Natural radioactivity contents in commonly consumed leafy vegetables cultivated through surface water irrigation in Lagos state, Nigeria

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ABSTRACT

In the industrialized area of Lagos, vegetables are mostly cultivated through surface water irrigation. Untreated surface water has the potential of being contaminated with radionuclides from industrial effluents. This study evaluated the concentration of radionuclides in the leafy vegetables cultivated through surface water irrigation in Lagos metropolis and the potential health risks associated with their consumption. The specific activities of $^{226}$Ra, $^{232}$Th and $^{40}$K in some commonly consumed leafy vegetables were determined using High Purity Germanium (HPGe) detector. To assess the radiation hazards associated with the consumption of these vegetables, annual effective dose (AED) and excess lifetime cancer risk (ELCR) were also determined. The specific activities of $^{226}$Ra, $^{232}$Th and $^{40}$K in the investigated samples ranged from 0.49±0.44 to 6.00±1.19 Bq/kg, with an average value of 2.08±0.59 Bq/kg for $^{226}$Ra, from 0.10±0.07 to 0.61±0.12 Bq/kg with an average value of 0.85±0.08 Bq/kg for $^{232}$Th and from 28.69±3.09 to 126.71±5.86 Bq/kg with an average value of 72.56±13.36 Bq/kg for $^{40}$K. The mean activities of $^{226}$Ra and $^{232}$Th were 40 and 56 times higher than the World Health Organization (WHO) reference values for $^{226}$Ra and $^{232}$Th in leafy vegetables respectively. The AED estimated from the consumption of vegetables was 0.048 mSv/y, which is about 16% of the reference AED value for radionuclides of natural origin in the total diet while leafy vegetable represents about 8% of the total diet of an adult in Lagos. The ELCR obtained from this study was this is lower than the world’s average value. This study has found elevated concentrations of $^{226}$Ra and $^{232}$Th in leafy vegetables, and noticeable increase in AED associated with $^{226}$Ra exposure in the consumption of leafy vegetables cultivated in Lagos. There are therefore potential radiological health risks to the health of the public from long-term consumption of leafy vegetables cultivated through surface water irrigation in Lagos, Nigeria.

KEYWORDS

Natural radioactivity; leaf vegetables; irrigation; effective dose

1. Introduction

Ionizing radiation is an integral part of the environment and everyone is exposed to radiation from natural sources. Radiation exposure, however, varies from one location to another depending on factors such as the type of radionuclides present, local geology, climatic condition, soil type, industrial and agricultural activities.

The knowledge of the behavior, distribution, and concentrations of naturally occurring radionuclides in environmental media are of great importance (Landa, 1980; Ravisankar et al., 2011). Environmental radiation monitoring is crucial to evaluate possible impacts on public health and the natural environment. This monitoring plays a vital role in providing guidelines for the use and management of environmental media such as water, soil, and plants. Further, regulations for controlling the exposure of the public to radionuclides are often dose-based. This is because doses result from the interaction of humans with radionuclides contained in environmental media (air, water, soil, and food). Among the various ways by which humans can get exposed to ionizing radiation, the uptake of radionuclides by agricultural plants that are consumed by humans is one of the most important (Tykva & Sabol, 1995).

Lagos is in the South Western part of Nigeria. It stretches over 180 km along the Guinea Coast of the Bight of Benin on the Atlantic Ocean. It is the smallest state in Nigeria but it is the most populous and most highly industrialized region. Some of the industries in Lagos metropolis use raw materials which contain naturally occurring radionuclide materials (NORM) thereby producing NORM in their wastes. Unfortunately, most of the industries discharge their NORM-containing effluents into the waterways. The continuous discharge of effluents carried through surface runoff will consequently...
lead to gross pollution of the natural resources and environment. Vegetable farming in Lagos metropolis is usually through irrigation and most sources of water for irrigation are untreated surface water (Figure 1). Shortage of land for farming in Lagos metropolis has also led to the use of setbacks along major highways, old dump sites, and the banks of drainage channels for the cultivation of vegetables. These activities could lead to elevated concentrations of NORM in plants. Vegetables are known to be of tremendous nutritional value, sources of vitamins, antioxidants and fibre. They are valuable in energy-limited diets, for example in weight and diabetics management. In Nigeria, green leafy vegetables have widespread acceptance as a dietary constituent and generally forming a substantial portion of the diet, in the preparation of soups and stews in homes (Hart, Azubuike, Barimalaa, & Achinewhu, 2005). The continuous use of untreated-surface water (carrying NORM) for irrigation via spraying will lead to direct contamination of leaves and excessive accumulations in agricultural land.

Agricultural land with high a level of radioactive waste will yield plants with elevated NORM because radionuclides are transported from the soil to the leaves of plants via root uptake and thus affect food quality and safety. The presence of elevated NORM concentration violates one of the three goals of the United Nations for sustainable food security, which is to ensure that all peoples have access to sufficient, nutritionally adequate, and safe food (Jibiri, Farai, & Alausa, 2007).

Although acute radiation effects are rare through ingestion, long-term accumulation, which is non-reversible is more severe as this may result in many health consequences in humans, including cancer. Exposure to carcinogens, including radionuclides through ingestion of foods over a long time will increase the risk of cancers.

The levels of heavy metals in vegetables from Lagos have been investigated and reported (Adeniyi & Owoade, 2009; Adu, Aderinola, & Kusemiju, 2012; Atayese, Eigbadon, Oluwa, & Adesodun, 2011; Ladipo & Doherty, 2011; Sobukola, Adeniran, Odedairo, & Kajihausa, 2009; Yusuf & Oluwole, 2009). The levels of natural radionuclides (238U, 232Th, and 40K) in the soil samples from dumpsites have also been investigated and reported to be higher than the permissible global values (Adeniji, Alatise, & Nwanya, 2013; Oladapo, Oni, Olawoyin, Akerele, & Tijani, 2012). There have been no
reports on the radiological effects on public health from crops cultivated in Lagos metropolis despite the heavy industrial activities and the fact that some farm-lands are former dumpsites.
The aim of this study, therefore, was to determine the concentrations of naturally occurring radionuclides in leafy vegetables, the Annual Effective Dose (AED), and Excess Life Cancer Risk (ELCR) from the consumption of leafy vegetables cultivated through irrigation in Lagos, so as to evaluate the potential radiological health risks associated with the consumption of these vegetables.

2. Materials and methods

2.1. Description of study locations

Major vegetable farms in ten different locations in Lagos metropolis were chosen for this study. These farms are the major suppliers of leafy vegetables to markets and grocery shops in the city. The vegetables are cultivated on these farms mainly through surface water irrigation (Figure 1). These farms are located in Iba Road, Okokomaiko, Dantata, Ibi-Abra, Lekki, Epe, Agbowa, Ikorodu, Ogudu and Alapere, covering Ojo, Ikorodu, Epe, Eti-Osa, Lagos Mainland, Mushin and Kosofe Local Government Areas of the State. The selected farms were bounded by latitude ranging from 6°27’N to 6°40’1.2’N and longitude ranging from 3°16’1.2’E to 3°32’60’E, at an elevation range of 6 to 7 m above sea level (Figure 2) determined by using a high sensitivity hand Global Positioning System (GPS etrex 10 outdoor, Garmin Ltd). All the investigated farms grow vegetables through surface water irrigation using surface water or shallow hand dug wells except those located at Ikorodu and Agbowa that used deep well water.

2.2. Sample collection and preparations

Vegetable sampling was carried out in the dry season, November 2016. The vegetables chosen for this study were the commonly consumed leafy vegetables cultivated through surface water irrigation in Lagos metropolis. The vegetables were Lagos spinach (Celosia argentea), African spinach (Amaranthus hybridus), Jews mallow (Corchurus olitorious), and Spring onion (Allium fistulosum) (see Figure 3). The vegetables collected were those harvested after they reached maturity and ready to be sold for consumption. A total of 75 vegetable samples were collected. These include 23 Lagos Spinach, 22 African Spinach, 13 Jews Mallow, and 17 Spring onion. The size of each farm and the availability type determined the sample size from each location. The collected samples were kept in well-labelled polyethylene bags for identification. The edible parts (leaves) of each sample were separated from the roots and stem. Each sample was thoroughly washed under running tap water to remove dirt, sand, insects and worms and each sample separated for analysis weighed about 800 g fresh weight. They were air dried in plastic trays for about six weeks and subsequently oven dried at a temperature of 100°C for about 1 h to attain constant weight. The samples were pulverized, using laboratory mortar and pestle. Each sample was made to pass through a 1 mm sieve to facilitate homogenization. The sieved samples were weighed using the Ohaus-CS series portable scale and an average of 75 g of each sieved sample was stored in 370 ml polyethylene sampling bottle. Each sample container was hermetically sealed and kept for at least 30 days to attain secular equilibrium between $^{226}$Ra, $^{232}$Th and their progenies.

2.3. Radioactivity measurement

Radioactivity measurements of the samples were carried out using the High Purity Germanium (HPGe) detector. The HPGe detector operates in a very low-temperature environment to reduce thermally generated electronic noise, using liquid nitrogen. This detector is a p-type, 45% relative efficiency, 2 KeV FWHM, resolution at 1.33 MeV Canberra detection system customized for measuring low activity samples. The detector is placed in a low background radiation environment and the detector crystal is surrounded by a 10 cm thick lead castle. The castle has a thin copper lining that attenuates low-energy gamma rays introduced by the lead castle. The system is calibrated regularly with a certified $^{232}$Th ore (IAEARGTh-1), $^{238}$U ore (IAEA/RIU-1), and $^{40}$K$^{2}$SO$^{4}$ (IAEARGK-1) to continuously monitor the centroid of photopeaks and the gamma-ray detection efficiency.

Each sample was placed on the detector and counted for an average of 43,200 sec. (12 h). Background spectra were also collected and the net sample count rate at each energy peak was obtained after subtraction of the corresponding background rate.

The gamma-ray energies used were $^{214}$Pb (351.9 keV), $^{214}$Bi (609.3, 1120 and 1764.5 keV), and $^{226}$Ra (186 keV) to obtain the specific activities of $^{226}$Ra. The gamma-ray energies used for the concentrations of $^{232}$Th were $^{228}$Ac (338.32, 911, 968.97 keV) and $^{208}$Tl (583.19, 860 keV). The specific activities of $^{40}$K were determined directly from its gamma line of 1460.8 keV. Standard nuclear electronics were used to process the signals. The pulses from the amplifier were collected and sorted using the ATOMKI Palmtop software multi-channel analyzer (MCA) installed on a desktop PC.

2.4. Calculations

2.4.1. Specific activity

For all samples, the corresponding specific activities were determined according to the methods of Shanthi, Kumaran, Raj, and Maniyan (2010) as shown in Equation 1.

$$A \left( \frac{Bq}{kg} \right) = \frac{C}{t \times m \times \varepsilon \times P_{V}}$$ (1)
where \( A \) is the specific activity of sample, \( C \) is the net count for the sample in the peak energy range, \( \varepsilon \) is the detector energy dependent efficiency, \( t \) is the counting time in seconds, \( P \) is the gamma-ray yield per disintegration of the nuclides (branching ratio information) and \( m \) is the mass of sample in kg.

### 2.4.2. Daily intake of radionuclide

Equation 2 was used to obtain the daily intake of radionuclides from the consumption of each vegetable as in Choi et al. (2008); Shanthi et al. (2010) with an addition of the \( f \) factor.

\[
\text{Daily intake (mBq)} = \frac{A}{C^2} \times \text{daily consumption rate} \times f
\]  

(2)

where \( A \) is the specific activity of the sample in mBq/kg, daily consumption rate in Kg and \( f \) is the number of days the vegetable is consumed in a week divided by 7 (days in a week).

### 2.4.3. Annual effective dose

The dose received by the public from the consumption of these vegetables was estimated from the total annual effective dose \( AED \) determined using Equation 3 (Ajayi & Adesida, 2009)

\[
AED = \frac{\sum_{i=1}^{n} A_i \times DCF_i \times I_v}{C^2}
\]  

(3)

\( A_i \) (Bq/kg) is the specific activity of radionuclide \( i \), \( DCF_i \) (mSv/Bq) is the dose conversion factor of radionuclide \( i \), \( I_v \) (kg) is consumption rate of the vegetable type. \( DCF \) values are \( 2.8 \times 10^{-7} \), \( 2.3 \times 10^{-7} \) and \( 6.2 \times 10^{-9} \) Sv/Bq for \( ^{226}Ra \), \( ^{232}Th \) and \( ^{40}K \) respectively (Tettey-Larbi, Darko, Cyril, & Appiah, 2013; UNSCEAR, 2000).

### 2.4.4. Excess lifetime cancer risk (ELCR)

Excess lifetime cancer risk (ELCR) was calculated using Equation 4 (Thabayneh & Jazzar, 2012). This was to

![Figure 4. Distribution of \(^{226}\)Ra concentrations in different vegetables according to sites.](image)

![Figure 5. Distribution of \(^{232}\)Th concentrations in different vegetables according to sites.](image)
estimate the potential carcinogenic effects of the long-term consumption of these vegetables,

\[
ELCR = AED \times RF \times DL
\]  

where AED is the annual effective dose, DL is the duration of life (70 years) and RF is the fatal cancer risk factor per Sievert (0.05 for the public).

### 3. Results and discussion

#### 3.1. Radioactivity distribution over the studied vegetables

Activities (fresh mass) of \(^{226}\text{Ra}\), \(^{232}\text{Th}\), and \(^{40}\text{K}\) in Lagos spinach ranged from 0.88 to 2.34 Bq/kg, 0.10 to 0.46 Bq/kg and 34.21 to 123.14 Bq/kg, respectively. In African Spinach, specific activity ranged from 0.49 to 2.98 Bq/kg, 0.12 to 0.54 Bq/kg and 43.53 to 126.71 Bq/kg for \(^{226}\text{Ra}\), \(^{232}\text{Th}\), and \(^{40}\text{K}\), respectively. In Jews mallow, specific activity ranged from 2.57 to 6.00 Bq/kg, 0.18 to 0.61 Bq/kg and 50.28 to 114.55 Bq/kg for \(^{226}\text{Ra}\), \(^{232}\text{Th}\) and \(^{40}\text{K}\), respectively. In Spring onions, specific activity ranged from 1.08 to 4.30 Bq/kg, 0.12 to 0.48 Bq/kg and 28.69 to 56.03 Bq/kg for \(^{226}\text{Ra}\), \(^{232}\text{Th}\) and \(^{40}\text{K}\), respectively.

The variation in the distribution of the mean natural radionuclides (\(^{226}\text{Ra}\), \(^{232}\text{Th}\) and \(^{40}\text{K}\)) concentrations in different vegetables (Figures 4–6) has been attributed to the geology and industrial activities in each location.

Jews mallow was observed to be a good accumulator of \(^{226}\text{Ra}\) as Jews mallow recorded the highest concentrations of \(^{226}\text{Ra}\) in all locations except for Spring onion from Agbowa and Dantata. In general, Spring onion showed a reduced ability for accumulating \(^{40}\text{K}\) as the lowest concentrations of \(^{40}\text{K}\) were recorded from Spring onion. Samples from Okoko had higher concentrations

![Figure 6. Distribution of \(^{40}\text{K}\) concentrations in different vegetables according to sites.](image)

![Figure 7. Average distributions of naturally occurring radionuclides in sampled vegetable.](image)
of $^{232}$Th when compared to the same sample type from other locations followed by African spinach from Ikorodu. The highest mean values of $^{40}$K were recorded in Lagos spinach also from Okoko followed by Jews mallow from Lekki. Okoko is a location that had a metal scrap dump close to the farm and Ikorodu is a location with a lot of industrial activities. The industrial activities around Okoko, Ikorodu could be accountable for the elevated concentrations of natural radionuclides in the vegetables cultivated at these locations.

Although Spring onion from Agbowa and Dantata had the highest concentrations of $^{226}$Ra they recorded the lowest concentrations of $^{40}$K. Jews Mallow from Lekki with a low concentration of $^{226}$Ra had the highest concentration of $^{40}$K. These results indicate that the concentrations of $^{226}$Ra and $^{40}$K are inversely proportional in vegetables.

Table 1 presents the overall average distribution of the radionuclides in the different sampled vegetables. The specific activity of the radionuclides varied by location and also by type of vegetables. In all, the value for $^{40}$K was the highest in the vegetables while, $^{232}$Th was the least (Figure 7). These results are as reported in literature. This is could largely because potassium derived from soil is an essential element for plants metabolism and so plants concentrates $^{40}$K more than $^{226}$Ra and $^{232}$Th. The highest average concentration for $^{226}$Ra was recorded from Jews mallow, the highest mean concentration of $^{40}$K was recorded from African Spinach closely followed by Jews mallow and the highest mean concentration of $^{232}$Th was recorded from Jews mallow followed by African Spinach. Jews Mallow was the best accumulator of studied natural radionuclides.

Table 2 shows the comparison of the mean concentrations of $^{226}$Ra, $^{232}$Th, and $^{40}$K in the studied vegetables. The overall mean values of $^{226}$Ra, $^{232}$Th, and $^{40}$K from all the studied vegetables together were 2.08 ± 0.59 Bq/kg, 0.85 ± 0.08 Bq/kg, and 72.56 ± 5.39 Bq/kg, (fresh mass), respectively. This study recorded the highest mean value for the activity of $^{226}$Ra in leafy vegetables when compared with reported values from similar studies in Portugal, Iran, Korea, India and Egypt. The mean specific activity for $^{226}$Ra obtained in this study was about 40 times greater than the WHO reference value of 0.050 Bq/kg and one to two orders of magnitudes higher than the results of similar studies. The mean specific activity of $^{232}$Th from this study was also one to two orders of magnitudes higher than the values reported from similar studies of Choi et al. (2008), Harb (2015) and Carvalho, Oliveira, and Malta (2016) and about 56 times greater than the WHO reference values of 0.015 Bq/kg for leafy vegetables. The mean specific activity recorded in this study for $^{40}$K was about 50% lower than the result reported by Choi et al. (2008) but about 32% higher than

| Sample Type | Location | $^{226}$Ra (Bq/kg) | $^{232}$Th (Bq/kg) | $^{40}$K (Bq/kg) |
|-------------|----------|-------------------|-------------------|-----------------|
| Lettuce     | Portugal | 0.30 ± 1.63       | 0.02 ± 0.06       | -               |
| Lettuce     | Iran     | 0.06 ± 0.03       | -                 | -               |
| Radish leaves |        | 0.23 ± 0.08       | -                 | -               |
| Tea         |          | 0.73 ± 0.48       | -                 | -               |
| Spinach     | Korea    | 0.156 ± 0.01      | 0.005 ± 0.00      | 185.7 ± 0.67    |
| Lettuce     |          | 0.137 ± 0.01      | 0.002 ± 0.00      | 96.88 ± 0.44    |
| Leafy vegetables | India | 0.03 ± 0.01      | -                 | 49.50 ± 8.4    |
| Lettuce     | Egypt    | 0.18 ± 0.07       | -                 | 59.79 ± 2.10    |
| Jews mallow |          | 0.04 ± 0.03       | 0.02 ± 0.03       | 41.46 ± 1.55    |
| Leafy vegetables | Lagos | 2.08 ± 0.59       | 0.85 ± 0.08       | 72.56 ± 5.36    |
| Ref value   | WHO      | 0.050             | 0.015             | -               |

Table 3. Mean specific activity (dry mass) from all sampled vegetables.

| Vegetable      | Activity concentration (Bq/kg) | $^{226}$Ra | $^{232}$Th | $^{40}$K |
|----------------|--------------------------------|------------|------------|---------|
| Lagos Spinach  | 14.45 ± 3.87                   | 2.80 ± 0.47| 623.84 ± 47.45 |
| African Spinach| 11.55 ± 3.13                   | 2.73 ± 0.62| 647.77 ± 41.91 |
| Jews Mallow    | 17.20 ± 5.65                   | 2.20 ± 0.65| 446.37 ± 38.61 |
| Spring Onion   | 22.99 ± 5.96                   | 2.52 ± 0.62| 416.63 ± 30.85 |

![Figure 8. Relationship between concentrations of $^{40}$K and $^{226}$Ra in vegetables.](image-url)
Comparison of daily intake of naturally radionuclides in leafy vegetables with literature.

The average results reported by Shanthi et al. (2010) and Harb (2015). The high values of specific activities of $^{226}$Ra and $^{232}$Th from this study when compared to their respective reference values are an indication that there are potential health risks with long-term consumption of leafy vegetables cultivated in Lagos metropolis.

Table 3 shows the mean specific activity for the samples using dry mass, a relationship between the concentrations of $^{226}$Ra and $^{40}$K was again observed. This is as earlier observed in Spring onion from Agbowa and Dantata and in Jews Mallow from Lekki. (Figures 4 and 6).

Figure 8 is the graph of the activities of $^{40}$K against $^{226}$Ra using values shown on Table 3. This graph shows a negative correlation in the way vegetables absorbed $^{40}$K and $^{226}$Ra. Vegetables that were good accumulators of $^{226}$Ra were poor accumulators of $^{40}$K and vice versa. This results suggests that if a plant is rich in $^{40}$K, this can reduce the ability for the plant to accumulate $^{226}$Ra. Therefore increasing the concentration of $^{40}$K in the soil, for example, using a fertilizer with high K value on soil could reduce the accumulation of $^{226}$Ra in leafy vegetables.

3.2. Daily intake of naturally radionuclides

Table 5 shows the amount of radionuclides that are ingested daily due to the selected leafy vegetables. The daily intake of radionuclides has been estimated based on the specific activity of each radionuclide, the daily consumption rate of each vegetable (as in seen Table 4) and a factor $f$, which takes care of the frequency per week. The highest values of naturally occurring radionuclides ingested are from the consumption of Jews mallow, followed by African spinach while values from Spring onion are the least.

Table 6 shows the comparison of the estimated daily intake of radionuclides with other similar studies. The average daily intake of $^{226}$Ra, $^{232}$Th, and $^{40}$K from spinach from this study were about 31 times, 210 times and 34% higher than the values reported for spinach by Choi et al. (2008). Comparing the values of total daily intake of $^{226}$Ra and $^{40}$K from this study and values from leafy vegetables in India (Shanthi et al., 2010), values from this study were about 300 and 5 times higher.

3.3. Annual effective dose and excess life cancer risk

The annual effective dose was calculated using the specific activities of the natural radionuclides in the vegetables and the average consumption rate of each vegetable. Information gathered from residents and responses from administered questionnaires provided rate are summarized in Table 4. The total AED from the consumption of vegetables was estimated with the assumption that an adult about consumes about 40 kg of vegetables in Lagos in a year.

Table 7 presents the estimated mean AED and the probability of cancer incidence in the population (ELCR) from each vegetable and from having all these vegetables in the diet of the public. From the estimated AED, the consumption of Spring onions gives the lowest contribution as expected while the highest contributions are from the consumption of Lagos and African Spinach. In this study, $^{226}$Ra was observed to have the highest contribution to the estimated AED closely followed by $^{40}$K, while $^{232}$Th was the least. The estimated annual internal doses from all diets due to normal background radiation sources are 4 $\mu$Sv, 80 $\mu$Sv, and 170 $\mu$Sv for $^{226}$Ra, $^{232}$Th, and $^{40}$K respectively (Bennett, 1995). The AED estimated from $^{226}$Ra, $^{232}$Th, and $^{40}$K were 61%, 4.2 % and 12% of their respective estimated annual internal doses. AED for $^{226}$Ra from the consumption of leafy vegetables alone is over six times the average results reported by Shanthi et al. (2010) and Harb (2015).
times the estimated value for $^{226}\text{Ra}$ from all diet. The contribution of $^{226}\text{Ra}$ to AED, therefore, raises a concern.

Forty kilogramme of leafy vegetables have been estimated to be consumed by an adult in this study while the average dietary intake of an adult per year is 500 kg (UNSCEAR, 2000), leafy vegetables therefore represent only about 8% of the average dietary intake of an adult per year. The total AED from the consumption of vegetables was 0.048 mSv, this is 16% of the recommended value of 0.3 mSv/y due to radionuclides of natural origin in all diet (UNSCEAR, 2000) further investigation is necessary. The ELCR obtained was $0.17 \times 10^{-3}$ this is lower than the world’s average value of $0.29 \times 10^{-3}$ (Thabayneh & Jazjar, 2012). This value, however, implies that there is an added probability of 170 cancer incidence out of a population of one million due to consumption of leafy vegetables cultivated in Lagos metropolis. The values for concentrations of $^{226}\text{Ra}$, $^{232}\text{Th}$ and the total AED from $^{226}\text{Ra}$ obtained from consuming these vegetables are of health concern. The Potential health risks associated with long-term exposure to $^{226}\text{Ra}$ and $^{232}\text{Th}$ include muscular weakness, paralysis, kidney disease, liver disease, cardiovascular disorder, chromosomal aberrations, leukaemia, benign tumours, bone and pancreas cancers, and death.

4. Conclusion

The specific activities of $^{226}\text{Ra}$, $^{232}\text{Th}$, and $^{40}\text{K}$ and their associated AED and ELCR from commonly consumed leafy vegetables cultivated through surface water irrigation have been evaluated. The average specific activities of $^{226}\text{Ra}$ and $^{232}\text{Th}$ in leafy vegetables were found to be 40 and 56 times greater than their respective WHO reference values. The AED from $^{226}\text{Ra}$ was 611% of estimated contribution of $^{226}\text{Ra}$ to annual internal dose from all diets due to normal background radiation sources. Also, concerning derived ELCR values, there is a likelihood of 170 cancer incidence out of a population of one million due to consumption of these leafy vegetables. This study has shown that there is a potential radiological effect on the health of the public from the consumption of vegetables cultivated through irrigation in Lagos metropolis. The use of uncontaminated water for irrigation and locating uncontaminated agricultural lands away from industrial activities in the suburb of Lagos state are possible means through which concentrations of NORM in vegetables can become reduced.

Disclosure statement

No potential conflict of interest was reported by the authors.

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