Nigerian Journal of Theoretical and Environmental Physics (NJTEP)
ISSN Print: 3026-9601
DOI: https://doi.org/10.62292/njtep.v3i2.2025.75
Volume 3(2), June 2025

Naturally Occurring Radionuclides Assessment in Soils of Cassava Mills within the Sedimentary Terrains of Southwestern Nigeria

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ABSTRACT

The assessment of naturally occurring radionuclides in soils, which serve as their primary reservoir, provides essential insights into the soil conditions, offering a detailed understanding of the radionuclides sources, distribution patterns, and potential impacts on both the environment and human health. The activity concentrations of naturally occurring radionuclides Uranium-238 (^{238}U), Thorium-232 (^{232}Th), and Potassium-40 (^{40}K) in representative soil samples obtained from five cassava processing mills (Double Crown, Ekueme, Olorungbogo, Olalandu, and Akewe) in Ilaro metropolis, Southwestern Nigeria, were assessed. Twenty (20) soil samples were collected, air dried, sieved, kept for twenty-eight days, and analyzed using a Sodium Iodide Scintillation NaI(TI) detector. The results revealed the highest mean activity concentrations of ^{40}K in Ekueme, Olorungbogo, Olalandu, and Akewe samples, while Double Crown revealed the highest mean activity concentrations of ^{238}U. Akewe samples showed the highest activity concentrations for all the natural radionuclides, although the values were within permissible limits. The Double Crown, Ekuneme, Olorungbogo, and Olalandu samples had values within the same range and at permissible background radiation levels. Also, the established radium equivalents, absorbed dose rates, annual effective dose equivalents, and external and internal indices for the complete set of soil samples were all below the recommended values. The parameters indicated a low radiation burden on the environment, ensuring the safety of the study area's inhabitants.

Keywords:
Activity concentration,
Cassava mills,
Ilaro,
Radionuclide,
Soils.

INTRODUCTION

Radioactive nuclides, unstable atoms due to their excess nuclear energy, emit new particles from the nucleus. Primordial radionuclides in the Earth's crust due to molten magma formations and weathering spontaneously disintegrate into various daughter nuclides to achieve stable elements (Ojo, 2022; Alaamer, 2008). According to Farai & Jibri (2000), most human exposures to radiation originate from natural radionuclides such as Uranium-238 (^{238}U), Thorium-232 (^{232}Th), and Potassium-40 (^{40}K) and their progenies. The decay chain of these primordial radionuclides emits new particles such as alpha, beta, and gamma radiation, which are significant sources of radiation exposure in the environment. Potassium (^{40}K) is virtually present in all foodstuffs as one of its essential constituents of cellular material (Jibiri et al., 2007). Exposure to radionuclides can harm living organisms, including humans, with an increased risk of cancer being the most common consequence (Kapanadze et al., 2019; Ademola et al., 2014). It is crucial to understand that low levels of exposure occur naturally without harm (Alaamer 2008), but the potential risks associated with radionuclides should not be underestimated. The degree of damage from these radionuclides will depend on the biochemical properties of the elements as well as the level and nature of exposures through ingestion, inhalation, and contact.

High variations in the activity concentrations of naturally occurring radioactivity have increased the extensive radiological surveys in many countries (UNSCEAR, 2000). The studies of natural environmental radioactivity in soils are of great importance because of the public's constant exposure to natural radionuclides at varying degrees depending on the mineral content of rocks in each region of the Earth

(Kapanadze et al., 2019; Obed et al., 2005; Radhakrishna et al., 1993). To assess the potential human health risks from natural radionuclides, the radiation dose estimations and distributions are vital as they could serve as the database for the monitoring of any alterations in the environment (Avwiri, 2005). Radiation measurements and assessments are necessary because radionuclides are not equally spread in the subsurface. So, naturally occurring radionuclides in the soil with activity concentrations higher than the radiological reference concentrations given by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) are harmful to human health. Abdul et al. (2010) opined that humans are usually exposed to radiation from natural environmental radionuclides in two ways: through direct exposure or from the accumulation of radionuclides in the body through food consumption or inhalation.

Exposure to radiation over a long period is associated with adverse health effects, and regrettably, the general populace is unaware of the latent radiological hazards linked with the water and soil they use. This research was borne out of the fact that people farm and dig wells very close to the cassava processing sites, even though the effluent discharging from the processed cassava could promote soil contamination, which would be picked up by the crops grown in such areas. Also, these contaminants can dissolve in the soil and seep into the groundwater, polluting the water the inhabitants use primarily for domestic and irrigation activities. This study, therefore, laid credence to the determination of activity concentrations of natural radionuclides (^{238}U, ^{232}Th, and ^{40}K) in the soils of some cassava processing mills within Ilaro metropolis, Ogun State, Nigeria. The study also assesses the effects of these radionuclides on the inhabitants of the study area, which is situated on the Ilaro formation composed mainly of sedimentary rocks underlain by massive clay and sandy soils (Figure 1). The primary occupation in Ilaro is farming crops such as cocoa, oranges, pineapples, cassava, yam, beans, and vegetables. Another occupation of the inhabitants of Ilaro is the massive processing of cassava into flakes that can be easily used for making traditional meals or dishes such as fufu and gari. This study considered five mills, Double Crown, Ekueme, Olorungbogo, Olalandu, and Akewe (Figure 2), located close to farming and residential plots.

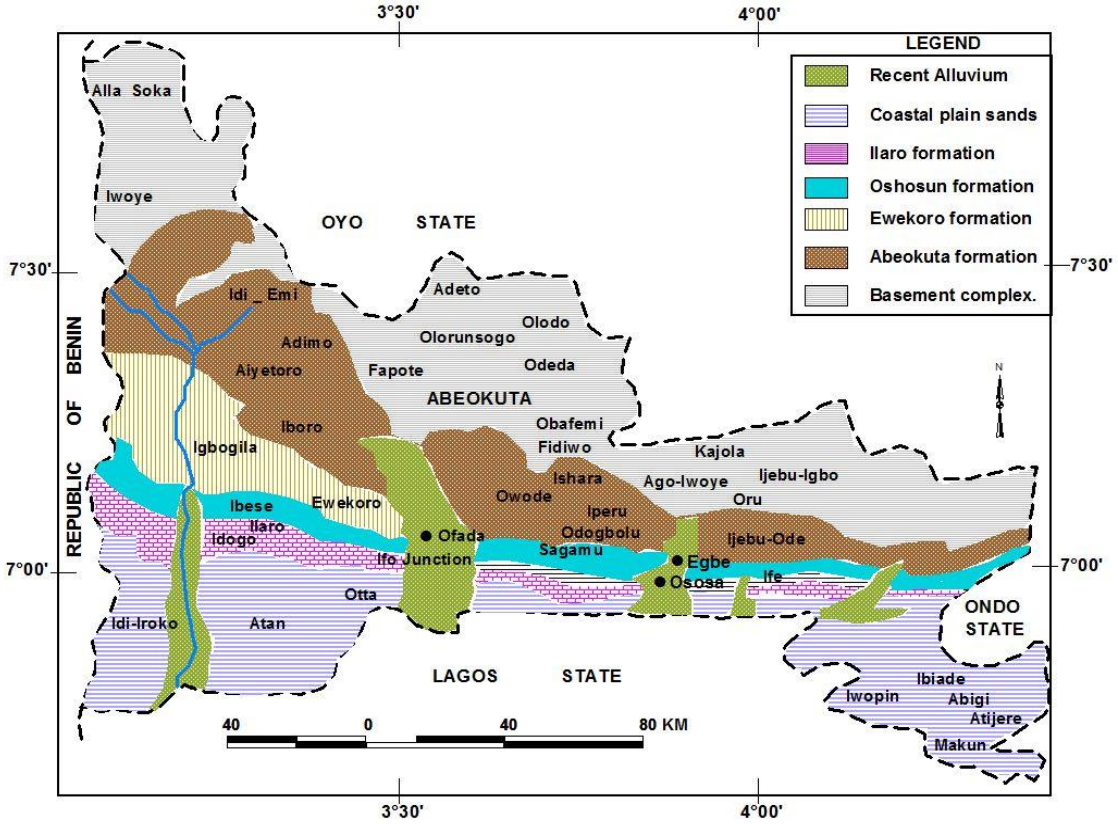

Figure 1: Geological Map of Ogun State showing Ilaro formation (Ojo et al., 2021)

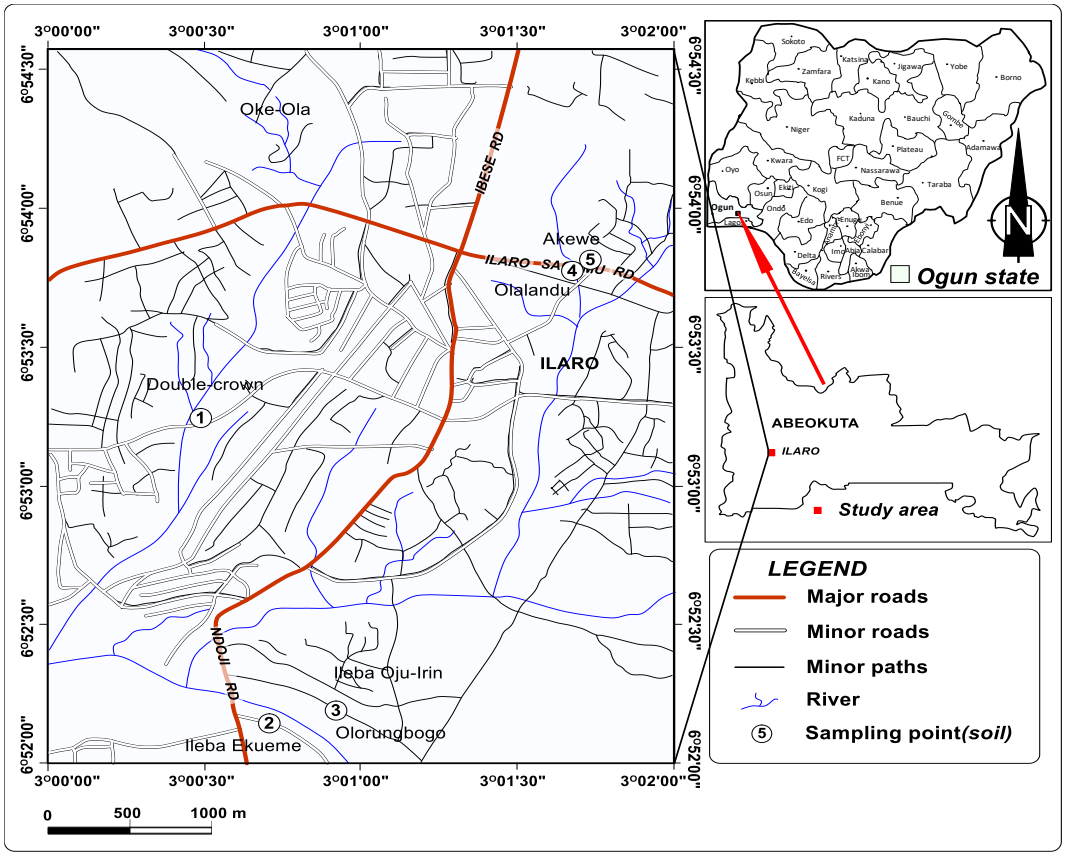

Figure 2: The Location Map of Ilaro showing the Study Areas

MATERIALS AND METHODS

Samples Collection, Preparation and Analysis

To collect soil samples of appropriate particle size, 1.0-1.2 kg of soil was taken at different sampling points in each of the study areas using a soil auger. Hand gloves were used to avoid contamination, and the geo-coordinates were recorded using the GPS. The number of soil samples obtained from each study area depends on its size, and twenty samples were collected in all the study areas. The samples were then sieved in a 2 mm mesh pan in the field to remove extraneous substances which could introduce errors in the results. The post-sieved samples were then filled into small black polyethene bags and numbered serially from S1-S20. Before the measurements of activity concentrations at the Radiation and Health Physics Laboratory, Department of Physics, the Federal University of Agriculture, Abeokuta, Ogun State, Nigeria, the soil samples were air dried for five days in a non-contaminated space in the laboratory. This precise process ensured the removal of any significant moisture in the samples, guaranteeing the accuracy of our results. To obtain uniform grain sizes of the soil for effective counting, a 500 µm mesh was used to sieve approximately 600 g of the soil samples filled into well-labelled white cylindrical plastic containers. The plastic containers were sealed and airtight using paper tape to prevent escape of ^{220}Rn and ^{222}Rn (gaseous radon). Afterwards, the samples were stored and sealed for twenty-eight days to bring the daughter radionuclide into secular radioactive equilibrium with their respective long-lived parents (Ojo, 2022; Bello & Farinre, 2015; Joseph & Nasiru, 2013).

The soil samples were subjected to spectrometric analysis using a Thallium activated Sodium Iodide Scintillation NaI(TI) detector connected to an amplifier and a computer program, MAESTRO, that matched gamma energies to a library of possible isotopes. The cylindrical plastic containers containing the samples were placed on the high geometry 7.6×7.6 cm NaI(TI) detector, shielded by 10 cm thick lead on the top and bottom and 15 cm thick lead on all sides. To reduce statistical uncertainty, the relative efficiency of 33% at 1.33 MeV and energy resolution of 2.0 keV was achieved in the system with 10,800 seconds of counting time (Perez & Pibida, 2004; Gilmore & Hemingway, 1995). The geometry and configuration were maintained throughout the analysis. The standard sources were used for calibration (IAEA, 2009). The activity concentrations of ^{238}U, ^{232}Th, and ^{40}K were determined from the spectra using the net area under the photo

peaks (Equation 1) since the counting rate is proportional to the amount of radioactivity in a sample.

$$\varepsilon(E_\gamma) = \frac{C_{net}}{A \times \gamma} \quad (1)$$

where C_{net} are the net peak counts, γ is absolute gamma decay intensity for the specific energy peak (including the decay branching ratio information) and $\varepsilon(E_\gamma)$ is the absolute full energy peak efficiency of the detector at this particular gamma-ray energy (Joseph & Nasiru, 2013; IAEA, 2009; Mohanty et al., 2004). To obtain the activity concentrations in Bq/kg, the peaks corresponding to 1764.5 KeV for ^{238}U, 2614.5 KeV for ^{232}Th and 1460 KeV for ^{40}K were considered. Also, to determine the background counts, an empty container of exact dimensions as those containing the samples were counted and then subtracted from the gross count.

Energy and Efficiency Calibrations

Identifying the photo peaks displaced in the spectrum generated by the detector is essential for measuring gamma radiation. The energy calibration of the NaI(TI) detector system involves the measurements of mixed standard sources of known radionuclides with well-defined energies provided by the IAEA (2003). The purpose is to establish a synergy between peak positions in the spectra and the corresponding gamma-ray energy (Dovlete & Povinec, 2004). The measured gamma-ray energies are usually used to identify nuclides in the spectra, and the energy calibration must be in the entire energy range of interest. A standard source of 200 ml unsealed 3.1 kBq Eu-155 and Sb-125 was used to calibrate the energy scale. This was carried out before general sample measurement and repeated before each measurement to ensure error-free data. The efficiency calibration links the energies and the gamma-ray detector's absolute total energy peak efficiency (Dovlete & Povinec, 2004). The uncertainty of the efficiency calibration is determined by the statistical uncertainty of the number of counts in the photo peaks and the uncertainty of the nuclear data. The Eu-155 standard source was counted for 600 seconds for the efficiency count of the detector, and the counts in the low-energy photo peaks (60.0, 86.5, and 105.3 keV) were recorded. The number of pulses counted was determined, and the values of detection efficiencies for intrinsic and absolute total efficiencies were estimated.

Radiological Parameters Estimation

Recent studies have shown that the estimation of radiological parameters can be used to obtain reliable conclusions on the health hazard status of irradiation on humans and their immediate environment (Ojo, 2022; Itota & Balogun, 2017; Bello & Farinre, 2015; Avwiri et al., 2013). In this study, the following radiological equivalents were estimated.

Radium Equivalent Activity

Radium equivalent (Ra_{eq}) was used to assess the health hazards associated with soils that contain ^{238}U (^{226}Ra), ^{232}Th and ^{40}K in Bq/kg (UNSCEAR, 2000). The distribution of these radionuclides in soils cannot be uniform, and in order to examine the total exposures of these three radionuclides, their activity concentrations in the samples are combined in terms of radium equivalent (Equation 2) in Bq/kg (Farai & Ademola, 2005; UNSCEAR, 2000).

$$Ra_{eq} = (A_K \times 0.077) + (A_u) + (A_{Th} \times 1.43) \quad (2)$$

where A_u, $A_{Th}$and $A_K$are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq/kg respectively. The published maximal permissible value of Ra_{eq} is 370 Bq/kg (UNSCEAR, 2000; OECD, 1979).

Absorbed Dose Rate

The absorbed dose rate (D) in nGy/hr for soils due to the activity concentrations of ^{238}U, ^{232}Th and ^{40}K, and their dose conversion factors of 0.042, 0.429 and 0.666 respectively can be estimated using Equation 3 derived by Beck et al. (1972).

$$D = 0.042A_K + 0.429A_U + 0.666A_{Th} \quad (3)$$

The published maximal permissible absorbed dose rate is 55 nGy/h (UNSCEAR, 2000).

Annual Effective Dose Rates

The annual effective dose rate measures the radiation risk associated with the air absorbed dose rate of low-level radiation on human tissues. The annual effective dose rates were calculated from the values of D by taking into cognizance the two principal conversion factors given by UNSCEAR (2000). These factors are 0.7 SvGy^{-1} that converts the air absorbed dose into effective dose, and 0.42 (outdoor) and 0.58 (indoor) occupancy factors that presume that workers in the study area resumes work by 8 am and closes 5 pm. The Indoor Annual Effective Dose Rate (IAEDR) and Outdoor Annual Effective Dose Rate (OAEDR) were estimated using equations (4) and (5) respectively.

$$IAEDR(mSvy^{-1}) = D(nGyh^{-1}) \times 8760(hy^{-1}) \times 0.7(SvGy^{-1}) \times 0.58 \times 10^{-6} \quad (4)$$

$$OAEDR(mSvy^{-1}) = D(nGyh^{-1}) \times 8760(hy^{-1}) \times 0.7(SvGy^{-1}) \times 0.42 \times 10^{-6} \quad (5)$$

The average annual effective dose equivalent for both indoor and outdoor annual effective dose equivalents is 0.460 mSv/year (UNSCEAR, 2000).

External Hazard Index

The external hazard index (H_{ex}) is an evaluation of the natural gamma radiation health hazards (Ibrahim, 1999). This index limits the radiation dose to the admissible permissible dose rate of 1 mSvyr^{-1} (Valentin, 2007). The external hazard index equation according to Hewamanna et al. (2001) is given as Equation (6).

$$H_{ex} = \left(\frac{A_u}{740}\right) + \left(\frac{A_{Th}}{520}\right) + \left(\frac{A_K}{9628}\right) \quad (6)$$

2.3.5 Internal Hazard Index

The internal hazard index (H_{in})should be less than unity for the radiation health hazard to be considered normal. Inhalation of some radionuclide is highly hazardous to the respiratory tract, and this hazard can be measured by the internal hazard index (Raghu et al., 2017; Ademola et al., 2014; Ibrahim, 1999) given by Equation (7).

$$H_{in} = \left(\frac{A_U}{185}\right) + \left(\frac{A_{Th}}{259}\right) + \left(\frac{A_K}{4810}\right) \quad (7)$$

RESULTS AND DISCUSSION

Overview of Gamma Spectrometric Results

The activity concentrations of the primordial radionuclides (^{238}U, ^{232}Th and ^{40}K) in the soil samples were presented in Table 1. Also, the mean activity concentrations of the radionuclides compared with their published global averages were shown in Table 2.

Table 1: The activity concentrations of the soil samples

Study Area	Samples	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)
Double Crown	S1	12.31±4.16	17.68±2.73	13.78±4.16
	S2	20.36±6.21	16.68±6.19	17.96±2.72
	S3	19.47±7.52	15.39±2.20	12.42±4.88
	S4	17.54±5.85	18.39±3.28	24.66±5.58
	S5	30.41±1.20	12.80±4.56	24.07±5.52
Ekueme	S6	4.99±3.77	15.39±1.50	10.19±5.08
	S7	19.95±6.07	16.78±4.35	10.87±4.26
	S8	10.56±3.70	19.75±3.89	32.80±5.22
	S9	19.49±5.35	15.77±7.42	27.95±7.82
Olorungbogo	S10	19.55±5.38	13.32±6.70	33.77±6.53
	S11	13.92±5.98	16.13±7.99	9.90±5.53
	S12	17.94±8.16	18.41±6.98	18.63±4.00
	S13	19.09±5.87	10.24±5.99	34.16±5.63
Olalandu	S14	15.53±8.15	15.52±5.89	45.81±6.62
	S15	19.09±6.27	12.50±6.07	23.49±6.57
	S16	12.31±4.16	18.41±5.74	30.28±3.68
	S17	17.94±5.22	12.25±3.80	36.10±3.43
Akewe	S18	8.61±1.73	15.91±3.97	26.98±6.53
	S19	21.97±7.73	18.22±6.56	59.18±3.24
	S20	30.41±1.10	17.39±4.10	25.05±3.93

In Double Crown samples, the activity concentrations of ^{238}U, ^{232}Th and ^{40}K ranged from 12.31±4.16-30.41±1.20, 12.80±4.56-18.39±3.28 and 12.42±4.88-24.66±5.58 Bq/kg, respectively. Also, their mean activity concentrations were 20.02±4.99, 16.19±3.79 and 18.58±4.57 Bq/kg, respectively. In Ekueme samples, the activity concentration of ^{238}U ranged between 12.31±4.16 and 30.41±1.20 Bq/kg with a mean value of 13.75±4.72 Bq/kg; ^{232}Th ranged from 15.39±1.50 to 19.75±3.89 Bq/kg with a mean value of 16.92±4.29 Bq/kg; and ^{40}K ranged between 10.19±5.08 and 32.80±5.22 Bq/kg with a mean value of 20.45±4.48 Bq/kg. In Olorungbogo samples, the activity concentrations of ^{238}U, ^{232}Th and ^{40}K ranged from 13.92±5.98-19.55±5.38, 10.24±5.99-18.41±6.98 and 9.90±5.53-34.16±5.63 Bq/kg, respectively. Their mean activity concentrations were 17.63±6.35, 14.53±6.92 and 24.12±5.42 Bq/kg, respectively. In Olalandu samples, the activity concentrations of ^{238}U ranged between 12.31±4.16 and 19.09±6.27 Bq/kg with a mean value of 16.22±5.95 Bq/kg, ^{232}Th ranged from 12.25±3.80-18.41±5.74 Bq/kg with a mean value of 14.67±5.38 Bq/kg, and ^{40}K ranged between 23.49±6.57 and 45.89±6.62 Bq/kg with a mean value of 33.92±5.08 Bq/kg. In Akewe samples, the activity concentrations of ^{238}U, ^{232}Th and ^{40}K ranged from 8.61±1.73-30.41±1.10, 15.39±1.10-18.22±6.56 and 25.05±3.93-59.18±3.24 Bq/kg respectively, with mean concentrations 20.33±3.52, 17.17±4.88 and 37.07±4.57 Bq/kg.

Table 2: Mean activity concentrations of the soil samples

Study Area	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)
Double Crown	20.02±4.99	16.19±3.79	18.58±4.57
Ekueme	13.75±4.72	16.92±4.29	20.45±4.48
Olorungbogo	17.63±6.35	14.53±6.92	24.12±5.42
Olalandu	16.23±5.95	14.67±5.38	33.92±5.08
Akewe	20.33±3.52	17.17±4.88	37.07±4.57
Global Averages	35	30	400

Generally, the determination of the specific activity concentration of individual radionuclides in the representative soil samples revealed the highest mean activity concentrations of ^{238}U and ^{40}K in the Akewe samples. High concentrations of ^{40}K in study soils were also observed in previous studies by Ojo (2022), Isinkaye & Emelue (2015), Ademola et al. (2014), and Ehirim & Itota (2013). The mean activity concentrations were lower than the published global averages, as shown in Table 2, and these results generally revealed that the radiation level within the study area posed no significant health threats to the inhabitants. The established radiological baselines of the naturally occurring radionuclide distributions in the study samples were estimated to determine potential radiation hazards further, as shown in Tables 3 and 4.

Estimations radiological baselines

The radium equivalents in the study samples were estimated to be lower than the published maximal permissible value of 370 Bq/kg (OECD, 1979). Akewe samples had the highest Raeq values, followed by Double Crown, as indicated in Table 3. Double Crown samples ranged between 42.43±11.09 and 50.55±8.14 Bq/kg, with a mean value of 46.50±9.87 Bq/kg. In Akewe samples, the Ra_{eq} values ranged from 33.43±7.90-54.34±2.96 Bq/kg, with a mean of 46.78±9.41 Bq/kg. Ekueme samples had Ra_{eq} ranging between 22.78±6.30 and 44.78±12.61 Bq/kg with a mean value of 39.52±11.36 Bq/kg. In Olorungbogo samples, Ra_{eq} ranged from 36.36±14.86-45.70±18.44 Bq/kg, with a mean value of 40.43±16.65 Bq/kg, and in samples obtained from Olalandu, the values of Ra_{eq} were between 38.23±10.91 and 41.25±17.08 Bq/kg, with a mean value of 39.80±14.02 Bq/kg. These values indicated normal gamma-absorbed output due to the combination of potassium and uranium in the study samples. The Ra_{eq} activities in the studies of Mehta et al. (2024) and Amanjeet et al. (2017) were low and within the permissible standard, as observed in the study.

The absorbed doses in air as a result of the primordial natural radionuclides in the study samples of Double Crown, Ekueme, Olorungbogo, Olalandu, and Akewe ranged from 17.63±3.78-22.58±3.78, 12.82±2.83-20.19±5.68, 16.44±6.74-20.74±8.32, 17.39±4.91-18.92±7.60 and 15.42±3.66-24.35±1.37 nGyh^{-1}, respectively (Table 3). Also, their average values of 20.15±4.86, 18.03±5.10, 17.75±7.56, 18.16±6.32 and 21.27±4.28 nGyh^{-1}, respectively, were lower than the standard admissible limit of 55 nGyh^{-1}. The absorbed dose rates of soil samples from some dumpsites within Ogun state, Nigeria were estimated by Ojo (2022) and ranged from 7.26-99.12 nGyh^{-1}, which implies that some of the samples had values within the same range as this study samples. The average absorbed doses in samples obtained from dumpsites in Port-Harcourt and Osogbo were 31.98 (Ehirim & Itota, 2013) and 28.80 nGyh^{-1} (Bamidele & Olatunji, 2014), which were within the same range as the study samples. Also, Bello & Farinre (2015) estimated that the mean absorbed dose rate in samples around the dumpsite within Abeokuta, Nigeria, was 55 nGyh^{-1}, higher than the average values obtained in this study.

Table 3: The soil samples radiological parameters

Study Area	Samples	D (nGy/hr)	Ra_{eq} (Bq/kg)	IAEDR (mSvyr^{-1})	OAEDR (mSvyr^{-1})
Double Crown	S1	*17.63±3.78*	*48.20±8.38*	$6.2\times10^{-2}\pm1.3\times10^{-2}$	$4.5\times10^{-2}\pm9.0\times10^{-3}$
	S2	*20.59±6.90*	*45.59±10.84*	$7.3\times10^{-2}\pm2.4\times10^{-2}$	$5.3\times10^{-2}\pm1.8\times10^{-2}$
	S3	*19.13±4.89*	*42.43±11.09*	$6.8\times10^{-2}\pm1.7\times10^{-2}$	$4.9\times10^{-2}\pm1.3\times10^{-2}$
	S4	*20.81±4.93*	*45.74±10.89*	$7.4\times10^{-2}\pm1.8\times10^{-2}$	$5.3\times10^{-2}\pm1.3\times10^{-2}$
	S5	*22.58±3.78*	*50.55±8.14*	$8.0\times10^{-2}\pm1.3\times10^{-2}$	$5.8\times10^{-2}\pm9.0\times10^{-3}$
	Mean	*20.15±4.86*	*46.50±9.87*	$7.1\times10^{-2}\pm1.7\times10^{-2}$	$5.2\times10^{-2}\pm1.2\times10^{-2}$
Ekueme	S6	*12.82±2.83*	*27.78±6.30*	$4.6\times10^{-2}\pm1.0\times10^{-2}$	$3.3\times10^{-2}\pm7.0\times10^{-3}$
	S7	*20.19±5.68*	*44.78±12.61*	$7.2\times10^{-2}\pm2.0\times10^{-2}$	$5.2\times10^{-2}\pm1.5\times10^{-2}$
	S8	*19.06±4.30*	*41.32±9.96*	$6.8\times10^{-2}\pm1.5\times10^{-2}$	$4.9\times10^{-2}\pm1.1\times10^{-2}$
	S9	*20.04±7.57*	*44.19±16.56*	$7.1\times10^{-2}\pm2.7\times10^{-2}$	$5.1\times10^{-2}\pm1.9\times10^{-2}$
	Mean	*18.03±5.10*	*39.52±11.36*	$6.4\times10^{-2}\pm1.8\times10^{-2}$	$4.6\times10^{-2}\pm1.3\times10^{-2}$

Olorungbogo	S10	*16.68±7.04*	*41.91±15.46*	$6.6\times10^{-2}\pm2.5\times10^{-2}$	$4.8\times10^{-2}\pm1.8\times10^{-2}$
	S11	*17.13±8.12*	*37.74±17.83*	$6.1\times10^{-2}\pm2.9\times10^{-2}$	$4.4\times10^{-2}\pm2.0\times10^{-2}$
	S12	*20.74±8.32*	*45.70±18.44*	$7.4\times10^{-2}\pm2.9\times10^{-2}$	$5.3\times10^{-2}\pm2.1\times10^{-2}$
	S13	*16.44±6.74*	*36.36±14.86*	$5.8\times10^{-2}\pm2.4\times10^{-2}$	$4.2\times10^{-2}\pm1.7\times10^{-2}$
	Mean	*17.75±7.56*	*40.43±16.65*	$6.5\times10^{-2}\pm2.7\times10^{-2}$	$4.7\times10^{-2}\pm1.9\times10^{-2}$
Olalandu	S14	*18.92±7.60*	*41.25±17.08*	$6.7\times10^{-2}\pm2.7\times10^{-2}$	$4.9\times10^{-2}\pm1.9\times10^{-2}$
	S15	*17.50±7.01*	*38.77±15.45*	$6.2\times10^{-2}\pm2.5\times10^{-2}$	$4.5\times10^{-2}\pm1.8\times10^{-2}$
	S16	*18.81±5.76*	*40.96±12.65*	$6.7\times10^{-2}\pm2.0\times10^{-2}$	$4.8\times10^{-2}\pm1.5\times10^{-2}$
	S17	*17.39±4.91*	*38.23±10.91*	$6.2\times10^{-2}\pm1.7\times10^{-2}$	$4.5\times10^{-2}\pm1.3\times10^{-2}$
	Mean	*18.16±6.32*	*39.80±14.02*	$6.5\times10^{-2}\pm2.2\times10^{-2}$	$4.7\times10^{-2}\pm1.6\times10^{-2}$
Akewe	S18	*15.42±3.66*	*33.43±7.90*	$5.5\times10^{-2}\pm1.3\times10^{-2}$	$3.9\times10^{-2}\pm9.0\times10^{-3}$
	S19	*24.05±7.82*	*52.58±17.36*	$8.6\times10^{-2}\pm2.8\times10^{-2}$	$6.2\times10^{-2}\pm2.0\times10^{-2}$
	S20	*24.35±1.37*	*54.34±2.96*	$8.7\times10^{-2}\pm4.0\times10^{-3}$	$6.3\times10^{-2}\pm3.0\times10^{-3}$
	Mean	21.27±4.28	46.78±9.41	$7.6\times10^{-2}\pm1.5\times10^{-2}$	$5.5\times10^{-2}\pm1.1\times10^{-2}$

The annual effective dose received due to the presence of radionuclides in the soil samples of Double Crown showed that the IAEDR ranged from 0.062±0.013-0.080±0.013 mSvyr^{-1}, with an average value of 0.071±0.017 mSvyr^{-1} (Table 3). The OAEDR ranged between 0.045±0.009 and 0.058±0.009 mSvyr^{-1} with a mean value of 0.052±0.012 mSvyr^{-1}. These values indicate the average radiation dose a person might receive in a year. Ekueme samples revealed that IAEDR ranged from 0.046±0.010-0.072±0.020 mSvyr^{-1}, while OAEDR ranged from 0.033±0.007-0.052±0.015 mSvyr^{-1}. The IAEDR and OAEDR mean values were 0.064±0.018 and 0.185±0.013 mSvyr^{-1}, respectively. Also, in Olorungbogo samples, the results showed that IAEDR had values between 0.058±0.024 and 0.074±0.029 mSvyr^{-1}, and OAEDR had values ranging from 0.042±0.017-0.053±0.021 mSvyr^{-1}. Their mean values were 0.065±0.027 and 0.047±0.019 mSvyr^{-1}, respectively. Furthermore, in Olalandu samples, the values for IAEDR and OAEDR ranged from 0.060±0.017-0.067±0.027 and 0.045±0.013-0.049±0.019 mSvyr^{-1}, respectively, with their mean values of 0.033±0.045 and 0.047±0.016 mSvyr^{-1}. In Akewe samples, the IAEDR ranged between 0.051±0.013 and 0.087±0.004 mSvyr^{-1}, and OAEDR ranged from 0.039±0.009-0.063±0.003 mSvyr^{-1}. Their mean values were 0.076±0.015 and 0.055±0.010 mSvyr^{-1}, respectively.

The indoor equivalent dose for staying within the cassava mills to work from 8 am to 5 pm is relatively high compared with the outdoor equivalent dose received by the workers and inhabitants of the study area. However, these values are within the published permissible average of 0.460 mSvyr^{-1}, indicating insignificant risks to human beings in the study areas. The values obtained were higher than the average dose equivalent of 0.025 mSvyr^{-1} in Port-Harcourt (Farai et al., 2007) and 0.036 mSvyr^{-1} in Abeokuta, Nigeria (Odunaike et al., 2009). According to Ojo (2022), the mean annual effective doses estimated around four dumpsites ranged between 0.0502 and 0.1038 mSvyr^{-1}, with some values within the dose equivalents obtained in this study.

The H_{ex} and H_{in} in Double Crown samples ranged from 0.052±0.011 - 0.068±0.011 and 0.137±0.034 - 0.219±0.028 mSvyr^{-1}, respectively, with mean values of 0.060±0.015 and 0.175±0.043 mSvyr^{-1} (Table 4). Ekueme samples H_{ex} and H_{in} ranged from 0.037±0.507-0.060±0.022 and 0.105±0.04-0.058±0.018 mSvyr^{-1}, respectively, with the mean values of 0.053±0.024 and 0.144±0.043 mSvyr^{-1}. In Olorungbogo samples, H_{ex} ranged from 0.050±0.020-0.062±0.025 mSvyr^{-1}, while H_{in} ranged from 0.150±0.055-0.172±0.072 mSvyr^{-1}, and their mean values were 0.156±0.062 and 0.055±0.022 mSvyr^{-1}, respectively. Olalandu samples had H_{ex} ranged from 0.050±0.023 - 0.055±0.017 mSvyr^{-1} with an average value of 0.052±0.019 mSvyr^{-1}, and H_{in} ranged from 0.138±0.045 - 0.156±0.059 mSvyr^{-1} with an average value of 0.149±0.051 mSvyr^{-1}, respectively. In Akewe samples, H_{ex} and H_{in} values ranged from 0.045±0.011-0.073±0.022 and 0.114±0.026-0.229±0.011 mSvyr^{-1}, respectively, with mean values 0.181±0.035 and 0.063±0.348 mSvyr^{-1}. The mean external and internal indices for all the representative soils were in the normal range; they were less than the published threshold value of unity, indicating low background radiation.

Table 4: External Hazard Index (H_{ex}) and Internal Hazard Index (H_{in})

Samples	H_{ex} (mSvyr^{-1})	H_{in} (mSvyr^{-1})
S1	$5.2\times10^{-2}\pm1.1\times10^{-2}$	$1.37\times10^{-1}\pm3.4\times10^{-2}$
S2	$6.1\times10^{-2}\pm2.1\times10^{-2}$	$1.78\times10^{-1}\pm5.8\times10^{-2}$
S3	$5.7\times10^{-2}\pm1.5\times10^{-2}$	$1.67\times10^{-1}\pm5.0\times10^{-2}$
S4	$6.2\times10^{-2}\pm1.5\times10^{-2}$	$1.71\times10^{-1}\pm4.5\times10^{-2}$
S5	$6.8\times10^{-2}\pm1.1\times10^{-2}$	$2.19\times10^{-1}\pm2.8\times10^{-2}$
Mean	$6.0\times10^{-2}\pm1.5\times10^{-2}$	$1.75\times10^{-1}\pm4.3\times10^{-2}$
S6	$3.7\times10^{-2}\pm5.0\times10^{-2}$	$8.9\times10^{-2}\pm2.7\times10^{-2}$
S7	$6.0\times10^{-2}\pm1.7\times10^{-2}$	$1.75\times10^{-1}\pm5.0\times10^{-2}$
S8	$5.6\times10^{-2}\pm1.3\times10^{-2}$	$1.40\times10^{-1}\pm3.6\times10^{-2}$
S9	$6.0\times10^{-2}\pm1.7\times10^{-2}$	$1.72\times10^{-1}\pm5.9\times10^{-2}$
Mean	$5.3\times10^{-2}\pm2.4\times10^{-2}$	$1.44\times10^{-1}\pm4.3\times10^{-2}$
S10	$5.6\times10^{-2}\pm2.1\times10^{-2}$	$1.64\times10^{-1}\pm5.6\times10^{-2}$
S11	$5.1\times10^{-2}\pm2.4\times10^{-2}$	$1.39\times10^{-1}\pm6.4\times10^{-2}$
S12	$5.2\times10^{-2}\pm2.5\times10^{-2}$	$1.72\times10^{-1}\pm7.2\times10^{-2}$
S13	$5.0\times10^{-2}\pm2.0\times10^{-2}$	$1.50\times10^{-1}\pm5.5\times10^{-2}$
Mean	$5.2\times10^{-2}\pm2.3\times10^{-2}$	$1.56\times10^{-1}\pm6.2\times10^{-2}$
S14	$5.0\times10^{-2}\pm2.3\times10^{-2}$	$1.53\times10^{-1}\pm6.8\times10^{-2}$
S15	$5.2\times10^{-2}\pm2.1\times10^{-2}$	$1.56\times10^{-1}\pm5.9\times10^{-2}$
S16	$5.5\times10^{-2}\pm1.7\times10^{-2}$	$1.38\times10^{-1}\pm4.5\times10^{-2}$
S17	$5.2\times10^{-2}\pm1.5\times10^{-2}$	$1.52\times10^{-1}\pm4.4\times10^{-2}$
Mean	$5.2\times10^{-2}\pm1.9\times10^{-2}$	$1.50\times10^{-1}\pm5.4\times10^{-2}$
S18	$4.5\times10^{-2}\pm1.1\times10^{-2}$	$1.14\times10^{-1}\pm2.6\times10^{-2}$
S19	$7.1\times10^{-2}\pm2.3\times10^{-2}$	$2.01\times10^{-1}\pm6.8\times10^{-2}$
S20	$7.3\times10^{-2}\pm4.3\times10^{-2}$	$2.29\times10^{-1}\pm1.1\times10^{-2}$
Mean	$6.3\times10^{-2}\pm2.6\times10^{-2}$	$1.81\times10^{-1}\pm3.5\times10^{-2}$

CONCLUSION

The radionuclides (^{238}U, ^{232}Th, and ^{40}K) mean activity concentrations in the representative soil samples were within the global averages. The effluents and organic solid wastes from the cassava mills did not significantly contribute to the radionuclide levels in the soils, and the variations in activity concentrations in the soils could be largely due to the different mineralogical contents of the soil. The radionuclide, ^{40}K, had the highest concentrations in all the soil samples, and Akewe revealed the highest mean activity concentrations of all the natural radionuclides, although the values were still below the recommended safety limits. The established radiological parameters were below the recommended standards and, therefore, showed a very low radiation burden on the environment, and the study areas could be regarded as having permissible levels of natural background radiation.

REFERENCES

Abdul, J., Waheed, A., Arshad S. B., Syed, S. A., Perveen, A., Saeed-Ur-Rehman and Muhammad, I. A. (2010). Measurement of soil radioactivity levels and radiation hazard assessment in southern Rechna interfluvial region, Pakistan. *Environmental Monitoring and Assessment, 169: 429-438.*

Ademola, A. K., Bello, A. K. and Adejumobi, A. C. (2014). Determination of natural radioactivity and hazard in soil samples in and around gold mining area in Hagunmodi, South-Western Nigeria. *Journal of Radiation Research and Applied Science, 7: 249-255.*

Alaamer, A. S. (2008). Assessment of human Exposures to Natural Sources of Radiation in soil of Riyadh, Saudi Arabia. *Turkish Journal of Engineering and Environmental Sciences, 32: 229-234.*

Amanjeet, Kumar, A., Kumar, S., Singh, J., Singh, P. and Bajwa, B. S. (2017). Assessment of natural radioactivity levels and associated dose rates in soil samples from historical city Panipat, India. *Journal of Radiation Research and Applied Sciences, 10: 283e288.* http://dx.doi.org/10.1016/j.jrras.2017.05.006.

Avwiri, G. O. (2005). Determination of Radionuclides Levels in Soil and Water around cement companies in Port Harcourt. *Journal of Applied Sciences and Environmental Management, 9(3):27-29.*

Avwiri, G. O., Osimobi J. C. and Agbalagba E. O. (2013). Natural occurring radionuclide variation with a

soil depth profile of Udi and Ezeagu local government areas of Enugu State, Nigeria. *Working and Living Environmental Protection*, 10(1):53-60.

Bamidele, L. and Olatunji, K.O. (2014). Assessment of Radiation Level of Refuse Dumpsites in Osogbo, Osun State, Southwestern Nigeria. *Nigerian Journal of Physics*, 25(1): 68-70.

Beck, H. L., De campo, J. A., and Gogolak, C. V. (1972). In Situ Ge(Li) and NaI(TI) Gamma-Ray Spectrometry, Report HASL-258. U.S. Atomic Energy Commission, New York.

Bello, R. and Farinre, O. Z. (2015). Assessment of activity concentrations of Radionuclide with Depth in wasteland soils in Abeokuta, Southwest, Nigeria. *Physical Science International Journal*, *5(1): 51-60.*

Dovlete, C. and Povinec, P. P. (2004). Quantification of uncertainty in gamma-spectrometric analysis of environmental samples, in Quantifying Uncertainty in Nuclear Analytical Measurements, IAEA-TECDOC-1401, International Atomic Energy Agency, Vienna. Results of the first worldwide proficiency test of gamma laboratory in Albania.

Ehirim, C. N. and Itota, G. O. (2013). Radiological Impact of a Municipal Solid Waste Dumpsite on Soil and Groundwater using 2-D Resistivity Tomography and Gamma Ray Spectroscopy. *Journal of Environmental Science, Toxicology and Food Technology, 2(5): 35-42.*

Farai, I. P. and Ademola, J. A. (2005). Radium Equivalent Activity Concentrations in Concrete Building Blocks in Eight Cities in South Western Nigeria. *Journal of Environmental Radioactivity*, *79: 119-125.*

Farai, I. P. and Jibiri, N. N. (2000). Baseline studies of terrestrial outdoor gamma dose rate levels in Nigeria. *Radiation Protection Dosimetry, 88: 247-54.*

Farai, I. P., Okwunakwe, C. E. and Makinde, O. S. (2007). Gamma Spectroscopy Assay of Soil Samples from waste Dumpsites in Port-Harcourt, Nigeria. In the Proceedings of the 16th International Conference on Radionuclide Metrology in Cape Town, Elsevier B.V, pp: 850-854.

Gilmore, G. and Hemingway, J. (1995). Practical Gamma-Ray Spectrometry. John Willy & Sons, New York.

Hewamanna, R., Sumithrarachchi, C. S., Mahawatte, P., and Nanayakkara, H. L. C. (2001). Natural radioactivity and gamma dose from Sri Lankan clay bricks used in building construction. *Applied Radiation and Isotopes, 54(2): 365-369.*

IAEA (2003). International Atomic Energy Agency. Guidelines for radioelement mapping wing gamma ray spectrometry data, IAEA-FECDOC-1363, Vienia-Austira.

IAEA (2009). International Atomic Energy Agency. Almera Proficiency Test on the Determination of Radionuclides in Spinach Soil and Water. IAEA-CU-2007-04. Analytical Quality in Nuclear Applications No. IAEA/AQ/3.

Ibrahim, N. (1999). Natural activities of ^{238}U, ^{232}Th, and ^{40}K in building materials. *Journal of Environmental Radioactivity*, *43(3): 255-258.*

Isinkaye, M. O. and Emelue, H. U. (2015). Natural radioactivity measurements and evaluation of radiological hazards in sediment of Oguta Lake, South East Nigeria. *Journal of Radiation Research and Applied Sciences*, 8: 459-469.

Itota, G. O. and Balogun, A. O. (2017). The Radiological Impact of a Municipal Solid Waste Dumpsite on Soil and Groundwater Using Gamma Ray Spectroscopy. *Physical Science International Journal*, *13(4): 1-6.*

Jibiri, N. N., Farai, I. P. and Alausa, S. K. (2007). Activity Concentration of Ra-226, Th-228 and K-40 in Different Food Crops from a High Background Area in Bisichi Jos Plateau State, Nigeria. *Radiation and Environmental Biophysics, 46: 53-59.*

Joseph, E. and Nasiru, R. (2013). Geometry correction in efficiency of a sodium iodide (Thallium Activated), NaI(Tl) detector. *Advances in Applied Science Research, 4(1): 400-406.*

Kapanadze, K., Magalashvili, A. and Imnadze, P. (2019). Distribution of natural radionuclides in the soils and assessment of radiation hazards in the Khrami Late Variscan crystal massif (Georgia). *Heliyon, 5(3): e01377.* https://doi.org/10.1016/j.heliyon.2019.e01377.

Mehta, V., Kumar, A., Shikha, D., Kapil C., Dahiya S., Kumara, S. and Karunakara, N. (2024). Assessment of concentration of radium, thorium, and potassium in soils of Rohtak and Jind districts of Haryana. *Journal of Radioanalytical and Nuclear Chemistry, 333:2987-2997.* https://doi.org/10.1007/s10967-023-09175-x

Mohanty, A. K, Sengupta, D., Das, S. K., Saha, S. K and Van, K. V. (2004). Natural radioactivity and radiation exposure in the high background area at Chhatrapur beach placer deposit of Orissa, India. *Journal of Environmental Radioactivity, 75(1): 15-33.* https://doi.org/10.1016/j.jenvrad.2003.09.004.

Obed, R. L., Farai, I. P. and Jibiri, N. N. (2005). Population dose distribution due to soil radioactivity concentration levels in 18 cities across Nigeria. *Journal of radiological protection, 25: 305-312.*

Odunaike, R. K, Alausa, S. K., Fasunwon, O. O, Orunsolu, B. A. & Ijeoma, G. C. (2009). Radiation dose survey of refuse dumpsites in Abeokuta in Ogun State in the Southwestern Zone of Nigeria. *Research Journal of Environmental Science, 3(2): 262-266.*

OECD (1979). Exposure to radiation from the natural radioactivity in building materials. Report by a group of experts of the OECD Nuclear Energy Agency. Paris, France: Organization for Economic Cooperation and Development.

Ojo A. O., Ogunyinka O. O., Daramola O. O. and Olaoye F. A. (2021). Hydro-chemical and Microbial Assessments of Water Resources around Cassava Mills in a Sedimentary Formation of Ilaro, Southwest Nigeria. *Applied Water Science, 11: 62.*

Ojo, A. O. (2022). Assessment of Naturally Occurring Radionuclide with Depths in the Soils of Selected Dumpsites, Ogun State, Southwestern Nigeria. *Jordan Journal of Physics, 15(4): 383-392.* https://doi.org/10.47011/15.4.7.

Perez, A. A. and Pibida, I. (2004). Performance of CDTE, HDGE and NaI(TI) detectors for radioactivity measurements. *Applied Radiation and Isotopes, 60(1): 41-47.*

Radhakrishna, A. P., Somashekarappa, H. M., Narayana, Y., and Siddappa, K. A. (1993). New natural background radiation area on the southwest coast of India. *Health Physics, 65(4): 390-395.* https://doi.org/10.1097/00004032-199310000-00006.

Raghu, Y., Ravisankar, R., Chandrasekaran, A., Vijayagopal, P., & Venkatraman, B. (2017). Assessment of natural radioactivity and radiological hazards in building materials used in the Tiruvannamalai District, Tamilnadu, India, using a statistical approach. *Journal of Taibah University for Science, 11(4): 523-533.* https://doi.org/10.1016/j.jtusci.2015.08.004.

UNSCEAR (2000). United Nations Scientific Committee on the Effects of Atomic Radiation (Report to the General Assembly). United Nations, New York.

Valentin, J. (2007). The Recommendations of the international commission on Radiological protection in ICRP 103, Elsevier Science publisher, pp: 100-120.