Evaluation of natural radioactivity levels in soil and various foodstuffs from Delta Abyan, Yemen

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ABSTRACT

The main purpose of this study was to measure the natural radioactivity in some foodstuffs and agricultural soils from the Abyan Delta in Yemen and study the interaction between soil and foodstuffs by calculating the transfer factor (TF). The annual effective doses to individuals were also calculated and compared with the reference levels. The investigation yielded outcomes that can be considered as the initial phase in the computation of levels of radioactivity for a staple foodstuff in Yemen. The activity concentrations of 226Ra, 232Th and 40K were determined by using the high purity germanium (HPGe) gamma ray spectrometer. In agricultural soils, the mean activity concentrations of 226Ra, 232Th and 40K were 33.15 Bq kg⁻¹, 77.25 Bq kg⁻¹, and 1220.59 Bq kg⁻¹, respectively, while the maximum values in foodstuffs were 4.88 ± 0.30, 2.50 ± 0.14 and 351.30 ± 11.25 (Bq Kg⁻¹), respectively. The average TF of 232Th and 40K were lower than the default values of 0.05 and 1.00 respectively, but the average TF value of 226Ra was slightly higher than the reference value of 0.04. The average effective dose to individuals from the intake of the food types was 8.448 μSv y⁻¹, which is much lower than the worldwide average annual effective dose.

1. Introduction

The imperative biological frameworks – including water assets, farming land, woodlands and the climate – decide the intake of human radioactivity. Food is the primary wellspring of radioactive components and in this way of the inward radiation measurement (Ramiza, Hussain, & Nasim-Akhtar, 2010). Radionuclides consumed by means of foodstuff represent a huge segment of the average radiation dosage to different body organs and are likewise a standout amongst the most imperative courses for long term wellbeing contemplations; Radioactivity concentrations may be elevated in local foodstuffs because they could be cultivated in high NORM areas (Fathabadi et al., 2017). Soil radionuclides can enter the food chain by express discharge on leaves or by transfer into parts of plants that are consumable for people and creatures (Nollet & Toldrás, 2012).

The radionuclides discharged into the earth from atomic structures – independent of typical activity or mishap, may lead to potential radiation exposure of the adjacent biota and people. Because of the dry and wet discharge of soil and vegetation, radioactive substances discharged and flowed into the atmosphere enter the earth environment, bringing about contact with people or biota or both; thus, investigation on radionuclides in farming zones is of general concern, the soil situations for farm produce will to a great extent decide the nature of the foodstuff delivered (Asaduzzaman, Khandaker, Amin, & Mahat, 2015). A fundamental feature of soil is its capacity to keep up and store radioactive isotopes over a drawn-out stretch of time. These isotopes can be brought into the earth through different outer sources. The food people eat changes starting with one place, then on to the next, starting with one individual, then onto the next. Averagely happening radionuclides enter the food chain generally from the earth. In this manner, changes in soil radionuclides are the significant wellspring of geographic inconstancy.

Different researchers have demonstrated that plants, vegetables, shrubs, weeds, lichens, fungi, and algae can take in, keep up and store radionuclides (Mahiban, Lenin, Godwin, & Rajan, 2013). The investigation of radionuclides in farming territories is indispensable, as they discover their way into the earth once they have landed; the vast majority of them are reused in the biota similarly as supplements. Radionuclides and soil synergy rely upon the chemical form of the elements and different soil features, including the mineralogical content, PH, organic matter composition and supplement status (Gustav, Peter, Sara, Sara, & Steve, 2013). The take-up of radionuclides relies upon these collaborations and furthermore relies upon the physiological and metabolic characteristics of the species (IAEA [International Atomic Energy Agency], 2006). The plant ingestion changes as well starting with one animal group, then on to the next; thus, the take-up of different foodstuff items is an auxiliary source of inconstancy.

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This investigation was carried out to give a solid radiological database for the volume radionuclides in foodstuffs gathered from the Abyan Delta in Yemen. The outcome of this investigation is proposed to screen the distinctive sorts of food that will permit a superior evaluation of the measurements for the locale’s populace living in the research territory because of the utilization of such food. The transfer factors (TF) from the soil to the distinctive sorts of the foodstuff were likewise evaluated.

2. Material and methods

2.1. Study area

Abyan is situated in the south of Yemen. It broadens roughly 280 km along the shore of the Inlet of Aden, with an inland profundity running from 30 to 70km; the investigation zone is displayed in Figure 1. Abyan is comprised of three noteworthy watersheds: Wadi Bana, Wadi Hassan, and Wadi Alwar. The previous Wadi (Bana and Hassan) had a substantial catchment territory of 7,400 and 3,200 km², respectively. The Spilover gathering at the lower end of the two rubbles was released into the consolidated Bana and Hasan deltas and is called the Abia Delta. The Abyan Delta is an immense plain, at the most astounding point of Bateis (around 170 meters above ocean level), where Wadi Bana enters. The separation from the tip of the delta to the Inlet of Aden is around 30 km, while the base of the delta is around 20 km. It is situated in the north and upper east and comprises a high mountain chain (700 to 1000 m) (Ewea, 2007).

The bedrocks uncovered in the northern piece of the research territory comprise of the center to upper Proterozoic metamorphic and intrusive rocks of the southern piece of the Arab Shield. These metamorphic rocks incorporate metavolcanic, amphibole biotite schists and gneisses, and also higher-standard migmatites. The intrusive rocks incorporate granites and gabbros (KOMEX, 2002).

The expansive catchment zones of the Bana and Hassan Wadis broaden upwards and drain the mountainous landscape. The immediate yearly precipitation in the Abyan delta, in any case, is low and scarcely surpasses 100mm every year. The average yearly rainfall of the Bana and Hassan Wadis are 370 and 250mm. Albeit the two wadis have a substantial catchment zone stretching out to the high precipitation regions, rainfall isn’t adequate for the farming nourished by the rain in the Abyan Delta (Atkins & Binnie, 1984).

2.2. Samples collection and preparation

Food and soil specimen from Abyan Delta, Yemen were gathered and arranged for the testing of regular radioactivity caused by $^{226}$Ra, $^{232}$Th, and $^{40}$K using gamma spectroscopic analysis.

2.3. Soil samples preparation

A sum of 28 topsoil specimen was from different farms in Abyan Delta, Yemen, with a depth of 5cm.
The specimens were gathered utilizing a stainless steel sampler. After the expulsion of stones and inorganic material, the specimen is dried in an oven at around 105°C, then smashed, ground to a fine powder, and homogenized by going through a 1 mm sieve, which is the best size for substantial minerals (Mavi & Akkurt, 2010). The specimen was set in a plastic holder 75 mm in diameter and 90 mm in height, permitted to remain for almost a month to accomplish a secular equilibrium in the vicinity of $^{226}\text{Ra}$ and inert gas radon ($^{222}\text{Rn}$) and its decay products, and afterward checked utilizing a gamma-beam spectrometer. Relying on the radionuclide quantity, the specimen is estimated after 12–24 hours.

2.4. Foodstuff samples

An aggregate of 28 specimens was gathered (from ten unique types: sorghum, corn, millet, onion, radishes, peanuts, arugula, mallow, and coriander). The specimens were cleaned with consumable water and distilled water and dried under sunlight and after that in a 50°C oven. At that point, they were ground into powder in the research facility and the powder was homogenized utilizing a sieve. Regularly, 250 cm$^3$ of each specimen was put in plastic compartments with measurements of 64 mm in breadth and a height of 80 mm. The specimens were weighed and kept for at least one month to enable the daughter products to enter secular equilibrium with their parents $^{226}\text{Ra}$ and $^{232}\text{Th}$ and after that estimated for 18–24 h based on the quantity of the radionuclides. Pollution of the food chain happens because of the immediate release of these radionuclides in the leaves of the plant, the assimilation of radionuclides root from tainted soil or water.

2.5. Radioactivity measurement

All specimens were estimated in the nuclear physics laboratory in the physics department of the Faculty of Sciences of the University of Assiut using a gamma-ray spectrometer with an HPGe GR4020 model and a multichannel analyzer of 16,384 channels. The identifier has closed coaxial gamma-ray detectors (type p) made out of high purity germanium (HPGe) in a vertical arrangement cooled by liquid nitrogen with the accompanying details: The detector has a relative efficiency of 40% and an energy resolution of 2 keV (FWHM) for the 1.332 MeV gamma-ray transition of $^{60}\text{Co}$. The germanium detector is inside a lead shield to diminish the environmental background with the accompanying details: 9.5mm (3/8 in) external jacket, thick, coarse carbon steel guard of 10 cm (4 in), low thickness background and slow coating of 1 mm (0.040 inches) of tin and 1.6mm (0.062 inches) of copper (Canberra, 2013).

The system was calibrated by both energy and efficiency. The calibration of the energy was done by the procurement of a spectrum of radioactive standards of known energies, for example, 137Cs (662 KeV) and 60Co (1332 and 1172 KeV). For the calibration of the efficiency, Canberra’s Geometry composer was utilized rather than the standard source (Canberra, 2013).

The spectra have been evaluated using the PC program Canberra’s Genie2000 for the estimation of natural radioactivity.

The radioactivity concentration of $^{226}\text{Ra}$ was resolved from the photopeaks of $^{214}\text{Pb}$ (295.22, 351.93 KeV) and $^{214}\text{Bi}$ (609.31, 1120.29, 1764.49 KeV). The $^{232}\text{Th}$ concentration was resolved from the $^{228}\text{Ac}$ photopeaks (911.2, 968.97 KeV), $^{232}\text{Pb}$ (238.63 KeV) and $^{208}\text{Ti}$ (583.19, 2614 KeV), while $^{40}\text{K}$ was resolved from the 1460.8 keV photopeak.

3. Results and discussion

3.1. Activity concentrations of radionuclides in foodstuffs

The activity concentrations of $^{226}\text{Ra}$, $^{232}\text{Th}$, and $^{40}\text{K}$ were ascertained in various sorts of foodstuff specimens from the ranches of the Abyan Delta in Yemen (Table 1). Table 1 shows significant variations between the average activity concentrations of $^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$ in the examined foodstuffs, where the average estimations of $^{226}\text{Ra}$ fluctuate between 0.69 ± 0.05 Bq kg$^{-1}$ (Radish) and 3.63 ± 0.25 Bq kg$^{-1}$ (Maize), the average estimations of $^{232}\text{Th}$ fluctuate between 0.44 ± 0.02 Bq kg$^{-1}$ (Radish) and 2.03 ± 0.13 Bq kg$^{-1}$ (Maize) while the average estimations of $^{40}\text{K}$ fluctuate between 91.43 ± 2.93 Bq kg$^{-1}$ (Pearl (cattail) millet) and 305.14 ± 9.77 Bq kg$^{-1}$ (Peanut).

From Table 1, the accompanying perceptions can be made:

- The highest activity concentration of $^{226}\text{Ra}$ was seen in peanuts, with an estimation of 4.88 Bq kg$^{-1}$, while the least estimate was seen in radish with an estimation of 0.62 Bq kg$^{-1}$.
- The most noteworthy activity concentration of $^{232}\text{Th}$ was seen in Maize with an estimation of 2.50 Bq kg$^{-1}$, while the least estimate was seen in Jew’s mallow with an estimation of 0.36 Bq kg$^{-1}$.
- The most noteworthy activity concentration of $^{40}\text{K}$ was seen in peanuts, with an estimation of 351.30 Bq kg$^{-1}$, while the least estimate was seen in Pearl or Cattail millet was 75.84 Bq kg$^{-1}$.
- In all specimens, the average activity concentration of $^{40}\text{K}$ in these foods is considerably
higher than $^{226}$Ra and $^{232}$Th. This might be expected to a limited extent to the expanded utilization of NPK fertilizers to improve crop yields after agriculturists experienced soil deterioration in the locale following decades of mining activities (Murtadha, Mohamad, & Najeba, 2017).

### 3.2. Comparison of activity concentrations of foodstuff samples with similar studies

Table 2 shows the comparison of $^{226}$Ra, $^{232}$Th, and $^{40}$K activity concentrations (Bq kg$^{-1}$) of the different food specimen under scrutiny and contrasts it with different values in the world. Table 2 demonstrates that the $^{226}$Ra activity concentration of the cereal/

### Table 1. Activity concentrations of different types of foodstuff from Abyan Delta, Yemen.

| S. No. | Type of foodstuff | $^{226}$Ra (Bq kg$^{-1}$) | $^{232}$Th (Bq kg$^{-1}$) | $^{40}$K (Bq kg$^{-1}$) |
|--------|-------------------|---------------------------|--------------------------|--------------------------|
| 1      | Sorghum 1         | 3.76 ± 0.24               | 1.67 ± 0.09              | 112.23 ± 3.60            |
| 2      | Sorghum           | 1.99 ± 0.16               | 1.73 ± 0.11              | 126.90 ± 3.04            |
| 3      | Sorghum 3         | 2.89 ± 0.21               | 1.70 ± 0.10              | 118.89 ± 3.81            |
| 4      | Sorghum 4         | 1.80 ± 0.15               | 1.43 ± 0.08              | 233.15 ± 7.47            |
| M.Value|                   | 2.61 ± 0.19               | 1.63 ± 0.09              | 147.54 ± 4.73            |
| 5      | Maize 1           | 1.79 ± 0.14               | 1.75 ± 0.14              | 164.07 ± 5.26            |
| 6      | Maize 2           | 2.02 ± 0.16               | 2.07 ± 0.13              | 201.60 ± 6.30            |
| 7      | Maize 3           | 3.87 ± 0.25               | 1.78 ± 0.12              | 175.47 ± 5.62            |
| 8      | Maize 4           | 4.30 ± 0.26               | 2.50 ± 0.14              | 212.05 ± 6.80            |
| M.Value|                   | 3.63 ± 0.25               | 2.03 ± 0.13              | 188.30 ± 6.03            |
| 9      | Pearl (catail) millet 1 | 2.31 ± 0.19 | 1.55 ± 0.10        | 111.59 ± 3.58 |
| 10     | Pearl (catail) millet 2 | 2.02 ± 0.16 | 1.27 ± 0.05        | 75.84 ± 0.43 |
| 11     | Pearl (catail) millet 3 | 2.36 ± 0.25 | 2.34 ± 0.14        | 80.54 ± 2.59 |
| 12     | Pearl (catail) millet 4 | 2.74 ± 0.22 | 1.90 ± 0.12        | 97.74 ± 3.14 |
| M.Value|                   | 2.58 ± 0.21               | 1.76 ± 0.10              | 91.43 ± 2.93            |
| 13     | Onion 1           | 1.07 ± 0.07               | 0.63 ± 0.03              | 125.05 ± 4.00            |
| 14     | Onion 2           | 1.06 ± 0.06               | 0.47 ± 0.03              | 115.71 ± 3.70            |
| 15     | Onion 3           | 1.07 ± 0.07               | 0.54 ± 0.03              | 120.15 ± 3.85            |
| M.Value|                   | 1.06 ± 0.07               | 0.55 ± 0.03              | 120.30 ± 3.85            |
| 16     | Radish 1          | 0.69 ± 0.05               | 0.48 ± 0.03              | 119.12 ± 3.81            |
| 17     | Radish 2          | 0.76 ± 0.05               | 0.44 ± 0.02              | 101.69 ± 3.26            |
| 18     | Radish 3          | 0.62 ± 0.04               | 0.39 ± 0.02              | 113.01 ± 3.62            |
| M.Value|                   | 0.69 ± 0.05               | 0.44 ± 0.02              | 113.01 ± 3.62            |
| 19     | Peanut 1          | 4.88 ± 0.30               | 1.90 ± 0.12              | 262.78 ± 8.42            |
| 20     | Peanut 2          | 1.44 ± 0.15               | 1.29 ± 0.07              | 351.30 ± 11.25           |
| 21     | Peanut 3          | 3.22 ± 0.25               | 1.62 ± 0.10              | 301.35 ± 9.65            |
| M.Value|                   | 3.18 ± 0.23               | 1.60 ± 0.10              | 305.14 ± 9.77            |
| 22     | Jew’s Mallow 1    | 0.89 ± 0.05               | 0.36 ± 0.02              | 93.67 ± 3.00             |
| 23     | Jew’s Mallow 2    | 1.14 ± 0.07               | 0.43 ± 0.03              | 93.04 ± 2.98             |
| 24     | Jew’s Mallow 3    | 0.95 ± 0.06               | 0.58 ± 0.03              | 116.52 ± 3.73            |
| M.Value|                   | 0.99 ± 0.06               | 0.46 ± 0.03              | 101.07 ± 3.24            |
| 25     | Arugula 1         | 0.81 ± 0.06               | 0.91 ± 0.04              | 163.60 ± 5.24            |
| 26     | Arugula 2         | 0.85 ± 0.05               | 0.56 ± 0.03              | 132.95 ± 4.26            |
| M.Value|                   | 0.83 ± 0.06               | 0.74 ± 0.03              | 148.28 ± 4.75            |
| 27     | Coriander 1       | 1.06 ± 0.07               | 1.06 ± 0.05              | 100.88 ± 3.23            |
| 28     | Coriander 2       | 1.16 ± 0.08               | 0.93 ± 0.05              | 116.84 ± 3.78            |
| M.Value|                   | 1.11 ± 0.08               | 1.00 ± 0.05              | 108.86 ± 3.49            |

M. = Mean.
3.3. Effective doses due to ingestion

The radiation dosage got because of food ingested is ascertained from the quantity of radionuclide stored in food, the concentration of activity of a specific radionuclide in food per unit of discharge, the rate of utilization of food products and the dosage per unit of activity ingested (Jibiri & Abiodun, 2012). The yearly viable dosage of ingestion for a grown-up individual from people in general because of the intake of radionuclides through the food eaten can be estimated by the metabolic models created by the International Commission on Radiological Protection (ICRP, 1996).

The viable dosage is a helpful idea that enables you to include the radiation dosages of various radionuclides and diverse types and sources of radioactivity. It depends on the dangers instigated by the impacts of radiation and the utilization of the metabolic model of the International Commission on Radiological Protection (ICRP) which gives important conversion factors to compute successful dosages from the aggregate concentrations of radionuclide activity estimated in food (ICRP, 1996).

Evaluations of the radiation-initiated health impacts related to the intake of radionuclides in the body are corresponding to the aggregate dosage of the radionuclides while dwelling in the different organs. Ingested radiation dosages are gotten by estimating the activities identified with radionuclides in food (Bq kg⁻¹) and increasing them by the measure of food expended amid a time frame (kg d⁻¹ or kg y⁻¹). At that point, a dose conversion factor (Sv Bq⁻¹) can be used to acquire a gauge of the dosage of ingestion. In this manner, as indicated by Till and Moore (1988), the dosage ingested is given by:

\[ H_{T,r} = \sum (U_i \times C_i) \times g_{T,r} \]  

Where \( i \) signifies the class of food, and the coefficients \( U_i \) and \( C_i \), speak of the yearly utilization rate (kg y⁻¹) and the radionuclide activity concentration (Bq kg⁻¹), respectively, and \( (g_{T,r}) \) is the dosage coefficient for the intake by ingesting radionuclide (Sv Bq⁻¹). The estimations of \( (g_{T,r}) \) for \(^{226}\text{Ra}, \text{^{232}Th}, \) and \(^{40}\text{K} \) are, \( 4.8 \times 10^{-8} \) Sv Bq⁻¹, \( 2.3 \times 10^{-7} \) Sv Bq⁻¹, and \( 5.9 \times 10^{-8} \) Sv Bq⁻¹, respectively, for grown-up individuals from the general population (Ogundari, 2012).

The food utilization information for various food crops in the Abyan Delta area of Yemen are presented based on the information from the Federal Office of Statistics (FOS) and the Food and Agriculture Organization (FAO). In this investigation, the individual dosage and dangers of the intake route depended on the positt that all foods were devoured at the generation site and that the required measure of food was delivered in a given area. Basically, food is gotten locally. Utilizing these conversion factors, the effective dosage of intake was evaluated and recorded in Table 3. The results demonstrates that the effective dose of sorghum 4 is considerably higher than that of different sorts of sorghum; this can be clarified by the fairly vast radioactive level of \(^{40}\text{K} \), and

| S. No. | Type foodstuff | Eff. Dose rate (µSv y⁻¹) |
|-------|----------------|--------------------------|
| 1     | Sorghum 1      | 20.364                   |
| 2     | Sorghum 2      | 20.521                   |
| 3     | Sorghum 3      | 20.437                   |
| 4     | Sorghum 4      | 29.729                   |
| 5     | Maize 1        | 20.099                   |
| 6     | Maize 2        | 25.998                   |
| 7     | Maize 3        | 22.500                   |
| 8     | Maize 4        | 28.048                   |
| 9     | Pearl or catail millet 1 | 3.828           |
| 10    | Pearl or catail millet 2 | 2.840           |
| 11    | Pearl or catail millet 3 | 3.978           |
| 12    | Pearl or catail millet 4 | 3.894           |
| 13    | Onion 1        | 2.428                    |
| 14    | Onion 2        | 2.189                    |
| 15    | Onion 3        | 2.300                    |
| 16    | Radish 1       | 2.522                    |
| 17    | Radish 2       | 2.520                    |
| 18    | Radish 3       | 2.161                    |
| 19    | Peanut 1       | 0.444                    |
| 20    | Peanut 2       | 0.488                    |
| 21    | Peanut 3       | 0.461                    |
| 22    | Jews Mallow 1  | 2.031                    |
| 23    | Jews Mallow 2  | 2.105                    |
| 24    | Jews Mallow 3  | 2.603                    |
| 25    | Arugula 1      | 3.643                    |
| 26    | Arugula 2      | 2.863                    |
| 27    | Coriander 1    | 2.672                    |
| 28    | Coriander 2    | 2.880                    |

Mean Value: 8.448
the viable dosage estimation of Maize can be effectively clarified by a similar explanation.

Clearly, the average effective dose ascertained from our example is much lower than the reference estimation of 2.4 mSv y\(^{-1}\) announced by UNSCEAR (1993).

### 3.4. Activity concentrations in agricultural soil

Table 4 demonstrates the consequences of the activity concentration of natural radionuclides \(^{226}\)Ra, \(^{232}\)Th, and \(^{40}\)K in soil specimens from various areas in Abyan Delta. The activity concentrations of \(^{226}\)Ra, \(^{232}\)Th and \(^{40}\)K ranged from 22.73 to 39.95 Bq kg\(^{-1}\), 50.4 to 94.95 Bq kg\(^{-1}\) and 924.57 to 1322.37 Bq kg\(^{-1}\), respectively. The average activity concentrations of \(^{226}\)Ra, \(^{232}\)Th, and \(^{40}\)K in soils were 33.15 Bq kg\(^{-1}\), 77.25 Bq kg\(^{-1}\) and 1220.59 Bq kg\(^{-1}\), respectively. The \(^{226}\)Ra, \(^{232}\)Th, and \(^{40}\)K outcomes demonstrate that they have higher activity concentrations than the worldwide average (35, 30, and 400 Bq kg\(^{-1}\)), respectively, \(^{226}\)Ra, \(^{232}\)Th, and \(^{40}\)K of these radionuclides (El-Gamal, Sidique, El-Haddad, & El-Azab Farid, 2018; UNSCEAR, 2000). The \(^{40}\)K activity level in the soil specimens was observed to be substantially higher than \(^{226}\)Ra and \(^{232}\)Th; this might be because of the way that natural radioactivity initially relies upon the land conditions, in summary, \(^{40}\)K activity is higher than the activity of thorium and radium and its descendants. A surplus of \(^{40}\)K activity was seen in the soil specimens, which might be because of farming exercises in the territory, including the utilization of potassium fertilizers, which thus raises the concentration of potassium in the soil.

### 3.5. Transfer factor (TF)

The ingestion of radionuclides in polluted soil represents a major step in the introduction of radionuclides into the human food chain; this fact is portrayed as a soil-plant transfer factor, defined as the proportion between plant activity and soil-particular activity. Plants are the primary receptors of the radioactive tainting of the food chain following the arrival of radionuclides. The plant transfer factor soil is thought to be a standout amongst the most imperative parameters in the environmental safety assessment needed for a nuclear facility. This parameter is important for an environmental transfer model that can be utilized to anticipate radionuclide concentrations in crops used to appraise human dose consumption.

Radionuclide transfer from soil to plant is communicated as transfer factor (TF), defined as the proportion of activity concentration (Bq kg\(^{-1}\)) of the plant’s dry weight to the activity concentration of the soil dry weight (Bq kg\(^{-1}\)) (IAEA [International Atomic Energy Agency], 1994).

#### Table 4. Transfer factor (TF) values for \(^{226}\)Ra, \(^{232}\)Th, and \(^{40}\)K in different foodstuff samples using data from table 1 for the activity concentrations of foodstuff (Bq kg\(^{-1}\)).

| S. No. | Type of Foodstuff | Activity concentrations of soil (Bq kg\(^{-1}\)) | Transfer factor (TF) |
|--------|-------------------|-----------------------------------------------|---------------------|
|        |                   | \(^{226}\)Ra | \(^{232}\)Th | \(^{40}\)K | \(^{226}\)Ra | \(^{232}\)Th | \(^{40}\)K |
| 1      | Sorghum 1         | 39.95 | 86.35 | 1219.1 | 0.0941 | 0.0193 | 0.0372 |
| 2      | Sorghum 2         | 39.85 | 89.6  | 1241.7 | 0.0559 | 0.0196 | 0.1424 |
| 3      | Sorghum 3         | 39.85 | 89.6  | 1241.7 | 0.0725 | 0.0190 | 0.0957 |
| 4      | Sorghum 4         | 32.70 | 75.4  | 1232.7 | 0.0550 | 0.0190 | 0.1891 |
| 5      | Maize 1           | 28.95 | 75.1  | 1269.5 | 0.0618 | 0.0233 | 0.1292 |
| 6      | Maize 2           | 38.46 | 88.95 | 1321.96 | 0.1183 | 0.0235 | 0.1525 |
| 7      | Maize 3           | 38.46 | 88    | 1321.96 | 0.1006 | 0.0202 | 0.1327 |
| 8      | Maize 4           | 32.6  | 71    | 1259.7  | 0.1319 | 0.0352 | 0.1683 |
| 9      | Pearl or cattail millet 1 | 29.4 | 77.65 | 1188.2 | 0.0786 | 0.0200 | 0.0393 |
| 10     | Pearl or cattail millet 2 | 30.7 | 67.9  | 1224.76 | 0.0658 | 0.0186 | 0.0619 |
| 11     | Pearl or cattail millet 3 | 36.667 | 83.933 | 1224.967 | 0.0889 | 0.0279 | 0.0657 |
| 12     | Pearl or cattail millet 4 | 32.15 | 94.95 | 1173.45 | 0.0852 | 0.0200 | 0.0833 |
| 13     | Onion 1           | 33.38 | 69.017 | 1197.333 | 0.0320 | 0.0091 | 0.1044 |
| 14     | Onion 2           | 33.38 | 69.017 | 1197.333 | 0.0317 | 0.0068 | 0.0966 |
| 15     | Onion 3           | 33.38 | 69.017 | 1197.333 | 0.0319 | 0.0078 | 0.1003 |
| 16     | Radish 1          | 29.20 | 66.075 | 1128.2 | 0.0235 | 0.0073 | 0.1048 |
| 17     | Radish 2          | 29.2  | 66.075 | 1128.2 | 0.0259 | 0.0066 | 0.1056 |
| 18     | Radish 3          | 29.2  | 66.075 | 1128.2 | 0.0211 | 0.0060 | 0.0901 |
| 19     | Peanut 1          | 38.65 | 80    | 1207.65 | 0.1263 | 0.0238 | 0.2176 |
| 20     | Peanut 2          | 36.83 | 98.87 | 1305.83 | 0.0429 | 0.0128 | 0.3055 |
| 21     | Peanut 3          | 36.83 | 98.87 | 1305.83 | 0.0874 | 0.0164 | 0.2308 |
| 22     | Jew’s Mallow 1    | 32.60 | 78.37 | 1322.37 | 0.0227 | 0.0045 | 0.0708 |
| 23     | Jew’s Mallow 2    | 32.60 | 78.37 | 1322.37 | 0.0348 | 0.0055 | 0.0704 |
| 24     | Jew’s Mallow 3    | 32.60 | 78.37 | 1322.37 | 0.0292 | 0.0075 | 0.0881 |
| 25     | Arugula 1         | 32.60 | 78.37 | 1322.37 | 0.0247 | 0.0117 | 0.1237 |
| 26     | Arugula 2         | 32.60 | 78.37 | 1322.37 | 0.0261 | 0.0072 | 0.1005 |
| 27     | Coriander 1       | 22.73 | 50.40 | 924.57  | 0.0466 | 0.0211 | 0.1091 |
| 28     | Coriander 2       | 22.73 | 50.40 | 924.57  | 0.0509 | 0.0185 | 0.1264 |
| Min.   | 39.95 | 94.95 | 1322.32 | 0.1319 | 0.0352 | 0.3055 |
| Max.   | 33.15 | 77.25 | 1220.59 | 0.0597 | 0.0157 | 0.1233 |
| Average| 33.15 | 77.25 | 1220.59 | 0.0597 | 0.0157 | 0.1233 |
The transfer factor (TF) was resolved by the relationship [27] as follows:

\[
TF = \frac{Bq \cdot Kg^{-1} \cdot dry \cdot crops}{Bq \cdot Kg^{-1} \cdot dry \cdot soil}
\]

Dry weight is favored on the grounds that the measure of radioactivity per kilogram dry weight is much lower than the sum per unit of fresh weight (Mohammad, Thamer, Muzahir, & Omar, 2016).

The transfer factors of $^{226}$Ra, $^{232}$Th, and $^{40}$K in soil and food in the research region were 0.0211–0.1319, 0.0045–0.0352 and 0.0619–0.3055, respectively, and the average estimates were 0.0597, 0.0157 and 0.1233, respectively (Table 4). Table 4 demonstrates that the most astounding transfer factors of $^{226}$Ra and $^{232}$Th were seen in the specimen numbers 8 (Maize), which were 0.1319 and 0.0352, respectively. The most astounding transfer factor of $^{40}$K was seen in specimen 20 (peanut) with an estimation of (0.3055). The change in TF might be because of the retention of radionuclides influenced by different parameters, for example, the soil and radionuclides physical and chemical characteristics, Plant species, development stages, rainfall, temperature, sunshine, and so forth (Mahiban et al., 2013).

The outcomes foresee that in this specific district, the potassium content is most noteworthy in the TF. This is on the grounds that potassium is an imperative element that makes plants prolific. In spite of the fact that potassium is a radioactive element, it doesn’t harm the water framework. Potassium is vital for plant development and adjusting to natural pressure. Subsequently, potassium has the most elevated number of transfer factor contrasted with radium and thorium. The mean TF estimations of $^{232}$Th and $^{40}$K were lower than the default estimations of 0.05 and 1.00, respectively, yet the average TF estimation of $^{226}$Ra was somewhat higher than the reference estimation of 0.04. This might be because of the expansion in the take-up of radium in plants by expanding the concentration of organic acids, particularly citrus extract, which plays a viable part in the ingestion of $^{226}$Ra by plants because of the reduced pH and the development of organic complexes (Nezami, Malakouti, Samani, & Maragheh, 2016; Prieto, Lozano, Rodriguez, & Tome, 2013).

4. Conclusion

In this research, radioactive concentrations of $^{226}$Ra, $^{232}$Th, and $^{40}$K radionuclides in the soil and in various foods frequently devoured by the populace in the Abyan Delta of Yemen were estimated by gamma-ray spectroscopy. The average concentrations of $^{226}$Ra, $^{232}$Th, and $^{40}$K in the soil specimens as set up by UNSCEAR (2000) were higher than the worldwide average of 33, 35, and 400 Bq kg$^{-1}$, respectively. The average activity concentrations of $^{226}$Ra, $^{232}$Th, and $^{40}$K in food specimens were 1.11 ± 0.08, 1.00 ± 0.05 and 108.86 ± 3.49, respectively. The average activity concentrations of $^{40}$K in food are significantly higher activity than the average concentrations of $^{226}$Ra and $^{232}$Th in all specimens. This is because of the huge utilization of NPK fertilizers by agriculturist following quite a while of mining activities in the region to improve crop yields and soil devaluation.

The average effective dosage of the person who ate the particular type of food was 8.448 µSv y$^{-1}$, which was much lower than the worldwide average yearly effective dosage of 2.4 mSv y$^{-1}$ UNSCEAR (1993).

The average TF estimates for $^{232}$Th and $^{40}$K were lower than the default estimations of 0.05 and 1.00, respectively UNSCEAR (1993), however, the average TF estimation of $^{226}$Ra was somewhat higher than the reference estimation of 0.04 (IAEA, 1994). Potassium had the most astounding TF in the investigation zone; this is because of the way that potassium is a key factor for plant fertilization.

Disclosure statement

The authors declare no conflict of interest.

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