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Assessment of natural radioactivity in mango, the influence of soil radioactivity, its radiation hazard indices and the overall excess lifetime cancer risk

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► ***Original article***

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ABSTRACT

Background: Radionuclide ingestion has raised a global concern due to its radiological implication on man. ***Materials and Methods***: Activity concentration of natural radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in soil, leaf and fruit samples of mango plants from Akure, Nigeria has been estimated using gamma ray spectrometer NaI (Tl) detector. Spectra analyses were performed with the Genie2K spectrometry software, version 2.1 (Canberra industries Inc). ***Results***: The mean activities concentration of ^{40}K, ^{226}Ra and ^{232}Th in soils were 469.72 ± 86.44, 25.17 ± 9.87 and 19.33 ± 6.98 Bq kg^{-1} respectively. The mean activities concentration of ^{40}K, ^{226}Ra and ^{232}Th in leaves were 444.76 ± 89.10, 20.43 ± 7.47 and 17.23 ± 7.39 Bq kg^{-1} respectively. The mean activities concentration of ^{40}K, ^{226}Ra and ^{232}Th in fruits were 439.54 ± 87.39, 18.96 ± 6.80 and 15.43 ± 5.64 Bq kg^{-1} respectively. The mean total absorbed dose rate in air and the mean annual effective dose equivalent for soil sample were estimated at 39.37 ± 11.43 nGy h^{-1} and 48.28 ± 14.01 µSv y^{-1}. ***Conclusion***: The mean radium equivalent, hazard indices and excess lifetime cancer risks (ELCR) through soil exposures are below the world average, but the mean annual effective dose equivalent and ELCR for different age groups, from radionuclide ingestion through mango consumption in the area are above the world average.

INTRODUCTION

The major source of human exposure to ionizing radiation comes from natural radiation in the environment, thus a comprehensive evaluation of exposure from this source constitute an important aspect of the overall assessment of population exposure [1-3]. Radon gas, which is a daughter of radium and uranium poses a health risk not only to uranium miners, but also to homeowners if it is left to accumulate in the home. Radon gas is the largest source of natural radiation exposure [4]. Natural radioactivity is common in the rocks and soil that makes up the planet [5, 6]. ICRP has estimated the probability of having a fatal cancer by relying primarily on the assessment of radiation effects by scientific bodies such as UNSCEAR and BEIR. It then determined what it calls the overall "health detriment" of radiation exposure using all the available risks parameters. In its results, the risk for the entire population is slightly higher than that of workers as a result of differences in certain variables, such as sex and age ranges, that were taken into considerations [5, 7].

Skarlou *et al.,* [8, 9] accessed the transfer of ^{134}Cs from two different soils to olives, oranges and mangoes during a three-year glasshouse pot experiment and obtained that radiocaesium appears to be distributed homogeneously within both plants, with a trend, showing major transfer towards orange fruits. The pulp of mangoes recorded higher radioactivity than the skin, while no ^{134}Cs was present in unprocessed olive oil. The authors then suggested that this trend may be as a result of water soluble caesium compounds being removed during the separation of olive oil [10]. Carini [11] also reported that radionuclide activity concentrations in fruit depend on the yield, and that low yield correlates with high concentrations of radionuclides. The radionuclide concentration in fruit varies with time of ripening. It may increase because of leaf to fruit or soil to fruit transfer of radionuclides, decrease because of growth dilution, and then increase again closer to ripening because of water loss due to ageing [11]. Mango and orange trees were grown in large pots on a calcareous loamy clay and an acid loamy sand soil.

This work has been carried out to estimate the activity concentration of various radionuclides in mango plants and fruits collected from Akure, Nigeria, and determine the resultant influence of soil radioactivity on fruit radioactivity. In addition, the deposition of industrial waste and application of fertilizers which are radiation sources poses a finite

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risk of radiation exposure which could cause an enhanced contamination of the environment.

Mango (*Mangiferaindica*) belongs to the *Anacardiaceae* family, to which cashew nut and some other fruit crops also belong. Mango forms an erect, well-branched and robust evergreen tree with a dense crown. Leaves stay on mango trees for a space of one to three years. Estimation of the activity concentration of mango fruit in the region is of utmost importance due to excessive and indiscriminate consumption of mango in Nigeria. Mango is a major fruit consumed in a large quantity by both young and old during its season. Nigeria is the most populous black nation and the result of its exposure to radiation cannot be overlooked.

MATERIALS AND METHODS

Nine samples were collected for radiological analysis. Three different samples each of soils, leaf and fruit samples were collected from 3 different locations in Akure. The soil samples were collected directly under the mango plants. The leaf and the fruit were collected from the same parent plant. The samples were packaged in labeled bag and were taken to center for energy research and development laboratory, Ile-Ife for analysis. The samples were processed according to the IAEA [12] recommended procedure. The samples were first sundried, then oven-dried at 110^{0}C to constant weight.

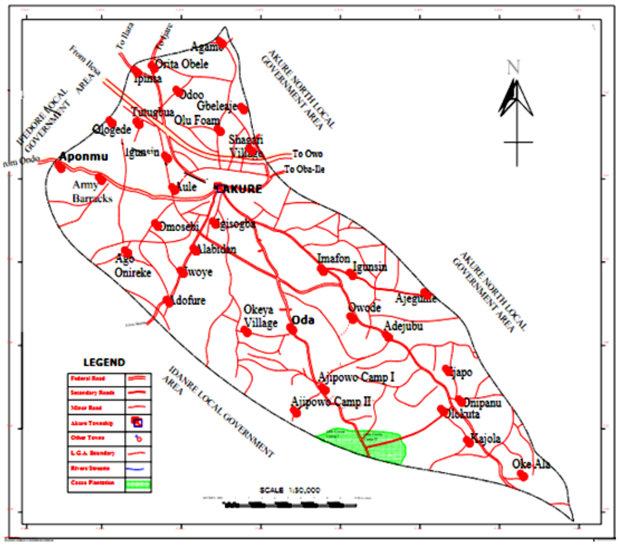

Figure 1. Map of Akure, "Study Area" (13).

The soil samples were pulverized and sieved using a 2 mm mesh screen in order to obtain a fine texture of soil samples. The fruit and the leaf were processed according to the recommended procedure by the IAEA [12]. The samples were first oven dried at 110^{o}C to obtain a moisture free sample and then weighed to obtain the dry weight. The dry plant and fruit samples were charred under a low flame. The samples were then ashed in a muffle furnace at a temperature of 450^{o}C to obtain a uniform white ash. The ashed samples were pulverized and stored in a 250 ml plastic bottle after being weighed and labelled. Equation 1 was used to determine the ash content in the plants [14]:

$$AC\ (\%) = \frac{Ash\ wt}{Dry\ wt}\ x\ 100 \quad (1)$$

Where; AC (%) is the percentage ash content,
Ash wt denotes the Ash weight,
Dry wt denotes the dry weight.

Sample analysis and activity concentration

The well prepared samples were taken to center for energy research and development laboratory, Ile-Ife, Nigeria for spectrometric analysis using gamma ray spectrometer. Soil samples were weighed into a container of known geometry for counting by high resolution gamma-ray spectrometer. Samples that require measurement of radium-226 are mixed with resin before been placed into the measurement container. The samples were allowed to stand for about 28 days to attain secular equilibrium between the parent radionuclides and their progeny before counting by the high-resolution gamma ray spectrometer.

The soils and plant samples were then set for geometry counting and the activity concentrations of natural radionuclides in the samples were determined using the gamma spectrometer [15, 16]. Activity concentration analysis were performed using a 76mm×76mm Sodium Iodide (Thallium doped) NaI (TI) scintillation detector (Canberra, USA). The output of the detector was connected to a Canberra Series 10 plus Portable Multichannel Analyzer (MCA) which recorded the gamma spectra of the soil samples as well as background radiation.

The calibration of the detector was achieved using a 500 cc sand standard radionuclide source, which was prepared using 0.07721 g measured gravimetrically from a master radionuclide solution source already calibrated using the NaI (TI) gamma spectrometric system. The gamma spectrometric analysis was achieved with the aid of a computer program which matched gamma energy at various energy levels to a library of possible isotopes in the energy range. In this study, activity concentration of ^{232}Th in soil was determined by the 911 keV gamma lines of ^{228}Ac while the activity concentrations of ^{226}Ra were determined by the 609 keV gamma lines of ^{214}Bi. The peak areas at 1460 keV was used to determine the activity concentration of ^{40}K.The following expression (equation 2 and 3) were used after applying the Compton corrections as described in IAEA (12); and EML Procedure Manual, [17].

The activity concentrations of radionuclides in soil samples were calculated using equation 2.

$$Activity(A) = (S \pm SD)x\ \frac{100}{E}\ x\ \frac{100}{a}\ x\ \frac{1000}{W_s}\ Bq\ kg^{-1}\ dry\ wt \quad (2)$$

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Similarly, the activity concentrations of radionuclides in ash of plant and fruit samples were calculated using equation 3.

$$Activity(A) = (S \pm SD)x\ \frac{100}{E}\ x\ \frac{100}{a}\ x\ \frac{1000}{W_A}\ x\ \frac{AC\%}{100}\ Bq\ kg^{-1}\ dry\ wt \quad (3)$$

Where;
S = Compton corrected background subtracted counts per second.
SD = Standard deviation due to counting.
E = Photo peak efficiency (%) of the detector.
a = Abundance (%).
W_S = Weight of the soils sample in grams.
W_A = Weight of the ash of biomass sample in grams.
AC% = Percentage ash content of plant sample

Standard radiological indices

The standard radiological indices was carried out to determine the gamma radiation hazards associated with radionuclides in rock and soil samples from the study area. Standard radiation hazard indices were used to evaluate the effects of the radiation on the health of human exposed to radiation and the environments.

Absorbed dose rate in air (ADRA or D)

The total absorbed dose rate in air, D (nGy h^{-1}) which is a resultant effect of a partial evaluation of the radiological hazard posed by the exposure to natural radiation due to the activity concentrations of radionuclides at 1 m above the ground is calculated using equation 4 [18].

$$D = 0.042A_k + 0.462A_u + 0.604A_{Th} \quad (4)$$

Where; A_k, A_U, and A_{Th} are the specific activity in Bq kg^{-1} of ^{40}K, ^{226}Ra and ^{232}Th respectively in the soil sample and 0.042, 0.462 and 0.604 (nGy h^{-1} per Bq kg^{-1}) are the concentration-to-dose conversion factors.

Annual effective dose equivalent (AEDE) for soils

The annual effective dose equivalent (AEDE) derived from the outdoor terrestrial gamma radiation at 1 m above the ground was estimated for the soil samples using an outdoor occupancy factor (OF) of 0.20 and the Dose Conversion Factor (DCF) of 0.70 Sv Gy^{-1} (19). The value was obtained using equation 5.

$$AEDE = ADRA \times DCF \times OF \times T \quad (5)$$

Where; T is duration of time =8760 h. ADRA is the absorbed dose rate DCF is the dose conversion factor OF is the outdoor occupancy factor.

Radium equivalent concentration and hazard indices

Radium equivalent concentration (Ra_{eq})

The radium equivalent is an index used to describe the gamma output from different mixtures of ^{226}Ra, ^{232}Th and ^{40}K in a material. From the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, the radium equivalent was calculated using the equation 6 [20].

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (6)$$

External and internal hazard indices (H_{ex}) and (H_{in})

The external hazard index (H_{ex}) is a concept that was used to evaluate the potential health risk associated with human and gamma radiation emitted by the radionuclides. Meanwhile, the internal hazard index (H_{in}) is a concept that was used to determine the internal exposure of living cell to radon and its products [18]. These indices were determined using equations 7 and 8, [21-23].

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (7)$$

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (8)$$

Annual effective dose equivalent (AEDE) and committed effective dose for mango fruits

The mean annual effective dose equivalent due to the consumption of mango fruit from the area can be estimated using the metabolic model developed by the International Commission of Radiological Protection and the consumption rate given by WHO [24-26], the effective dose equivalent H to a certain tissue T due to intake of natural radionuclide r is given by equation 9:

$$H_{T,r} = \sum(U^i \times C^i_r) \times g_{T,r} \quad (9)$$

Where, i denotes the food/fruit group, the coefficients U^i and C^i_r are the consumption rates in kg y^{-1} and activity concentration of the radionuclide r in Bq kg^{-1}, $g_{T,r}$ respectively, is the dose conversion coefficient for the ingestion of radionuclide r in Sv Bq^{-1} in tissue T.

The committed effective dose to an individual over an average life span of 50 y was estimated using equation 10 [27,28].

$$C_d = 50 \times H_{T,r} \quad (10)$$

$H_{T,r}$ is the effective dose equivalent H to a certain tissue T due to intake of natural radionuclide r.

Excess lifetime cancer risks

The excess lifetime cancer risk is an expression that estimates the probability of an individual developing cancer over a lifetime at a given exposure level. This was calculated and presented as a value representing the number of cancers expected in a given number of people on exposure to a carcinogen at a given dose. It is worth noting that an increase in the ELCR causes a proportionate increase in the rate at which an individual can get cancerous diseases like

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prostate cancer, cancer of the breast, or blood cancer. The estimation of excess lifetime cancer risk (ELCR) was done using the equation 11[29].

$$ELCR = AEDE \times DL \times RF \times 10^{-3} \quad (11)$$

Where; AEDE is the mean annual effective dose equivalent, while DL is the average duration of life (estimated to 45.5 years in Nigeria (30)), Risk Factor is the *RF* in (Sv^{-1}), i.e. fatal cancer risk per Sievert. According to Taskin *et al.* (29) and for stochastic effects, ICRP uses *RF* as 0.05 for the public.

RESULTS

The activity concentrations of the naturally occurring radionuclides has been assessed in the collected and analyzed soil, leaf and fruit samples of mango plants and the results were shown in table 1. The radionuclides detected in all the samples were ^{40}K, ^{226}Ra, and ^{232}Th.

Table 1. Activity concentration of radionuclides in soil, leaf and fruit samples.

Sample	Radioactivity content (Bq kg^{-1})		
	K-40	Ra-226	Th-232
Soil			
Soil 1	502.34 ± 97.95	24.18 ± 8.52	19.76 ± 7.11
Soil 2	423.42 ± 78.74	26.13 ± 11.02	20.13 ± 8.18
Soil 3	483.40 ± 82.64	25.19 ± 10.07	18.09 ± 5.66
Mean	469.72 ± 86.44	25.17 ± 9.87	19.33 ± 6.98
SD	33.64 ± 8.29	0.80 ± 1.03	0.89 ± 1.03
Mangoes leaves			
Leaf 1	477.64 ± 99.18	18.22 ± 6.72	16.38 ± 6.25
Leaf 2	395.24 ± 65.76	21.08 ± 8.12	18.14 ± 8.32
Leaf 3	461.39 ± 102.36	21.99 ± 7.57	17.16 ± 7.60
Mean	444.76 ± 89.10	20.43 ± 7.47	17.23 ± 7.39
SD	35.64 ±16.55	1.61 ±0.58	0.72 ±0.86
Mangoes fruits			
Fruit 1	484.38 ± 88.77	17.15 ± 5.86	15.26 ± 4.86
Fruit 2	386.41 ± 99.03	19.72 ± 8.17	16.20 ± 5.75
Fruit 3	447.82 ± 74.36	20.02 ± 6.37	14.84 ± 6.30
Mean	439.54 ± 87.39	18.96 ± 6.80	15.43 ± 5.64
SD	40.42 ±10.12	1.29 ± 0.99	0.57 ± 0.59

SD = Standard deviation

Activity concentrations of natural radionuclides in soil, leaf and fruit samples

The activity concentration of the three primordial radionuclides were detected in the samples analyzed which includes ^{40}K, ^{226}Ra, and ^{232}Th. ^{40}K has the highest activity concentration in each of the analyzed samples, while ^{232}Th has the lowest concentration. The activity concentrations of ^{226}Ra and ^{232}Th are relatively low compared with that of ^{40}K and this could be due to the fact that, ^{40}K is an essential element required in plant growth and can be enhanced through the application of chemical based fertilizers for planting purposes. Also, ^{226}Ra and ^{228}Ra (daughters of ^{238}U and ^{232}Th respectively), are gases, and hence are not only mobile, but also escaped from the soil matrix since it is an open system [31]. The three primordial radionuclides found in the soil samples were also detected in the leaf and fruit samples, with ^{40}K having the highest mean activity of (444.76±89.10 Bqkg^{-1}) and (439.54±87.39 Bqkg^{-1}), ^{232}Th has the least activity of (17.23±7.39 Bqkg^{-1}) and (15.43 ± 5.64Bqkg^{-1}) while ^{226}R has a concentration of (20.43± 7.47 Bqkg^{-1}) and (18.96 ± 6.80 Bqkg^{-1}) in leaf and fruit of mango respectively. The mean activity concentration is shown in figure 2.

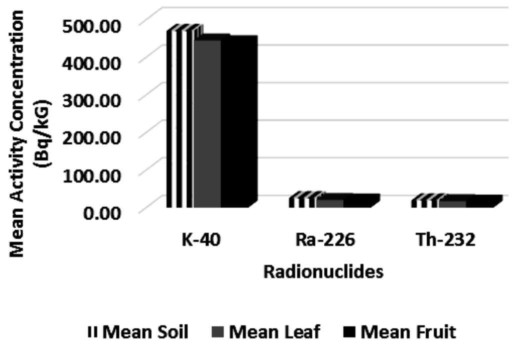

Figure 2. Mean Activity concentration of radionuclides in samples.

Absorbed gamma dose rates and annual effective dose equivalent in soil sample

The absorbed gamma dose rates in air at 1 m above the ground have been estimated for the study area using equation 4. The values for each of the radionuclides were estimated using their respective activities from table 1. The annual effective dose equivalent (Sv/y) due to ingestion of radionuclides from soil samples was calculated using equation 5 and the values were presented in table 2. Figure 3 shows the contributions of absorbed gamma dose rate from radionuclides in soil samples, while figure 4: shows the annual effective dose equivalent in soil samples.

Radium equivalent dose rate and hazard indices in soil samples

The radium equivalent dose rates, the external and the internal hazard indices were estimated using equations 6, 7 and 8 respectively. The estimated values were presented in table 3.

Table 2. Absorbed gamma dose rates and annual effective dose equivalent in soil samples.

Soil Samples	Absorbed Dose Rate in soil(nGyh^{-1})			Total Absorbed Dose Rate in Air (nGyh^{-1})	Annual Effective Dose Equivalent (µSv y^{-1})
	K-40	Ra-226	Th-232		
Soil 1	19.73 ± 3.63	11.63± 4.56	11.68± 4.22	43.04 ± 12.41	52.78 ± 15.22
Soil 2	18.68 ±3.74	9.44± 3.45	10.41± 4.46	38.53 ± 11.65	47.25 ± 14.29
Soil 3	18.46 ±3.67	8.76± 3.14	9.32± 3.41	36.54 ± 10.22	44.81 ± 12.53
Mean	18.96 ±3,68	9.94± 3.72	10.47± 4.03	39.37 ± 11.43	48.28 ± 14.01
SD	0.55± 0.05	1.22± 0.61	0.96± 0.45	2.72 ± 0.91	3.33 ± 1.12

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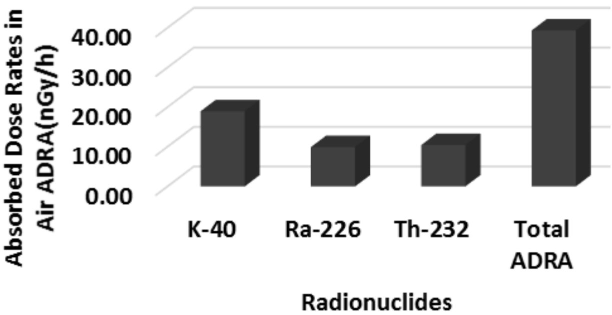

Figure 3. Contributions of absorbed gamma dose rate from radionuclides in soil samples.

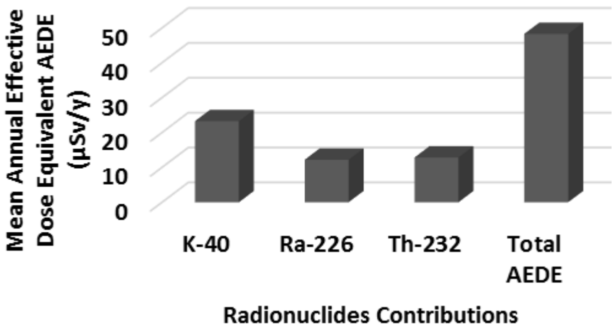

Figure 4. Annual effective dose equivalent in soil samples.

Table 3. Radium Equivalent Dose Rate and Hazard Indices in Soil Samples.

Sample	Radium Equivalent (Bq/Kg)	External Hazard Index	Internal Hazard Index
Soil 1	91.12±26.23	0.25±0.07	0.31±0.09
Soil 2	87.52±28.78	0.24±0.08	0.31±0.11
Soil 3	88.28±24.53	0.24±0.07	0.31±0.09
Mean	88.97±26.51	0.24±0.07	0.31±0.10
SD	1.55 ± 1.75	0.005 ±0.005	0.00 ± 0.01

Annual effective dose equivalents in mango fruits and excess lifetime cancer risk (ELCR)

The variation of the annual consumption rate of mango fruits in a year for different age groups was supplied by WHO [(25)] and shown in table 5 while the ingested dose conversion factor of different radionuclides and for different age groups were supplied by IAEA,[(32)] and presented in table 4.Considering this dose conversion factor and annual consumption of mango, the mean total annual effective dose equivalent from mango fruits were estimated for different age group using equation 9, and the values were presented in table 6.

Table 4. Radionuclides and their ingested dose conversion factor.

Radionuclides	Ingested Dose Conversion Factor Per Age Group					
	(0-1)yr	(1-2)yrs	(2-7)yrs	(7-12) yrs	(12-17) yrs	>17yrs
^{40}K	6.2E-8	4.2E-8	2.1E-8	1.3E-8	7.6E-9	6.2E-9
^{214}Bi	1.4E-9	7.4E-10	3.6E-10	2.1E-10	1.4E-10	1.0E-10
^{214}Pb	2.7E-9	1.0E-9	5.2E-10	3.1E-10	2.0E-10	1.4E-10
^{224}Ra	2.7E-6	6.6E-7	3.5E-7	2.6E-7	2.0E-7	6.5E-8
^{226}Ra	4.7E-6	9.6E-7	6.2E-7	8.0E-7	1.5E-6	2.8E-7
^{228}Ac	7.4E-9	2.8E-9	1.4E-9	8.7E-10	5.3E-10	4.3E-10
^{232}Th	4.6E-6	4.5E-7	3.5E-7	2.9E-7	2.5E-7	2.3E-7

Table 5. Annual Mango Consumption per Age Group.

Age Group (yr)	Annual Mango Consumption (Kg/y)
7-12	1.8E2
12-17	3.0E2
>17	4.3E2

Source: WHO (2003)

Table 6. The Mean Annual Effective Dose Equivalent from Mango Fruit Consumption for Three Different Age Groups.

Age Groups	Mean Annual Effective Dose Equivalent (Sv y^{-1})				ELCR
	K-40	Ra-226	Th-232	Total	
7-12 y	0.001029	0.002731	0.000806	0.004565	0.015978
12-17 y	0.001002	0.008534	0.001158	0.010693	0.037426
>17 y	0.001172	0.002283	0.001526	0.004981	0.017434

The 50 years committed effective dose was estimated for the adult age > 17 years using equation 10, and the value has been given as 0.24905 Sv y^{-1}. Figure 5 shows the mean annual effective dose equivalent in mango fruit samples.

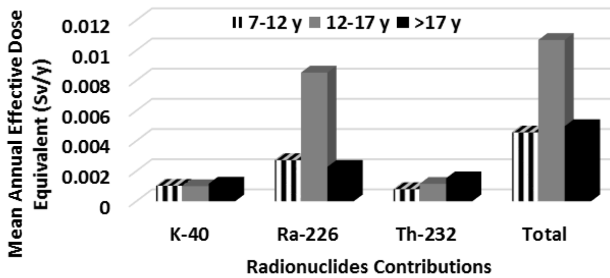

Figure 5. Mean Annual Effective Dose Equivalent in Mango Fruit Samples. The excess lifetime cancer risk (ELCR) for radiation exposure from soil and the ingested radionuclides from the consumption of mango fruit were estimated using equation 11 to be 1.69 x 10^{-4} for soil exposure, and 1.60 × 10^{-2}, 3.74 ×10^{-2} and 1.74 × 10^{-2} for age-groups 7-12 y, 12-17 y and >17 y respectively.

DISCUSSION

The radiation exposure from the primordial radionuclides as reported in the study area is within the permissible limit of 1.0 mSv y^{-1} by ICRP [(7)], which shows that there is no significant health risk from radiation exposure through ingestion or inhalation. The values for the three radionuclides, which followed the same trend both in the soil, leaf and fruit samples with ^{40}K having the highest activity is well expected because it is a naturally occurring radionuclide which abounds in the earth crust. The activity concentration of the soil samples analyzed compared reasonably well with the worldwide average concentrations of 400, 40, 40 Bq $kg^{-1}$for ^{40}K,^{226}Ra,^{232}Th respectively as reported by UNSCEAR, [(19)].

The mean absorbed dose rate from measured activity concentrations in the soil sample is lesser than the world average value of 60 $nGyh^{-1}$ [(18)]. The mean annual effective dose equivalent recorded for the soil sample is lower than the world average value

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of 70 µSvy^{-1} and about 4.8% of the 1.0 mSv y^{-1} recommended by the International Commission on Radiological Protection [7] for members of the public. This implies that the environment does not pose any significant health risk for the inhabitants of the study area.

The radiation and hazard index are lower than the UNSCEAR recommendation of 370 Bq kg^{-1} and 1 respectively [18]. UNSCEAR, [18] recommends that any Ra_{eq} Concentration value that exceeds 370 Bq kg^{-1}, or mean external and internal hazard indices that exceed 1, could pose radiation hazards to human. The overall result implies that there are no significant health risk to the inhabitants of the study area due to environmental radiation and the environment is safe for human habitation. The ratio of radionuclides uptake by fruit samples implies that fruit takes up more potassium than uranium and thorium. Potassium is an essential element needed for plant growth, hence its high uptake ratio is well expected. The activity concentration in the fruits and soils shows a linear dependence and higher concentration in potassium than uranium and thorium.

The mean total annual effective dose equivalent from the consumption of mango fruits by different age groups shows that the age group 12-17 y has the highest effective dose equivalent and are prone to higher radiation hazard than other age group because of its high ingested dose conversion factor. This may arise because this age group are in their growing stage and most of their organs are rapidly developing making it to be more sensitive to radiation exposure.

The excess lifetime cancer risk (ELCR) for radiation exposure from soil shows that the ELCR for soil exposure is lower than the world average of 2.9×10^{-4} [19]. This implies that the radiation exposure through soil channel for the area does not pose any significant health risk on the inhabitant of the area. Nevertheless, the ELCR from the ingested radionuclide through mango fruit consumption is higher for all the age groups than the world average. Reduction in consumption rate of the fruit could help to reduce the exposure rate and thereby lowering the radiological risk involved.

CONCLUSION

The activity concentration of natural radionuclides, (^{40}K, ^{226}Ra, ^{232}Th), in some samples of mango fruit, leaf and soils, from Akure, Nigeria have been measured using gamma ray spectrometer. The activity concentrations have been used to estimate the outdoor absorbed dose rate in the air and resulting radiological implications on the people living in the study area as a result of the fruit consumption. The total absorbed dose rate evaluated from measured activity concentrations in the soil sample were lesser than the world average value of 60 nGyh^{-1}. The hazard indices evaluated are less than 1 and hence the environment is safe for the inhabitants. ELCR from the ingested radionuclide through mango fruit consumption that is higher than the world average .implies that the average annual consumption of mango fruit should be reduced for it to be safe for human consumption. The result of the transfer factors show that mango fruits grown on soils with moderate activity concentration is safer for consumption than the one grown on soils with high activity concentration.

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Conflict of interest: The authors declare that they have no competing interests.
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