absorbed dose rates was obtained to be 28.99$nGyh^{-1}$. It was observed that absorbed dose rate values for all the garri samples were higher than the worldwide limit of 55.0$nGyh^{-1}$(UNSCEAR, 2000) because of very high concentrations of K-40. A high concentration of K-40 in cassava tubers from which garri was produced may be responsible for the increase. This is also a pointer to high concentrations of K-40 in the soils where the tubers were cultivated. All other foodstuff samples gave values that were below the worldwide mean value. Similar work was done by Osanai *et al.* (2021).

As a result of several types of naturally occurring radionuclides released into the environment due to hydrogen explosion in eastern Japan, Osanai *et al.* (2021) compared the standard set for the values of NORMs in foodstuffs by the health ministry to the actual activity concentration and ADR of the NORMs in foodstuffs in Japan. They concluded that the ACED for all the foodstuffs were under 1 mSv/yr, which was the limit set by the health ministry. Osanai *et al.* (2021), however, stated that consuming the considered foodstuffs posed no radioactive harm to the people of Japan. Akkurt and Gunoglu (2014) performed an adequate examination of the possible effects of natural radionuclides in sedimentary rocks located in Turkey. Assessment of sedimentary layers of rocks showed that they harboured some naturally occurring radioactive materials. However, they concluded that the usage and mining of sedimentary rocks in Turkey posed no radioactive harm to people as the ADR of the NORMs in the rocks is less than the acceptable global limit. Measurement of the exhalation rate of radon was done by Kaliprasad *et al.* (2017). It was discovered that the ADR for radon in the study area was less than the global recommended limit. The related ADR of the radionuclide in the soil was determined and found to fall within the acceptable global range. The soil is used for various purposes, such as farming and the construction of buildings and bridges; therefore, Kasiprasad *et al.* (2017) explained the need to ensure the soil is free of NORMs. Examination of the rate of the exhalation of radon showed no significant radiation hazard was posed to the inhabitants of the study area.

Table 5 shows the determined annual committed effective doses of the radionuclides to the consumers of the foodstuff samples. The lowest ACED of Th-232 was from corn witha value 0.015$mSvh^{-1}$ and the highest was from garri with value 1.136$mSvh^{-1}$. The average ACED value for Th-232 is0.241 $mSvh^{-1.}$ The ACED for U-238 recorded the lowest value from corn with value 0.003$mSvh^{-1}$ and the highest from garri with value 0.185$mSvh^{-1}$. The average ACED value for U-238 is 0.044 $mSvh^{-1}$. The lowest ACED value for K-40 was from corn with value 0.025$mSvh^{-1}$ and the highest from garri with value 1.158mSvh^{-1}. The mean ACED value of K-40 is 0.180mSvh^{-1}. The values obtained were below the world limit of 1mSvh^{-1} (ICRP, 2007). Figure 6 revealed that the ACED for Th-232, U-238 and K-40 are less than the global limit. Van *et al.* (2019) compared the Annual Committed Effective Dose Rate (ACED) of foodstuffs consumed by the people of Red River Delta in Vietnam to the ACED of other countries and concluded that the foodstuffs in Vietnam are safe for consumption because the ACEDs estimated for all the NORMs were found to be below the Global Limit of 1 mSv/yr. Absar *et al.* (2021) examine tea leaves' naturally occurring radioactive elements using a Gamma-ray spectrometer. The average annual effective dose rate was estimated and compared with the recommended limit of 1 mSv/yr. The ACED from tea leaves was found to be under the global limit. Drinking of tea from tea leaves was thereafter discovered not to be harmful for people in the study area. Isinkaye *et al.*, (2021) compared locally bred and natural river catfishes by assessing natural radionuclides like k-40, U-238, Ra-226, Th-232 and Ra-228 for the two breeds. Findings from the work of Isinkaye *et al.* (2021) revealed that the ACED obtained for the local and the natural rivers breeds were both within the acceptable global range and limit; therefore, two considered breeds of fishes are safe for consumption (Isinkaye *et al.*, 2021).

CONCLUSION

In conclusion, this study so far showed that the foodstuff samples from Ode-Irele contain Potassium (K-40), Uranium (U-238) and Thorium (Th-232). The absorbed dose rate (ADR) values and annual committed effective dose (ACED) values determined were found to be within the global recommended limits. This implied that the frequently consumed foodstuffs by the people of the community would not pose any significant radiological health risk to them.

CONFLICT OF INTEREST

The authors declare no conflict of interest

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