Abstract

Determining radioactivity levels in foodstuffs is of great importance for the protection of human health. In addition, the literature includes few studies related to this subject in Turkey. In this study, gamma spectroscopic system was used in order to measure $^{226}$Ra, $^{232}$Th, $^{40}$K and $^{137}$Cs activity concentrations in vegetables and fruits produced in Elazığ Region. The average activity concentrations in vegetables was calculated as $0.64 \pm 0.26$ Bq kg$^{-1}$ for $^{226}$Ra, $0.65 \pm 0.14$ Bq kg$^{-1}$ for $^{232}$Th, $13.98 \pm 1.22$ Bq kg$^{-1}$ for $^{40}$K, and $0.54 \pm 0.04$ Bq kg$^{-1}$ for $^{137}$Cs. The average activity concentrations in fruits were $1.52 \pm 0.34$, $0.98 \pm 0.23$, $18.66 \pm 1.13$ and $0.59 \pm 0.16$ Bq kg$^{-1}$, respectively for $^{226}$Ra, $^{232}$Th, $^{40}$K and $^{137}$Cs. Total committed effective dose value was determined as 20 and 30.55 lSv y$^{-1}$, respectively for vegetables and fruits. The findings were compared with previous data reported for Turkey and other regions of the world.

Keywords

Effective dose - Food stuff - Internal dose - Elazığ

Introduction

Natural radionuclide concentrations in environmental samples varies according to geographical and geological factors [1]. Natural sources of radioactivity in the environment are called naturally occurring radioactive materials, and are categorized as being of terrestrial or cosmic origin [2]. Humans are exposed to both internal and external radiation from these natural sources. Internal exposure occurs through the intake of terrestrial radionuclides through inhalation or ingestion. Inhalation exposure dose results from the existence of dust particles in air, including radionuclides from $^{238}$U and $^{232}$Th decay series. The biggest contribution to inhalation exposure comes from short half-life decay products of radon. Ingestion exposure dose mostly results from $^{238}$U and $^{232}$Th series radionuclides and $^{40}$K in drinking water and foodstuff. In addition, $^{137}$Cs is the most important fission product released to the environment as a result of nuclear activities, because this radionuclide rapidly passes to foodstuffs and creates a dose effect [3]. The literature includes this type of studies [4–10]. The aim of this study is to determine the exposure dose of $^{226}$Ra, $^{232}$Th, $^{40}$K and $^{137}$Cs radionuclide concentrations in fruits and vegetables produced in the Elazığ Region of Turkey, which are frequently consumed by local residents. The significance of the study is that it is the first study to determine the background radiation levels in such food products in this region and will provide data for future studies and in case of a nuclear accident (as in Chernobyl nuclear accident) or nuclear fallout, to determine level of contamination.

The province of Elazığ is located in the Eastern Anatolian Region, between longitude $38^\circ30'–40^\circ21'E$ and latitude $38^\circ17'–39^\circ11'N$. Its surface area is $9,151 \text{ km}^2$ and the average altitude is $1,067 \text{ m}$. The region is divided into 11 administrative regions, with a total population of 540,000 (Fig. 1). Approximately 50 % of the province consists of grasslands, 28 % is agricultural land, 12 % forest, and 10 % is dams and lakes. A continental climate prevails; winters are cold and snowy, and summers are hot and arid. The province is rich in mineral resources, and mining...
activities include copper, fluoride, chalcopyrite, zinc, lead, chrome, manganese, molybdenum, iron and wolfram [11].

Materials and methods

Radioactivity measurements in vegetable and fruit samples

Samples of fruits and vegetables produced and frequently consumed in the region were provided from a public market. Any soil or foreign materials on the samples were removed so that they were suitable for consumption, divided into small pieces, and washed under distilled water. They were kept at room temperature for 3 months without allowing any contamination and then totally oven-dried at 105 °C. Afterwards, incineration was applied, which was realized through dry ashing. The temperature of the oven was increased to 250 °C and was continued until the samples were reduced to ash. The ashed samples were then homogenized and transferred into a plastic container (5 cm height × 5 cm diameter). Finally, the samples were sealed and stored for a period of about 1 month before counting, in order to allow equilibrium between 226Ra and its short-lived decay products.

The activity concentrations of 226Ra, 232Th, 40K and 137Cs radionuclides in vegetable and fruit samples were determined using a gamma spectroscopic system, comprising a 2" × 2" NaI(Tl) well-type detector and a detector surrounded by a cylindrical lead shield (thickness, diameter and length approximately 3.5, 13.7 and 15.5 cm, respectively). The detector window was made of aluminum of 0.50 mm thickness. Energy calibration of detector was performed by using 60Co (37 kBq) and 226Ra (370 kBq) point sources. Photopeak efficiency was 24 %. 226Ra, 232Th, 40K and 137Cs activity concentrations in vegetable and fruit were based on the detection of 609.3, 583, 1461 and 662 keV energy gamma rays transmitted by 214Bi, 208Tl, 40K and 137Cs, respectively.
Calculation of activity concentration in vegetable and fruits

The activity concentrations in vegetable and fruit samples were calculated using Eq. (1)

\[ A(Bq \text{ kg}^{-1}) = \frac{C}{M_e \varepsilon P_\gamma} \] (1)

where \( C \) is the gamma ray count (number per second), \( \varepsilon \) is the detector efficiency of the specific gamma ray, \( P_\gamma \) is the absolute transition probability of gamma decay and \( M_s \) is the mass of the sample (kg) [12].

Dose estimation

Ingestion dose occurring through the intake of radionuclides depends on the consumption rate of foodstuff and the concentration of the radionuclide involved. Ingestion dose is calculated with the Eq. (2) [3, 13, 14]

\[ H_{Ti} = \sum (U^i C_i^r) g_{Ti} \] (2)

where \( i \) is foodstuff group, \( U^i \) and \( C_i^r \) are annual consumption rate (kg) and radionuclide activity concentration (Bq kg\(^{-1}\)), respectively for their coefficients, and \( g_{Ti} \) is dose conversion coefficient for \( r \) radionuclide (Sv Bq\(^{-1}\)). Dose conversion coefficients of \(^{226}\)Ra, \(^{232}\)Th, \(^{40}\)K and \(^{137}\)Cs radionuclides for the adult members of society are \( 4.5 \times 10^{-8}, 2.3 \times 10^{-7}, 6.2 \times 10^{-9} \) and \( 1.3 \times 10^{-8} \) Sv Bq\(^{-1}\), respectively [13, 15, 16].

Results and discussion

Table 1 shows the natural and manmade radionuclide activity concentrations measured in samples of vegetables and fruits frequently consumed in Elazığ and its surrounding region. Minimum detectable activity values for vegetable and fruit samples were calculated as 0.02 Bq for

| ID | Species | Scientific name | Activity concentrations of vegetables and fruits (Bq kg\(^{-1}\)fresh weight) |
|----|---------|-----------------|--------------------------------------------------|
|    |         |                 | \(^{226}\)Ra  \(^{232}\)Th  \(^{40}\)K  \(^{137}\)Cs |
|    |         |                 | BDL  BDL  BDL  BDL  BDL  BDL  BDL  BDL  BDL |
|    |         |                 | F1 Bell pepper  \textit{Capsicum annuum} L. | BDL  BDL  7.21 ± 0.91 0.48 ± 0.04 |
|    |         |                 | F2 Parsley  \textit{Petroselinum crispum} (Mill.) Nyman & A.W. Hill | BDL  BDL  44.77 ± 1.90 BDL |
|    |         |                 | F3 Scallion  \textit{Allium cepa} L. | BDL  0.84 ± 0.17 29.41 ± 1.85 BDL |
|    |         |                 | F4 Pumpkin  \textit{Cucurbita moschata} Duchesne ex Poir. | BDL  BDL  2.14 ± 1.36 BDL |
|    |         |                 | F5 Leek  \textit{Allium ampeloprasum} | 0.64 ± 0.37 10.02 ± 1.15 BDL |
|    |         |                 | F6 Radish  \textit{Raphanus sativus} L. | 0.11 ± 0.04 0.47 ± 0.05 3.43 ± 0.34 0.17 ± 0.01 |
|    |         |                 | F7 Kale  \textit{Brassica oleracea} Acephala | BDL  0.64 ± 0.24 5.78 ± 1.57 BDL |
|    |         |                 | F8 Capsicum  \textit{Capsicum annuum} L. | BDL  BDL  5.78 ± 0.63 BDL |
|    |         |                 | F9 Cabbage  \textit{Brassica oleracea} Capitata | 0.95 ± 0.09 26.95 ± 0.95 BDL |
|    |         |                 | F10 Tomato  \textit{Solanum lycopersicum} L. | 0.45 ± 0.08 10.73 ± 0.70 BDL |
|    |         |                 | F11 Eggplant  \textit{Solanum melongena} L. | 0.99 ± 0.19 16.57 ± 1.60 0.79 ± 0.06 |
|    |         |                 | F12 Lettuce  \textit{Lactuca sativa} L. | BDL  BDL  30.93 ± 1.41 0.72 ± 0.05 |
|    |         |                 | F13 Spinach  \textit{Spinacia oleracea} L. | 0.80 ± 0.33 9.84 ± 0.92 BDL |
|    |         |                 | F14 Peppermint  \textit{Mentha spicata} L. | 0.60 ± 0.36 2.22 ± 1.05 BDL |
|    |         |                 | F15 Garden Cress  \textit{Lepidium sativum} L. | 0.54 ± 0.61 3.97 ± 1.90 BDL |
|    |         |                 | Average | 0.64 ± 0.26 0.65 ± 0.14 13.98 ± 1.22 0.54 ± 0.04 |
|    |         |                 | F16 Melon  \textit{Cucumis melo} L. | 1.01 ± 0.13 0.48 ± 0.13 35.49 ± 0.99 0.53 ± 0.04 |
|    |         |                 | F17 Pear  \textit{Pyrus} spp. | BDL  1.96 ± 0.33 13.62 ± 1.60 BDL |
|    |         |                 | F18 Quince  \textit{Cydonia oblonga} Mill. | 2.81 ± 0.45 1.14 ± 0.31 23.01 ± 1.40 0.64 ± 0.27 |
|    |         |                 | F19 Grapes  \textit{Vitis vinifera} L. | BDL  0.26 ± 0.12 1.34 ± 0.63 BDL |
|    |         |                 | F20 Watermelon  \textit{Citrullus lanatus} (Thunb.) Matsum & Nakai | BDL  BDL  34.44 ± 0.88 BDL |
|    |         |                 | F21 Apple  \textit{Malus domestica} Borkh. | 0.73 ± 0.45 1.04 ± 0.26 4.04 ± 1.25 BDL |
|    |         |                 | Average | 1.52 ± 0.34 0.98 ± 0.23 18.66 ± 1.13 0.59 ± 0.16 |

BDL below detection limit
Average activity concentrations of 226Ra, 232Th, 40K and 137Cs of vegetable samples were 0.64 Bq kg$^{-1}$ (SD: 0.26), 0.65 Bq kg$^{-1}$ (SD: 0.14), 13.98 Bq kg$^{-1}$ (SD: 1.22) and 0.54 Bq kg$^{-1}$ (SD: 0.04), respectively. The activity concentrations ranged between 0.11 and 0.99 Bq kg$^{-1}$ for 226Ra; 0.47–0.84 Bq kg$^{-1}$ for 232Th; 2.14–44.77 Bq kg$^{-1}$ for 40K; and 0.17–0.79 Bq kg$^{-1}$ for 137Cs. Average concentrations of 226Ra for fruits were 1.52 Bq kg$^{-1}$ (SD: 0.34) and the values ranged between 0.73 and 2.81 Bq kg$^{-1}$. 232Th concentrations ranged between 0.26 and 1.96 Bq kg$^{-1}$ (average 0.98 Bq kg$^{-1}$, SD: 0.23). The average activities of 40K and 137Cs radionuclides were 18.66 Bq kg$^{-1}$ (SD: 1.13) and 0.59 Bq kg$^{-1}$ (SD: 0.16), respectively. 40K concentrations ranged between 1.34 and 35.49 Bq kg$^{-1}$.

Effective dose values exposed due to radionuclides taken into body through the consumption of fruit and vegetable samples are shown in Table 2. Primarily, average activity concentration (Bq kg$^{-1}$) for each radionuclide was multiplied by food consumption rate, and annual activity intake value was determined in Bq unit. Food consumption rate was taken as 73 kg a$^{-1}$ for both fruits and vegetables. This value represents the average consumption for Turkey [17]. The effective dose value was then determined by multiplying annual activity intake value by effective dose coefficient. Effective dose values of fruit samples for all radionuclides (226Ra, 232Th, 40K and 137Cs) were higher than those for vegetable samples. Average effective exposure dose through the consumption of vegetable samples were 2.12 µSv y$^{-1}$ (SD: 0.86), 11.04 µSv y$^{-1}$ (SD: 2.3), 6.33 µSv y$^{-1}$ (SD: 0.55) and 0.51 µSv y$^{-1}$ (SD: 0.04), respectively for 226Ra, 232Th, 40K and 137Cs. Effective dose values of 226Ra, 232Th, 40K and 137Cs ranged between 0.36 and 3.25, 7.89 and 14.10, 0.97 and 20.26 and 0.16 and 0.75 µSv y$^{-1}$, respectively.

Table 2 Dose coefficients and committed effective dose values for 226Ra, 232Th, 40K and 137Cs

| Radioisotopes | Activity intake (Bq) | Effective dose coefficient (µSv Bq$^{-1}$) | Committed effective dose (µSv y$^{-1}$) |
|--------------|----------------------|------------------------------------------|----------------------------------------|
|              | Range                | Average                                  |                                        |
| Vegetables   |                      |                                          |                                        |
| 226Ra        | 47 ± 19              | 0.045                                    | 0.36 ± 0.13–3.25 ± 0.62, 2.12 ± 0.86   |
| 232Th        | 48 ± 10              | 0.23                                     | 7.89 ± 0.84–14.10 ± 2.85, 11.04 ± 2.3  |
| 40K          | 1021 ± 89            | 6.2 × 10$^{-3}$                          | 0.97 ± 0.62–20.26 ± 0.86, 6.33 ± 0.55  |
| 137Cs        | 39 ± 3               | 1.3 × 10$^{-2}$                          | 0.16 ± 0.01–0.75 ± 0.06, 0.51 ± 0.04   |
| Fruits       |                      |                                          |                                        |
| 226Ra        | 111 ± 25             | 0.045                                    | 2.40 ± 1.48–9.23 ± 1.48, 4.99 ± 1.13   |
| 232Th        | 72 ± 17              | 0.23                                     | 4.37 ± 2.02–32.91 ± 5.54, 16.56 ± 3.91 |
| 40K          | 1362 ± 83            | 6.2 × 10$^{-3}$                          | 0.61 ± 0.29–16.06 ± 0.45, 8.44 ± 0.52  |
| 137Cs        | 43 ± 12              | 1.3 × 10$^{-2}$                          | –                                      |

Table 3 Average effective dose values for Elazığ Region and its comparison with literature

| Region/country          | Committed effective dose (µSv y$^{-1}$) |
|-------------------------|----------------------------------------|
|                         | Vegetables | Fruits | Foodstuff |
| North America           | 110        |        |           |
| Asia                    | 110        |        |           |
| Europe                  | 110        |        |           |
| Korean                  | 110        |        |           |
| Jos Plateau/Nigeria     | (0.2–2.164)|        |           |
| Accra metropolitan area/Ghana | 4,640   |        |           |
| Rize/Turkey             | 227        | 63     |           |
| Elazığ/Turkey           | 20         | 30.55  |           |

Table 3 shows committed effective dose values reported for some countries and regions [3, 18–21]. Total adult...
effective dose from vegetables and fruits frequently produced and consumed in Elazığ Region for $^{226}$Ra, $^{232}$Th, $^{40}$K and $^{137}$Cs radionuclides were calculated as 20 $\mu$Sv y$^{-1}$ (SD:3.75) and 30.55 $\mu$Sv y$^{-1}$ (SD:5.72), respectively. In summary, this study found that adults living in the study region intake a radiation dose of approximately 50.55 $\mu$Sv y$^{-1}$ from fruit and vegetable consumption. This radiation dose (50.55 $\mu$Sv y$^{-1}$) is lower than the world average value (290 $\mu$Sv y$^{-1}$) and presents no risk to public health [3]. Dose values obtained in this present study reflect other reported values in general.

**Conclusion**

$^{226}$Ra, $^{232}$Th, $^{40}$K and $^{137}$Cs radionuclide concentrations in vegetables and fruits that are produced and frequently consumed in the Elazığ Region of Turkey were determined in this study. It was found that the radiation dose due to consumption of vegetables and fruits was less than the world average, and poses no threat to public health. The results were lower than the committed effective dose values reported for various regions and countries.

**Acknowledgments** We thank Dr. Mehmet Emin Sönmez for his contribution to producing the maps.

**Open Access** This article is distributed under the terms of the Creative Commons Attribution License which permits any use, distribution, and reproduction in any medium, provided the original author(s) and the source are credited.

**References**

1. Badran HM, Sharshar T, Elnimer T (2003) Levels of $^{137}$Cs and $^{40}$K in edible parts of some vegetables consumed in Egypt. J Radioanal Nucl Chem 67:181–190
2. Kathren RL (1998) NORM sources and their origins. Appl Radiat Isot 49(3):149–168
3. UNSCEAR (2000) Sources and effects of ionizing radiation. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the General Assembly, with scientific annexes, United Nations, New York
4. Keser R, Korkmaz Görür F, Akçay N, Okumuşoğlu NT (2011) Radionuclide concentration in tea, cabbage, orange, kiwi and soil and lifetime cancer risk due to gamma radioactivity in Rize, Turkey. J Sci Food Agric 91:987–991
5. Scheibel V, Appoloni CR, Schechter H (2006) Natural radioactivity traces in South-Brazilian cereal flours by gamma-ray spectrometry. J Radioanal Nucl Chem 270(1):163–165
6. Jevremovic M, Lazarevic N, Pavlovic S, Orlic M (2011) Radionuclide concentrations in samples of medicinal herbs and effective dose from ingestion of $^{137}$Cs and natural radionuclides in herbal tea products from Serbian market. Isot Environ Health Stud 47(1):87–92
7. Ota T, Sanada T, Kashiwara Y, Morimoto T, Sato K (2009) Evaluation for committed effective dose due to dietary foods by the intake for Japanese adults. Jpn J Health Phys 44(1):80–88
8. Akhter P, Rahman K, Orfi SD, Ahmad N (2007) Radiological impact of dietary intakes of naturally occurring radionuclides on Pakistani adults. Food Chem Toxicol 45:272–277
9. Bolca M, Saç MM, Çokuysal B, Karali T, Ekdal E (2007) Radioactivity in soils and various foodstuffs from the Gediz River Basin of Turkey. Radiat Meas 42:263–270
10. Kılıç Ö, Belivermiş M, Topçuoğlu S, Çotuk Y (2009) $^{232}$Th, $^{238}$U, $^{40}$K, $^{137}$Cs radioactivity concentrations and $^{137}$Cs dose rate in Turkish market tea. Radiat Eff Defects Solids 164(2):138–143
11. Strategic Plan of Municipality of Elazığ (2010) Municipality of Elazığ, Elazığ, Turkey
12. Baykara O, Doğru M (2009) Determination of terrestrial gamma, $^{238}$U, $^{232}$Th and $^{40}$K in soil along fracture zones. Radiat Meas 44:116–121
13. International Commission on Radiological Protection (1996) Age-dependent doses to members of the public from intake of radionuclides: part 5. Compilation of ingestion and inhalation dose coefficients. Annals of the ICRP 26(1). ICRP Publication 72. Pergamon Press, Oxford
14. Till JE, Moore RE (1998) A pathway analysis approach for determining acceptable level of contamination of radionuclides in soil. Health Phys 55:541–548
15. International Commission on Radiological Protection (1994) Age-dependent doses to members of the public from intake of radionuclides: part 2. Ingestion dose coefficients. Annals of the ICRP 23(3/4). ICRP Publication 67. Pergamon Press, Oxford
16. International Atomic Energy Agency (IAEA) (2005) Derivation of activity concentration values for exclusion, exemption and clearance. In: Safety reports series. IAEA, Vienna
17. Türkiye Atom Enerjisi Kurumu (TAEK) (2007) Türkiye İcin Doz Değerlendirmeleri. Milenyum Form Ofset, Ankara
18. Choi M-S, Lin X-J, Lee SA, Kim W, Kang H-D, Doh S-H, Kim D-S, Lee D-M (2008) Daily intakes of naturally occurring radioisotopes in typical Korean foods. J Environ Radioact 99:1319–1323
19. Jibiri NN, Farai IP, Alausa SK (2007) Estimation of annual effective dose from ingestion of naturally occurring radionuclides in foodstuffs in tin mining area of Jos-Plateau, Nigeria. J Environ Radioact 94:31–40
20. Awudu AR, Faanu A, Darko EO, Emi-Reynolds G, Adukpo OK, Kpeglo DO, Otoo F, Lawuvi H, Kpodzo R, Ali ID, Obeng MK, Ayeman B (2012) Preliminary studies on $^{226}$Ra, $^{228}$Ra, $^{232}$Th and $^{40}$K concentrations in foodstuffs consumed by inhabitants of Accra metropolitan area, Ghana. J Radioanal Nucl Chem 291:635–641
21. Korkmaz Görür F, Keser R, Akçay N, Dizman S, As N, Okumuşoğlu NT (2011) Radioactivity and heavy metal concentrations in food samples from Rize, Turkey. J Sci Food Agric 92:307–312