Dependence of activity concentration of natural and artificial radionuclides on depth in soil samples from Antalya in Turkey

Canel Eke¹ ² *, Osman Agar¹ ³ and Ismail Boztosun¹ ⁴

¹ Akdeniz Üniversitesi, Nükleer Bilimler Uygulama ve Araştırma Merkezi, 07058, Antalya, Turkey
² Akdeniz University, Faculty of Education, Department of Secondary Science and Mathematics Education, Division of Physics Education, 07058, Antalya, Turkey
³ Karamanoğlu Mehmetbey University, Department of Physics, 70100, Karaman, Turkey
⁴ Akdeniz University, Faculty of Science, Department of Physics, 07058, Antalya, Turkey

*E-mail: ceke@akdeniz.edu.tr

Abstract. In this study, we attempt to determine the dependence of activity concentration of natural (²³⁸U, ²³²Th, ⁴⁰K) and artificial (¹³⁷Cs) radionuclides on depth in soil samples from Antalya in Turkey. Soil samples were collected at different depths (0-10 cm, 10-30 cm, 30-50 cm, 50-70 cm, 70-100 cm and 100-200 cm). Each soil samples were counted by using a high purity Germanium detector (HpGe). For each soil sample, activity concentration, absorbed dose rate, radium equivalent activity, external and internal hazard index were calculated and compared with the published results.

1. Introduction

²³⁸U, ²³²Th, ⁴⁰K are natural radioactive sources and ¹³⁷Cs, ¹³¹I, ⁹⁰Sr and ⁹⁵Zr are artificial radioactive sources in environment. ²³⁸U, ²³²Th, their decay products and ⁴⁰K are the largest contributor to the external dose of the world population [1]. Besides naturally occurring radionuclides, artificial or manmade radioactivity on earth surface is due to anthropogenic activities such as the test of various nuclear weapons, explosions, nuclear power plant leakage and nuclear facility accidents. The isotope ¹³⁷Cs is the most important constituent detected by its gamma radiation in the environment among the class of artificial isotopes released as fission products, such as ⁹⁰Sr and ⁹⁵Zr. The importance of this fission product is attributed to its long half-life of 30.17 years, and a high energetic gamma emitter (662 keV) that contribute to people’s dose due to the external radiation exposure [2,3].

A wide range of research has been performed to determine the dependence of activity concentration of natural and artificial radionuclides on depth in soil samples [4,5,6,7].

In this paper, our purpose is to determine the dependence of activity concentration of ²³⁸U, ²³²Th, ⁴⁰K and ¹³⁷Cs on the depth in soil samples and to calculate absorbed dose rate, annual effective dose equivalent, radium equivalent activity, internal and external hazard index.
2. Materials and Methodology

2.1. Sample Collection and Preparation
Six soil samples were collected about 3-4 kg at different depths (0-10 cm, 10-30 cm, 30-50 cm, 50-70 cm and 100-200 cm) from Antalya in Turkey. Each soil samples were sieved 2 mm mesh and dried 130°C for 24 h in a oven. Samples were put 1000 ml Marinelli beaker and weighed. They were kept and sealed for 40 days to come to secular radioactive equilibrium between \(^{226}\)Ra, \(^{232}\)Th and their decay products.

2.2. Gamma-ray Spectrometry Measurement System
Each soil samples were counted 50000s by using High Purity Germanium Detector (HpGe) (AMATEK-ORTEC (GEM40P4-83). The energy resolution of the detector is 1.85 keV at gamma-ray energy 1332 keV of \(^{60}\)Co and its relative efficiency is 40% and energy resolution is 768 eV at gamma energy 122 keV of \(^{57}\)Co. The details can be found in Refs. [8,9,10].

2.3. Determination of Activity Concentration and Dose Assessments
To determine dependence of activity concentration \(A\) (Bq/kg) of natural and artificial radionuclides on depth in soil samples from Antalya in Turkey, we used following well known equation [11]:

\[
A = \frac{N}{m \cdot t \cdot \epsilon_0 \cdot P_y}\quad (1)
\]

Where \(N\) is number of count, \(m\) (kg) is mass of the sample, \(t\) (sec) is counting time, \(\epsilon_0\) is detector efficiency and \(P_y\) is gamma-ray emission probability.

To calculate absorbed dose rate, annual effective dose equivalent, radium equivalent activity, external and internal hazard index were used by following equations from [12,13,14,15] as shown in table 1.

| Dose assessments               | Unit   | Equation                                      |
|-------------------------------|--------|-----------------------------------------------|
| Absorbed dose rate (D)        | nGy h\(^{-1}\) | \(D = 0.462A_U + 0.604A_{Th} + 0.0417A_K\)   |
| Annual effective dose equivalent (AEDE) | \(\mu\)Sv \(y\)^\(-1\) | \(AEDE = D \times 8760 \times 0.7 \times 0.2 \times 10^{-3}\) |
| Radium equivalent activity (Ra\(_{eq}\)) | Bq kg\(^{-1}\) | \(Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_K\) |
| External hazard index         |        | \(H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810}\) |
| Internal hazard index         |        | \(H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810}\) |

Where \(A_U\), \(A_{Th}\) and \(A_K\) are activity concentration of \(^{238}\)U, \(^{232}\)Th and \(^{40}\)K respectively. 0.462, 0.604 and 0.0417 are dose coefficients from Ref.[12]. Minimum detectable activities (MDA) are 1.43 Bq kg\(^{-1}\), 1.07 Bq kg\(^{-1}\), 2.19 Bq kg\(^{-1}\), 8.82 Bq kg\(^{-1}\) and 0.41 Bq kg\(^{-1}\) for \(^{214}\)Pb (351 keV), \(^{214}\)Bi (609 keV), \(^{228}\)Ac (911 keV), \(^{40}\)K (1460 keV) and \(^{137}\)Cs (661 keV) respectively.

3. Results
Activity concentrations of natural and artificial radionuclides are given in table 2. Results of dose assessments are given in table 3.
According to Ref. [12] for 238\textsuperscript{U} activity concentration, world average value is 33 Bq/kg, for 232\textsuperscript{Th}, world average value for activity concentration is 45 Bq/kg, for 40\textsuperscript{K}, world average value for activity concentration is 420 Bq/kg, the average values of activity concentration of 238\textsuperscript{U}, 232\textsuperscript{Th} and 40\textsuperscript{K} in present study is less than the world average value. Activity concentration of 214\textsuperscript{Pb}, 214\textsuperscript{Bi}, 232\textsuperscript{Th} and 40\textsuperscript{K} values are higher than world average value at depth of 10-30 cm and activity concentration 214\textsuperscript{Pb} and 232\textsuperscript{Th} values are higher than world average value at depth of 50-70 cm. Most of the 137\textsuperscript{Cs} activity concentration values are lower than minimum detectable activity.

According to Ref. [12] for absorbed dose rate, world average value is 59 nGy/h, the average value in present study is less than the world average value, for annual effective dose equivalent world average value is 70 μSv/y, the average value in present study is less than the world average value. Activity concentration of 214\textsuperscript{Pb}, 214\textsuperscript{Bi}, 232\textsuperscript{Th} and 40\textsuperscript{K} values are higher than world average value at depth of 10-30 cm and activity concentration 214\textsuperscript{Pb} and 232\textsuperscript{Th} values are higher than world average value at depth of 50-70 cm. Most of the 137\textsuperscript{Cs} activity concentration values are lower than minimum detectable activity.

**Table 2. Activity concentration of 238\textsuperscript{U}, 232\textsuperscript{Th}, 40\textsuperscript{K} and 137\textsuperscript{Cs}**

| Soil depth (cm) | 214\textsuperscript{Pb} (Bq/kg\textsuperscript{-1}) (351 keV) | 214\textsuperscript{Bi} (Bq/kg\textsuperscript{-1}) (609 keV) | 228\textsuperscript{Ac} (Bq/kg\textsuperscript{-1}) (911 keV) | 40\textsuperscript{K} (Bq/kg\textsuperscript{-1}) (1460 keV) | 137\textsuperscript{Cs} (Bq/kg\textsuperscript{-1}) (661 keV) |
|-----------------|-------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|
| 0-10            | 8.49 ± 0.08                                                 | 7.79 ± 0.06                                                 | 9.42 ± 0.03                                                 | 54.25 ± 3.28                                                | <MDA                                                       |
| 10-30           | 48.30 ± 0.64                                                | 43.18 ± 0.46                                                | 84.10 ± 0.43                                                | 443.54 ± 50.08                                              | <MDA                                                       |
| 30-50           | 36.34 ± 0.75                                                | 31.02 ± 0.52                                                | 58.23 ± 0.13                                                | 311.71 ± 16.24                                              | 0.52                                                       |
| 50-70           | 7.82 ± 0.07                                                 | 7.53 ± 0.06                                                 | 10.20 ± 0.75                                                | 50.24 ± 8.44                                                | <MDA                                                       |
| 70-100          | 4.32 ± 0.04                                                 | 3.96 ± 0.02                                                 | 3.44 ± 0.60                                                 | 17.67 ± 2.19                                                | <MDA                                                       |
| 100-200         | 4.21 ± 0.07                                                 | 3.80 ± 0.05                                                 | 2.90 ± 0.19                                                 | 13.06 ± 0.65                                                | <MDA                                                       |
| Average value   | 18.25                                                      | 16.21                                                      | 28.05                                                      | 148.45                                                      |

MDA: Minimum Detectable Activity

According to Ref. [12] for 238\textsuperscript{U} activity concentration, world average value is 33 Bq/kg, for 232\textsuperscript{Th}, world average value for activity concentration is 45 Bq/kg, for 40\textsuperscript{K}, world average value for activity concentration is 420 Bq/kg, the average values of activity concentration of 238\textsuperscript{U}, 232\textsuperscript{Th} and 40\textsuperscript{K} in present study is less than the world average value. Activity concentration of 214\textsuperscript{Pb}, 214\textsuperscript{Bi}, 232\textsuperscript{Th} and 40\textsuperscript{K} values are higher than world average value at depth of 10-30 cm and activity concentration 214\textsuperscript{Pb} and 232\textsuperscript{Th} values are higher than world average value at depth of 50-70 cm. Most of the 137\textsuperscript{Cs} activity concentration values are lower than minimum detectable activity.

**Table 3. Results of dose assessments**

| Soil depth (cm) | D (nGy/h\textsuperscript{-1}) | AEDE(μSv/y\textsuperscript{-1}) | Ra\textsubscript{eq} (Bq/kg\textsuperscript{-1}) | H\textsubscript{ex} | H\textsubscript{in} |
|-----------------|--------------------------------|-------------------------------|-----------------------------------------------|---------------------|---------------------|
| 0-10            | 11.71±0.72                     | 14.36±0.88                    | 25.78±1.58                                    | 0.069±0.004         | 0.092±0.006         |
| 10-30           | 90.42±10.28                    | 110.89±12.60                  | 200.15±22.75                                  | 0.540±0.061         | 0.664±0.075         |
| 30-50           | 63.73±3.54                     | 78.16±4.34                    | 140.96±7.82                                   | 0.380±0.021         | 0.471±0.026         |
| 50-70           | 11.80±1.99                     | 14.47±2.44                    | 26.13±4.40                                    | 0.070±0.012         | 0.091±0.015         |
| 70-100          | 4.73±0.59                      | 5.80±0.72                     | 10.42±1.30                                    | 0.028±0.004         | 0.039±0.005         |
| 100-200         | 4.15±0.22                      | 5.08±0.27                     | 9.16±0.48                                     | 0.024±0.001         | 0.035±0.002         |
| Average value   | 31.09                          | 38.13                         | 68.77                                          | 0.186               | 0.232               |

According to Ref. [12] for absorbed dose rate, world average value is 59 nGy/h, the average value in present study is less than the world average value, for annual effective dose equivalent world average value is 70 μSv/y, the average value in present study is less than the world average value. According to [12] for Radium equivalent activity world average value is 370 Bq/kg, the average value in present study is less than the world average value. H\textsubscript{ex} and H\textsubscript{in} values should be less than unity [12,13,16]. In present study, H\textsubscript{ex} and H\textsubscript{in} values are lower than unity. Absorbed dose rate and annual effective dose equivalent values are higher than world average value at depths of 10-30 cm and 30-50 cm. Radium equivalent activity values are lower than world average value.
4. Conclusion
Dependence of activity concentration of natural and artificial radionuclides on depth was studied in soil samples by using a high purity Germanium detector (HpGe) from Antalya in Turkey. For each soil samples activity concentration, absorbed dose rate, annual effective dose equivalent, radium equivalent activity, internal and external hazard index were calculated. Activity concentration of $^{214}$Pb, $^{214}$Bi, $^{232}$Th and $^{40}$K values are higher than world average value at depth of 10-30 cm and activity concentration $^{214}$Pb and $^{232}$Th values are higher than world average value at depth of 50-70 cm. Most of the $^{137}$Cs activity concentration values are lower than minimum detectable activity. Absorbed dose rate and annual effective dose equivalent values are higher than world average value at depths of 10-30 cm and 30-50 cm. Average values of activity concentration of $^{238}$U, $^{232}$Th and $^{40}$K lower than world average value. Average values of absorbed dose rate, annual effective dose equivalent and radium equivalent lower than world average value. Internal and external hazard index values are lower than unity. Activity concentration of natural and artificial radionuclides can investigate in detail in this area in future and also these results can be useful to compare with future studies.

References
[1] Nada A, Abd-El Maksoud T M, Abu-Zeid Hosnia M, El-Nagar T, Awad S 2009 Appl.Radiat.Isot 67 643-649
[2] Celik N, Cevik U, Celik A, Koz B 2009 J. Hazard. Mater. 162 146–153
[3] Bara S V, Arora V, Chinnaesakki S, Sartandel S J, Bajwa B S, Tripathi R M, Puranik V D 2012 J. Radioanal. Nucl. Chem. 291 769–776
[4] Shetty P K, Narayana Y, Rajashekar K M 2011 J. Radioanal. Nucl. Chem. 290 159–163
[5] Mabit L, Dornhofer P, Martin P, Toloza A, Zupanc V 2012 Indian J. Pure Appl. Phys. 50 45-48
[6] Saleh I H 2012 Turkish J. Eng. Env. Sci. 36 236-248
[7] Belvermis M 2012 Radiat.Prot.Dosim. 151 (3) 511-521
[8] Eke C, Boztosun I 2014 J. Radioanal. Nucl. Chem. 301 (1) 103-108.
[9] Agar O, Boztosun I, Korkmaz, M E, Ozmen, S F 2014 Radiat.Prot.Dosim. DOI:10.1093/rpd/ncu027
[10] Ozmen S F, Boztosun I, Yavuz M, Tunc M R 2014 Radiat.Prot.Dosim. 158 (4) 461-465.
[11] Agbalagba E O, Awwiri G O, Chad-Umoreh Y E 2012 J. Environ. Radioact. 109 64-70
[12] UNSCEAR 2000, United Nations Scientific Committee on the Effect of Atomic Radiation. Sources and Effects of Ionizing Radiation. Report to General Assembly, with Scientific Annexes, NewYork, United Nations
[13] Uosif M A M, El-Taher A, Abbady A G E 2008 Radiat.Prot.Dosim. 131 (3) 331-339.
[14] Ravisankar R, Vanasundari K, Chandrasekaran A, Rajalakshmi A, Suganya M, Vijayagopal P,Meenakshisundaram,V 2012 Appl. Radiat. Isot, 70 699-704
[15] NEA-OECD 1979 Exposure to natural radioactivity in building materials. Report by NEA group of Experts of the nuclear energy agency, OECD, Paris, France
[16] Ramasamy V, Sundarajan M, Paramasivam K, Meenakshisundaram V, Suresh G 2013 Appl. Radiat. Isot, 73 21-31.